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Proceedings
15th Central Hardwood Forest Conference

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University of Tennessee, Knoxville, TN
February 27 – March 1, 2006

Edited by:
David S. Buckley
Wayne K. Clatterbuck

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FOREWORD

The Central Hardwood Forest Conference is a series of biennial meetings that have been hosted by universities and research stations of the U.S. Department of Agriculture Forest Service in the central hardwood forest region in the Eastern United States. The objective of the conference is to bring together forest managers and scientists to discuss research and issues concerning the ecology and management of forests in the central hardwood region. This, the 15th Conference, included presentations pertaining to forest health and protection; ecology and forest dynamics; natural and artificial regeneration; forest products; wildlife; site classification; management and forest resources; mensuration and models; soil and water; agroforestry; and fire. The conference consisted of 86 oral presentations and 30 poster presentations resulting in the papers and abstracts published here.

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David S. Buckley coordinated the peer review process and Wayne K. Clatterbuck coordinated the meeting facilities and the registration.

REVIEW PROCEDURES

Manuscripts for oral presentations were assigned to one of the editors and peer-reviewed by at least two professionals unless otherwise indicated. Reviews were returned to authors to revise their manuscripts. Revised manuscripts were then submitted to the Southern Research Station, Forest Service U.S. Department of Agriculture for final editing and publishing. Authors are responsible for the accuracy and content of their papers.

Mary A. Arthur, David S. Buckley, Stacy L. Clark, Wayne K. Clatterbuck, Luben Dimov, Jordan M. Marshall, Christopher M. Oswalt, Callie J. Schweitzer, and Jeffrey W. Stringer comprised the conference review team and provided reviews of abstracts and multiple manuscripts.

The Steering Committee is grateful to the following professionals for providing peer reviews of manuscripts for the proceedings:

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The 15th Central Hardwood Forest Conference logo and website were developed by Jordan M. Marshall.

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CONTENTS

PLENARY PAPERS

Moderator:

Wayne Clatterbuck
University of Tennessee

THE RESILIENCE OF UPLAND-OAK FOREST CANOPY TREES TO CHRONIC AND ACUTE PRECIPITATION MANIPULATIONS

Paul J. Hanson, Timothy J. Tschaplinski, Stan D. Wullschleger, Donald E. Todd, Jr., and Robert M. Augé[1]

Abstract—Implications of chronic (±33 percent) and acute (-100 percent) precipitation change were evaluated for trees of upland-oak forests of the eastern United States. Chronic manipulations have been conducted since 1993, and acute manipulations of dominant canopy trees (*Quercus prinus*; *Liriodendron tulipifera*) were initiated in 2003. Through 12 years of chronic manipulations tree growth remained unaffected by natural or induced rainfall deficits even though severe drought conditions dramatically reduced canopy function in some years. The resilience of canopy trees to chronic-change was the result of a disconnect between tree growth phenology and late-season drought occurrence. Acute precipitation exclusion from the largest canopy trees also produced limited growth reductions from 2003 through 2005. Elimination of lateral root water sources for the acute treatment trees, via trenching midway through the 2004 growing-season, forced the conclusion that deep rooting was a key mechanism for large-tree resilience to severe drought.

INTRODUCTION

Changes in regional precipitation expected to result from increasing global temperatures are predicted to have a major effect on the composition, structure and productivity of forest ecosystems (Houghton and others 2001). Such predicted changes raise concerns about terrestrial ecosystem productivity, biogeochemical cycling, and the availability of water resources (Kirschbaum and Fischlin 1996, Melillo and others 1990) and the IPCC Working Group II Third Assessment Report (McCarthy and others 2001) requested further research on the response of ecosystems to multiple stresses (e.g., increased temperature and drought). Unfortunately, the direction and magnitude of expected changes in precipitation remain highly uncertain (Houghton and others 2001). Given this uncertainty, manipulative field experiments can play a powerful role in the identification of gradual and threshold ecosystem responses that might result from future precipitation changes. This paper describes the results of multi-year chronic and acute precipitation manipulations designed to evaluate the sensitivity of upland-oak forest tree species to natural and manipulated water deficits. The paper summarizes the responses for large trees, which are defined as trees having a dbh greater than 0.1 m. Sapling growth is described elsewhere (Hanson and others 2001, 2003b).

EXPERIMENTAL SITE

The experiments were located on the Walker Branch Watershed (35°58' N and 84°17' W), a part of the U.S. Department of Energy's (DOE's) National Environmental Research Park near Oak Ridge, Tennessee (Johnson and Van Hook 1989). Long-term (50-year) mean annual precipitation was 1352 mm and mean annual temperature was 14.2 °C. The soils are primarily Typic Paleudults derived from dolomitic bedrock. Plant extractable water (water held between 0 and -2.5 MPa) for the upper meter of soil is approximately 183 mm. A large fraction of this water (44 percent) is held in the upper 0.35 m of the soil profile, which is the location of 60 percent of all fine roots in the 0-0.90 m soil profile (Joslin and Wolfe 1998). The soils are highly weathered and very deep (> 10m) on ridge tops and therefore retain little evidence of their carbonate parent material. Deep rooting may be a source of some water. Early aerial photographs show that the study area was forested in the late 1930's (http://tde.ornl.gov/landuse.html), but several large dominant trees show open growth characteristics suggesting some harvesting before that time. The forest on Walker Branch Watershed is a centrally located example of the eastern broadleaf forest province

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as defined by Bailey (1983) and historically has been characterized as a *Quercus*/*Carya* forest. Insect outbreaks in the early 1980s, however, decimated the *Carya* populations (Dale and others 1990), and the current forests are better termed upland oak forests.

Quercus spp. and *Acer* spp. are the major canopy dominants across all slope positions. *Liriodendron tulipifera* L. is a canopy dominant on the lower slope positions, and *Acer rubrum* L., *Nyssa sylvatica* Marsh. and *Oxydendrum arboreum* (L.) DC are the predominant species occupying mid-canopy locations. In March of 1994, stand basal area averaged 21.1 m^2/ha (Hanson and others 2001). By April 2004, the mean basal area across all plots had increased to 25.4 m^2/ha (table 1). The number of saplings (trees < 0.1 m dbh) across the study area averaged 3079 trees/ha in 1994 falling to 1881/ha in April of 2005. Saplings contributed an additional 3, 2.6, and 2.5 m^2/ha to total stand basal area in 1994, 1999, and 2005, respectively (table 1). In 1994, *Acer rubrum* L. and *Cornus florida* L. made up 59 percent of all saplings and 53 percent of the sapling basal area (Hanson and others 2001).

PROCEDURES

Chronic Precipitation Manipulation

The Throughfall Displacement Experiment (TDE) is a multi-year chronic precipitation manipulation study. It was constructed across a 2-ha portion of an upper sub-catchment of the Walker Branch Watershed in 1992 and 1993. The site was chosen because of its uniform slope, consistent soils, and a reasonably uniform distribution of vegetation. The TDE system and its performance are described in detail by Hanson and others (1995, 1998, 2003a). Early aerial photographs show that the TDE study area was forested in 1935, but several large dominant trees show open-growth characteristics, confirming that selective cutting along the ridge had been done before that time (Dale and others 1990).

Manipulations of throughfall amounts reaching the forest floor were made by passively transferring a fraction of the throughfall from one experimental plot to another. There were three (80 x 80 m) experimental plots: one wet, one dry, and one ambient. Each plot was divided into 100 8 x 8 m subplots that served as locations for repetitive, nondestructive measurements of soil and plant characteristics. An 8 m buffer zone around the edge of all plots (16 m between plots) was treated but not used for the observations of tree and sapling growth. On the dry plot, throughfall precipitation was intercepted in ~1900 below-canopy troughs (0.3 x 5 m) made of greenhouse grade polyethylene that was suspended at an angle above the forest floor (~33 percent of the ground area was covered). The intercepted throughfall was transferred by gravity flow across the ambient plot and distributed onto the wet treatment plot through paired drip holes spaced approximately 1 m apart.

The experimental area was located at the upper divide of the watershed so that lateral flow of water into the plots from upslope did not occur. The site had a southern aspect. Reductions in soil moisture anticipated from the experimental removal of 33 percent of the throughfall were designed to be comparable to the growing season having the lowest recorded rainfall during the dry 1980s decade (Cook and others 1988).

Acute Precipitation Manipulation

Because results of the TDE study (Hanson and others 2001) showed greater than expected resilience of tree growth in response to chronic drought, a follow up study was conceived to quantify responses to acute soil water deficits. This study termed the 'TARP' study used understory tents for the removal of 100 percent of the growing-season throughfall and stem flow from large, individual canopy trees. Two species representative of two distinct plant functional types *L. tulipifera* (yellow-poplar) and *Q. prinus* (chestnut oak) were manipulated (n = 4 for each species treatment combination). Each treatment ambient plot area was the same, and exceeded the projected canopy spread for the largest trees. Each tent covered an area with a minimum circular radius of 10 m from the target tree bole. The TARP tents and water collection gutters were installed before leaf-out in March of 2003 and have been left in place through the 2005 growing season. Photographs of the experimental system are available at the following web site: http://tarp.ornl.gov.

Table 1—Cumulative basal area of (A) individual tree species > 0.1 m d.b.h. and (B) saplings for the Throughfall Displacement Experimental area in March 1994, December 1999, and April 2005[a]

	Cumulative basal area		
Species	March 1994	December 1999	April 2005
	$m^2\ ha^{-1}$		
(A) Trees > 0.1 m d.b.h.			
Acer rubrum L.	2.40	2.92	3.39
A. saccharum Marsh.	0.56	0.66	0.72
Carya sp.	0.44	0.42	0.46
Cornus florida L.	0.16	0.13	0.11
Liriodendron tulipifera L.	1.64	1.62	1.82
Nyssa sylvatica Marsh.	2.97	3.07	3.26
Oxydendrum arboreum [L.] D.C.	0.77	0.83	0.86
Prunus serotina Ehrh.	0.11	0.16	0.22
Quercus alba L.	4.17	4.95	5.04
Q. prinus L.	5.72	6.02	7.09
Q. sp.	2.04	1.83	2.18
Misc. conifers	0.15	0.15	0.17
Misc. hardwoods	0.00	0.04	0.08
Total trees	21.15	22.80	25.40
(B) Saplings are plants > 1 m and < 0.1 m d.b.h.			
Acer rubrum L.	0.97	0.96	1.11
A. saccharum Marsh.	0.05	0.06	0.07
Carya sp.	0.02	0.02	0.06
Cornus florida L.	0.62	0.49	0.31
Fagus grandifolia J.F. Ehrh.	0.03	0.05	0.07
Nyssa sylvatica Marsh.	0.36	0.30	0.22
Oxydendrum arboreum [L.] D.C.	0.29	0.30	0.25
Prunus serotina Ehrh.	0.19	0.15	0.14
Quercus sp.	0.14	0.12	0.10
Q. alba L.	0.04	0.04	0.04
Q. prinus L.	0.01	0.01	< 0.01
Rhamnus sp.	0.16	0.11	0.03
Sassafras albidum (Nutt.) Nees	0.05	0.03	0.03
Miscellaneous	0.03	0.02	0.03
Total saplings	2.97	2.64	2.47
(C) Total basal area	23.93	25.44	27.87

[a] A total of 18 tree species and 20 sapling species were present on the measurement plots, but some groups were combined for presentation in this table.

Trenching of the TARP plots was not done initially to avoid the artifacts of root severing and to allow external tree roots to continue to extract water from the target dry plots. In July of 2004 (following limited tree response to the acute treatments) the TARP treatment plots were trenched with a ditcher to a depth of 50 to 60 cm and width of 20 cm to eliminate potential lateral root water sources. This process severed 100 percent of the lateral roots over this depth representing more than 80 percent of the total know root population at this site (Joslin and Wolfe 1998).

Soil Water Content, Water Potential and Weather

Soil water content (percent, v/v) was measured in both studies with a time domain reflectometer (TDR; Soil Moisture Equipment Corp., Santa Barbara, California) following the procedure of Topp and Davis (1985) as documented for soils with high coarse fraction content (Drungil and others 1987). On the TDE, Three hundred ten sampling locations were installed at an 8 x 8 m spacing across the site giving more than 100 soil water monitoring locations per plot. For the TARP study, each experimental tree was instrumented with four TDR locations within the canopy drip line. Each of these TDR measurement sites consisted of two pairs of TDR waveguides installed in a vertical orientation (0-0.35 and 0-0.7 m). The surface (0-0.35 m) TDR measurements coincide with the zone of maximum root density in these soils. TDR measurements were obtained biweekly during the growing season and approximately monthly during the dormant season on the TDE study, and periodically during physiological campaigns for the TARP study. Automated hourly observations of soil water status were also logged using heat-dissipation probes (CS615 water content reflectometer; Campbell Scientific, Logan, Utah) installed in vertical profiles within each of the TDE and TARP treatment plots.

The TDR soil water content measurements were adjusted for the coarse fraction of these soils (mean coarse fraction of 14 percent) and converted to soil water potentials using laboratory derived soil moisture retention curves for the A, A/E and E/B horizons (Hanson and others 2003a). To facilitate comparisons of the severity of soil water deficits between years, the minimum soil water potential (MPa) and calculate a water stress integral (units of MPa d; Hanson and others 2003a) were measured or estimated for all years and treatments.

Weather data including air temperature, relative humidity, and soil temperatures (0.1 and 0.35 m) were logged hourly on each treatment plot. Rainfall, solar irradiance (Pyranometer sensor, LiCor Inc., Lincoln, NE) and photosynthetic photon flux density (Quantum sensor, LiCor Inc.) were also measured continuously and logged as hourly means for one above-canopy location in the vicinity of both experiments.

Measurements of Tree Growth

Diameter measurements of all individual trees greater than 0.1 m dbh and a record of their presence/mortality were recorded annually for the TDE experiment. *Quercus alba* L., *Q. prinus* L., *A. rubrum*, *L. tulipifera*, and *Nyssa sylvatica* trees greater than 0.2 m dbh were fitted with dendrometer bands (170 trees) for biweekly measurements of stem circumference during each growing season as described by Hanson and others (2001). These five species made up almost 80 percent of the basal area of the experimental area (table 1). Similar dendrometer band measurements were conducted for all *Q. prinus* and *L. tulipifera* trees manipulated as a part of the TARP study.

Measured changes in the circumference of each tree were combined with information on its initial stem diameter to obtain the change in stem basal area over time (cm^2 per year). All dendrometer bands were installed during the dormant season, ahead of the initial growth measurements, to eliminate potential first year bias in the dendrometer band measurements (Keeland and Sharitz 1993). This paper focuses on cumulative annual tree growth data and shrink/swell patterns capable of being measured by dendrometer bands are not important to the current discussion.

Statistical Analyses

The unreplicated nature of the TDE is not ideal (Hurlbert 1984), but the resulting pseudoreplication is recognized as a reasonable approach when costly large-scale experimental field designs are undertaken

(Eberhardt and Thomas 1991). To minimize the possibility that spatial variation would be confounded with treatment effects, the TDE observations were preceded by judicious selection of homogeneous sites (considering aspect, vegetation, and soils), detailed characterization of site environmental parameters, and pretreatment measurements for key response variables (Hanson and others 2001). Growth responses on the TDE were analyzed using individual trees growth (n = 200 to 250) as the experimental unit. In support of the use of individual trees as the experimental unit, Hanson and others (1998, 2001, 2003a) demonstrated that the individual 8 x 8 m resolution soil water measurements across the TDE plots were not correlated with each other and could therefore be treated as independent measurements. Nevertheless, to further account for bias in growth rates caused by pretreatment plant size and growth rate, the initial basal area of individual saplings was used as a covariate in analysis-of-variance tests of treatment effects. Such covariates were significant and appropriate for their intended purpose.

The TARP study was conducted on fully replicated mature trees with randomly assigned ambient or dry-plot treatments. One-way analysis of variance with covariates based on initial basal area was used to evaluate significant annual growth responses in the TARP study. Additional regression analyses relating individual tree responses to tree-specific soil water content data are planned for a future paper. Statistical analyses were conducted with SPSS 6.1 for Macintosh (SPSS, Inc.).

RESULTS AND DISCUSSION

Interannual Weather 1993 to 2005

Weather conditions exhibited substantial interannual variation from 1993 through 2005 (Hanson and others 2003, http://tde.ornl.gov/tdedata.html). Lower-than-average annual precipitation was measured in 1993 (-16 percent), 1995 (-16 percent), 1998 (-9 percent), 1999 (-15 percent), 2000 (-11 percent), and 2001 (-27 percent). Above-average precipitation was observed in 1994 (+24 percent), 1996 (+21 percent), 1997 (+8 percent), 2003 (+13 percent), and 2004 (+7 percent). Growing-season precipitation (May to September) was near normal in 1994, 1999, 2000, 2002, and 2004, but it was 26 to 38 percent less during the drought years of 1993, 1995, and 1998. Growing-season precipitation was 47, 22, and 29 percent higher than normal in 1996, 1997, and 2003, respectively. Mean annual air temperature and annual incident solar radiation were not as variable as annual precipitation, but mean annual air temperatures in 1993, 1998 and 2002 were warmer than in the other years. Cumulative annual incident solar radiation at the site was similar across years ranging from 2643 to 3155 MJ m-2.

Observed Patterns of Soil Water Potential

The seasonal patterns of mean TDR soil water potential by treatment in the 0 to 0.35 and 0.35 to 0.7 m depth increments from 1993 through August of 2005 are shown for the TDE and TARP manipulations in figures 1 and 2, respectively. Minimum daily soil water potentials for the 0 to 0.35 m depth showed that significant ambient drought occurred in 1993, 1995, 1998, 1999, 2000, and 2002 (sustained values below -0.7 MPa in figure 1). In years with significant dry periods (1993, 1995, 1998, 1999, and 2002), long periods without rainfall caused treatment differentials to be minimized. Following the depth of drought, treatment differences redeveloped as the soils refilled at a faster and slower rate on the wet and dry plots, respectively. No treatment differences were ever observed during the dormant seasons when all soils returned to field capacity.

Water in the 0.35 to 0.7 m depth remained available for plant use throughout the drought periods in all years with consistent evidence of reduced water availability at depth observed only during the severe late-season droughts of 1998 and 2002. Annual water stress integrals (Hanson and others 2001, 2003a), which account for the duration of drought, demonstrate that the 1993, 1999, and 2002 droughts (-92, -31 and -114 MPa d, respectively) were not sustained as long as those occurring in 1995 and 1998 (-168 and -217 MPa d, respectively).

Acute soil moisture treatments associated with the TARP study diverged from ambient plot conditions within one month after the initiation of treatments in 2003 and 2004 (fig. 2). Surface soils were allowed

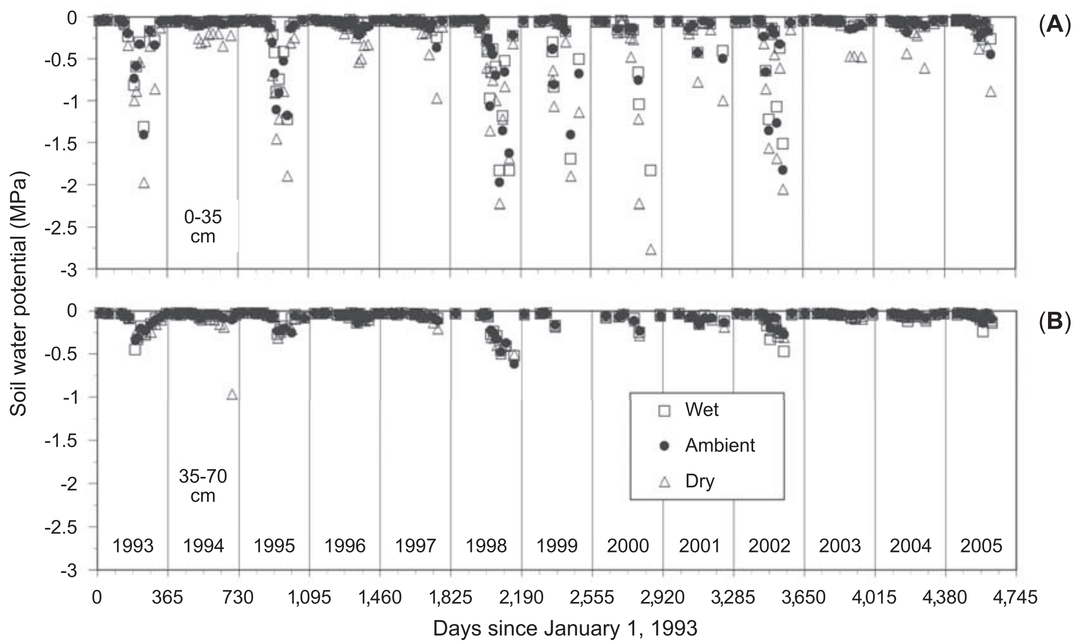

Figure 1—(A) Soil water potentials for the 0- to 0.35-m and (B) 0.35- to 0.7-m soil depth from 1993 through 2005. Data are the mean values (n = 100 or 30 starting in 2001) for the wet, ambient, and dry plots of the throughfall displacement experiment (TDE). Treatments were initiated on July 14, 1993.

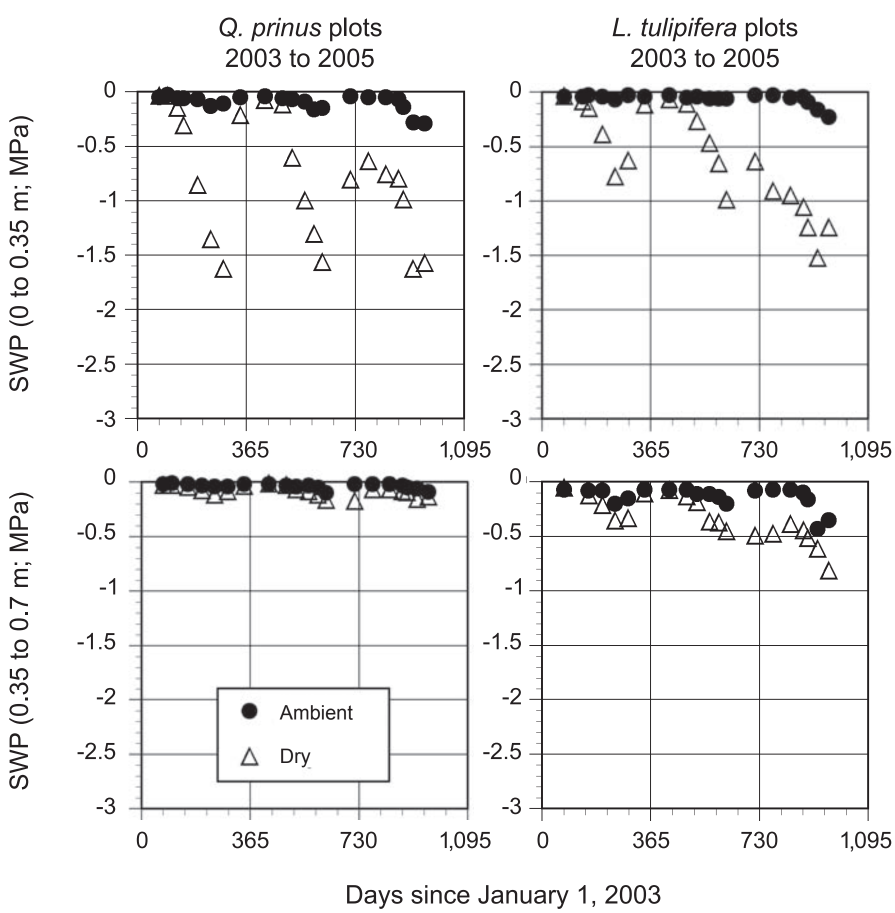

Figure 2—Pattern of soil water potential in the 0- to 0.35-m and 0.35- to 0.7-m for the TARP study from 2003 through 2005.

to return to field capacity during the winter of 2003/2004, but were maintained at acute drought levels throughout the winter of 2004/2005. Partial refilling of surface-soil water stocks in February and March of 2005 was evident the dry plots of the *Quercus* plots and was presumed to result from hydraulic redistribution (Burgess and others 1998) via roots having access to deep water supplies.

Responses to Chronic Precipitation Change

Through 12 years of chronic manipulations, individual tree annual growth, measured on a subset of trees with dendrometer bands, remained unaffected by natural or induced rainfall deficits even though severe drought conditions were observed to dramatically reduce canopy function in some years (Wilson and Hanson 2003). Hanson and others (2001, 2003b) showed that the observed resilience of these upper-canopy *Acer*, *Nyssa*, *Liriodendron, and Quercus* trees was the result of a disconnect between their early-summer growth phenology and normal late-season occurrence of drought.

Analysis of cumulative tree basal area growth over the entire experimental period from 1993 through 2005, however, showed a significant influence of the TDE precipitation treatments (fig. 3). Dry plot tree growth was lower than both the ambient and wet treatments, but wet plot growth did not exceed ambient growth. Tree size did not have a dramatic influence on the response to chronic precipitation manipulations. Although not justified in this paper, current analyses of element cycles for the TDE suggest that long-term chronic increases in precipitation may increase leaching of beneficial base cations (Johnson and others 2002), and drought conditions may lead to immobilization of mineral elements (Paul J. Hanson, unpublished data). Both processes could lead to reductions in growth over time.

Responses to Acute Precipitation Change

Results from the TDE study led us to hypothesize that an acute early spring precipitation deficit would force drought conditions to overlap tree growth phenology on Walker Branch and lead to significant current-year growth reductions. The acute precipitation exclusion in the TARP experiment, however, produced limited growth (fig. 4) or physiology effects through three consecutive growing seasons (data not shown). The TARP growth data provide further evidence of the resilience of upland-oak canopy trees to drought on Walker Branch.

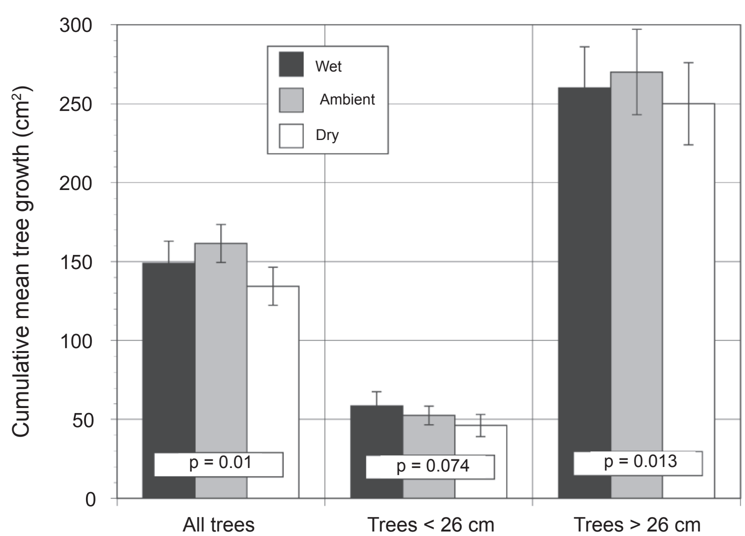

Figure 3—Cumulative individual tree basal area growth (cm^2 ± 95 percent C.I.) from 1994 through 2005 as a function of the chronic throughfall displacement experiment (TDE) treatments for all defined trees (woody plants > 10 cm d.b.h.), and the same analysis for defined trees < or > 26 cm d.b.h.

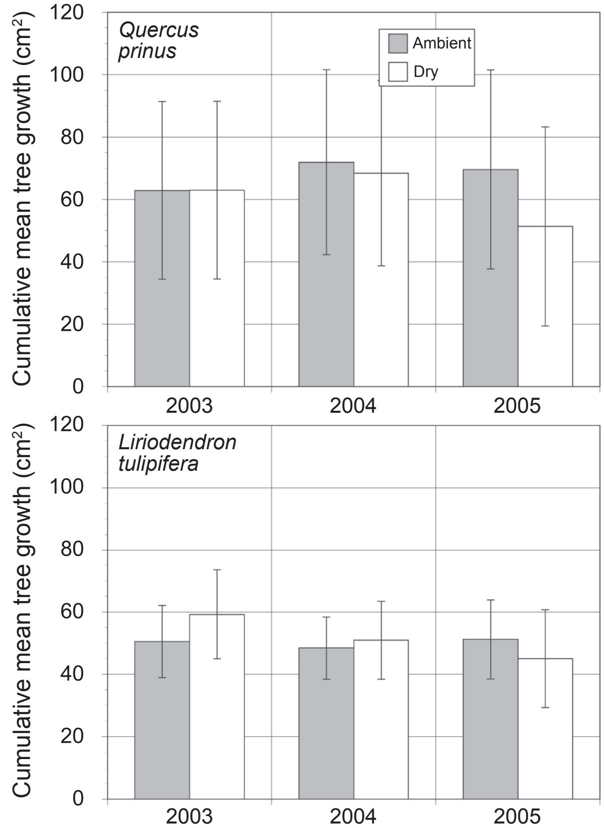

Figure 4—Annual cumulative tree growth (cm^2 ± 95 percent C.I.) for *Quercus prinus* (upper box) and *Liriodendron tulipifera* (lower box) trees in response to the acute precipitation manipulations (100 percent growing-season removal) of the TARP study in 2003, 2004, and 2005.

Trenching around each dry-plot tent midway through the 2004 growing season was conducted to determine if lateral root water sources were responsible for the resilience of the trees exposed to acute droughts. The manipulation showed no negative influence on continuous observations of water use by the sapflow method (Wullschleger and Hanson, in press) and allowed for the conclusion that deep rooting must be a key mechanism for large-tree resilience to severe drought. Although such a conclusion is common for woody plants in dryland ecosystems of the western United States and deep roots are known for oak forests (Phillips 1963, Stringer and others 1989, Canadell and others 1996), such a conclusion was unexpected for the upland-oak forest of Walker Branch for two reasons (1) measured root densities at depth were very low at this site, and (2) dramatic canopy physiological effects and leaf senescence were observed during the drought of 1998 when deep soil moisture was non-limiting. The TARP manipulations, however, clearly demonstrate that the largest individual *Q. prinus* and *L. tulipifera* trees in this forest have an effective mechanism for the extraction of deep soil water resources. Observations to quantitatively evaluate the presence and water transport capacity of roots below 90 cm for the Walker Branch forest are underway.

Conclusions Relevant To Ecosystem Modeling

In their current form, ecosystem models used for assessments of the impacts of climatic change on eastern forests overestimate the severity and influence of precipitation deficits on the upland forests of Walker Branch (Hanson and others 2004). The precipitation manipulation experiments on Walker Branch demonstrate the following needed improvements to ecosystem models of eastern deciduous forests: an understanding of the timing of growth phenology and drought, an improved characterization of root hydraulic architecture and soil water supplies with depth, and the need to understand how stored nonstructural carbohydrate (Tschaplinski and Hanson 2003) and element reserves vary form year to year and when such pools become limiting to current-year growth.

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CARBON DIOXIDE FLUXES IN A CENTRAL HARDWOODS OAK-HICKORY FOREST ECOSYSTEM

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Abstract—A long-term experiment to measure carbon and water fluxes was initiated in 2004 as part of the Ameriflux network in a second-growth oak-hickory forest in central Missouri. Ecosystem-scale (~ 1 km^2) canopy gas exchange (measured by eddy-covariance methods), vertical CO_2 profile sampling and soil respiration along with meteorological parameters were monitored continuously. Early results from this forest located on the western margin of the Eastern Deciduous Forest indicated high peak rates of canopy CO_2 uptake (35-40 μmol/m^2/second) during the growing season in the relatively wet year of 2004. Late growing-season CO_2 uptake rates declined despite the absence of drought, suggesting declining leaf photosynthetic capacity that preceded leaf fall or removal of leaf area by herbivory. Canopy CO_2 profile measurements in summer indicated substantial accumulation of CO_2 (~ 500 ppm) near the surface in still air at night, venting of this buildup in the morning hours under radiation-induced turbulent air flow, and small vertical gradients of CO_2 during most of the subsequent light period with minimum CO_2 concentrations in the canopy. Flux of CO_2 from the soil ranged from 2 to 8 μmol/m^2/second during the growing season and increased with temperature. Flux of forest floor CO_2 fell below 1 μmol/m^2/second during mid-winter periods. Data from this site and others in the network will also allow characterization of regional spatial variation in carbon fluxes as well as inter-annual differences attributable to climatic events such as droughts.

INTRODUCTION

Traditionally, foresters have assessed the economic value of forests based on quantity and quality of stem wood production. While this assessment remains an important perspective on resource use, there are other approaches that have both economic and ecological utility. The eddy-covariance (EC) technique to monitor exchanges of CO_2, water vapor, and heat at the interface between vegetation and the atmosphere allows a more complete accounting of carbon balance in forest ecosystems (Baldocchi and others 1988, Baldocchi 2003). As carbon uptake or loss is the primary determinant of productivity of forest ecosystems, EC measurements can provide a valuable tool for foresters, forest ecologists and those interested in assessing the capacity of forests to sequester carbon. The latter may be of increasing economic importance as greenhouse gas emissions force climate change.

In the Central Hardwoods Region there are now at least three EC sites operating in forest ecosystems (Walker Branch, TN; Morgan Monroe State Forest, IN; Missouri Ozarks, MO). The Missouri site is the most recent addition and a primary objective of the project is long-term quantification of carbon fluxes of a Central Hardwoods forest in this forest-prairie transition region expected to be limited by water availability. The site has been operating since June of 2004 and data are now available to illustrate the potential value of such research to the forestry community.

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STUDY AREA

The Missouri Ozark Ameriflux site (MOFLUX) site (38°40' N, 92°12' W) is located in the Ozark Border physiographic region at the Baskett Research and Education Area (BREA, owned and managed by the University of Missouri) 30 km SE of Columbia, Missouri, USA. The vegetation at the site, assessed both by long term permanent plot measurements distributed across the BREA (Pallardy and others 1988, Pallardy and Coonley 2005) and from plots placed on spoke-like transects within the footprint of the tower (unpublished), is an oak-hickory forest dominated by white oak (*Quercus alba* L.) and with contributions of several other oak species (black oak, *Q. velutina* Lam.; northern red oak, *Q. rubra* L.; Shumard oak, *Q. shumardii* Buckl.; chinkapin oak, *Q. muehlenbergii* Engelm.; and post oak, *Q. stellata* Wangenh.) and hickories (primarily shagbark hickory, *Carya ovata* [Mill.] K. Koch). A dense understory of sugar maple (*Acer saccharum* Marsh.) is found beneath the canopy, along with eastern redcedar (*Juniperus virginiana* L.) (the latter in localized disturbed areas). Vegetation sampling in the footprint of the eddy flux tower at the site indicated tree density of 583 trees/ha (≥ 9 cm dbh) and tree basal area of 24.2 m^2/ha. Canopy height ranges from 17 to 20 m and leaf area index, measured by leaf litter collection, is about 4.2. Dominant soils are a broadly distributed type classified as Weller silt loam and another type "Steep Stony Land" localized to limestone outcrop areas (Krusekopf and Scrivner 1962). Ridges alternate with relatively gentle side slopes leading to ephemeral streams in shallow valleys with a total local elevation range of 175-245 m across the area. The climate of the area is warm, humid and continental. The monthly mean temperature (1971-2000) is –2.3 °C in January and 25.2 °C in July (http://www.ncdc. noaa. gov/oa/climate/online/ccd/nrmavg.txt). Annual precipitation averages 1023 mm from 1971 to 2000 (http:// www.ncdc.noaa.gov/ oa/climate/online/ccd/nrmocp.txt). The study site is centered on a SW facing ridge with gently sloping SE- and NW-facing sides surrounded by a basin about 1 km in diameter. The eddy flux tower is located at the top of this elongated ridge roughly in the center of the basin.

MEASUREMENTS

An EC system is installed at a height of 30.48 m at the top of a walkup tower. It consists of a R. M. Young 81000 three-dimensional sonic anemometer (R. M. Young Company, Traverse City, MI, USA) and a LI-7500 open path gas analyzer (LI-COR Inc., Lincoln, NE, USA). Data are recorded at 10 Hz by a personal computer sheltered at the base of the tower. Vertical fluxes of CO_2, water vapor, temperature and momentum are computed every 30 minutes after two-dimensional coordinate rotation to eliminate errors in fluxes attributable to sonic anemometer tilt relative to the terrain surface, despiking to remove spurious extreme values occasionally produced by the sonic anemometer and CO_2 analyzer, and Webb correction of CO_2 concentrations to adjust for the effects of temperature and water vapor fluxes on CO_2 density (Webb and others 1980).

Also in operation is a CO_2/water vapor profile sampling system. Atmospheric CO_2 concentration and water vapor content are measured by a LI-7000 gas analyzer (LI-COR Inc., Lincoln, NE, USA) at heights of 0.15, 0.30, 0.61, 0.91, 1.52, 3.05, 6.1, 9.14, 12.19, 16.76, 22.86 and 30.48 m. Samples are drawn through Teflon tubing progressively from top to bottom in a continuously recurring cycle. These measurements allow continuous monitoring of the dynamic vertical CO_2 gradient within the ecosystem for estimation of CO_2 storage and correction of eddy-covariance flux data to provide Net Ecosystem Exchange (NEE) of CO_2.

Soil respiration is monitored continuously with an automated system that samples eight tip-down chambers of the design by Edwards and Riggs (2003) that are distributed 30-40 m from the tower along the SE slope.

RESULTS AND DISCUSSION

Eddy-covariance measurement of CO_2 flux is based on very fast (10-20 Hz) measurements of both vertical air movement and CO_2 concentration at the tower top (Aubinet and others 2000, Baldocchi and others 1988, Baldocchi 2003). For example, upward air movement away from the canopy combined with a concurrent fall in CO_2 concentration, or downward air movement into the canopy combined with an increase of CO_2 concentration, indicates depletion of CO_2 of the air below and therefore net CO_2 uptake in photosynthesis. Raw data are usually processed to provide half-hourly values of CO_2 and H_2O flux.

The daily march of EC CO_2 flux data (fig. 1) often shows a distinct pattern. Still air at night results in buildup of CO_2 near the surface by plant and heterotrophic respiration. This dynamic pattern is captured by the profile sampling system which draws air samples from the tower top to the forest floor (fig. 2). Nighttime buildups of CO_2, which can reach 500 µmol/mol or more, are subsequently vented upward (indicated by negative flux values) early the next morning as increasing solar radiation induces increased turbulence and higher daytime wind velocities (fig. 1). Venting is followed by photosynthetic uptake of CO_2 that under well-watered, sunny conditions roughly follows the sinusoidal pattern of solar illumination of the forest canopy. Daytime minimum CO_2 concentrations in the profile are located within the canopy between 5 and 18 m (fig. 2).

Nighttime accumulation of CO_2 near the surface reflects intense respiration from the soil, especially during the growing season (fig. 3A). Soil respiration ultimately depends on the fixed carbon inputs provided by plant litter and carbohydrate translocation to the root system in living trees. However, environmental controls on the process are also quite important. In winter (fig. 3B) low temperatures limit daily mean soil respiration to less than 1 µmol/m^2/second, whereas in summer, when soil temperatures may exceed 25 C in the upper soil (fig. 3A), the daily rate may reach 8 µmol/m^2/second or more. Soil water content may reduce soil respiration independent of temperature (Hanson and others 2003), but during the wet year of 2004 there was little evidence of such limitation at the Missouri site (fig. 3). Interestingly, heavy rain (in the present study >37 mm over the course of a day) may temporarily restrict loss of CO_2 from the soil surface by the formation of a diffusion cap that presumably arises from filling of the soil pore space with water (see arrows in fig. 3A).

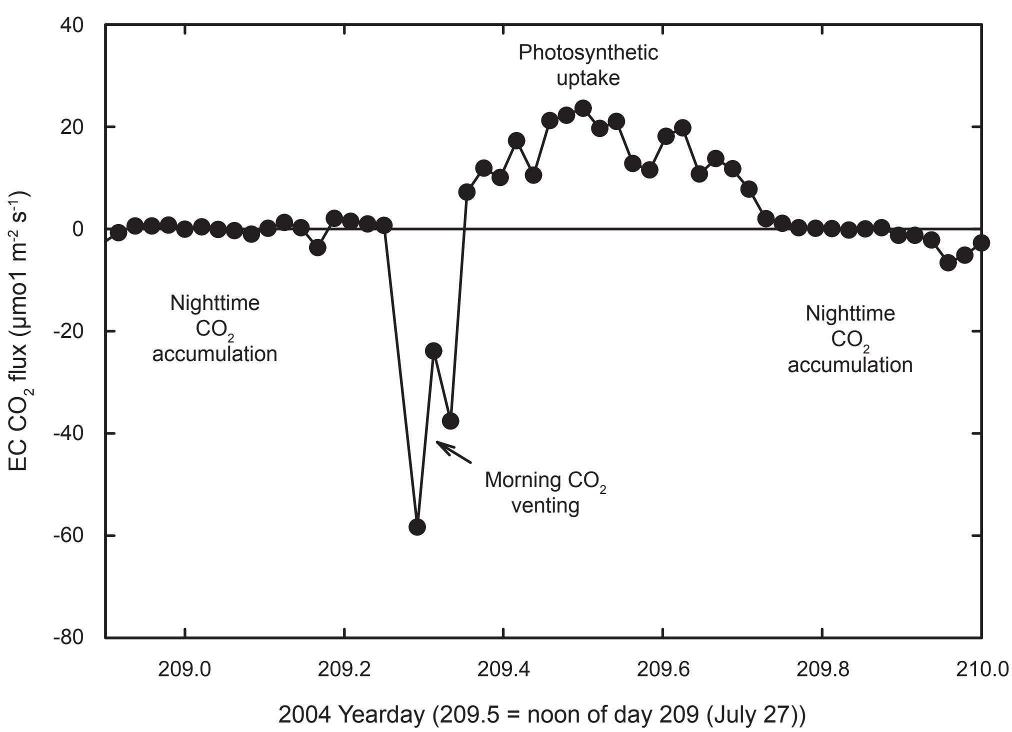

Figure 1—Typical diurnal pattern of CO_2 flux derived from eddy-covariance (EC) measurements at the tower top (30.48 m) at the Missouri Ozark Ameriflux site.

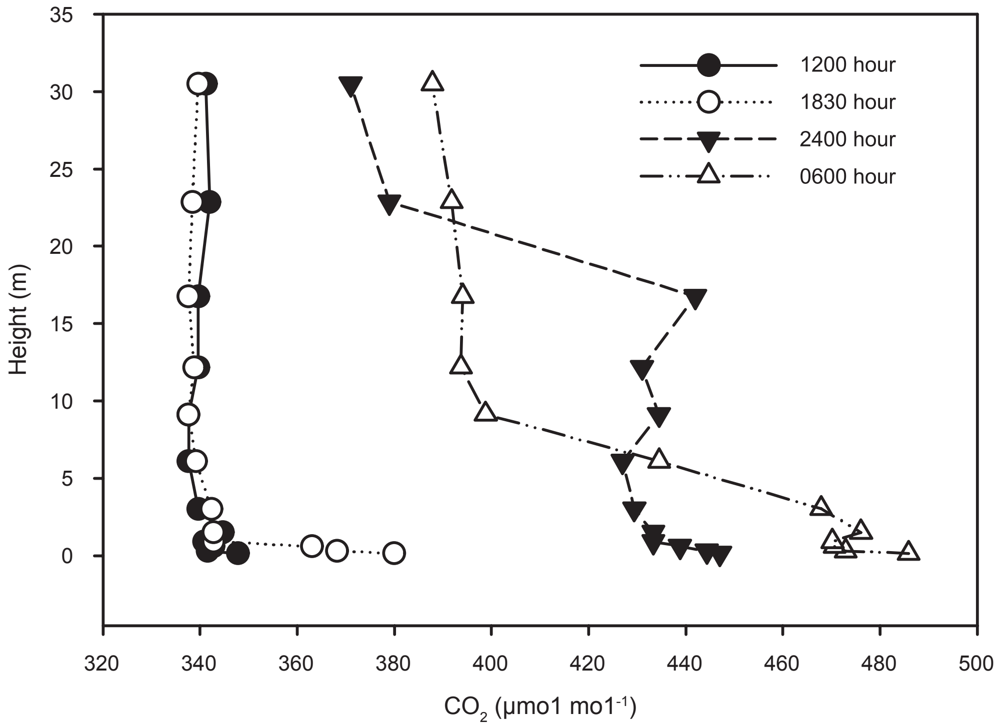

Figure 2—Vertical profiles of CO_2 concentration measured with the Missouri Ozark Ameriflux site CO_2 profile sampling system at four representative times during the diurnal cycle of CO_2 exchange on day 175 (June 23, 2004).

Peak EC CO_2 fluxes at the Missouri site reached 35-40 μmol CO_2/m^2/second during the 2004 growing season (fig. 4), values that are surprisingly high considering its location in the relatively xeric western reaches of the Central Hardwoods region. These flux values are comparable with flux data for CO_2 from deciduous forest EC sites elsewhere (Baldocchi and others 2001, Curtis and others 2002, Ehman and others 2002, Schmid and others 2000, Wilson and Baldocchi 2001). The data in figure 4 also reinforce the recurring nature of the diurnal pattern described in figure 1.

When EC-based flux rates are adjusted for CO_2 storage in the vertical air column, an estimate of NEE of CO_2 can be derived. Mean daily NEE data for CO_2 from the initiation of measurement in mid-June 2004 through the end of the year are shown (fig. 5). The seasonal pattern of NEE is clearly observable through the leaf-on season which ends by mid-October (Day 290). Interestingly, late growing season NEE was reduced despite a lack of limitation by soil water availability or temperature (e.g., Days 200-250). Modeling of NEE based on photosynthetic process models (Gu and others 1999) did not explain all of this reduction and it is possible that the deviation may be attributable to senescence-related metabolic changes although it precedes any visible signs of autumn coloration, or because of leaf area removal by herbivory. Seasonal variations in foliar photosynthetic capacity consistent with this pattern have been observed in eastern Tennessee by Wilson and others (2000). In early winter, NEE values hover around zero, likely reflecting a balance between some residual CO_2 uptake by the evergreen *Juniperus virginiana* on the site and wintertime soil respiration (fig. 3B).

The data provided by the suite of instrumentation on this site enable a comprehensive understanding of short-term dynamics and mid-to-long term drivers of forest productivity. Straightforward integration of NEE on an annual basis provides an independent estimate of ecosystem productivity to compare with conventional biometric (e.g., dendrometer band estimates of growth and whole-tree biomass accounting based on destructive sampling) and the status of a particular forest as a source or sink for CO_2. Once

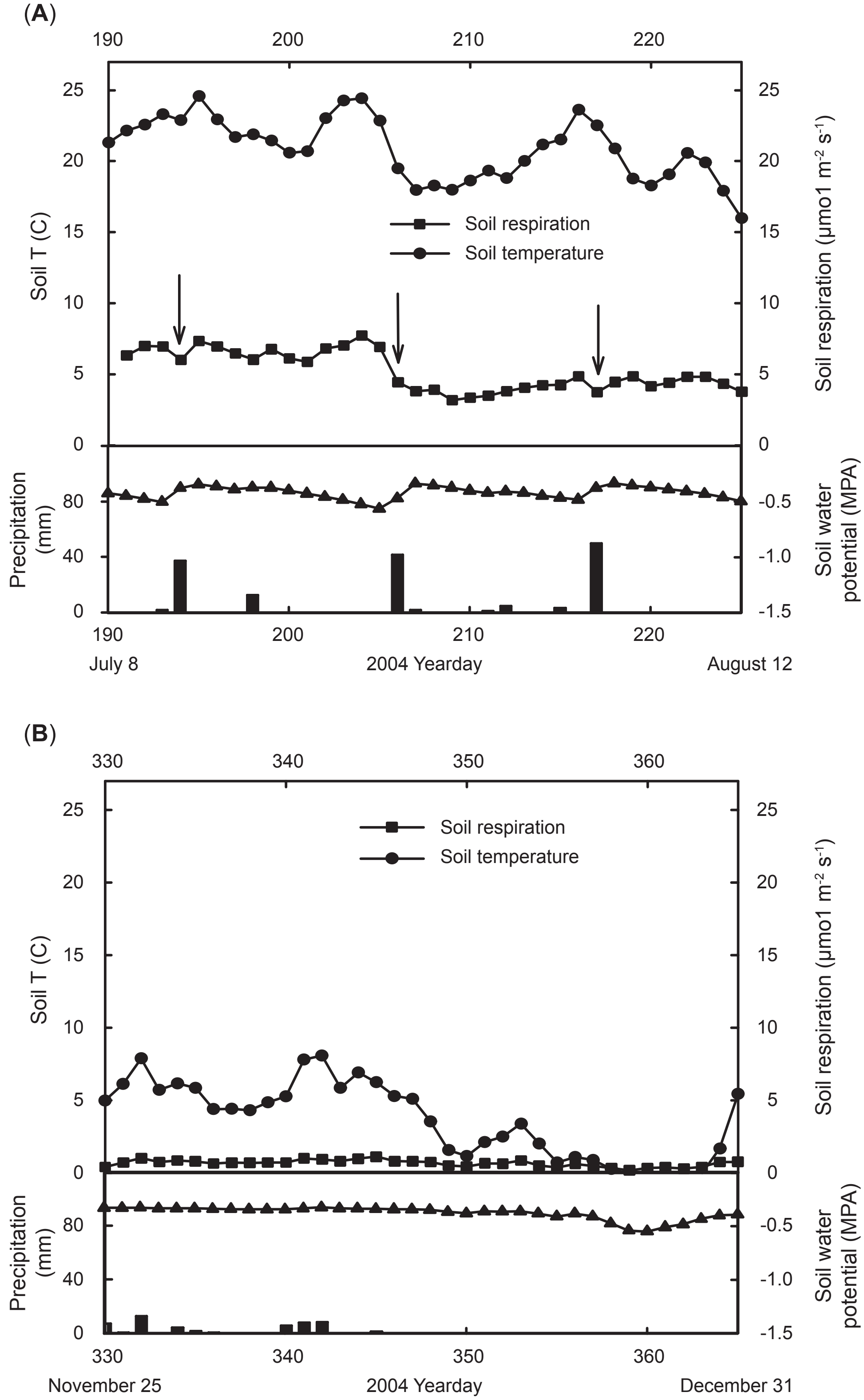

Figure 3—Thirty-five-day traces of soil respiration, soil temperature at 5 cm depth, soil water potential in the upper 30 cm, and precipitation events for the growing season (A) and the dormant season (B) of 2004 at the Missouri Ozark Ameriflux site [arrows in (A) indicate rain events that were associated with dips in soil respiration].

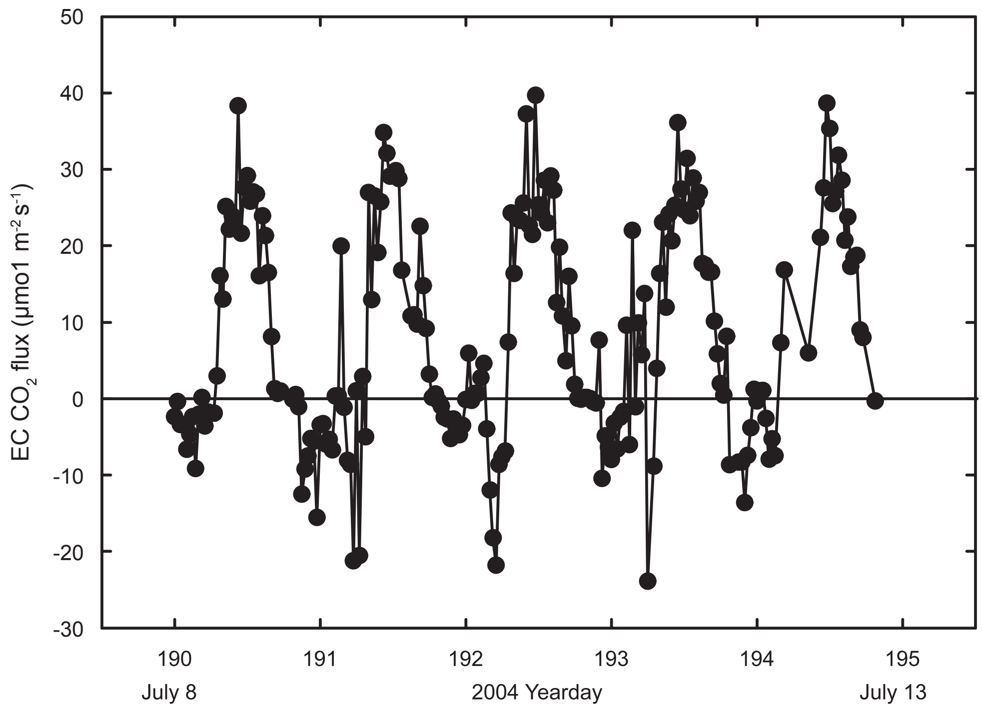

Figure 4—Eddy-covariance (EC) CO_2 fluxes for 5 days in midsummer 2004 at the Missouri Ozark Ameriflux site (compare with figure 1).

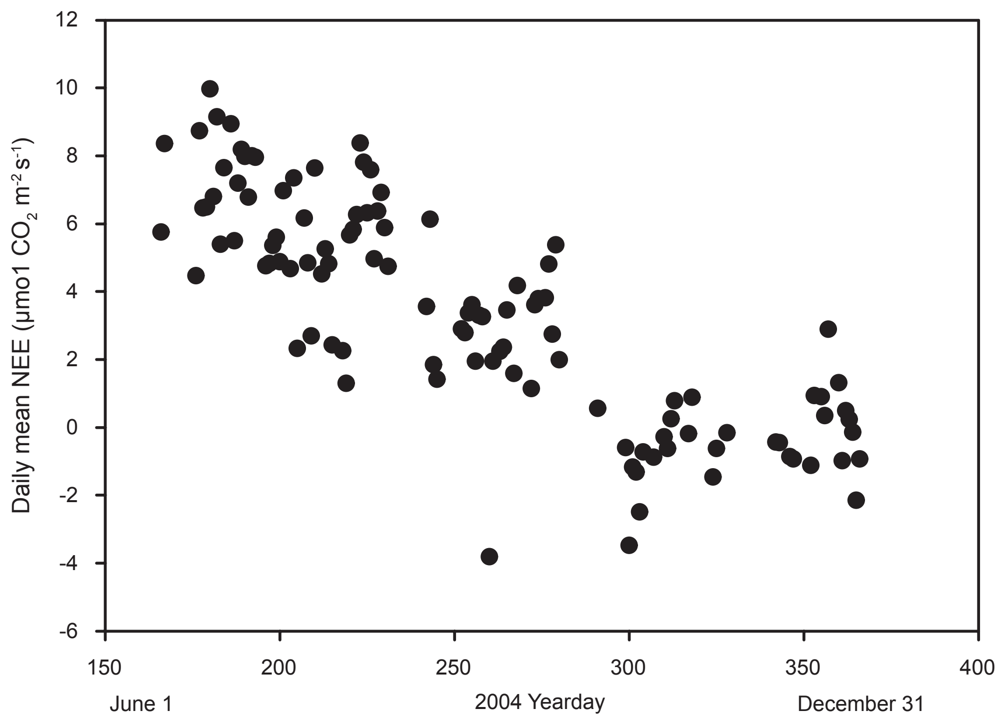

Figure 5—Mean daily net ecosystem exchange (NEE) of CO_2 at the Missouri Ozark Ameriflux site based on eddy-covariance CO_2 flux data corrected for CO_2 storage as estimated with the CO_2 profile system.

an adequate data set is in hand, models can be developed that accurately predict CO_2 exchange based on conventional meteorological variables as drivers (Gu and others 1999, Hanson and others 2004). In this way, CO_2 exchange at a regional scale can be estimated for forest ecosystems with similar species composition. We are also in the process of building biometric data sets against which to contrast annual NEE data as an independent test of the eddy-covariance method to resolve net carbon exchange in this forest.

Although this approach to ecosystem–level carbon exchange has much promise, some issues remain to be worked out. For example, if the topography of the site is dissected and prone to night drainage air (so-called "complex terrain") then some CO_2 produced at night in still air will "leak" away unmeasured. Practical and theoretical methods are being developed to deal with these issues (Gu and others 2005).

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MENSURATION AND MODELS

Moderator:

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THE SINE METHOD AS A MORE ACCURATE HEIGHT PREDICTOR FOR HARDWOODS

Don C. Bragg[1]

Abstract—Most hypsometers apply a mathematical technique that utilizes the tangent of angles and a horizontal distance to deliver the exact height of a tree under idealized circumstances. Unfortunately, these conditions are rarely met for hardwoods in the field. A "new" predictor based on sine and slope distance and discussed here does not require the same assumptions for accurate height determination. Case studies using a sycamore (*Platanus occidentalis* L.), a water oak (*Quercus nigra* L.), and a southern red oak (*Q. falcata* Michx.) from southern Arkansas are presented to emphasize the sensitivity of the tangent method to erroneous measurement procedures. When heights were measured properly and under favorable circumstances, the results obtained by the tangent and sine methods differed only by about 2 percent. Under more challenging conditions, however, errors ranged from 8 to 42 percent. These examples also highlight a number of distinct advantages of using the sine method, especially when exact tree height is required.

INTRODUCTION

Tree height is one of the most conventional attributes of forest mensuration. Equipment and methods specifically designed to enumerate the vertical dimension of individual trees have been available since the earliest years of forestry (for example, Noyes 1916; Schlich 1911). Few people have questioned the application of these techniques because they are based on fundamental geometric or trigonometric principles. Given textbook definitions of tree height measurement under idealized circumstances, there seemed little need for criticism.

Unfortunately, the accuracy of height measurement has for too long been taken for granted. If carelessly applied, the conventional method of height determination is prone to significant errors. Even subtle violations of the assumptions of this technique (for example, an almost imperceptible lean in a tall tree) can produce noticeable departures from the exact height. In all fairness, it has only been in recent years that technology has caught up to the science behind tree height measurement, making it possible to control or eliminate this error (Blozan, W. 2004. Tree measuring guidelines of the Eastern Native Tree Society. Unpublished report. http://www.uark.edu/misc/ents/measure/tree_measuring_guidelines.htm. [Date accessed: August 20, 2005].

This paper briefly reviews the basic assumptions behind the traditional height measurement technique, including some that can lead to significant errors in height estimation. I will also describe a "new" estimator of height that uses a set of trigonometric relationships that is not sensitive to the same assumptions. Differences between the tangent and sine methods are illustrated in case studies of height measurements of hardwoods in southern Arkansas.

METHODS

Basic Height Measuring Principles

Mathematically speaking, hypsometers typically apply a technique that utilizes the tangents of angles and a horizontal distance to determine tree height. Figure 1 illustrates the basic principles of height determination. With accurate distance and angle measurements, tangent-based hypsometers determine total tree height (TanHT) as follows:

$$\text{TanHT} = [\tan(A) \times b] + [\tan(A') \times b] \qquad (1)$$

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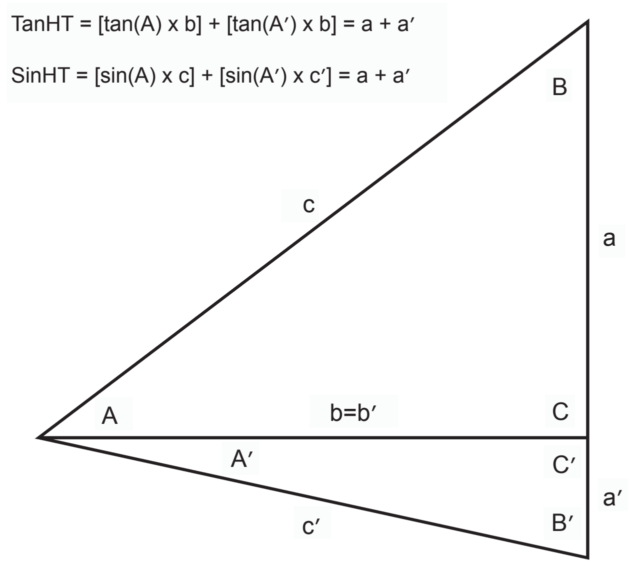

Figure 1—The trigonometric basis for height determination, using both the tangent method (TanHT equation) and the sine method (SinHT equation). Triangles ACB and A′C′B′ are both right triangles. On perfectly flat ground with a truly vertical tree, a + a′ = true tree height, b = horizontal distance, and c and c′ are slope distances.

where the angles A and A′ are measured in degrees, and the distance b is the true horizontal distance from the observer to the stem. Note that under ideal conditions (a tree with no significant diameter on a flat surface with a perfectly vertical stem and its highest living point centered over the bole (fig. 2), the tangent method produces an exactly correct standing height (Husch and others 2003).

However, these conditions are rarely met, especially with hardwoods. A very large proportion of trees lean, have bends or angles in their upper boles, or are found on sloping ground, and these departures from the ideal make it necessary to take corrective actions to predict true height using the tangent method (Falconer 1931, Krauch 1918). Crown asymmetry and shape can also cause problems (Husch and others 2003). For instance, many if not most large hardwoods (especially those growing in relatively open conditions) develop a widely spreading crown with no obvious apex. Under these circumstances, height measurements will almost invariably be taken from a point associated with an edge of the crown (rather than over the bole), biasing tree height estimates using the tangent method upward (fig. 3).

Few people actually adjust for ground slope, tree lean, or skewed crown apex in the field, and failure to make such corrections results in at least some degree of error. When corrections are applied, they are often more ad hoc than mathematically based. For instance, techniques to adjust for the unseen apex of a tree crown include measuring the highest visible limb or projecting through the crown towards an assumed crown peak, even though neither method ensures an actual representation of a real tree top. Some workers average multiple tangent measurements to estimate total height, but have no means to determine if their original numbers are reliable. Others willingly accept solitary tangent heights, knowing that they only need an approximate value.

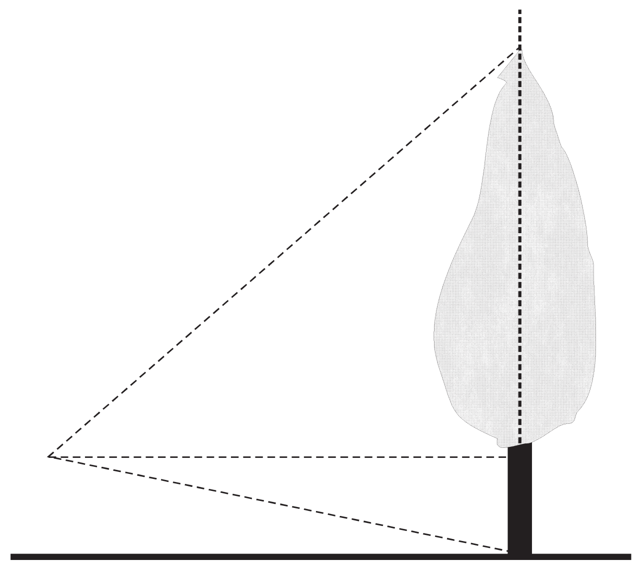

Figure 2—Idealized tree height measurement, where a perfectly vertical tree has its highest live crown directly over its stem. Under these specific circumstances, the tangent method will give exact tree height (without correction).

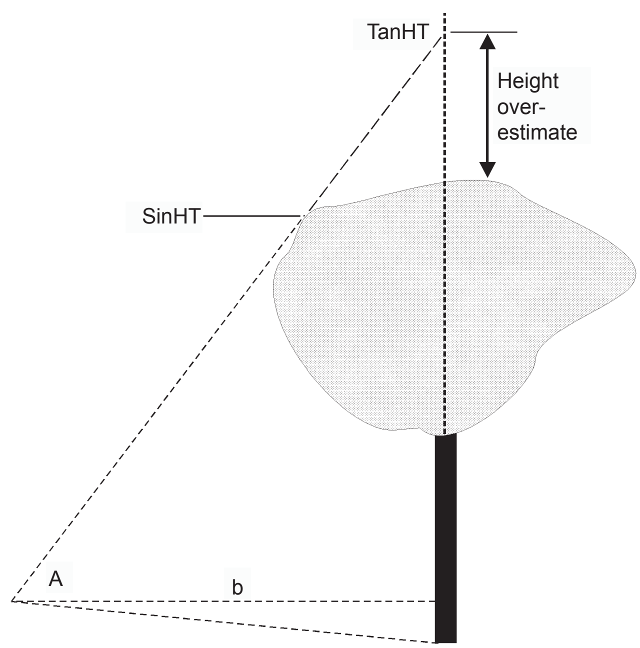

Figure 3—Overestimation bias from the tangent method of height measurement applied to a diffuse crown typical of most hardwoods. The tangent height (TanHT) relies on the angle A and horizontal distance b and projects a non-existent crown apex, which, without correction, overestimates tree height. A direct measurement of the crown intersection, the sine height method slightly underestimates true tree height.

Fortunately, there is a different technique based on slope distances and the sines of the angles capable of good height estimates under real-world field conditions. This estimator resembles the tangent-based approach, with some notable exceptions:

$$\text{SinHT} = [\sin(A) \times c] + [\sin(A') \times c'] \tag{2}$$

In this equation, c and c' are slope (not horizontal) distances, and the sine of angles A and A' is used (fig. 1). This technique is possible because accurate and inexpensive laser distance measuring equipment is now available and can be used to directly measure the slope distance to the highest and lowest points of the tree.

Under perfect conditions, TanHT = SinHT = exact standing tree height. However, the sine method is more reliable under less-than-ideal circumstances than the tangent method because it is based on an actual measurement to a real point on a crown, and does not involve projecting a hypothetical crown top based on an angle and a distance measurement (fig. 3). So long as the angles and slope distances are accurate, the trigonometry behind the sine method also ensures that only the true vertical height component is estimated, making the technique insensitive to the slope of the land, the lean of the tree, or the width of the crown (fig. 4).

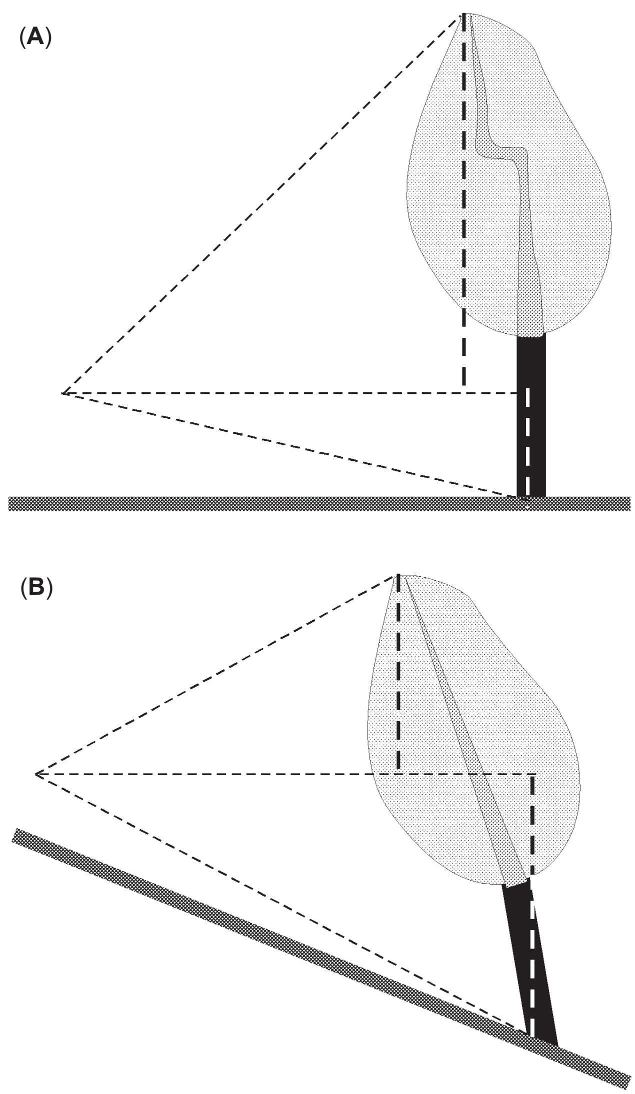

Figure 4—Diagram of how the sine method calculates true tree height for (A) an offset hardwood crown and (B) for a leaning hardwood with an offset crown on sloping ground. Uncorrected tangent-based measurements would overestimate height under both conditions.

Study Implementation

To illustrate the implications of different hardwood crown attributes for height estimates, sample trees were measured using a Laser Technology Impulse 200LR™ laser rangefinder. The 200LR was chosen for its high degree of distance (± 0.2 feet at 1885 feet) and angular (± 0.1 degree) accuracy (Carr 1996). The default height function incorporated in the 200LR calculates the exact horizontal distance to the stem, measures the angles to the top and bottom of the tree, and then uses the tangent method to derive a height estimate (to the nearest 0.1 foot). The 200LR can also be used to determine upper and lower slope distances (and their corresponding angles) using separate functions. Thus, the same laser rangefinder can also be used to provide the sine method height, thereby eliminating potential errors caused by using different technologies.

Three hardwood trees on the grounds of the University of Arkansas-Monticello and the Crossett Experimental Forest (table 1) were selected for measurement. Each was selected to highlight a particular attribute that may influence hardwood height measurement accuracy. A sycamore (*Platanus occidentalis* L.) was chosen because of its lack of obvious lean, while an open-grown water oak (*Quercus nigra* L.) was selected because of its broadly spreading crown, and the southern red oak (*Q. falcata* Michx.) was picked because of its pronounced lean.

It should be noted that this limited sample was used specifically to show the risks of inappropriately applying the tangent method. Even though this may seem to be a "stacked deck" approach to evaluating the techniques, my intention was to highlight the relative insensitivity of the sine method to even gross misapplications of height measurement techniques. After all, even the best trained field crews are not likely to spend much time carefully determining the extent of lean or the skew of crowns unless the trees are obviously affected. Rather, they are more likely to assume that modest departures produce very minor differences in the predicted heights. Indeed, this is often part of their instruction: Avery and Burkhart (1994) state that clinometers can accurately (within 2 to 5 percent) predict height for trees leaning up to 5 degrees. With small trees, or for those conducting a large-scale inventory, this magnitude of error is rarely problematic. For those requiring greater accuracy, even this is unacceptable.

RESULTS AND DISCUSSION

Favorable Conditions

I first tested the 200LR under conditions that approached the ideal. When the two methods were used to estimate the height of a 32 foot tall vertical light pole from horizontal distances ranging from 66 to 107 feet, they produced height estimates that differed by less than 0.2 feet (< 0.6 percent). Thus, there was no

Table 1—Basic attributes of southern Arkansas hardwoods used to highlight differences in height measurement techniques

Tree	Diameter at breast height	Horizontal distance[a]	Defining attribute[b]
	inches	*feet*	
Sycamore	18.8	124	No visible lean
Water oak	46.4	79–255[c]	Wide crown
Southern red oak	40.1	116–182[c]	20 degree lean

[a] Horizontal distance between the measuring station and the tree.
[b] The reason why the tree was chosen for this comparison.
[c] Multiple stations were used at varying distances from the tree.

meaningful difference between the estimates produced by the techniques, given the stated accuracy of the instrument.

In the case of the sycamore with good apical dominance (fig. 5), the tangent method produced a height estimate (72.3 feet) only slightly (2.0 percent) lower than that produced by the sine method (73.8 feet). This small difference arose because the sycamore leaned almost imperceptibly away from the measuring device, so that its highest live leader was not positioned directly over the point to which the horizontal distance was measured.

Wide Crowns

When the height of the water oak was measured from over 250 feet away, the difference between the height estimate produced by the tangent technique (66.8 feet) and that produced by the sine technique (69.1 feet) was moderate (3.3 percent). At this distance, it was possible to view the top of the entire crown (fig. 6), and selection of the crown apex was greatly facilitated. However, this does not change the tangent method assumption that the highest point is located over the point to which the horizontal distance is measured. Thus, the 3.3-percent difference between the height estimates indicates that there is still an obvious offset when the tangent method is used.

When measured from up close (78.5 feet away, horizontal distance), the tangent method yielded a height estimate of 62.4 feet and the sine method one of 67.8 feet (an 8.0-percent difference) for exactly the same leader mentioned in the previous paragraph. At this close proximity, it is virtually impossible to detect

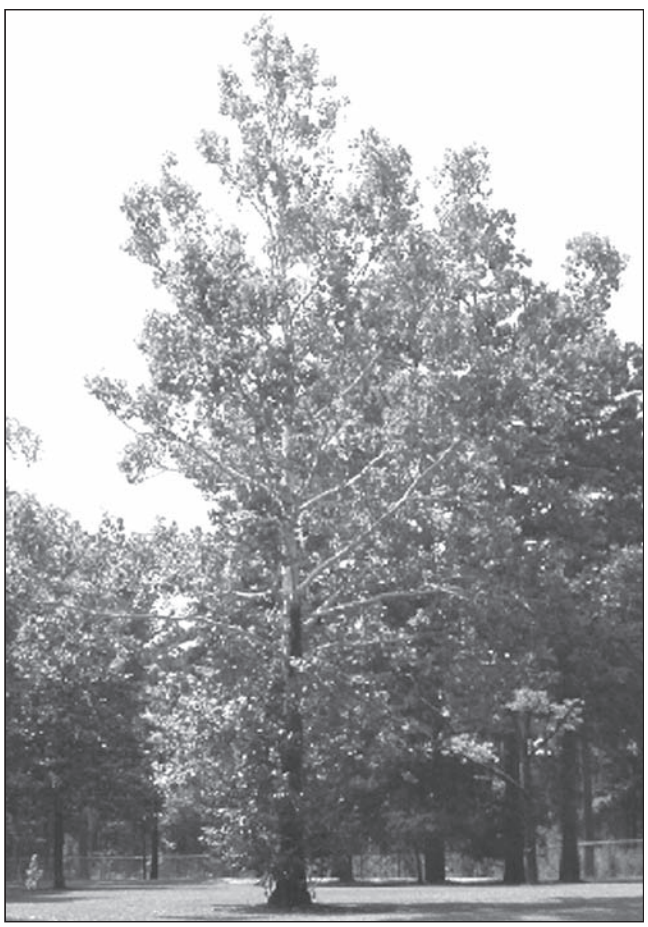

Figure 5—A sycamore with little apparent lean. Picture was taken approximately 125 feet from the stem.

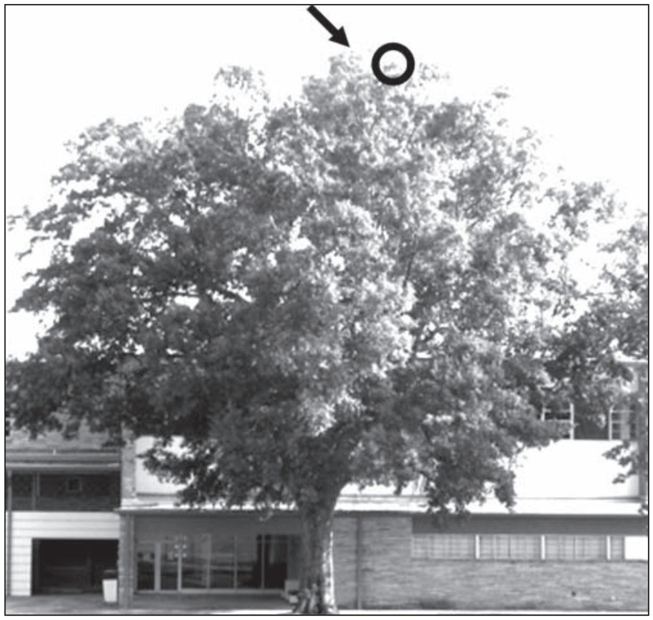

Figure 6—The water oak with a broadly spreading crown. Picture was taken approximately 250 feet from the stem. The arrow identifies the highest visible leader at 250 feet, compared to the circled leader that appeared highest at 106 feet.

the highest point on the crown without first having spotted it at a distance (which is not always possible, especially in dense stands). The nature of how tangent heights are determined (indirect placement of crown top by using horizontal distance and angle, often to an approximated apex) creates a much greater potential for error than the sine method.

To further illustrate this, I selected another viewing point 106 feet from the water oak. At this location, it appeared that a different leader was the highest point on the tree (fig. 6). This new high point produced a tangent height of 73.4 feet. When the sine method was used, however, it produced a height estimate of only 62.4 feet, and it was clear that this leader was in a subordinate crown position. Even though the tangent method predicted a height closer to the true height of the tree, it arrived at this value through compensating errors rather than as a consequence of the validity of the technique. In other words, without strict controls, the observer cannot account for the accuracy of a lone measurement under the tangent method.

Pronounced Lean

A leaning southern red oak provided a classic example of the potential for serious errors in height estimation using the tangent method. This tree was selected for its prominent inclination (20 degrees from vertical) (fig. 7a) specifically to emphasize the effect of lean on height determination. When the tree leaned away from the observer, the tangent method yielded a height estimate of 77.4 feet and the sine method one of 79.3 feet. When this red oak was measured away from its predominant axis of lean, the highest branch was actually offset slightly behind the vertical axis of the tree, and this resulted in a relatively minor (~2 feet) underestimate of tree height.

At a point perpendicular to the lean of the southern red oak, the tangent method yielded a height estimate of 80.2 feet and the sine method one of 80.5 feet. The close correspondence between estimates based on the two methods and a perpendicular perspective indicates that the techniques give very similar results if they are applied properly.

(**A**) (**B**)

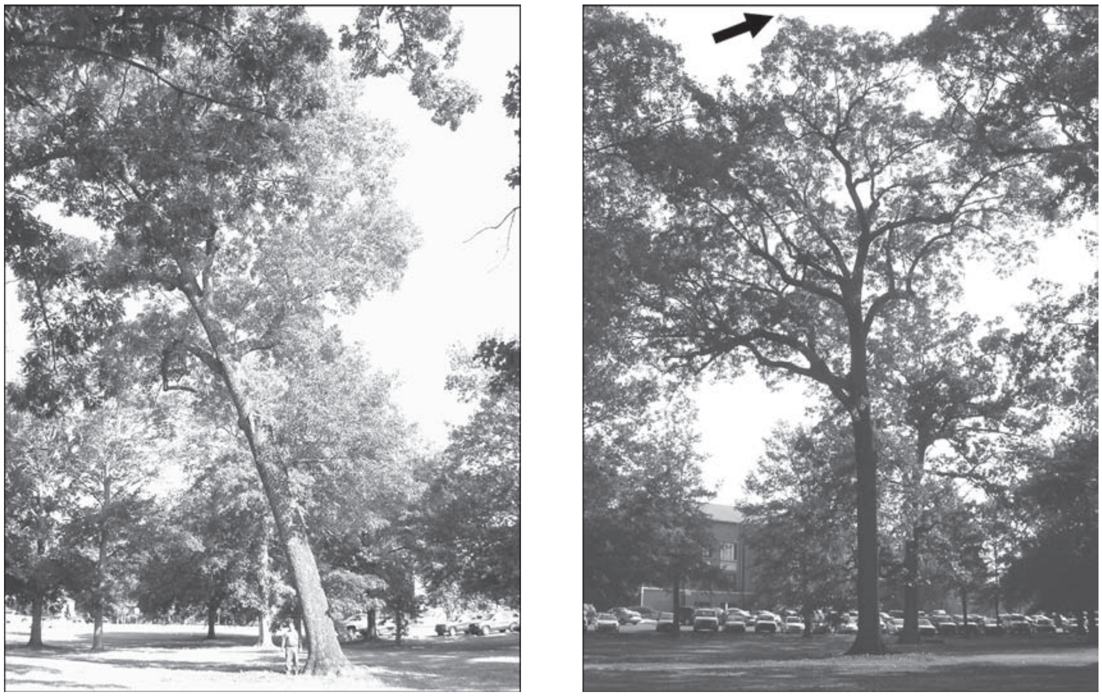

Figure 7—Strongly (20 degrees) leaning southern red oak, with pictures taken from about 100 feet away for the (A) perpendicular to the lean and (B) into the lean perspectives. The arrow in (B) indicates the apparent top of the crown, and indicates the lack of visible lean from this direction at this distance.

However, when the southern red oak was measured with the lean toward the observer, a new branch of the crown (identified by an arrow in figure 7b) appeared to be tallest. This branch was located significantly closer to the measurement station than the vertical bole axis, and therefore the tangent method (if not corrected for horizontal distance) would project a height much greater than the true value. Not surprisingly, the unadjusted tangent method produced a height estimate of 110.8 feet, 33 feet (42 percent) higher than the 77.8- foot estimate obtained by using sines.

Though this last trial violated accepted height measuring procedures, from exactly this vantage point (fig. 7b) the oak did not have an obvious lean, and thus could have misled some observers. Technology is increasingly making the direct measurement of sample trees less necessary. Laser-based dendrometers already on the market are capable of accurate diameter measurement from a distance, so remotely sensed stem measurements will probably become commonplace before long. If this happens, workers may never actually walk up to trees to measure them and large errors may result if the tangent method is used to determine height and tree lean goes undetected.

Tangent Versus Sine Tree Height Determination

As shown in the previous discussion, the tangent method is very sensitive to the point of the crown chosen to represent tree height, especially in wide, skewed, or flat-topped hardwoods. It is possible to avoid large errors in height estimates using the tangent method, but to do this careful measurement of true horizontal distance must be made. In practice, this means identifying the point on the ground directly below the highest point of the tree, a difficult if not impossible prospect under most circumstances.

The sine method avoids inappropriately determined horizontal distances by measuring a real point of the crown, not the projected or assumed apex as with the tangent method. This means that the sine method will never overestimate tree height, which is possible when the tangent method is used incorrectly.

Therefore, to accurately estimate height using the sine method, all one has to do is take appropriate distance and angle readings and correctly identify the highest point on the tree.

However, under some circumstances it can be difficult to find an adequate opening through the canopy to determine slope distance and make a height determination with the sine method. The tangent method does allow for the user to approximate where the top of the crown is (assuming enough can be seen), but this "advantage" is also the flaw that makes inappropriate estimates of tree height possible. Fortunately, since the sine method does not require that a specific viewing distance or direction be used in order to estimate height, it is possible to maneuver around the subject tree until the crown apex becomes visible. The effort expended searching for a good (clear) shot at the highest point of a tree when the sine method is employed is not likely to be greater than the amount of time spent collecting multiple height estimates to average for a more accurate tangent height.

Finally, since it makes use of an actual point on the crown (and does not presume to project one), the sine method is also not as prone to close- proximity errors as the tangent method. This is very advantageous in forests with dense canopies, especially when the trees are all of approximately the same size, since the tangent method should be measured using an angle of 45 degrees or less to help minimize error (fig. 8).

Although considerably more expensive and cumbersome to use, laser technology and sophisticated electronics can substantially improve hardwood height estimates, regardless of the technique. Errors in height prediction can be even more pronounced if older technologies (for example, using clinometers with cloth measuring tapes or pacing) are combined without regard to the degree of error these imprecise techniques impart.

It is also important to remember that any measurement technique requires proper application and the measurement of a consistent standard. It will, for example, always behoove the observer to correctly identify the highest live point of the tree, regardless of the height measurement technique. Accurate

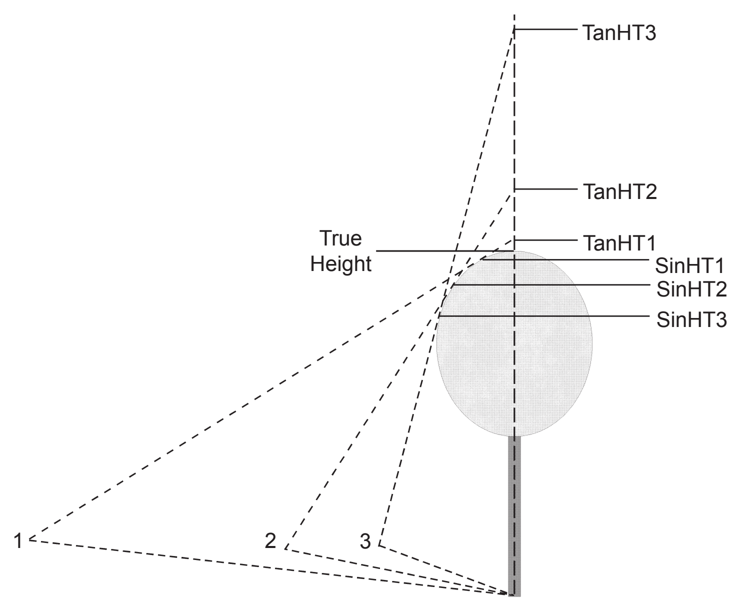

Figure 8—The relative impacts of closeness on height errors for both the tangent and sine methods, given an idealized and opaque hardwood crown. As one approaches the outer edge of the crown (gets closer to the stem), the tangent method provides increasingly greater overestimates, while the sine method underestimates height (although at a lower rate than the tangent).

horizontal distance measurements and reliable angle readings are just as critical in the sine method as they are for the tangent approach. The sine method may be less sensitive to most of the assumptions of the tangent method, but it still requires appropriate implementation to ensure that the highest accuracy is achieved.

CONCLUSIONS

Under typical circumstances, the sine method is the most reliable means currently available to determine standing tree height, largely because it is relatively insensitive to some of the underlying assumptions of the tangent method. Unfortunately, only recently has technology permitted the use of the sine method, whereas the tangent method has been ingrained into procedures and instrumentation for many decades. However, a growing number of individuals and organizations (such as the Eastern Native Tree Society) have begun to tout the advantages of the sine method (ENTS 2005).

Hopefully, the need for consistent and accurate height determination, especially in an era of remotely-sensed and modeled measurements, will encourage more people to use the sine approach. Certainly, in cases where high accuracy is called for (for example, the measurement of champion trees) or conditions exist that would seriously bias height measurement (for example, broad or offset crowns, leaning trees, or steeply sloping terrain), any extra time spent correctly determining height is well worth the effort.

ACKNOWLEDGMENTS

I would like to recognize the work of the Eastern Native Tree Society, especially Will Blozan, Robert Leverett, and Colby Rucker, for the promotion of the sine method of height determination. Kirby Sneed and Steven Wagner (USDA Forest Service) helped collect the tree heights used in this paper. My thanks also to Will Blozan, Paul Doruska, Mike Shelton, and two anonymous reviewers who helped improve the content of this paper.

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A DIAMETER DISTRIBUTION APPROACH TO ESTIMATING AVERAGE STAND DOMINANT HEIGHT IN APPALACHIAN HARDWOODS

John R. Brooks[1]

Abstract—A technique for estimating stand average dominant height based solely on field inventory data is investigated. Using only 45.0919 percent of the largest trees per acre in the diameter distribution resulted in estimates of average dominant height that were within 4.3 feet of the actual value, when averaged over stands of very different structure and history. Cubic foot and board foot yields on a per acre basis can be easily obtained based solely on field tally of tree diameters and total height on inventory samples.

INTRODUCTION

In many different cover types, stand volume per acre can be accurately determined as a function of stand basal area and average dominant height (Brooks and Wiant 2004). The determination of average dominant height normally requires the subjective assignment of crown class and the measurement of tree total height. Previous studies have shown that stand average dominant height can be accurately predicted using a percentage of the diameter distribution, when arranged in decreasing size order (Bailey and Brooks 1994, Bailey and Martin 1996, Brooks 2003). This percentile of the diameter distribution in pines has been shown to be very stable and can be used to extract average dominant height from inventory data when crown class assignment has been omitted. The estimation of hardwood stand volume based on these two stand level variables has also been shown to be quite stable (Brooks and Wiant 2004) but this diameter distribution approach has never been reported for the determination of average dominant height in more variable hardwood populations. This study uses permanent sample plot data collected in three very different hardwood stand conditions to test this application for the estimation of stand average dominant height.

METHODS

Three Appalachian hardwood datasets were selected for study based on the precision of measurements and the diversity of stand types. All three locations involve permanent fixed area sample plots where dbh, total height and crown class were recorded for all trees 4.6 inches dbh and larger. Diameters were measured to the nearest 0.1 inch with a diameter tape, while total heights were recorded to the nearest 0.1 foot with an Impulse laser hypsometer. The first dataset represents the initial measurement and some remeasurement data on 40 square 0.2 acre sample plots located on the West Virginia University Research Forest (WVURF) located in north central West Virginia. This forest is approximately 75 years old and is predominately even-aged. The forest is composed of two broad cover types; mesophytic and oak types. In general, the mesophytic types occur on north and east-facing aspects and coves while the oak types occur on south and west aspects and ridges. Descriptive statistics of the forest structure are displayed in table 1. The second dataset represents 67 circular 0.2 acre permanent sample plots located near Daily, West Virginia (Tygart). This forest was originally even-aged prior to a diameter limit selection harvest in the early 1970s. Dominant species include white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), scarlet oak (*Q. coccinea* Muenchh.), yellow-poplar (*Liriodendron tulipifera* L.) and northern red oak (*Q. rubra* L.). Descriptive statistics of the forest structure are displayed in table 1. The third dataset is based on 15 circular 0.1 acre permanent plots located in southeastern Ohio. This forest includes dominant trees of 110 years of age and is dominated by maples (Acer spp.), oaks (Quercus spp.) and American beech (*Fagus grandifolia* Ehrh.). Descriptive statistics of the forest structure are displayed in table 1.

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Table 1—Descriptive forest statistics for the three hardwood datasets

Forest	No. plots	TPA	BAAC	Max DBH	DHT
			ft²		*ft*
WVURF	57	193.3	153.7	35.0	89.4
Tygart	67	228.6	107.7	29.5	73.4
Ohio	15	207.3	83.8	28.1	71.6

TPA = trees per acre; BAAC = basal area per acre; DHT = average dominant height;
WVURF = West Virginia Univeristy Research Forest.

For each dataset, all inventory data were sorted by plot number in decreasing dbh and total height order. For each plot, a percentile of the diameter distribution was identified where the average total height of the current tree and all larger trees was approximately equal to the average height of all dominant and codominant trees, regardless of species type. This percentile was identified for each plot and the mean and variance of this value was determined for each dataset and across all plots and locations. To ascertain whether a single percentile could accurately estimate stand dominant height across these very different stand conditions, the average bias and root mean squared error (RMSE) between actual and estimated average dominant height was determined for each plot in each of the three datasets. In addition, the sensitivity of the mean dominant height estimation error was examined as the percentile of the ranked diameter distribution was varied from 10 to 90 in steps of 10 percent.

RESULTS AND DISCUSSION

The diameter distribution percentile that equates to average dominant height was calculated for each sample plot of the 3 forests examined. These percentiles ranged from 9 to 84 percent, with a mean of 45.0919 percent when averaged across all plots (fig. 1). Although visually quite variable, the variance across all plots is only 0.024918. The average diameter distribution percentile and its associated variance are shown by forest and across all plots (table 2). To determine whether a single percentile could be used to accurately estimate average dominant height, the average height of all trees in the upper 45.0919

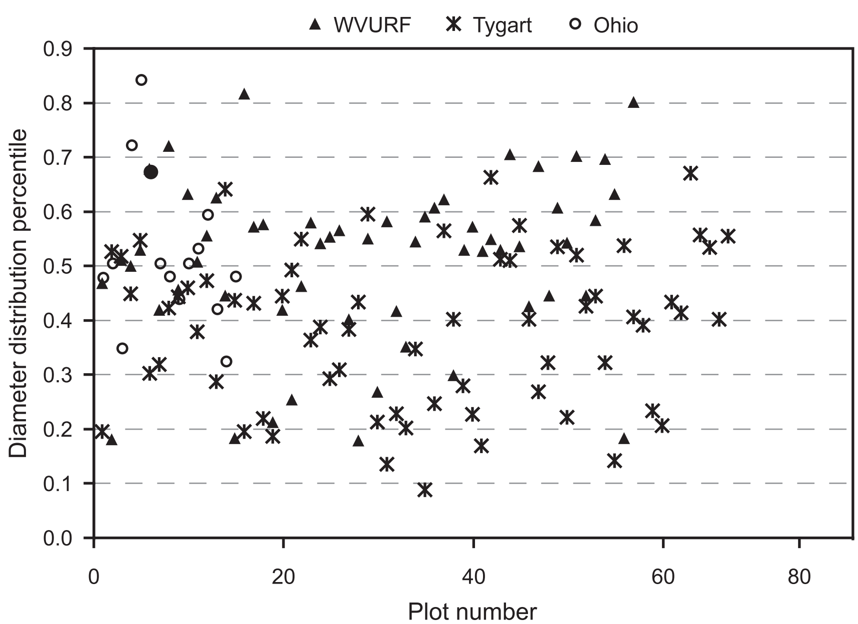

Figure 1—Distribution of average dominant height percentiles by plot and location.

percent of the diameter distribution was calculated for each plot and compared to the known average dominant height based on total height and crown class assignment. Both average bias and RMSE of this height difference was evaluated. Average bias ranged from -8.7 feet (Ohio) to 1.3 feet (WVURF) with a mean across all plots of -1.5 feet (table 3). Based on average bias, the percentage of plots within 10 feet of the actual dominant height ranged from 96 (WVURF) to 60 percent (Ohio). Across all the datasets tested, 88 percent of the individual plots were estimated within 10 feet of the actual value. Similar results were obtained when the RMSE of the prediction error was evaluated. RMSE ranged from 2.5 (WVURF) to 8.7 feet (Ohio). The average error across all plots was 4.3 feet. The percentage of plots within 10 feet of actual dominant height was identical to that expressed for average bias.

To evaluate the sensitivity of the percentile value, the diameter distribution percentile was varied from 10 to 90 percent of the ranked distribution and average dominant height error was calculated at each step. Average error was within 10 feet of the actual dominant height value for an extended range, the smallest of which was with the Ohio dataset where a 10 foot error was obtained within a range from 10 to 50 percent of the ranked diameter distribution (fig. 2).

Prediction of average dominant height in central hardwoods without the field assignment of crown class appears feasible given the stability of the diameter distribution percentile. The plot data selected for study was chosen due to large differences in stand history and structure. The WVURF plots are the

Table 2—Mean and variance of the average dominant height percentile by location and across all locations

	Dominant height percentile	
Forest	Mean	Variance
WVURF	0.4492	0.0231
Tygart	0.3858	0.0202
Ohio	0.5233	0.0188
All	0.4295	0.0249

WVURF = West Virginia Univeristy Research Forest.

Table 3—The average bias, RMSE prediction error and percentage of plots having an average bias within 10 feet of the actual dominant height

Forest	Average bias	RMSE	Percent within 10 feet
	- - - - - - *feet* - - - - - -		
WVURF	1.3	2.5	96.5
Tygart	-2.4	4.9	88.1
Ohio	-8.7	8.7	60.0
All	-1.5	4.3	88.5

WVURF = West Virginia Univeristy Research Forest.; RMSE = root mean squared error.

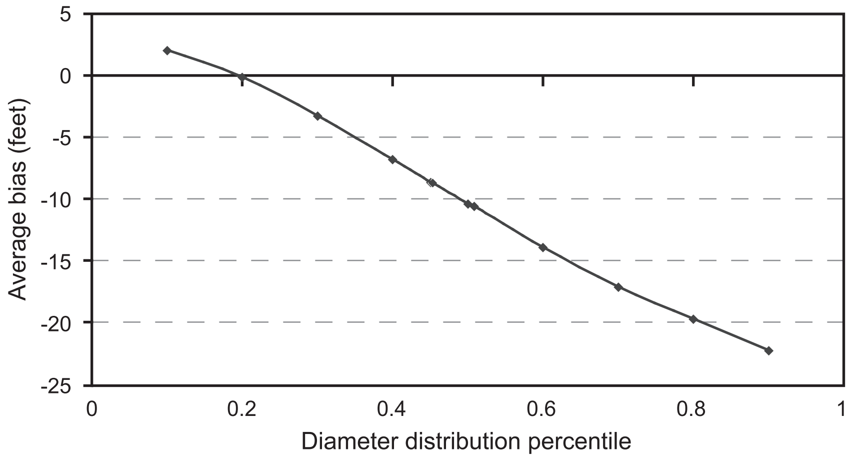

Figure 2—Average dominant height bias in feet by diameter distribution percentile for all sample plots in the Ohio location.

most uniform providing a dominant height RMSE of only 2.5 feet over 57 permanent plots. This error is arguably less than traditional measurement error. In the Tygart dataset, some of the overstory was removed in the early 1970s. The average diameter distribution percentile was smaller in this forest, reflecting the need to only include a portion of the largest trees. In the Ohio dataset, the forest has a much more developed stand structure with many sugar maples developing into the codominant crown class from existing gaps in the canopy. In this situation, much more of the diameter distribution is needed to quantify the average dominant height. Based on field measurements of diameter and total height, both basal area per acre (total and sawtimber only) and average dominant height can be quickly determined and whole stand volume (ft^3 and bf) can be estimated using equations published by Brooks and Wiant (2004, in press). Their results indicate that over 90 percent of the variation in volume yield can be explained by these two stand level variables.

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DEVELOPMENT OF INTERIM OAK ASSESSMENT GUIDELINES FOR THE SILVAH DECISION-SUPPORT SYSTEM

Patrick H. Brose[1]

Abstract—Updates to the SILVAH decision-support system make it more applicable to the mixed oak forests of Pennsylvania and other mid-Atlantic states. This update required establishing interim inventory guidelines for assessing the competitive ability of advance oak regeneration. This assessment was complicated by oak's growth strategy, emphasizing root development in lieu of stem development. Regression analysis of an oak height growth data set from the Piedmont region of Virginia was used to compare stem height, basal diameter, and root collar diameter over 3 years in shelterwood stands. If the oak stems were not top-killed, then there was no difference in the coefficients of determination among the three variables. Conversely, when the stems were top-killed, root collar diameter explained much more of the subsequent height growth than either basal diameter or stem height because many small oak stems produced tall vigorous sprouts. Examination of these sprouts revealed that they had large root systems and shared certain characteristics such as number of stems, number of full-sized leaves, and stem height. These findings indicate that root collar diameter should be examined when assessing oak regeneration in previously disturbed stands and should provide guidance as to what stem characteristics indicate small oak stems with large root systems.

INTRODUCTION

SILVAH is a quantitative and systematic approach to forest management developed following decades of research by personnel of the USDA Forest Service's Forestry Sciences Laboratory in northwestern Pennsylvania (Marquis and others 1992). SILVAH is geared primarily for the cherry-maple and northern hardwood stands of the Allegheny Plateau region and it has a documented record of prescribing appropriate treatments for these forest types in that part of Pennsylvania. SILVAH's oak component was less well developed and in late 1999, the Pennsylvania Bureau of Forestry (PA-BoF) encouraged the lab to remedy that deficiency.

In January 2000, representatives of the PA-BoF, USDA Forest Service's Northeastern Research Station and Allegheny National Forest, The Pennsylvania State University's School of Forest Resources, forest industry, and forest consulting firms met for 3 days in State College, PA to begin improving SILVAH's oak component. The meeting had three purposes: (1) to organize existing oak management knowledge into SILVAH's decision-making framework; (2) to develop interim guidelines for inventory procedures; and (3) to identify and prioritize knowledge gaps for future research. One of the first knowledge gaps encountered was how to identify competitive oak regeneration, i.e., a stem ready to compete for a dominant or co-dominant crown position in a regenerating stand.

Existing guidelines from the Ozarks use stem height to identify competitive oak reproduction. Ivan Sander and others (1976) determined that oak stems > 4.5 feet tall were the only ones large enough to reliably capture dominant or strong co-dominant crown positions after harvesting of the existing stand. The 4.5-foot stem height threshold fit well into SILVAH's "stocked plot" concept and prescriptive framework but the committee members felt, based on their collective experience, that it was too tall for most Pennsylvania oak forests so a 3-foot threshold was adopted as an interim height guideline.

There were three concerns regarding the use of oak regeneration guidelines developed elsewhere. The primary concern was the adequacy of stem height alone to indicate the competitiveness of oak regeneration given the fact that oak seedlings and seedling sprouts emphasize root development more

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than stem growth (Kelty 1989; Kolb and others 1990; Miller and others 2004). The concern over root development meant that assessing oak regeneration with stem height might be misleading because small oaks may actually have large enough root systems to compete following a harvest. This is especially true if the oak stem is broken during the harvesting operation resulting in a new, vigorously growing sprout or if prescribed fire is used during the regeneration process (Brose and others 1999a, 1999b).

Another concern was the dissimilarities between Pennsylvania and the Ozarks in terms of site quality, major competing species, disturbance regimes, and overstory density (full sunlight versus partial shade) and their influence on seedling growth. Most Pennsylvania oak forests are better quality than those of the Ozarks. Major species competing with oak in Pennsylvania include black birch (*Betula lenta* L.) and red maple (*Acer rubrum* L.). These two species are absent or not nearly as troublesome in the Ozarks.

Pennsylvania oak forests have been and are subject to defoliation by gypsy moth (*Lymantria dispar* L.) and subsequent salvage operations while the Ozarks still lack this pest. Consequently, oak regeneration in many Pennsylvania forests develop for years in partial shade while the Ozark guidelines assume complete canopy removal for their growth and survival projections.

Reanalyzing an existing data set (Brose 1997) offered a way to address the concern about which morphological attribute would effectively assess the competitive capacity of oak regeneration. That data set contained oak height growth data collected over 3 years and allowed direct comparisons of the ability of pre-treatment stem height, basal diameter, and root collar diameter (RCD) to post-treatment growth. Basal diameter was also part of Sander's research and was used by Loftis (1990) in his probabilistic regeneration model for the southern Appalachian Mountains. Basal diameter is usually measured where the stem emerges above the leaf litter. RCD is commonly used to measure root size in oak planting operations (Stroempl 1985; Johnson and others 1986; Kennedy 1993; Spetich and others 2002). The root collar is the transition point between stem and root and is identifiable by a ring of callous tissue and dormant buds. Generally, it is found in the upper 1-inch of soil. Because of oak's emphasis on root development, basal diameter or root collar diameter may be a better measure than stem height in explaining subsequent growth.

This paper reports the findings of the data reanalysis. The initial objective was to compare the ability of basal diameter, root collar diameter, and stem height to explain the variation in oak stem growth following top-kill and sprouting. Findings from that analysis spurred a second objective: to provide guidance for determining when root collar diameter should be included in the size assessment of oak regeneration.

METHODS

Site Description

The data set was compiled from a study that took place from 1994 to 1998 in three mixed-oak shelterwood stands at the Horsepen Wildlife Management Area in central Virginia. The stands ranged from 15 to 50 acres and were similar to each other in landform, soils, species composition, and structure. All were situated on the top and upper side slopes of gently rolling hills at elevations of 500-600 feet above sea level. Soil series for all three stands was a Cecil sandy loam with an oak site index of 70 feet (base age 50). The stands originated in the late 1890s, were even-aged, and had been partially harvested about 1990, reducing basal area from 120 to 60 square feet per acre. The resultant shelterwood had about 50 percent canopy closure. The most abundant canopy species were the upland oaks [black oak (*Quercus velutina* Lam.), chestnut oak (*Q. prinus* L.), northern red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), and white oak (*Q. alba* L.)]. American beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), flowering dogwood (*Cornus florida* L.), mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), pignut hickory (*C. glabra* (Mill.) Sweet), red maple, and yellow-poplar (*Liriodendron tulipifera* L.) also were present, especially in the midstory. The heavy partial cut resulted in abundant, well-distributed, advance regeneration (> 20,000 stems per acre) with all canopy species represented. Red maple and yellow-poplar regeneration were the tallest stems, generally ranging from 8 to 10 feet in height, while oak reproduction was usually between 2 and 3 feet tall. Given these conditions, the study site was quite similar to Pennsylvania oak forests so the data set also satisfies the concerns of the committee about forest dissimilarity between Pennsylvania and the region of origin of the reanalyzed data set.

Study Design and Implementation

Each of the three stands was divided into four treatments (spring, summer, and winter burns, and an unburned control). In 1994, prior to the prescribed fires, 304 oak stems representing all five upland oak species were tagged for growth and height measurements. These stems were visually judged to represent the range in height of surrounding reproduction. For each tagged stem, species, basal diameter, number of stems, number of mature leaves, root collar diameter, and stem height were recorded.

Prescribed burns were conducted in February (winter), April (spring), and August (summer) 1995 by personnel of the Virginia Department of Game and Inland Fisheries. Drip torches were used to light the prescribed fires in a strip head-fire ignition pattern. The initial strip head-fire was lit along the uphill or downwind side of the treatment block and was about 10 feet wide. Once the initial strip was burned, subsequent strips were wider and systematically ignited moving in either a downhill or upwind direction until the entire treatment block was completely burned. Fire behavior was typical for the seasons, according to the experienced fire personnel conducting the burns. Spring fires produced flame lengths of 2 to 4 feet with rates of spread ranging from 5 to 10 feet per minute. Summer and winter burns were similar to each other and exhibited 1 to 2 feet flame lengths and rates of spreads from 1 to 5 feet per minute.

Tagged stems in the control, spring burn, and winter burn treatments were measured for height growth in fall 1995, 1996, and 1997. Tagged stems in the summer burn treatment were measured for height growth in fall 1996, 1997, and 1998 because many of the stems did not initially sprout until 1996.

Statistical Analysis

Earlier analysis of sprout growth rates found no significant differences among the oak species (Brose and Van Lear 1998), so height growth data were pooled to increase sample size and then separated by treatment. Stepwise regression was used to determine which of the three variables or combinations had the most influence on third-year stem height (SAS 2002). Simple linear regression was used to evaluate the ability of the three variables to explain third-year stem height by comparing their coefficients of determination. Each of these were rated as extremely poor ($r^2<0.20$), poor ($r^2=0.20 – 0.39$), fair ($r^2=0.40 – 0.59$), good ($r^2=0.60 – 0.80$), and excellent ($r^2>0.80$) predictors of third-year stem height.

The initial stepwise regression analysis showed the importance of RCD in predicting third-year stem height so stepwise regression was used to determine which aboveground stem characteristics best explained RCD size. Variables used in this analysis included basal diameter, number of stems per rootstock, number of mature leaves per stem, and stem height.

To develop field criteria for judging when to examine root collars, oak stems were sorted by pre-treatment and post-treatment heights into four groups. Small oaks were < 4.5 feet before and at the end of the study. Small-large oaks were < 4.5 feet to begin with but were > 4.5 feet by the third year. Large-small oaks were > 4.5 feet at the beginning of the study but did not attain that height by the end of the third growing season. Large oaks exceeded 4.5 feet before and after the study. Analysis of variance with Student-Keuls mean separation test was used to determine whether there were differences in the number of stems per rootstock and number of leaves per stem among the four groups. Residuals were examined for compliance with statistical assumptions and alpha was 0.05.

RESULTS

Of the 304 tagged oak stems, 83 were dropped from the reanalysis because they failed to sprout following the fires or were never top-killed by the fires. The remaining 221 stems were evenly distributed among the five oak species with 37 to 48 stems per species and among treatments with 48 to 66 oaks per treatment.

All four of the models derived from stepwise regression analysis explained between 64 and 71 percent of the variability in early height growth of sprouting oak stems, regardless of treatment (table 1). However, the models differed profoundly in their makeup. Root collar diameter was the major explanatory variable of early height growth in all the burn treatments. In fact, it was the only variable in the spring and winter burn models and accounted for over 90 percent of the coefficient of determination in the summer burn model. In the unburned control, stem height and basal diameter were the only components of the model.

Basal diameter, root collar diameter, and stem height all provided fair coefficients of determination ranging from 0.484 to 0.533 when oaks were not top-killed (table 2). However if they were forced to sprout, basal diameter and stem height produced poor and fair coefficients of determination ranging from 0.224 to 0.460, depending on season of burn, while root collar diameter had good coefficients of determination of 0.642 to 0.676.

Stepwise regression of the aboveground stem characteristics produced a model that explained about 67 percent of the variability in root collar diameter. Of the model's components, basal diameter and stem height were the two key variables, accounting for over 90 percent of the coefficient of determination.

Table 1—Models developed from stepwise regression analysis relating the total amount of height growth (stem height at age 3 minus initial stem height) of oak reproduction over 3 years to the pretreatment morphological attributes of basal diameter (BD), stem height (SH), and root collar diameter (RCD)

Treatment	n	Model	r^2
Control	66	Growth = 0.126 + 2.051(BD) + 0.342(SH)	0.664
Spring burn	55	Growth = 0.177 + 1.919(RCD)	0.642
Summer burn 1	48	Growth = 0.461 + 2.539(RCD)	0.665
Summer burn 2	48	Growth = 0.291 + 2.01(RCD) + 0.27(SH)	0.710
Winter burn	52	Growth = 0.400 + 2.089(RCD)	0.676

Table 2—Comparison of the coefficients of determination (r^2) of pre-burn basal diameter, root collar diameter, and stem height by treatment for explaining total height growth of sprouting oak stems through 3 years

Treatment	n	Basal diameter	Root collar diameter	Stem height
Control	66	0.509	0.484	0.553
Spring burn	55	0.460	0.642	0.224
Summer burn	48	0.344	0.665	0.454
Winter burn	52	0.301	0.676	0.326

Simple linear regression of these variables with root collar diameter showed that each explained about 50 percent of the variability in root collar diameter (figs. 1 and 2). Other variables that contributed significantly to the model were number of stems and number of leaves.

Analysis of variance indicated that small-large and large oak regeneration had significantly more stems per rootstock and leaves per stem than the other two size classes (fig 3).

DISCUSSION

Mixed-oak forests are tremendously important to Pennsylvania for a wide variety of ecological and economic reasons. They are declining in number and extent for numerous reasons and require active, scientifically sound management to stop this decline. Revising SILVAH to be more applicable in mixed-oak forests is an important step in that regard. Using collective knowledge from foresters and reanalyzing data sets from other regions accelerated this revision and produced interim guidelines in months, not years.

Sander (1971, 1972) set forth the 4.5-feet stem height as the threshold for identifying competitive oak regeneration. His regression equation had a low coefficient of determination (0.32), indicating that something else was influencing new sprout growth. He theorized the missing variable was root size and that it was probably better correlated with sprout growth than stem size.

These results support Sander's theory. In this study, coefficient of determination of basal diameter or stem height when the stem was top-killed and sprouted ranged from 0.22 to 0.46, comparable to that of Sander's work. However when root collar diameter was used, it provided a better model as indicated by an increase in coefficient of determination to between 0.64 and 0.68. RCD is the superior indicator of future early height growth in oak regeneration if top-kill and sprouting is likely to occur.

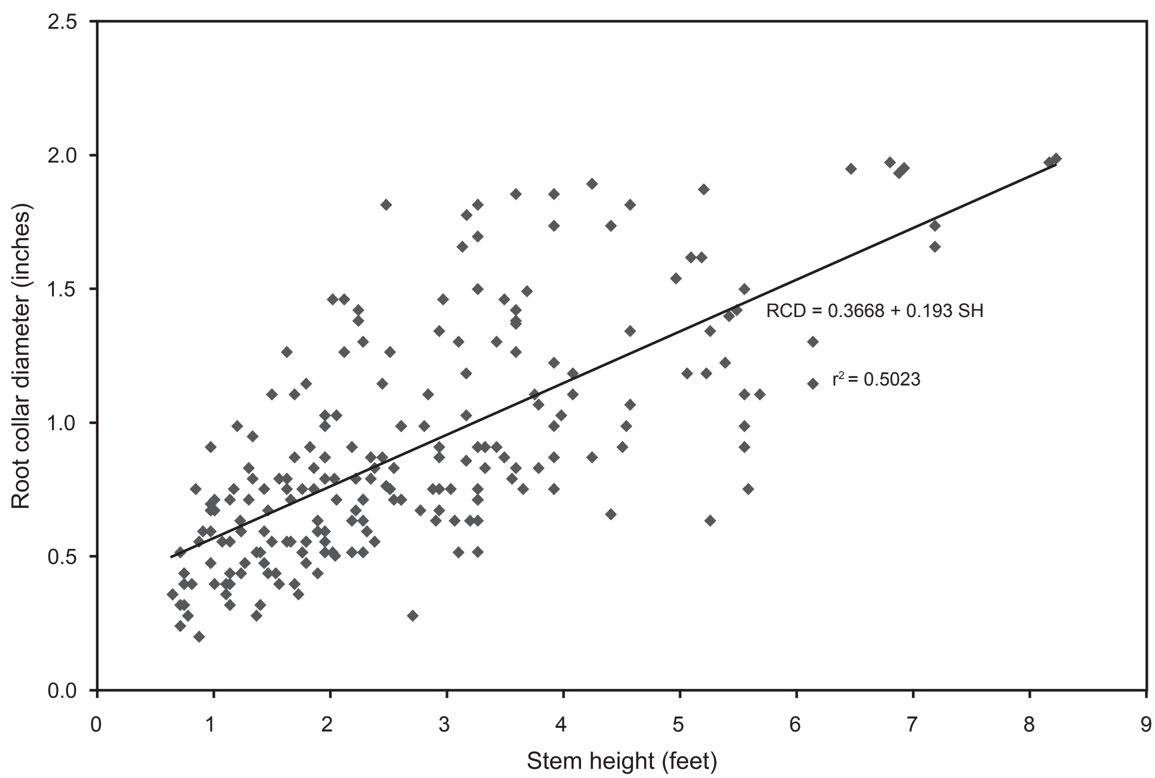

Figure 1—Simple linear regression of stem height (SH) and root collar diameter (RCD) for 221 mixed oak stems growing in shelterwood stands. The coefficient of determination (r^2) indicates that stem height explains approximately half the variation found in root collar diameter.

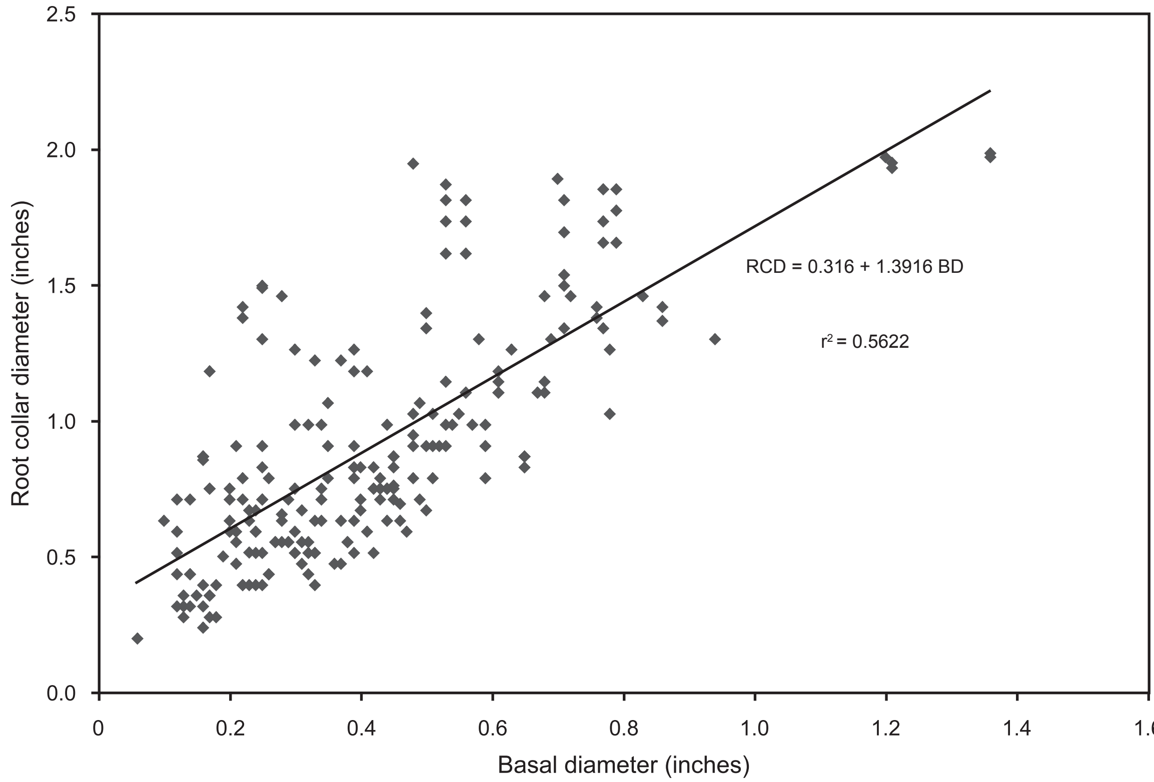

Figure 2—Simple linear regression of basal diameter (BD) and root collar diameter (RCD) for 221 mixed oak stems growing in shelterwood stands. The coefficient of determination (r^2) indicates that basal diameter explains a little more than half the variation found in root collar diameter.

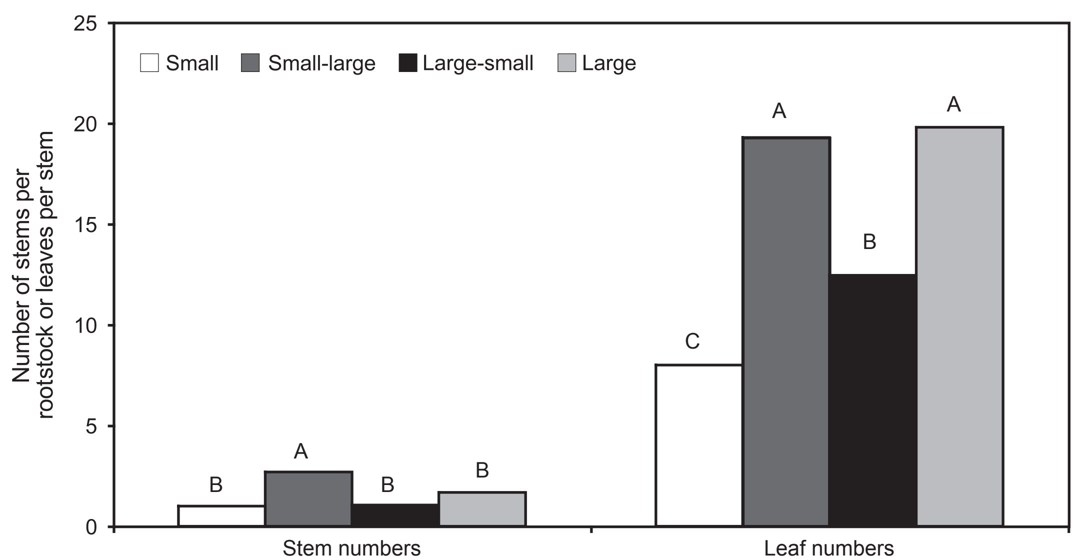

Figure 3—The mean numbers of stems per rootstock and leaves per stem for the four size classes of oak regeneration. Columns with different letters are significantly different for that stem characteristic at alpha = 0.05.

Conversely, if the oak reproduction is not forced to sprout, as in the control, then there appears to be no difference among the three stem characteristics in terms of their ability to explain subsequent height growth. In this setting, basal diameter, root collar diameter, and stem height all produced comparable models (coefficients of determination ranged from 0.48 to 0.53). Apparently in this scenario, it would not matter which stem characteristic was measured to assess size adequacy of the oak regeneration. However, avoiding top-kill of oak regeneration during timber harvests and prescribed burns is unlikely.

Sander also stated that root size would be difficult, if not impossible, to assess in the field, making stem size the preferred measurement. Obviously it is easy and quick to measure basal diameter or stem height but assessing root collar diameter requires the forester to do a little digging. Fortunately, this study provides some valuable clues as to which small oak stems have large root systems and are capable of rapid height growth, so digging to expose the root collar on every oak stem is unnecessary.

First, the relationship between stem size and root size is fairly linear despite oak's proclivity to emphasize root development in lieu of stem height growth. In this study the coefficients of determination for the basal diameter–root collar diameter and stem height–root collar diameter regressions were 0.56 and 0.50, respectively. In other words, larger oak stems will generally have larger root systems so usually oak regeneration can be assessed for its potential competitiveness based on stem height.

However, stem height may not always be the best criteria. In this study, 84 oak stems, or 38 percent of stems < 4.5-feet tall before the fires, produced sprouts that grew past the 4.5-foot mark within 3 years. This suggests that, at times, it is worthwhile to look at root collars. These stems, classified as small-large, had some other characteristics in common that help identify them. First, they were usually multiple stemmed, averaging nearly three stems per rootstock before they were top-killed. The other small oak stems seldom had more than one stem. Number of leaves also was related to number of stems. The small-large oak stems averaged almost 20 leaves, more than double that of the other small oaks. Minimum pre-burn basal diameter, root collar diameter, and stem height of the small-large oaks were 0.3 inches, 0.75 inches, and 2.0 feet, respectively. Species of oak does not appear to be a factor in determining which small oaks were capable of rapid sprout growth following top-kill by the prescribed fires.

Finally, stand history can help us identify when it is worthwhile to look at root collars. This study was done in 4-year-old shelterwood stands. The previous cut and the time between it and the study promoted root development by the oak reproduction (Miller and others 2004). Had this study been done in undisturbed, fully stocked stands, root development of the oak regeneration would have been retarded by the dense shade resulting in few, if any, oak stems capable of rapid height growth.

Users of the SILVAH decision-support system now have interim inventory guidelines for identifying competitive oak regeneration. They are:

1. Three foot is the minimum height to judge competitiveness of oak stems on medium-quality sites. This mark will vary some according to site quality and species composition, but overall, this is a safe, sound point of reference.

2. Shorter oak stems with root collar diameters > 0.75 inches can also be considered competitive. These are most likely found in previously disturbed stands and can be tentatively identified by height (> 2.0 feet tall), basal diameter (> 0.30 inches), multiple stems, and have > 20 normal-sized leaves.

3. Check root collars on oak stems in the first two or three plots. This will help develop a "stand-specific eye" for characteristics of oak stems that have large root systems capable of supporting rapid height growth upon release. After that, check only those stems exhibiting those characteristics.

Like all of SILVAH's guidelines, these oak inventory guidelines are a supplement and not a substitute to a forester's professional judgment. They are also interim in that two long-term oak regeneration studies now under way will supercede them in a few years.

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DIGITAL PHOTO MONITORING FOR TREE CROWN FOLIAGE CHANGE EVALUATION

Neil Clark and Sang-Mook Lee[1]

Abstract—Assessing change in the amount of foliage within a tree's crown is the goal of crown transparency estimation, a component in many forest health assessment programs. Many sources of variability limit analysis and interpretation of crown condition data. Increased precision is needed to detect more subtle changes that are important for detection of health problems. Digital photomonitoring can be used to increase the precision of these measures provided exact camera parameter replication is performed and movement of canopy structures is not severe. Two measures of transparency (compactness and DSO, or fractal dimension of silhouettes minus fractal dimension of outlines) show sensitivity to small branches or small canopy gaps, but may offer some unique descriptive information over area ratio measures. Point-wise and region-wise transparency distribution maps provide easy to interpret visual representations of localized transparency.

INTRODUCTION

Visual inspection is often the first step in evaluating the health of an organism. Farmers visually inspect their plant crops on a regular basis to determine when to water, fertilize, or treat an insect or disease outbreak. Likewise, visual inspection is often a key indicator of tree health. National and international forest health monitoring programs (Huettl 1993) such as the Environmental Monitoring and Assessment Program (EMAP) (Tallent-Halsell 1994), which is now Forest Health Monitoring (FHM) (Mangold 1998), and the United Nations Economic Commission for Europe (UN-ECE) (Ferretti 1997) collect tree crown indicators to assess forest health.

Though many variables have been proposed for tree health assessment (Innes 1993), many of these have been dropped from national assessment programs for various reasons-cost, lack of applicability over wide regions, species-specificity, etc. These monitoring programs required cost-effective means of assessing large areas of forest, consisting of many species, over short time intervals. One measure that is common to nearly all programs is the judgment of the amount of foliage present. This ordinal measure has been called crown thinning, defoliation, or transparency and its definition varies slightly among programs (Innes 1993). Foliage amount and condition is a general indicator over all species and serves as an integrative index of current tree condition.

First, challenges of visual foliage measurement are discussed. Then previous applications of photographic methods for tree crown assessment are summarized. This is followed by a brief discussion of the trend toward digital sensors and associated factors. Various crown analysis methods are discussed, and an example of morphological and area-based transparency estimation is given. Finally, ideas for future research are presented and details are provided on ways to increase foliage change estimation precision using digital photographs from monumented viewpoints.

FOLIAGE MEASUREMENT CHALLENGES

Sampling foliage of mature trees involves many challenges with the primary challenge being access (Barker and Pinard 2001). Many creative means are being applied to access tree canopies including climbing with ropes, walkway and crane construction, lift trucks, and scaffolding. Destructive sampling (i.e., cutting a portion or the entire tree) is widely implemented and required for studies where biomass

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must be determined (Montès and others 2000). Litter trap sampling is a standard technique for measuring deciduous foliage over an area, but may have some limitations for individual trees and for forest health assessment as the leaves are then dead.

Visual methods offer an alternative to the physical access problems but face problems due to occlusions caused by overlapping structures as well as other objects in the foreground or background (Ansley and others 1988, Bréda 2003, Dobbertin and others 2004, Lindsey and Bassuk 1992). This issue is identified as a clumping factor in studies of leaf area index (LAI) using visual methods (Chen and others 1997). Observer bias has been a widely documented issue with visual crown condition estimation (Dobbertin and others 2004, Innes 1988, Solberg and Strand 1999). Light conditions are also shown to cause problems (Dobbertin and others 2004).

Though not explicitly set forth in the literature, perspective effects exist caused by viewpoint locations, which are typically constrained by height of observation point and number of observation points considered. Field manuals (USDA Forest Service 2004) typically specify that the viewpoint be located at least tree height distance away from the base of the tree and that two observers create nearly perpendicular sighting angles to the tree. This still leaves a portion of the crown unobserved. Control on azimuthal relocation is rarely specified. The effects of overlooking this control will vary in proportion to the asymmetry of the crown structures within the overall crown space.

USE OF PHOTOGRAPHY FOR VEGETATION ASSESSMENT

Photography is used for detecting (Haering and others 1997), classifying, identifying (Soille 2000), and measuring (Brown and others 2000) vegetation from forest to agriculture and rangeland to wetland. Hemispherical photography is commonly used to evaluate LAI, throughfall, and understory light environment (Hale and Edwards 2002, Rich 1990). Photography also has been used to some extent for evaluating foliage on trees (Curtis and Kelley 1993, Lindsey and Bassuk 1992, Mizoue and Masutani 2003) as well as branch architecture without leaves (Stebbins 1975, Wagar and Heisler 1986).

Photograph collection methods vary among applications, although a few issues are common to all. Perhaps one of the most critical issues in using cameras in outdoor environments is light. As the sun is the dominant light source in outdoor photography, the amount, orientation, and characteristics of radiant input are not fully controllable. Some control can be applied by collecting photographs only under certain atmospheric conditions (i.e., clear or overcast), at a specific time of day, or at specified positions relative to the light source and the object of interest. Lens filters and other light blocking or reflecting media, such as an object to mask the solar disk for hemispherical photos (Peper and McPherson 2003) or a background screen (Ansley and others 1988) may be employed. Penumbral effects need to be evaluated in quantitative applications (Clearwater and others 1999, Wagner 1998). Stebbins (1975) utilized flash photography at night to control lighting and eliminate background effects. Tanaka and others (1998) also used active remote sensing with a scanning laser for 3D modeling.

Cameras and media are also selected based on the frequencies of spectral response they detect. Black and white negative film is typically chosen for applications requiring the most precise quantification of total light as it has a wide dynamic range. Red, green, blue (RGB) color photography is used for applications where classification (i.e., leaves vs. stem) is needed. Infrared wavelengths can be measured to provide higher contrast for vegetation condition.

Scale is another consideration when using photography for evaluation. Scale can be modified by the position relative to the object of interest or by optical magnification. With film photography scale was often ignored provided the object of interest was visible. Scale and output image resolution are critical when using digital imagery for quantitative measurements. As with any spatial sampling, image data must be acquired at a scale at which objects of interest can be resolved. In addition to analytical determinations of image resolution, camera and scene characteristics must also be considered. Frazer and others (2001) indicate that resolution limitations can be quite restrictive with the extreme field of view of hemispherical photography.

Photographic monitoring is the use of cameras to reexamine the same scene over time (Hall 2001). This technique lends itself to qualitative analysis that allows the investigator to visualize change. The quality of the analysis is inherent in the magnitude of change and the ability to perceive the desired elements for analysis. Some examples include examining the abundance of grasses and herbaceous vegetation across a landscape, or the visualization of change as a forest grows or is harvested over the course of decades.

ANALOG TO DIGITAL CONVERSION

Digital cameras are pervasive in the consumer market. These devices have improved tremendously in the last 10 to 20 years, to the point that direct comparisons are being made between digital and film photos (Frazer and others 2001, Hale and Edwards 2002). Digital cameras offer several advantages: there is no expense for film development; output is immediately available for field verification and image processing, transmission, or analysis; there is more flexibility of spectral range; and optics are smaller and cheaper.

Film media have been rigorously vetted within the scientific community, while much is unknown about digital image creation. Film emulsions react predictably, whereas digital results may be subject to electrical corrections and operations that may vary with the change of scene. Depending on the manufacturer of the sensor, these operations may be proprietary and impossible to correct.

Issues of concern that have been identified with some current digital systems are:

- Smaller optics of consumer-level digital cameras limit light capture and widen depth of field for given aperture.
- Imprecise optics not designed for spectral or dimensional measurement can cause color blurring and chromatic aberration (Frazer and others 2001).
- Limited dynamic range, especially for single-chip color formats, causes detail to be lost in either bright or dark regions.
- Single chip color consumer-level cameras usually output RGB data with 8 bits per channel providing limited quantification (256 levels).
- Limited spatial resolution is especially problematic with hemispherical lenses where field of view is fixed (Frazer and others 2001).
- A large number of manipulations can be required, and this can make it difficult to keep track of settings.

2D CROWN ANALYSIS

Analytical procedures depend on the project objectives. The simplest analysis is a qualitative visual comparison revealing obvious changes (i.e., much more sky visible through the crown). Quantitative comparisons are more frequently applied to supply more information and a higher level of precision. Caution must be applied when attempting to be overly precise when using 2D methods to estimate the quantity of objects in a 3D space, as assumptions about their distribution and orientation are important (Chen and others 1997).

Dot grids provide a manageable method of estimating proportions or even the area of a 2D planar region if scale is known. Dot grid techniques have been applied to oblique photographs of tree crowns (Seiler and McBee 1992, Wagar and Heisler 1986). Others have used computers to quantify classified pixels of digital photographs (Curtis and Kelley 1993, Lee and others 1983, Lindsey and Bassuk 1992). With greater access to digital imagery and immense computing power, the trend is toward more advanced image processing for increased information extraction (Dobbertin and others 2005, Lee and others 2003, Montès and others 2000, Paruelo and others 2000, Peper and McPherson 2003).

Regression analysis has been used to estimate total leaf area from silhouette area (SA) measurements. Some have found a linear relationship (Lindsey and Bassuk 1992, Peper and McPherson 2003) while others (Ansley and others 1988, Paruelo and others 2000) noted a curvilinear relationship, which might be expected with increased foliage density. This may be dependent on overall canopy size and architecture as well as species factors.

TRANSPARENCY

Photographic methods are beginning to be applied for the purpose of foliage change evaluation. A substitute might be examining the change of transparency estimates over time. Lee and others (2003) present a method that uses the FHM collection methods and definition of transparency. Transparency is defined as the amount of skylight visible through the live, normally foliated portion of the crown (USDA Forest Service 2004). The authors used image processing techniques to automatically generate a boundary that would be considered the "live, normally foliated portion." Within this boundary they present three methods of transparency estimation: area-ratio, point-wise, and region-wise. Area ratio is simply the count of sky pixels within the boundary divided by the count of plant pixels. Point-wise and region-wise transparency distribution maps use two different sampling strategies to determine localized transparency across the 2D plane (fig. 1). Direct comparisons to human observer estimates were good, provided woody components could be removed for sparsely foliated conditions.

Mizoue (2001) avoided the problem of trying to define the ambiguous region of consideration by using silhouettes(area) and outlines(perimeter). He presented a measure termed DSO calculated by

$$DSO = Ds - Do \qquad (1)$$

where Ds is the fractal dimension of the silhouette and Do is the fractal dimension of the outline. The fractal dimensions tend to converge with increased transparency. Exponential functions relating DSO to crown transparency were created for different species.

Compactness, defined by

$$perimeter^2 / area \qquad (2)$$

is often used in computer vision as a shape descriptor. While DSO is more sensitive at low levels of transparency, compactness is most sensitive where transparency is high. It should also be noted that

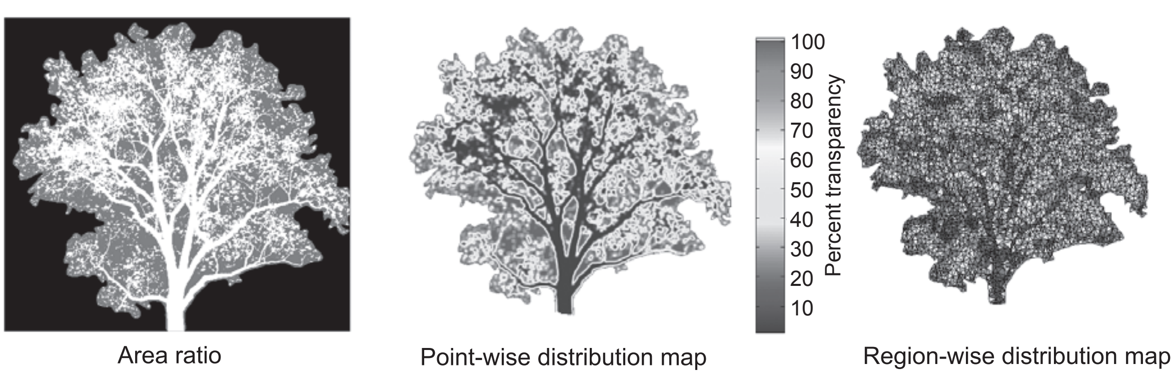

Figure 1—Area ratio (left) is the ratio of sky pixels (gray) to plant pixels (white) within a defined area (gray + white). Point-wise and region-wise transparency maps use different sampling methods to map the distribution of transparency over the projected crown space.

because the perimeters in digital image processing have discrete representations (pixels), these measures are affected by the resolution of the images.

Both of these methods are sensitive to spatial heterogeneity. DSO, compactness, and area-ratio are calculated (table 1) for different texture patterns (fig. 2). In the case of many small twigs (Image B of fig. 2) or small gaps (Image G of fig. 2) the proportion of perimeter to total area increases, causing DSO (value inversely related to transparency) and compactness to demonstrate a greater degree of transparency than area ratio. The analyst must decide which method is the most descriptive. Many small bare twigs represent areas where leaves should be present, while larger gaps are often places where large branches are missing and not part of the "live, normally foliated part of the crown." Much of this also has to do with the scale of the photographs and the severity and pattern of foliage presence or absence.

Table 1—Area ratio, DSO, and compactness measures for sample images

Image	Area ratio	DSO	Compactness
A	0.44	0.25	5206
B	0.44	0.18	9604
C	0.32	0.25	6126
D	0.24	0.31	4440
E	0.18	0.44	1728
F	0.14	0.59	749
G	0.09	0.50	1363

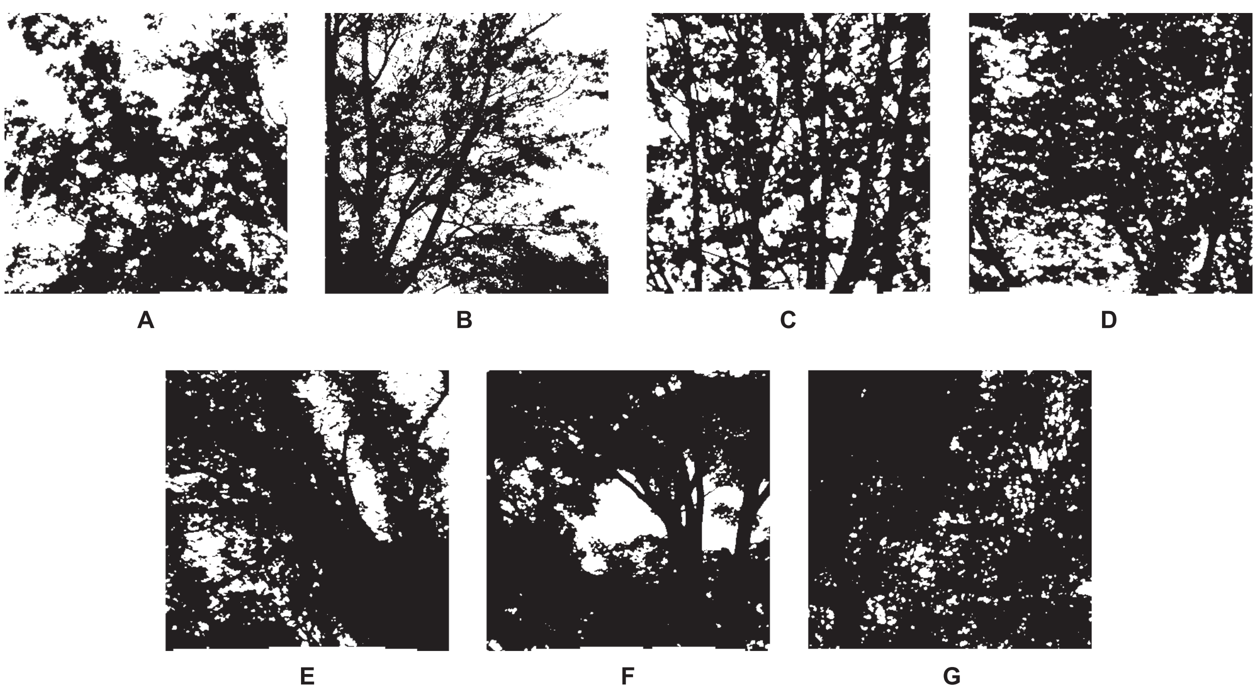

Figure 2—Examples of transparency patterns showing different amounts and distributions of plant structures (black).

TREND ANALYSIS

As previously mentioned there can be substantive variation in the size, shape, number, and spatial arrangement of leaves and branch structures. Therefore, comparisons of transparency measurements between different trees or even between different perspectives of the same tree are not very meaningful. However, one purpose of transparency estimation is to determine the change in the amount of foliage over time. Repeat measures using photo monitoring over short periods of time would limit many sources of extraneous variability and increase precision for this change analysis. For this technique to be successful, camera parameters must be recreated precisely, and tree structures must not have changed positions significantly.

Camera parameters include the optics, exposure and other optional settings, and the location of the camera in relation to the tree. Limiting the amount and nature of change in these parameters between observations is critical. Situations may require the use of a different camera or lens, but testing should be done to ensure the compatibility of the results.

Unfortunately, illumination can not be controlled in the outdoor environment, so exposure settings will need to be adjusted. If plenty of light is available and the crown structures are relatively unaffected by the wind, the recommendation would be to use the smallest aperture setting available. Underexposure by 1 or 2 stops is usually required to preserve sunlight and stray foliage with dominant sky background. It is also helpful to reduce penumbral and image blooming effects.

Relocating the camera can be easy with the proper preparation. If it is possible, permanent markers can be set to reestablish the azimuth. Otherwise, permanent features can be selected and photographed for future reference. These features can be used to triangulate the position for relocation. Find features at different depths that can be aligned relative to one another. The junction of major branches on the tree of interest may be helpful. It is a good idea to have multiple tie points in case a branch breaks or some other change occurs.

Tree structures may be affected by wind and other dynamics (loading caused by foliage, moisture, etc.) It is best to avoid collecting data under windy conditions. Other structural dynamics may be unavoidable, in which case it must be determined what detriment these are to the analysis. There may be small movements of leaves and branch growth. Different leaves (in deciduous trees) virtually guarantee that exact replication of the viewpoint to every structure is not possible. However, if assumptions can be made about the semi-rigid nature of large woody structures and relative consistency of bud locations between years, there is still an advantage in monumented viewpoints. Also, as a tree grows the apical meristems will naturally be dispersed over a broader area. For this reason the length of time between sampling should be reasonably short relative to the growth rate of the tree.

These controls allow more appropriate comparison of transparency estimates to be made. Comparison using area ratio, point-wise and region-wise transparency density maps, compactness, and DSO can be done with some confidence. If replication is performed well, it may be possible to perform localized change detection (fig. 3).

SUMMARY AND CONCLUSION

While contact or destructive sampling provides the best results for foliage measurement, canopy access and associated costs largely prohibit this type of sampling for applications requiring large numbers of trees to be observed. Litter trap sampling of deciduous trees is informative, but challenging at the individual tree level. Visual assessment has been a useful method, particularly for tree health appraisal.

Repeated measures designs are useful for minimizing extraneous variability. Unless a number of assumptions are made regarding the uniform distribution of crown structures within a generalized crown space, perspective control should be maintained over time for maximum precision. Further study is

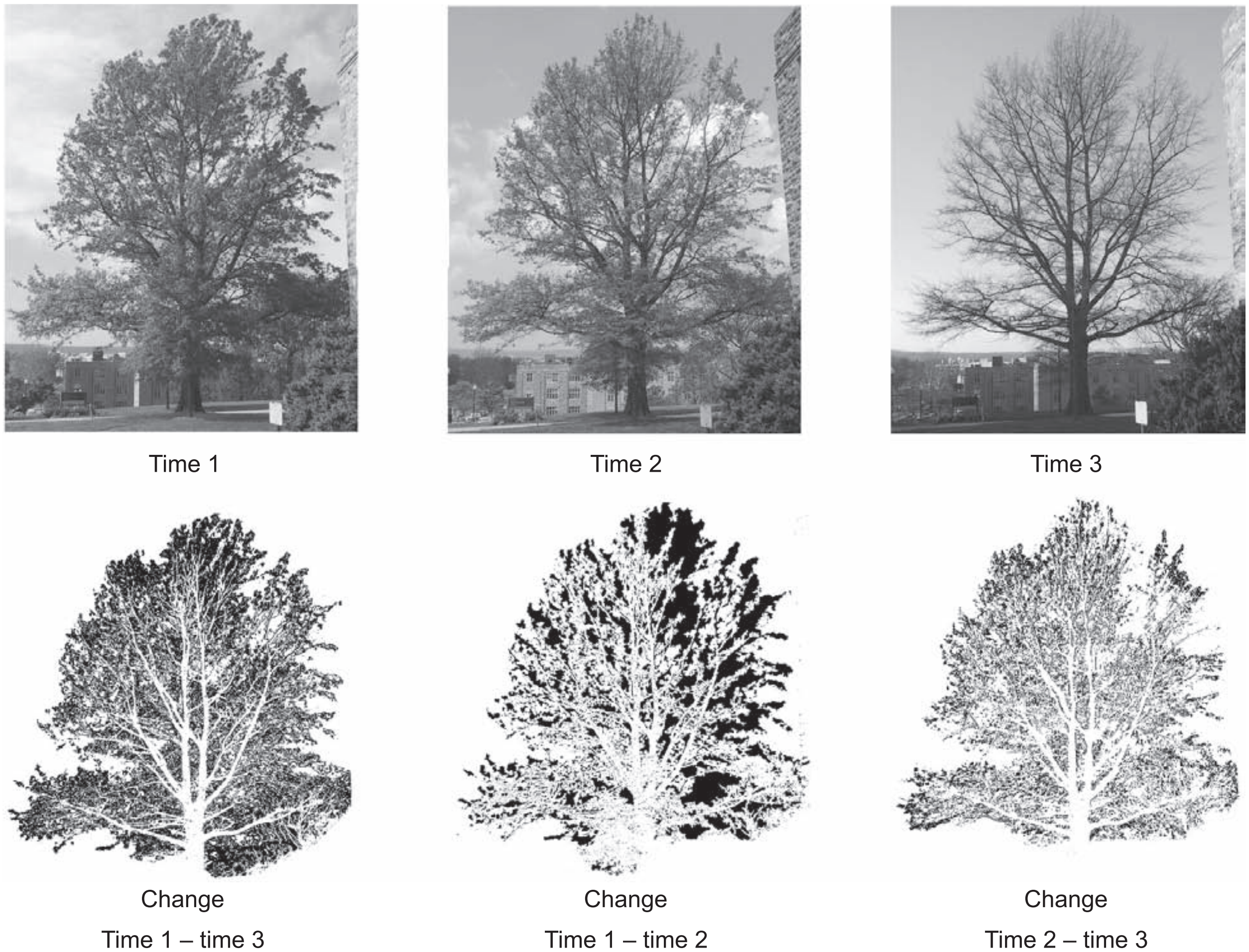

Figure 3—Photos taken at three different times from a monumented viewpoint (top) and visual depiction of localized silhouette area (SA) change (bottom).

needed to examine the tolerances required for perspective control and whether this is possible given the dynamics of the crown structures.

Interpretation of results varies with application. Foliage change can vary as a result of a number of factors and may vary systematically within the crown. Symptomatic characteristics such as discoloration, dead and skeletonized leaves, and wilting may not be detected in underexposed images and would need to be noted before the observer left the plot. Investigation should be made into the creation of transparency coefficients (analogous to LAI, light extinction (Smith 1993), and shading coefficients (Nowak 1996)). These methods also can be used to judge the decline or recovery of trees from various damaging agents. Biological thresholds where defoliation affects tree growth or mortality might be determined by photographic analysis.

Though not explicitly considered with visual methods, scale is a consideration for spatial sampling. This comes to the forefront with digital imaging as the data is sampled and recorded in discrete amounts and over discrete tessellated regions. This should be investigated over a range of transparencies.

These digital photographic methods allow low-cost raw data collection. These data can readily be analyzed by numeric methods, providing consistent estimates over remeasurement cycles. Data are also easily archived and organized without requiring a great amount of physical storage space.

Disadvantages of the proposed method include the need for precise realignment and re-creation or calibration of lighting and camera parameters. This technique is also limited to situations where a large portion, if not all, of the tree crown can be viewed without overlap from other trees or objects in the foreground or background.

Area ratio alone, as a single measure of transparency, lacks specificity of description and does not account for scale explicitly. DSO and compactness provide more information about the complexity of the 2D shape, and thus some indication of porosity. Additionally these methods do not require explicit parameters for creating a crown outline. Transparency distribution maps can allow precise analysis of foliage change over time, provided that spatial changes can be corrected or assumed. Photographic monitoring shows promise for enabling more precise estimates of change in the amount of foliage over time.

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STOCKING EQUATIONS FOR REGENERATION IN MIXED OAK STANDS

Songlin Fei, Kim C. Steiner, and James C. Finley[1]

Abstract—Regeneration stocking equations for mixed-oak stands were developed based on data collected from nearly 14,000 plots in the central Appalachians. Maximum stand density was identified by plotting aggregate height against number of seedlings per plot, and was used as the reference level of the average maximum stand density (100 percent stocking or A-level stocking). Minimum stand density (B-level stocking) was estimated using the crown area and seedling height relationship of open-grown seedlings. Stocking equations were developed separately for plots having average seedling height below and above 9 feet. The resulting stocking equations provide an objective basis for evaluating stocking of young regeneration in the upland mixed-oak forest.

INTRODUCTION

Appropriate stocking equations or stocking charts, which serve as measures of stand density, have long been sought by foresters. Stocking can be measured using numbers of trees, quadratic mean diameter, mean volume, dominant height, or other stand properties appropriate to the concept of density (quantity per unit area). All stocking guides share one common concept – relative density. Relative density is the ratio of absolute density to a reference level. Measures of relative density assess crowding in forest stands by comparing the growing space available per tree with the growing space available to trees of the same size at some reference level of density (Stout and Larson 1988). Generally, the two major approaches to measure stocking are typified by: Reineke's (1933) stand density index (SDI) and Gingrich's (1967) stocking diagram. Most stocking charts, diagrams, and monographs are suitable only for bigger trees (> 12 feet in height or > 1 inch in dbh), and older stands (> 20 years). No stocking guide exists for seedlings or young stands for the upland mixed-oak forest. The seedling stage is very important because it determines the future stand structure. Failure to obtain adequate stocking of desired species can leave a stand unproductive for many years. Hence, developing a stocking guide for the regeneration stage is necessary and pressing, and that was the objective of this study.

SOURCE OF DATA

Three sets of data were used in this study. The first data set was collected in 52 mixed-oak stands in Pennsylvania. Depending on stand size, 15 to 30 permanent center points were systematically installed in a square grid on each stand. Four permanent sample plots with a radius of 3.72 feet (0.001-acre) were established around the center points at each cardinal direction at a distance of 16.5 feet. On each plot, all tree seedlings regardless of origin were recorded by species and height class and seedling cover percentage (i.e. percentage of plot area covered by seedling canopy) was estimated. All stands were measured approximately one year before harvest, 33 stands were re-measured one year after harvest, 16 stands were re-measured four years after harvest, eight stands were re-measured five years after harvest, and four stands were re-measured six years after harvest.

Data from 15 mixed-oak stands with stand ages of 6-12 years were also included in this study. The overstory of each of the 15 stands was removed 6-12 years prior the time of assessment, and the stand regenerated successfully after harvest. These stands were intentionally chosen to represent crown-closure or near crown-closure conditions. Depending on the size of the stand, 15 to 40 plots with a radius of 7.44 feet (0.004 acre plots) were sampled throughout the stands. In total, 504 plots were included in this data set. On each plot, all seedlings or saplings regardless of their origin were recorded by species and height, and percentage of crown cover was estimated.

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The final data set provided information for open-grown trees. Based upon abundance and availability, 567 open-grown trees that included the six major regeneration species in this region were measured in this data set: 81 red maples (*Acer rubrum* L.), 97 black birches (*Betula lenta* L.), 38 blackgums (*Nyssa sylvatica* Marsh), 92 white oaks (*Quercus alba* L.), 125 chestnut oaks (*Q. montana* Willd.), and 134 northern red oaks (*Q. rubra* L.). All selected trees had no competing neighbors at the time of measurement, and they were measured in stands that provided data for the 1st and 2nd data set. For each tree, species, height, stem dbh, and crown diameter were recorded. In order to have best crown size estimation, crown diameters were measured in four directions: longest dimension of the crown, and 45, 90, and 135 degrees off the longest dimension through the center.

DEVELOPMENT OF STOCKING GUIDES

Average Maximum Density

Plots from the first two data sets that had at least one seedling were utilized to identify plots that were experiencing the maximum level of competition. Aggregate height (Fei and others), a composite measure of stand density, was calculated on each plot and then plotted against seedling density on a log-log scale (fig. 1). Two clear boundaries are apparent. The lower boundary is the minimum plot aggregate height for a given number of seedlings. It represents plots covered only with seedlings of the smallest height (one inch in this study). The upper boundary corresponds to the observed maximum aggregate heights over the range of observed seedling densities. To ensure that the observed maximum aggregate height represents the biological average maximum level of competition or the ecological maximum carrying capacity, plots around the upper boundary were further examined. Figure 1 was divided into 0.05 unit width slices along the x-axis, and the top two plots near the upper boundary in each slice were then selected. For all selected plots, percentage of seedling cover was further checked, and plots with less than 90 percent seedling cover (by measurement) were eliminated. The remaining selected plots were the ones chosen to represent the biological frontier. In total, 110 plots were used to define the biological frontier. Maximum aggregate

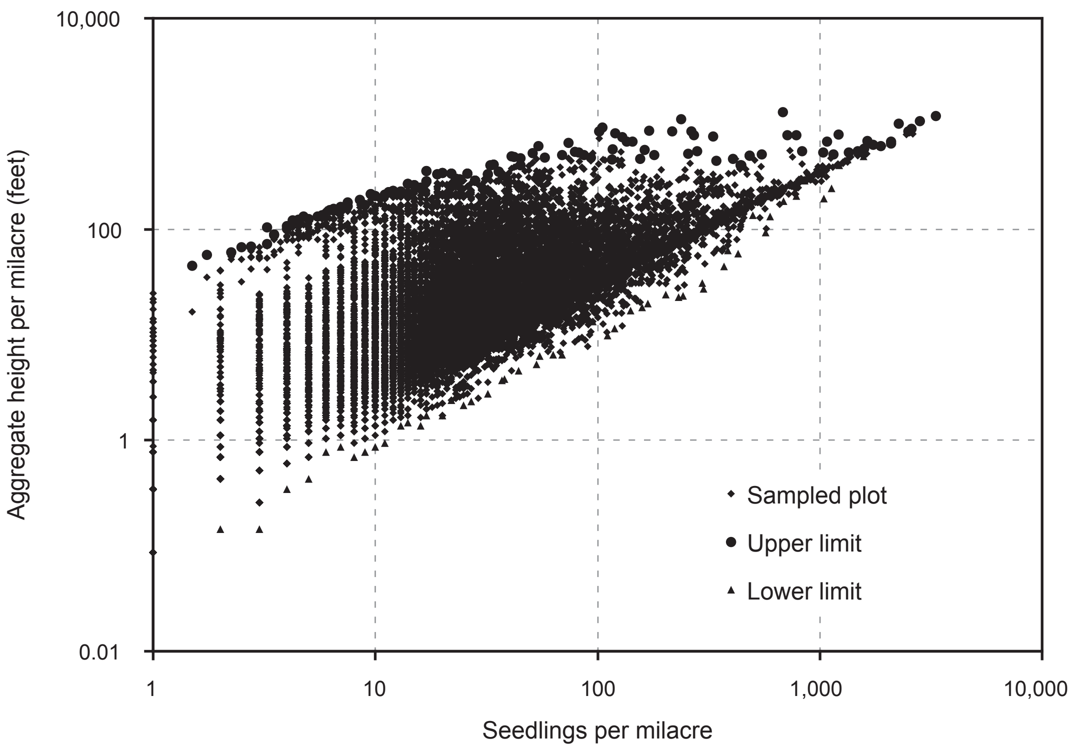

Figure 1—Relationships between aggregate height and number of seedlings per milacre on 13,853 surveyed plots. Plots with maximum or minimum aggregate height at a given density are highlighted.

height increases as seedling density increases. But the increase is progressively smaller as the number of seedlings per milacre increases. The upper and lower boundaries converge as seedling density approaches the maximum.

As with Gingrich's (1967) stocking guide and Reineke's (1933) SDI, average maximum competition was selected to serve as the reference level to develop regeneration stocking equations. To develop stocking equation, we first analyzed relationship between average crown area and height for seedlings experiencing the average maximum level of competition (seedlings in the 110 biological frontier plots). Crown area was determined simply by dividing plot size by the total number of seedlings in these frontier plots. Regression analysis was then carried out by using crown area as the dependent variable and average seedling height as the independent variable. Since the relationship between crown area and seedling height has a significant shift for seedlings above and below 9 feet tall on average (Fei 2004), two different regression lines were fitted to represent the two different crown area-height relationships. Using the crown area-height relationship, the stocking level on a plot then can be calculated as follows if seedling height is measured in feet:

$$\begin{aligned} S &= [(N \bullet 0.0682 \bullet AvgHt^{1.0032}) / (m \bullet 43560)] \bullet 100 \\ &= (0.00016/m) \bullet N \bullet AvgHt^{1.0032} \\ &= (0.00016/m) \bullet N \bullet (\Sigma h_i / N)^{1.0032} \qquad (AvgHt < 9 \text{ feet}) \end{aligned} \tag{1}$$

$$\begin{aligned} S &= [(N \bullet 0.0044 \bullet AvgHt^{2.3667}) / (m \bullet 43560)] \bullet 100 \\ &= (0.00001/m) \bullet N \bullet AvgHt^{2.3667} \\ &= (0.00001/m) \bullet N \bullet (\Sigma h_i / N)^{2.3667} \qquad (AvgHt \geq 9 \text{ feet}) \end{aligned} \tag{2}$$

where

S = percentage of School of Forest Resources, regeneration stocking
N = the total number of seedlings per plot
AvgHt = the average height of all seedlings
m = the size of plot in acres
h_i = height of seedlings on the sampled plot (i = 1, ……, N)

Average Minimum Density

Average minimum stand density at full canopy closure, or Gingrich's (1967) B-level stocking, represents an ideal condition in which a stand is fully covered with seedlings with maximum crown area and no inter-seedling competition. Crown areas of open-grown seedlings were used to define the maximum crown area. Crown area of open-grown seedling was calculated using average crown diameters from field measurement. To compute the minimum density at a given average seedling height, the relationship between crown area and seedling height of open-grown seedlings was used.

Regression analyses of crown diameter against seedling height were performed by species. Comparisons of regression coefficients among different species indicated that the overall relationship between crown diameter and seedling height is not significantly different among species, although crown diameter of oak species was slightly greater than non-oak species when seedling heights are small (fig. 2). Consequently, the same crown area-diameter relationship was used for the six major regeneration species. Minimum number of seedlings with maximum crown area that can fully cover a plot can then be calculated by dividing total plot area with average maximum crown area of seedlings at given average height. Since the relationship between crown area and seedling height also has a significant shift for open-grown seedlings above and below 7 feet tall on average (Fei 2004). Two different equations were developed for seedlings < 7 feet tall and for seedlings ≥ 7 feet tall:

$$N = (43560 \cdot m) / (0.4051 \cdot AvgHt^{1.50}) = 107529 \cdot m / AvgHt^{1.50} \quad (AvgHt < 7 \text{ feet}) \tag{3}$$

$$N = (43560 \cdot m) / (0.0479 \cdot AvgHt^{2.55}) = 909395 \cdot m / AvgHt^{2.55} \quad (AvgHt < 7 \text{ feet}) \tag{4}$$

where

N = the minimum number of seedlings per plot
m = the size of plot in acres
AvgHt = the average height of seedlings

Because less than 10 open-grown seedlings with height smaller than one foot were measured, the minimum number-height relationship for small size seedlings is not as robust as for larger seedlings.

DISCUSSION

Regeneration equations developed above have reasonable quantitative connections with the former stocking guides. For instance, if there is only one tree with minimum crown area (A-level) on a milacre plot and the plot is fully stocked, then the height of the tree must be ≥ 49 feet based on the regeneration stocking equation. Using the highly deterministic height-diameter relationship of trees in the upper-limit plots (*Height* = 8.79*dbh* + 6.69, $r^2 = 0.83$), the correspondence tree must have a dbh ≥ 4.8 inches. With the same scenario, Gingrich's (1967) equation predicts a minimum dbh of 4.0 inches for oak and hickory species; McGill's (1999) equation predicts a minimum dbh of 4.7 inches for northern red oak; while Stout's (1988) equations predict a minimum dbh of 4.5 inches for red maple. In an alternative scenario, if there is only one tree with maximum crown area (B level) on a milacre plot and the plot is fully stocked, then the height of the tree must be ≥ 15 feet based on the resulting regeneration stocking, and the correspondence tree must have a dbh ≥ 1.7 inches by the height-diameter relationship of open-grown

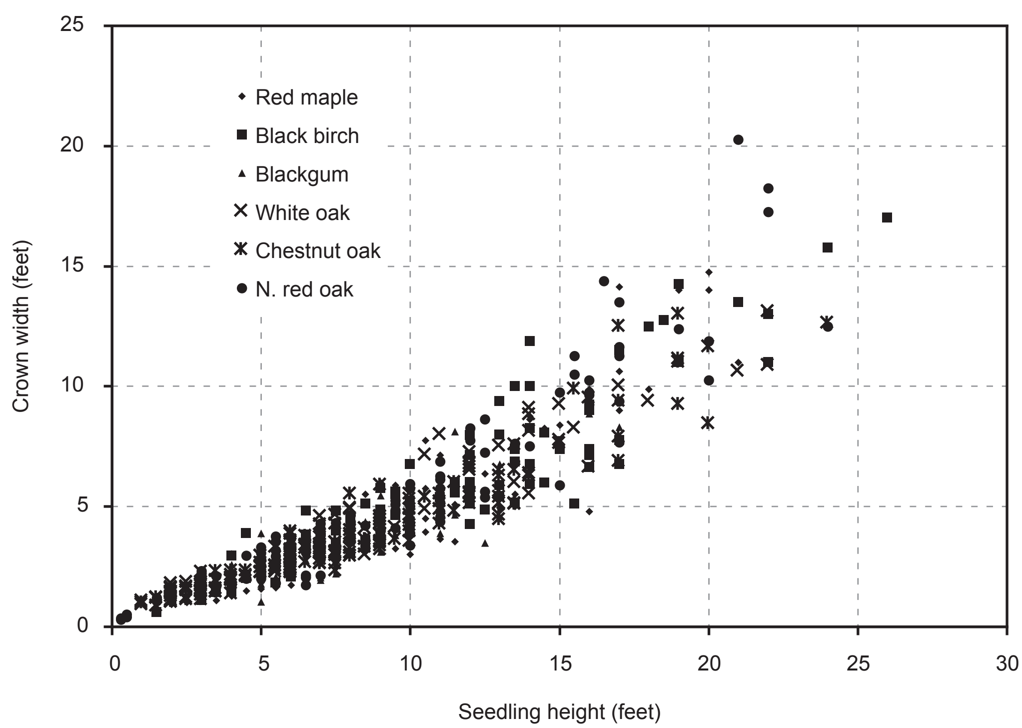

Figure 2—Relationship between crown diameter and seedling height by species for open-grown seedlings and small saplings.

trees (*Height* = $-0.90dbh^2 + 7.82dbh + 4.18$, $r^2 = 0.87$). Based on Gingrich's and McGill's equations, the minimum dbhs in the second scenario are 2.3, 1.6 inches, respectively. Both scenarios indicate a good connection between the regeneration stocking and other stocking guides for mature stands.

The use of the regeneration stocking equations is rather simple. The equations can be used both in pre- and post-harvest situations. For example, if a milacre plot has 100 seedlings with average height of three feet, we can plug these parameters in equation (1) and calculate the stocking value, which is about 50 percent. By plugging these parameters in equation (3), we can determine that we need 21 seedlings with average height of three feet to reach the B-level stocking. Hence, this plot will eventually reach full stocking if no major disturbances occur. Forest manager can use the stocking value to determine if the current stocking is adequate for their management goal. The resulting regeneration stocking equations provide an acceptable and objective basis for evaluating stocking of tree regeneration in the upland mixed-oak forest. We suggest other researchers explore the use of the stocking equations for describing and assessing regeneration stocking.

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A FORM OF TWO-PHASE SAMPLING UTILIZING REGRESSION ANALYSIS

Michael A. Fiery and John R. Brooks[1]

Abstract—A two-phase sampling technique was introduced and tested on several horizontal point sampling inventories of hardwood tracts located in northern West Virginia and western Maryland. In this sampling procedure species and dbh are recorded for all "in-trees" on all sample points. Sawlog merchantable height was recorded on a subsample of intensively measured (second phase) sample points and these heights were predicted on the non-intensive (first phase) sample points. Regression analysis was used to predict heights on first phase points in order to achieve an estimate of board foot volume per acre for every point. Results indicate an improved estimate of the mean volume per acre when compared to traditional double sampling using basal area as the auxiliary variable. An unbiased sampling error was also achieved in this process.

INTRODUCTION

One of the major influences on forest inventory over the last few decades has been the desire to reduce field data collection time without sacrificing the accuracy and precision of sample based estimates of trees per acre, basal area, weight, and volume. The switch to the point sampling system, introduced by Grosenbaugh in late 1950s, was fueled by the obvious time savings as fewer "in-trees" were measured per sampling unit. Over the last 30 years there has been a slow migration to using larger basal area factors (BAFs) in sawtimber inventories, spurred by the empirical evidence that it provides less biased estimates of stand volume, but more likely due to the fact that fewer "in-trees" would be measured thus saving field data collection time (Wiant and others 1984, Brooks and McGill 2004). During this same period there was a parallel reduction in fixed area plot size from 0.25 and 0.20 acre plots to those of 0.1 acre in size. In the 1960s, a sampling technique commonly referred to double sampling was introduced by Freese (1962).

This sampling technique was developed to take advantage of the relationship between the variable of interest and some easily measured and highly correlated auxiliary variable so that only a subset of the overall sampling units would be intensively measured. One drawback to double sampling was that since dbh and species are only recorded on second-phase (intensive) points, no direct method of creating a stand and stock was available, though procedures were developed for their estimation (Matney and Parker 1991, Shiver and Borders 1996). Should an inventory require more accurate stand and stock tables, there are ways to do this without intensively measuring every tree on all sampling units. An inventory system can be designed where dbh, product, and species are tallied on all points, and tree heights are only measured on a subsample of these plots. Under the proposed sampling system, dbh, species, and sawlog merchantable heights would only be measured on second-phase (intensive) points. On all first-phase (non-intensive) samples, only dbh and species would be recorded. Using regression analysis, all heights necessary for volume estimation would be predicted on a species or species group basis. While this process requires more time than the use of traditional double sampling, it would be more efficient than measuring heights on all sampling units. This design would permit an accuracy equivalent to the intensive measurement of all sampling units for stems and basal area per acre. In areas where there are large variations in value based on species and size, diameter distribution data becomes increasingly important and may warrant the additional field inventory time. Although this technique has been employed in the South, no published record of the effects of height prediction on the accuracy and precision of typical volume sampling statistics has been found. The research that follows will:

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1. Outline an inventory system where board foot volume is known (measured) on intensive points and estimated on all non-intensive points based on regression analysis to estimate sawlog merchantable height.
2. Through computer simulation, evaluate the behavior of the mean volume per acre and associated sampling error.

PROCEDURES

Datasets from several areas in West Virginia and Maryland were available for analysis in this study. Each dataset included measurements of species, dbh, and sawlog merchantable height on every point which permitted the comparison of both two-phase sampling methods (double sampling and height regression sampling) to estimates where all "in-trees" were intensively measured on all sampling units. The WVU Research Forest, Coopers Rock State Forest and the Coopers Rock Annex datasets are based on a 1999-2000 inventory conducted at both Coopers Rock State Forest and the West Virginia University Research Forest located in Monongalia and Preston Counties, WV. Primary species found in this inventory included yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), chestnut oak (*Q. prinus* L.), and black cherry (*Prunus serotina* Ehrh.). These datasets were based on a BAF 20 point sampling inventory on a systematic grid. The Compartment 14, 1967 Single Species and Trout Pond datasets were also collected on the West Virginia University Research Forest as part of other research projects. The Tygart dataset was collected in the summer of 2004 from the Tygart Tract located in Dailey, WV. The tract is approximately 10 miles south of Elkins, WV and approximately 426 acres were inventoried. Primary species consisted of red maple, northern red oak, and chestnut oak. The original dataset consisted of 67, 1/5 acre circular plots where species, dbh (nearest 0.1 inch), sawlog merchantable height (0.1 foot) and total height (0.1 foot) were measured. Horizontal distance from plot center to every "in-tree" was also recorded to the nearest foot using an Impulse laser. The Savage River dataset comes from the Savage River State Forest in Garrett County, MD courtesy of the Maryland Forest Service. Primary species consisted of red oak, red maple, and chestnut oak. This dataset consisted of 214, 1/5 acre circular plots which formed the basis of a continuous forest inventory system located throughout the 53,473 acre forest. At each plot, species, dbh (nearest 0.1 inch), and number of 8-foot logs were tallied for every "in-tree". Horizontal distance from plot center to every "in-tree" was also recorded to the nearest foot using an Impulse laser. All datasets originally based on fixed area plots included accurate measurements of horizontal distance to each "in-tree". These datasets were converted to point sample inventories based on a BAF of 20. All trees having a horizontal distance from point center equal to or less than the critical distance for that tree size were included in the final dataset.

Since all datasets were originally based on the intensive measurement of all "in-trees" on all points, board foot volume of every "in-tree" was calculated based on field measurements of dbh and sawlog merchantable height and the board foot volume equations published by Scott (1979) for International ¼ inch log rule. In this study, the "actual" mean volume per acre used for comparison purposes is based on simple random sampling statistics of this horizontal point sample data.

To conduct the double sample point sample inventory, the existing datasets were sampled using a 1:4 ratio where one out of every four samples points was selected as an intensively measure point utilizing the recorded species, dbh and sawlog merchantable height data. On all other points, only species and dbh were utilized. A ratio of means estimator was used to calculate mean board foot volume per acre and the associated standard error employing basal area as the auxiliary variable (Shiver and Borders 1996).

Height regression sampling was applied to the same samples selected in double sampling inventory to minimize variation between the two systems. In this case, the same points that were selected as second phase sampling units (intensively measured sample points) in the double sample inventory were also used as a basis for the merchantable height regressions. Under this two-phase sampling system, species, dbh and sawlog merchantable height were utilized on intensive points while only species and dbh were used on non-intensive points. Regression analysis was used to predict sawlog merchantable heights on all non-intensive points, thus providing the necessary information to calculate boardfoot volume for every sample point. A common height model mentioned by Avery and Burkhart (2002) was used and is of the form:

$$Ln(MHT) = \beta_0 + \beta_1\left(\frac{1}{DBH}\right) + e_i \tag{1}$$

where

DBH = diameter at breast height (inch)
MHT = sawlog merchantable height (feet)
β_0, β_1 = parameters to be estimated from the data
e_i = error (feet)

Separate parameters were established for each species whenever a sample size of five or more was available. If less than five observations were available, the species was grouped in the "all other" category.

Two different methods for data analysis were conducted and evaluated for height regression sampling, each producing a different set of results. Sampling error for Method 1 is easily calculated but not statistically sound while Method 2 provides a more rigorous approximation of the sampling error.

Method 1 (SRS method) for height regression sampling calculates inventory statistics for board foot volume per acre using simple random sampling techniques. The assumption is made that the error associated with predicted heights on non-intensive (first phase) points is minimal and that the estimates of volume per acre and the associated standard error, can be estimated using simple random sampling statistics.

Method 2 (ratio method) for height regression sampling uses an estimate of volume (using predicted heights for all trees) for each point. The actual volume on just the intensively measured points is based on measured tree heights. At this point the dataset can be treated as a double sample where actual volume is the variable of interest and estimated volume is the auxiliary variable. The mean volume per acre and standard error can be calculated using equations (2) and (4) respectively. A ratio estimator was used to find the mean volume per acre:

$$\bar{y}_{hrs} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} \times \frac{\sum_{i=1}^{n'} x_i}{n'} = \hat{R}\bar{x}' \tag{2}$$

where

$\bar{y}_{hrs}$ = mean volume per acre
y_i = actual volume per acre on intensive points
x_i = predicted volume per acre on intensive/non-intensive points
n = number of intensive points
n' = total number of points

The variance of the ratio can be calculated from the equation:

$$S_{\hat{R}}^2 = \frac{\sum_{i=1}^{n} y_i^2 - 2\hat{R}\sum_{i=1}^{n} x_i y_i + \hat{R}^2 \sum_{i=1}^{n} x_i^2}{n-1} \tag{3}$$

where

$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i}$$

The overall variance can be calculated by (Shiver and Borders 1996):

$$S^2_{\bar{y}_{hrs}} = \frac{S^2_y}{n'} + \frac{S^2_{\hat{R}}}{n}\left(\frac{n'-n}{n'}\right) \quad (4)$$

In order to investigate the estimation properties of both the mean and standard error for the sampling techniques described, a Visual Basic 6.0 simulation program was written to resample existing datasets where second phase sample points were selected at random (without replacement). This procedure was employed for both double sampling and height regression sampling (methods 1 and 2). For each simulation, a 1:4 ratio of intensive to non-intensive samples was employed where all intensive (second phase) points were selected using a random number generator, thus providing unique inventories each simulation. A total of 500 simulations were conducted for each dataset, providing estimates of the mean volume per acre and the standard error for each of the 500 simulations.

RESULTS

For each of the 8 inventory datasets, mean board foot volume per acre was estimated using measured diameters and sawlog merchantable heights that were available for every "in-tree" in the dataset. The simple random sampling statistics based on these measurements are considered the actual volumes for this study. One out of every four points was then selected to be used as an intensively measured sample point (second phase) for both a traditional double sample and the proposed height regression sampling technique. For the intensively measured points, species, dbh and sawlog merchantable height measurements were utilized. For the non-intensive (first phase) sample points, only species and dbh information was used. Table 1 includes the mean board foot volume estimate based on the simple random sample mean (SRS) from the assumed "actual" volume, the mean based on a double sample ratio of means estimator (DS) and two estimates based on the use of height regression sampling (HRS) using the two estimation methods described previously. In five of the eight inventories, the mean board foot volume based on the HRS method 1 procedure was more accurate than the common double sampling approach using basal area as the auxiliary variable (table 1). While in all but one of the inventories, the mean board foot volume based on the HRS method 2 procedure was more accurate than the double sampling approach (table 1). The results of the regression process indicate that some increase in variance with increasing tree size occurred, but the distribution of merchantable height errors appeared random (fig. 1). In most cases, predicted heights were within 10 feet of the actual height of each tree at least 60 percent of the time (table 2). The estimated standard errors for each sampling scheme are shown in table 3. In each of the eight inventories, both HRS method procedures resulted in an estimate of the standard error that were closer to that based on the complete measurement of every sample tree (SRS). Both the DS and HRS systems used the same 1:4 ratio of second phase to first phase samples and all intensively measured points (second phase) were the same sample points in both instances.

The results from the 500 simulations conducted on each of the 8 inventory datasets indicate that the HRS method 2 estimates of the mean board foot volume per acre had a lower RMSE in all cases and a smaller average bias in 5 of the 8 inventories tested (table 4). Only one of the HRS method 1 estimates had a smaller average bias but all eight inventories still had a lower RMSE. Both the DS and HRS simulations provided what appeared to be unbiased estimates of the mean board foot volume per acre, with both HRS procedures showing a higher level of precision (fig. 2). The estimates of the sampling error for the

Table 1—The mean and bias in board foot volume per acre for inventory tract and sampling scheme

			Mean board foot volume per acre				Difference from SRS		
Tract	Acres	Points	SRS	DS	HRS (srs)	HRS (ratio)	DS	HRS (srs)	HRS (ratio)
Tygart	426	67	7,883.4	7,935.5	7,834.8	7,840.7	52.1	-48.6	-42.7
WVU Research Forest	7,594	2,013	9,676.1	9,730.9	9,520.8	9,640.9	54.7	155.4	-35.3
Coopers Rock State Forest	4,037	1,081	10,643.7	10,426.8	10,589.0	10,743.4	-217.0	-54.8	99.7
Coopers Rock Annex	364	98	10,341.9	9,945.2	10,511.0	10,418.4	-396.8	169.0	76.5
Compartment 14	138	52	11,076.6	10,909.2	11,209.8	11,053.8	-167.4	133.2	-22.7
1967 single species	3,500	384	2,539.4	2,531.3	2,473.0	2,546.5	-8.1	-66.3	7.1
Trout Pond	N/A	30	14,591.6	14,988.3	13,899.0	13,718.9	396.5	-692.9	-872.9
Savage River	53,473	214	10,363.2	8,359.0	10,551.4	10,732.6	-2,004.2	188.2	369.4

SRS = simple random sample mean; DS = double sample ratio of means estimator; HRS = height regression sampling.

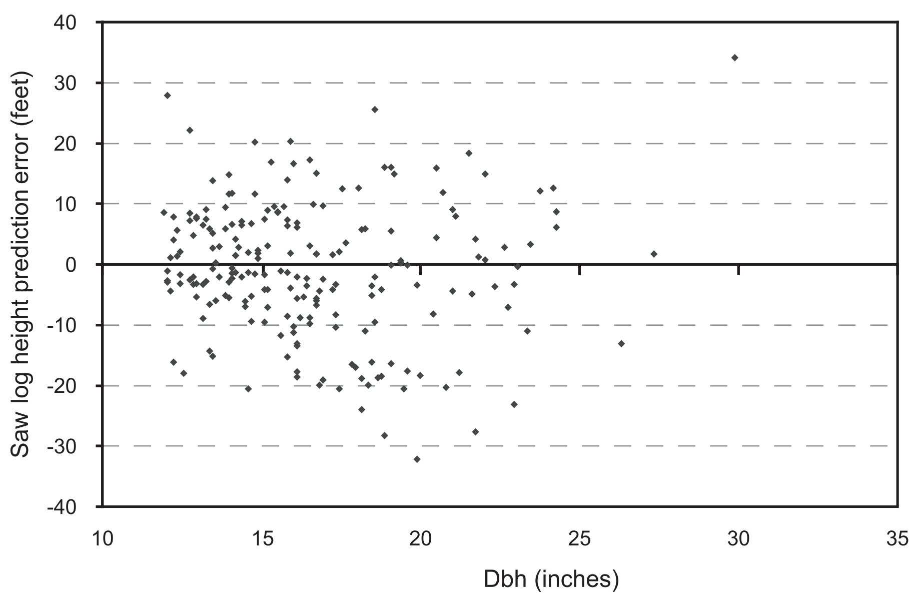

Figure 1—Height prediction error (foot) by d.b.h. across all species (Tygart Tract).

Table 2—Percentage of predicted saw log heights within 10 percent of the actual measured height by inventory tract

Tract	n	Within 10 feet	Percent within 10 feet
Tygart	210	144	68.57
WVU Research Forest	8,052	5,331	66.21
Coopers Rock State Forest	4,892	2,158	44.11
Coopers Rock Annex	392	240	61.22
Compartment 14	254	158	62.20
1967 single species	1,253	966	77.09
1967 species specific	331	261	78.85
Trout Pond	178	132	74.16
Savage River	932	630	67.60

Table 3—Standard error by inventory tract and sampling scheme

	Standard error (board foot per acre)				Standard error of the mean			
Tract	SRS	DS	HRS (srs)	HRS (ratio)	SRS	DS	HRS (srs)	HRS (ratio)
					percent			
Tygart	683.8	1,055.2	659.2	662.0	8.7	13.3	8.5	8.4
WVU Research Forest	153.9	230.6	145.5	159.7	1.6	2.4	1.7	1.7
Coopers Rock State Forest	200.1	343.4	192.4	214.6	1.9	3.3	2.0	2.0
Coopers Rock Annex	653.2	911.9	626.2	670.5	6.3	9.2	6.4	6.4
Compartment 14	916.3	1,534.8	894.6	890.7	8.3	14.1	8.0	8.1
1967 single species	130.9	152.3	119.9	146.7	5.2	6.0	5.9	5.8
Trout Pond	1,254.8	1,717.8	1,190.8	1,354.4	8.6	11.5	9.7	9.9
Savage River	481.0	1,840.8	480.4	502.2	4.6	22.0	4.8	4.7

SRS = simple random sample mean; DS = double sample ratio of means estimator; HRS = height regression sampling.

Table 4—Average bias and root mean squared error for volume estimates by inventory tract and sampling scheme (based on 500 simulations)

			Average bias (board foot per acre)			RMSE (board foot per acre)		
Tract	Acres	Points	DS	HRS (srs)	HRS (ratio)	DS	HRS (srs)	HRS (ratio)
Tygart	426.0	67.0	82.4	69.5	33.5	952.9	239.8	223.7
WVU Research Forest	7,594.0	2,013.0	8.3	-125.0	3.0	197.1	137.8	57.0
Coopers Rock State Forest	4,037.0	1,081.0	-15.6	-146.0	10.8	266.0	168.8	82.0
Coopers Rock Annex	364.0	98.0	39.0	163.7	74.5	787.4	326.3	286.0
Compartment 14	138.0	52.0	75.3	189.5	198.3	1,413.3	494.1	471.0
1967 single species	3,500.0	384.0	-3.4	-72.7	-3.3	75.0	90.0	52.5
Trout Pond	N/A	30.0	-330.7	324.0	158.6	1,290.8	613.1	524.2
Savage River	53,473.0	214.0	20.8	-192.9	-55.9	1,283.3	301.4	237.8

DS = double sample ratio of means estimator; HRS = height regression sampling; SRS = simple random sample; RMSE = root mean squared error.

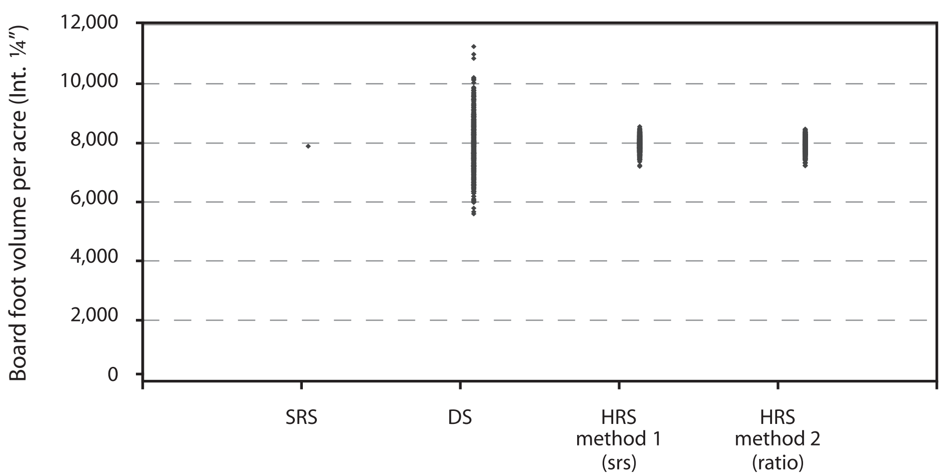

Figure 2—Variation in mean board foot volume per acre by sampling type for the Tygart Tract (based on 500 simulations).

HRS procedures were centered around the SRS estimate an appeared less variable than the traditional DS estimates (fig. 3). The DS estimates appeared to be biased in a positive direction. The relationship between actual and predicted volume, which was used to estimate the HRS sampling error, had a correlation coefficient of 0.999 and this relationship is depicted in figure 4.

DISCUSSION

The overall effect on mean volume per acre when some sampling units have measured heights and others have estimated heights is unknown. The variance is most likely reduced as the natural variation in heights by diameter and thus on volume has been removed through the prediction process.

The use of regression analysis to predict merchantable heights to obtain volume estimates on a subset of sampling units has provided some positive results. Mean volume estimation was usually more accurate

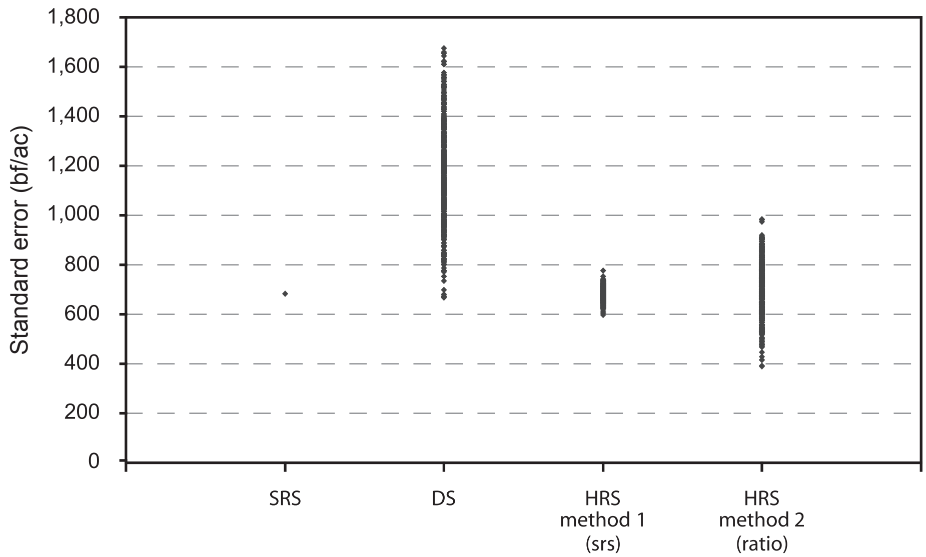

Figure 3—Variation in the standard error (board feet per acre) by sampling type for the Tygart Tract (based on 500 simulations).

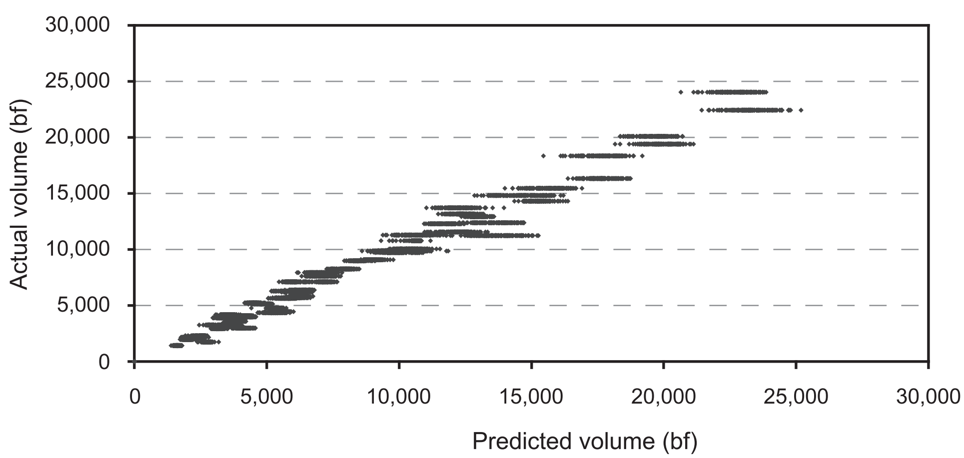

Figure 4—Relationship between actual and predicted volumes based on estimated heights for phase 2 points on the Tygart Tract (based on 500 simulations).

and precise than the traditional DS procedures. This study employed two different methods for achieving an estimate of sampling error. Method 1 employed a simple random sampling estimate of variance ignoring the fact that sawlog merchantable heights were predicted on all non-intensive (first phase) samples. In HRS method 2, the analysis was reformulated as a true double sampling application where a ratio estimator was used to estimate the sampling error. For most of the inventories investigated, both HRS sampling methods provided a smaller standard error than traditional DS approach. It appears that both HRS sampling methods provide positive results and although method 1 ignores the effect of height prediction on the overall variance, it still resulted in a seeming unbiased estimate of the mean board foot volume per acre and an unbiased, but slightly less variable, estimate of the sampling error.

The application of the HRS procedure is not warranted in many cases. The measurement of dbh on every sample tree may require more time resources than a single inventory can justify. However, in those situations where the additional diameter distribution data is desired, this procedure requires less field collection time than the complete enumeration of every sample point and provides reasonably accurate estimates of mean volume per acre even in variable hardwood populations.

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EVALUATION OF LANDSAT IMAGERY FOR DETECTING ICE STORM DAMAGE IN UPLAND FORESTS OF EASTERN KENTUCKY

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Abstract—Two categories of forest canopy damage (none to light vs. moderate to heavy) resulting from a 2003 ice storm in eastern Kentucky could be identified on readily available Landsat Thematic Mapper imagery using change detection techniques to evaluate the ratio of spectral bands 4 and 5. Regression analysis was used to evaluate several model formulations based on the spectral ratio and topographic variables for detecting the two categories of damage, which could be applied with a geographic information system. Results of this study suggest that moderate to heavy forest canopy damage caused by ice storms can be detected on sample plots from satellite imagery. Additional work is needed, however, to determine if these results can be used to produce an accurate landscape-scale map of canopy damage beyond the study area.

INTRODUCTION

Ice storms are a major, recurring type of disturbance in deciduous forests of the Eastern United States, with annual probability of occurrence ranging from 0.11 to 0.22 (U.S. Department of Agriculture Forest Service 1969, Hauer and others 1994). Mapping and assessing the extent and severity of storm damage in managed forests is necessary to estimate economic loss, salvage products, and plan recovery activities. Aerial photography is typically used for such assessment following a disturbance event (Lewis 2004), but results in unanticipated costs for its procurement and interpretation. Conventional Landsat Thematic Mapper (TM) satellite imagery has been shown to be useful for detecting forest damage to tree canopies resulting from insects (Vogelmann and Rock 1989) and ice (Burnett 2003). Because Landsat TM imagery is economical, readily available, and generally well suited to detect changes in vegetation (U.S. Department of Agriculture Forest Service 1995), methods for using it to detect and assess forest damage resulting from ice storms could be of significant practical value to managers.

A major ice storm occurred on February 15, 2003, in a large area of northeastern Kentucky and southeastern Ohio that included parts of the Daniel Boone and Wayne National Forests. Up to 2 inches of ice accumulated on exposed surfaces, causing breakage of limbs and stems, and uprooting (fig. 1). A report for the Wayne National Forest indicated that damage "...appeared to be light to moderate over the entire district, with many trees having some crown damage. In smaller pockets, ranging up to hundreds of acres in size, damage ranged from heavy to severe ..." (U.S. Department of Agriculture Forest Service 2003). Initial effects of forest damage resulting from this storm were assessed from conventional aerial photography (Lewis 2004). The success of other workers in using satellite imagery to assess levels of ice damage in mesophytic forests of Vermont (Burnett 2003) has encouraged us to test those methods in predominately upland oak forests of eastern Kentucky. The scope of our study was limited by available resources to a rudimentary application of well-developed methodology used to detect change in forest conditions from Landsat imagery (Heikkonen and Varjo 2004).

PROCEDURES

Study Site and Data Collection

An area representative of common forest types and typical ice damage was selected near Morehead, KY, in the Morehead District of the Daniel Boone National Forest (38.1º N, 83.5º W). Forest composition consists of over 40 commercial species that are distributed primarily in relation to moisture regime. On mesic sites of coves and northerly slopes are northern red oak (*Quercus rubra* L.), American basswood

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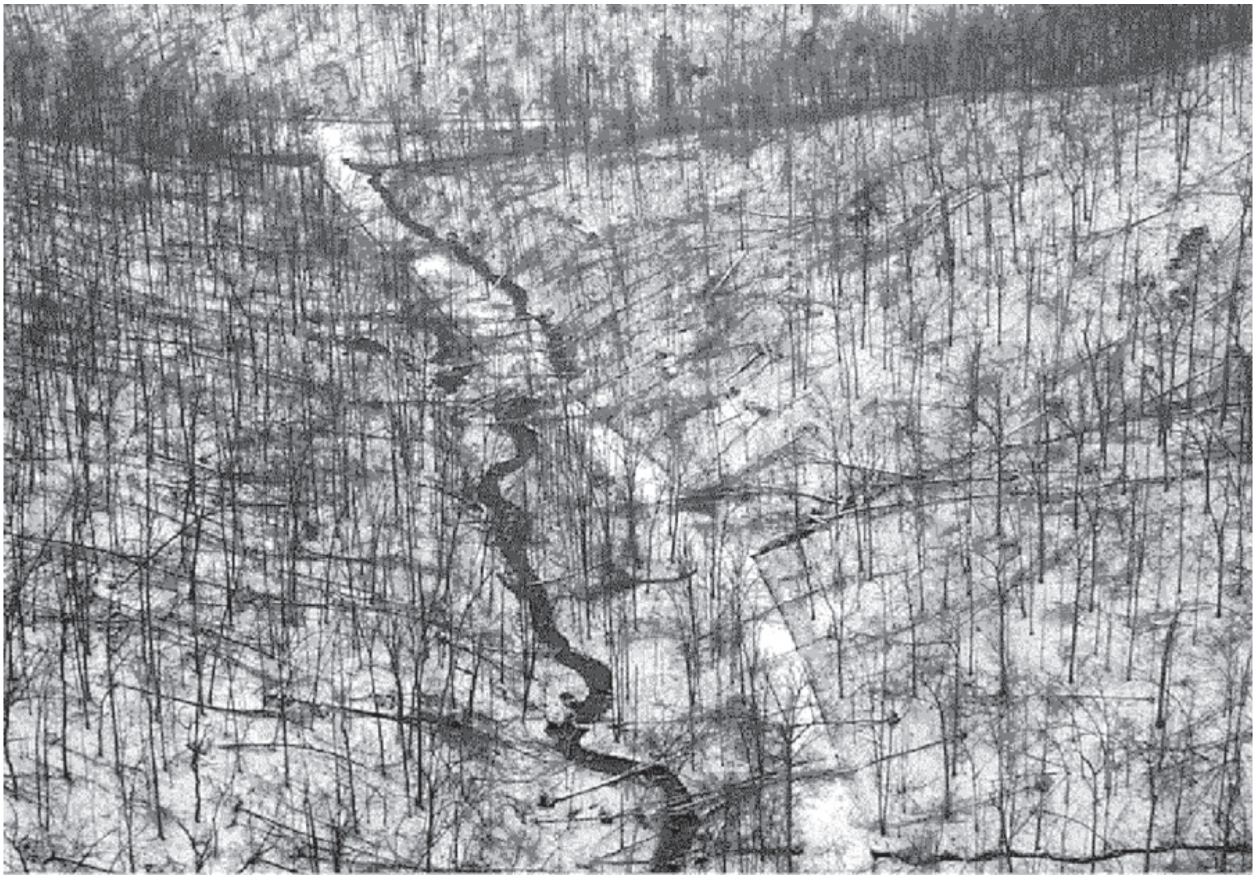

Figure 1—Aerial view of forest disturbance resulting from an ice storm that occurred on the Wayne National Forest in February 2003. The proportion of trees uprooted appears to be greater on the slope on the left than on the right.

(*Tilia americana* L.), American beech (*Fagus grandifolia* Ehrh.), yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), black birch (*Betula lenta* L.), red maple (*Acer rubrum* L.), and Canadian hemlock (*Tsuga canadensis* [L.] Carr.). Westerly slopes are occupied by yellow-poplar, northern red oak, white oak (*Q. alba* L.), and hickories (*Carya* spp. Nuttall.). On xeric southerly slopes and ridges are chestnut oak (*Q. prinus* L.), white oak, Virginia pine (*Pinus virginiana* Mill.), and shortleaf pine (*P. echinata* Mill.). Understory tree species include flowering dogwood (*Cornus florida L.*), sourwood (*Oxydendrum arboreum* [L.] DC.), and blackgum (*Nyssa sylvatica L.*). Two shrubs are widespread: rosebay rhododendron (*Rhododendron maximum* L.) on moist slopes and mountain laurel (*Kalmia latifolia* L.) on drier sites. Stand basal areas ranged from 70 to 120 square feet per acre.

Aerial photography was obtained soon after the storm for mapping the extent of the disturbance and assessing the severity of damage to forest resources. A study area of approximately 3,400 acres was selected on the basis of ground reconnaissance and aerial photography to include the range of disturbance, which varied from undisturbed patches of trees to canopy gaps associated with almost complete uprooting and crown breakage. The 1:10,000 scale, leaf-off, panchromatic photography was electronically scanned at 800 dpi, orthorectified to establish a coordinate system and remove image distortions resulting from camera and terrain sources, and displayed on a computer monitor at a scale of approximately 1:24,000. Plot locations were selected from a computer-generated grid overlaid randomly on the image; the grid intersects defined the center of potential plot locations. Intersects were randomly selected and a standard density grid was used to assign canopy damage to four categories:

Category	Range of canopy damage
None	No apparent damage to forest canopy
Light	< 25 percent of canopy damaged
Moderate	From 25 to 65 percent of canopy damaged
Heavy	More than 65 percent of canopy damaged

The categories were defined prior to classification of the sample plots on the digital image and had been used by the third author in an unreported trial of forest damage resulting from a windstorm. Selection of grid intersections continued until approximately 30 plots were chosen in each category of canopy damage. Coordinates of the location of each plot were recorded from the scanned photographic images using geographic information system (GIS) software. The GIS was also used to derive aspect (degrees azimuth) and gradient (percent) at each plot location from a digital elevation dataset. Elevation varied relatively little in the study area, from 800 to 1,250 feet, and was not tested for significance.

Each plot selected from the aerial photographs was located in the field during the following summer using a geographic positioning system to navigate to the recorded map coordinates. The plotless inventory method (Grosenbaugh 1952) was employed, and each sample tree identified by a 10-factor prism was classified as damaged or not damaged. Forest type on each plot was subjectively classified to provide supplemental information on variability of ice damage by species composition.

We obtained a cloud-free Landsat TM image of the study area for June 2002 and July 2003. A Landsat image represents an area about 106 by 115 miles in extent and consists of a grid of picture elements, or pixels. Each square pixel represents a ground area of approximately 0.22 acre. Data associated with each pixel consists of values for seven spectral bands, and the magnitude of these values varies depending on characteristics of objects or vegetation on the ground that reflects light to sensors on the satellite.

We used the moisture stress index (MSI) as the response variable to quantify forest damage (Hunt and Rock 1989). MSI is the ratio of mid-infrared band 5 (1.55–1.75 microns) to near-infrared band 4 (0.76–0.90 microns) and has been found useful for detecting the moisture content of vegetation because of differences in reflectance by the two bands. MSI is not without problems, however, because it may be influenced by factors unrelated to the disturbance event, such as soil moisture beneath vegetation or defoliation by insects. We used MSI as the response variable because we hypothesized that less photosynthesizing biomass would be present after the event than before it as a consequence of canopy gaps resulting from crown breakage and uprooted trees. MSI was calculated for each pixel in the study area satellite image scenes before (MSIb) and after (MSIa) the ice storm and extracted to a database for pixels containing a field plot. Data were not normalized for differences in atmospheric conditions between the two image dates.

Data Analysis

The kappa statistic (Cohen 1960) was used to test for agreement between categories of forest damage on the sample plots estimated from aerial photography and determination of damage in the field. We used chi-square to test for independence of damage category with aspect and gradient classes. Analysis of variance (ANOVA) was used to test the hypothesis that damage category had no significant effect on MSI at the 0.05 percent level of probability. The difference (MSId) between pre- and post-disturbance MSI was used as the ANOVA response variable, which follows methodology typically used in studies of vegetation change detection based on satellite imagery (Burnett 2003). Treatments consisted of the four categories of canopy damage determined by means of ground examination at each plot location. Significant differences among damage categories were separated by the Bonferroni test at the 0.05 level of probability.

We used logistic regression to evaluate formulations of prediction models that could be useful in automated detection of forest damage on satellite imagery obtained before and after an ice storm:

$$\text{logit (DC)} = \text{function of (MSIb, MSIa, MSId, aspect, gradient)} \quad (1)$$

The dependent variable, DC, is a binary damage category (i.e., None or Light vs. Moderate or Heavy). Two model formulations were evaluated that included either MSId alone or a combination of MSIa and MSIb. Aspect was transformed from a circular to a continuous measure by taking the sine and cosine of the direction in which each plot faced. A probability level of $p = 0.05$ was used to retain independent variables in the model. The two model formulations were tested with data for three groups of forest type (see table 1): (1) all types, (2) the two predominant types of mesic oak and mixed mesophytic, and (3) the majority type of mesic oak. Unlike the ANOVA, which tested for the effect of damage categories on the change of MSI before and after the ice storm, these regression analyses provided an evaluation of two methods of expressing MSI and the value of topographic variables for detecting and mapping ice storm damage using a GIS.

RESULTS AND DISCUSSION

Damage Assessment

A total of 117 plots representing 4 categories of forest canopy damage were selected for study using aerial photography (table 2). The required number of plots selected for two categories, None and Moderate, was less than desired. Agreement was high, > 90 percent (kappa = 0.87), between the classification of damage estimated from aerial photography compared to damage assessed in the field. Six plots were discarded as a result of missing field data or outlier values of MSIb and MSIa, leaving 111 plots for subsequent analysis.

Sample plots were generally distributed uniformly among quadrants of azimuth, although fewer plots (17) were situated on northerly aspects. Chi-square tests indicated that category of canopy damage varied by aspect class ($p < 0.000$); plots with westerly and northerly aspects tended to receive None to Light damage while plots with easterly aspects received Heavy damage. Slope gradient of the sample plots ranged from

Table 1—Number of sample plots and mean values of moisture stress index by forest type before and after a February 2003 ice storm on the Morehead District of the Daniel Boone National Forest[a]

Forest type	Plots[b]	MSIb[c]	MSIa[c]	MSId ± SE[c]
Mesic oak	55	0.756	0.815	0.069 ± 0.014
Mixed mesophytic	32	0.766	0.819	0.043 ± 0.018
Mixed oak-pine	5	0.744	0.722	-0.022 ± 0.043
Mixed oak-yellow pine	8	0.784	0.785	0.001 ± 0.026
Yellow pine	2	0.804	0.681	-0.123 ± 0.028
Xeric oak	9	0.792	0.818	0.025 ± 0.040
Total	111	0.764	0.810	0.045 ± 0.010

MSI = moisture stress index; SE = standard error.
[a] MSI is the ratio of Landsat spectral band 5 to band 4; MSIb was determined from June 2002 imagery (before the ice storm); MSIa was determined from July 2003 imagery (after the storm); MSId is the difference between MSIa and MSIb.
[b] Six of the 117 total plots (see table 1) were omitted from the analysis because of missing data or values of MSI considered as outliers.
[c] There were no significant differences of MSIb, MSIa, or MSId among forest types at alpha = 0.05.

Table 2—Error matrix for two methods of classifying forest canopy damage resulting from a February 2003 ice storm on the Morehead District of the Daniel Boone National Forest

Classified from ground examination	Classified from aerial photography (sample plots)				
	None	Light	Moderate	Heavy	Total
None	25	0	0	1	27
Light	0	31	0	0	31
Moderate	4	0	24	0	28
Heavy	3	0	2	26	31
Total	32	31	27	27	117

6 to 74 percent. Chi-square analysis indicated that damage category did not vary by class of slope gradient (p = 0.064), although plots with Heavy canopy damage tended to occur on steeper (> 40 percent) slopes.

Six forest types were identified on the 111 sample plots (table 1). The predominant forest types were mesic oak and mixed mesophytic, which together accounted for 78 percent of the plots. Mean MSId increased by 0.045 in July 2003, indicating that less photosynthesizing vegetation was present after the ice storm compared to before. MSIa, MSIb, and MSId did not differ among forest types (table 1), which allowed pooling of data from all plots for the change detection analysis. ANOVA of the MSId data indicated that category of damage had a significant (p = 0.001) effect on MSId. Separation of significant damage category means using the Bonferroni test indicated that there were real differences between the Light and Medium categories (p = 0.01) and between the Light and Heavy categories (p = 0.01); there was no real difference between the None and Light categories or between the Medium and Heavy categories. Therefore, two new damage classes were formed for further analysis by combining None and Light, and Medium and Heavy. Analysis of these two new damage classes revealed significant (p<0.01) differences of MSId. Results of a supplementary analysis not described in detail here indicate that simple unsupervised and supervised classifications of the two damage classes based on MSId produced accuracy levels of about 60 percent.

Our findings agree with those reported by Burnett (2003), who found that damage to hardwood forest canopies can be detected by low-resolution Landsat TM imagery. Our results differed from those of Burnett, however, in that we were unable to detect levels of damage. A difference between our study and that of Burnett (2003) is forest type, which was mixed mesophytic in Vermont and predominantly oak in Kentucky. How these forest types differ in response to the ratio is unknown, but such a difference may contribute to the discrepancy between Burnett's findings and our own. Our results agree with those of Lewis (2004), who reported difficulty in separating medium and heavy levels of storm damage using conventional aerial photography.

Damage Modeling

We developed six predictive models for evaluating two expressions of MSI and three groupings of forest type (table 3). Accuracy in detecting canopy damage increased slightly as variation in forest type decreased, from an average of 75 percent for all six types (models 1 and 2 in table 3) to 83.5 percent for the single forest type (models 5 and 6). Likewise, the optimum expression of MSI changed from MSIb and MSIa, for the analysis including all forest types, to MSId alone for the single type. In formulations based on MSIb and MSIa (models 2, 4, and 6), the two variables probably accounted for variation associated with different forest types, somewhat as if a covariate had been included in the ANOVA used for the damage category analysis.

Table 3—Comparison of two regression model formulations that utilized three forest type groupings for relating moisture stress index and topographic variables to forest canopy damage caused by an ice storm in February 2003 on the Morehead District of the Daniel Boone National Forest[a b]

Dependent variables[c] or statistic[d]	All (n = 111)		MO + MM (n = 87)		MO (n = 55)	
	MF1[e]	MF2	MF1	MF2	MF1	MF2
MSId	1[f]	—	0	—	1	—
MSIb	—	1	—	1	—	0
MSIa	—	1	—	1	—	1
Aspect (degrees)	1	0	1	1	1	0
Gradient (percent)	0	0	1	1	1	1
ROC (percent)	80	86	87	89	93	93
Accuracy (percent)	73	77	78	79	85	82
Model number	1	2	3	4	5	6

[a] Forest type (see table 1) groupings: (1) all sampled, (2) the two predominant types of mesic oak and mixed mesophytic, and (3) mesic oak.
[b] Damage categories: none and little vs. moderate and heavy.
[c] MSIa = moisture stress index (MSI) after the storm, MSIdb = MSI before the ice storm,
MSId = difference between MSIa and MSIb. MSI was determined from pre- and post- Landsat imagery as the ratio of spectral band 5 to band 4.
[d] ROC = receiver operator curve; Accuracy = percent of plots classified correctly.
[e] Model formulation (MF) 1 tests MSId with aspect and gradient; MF2 tests MSIa and MSIb with aspect and gradient.
[f] 0 = variable tested in the model but omitted from the final formulation because it was not significant at the $p \leq 0.05$ level of probability; 1 = variable tested in the model and retained because it was significant at the $p \leq 0.05$ level of probability; — indicates variable not tested in the model.

Topographic variables varied in their importance in the prediction models. Aspect and gradient generally were not important for predicting canopy damage for all forest types combined. Their value increased, however, with increased uniformity of species composition. Including topographic variables in a model involves additional work because digital elevation data must be obtained for the image area, followed by derivation of the variables and assignment of a value to each pixel of the Landsat image. Finally, however, a relationship must be established between canopy damage and the important topographic variables to provide coefficients for the prediction model.

Our analysis suggests a likely increase in overall accuracy of damage assessment by developing a model for each individual forest type. Application of a system of models using a GIS would be problematic, however, because an accurate determination of forest type would be required for each pixel of a Landsat image. Model 2 is appealing for general application because it utilizes only MSIb and MSIa, and has high relative accuracy (77 percent). The classification error matrix (table 4) based on model 2 resulted in about equal levels of false negative (10.5 percent) and false positive (12.5 percent) predictions.

The predictive models indicated that pre- and post-disturbance MSI and topographic variables accounted for much of the variation in forest damage resulting from the February 2003 ice storm in eastern Kentucky. Our results agree largely with those of Millward and Kraft (2004), who found that aspect, species composition, and weather conditions during an ice storm event were important factors in determining the pattern and extent of forest damage. Although we could detect differences in MSI based only on two canopy damage classes (None and Light vs. Medium and Heavy), this degree of discrimination will likely be adequate for most assessments because it will allow identification of areas of potential salvage and regeneration needs. We can not speculate on how our results would have changed if

Table 4—Error matrix for a regression model of crown damage in all forest types resulting from a February 2003 ice storm on the Morehead District of the Daniel Boone National Forest

Classified by regression model 2[a]	Classified by field examination (sample plots) Not damaged	Damaged	Total
Not damaged	39	12	51
Damaged	14	46	60
Total	53	58	111

[a] Provided in table 3.

we had used values of MSI that had been corrected for image differences occurring between the two years of observation, although making such corrections is clearly recommended (Vogelmann and Rock 1989).

In summary, we demonstrated that moderate to heavy ice damage in forests of eastern Kentucky could be detected on Landsat TM imagery using an index of moisture stress. The degree of canopy damage resolution that we attained with satellite imagery was slightly lower than the level achieved by conventional methods using aerial photography; better results would likely be achieved with satellite imagery of higher resolution. A possible limitation of the satellite imagery method, however, is that ground verification of damage will probably be required unless the manager assumes that changes in pre- and post-disturbance MSI values were caused by a known weather event, such as an ice storm, and not, for example, from recent unknown insect defoliation. We consider this technique of using Landsat TM imagery to detect canopy damage resulting from ice storms to be promising. Additional refinement and testing with independent data is needed, however, before the technique can be considered an operational tool for producing accurate maps of canopy damage resulting from ice storms.

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MESAVAGE AND GIRARD FORM CLASS TAPER FUNCTIONS DERIVED FROM PROFILE EQUATIONS

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Abstract—The Mesavage and Girard (1946) average upper-log taper tables remain a favorite way of estimating tree bole volume because they only require the measurement of merchantable (useable) height to an indefinite top diameter limit. For the direct application of profile equations, height must be measured to a definite top diameter limit, and this makes the collection of data more arduous, particularly in hardwoods, since in many cases both the height to the top diameter limit (stopper top) and the stopper top diameter must be measured. In this paper, Girard form class is used to convert a regular profile function into a Mesavage and Girard type taper model requiring only the measurement of merchantable height. The advantages of the new approach include: 1) the derived model's upper log tapers are species specific, 2) the model describes the taper in the butt log, and 3) pulpwood and sawtimber trees can use the same model and height measure. Like the Mesavage and Girard taper tables, the converted profile equations have the disadvantage of requiring an average form class, preferably by dbh class. The source code for the profile conversion algorithm in C++, or BASIC can be downloaded from www.timbercruise.com, www.cfr.msstate.edu, or by contacting the authors. The program is short and can be quickly embedded in any cruise program implementing profile functions.

INTRODUCTION

Tree volume tables based on Girard form class (Avery and Burkhart 1994), and the upper-log taper tables for Southern conifers and Eastern hardwoods (Mesavage and Girard 1946) are still in wide spread use throughout the entire Eastern US. This use continues in spite of the fact that for most commercial tree species, stand origins, and geographic regions, highly accurate tree profile functions are available. There are two primary reasons for the continued use of these out-of-date and flawed tables. These are: 1) many timber cruisers have relied on volumes derived from the taper tables for years and are very reluctant to change volume estimation systems even though they recognize that by changing to species specific profile functions the accuracy and consistency of tree volume estimates could be improved dramatically, and 2) height measurement in the field is quicker because heights are measured to an indefinite top (usable or merchantable). The heights of trees assigned to a profile function must be measured to a definite top, and when the tree is not merchantable to the targeted definite top, the stopper top must be estimated and recorded. The old taper tables are out-of-date because the character of timber has changed significantly due to genetics and management practices. They are also seriously flawed because they are not species, stand origin, or geographic region specific and make the assumption that upper-log tapers are independent of form class and provide no taper rates in the first log.

This paper describes a procedure developed to effectively convert a tree profile function into a form that requires only the field measurement of height to an indefinite top diameter. The procedure is a simple numerical algorithm that calculates the total height of a tree from dbh, form class height, and form class. Once this procedure is included in a timber cruise program, users of the program can take advantage of the accuracy of tree profile functions without increasing the complexity of field measurements.

METHODS

Profile equations are algebraically complex functions that predict diameter at any height (h) above ground from diameter breast height (dbh), total height (H), and the height h of the desired diameter. Outside bark profile equations (O) predict outside bark diameter (dob), and inside bark profile functions (I) predict inside bark diameter (dib). These functions can be written abstractly as dob = O(h, dbh, H) and dib = I(h, dbh, H).

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Girard form class (F) is defined as the percentage the scaling diameter (sd) of the first 16 foot log is of dbh.

$$F = 100\frac{sd}{dbh} \tag{1}$$

Traditionally the assumption has been made that stump height is 1 foot, and log trim is 0.3 feet, and thus the height above ground (g) of the scaling diameter of the first 16 foot log is 17.3 feet. Stump heights are now around 0.5 feet, and the form class height could be set at 16.8 feet. Even though form class calculated at 16.8 feet would differ little from form class calculated at 17.3 feet, for current tree volume estimates to be comparable with past estimates form class height should be kept at 17.3 feet. However, if a departure from the height of 17.3 feet presents no problems, a form class height measurement point higher up on the bole will improve the accuracy of the profile function calculated from dbh and F. That is, when dbh and F are used to determine H, the closer the form class height g is to H the better the estimate of H will be.

If the dbh and total height H of a tree are known, the scaling diameter of the first log sd = dib = $I(h, dbh, H) = I(g, dbh, H)$. The scaling diameter of the first log is the value of the inside bark diameter at the form class height g (i.e., $h = g$). Thus, the form class equation (1) can be rewritten as

$$F = 100\frac{I(g, dbh, H)}{dbh} \tag{2}$$

Equation (2) can be solved for the total height H using a number of procedures for solving for roots of an equation such as the bisection, Newton, secant, or regula falsi fixed point iterations (Burden and others 1981). Finding the value of H satisfying equation (2) by a fixed point iteration requires that the equation be written in the following form:

$$f(x) = f(x = H) = 100\frac{I(g, dbh, x = H)}{dbh} - F = 0 \tag{3}$$

where

$x = H$ has been used to designate that x and H are equivalent. In the case F is expressed as a ratio of outside bark diameters, $I(h, dbh, H)$ equation (3) must be replaced by $O(h, dbh, H)$.

The root ($x^* = H^*$) of the nonlinear equation (3) is the total height of the tree with the specified value of dbh, g, and F. Any of the above fixed point iterations can be used to find the root H^*, but the method of bisection, while being the slowest to converge to a solution, always converges. The other methods often diverge unless the initial guess of the solution falls inside an often narrow range of convergence for the method. The bisection method can be stated in algorithmic form:

Let $f(x)$ be a piece-wise continuous function on a closed interval [A, B] with $f(A)f(B) \leq 0$, then use the following steps to find the root of the equation $f(x) = 0$ having a specified maximum allowable error of MAXE.

1. Compute the mid-point M = (A + B)/2 of the interval [A, B]
2. Compute the maximum error of the iteration of the best estimate (M) of the equation's root as E = (B – A)/2
3. If E ≤ MAXE, the root of the equation is M. Otherwise
   a. If $f(A)f(M) \leq 0$, set B = M. Otherwise, set A = M
   b. Repeat steps 1 to 3 until the error condition in step 3 is satisfied

EXAMPLE

To illustrate the solution procedure, consider the cubic foot volume of a cherry bark oak (*Quercus falcata* var. *pagodi folia* Ell.) tree with a *dbh* = 18 inches, *F* = 88, and a usable (merchantable) height of 3.5 16 foot logs. The cherry bark oak profile function used is presented in Matney and others 1985. For the example tree, the root of equation (3) is between A = 117.3 and B = 127.3. The solution for total height is between A = 117.3 and B = 127.3 because *f*(117.3) < 0 and f(127.3) > 0. The solution range is easy to find. Starting with a total height of 17.3 feet, the total height (*H*) is incremented by a fixed amount (INC) until f(*H*) ≥ 0. B is set to *H*, and A is set to B – INC. The INC for the example was 10 feet, but other increment values could be used. Table 1 summarizes the bisection of the interval [A, B] = [117.3, 127.3] with a maximum allowable error of 0.25 feet. The final total height estimate of 119.33 feet has an actual maximum error of 0.15625 which is less than 0.25 feet. Figure 1 presents the graph of equation (3) showing that the function is monotonically increasing and will cross 0 for some total height value exceeding the form class height.

Table 1—Determination of the total height of a tree with a d.b.h. of 18 inches and a form class of 88 using the method of bisection for solving for roots of nonlinear equations

n	A	B	M = (A + B)/2	f(A)	f(B)	f(M)	Error = (B – A)/2
0	117.30	127.30	122.30	-0.21114	0.76453	0.29593	5.00000
1	117.30	122.30	119.80	-0.21114	0.29593	0.04751	2.50000
2	117.30	119.80	118.55	-0.21114	0.04751	-0.08050	1.25000
3	118.55	119.80	119.18	-0.08050	0.04751	-0.01617	0.62500
4	119.18	119.80	119.49	-0.01617	0.04751	0.01575	0.31250
5	119.18	119.49	119.33	-0.01617	0.01575	-0.00019	0.15625

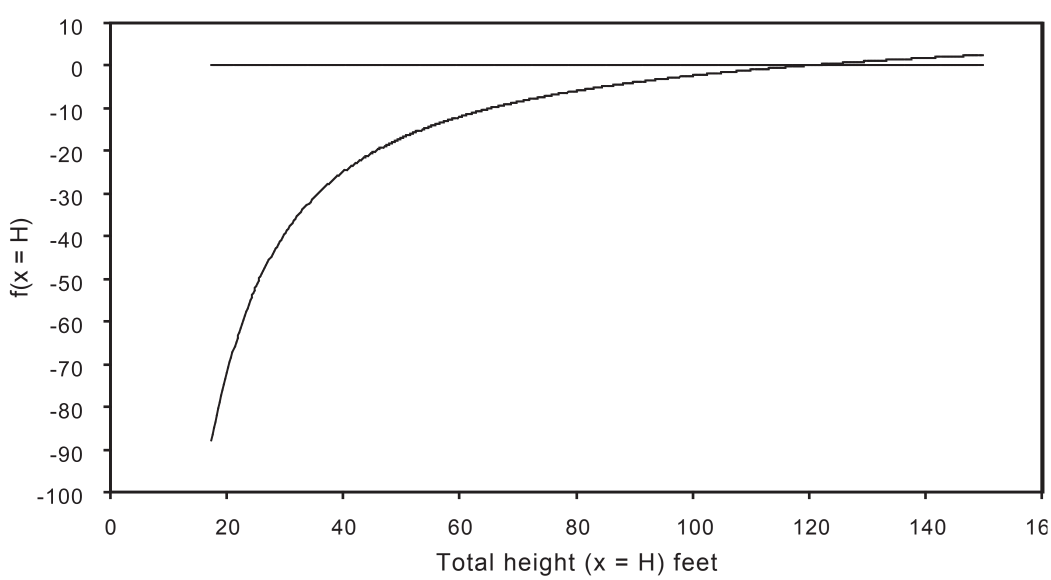

Figure 1—Graph of the function f(x = H) for a cherry bark oak tree with dbh, form class height, and form class of 18 inches, 17.3 feet, and 88, respectively.

Given that total height is now known, the volume from stump height to any indefinite top limit ≤ H^* = 119.33 feet is easily calculated. For example, the cubic foot ib and ob volumes of a 3.5 log tree are 116.33 and 129.82 cubic feet. The cubic volume computations were approximated by Smalian's cubic volume rule using a 4-foot bolt length. The initial values for A and B are readily obtained by setting A = 17.3, incrementing A by some value (INC) such as 10 until $F(A) \geq 0$, and then setting B = A and A = B –INC.

C++ SOURCE CODE

The C++ source code for the bisection routine (HtFromDbhFC) for calculating total height from dbh and form class is presented in the appendix. The main program uses the dbh and form class from the Example to illustrate the computation of the total height and ib and ob cubic foot volume of the 3.5 log merchantable length. A Microsoft Visual C++ dialog project implementing the code can be directly accessed at the link www.timbercruise.com/Downloads/Software/HtFromDbhFormClass.zip or by visiting the Web site www.cfr.msstate.edu to obtain a. The links are case sensitive.

DISCUSSION

This procedure forces the profile function to have the desired form class. Like all procedures the algorithm will fail for illogical conditions. If the form class is too large, the scaling diameter of the first log will be greater than or equal to dbh inside bark and the procedure will fail to converge. Before calling the procedure the user should make sure that the ratio of scaling diameter to dbh inside bark is not too close to one. Otherwise, the procedure will converge provided the maximum height input is set sufficiently large. If the form class is too large, the routine will converge but to a ridiculously high value. If the form class is too low, the estimated total height may be less than the measured merchantable height. In either case, the specified form class for the tree will probably be erroneous.

The commercially available cruise program Timber Cruise (TCruise) implements the algorithm as an optional procedure for using profile functions. With the option selected, users can simply measure merchantable heights while improving their volume estimates by using a profile function that is specific to the tree species being measured. A trial version of TCruise is available at www.timbercruise.com.

In the case that the profile function is a function of Girard form class, a form class height other then 17.3 feet must be selected. For the profile functions inside TCruise published by Clark and others 1991 involving Girard form class, the program sets form class height to the top of the second log (i.e., 33.6 feet).

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APPENDIX

C++ source code in the example project using the bisection fixed point iteration method for determining total tree height from dbh and form class

```
//
#include <stdlib.h>
#include <stdio.h>
#include <math.h>

int main(int argc, char* argv[])

{
	// Outputs
	double csErrorMsg;
	double dCFVIB;
	double dCFVOB;
	double dTOT_HT;
	int nError;

	// Inputs
	double dDBH = 15.0;
	double dFC = 80.0;
	double dFC_HT = 17.3;
	double dGFC = 0.0;
	double dMAX_HT = 275.0;
	double dMHT = 3.5;

	double dSHt = 1.00;
	double dBoltLen = 4.0;

	// Calculate total tree height
	dTOT_HT = HtFromDbhFC(dDBH, dFC, dFC_HT, dMAX_HT,
					dGFC, &CBO_DIB, nError);

	// Convert merchantable height in logs to feet
	if(dMHT < 8.0)
	{
		dMHT = 16.0*dMHT;
	}

	// Convert to height above ground
	dMHT += dSHt; // Add stump height

	// Compute ob and ib cubic foot volume between the heights
	// of dSHt and dMHT
	dCFVIB = GetCubicVolume(dDBH, dTOT_HT, dGFC, &CBO_DIB,
					dSHt, dMHT, dBoltLen);

	dCFVOB = GetCubicVolume(dDBH, dTOT_HT, dGFC, &CBO_DOB,
					dSHt, dMHT, dBoltLen);

	}
```

```
		csErrorMsg = "";
		if(nError != 0)
		{
			csErrorMsg = "Illogical input";
		}

		return 0;
}
*/

// Function for calculating total tree height from dbh, form class, and
// form class height
//
// Input
//
// dDbh        = diameter breast high
// dFC         = Girard type form class
// dFCHt       = form class height
// dMaxHt      = Maximum allowed total height
// dGFC        = Girard form class. This is for profile functions that
//               use Girard FC. In this case the form class height dFCHt
//               must be greater then 17.3 feet.
// pfIbProfile = pointer the the inside bark profile function
//
// Output
//
// Total height = return value
// nError      = error code (0= no error, 1 = illogical inputs)
//


double HtFromDbhFC(double dDbh, double dFC, double dFCHt, double dMaxHt,
                                        double dGFC, PROFILE pfIbProfile, int& nError)
{
   double dPHt, dTHt, dHtInc, dHtLower, dHtMid, dHtUpper, dFCTest, dMaxError;

   nError = 0;
		dPHt = dFCHt;
		dTHt = dFCHt;
   dHtUpper = dFCHt;
		dHtInc = (dMaxHt - dFCHt)/20.0;

   dFC = dFC/100.0F;
   while((dHtUpper = dHtUpper + dHtInc) < dMaxHt)
   {
      dTHt = dHtUpper;
      dFCTest = (*pfIbProfile)(dDbh, dTHt, dGFC, dPHt)/dDbh;
      if(dFCTest >= dFC)break;
   }

   if(dHtUpper > dMaxHt)
   {
      nError = 1; // Could not calculate a total ht for the FC. Check Dbh, Hm, and FC for logic
```

```
      return(dMaxHt);
    }

      dHtLower = dHtUpper - dHtInc;
      dMaxError = dHtUpper - dHtLower;
      dHtMid = (dHtLower + dHtUpper)/2.0F;

      while((dMaxError = dMaxError/2.0F) > 0.25F)
      {
        dTHt = dHtMid;
        dFCTest = (*pfIbProfile)(dDbh, dTHt, dGFC, dPHt)/dDbh;

        if(dFCTest <= dFC)
        {
          dHtLower = dHtMid;
        }
         else
        {
          dHtUpper = dHtMid;
      }

     dHtMid=(dHtLower + dHtUpper)/2.0F;
   }

  return(dHtMid);
}

// Cherry bark oak outside bark profile function
//
// Input
//
//  dDbh = diameter breast high
//  dTHt = total tree height
//  dPHt = height of output diameter
//  dGFC = Girard form class. This is for profile functions that
//              use Girard FC.
//
//  Output
//
//  Diameter outside bark at the height dPHt = return value
//

double CBO_DOB(double dDbh, double dTHt, double dGFC, double dPHt)
{
   static double dPar[3] = {0.779945, 0.126221, 1.0412989};
            double dDOB, dWorkA, dWorkB, dWorkC;

            if( (dPHt < dTHt) && (dPHt > 0.))
            {
                        dWorkA =dPar[0]*(pow(dTHt, dPar[1]));
                        dWorkB =-tan(dWorkA)/log(1.0 - pow((1.0-4.5/dTHt), dPar[2]));
                        dWorkA =dDbh/dWorkA;
                        dWorkC = -log(1.0 - pow((1.0 - dPHt/dTHt), dPar[2]))*dWorkB;
```

```
                dDOB = dWorkA*atan(dWorkC);
        }
        else
        {
                if(dPHt >= dTHt)
                {
                        dDOB = 0.0;
                }
                 else
                {
                  dWorkA = dPar[0]*(pow(dTHt, dPar[1]));
                  dWorkA = dDbh/dWorkA;
                  dDOB = 1.570796327*dWorkA;
                }
        }
     return (dDOB);
}

// Cherry bark oak inside bark profile function
//
// Input
//
// dDbh = diameter breast high
//  dTHt = total tree height
//  dGFC = Girard form class. This is for profile functions that
//            use Girard FC.
//
// Output
//
//  Diameter inside bark at the height dPHt = return value
//

double CBO_DIB(double dDbh, double dTHt, double dGFC, double dPHt)
{
        static double dPar[5] = {0.767290, 0.130027, 1.0560755F, 0.000,0.945};
   double dDIB, dWorkA, dWorkB, dWorkC, dWorkD;

        if( (dPHt < dTHt) && (dPHt > 0.))
        {
                dWorkA = dPar[3] + dPar[4]*dDbh;
                if(dWorkA < 0.0)dWorkA=0.0;
                dWorkB = dPar[0]*pow(dTHt, dPar[1]);
                dWorkC = -tan(dWorkB)/log(1.0 - pow((1.0 - 4.5/dTHt),dPar[2]));
                dWorkB = dWorkA/dWorkB;
                dWorkD = -log(1.0 - pow((1.0 - dPHt/dTHt), dPar[2]))*dWorkC;
                dDIB = dWorkB*atan(dWorkD);
        }
     else
        {
               if(dPHt >= dTHt)
               {
                        dDIB=0.;
```

```
                }
                else
                {
                  dWorkA = dPar[3] + dPar[4]*dDbh;
                  if(dWorkA < 0.0)dWorkA=0.0;
                  dWorkB = dPar[0]*(pow(dTHt, dPar[1]));
                  dWorkB = dWorkA/dWorkB;
                  dDIB = 1.570796327*dWorkB;
                }
        }
        return (dDIB);
}

// Cubic foot volume calculation function
//
// Input
//
// dDbh = diameter breast high
/ dTHt  = total tree height
//  dGFC = Girard form class. This is for profile functions that
//              use Girard FC.
// dBeginH = height of the large end of log
//  dEndH = height of the small end of log
//dBoltLen = bolt length for Smalian's cubic volume rule
// pfProfile = pointer to the profile function
//
// Output
//
// Cubic foot volume between the heights dBeginH and dEndH  = return value
//

double GetCubicVolume(double dDbh, double dTHt, double dGFC, PROFILE
pfProfile,
                                        double dBeginH, double dEndH, double dBoltLen)
{

        double dPHt = dBeginH;
        double dDLE = (*pfProfile)(dDbh, dTHt, dGFC, dPHt);
        double dDSE;

        double dCFV = 0;

        while((dPHt = dPHt + dBoltLen) < dEndH)
        {
                dDSE = (*pfProfile)(dDbh, dTHt, dGFC, dPHt);
                dCFV += 0.002727*(dDSE*dDSE + dDLE*dDLE)*dBoltLen;
                dDLE = dDSE;
        }

        dBoltLen = dTHt - (dPHt - dBoltLen);
        dDSE = (*pfProfile)(dDbh, dTHt, dGFC, dEndH);
        dCFV += 0.002727*(dDSE*dDSE + dDLE*dDLE)*dBoltLen;

   return dCFV;
}
```

PREDICTING THE COVER-UP OF DEAD BRANCHES USING A SIMPLE SINGLE REGRESSOR EQUATION

Christopher M. Oswalt, Wayne K. Clatterbuck, and E.C. Burkhardt[1]

Abstract—Information on the effects of branch diameter on branch occlusion is necessary for building models capable of forecasting the effect of management decisions on tree or log grade. We investigated the relationship between branch size and subsequent branch occlusion through diameter growth with special attention toward the development of a simple single regressor equation for use in future hardwood stem quality models. Data were obtained from 21 boards representing 3 logs of the first 21 feet of one cherrybark oak originating from a planted stand north of Vicksburg, MS. Double cross-validation methods were used to evaluate fitted models. A non-linear model form ($Y = a^{*}BK_{max}{}^{b}$, where Y = overwood, BK_{max} = maximum branch-knot diameter and a and b are parameters) provided the best fit. The model explained approximately 50 percent of the variation in overwood.

INTRODUCTION

Silviculturists have long realized the importance of tree or log grade. However, the implications of silvicultural activities on stem structure have been largely overlooked. This is particularly the case of recent large-scale replanting efforts in the Lower Mississippi Alluvial Valley (King and Keeland 1999, Twedt and Wilson 2002), where many monospecific plantations lacking natural analogs are being created. Unlike some softwood products, grade production in hardwood trees is a more important factor in valuation than volume because of the great differential between the highest and lowest grades of lumber or veneer products produced. For example, the price differential between red oak FAS and 1F alone and FAS and 2A alone was 219 percent and 264 percent in March of 2005, respectively (Hardwood Market Report, 3/05/05). Therefore, understanding the impacts of silvicultural activities on the production of hardwood tree grade is critical.

Experimental methods of acquiring causal information regarding the impacts of management activities on tree structure are needed, and in some cases are underway (Clatterbuck and others 1987, Oliver and others 1990). Complementary techniques that can expedite acquisition of needed information are necessary. Stem analysis techniques combined with modeling methods can improve our understanding in the interim, and help guide current and future land management decisions.

As gross crown dimensions are proportional to and determinants of tree growth (Assman 1970, Rennolls 1994), the number and size of branches within the crown are major determinants of stem structure and, therefore, wood quality. Wood quality is heavily affected by the development of first-order branches within the crown, particularly the self-pruning and subsequent occlusion of branches as crown recession occurs (Makinen 1998, Makinen and Colin 1998, Makinen and Makela 2003). Thus, a logical first step is to evaluate the effects of variable branch sizes on the stem diameter needed for branch occlusion.

Information on the effects of branch diameter on branch occlusion is necessary for building models capable of forecasting the effect of management decisions on tree or log grade. However, little is known regarding the relationship between branch size and the occlusion of that branch through diameter growth following crown recession. The knowledge gap is particularly large for hardwoods, including highly valuable species such as cherrybark oak (*Quercus pagoda* Raf.). Models combining growth and development of stem structure, including internal characteristics, are in development (Maguire and others

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1994, Makela and Makinen 2003). However, researchers have focused primarily on conifer species [e.g. Norway spruce (*Picea abies* (L.) Karst), Scots pine (*P. sylvestris* L.) and Loblolly pine (*P. taeda* L.)].

The primary objective of this research was to quantify the relationship between branch size and subsequent branch occlusion through diameter growth. Special attention was paid to the development of a simple single regressor equation for use in future hardwood stem quality models.

METHODS

Data

Data were obtained from 21 boards representing 3 logs of the first 21 feet of one cherrybark oak. The tree originated from a stand of planted cherrybark oak on land owned by Anderson-Tully Company, north of Vicksburg, MS (322553N, 0904306W). The tree was blown over in a local windstorm event in 2002, but the bole remained intact. Tree diameter at breast height (dbh) was 41 cm and total height was 31 m at age 36 years. Three logs, representing the merchantable portion of the tree were removed for sawing.

Each log end was divided into quarters and marked for reassembly following sawing. All boards were flat sawn in the field using a Wood-Mizer (Wood-Mizer Products Inc., Indianapolis, IN) portable band saw with a 2mm kerf. The first cut for each log followed the log pith. Boards were carried to the laboratory and the logs were reassembled. Distance from the pith to each board face was recorded. Mean sawn board thickness was 2.82 cm with a range of 2.3 to 4.6 cm.

Branch-knots were numbered and mapped along 3 axes according to board-face location, height from base of tree, and distance from the centerline of each board (board centerline corresponded to initial quarter lines drawn for reassembly). In addition, branch-knot diameter was recorded at each location. Branch-knots retained a unique identifier among sequential boards to chart the development of each branch. For each branch, maximum diameter and stem radius at the point where a branch no longer appeared (hereafter referred to as overwood) were calculated for development of simple predictive equations.

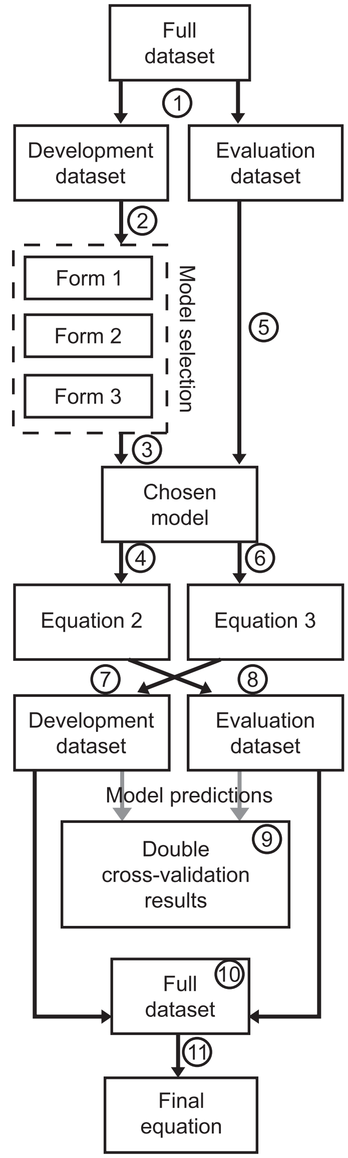

Figure 1—Flowchart illustration of model development and evaluation.

Model Building and Evaluation

Branch-knot mapping produced a total of 287 points and 105 unique branches for the 21-foot length. Only branches that could be followed from inception at the pith were used for model-building and model evaluation (n = 66). Figure 1 illustrates the analysis procedure. Data were randomly split into two datasets. One dataset was used for model fitting and parameterization (hereafter known as the development dataset). A holdout dataset was used for model evaluation (hereafter known as the evaluation dataset). Observed data in the development dataset were fitted to each model form (table 1) using the PROC REG and PROC NLIN procedures (SAS Institute Inc. 1989). Ordinary least-squares were utilized for parameter estimation. Mean square error (MSE), error sum of squares (SSE), coefficient of determination (R2) and the PRESS statistic were used to evaluate the appropriateness of each fitted model and choose the “best” performer.

Table 1—Summary statistics for each fitted model of branch-knot diameter and overwood

Statistic	Model form $Y = Y_0 + aX$	$Y = a\ (1\text{-}e^{-bX})$	$Y = aX^b$
R	0.61	0.63	0.68
R^2	0.37	0.39	0.46
a	0.12	9.5	3.49
SE{*a*}	0.03	0.87	0.65
b		0.17	0.29
SE{*b*}		0.05	0.06
Y_0	5.16		
SE{Y_0}	0.66		
MSE	7.54	7.33	6.48
SSE	233.6	227.28	200.95
PRESS	269.54	254.22	219.84
SEE	2.75	2.71	2.55

Note: Empty cells are a result of incomplete alignment of parameter labels.

Three biologically reasonable candidate model forms consisting of one regressor, maximum branch-knot diameter achieved (BK_{max}) were proposed:

Model Form (1) $Y = Y_o + a^* BK_{\max}$

Model Form (2) $Y = a\left(1 - e^{-b * BK\max}\right)$

Model Form (3) $Y = a^* BK_{\max}{}^{b}$

where

Y = overwood
Y_0, a, and b are parameters

The predictive capability of the chosen model was evaluated. The developed model was used to predict each case in the evaluation dataset and the mean squared prediction error (MSPR) (Neter and others 1996) was calculated with:

$$\text{MSPR} = \frac{\sum_{i=1}^{n}\left(Yi - \hat{Y}i\right)^2}{n} \quad (1)$$

where

Yi = the value of the response variable in the *i*th validation case
$\hat{Y}i$ = the predicted value for the *i*th validation case based on the development dataset
n = the number of cases in the evaluation dataset

Comparison of the MSPR with MSE of the model fit with the development dataset can be used as indication of the predictive ability of the model. The mean ($\bar{e}$) of the prediction errors for all cases of the evaluation dataset was computed as an estimate of model prediction bias (Zhang 1997). In addition, the model was quantitatively tested by a double cross-validation procedure (Neter and others 1996, Zhang 1997). Following the evaluation of the initial model, the evaluation dataset was used to reparameterize the model. The reparameterized model was used to predict each case from the development dataset and the same metrics were calculated and compared. Cross-validation is considered an effective method for model evaluation and obtaining nearly unbiased estimators of prediction error (Neter and others 1996, Zhang 1997). Final estimation of model parameters were derived from the full (n = 66) dataset (Neter and others 1996).

RESULTS

Model Selection

No significant evidence was observed for problems of unequal error variances. Residual analysis resulted in no significant trends in the plots of residuals against the predictions. Therefore the assumptions of least-squares were satisfied.

The linear model $Y = Y_o + a^* BK_{max}$ and non-linear models $Y = a\left(1 - e^{-b*BK\max}\right)$ and $Y = a^* BK_{max}{}^b$ were fitted to the development dataset. Regression analyses revealed that the model $Y = a^* BK_{max}{}^b$ fit the development dataset best (table 1). The linear model $Y = Y_o + a^* BK_{max}$ was the poorest fit. The correlation coefficient and coefficient of determination was highest for $Y = a^* BK_{max}{}^b$ and the MSE, SSE and PRESS statistic were lowest (table 1). The standard error of the estimate was also smaller for the $Y = a^* BK_{max}{}^b$ model (table 1). The model chosen was $Y = a^* BK_{max}{}^b$.

Model Evaluation

Examination of the residuals from the regression solution of the chosen model revealed no heteroscedasticity. All parameter estimates were statistically significant at $\alpha = 0.05$. The fitted model resulted in the following equation:

$$\text{Overwood} = 3.49 ^* \ BK_{max}{}^{0.29} \qquad (2)$$

The SSE for the model fitted with the development dataset was 200.95 (table 2). The PRESS statistic (219.84) was reasonably close to the SSE and supports the validity of the fitted regression model and of MSE as an indicator of the predictive capability of this model (Neter and others 1996). The initial fitted model resulted in a significant moderate relationship with only moderate predictive power (R = 0.68, $R^2 = 0.46$, P < 0.001) (fig. 2A).

Using equation (2), each case in the evaluation dataset was used to predict overwood (fig. 2B). Calculated mean prediction error was -0.36 cm and MSPR was 4.85 (table 2). MSPR of the evaluation dataset was comparable with MSE of the development dataset suggesting that MSE based on the development dataset is a valid indicator of the predictive capability of the model.

Reparameterization of the model using the evaluation dataset resulted in the following equation:

$$\text{Overwood} = 2.83 ^* \ BK_{max}{}^{0.35} \qquad (3)$$

The SSE and PRESS statistic were 152.96 and 167.94, respectively (table 2). Similar to the model fitted to the development dataset, the model fitted to the evaluation dataset ([equation (3)] indicated a significant moderate relationship with moderate predictive power (R = 0.74, $R^2 = 0.54$, P < 0.001) (fig. 3A). However, the model fit was slightly improved over the model fit to the development dataset. Using equation (3), each case in the development dataset was used to predict overwood (fig. 3B). Calculated mean prediction error was 0.33 cm and MSPR was 6.32 (table 2).

Parameterization of the model using the full dataset resulted in the final equation:

$$\text{Overwood} = 3.17 ^* \ BK_{max}{}^{0.32} \qquad (4)$$

The final model was similar to the previous model fits and indicated a significant relationship with moderate predictive power (R = 0.70, $R^2 = 0.50$, P < 0.001) (table 2, fig. 4).

Table 2—Double cross-validation summary for the fitted nonlinear model form $Y = aX^b$ for branch-knot diameter and overwood

Statistic	Model-building dataset	Validation dataset	Full dataset
a	3.49	2.83	3.17
SE{*a*}	0.65	0.53	0.42
b	0.29	0.35	0.32
SE{*b*}	0.06	0.06	0.04
SSE	200.95	152.96	357.59
PRESS	219.84	167.94	374.18
MSE	6.48	4.93	5.59
MSPR	6.32	4.85	
R^2	0.46	0.54	0.5
R	0.68	0.74	0.7
SEE	2.55	2.22	2.36
$\bar{e}$	0.33	-0.36	

Note: Empty cells are a result of not calculating some metrics for the full dataset.

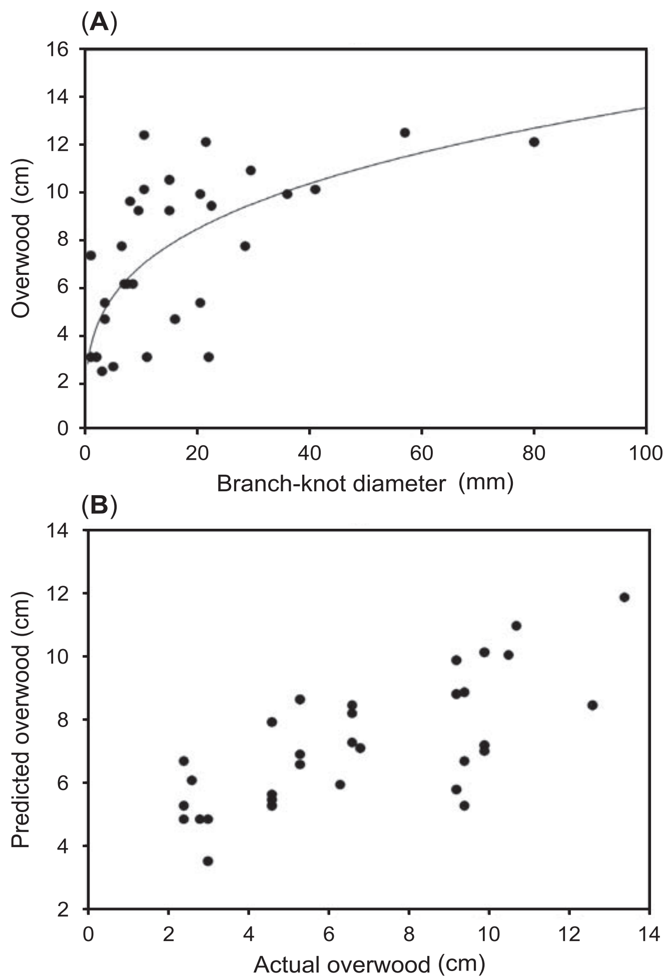

Figure 2—Branch-knot diameter and overwood with nonlinear model fitted to the model-building dataset (A) and actual by predicted overwood (B) using validation dataset for cherrybark oak planted in Vicksburg, MS.

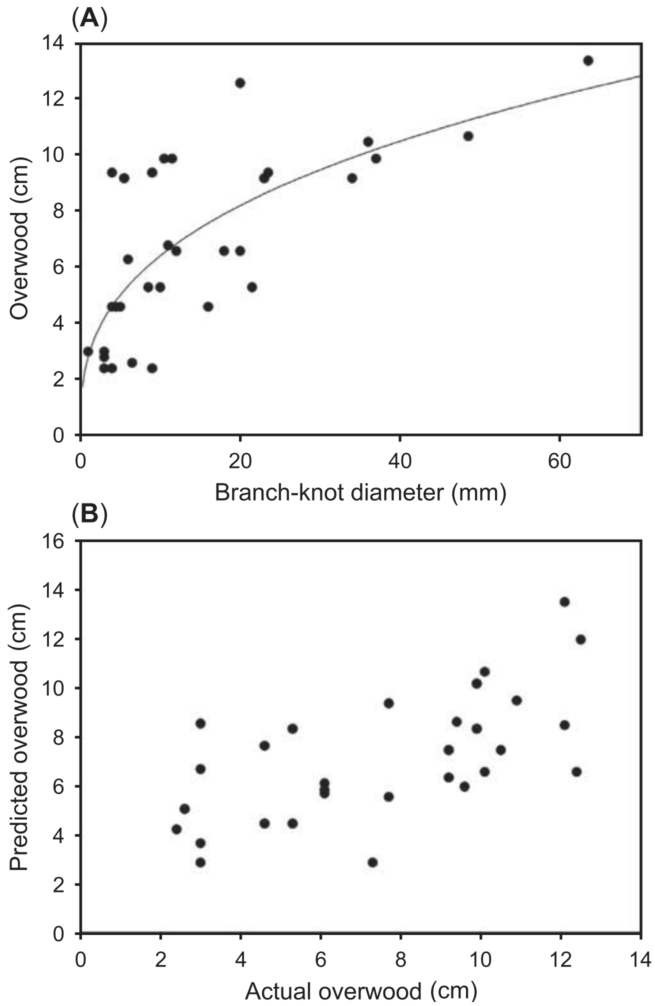

Figure 3—Branch-knot diameter and overwood with nonlinear model fitted to the validation dataset (A) and actual by predicted overwood (B) using model-building dataset for cherrybark oak planted in Vicksburg, MS.

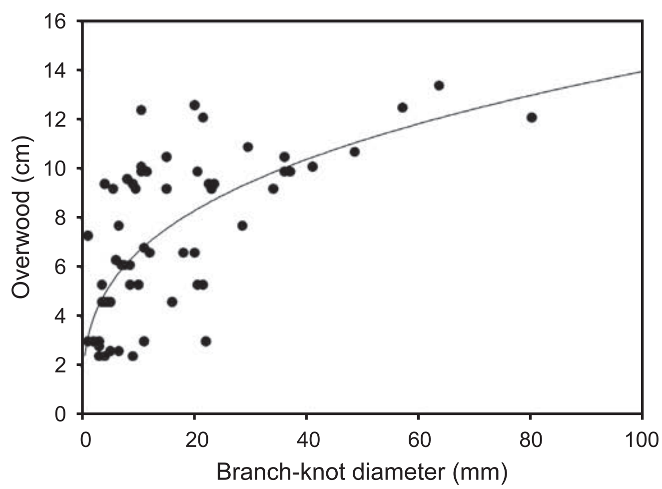

Figure 4—Branch-knot diameter and overwood with nonlinear model fitted to the full dataset for cherrybark oak planted in Vicksburg, MS.

DISCUSSION AND CONCLUSION

The model presented in this study will be used in the development of future models for forecasting stem quality in hardwoods as a result of silvicultural decisions. Although the predictive power is intermediate, this equation, to the authors' knowledge, represents the first attempt of its kind to quantify the relationship between branch size and branch occlusion in cherrybark oak. As a result, limited information exists regarding insights into the relation of branch size to overwood.

The final equation explained only 50 percent of the variation in the full dataset. A share of the unexplained variation may be explained by the constraints of the data collection methodology. The methodology involves very low longitudinal resolution (2.3 to 4.6 cm). That is, branch-knot observations were only available on cut board faces. As a result, accurate measures were unavailable for some branches. For example, a branch may have been completely occluded 0.5 cm within a 4 cm board. The recorded measure of occlusion would include the actual 0.5 cm and the error of the additional 3.5 cm of the cut board. The use of computer tomography (CT), such as that used by Moberg (2001), may be the only method capable of reducing this type of error. However, such equipment is often not available. Additionally, the resolution obtained through CT-scan image analysis makes it difficult to capture accurate small branch-knot observations (Gronlund 1995, Oja 1999).

Some of the unexplained variation in the model may be due to differences in the length of the residual dead branch following breakage from the stem. One key assumption in this model is that pruning of dead branches happens in a static manner. This assumption may or may not be valid. However, incorporation of variables to describe or predict the variation in branch breakage or length of branch stub is quite complex. This complexity was not considered when the model was developed and evaluated.

By removing the temporal aspect from the dataset and not attempting to predict occlusion rates, the developed model should have application outside of the tree in which the data was collected. Furthermore, by focusing on a linear measure of wood required to completely occlude a given branch, the effect of site, crown position and growth rate should be removed. However, as the dataset only consisted of occluded branches from within one tree, further tests are required to evaluate model predictions from a completely independent dataset. In addition, model performance should also be evaluated when incorporating data from different sites and stem development histories.

The results from this study represent one planted tree. Relationships may vary between plantation and natural stand development. Variable stand density may also impact this relationship. As such, additional datasets are desired for future analyses and to further test this quantification of the relationship between branch size and branch occlusion.

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SOIL AND WATER

Moderator:

Jeff Stringer
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LONG-TERM STREAM CHEMISTRY MONITORING ON THE FERNOW EXPERIMENTAL FOREST: IMPLICATIONS FOR SUSTAINABLE MANAGEMENT OF HARDWOOD FORESTS

Mary Beth Adams and James N. Kochenderfer[1]

Abstract—Long-term monitoring of stream chemistry of forested watersheds on the Fernow Experimental Forest in West Virginia has been conducted to determine the effects of both human-induced and natural disturbances on nutrient cycling and stream chemistry. We compare mean annual stream water pH, and nitrate (NO_3), sulfate (SO_4), and calcium (Ca) concentrations from 6 gauged Fernow watersheds with different disturbance regimes for the last 30 years. Most disturbances are not sufficiently large in area or extent to have a detectable effect on stream chemistry (diameter-limit or selection harvesting, clearcutting, windstorms). Fertilization, acidic deposition at ambient levels, maintaining watersheds devoid of vegetation, and conversion to conifers significantly affected stream water chemistry. Implications for managing hardwood forests for sustainability are discussed.

INTRODUCTION

Long-term watershed monitoring is a hallmark of the USDA Forest Service Research and Development. Because trees are long-lived organisms and because of the temporal variability associated with climate and other factors, such long-term research is necessary in order to understand the effects of forest management activities and natural disturbances on forest ecosystem processes. In this manuscript we present long-term stream chemistry data from the Fernow Experimental Forest (FEF), one of the few such long-term studies of stream chemistry in the central Appalachians, and discuss effects of both human-induced and natural disturbances on nutrient cycling and stream chemistry. In particular, we evaluate timber harvesting, deforestation, fertilization, acidic deposition and changes in dominant species.

We present data from 6 gaged watersheds (WS) on the FEF (table 1). The stream flow records date back to 1951, and we use stream chemistry data collected beginning in 1971. Older stream chemistry data, and data from other sources, are used to illustrate specific points, as needed. Many of the data have been published previously, as partial data sets; this represents one of the first presentations of more than 30 years of stream chemistry data.

The Watersheds

The FEF (39.03° N, 79.67° W) is located in north-central West Virginia, in the Allegheny Mountain section of the mixed mesophytic forest. Central Appalachian forests have been shaped by a mixture of natural and human caused disturbances including wind, fire, logging, and agricultural use, creating a diverse mosaic of forest stands. More *recently*, several insects and diseases, most of them non-native, have severely impacted Appalachian forests. The chestnut blight (*Cryphonectria parasitica*) has been the most devastating, virtually eliminating American chestnut (*Castanea dentata* [Marsh.] Borkh.), which formerly comprised 25 percent of Appalachian forests, including those of the FEF. Acidic deposition and other air pollutants are a more recent, chronic disturbance (Adams 1999).

Diversity is an important characteristic of central Appalachian forests, and the FEF vegetation fits into Core's (1966) mixed central hardwood forests floristic province. Common tree species on the sites with higher site index are yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), red oak (*Quercus rubra* L.) and basswood (*Tilia americana* L.). Dominant tree species on the poorer sites include white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.),

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Table 1—Fernow watersheds: treatment histories and descriptive references

WS	Area	Treatment	Treatment date	References
	ha			
1	30	Clearcut to 15 cm d.b.h. except culls	1957–58	Patric and Smith 1978
		Fertilized with 500 kg urea per ha	May, 1971	Kochenderfer and Aubertin 1975
2	15	43 cm diameter limit cut	1958	
		43 cm diameter limit (11 ha)	1972, 1988, 2004	
		Fertilized with 336 kg N/ha and 224 kg/ha P_2O_5, 1.3 ha	April, 1976	Helvey and others 1989
		43 cm diameter limit cut, 5 ha	1978, 1997	
3	34	Intensive selection cut, including cull trees > 12.7 cm d.b.h	1958–59, 1963	Aubertin and Patric 1974, Kochenderfer and others 1990
		0.16 ha patch cuttings totaling 2.3 ha, cut down to 12.7 cm, 2-12 cm stems sprayed with herbicide	July,1968–August, 1968	
		2-12 cm stems treated with herbicide then clearcut to 2.5 cm d.b.h., except for a partially cut 3.0 ha shade strip along the stream channel	July, 1969–May, 1970	
		Shade strip clearcut	November, 1972	
		Natural recovery	November, 1972–present	
		Ammonium sulfate fertilizer applied	December, 1989–present	Edwards and others 2002
4	39	No treatment; natural recovery since 1905		Reinhart and others 1963
6	22	Lower 11 ha clearcut	1964	
		Maintained barren with herbicides	March, 1965–October, 1969	
		Upper 11 ha clearcut	1967–68	
		Maintained barren with herbicides	May, 1968–October, 1969	
		Planted Norway spruce	1973	
		Aerial application, herbicide to release spruce	1975, 1980	
7	24	Upper 12 ha clearcut	1963–64	Patric and Reinhart 1971
		Maintained barren with herbicides	May, 1964–October, 1969	
		Lower 12 ha clearcut	1966–67	
		Entire watershed maintained barren with herbicides	May, 1967–October, 1969	Kochenderfer and Wendel 1983
		Natural recovery	October, 1969–present	Adams and others 1995

WS = watersheds.

hickory (*Carya* spp.), red maple (*A. rubrum* L.), and American beech (*Fagus grandifolia* Ehrh). A partial list of more than 500 species of vascular flora found on the FEF (Madarish and others 2002) illustrates the diversity of these forests.

The growing season on the FEF extends from May through October, and the average length of the frost free season is 145 days. Annual precipitation is about evenly distributed between growing and dormant seasons, averaging 145.8 cm. Precipitation often occurs in the form of snow during the winter but a snowpack usually does not exist for extended periods. Average annual air temperature is 9.2°C (Pan and others 1997), and mean monthly temperatures range from -18°C in January to 20.6°C in July. Potential evapotranspiration on the Fernow was estimated to be 56 cm per year (Patric and Goswami 1968).

The hydrometeorologic network used on the Fernow is described by Adams and others (1994). All of the watersheds are instrumented with 120° V-notch weirs, with FW-1 water level recorders and 7-day strip charts to measure streamflow continuously. Stream water grab samples have been collected from the watersheds on a weekly or bi-weekly basis since 1960. Solution samples are analyzed as described in Edwards and Wood (1993). Watershed 4 (WS4) serves as the reference watershed, against which all others are compared. WS4, and most of the Elk Lick watershed which makes up most of the FEF, was cut around 1905. The watersheds and their respective treatments are described in table 1.

What We've Learned:

Figure 1 shows annual stream water pH from 6 streams on the FEF. Stream pH is often used as an indicator of water quality, particularly in reference to aquatic organisms, such as trout (Cleveland and others 1986). Figure 1 suggests that annual stream pH, at least on the FEF watersheds, is not particularly sensitive to disturbance. Only on WS3 has stream pH decreased significantly over time (Edwards and others, in press), as the result of experimental fertilizer additions. Since 1989 we have been applying ammonium sulfate fertilizer at twice ambient nitrogen (N) and sulfur(S) deposition levels to WS3 to

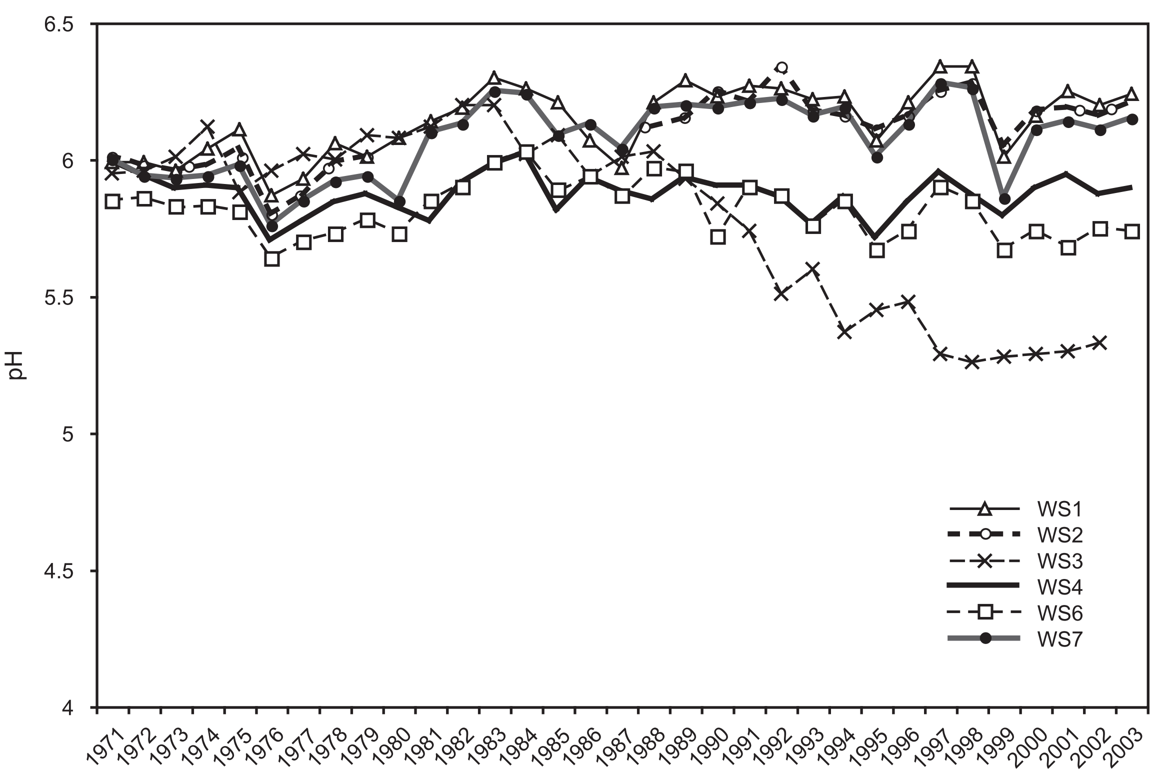

Figure 1—Annual volume-weighted stream pH from six watersheds on the Fernow Experimental Forest.

evaluate watershed acidification responses. Clearly, watershed acidification can be induced after long periods of acidic deposition: treatments to WS3 represent 28 years of ambient deposition. However, most streams in the FEF are still between pH 5.5 and 6.5, despite acidic bedrock, clearcutting (WS3 early years), repeated cuttings (WS2), years of ambient acidic deposition (WS4), repeated blowdown of trees (WS4), and even conversion to conifers (WS6).

Trends in NO_3-N concentrations are shown in figure 2. Nitrate (NO_3) is a concern because elevated NO_3 concentrations in water can have significant implications for ecosystem processes, as well as human health implications. A high rate of NO_3 leaching from a watershed is one symptom of nitrogen (N) saturation (Aber and others 1998, Fenn and others 1998). Research in other forest types has reported elevated NO_3 losses as a result of clearcutting (Likens and others 1970, Niemenen 1998, Waide and others 1988). To evaluate clearcutting effects on the FEF, we might compare concentrations in WS3, WS6, WS7, and WS1 to WS4, the reference WS. WS3 was clear cut in 1969-1970, therefore these concentrations represent the most recent post-clearcutting data. WS6 and WS7 were clearcut and maintained barren in the mid-1960's (table 1), but permitted to regenerate beginning in 1969/1970, the same year as WS3. We know that on WS1, which was clearcut in in 1958, stream flow and water quality returned to pretreatment levels within 2-4 years post-clearcutting (Kochenderfer and Aubertin 1975), so we will not consider WS1 in this discussion of clearcutting effects. Aubertin and Patric (1974) reported that clearcutting WS3 had a negligible effect on most of the stream chemistry analytes they evaluated; they did record that stream water NO_3-N concentrations showed a slight increase in July and August of 1970, then declined to base levels again before increasing in response to a 64 mm rainfall in December 1970. Thereafter concentrations were comparable to those from WS4. Note however, that stream water NO_3-N concentrations draining WS6 and WS7, which regenerated the same year as WS3, are more than twice the concentrations of WS3, for at least the first 4-5 years. We attribute this large difference not

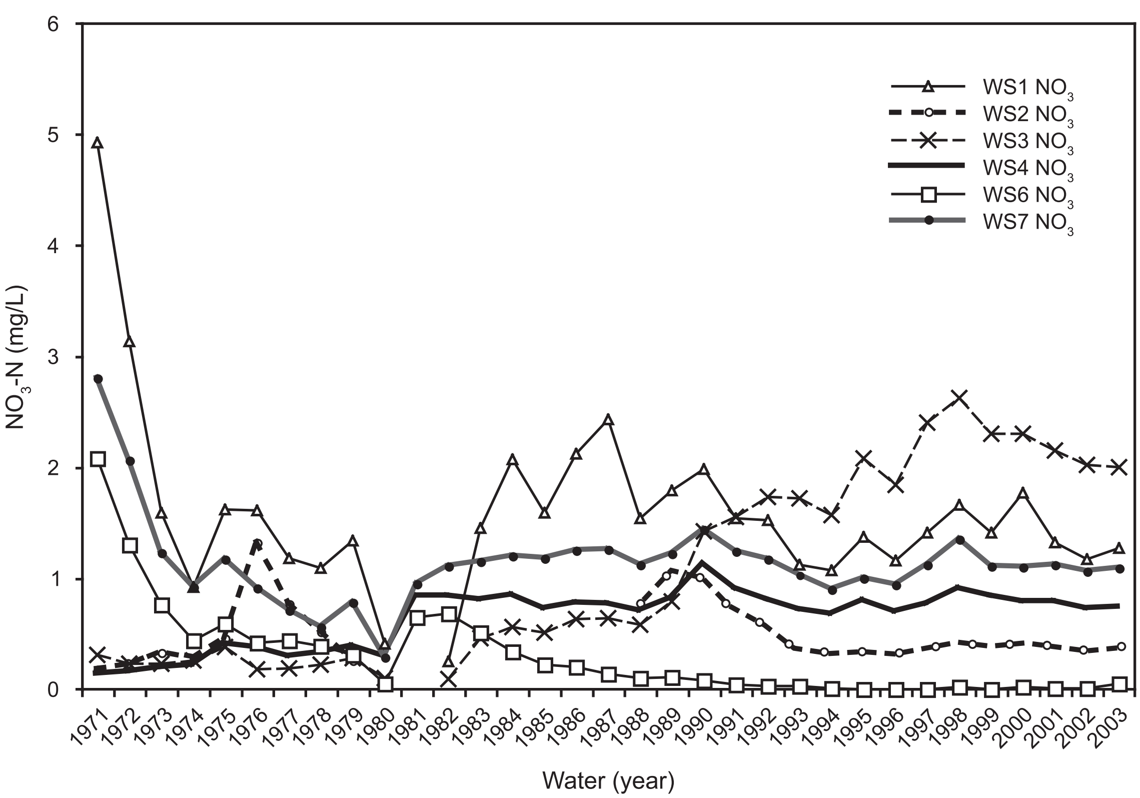

Figure 2—Annual volume-weighted stream NO_3-N concentrations from six watersheds on the Fernow Experimental Forest.

to the clearcutting of WS6 and WS7, but to the herbicide treatments, since WS3 NO_3-N concentrations remained quite low. WS6 and WS7 were maintained barren of vegetation for a number of years through repeated herbicide applications, as part of a study to evaluate water yields and the sources of water flow within a watershed. Thus there was no vegetative sink for the nutrients which were quickly released by the decomposition of slash and organic matter. Once the stands on WS6 and WS7 began to regrow, stream water NO_3 concentrations decreased quickly as N uptake again became an important sink. This distinction is important for forest managers. It is obviously not desirable to maintain a forested area devoid of vegetation, due to concerns about erosion, nutrient losses, habitat, among others, but clearcutting need not result in large increases in N loss from a watershed. Similar results were reported at Hubbard Brook (Likens and others 1970).

Fertilization can significantly increase NO_3 leaching from a watershed, whether it arrives in one large application (WS1, WS2), or chronic levels (WS3). The very high NO_3-N concentrations associated with WS1 can be attributed to a fertilizer application of 500 kg/ha of urea (230 kg/ha of soluble N) in May 1971 (Aubertin and others 1973). A slight, short-lived peak in annual NO_3-N concentration is also observed for WS2 in 1972, which also received a single large application of N fertilizer to a portion of the watershed (Helvey and others 1989). Stream water NO_3-N concentrations have been increasing steadily as a result of relatively low levels of fertilizer additions (35 kg N/ha/year and 40 kg S/ha/year), applied since in 1989 to WS3. Fertilizer applications of ammonium sulfate to WS3 have been rapidly mineralized and nitrified (Gilliam and others 1994, 2001), and move quickly through the soil profile (Edwards and others, in press). Although there is evidence of increased uptake by the vegetation (Adams and others 1993; DeWalle and others, in press), total exports and concentrations of N have increased significantly as a result of the watershed acidification treatment (Adams and others, in press). The elevated leaching of NO_3-N has led to hypothesis that WS4 (Fenn and others 1998, Peterjohn and others 1996, Stoddard 1994), WS3 (Gilliam and others 2001, Peterjohn and others 1996) and even WS7 (May and others 2005) may be N saturated, in response to ambient (WS4, WS7) or artificially elevated (WS3) levels of acidic deposition. While there is still much debate about the implications and definitions of N-saturation, these findings suggest that all forests are not necessarily net N sinks, with near-infinite N retention capacity.

All of the watersheds are leaching some level of NO_3-N (fig. 2), even WS4, the reference watershed, with the eventual exception of WS6. WS4 is one of the few examples of elevated stream NO_3 associated with ambient levels of N deposition. A comparison of WS6 and WS7 early data showed that stream water concentrations draining these 2 watersheds during the devegetated (barren) stage of the study were similar (Kochenderfer and Aubertin 1975). Nitrate concentrations remained elevated through 1971, and declined during the regeneration stage. Stream water concentrations of NO_3-N did not decline as far or as continually on WS7 as they did on WS6. WS6, which was replanted to Norway spruce in 1973, now shows little or no annual export of NO_3. This is due at least in part to statistically significant decreases in stream flow resulting from the change in tree species (Hornbeck and others 1993). Conifer stands have greater transpiration and interception rates than hardwood stands (Swank and others 1988). However, note that both flow-weighted (fig. 2) and non-weighted (data not shown) concentrations have decreased to near detection limits, which suggests a change in N cycling within the watershed as well, independent of changes in water availability. We are continuing to investigate N cycling in WS6 to identify the specific processes by which this watershed is fully retaining N. Note that stream water NO_3-N concentrations from WS2 also are quite low. The stand on WS2 received a diameter limit cut in 1958, 1972, 1988, 1997 and 2004 (table 1), and no evidence of the treatments has shown up in annual stream water concentrations of NO_3-N. One hypothesis to explain this is that by increasing growth, each of the repeated cuttings has created an increased demand for N for growth of the remaining trees, which are probably more vigorous as a result of more light and more growing space; this results in lower stream water concentrations and export. This hypothesis remains to be evaluated, however. It is also probable that the basal area removed by each of the cuts may have been sufficiently small and dispersed through the watershed that effects could not be detected. Hornbeck and others (1993) determined that, to detect a significant effect of removal upon annual water yield, approximately 25 percent of the basal area of a watershed would need to be removed. None of the cuts in WS2 removed more than 20 percent of the basal area.

Figure 3 shows stream water SO_4 concentrations. Sulfate is a concern because it is associated with soil acidification, and because S has historically been the dominant component of acidic deposition. Deposition of SO_4 has decreased significantly during the last 15 years (Likens and others 2001). Yet, because of these changes and the reactions controlling SO_4 adsorption, SO_4 continues to be an important anion in soil and water exchange and acidification processes. Sulfate concentrations from WS3 have increased as a result of the watershed acidification treatment, although retention by the watershed is occurring (Edwards and others, in press). Overall, SO_4 concentrations appear to be declining or leveling off in recent years, despite increases from early levels. Because SO_4 adsorption is a reversible process, it is difficult to determine what the effects of decreasing SO_4 deposition may be in these watersheds. However, other than the fertilization of WS3, which is a direct addition, there seem to be little or no effects of the other disturbances on stream water SO_4 concentrations.

Figure 4 shows the long-term stream water concentrations of Ca from the six watersheds. Base cation depletion from soils has been hypothesized as a concern due to clearcutting (Fuller and others 1987), acidic deposition (Johnson and others 1991), or a combination of the two (Adams and others 2000). For most of the watersheds, the trends are very similar to those of NO_3-N. Ca concentrations have increased on WS3 as a result of the acidification treatment, and while trends are similar to those of both SO_4 and NO_3-N concentrations, analyses suggest that NO_3 is probably the dominant anion driving Ca leaching on WS3 (Edwards and others, in press). Evidence also exists to suggest cation mobilization and depletion occurring in WS3; the evidence is strongest in soil water and peak flow concentration data, and less strong for baseflow concentration data (Edwards and others, in press).

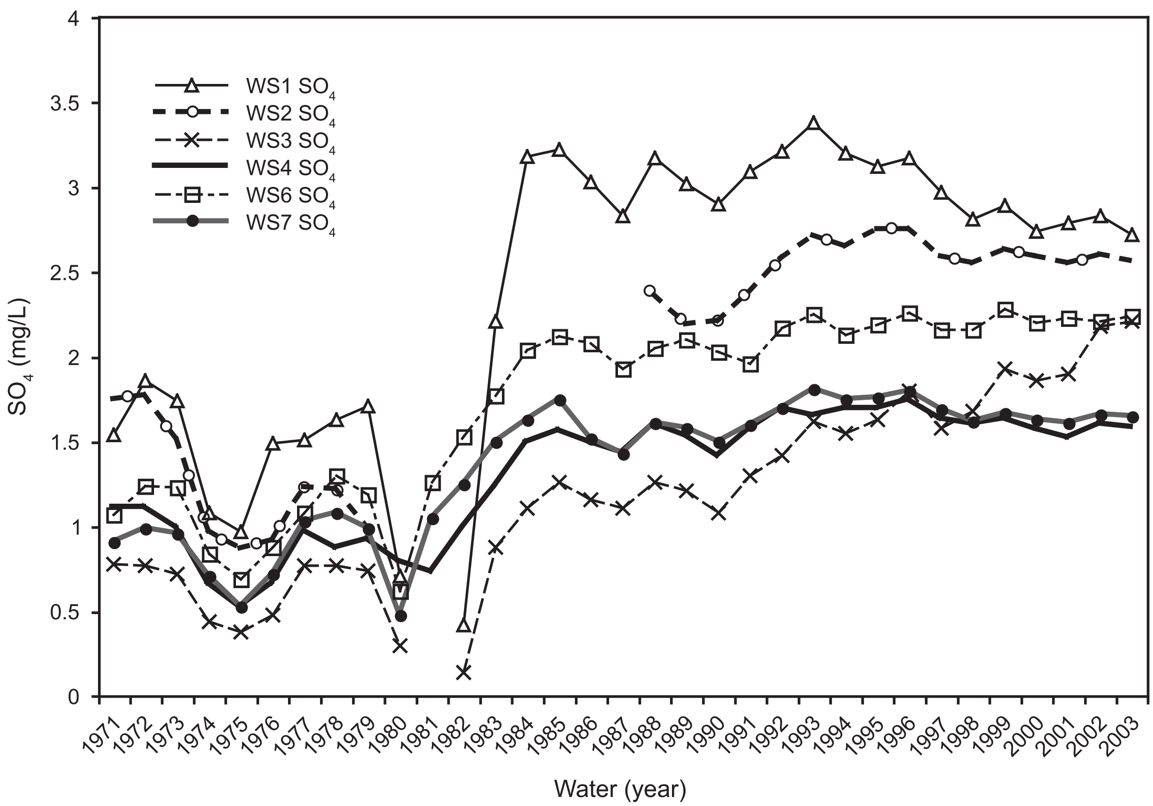

Figure 3—Annual volume-weighted stream SO_4 concentrations from six watersheds on the Fernow Experimental Forest.

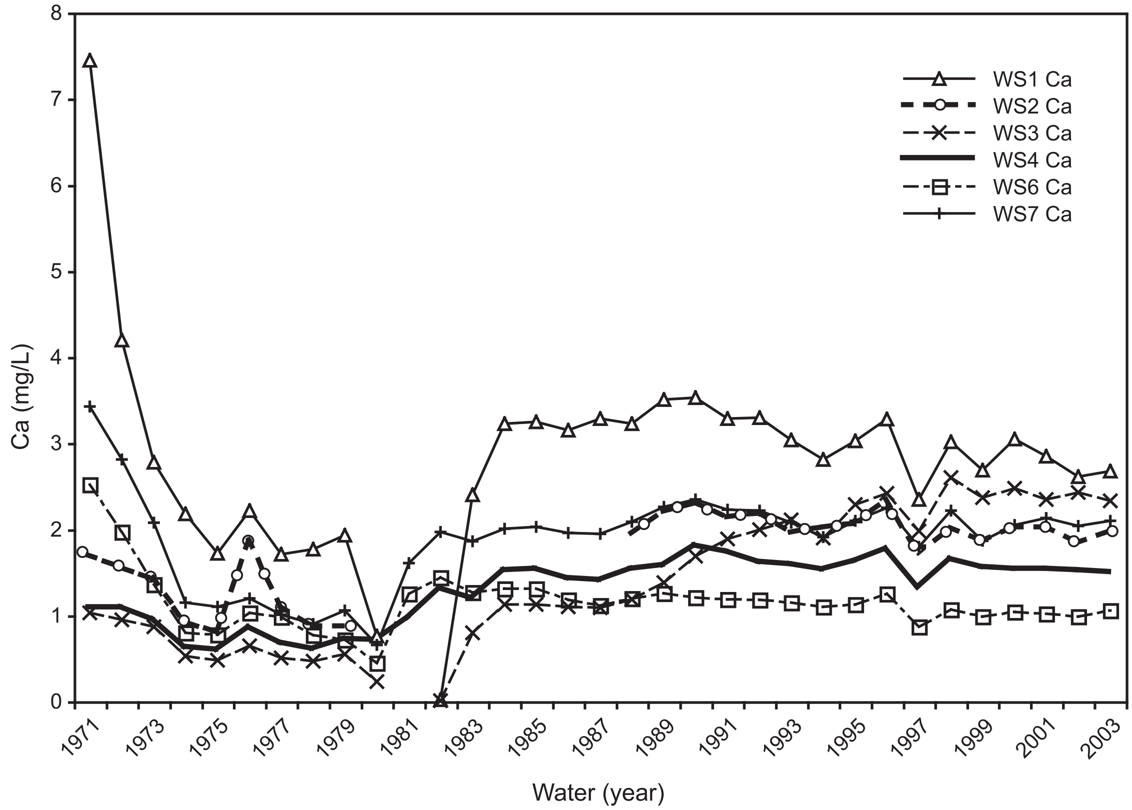

Figure 4—Annual volume-weighted stream Ca concentrations from six watersheds on the Fernow Experimental Forest.

Stream water nutrient concentrations on WS1 are consistently the highest or among the highest for most of those shown in figures 1-4, and for specific conductivity. One explanation could lie with the extreme treatments WS1 has received (the "logger's choice" placement of skid roads during the 1958-1959 clearcutting, a single large application of fertilizer). However, the earliest stream chemistry data available from the FEF show that specific conductance of water draining WS1 was consistently about 1.5-2 times that draining WS4, and the other untreated watersheds (Kochenderfer and Aubertin 1975), even before treatments began.

Significant natural disturbances occurred in 1975, 1985 and 1986 (record rainfall events), and 1993 and 1998 (windstorms which blew down large volume of trees on WS4; Adams and others 2003). These disturbances are not reflected in the annual streamflow chemistry trends in figures 1-4. The windthrow storms, which created 3.5 m^3/ha of new down dead wood each, also did not show up in weekly stream water concentrations or annual sediment exports (data not shown). It is likely that even though these were severe events on a local scale, the effects on the vegetation were not sufficient to significantly change nutrient uptake on the watershed scale. In years with above average rainfall, the watersheds have significantly greater annual flows and nutrient exports, and stream chemical concentrations may be affected as well.

IMPLICATIONS

Stream water chemistry can record and reflect significant disturbances to a forested watershed. Specifically, severe disturbance to the vegetation over a relatively long duration, and fertilization were found to affect stream chemistry. Vegetation appears to significantly regulate or moderate the flux of nutrients from forested watersheds. When vegetation is removed for a long period of time, there are dramatic effects on stream chemistry, as reflected by WS6 and WS7, resulting from the herbiciding treatment. Merely clearcutting, as was done with WS3, proved to have only minor effects on stream chemistry. Repeated partial cuttings, as on WS2 or mimicked in the windstorms on WS4, were neither severe nor long-term enough to produce significant changes in nutrient exports. The conversion of WS6 to spruce had a significant effect on stream water chemistry, and provides further evidence of the importance of the role of vegetation as a regulator of nutrient cycling processes. In this case, the low stream water NO_3 concentrations reflect changes in water movement through a stand as a result of higher interception and transpiration by the spruce relative to the native hardwoods, the effects of greater nutrient uptake due to the potential for year-round physiological activity as temperatures during the dormant season permit, and changes in litter quality and decomposition that can result from species conversion.

The second activity that significantly affected the nutrient cycling of the watersheds, as reflected in annual stream water chemistry, was the application of fertilizer. On WS1, a large single dose of urea fertilizer resulted in an immediate large pulse of NO_3 from the watershed. The treatment of the upper reaches of WS2 also resulted in a small pulse, although not as large as from WS1. Finally, chronic additions of relatively low levels of fertilizer to WS3 resulted in large increases, and continuous, changes in nutrient cycling. The effects on stream water NO_3 concentrations were observed relatively rapidly. Interestingly, chronic fertilization of WS3 produced stream water concentrations similar to those from maintaining WS6 and WS7 barren of vegetation.

Therefore, land managers who wish evaluate the potential for changes in nutrient cycling, which can lead to nutrient depletion and deficiencies due to their management activities should consider the extent of the disturbances to vegetation, and the nutrient uptake processes. Management actions which would result in significant disturbance of the vegetation and its ability to take up and cycle nutrients should be carefully considered, and may require careful planning to minimize the effects. Effects on nutrient cycling are of course not the only management objective that most land managers must consider. However, the results from the FEF show that disturbance need not always result in negative effects on nutrient cycling and water quality. Finally, we add the caveat that some of the effects that we have reported will vary depending on nutrient inputs, vegetation type, geology, soils, and forest health. As always, land managers must consider their particular set of circumstances when making management decisions.

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ECOSYSTEM RESTORATION TREATMENTS AFFECT SOIL PHYSICAL AND CHEMICAL PROPERTIES IN APPALACHIAN MIXED OAK FORESTS

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Abstract—This study presents an analysis of the effect of ecosystem restoration treatments on soil properties in the oak forests of southern Ohio. The treatments were (1) prescribed fire, (2) mechanical thinning, (3) fire and thinning, and (4) passive management (control). Fire and thinning resulted in increased mineral soil exposure, with the effect decreasing by the fourth post-treatment year. No significant effect on soil compaction was observed. Soil pH increased after fire and thinning+fire, but not thinning alone, and this effect persisted. P availability was lower in burned areas, whereas available Ca, K, and Al were not significantly affected. Ca:Al ratios were higher in burned areas the first year after treatment; this effect was greatly reduced by the fourth post-treatment year. These results suggest that prescribed fire and restoration thinning can be applied to this forest type without significant negative effects on the soil resource.

INTRODUCTION

The mixed oak forests of the Midwestern U.S. are far different from those encountered by early settlers and land surveyors. In addition to periodic harvesting, most of the oak forest region has been subjected to effective fire suppression for most of a century and to chronic deposition of the by-products of fossil fuel consumption for even longer. The result of these factors has been the development of forests that have greater stem density (especially in the understory and midstory), greater basal area, and greater fuel accumulations than those present prior to Euro-American settlement.

The Fire and Fire Surrogate Network Project was initiated in the late 1990's in an effort to evaluate the efficacy of four approaches for simultaneously reducing wildfire hazard and facilitating ecosystem restoration (Weatherspoon 2000). The four approaches are (1) passive management, (2) restoration of ecosystem function through the reintroduction of low intensity, dormant season fire at historic intervals, (3) restoration of community structure through mechanical treatment, involving thinning from below to approximately historic basal area, stem density, and tree species composition, and (4) the combination of those functional and structural approaches (Weatherspoon 2000).

Within this context, the specific objectives of this study were to assess the effect of these four ecosystem restoration approaches on soil nutrient status and physical properties in Ohio oak forests, and to evaluate the impact that any effects might have on decisions to implement one or more of these management approaches more broadly.

SITES

The three experimental blocks comprising the Ohio Hills Site of the National Fire and Fire Surrogate Network are located on the unglaciated Allegheny Plateau of southern Ohio. The climate of the region is cool, temperate with mean annual precipitation of 1024 mm and mean annual temperature of 11.3 °C (Sutherland and others 2003). The forests of the region developed between 1850 and 1900, after the cessation of cutting for the charcoal and iron industries (Sutherland and others 2003). The current canopy composition differs little from that recorded in the original land surveys of the early 1800's. The most abundant species in the current canopy are white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), hickories (*Carya* spp. Nutt.), and black oak (*Q. velutina* Lam.)(Yaussy and others 2003).

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Each of the three replicate blocks is composed of four treatment units of 19-26 ha, each of which is surrounded by a buffer of approximately 10 ha. Both the core treatment unit and its corresponding buffer receive the experimental treatment. These treatment units were designed to include all combinations of elevation, aspect, and soil, and approximated the local watershed scale in area. The replication within the Raccoon Ecological Management Area (39°11′ N, 82°22′ W) and the replication within Zaleski State Forest (39°21′ N, 82°22′ W) are both located in Vinton County, OH. They are underlain by sandstones, siltstones, and shales of Pennsylvanian age (Boerner and Sutherland 2003). The soils were formed in place from residuum and colluvium, and are dominated by Steinsburg and Gilpin series silt loams (typic hapludalfs) (Boerner and Sutherland 2003). The replication within Tar Hollow State Forest (39°20′ N, 82°46′ W) is located in Ross County, OH. Tar Hollow is underlain primarily by sandstone of Pennsylvanian age, and the soils are dominated by Muskingum series sandy loams (typic dystrochrepts). Some of the Tar Hollow ridgetops are capped by loess deposits in which Wellston series silt loams (alfic hapludults) have developed.

PROCEDURES

Experimental Design

Treatments were randomly allocated among treatment units within a replicate, and all treatments units were sampled through the pre-treatment year 2000. Treatments consisted of prescribed fire, mechanical treatment involving thinning from below to a basal area comparable to that present prior to Euro-American settlement, the combination of prescribed fire and mechanical treatment, and an untreated control.

The prescribed fires were applied during March and April of 2001. These dormant season fires were designed to be similar to the predominant mode of natural fires in the region. Flame lengths varied from <20 cm to approximately 2 m. Maximum temperatures recorded by thermocouples at 25 cm above the forest floor averaged 152 °C, and the single maximum temperatures recorded in individual treatment units averaged 318 °C (Iverson, and others 2003, 2004). These fires consumed unconsolidated leaf litter and fine woody fuels while leaving the majority of the coarse woody fuels charred.

Mechanical treatment was accomplished between September 2000 and April 2001, and focused on understory and midstory stems. The goal was a residual basal area of approximately 14 m^2/ha, but this goal was not achieved at any of the study sites. Thinning left an average of 21 m^2/ha in residual basal area. Units that were subjected to both mechanical treatment and burning were thinned at least two months prior to burning.

Field and Laboratory Methods

Within each treatment unit ten sample plots of 0.10 ha were established such that the suite of ten plots spanned the full range of landscape positions. Samples of approximately 400 g fresh mass of the top 15 cm of the A + Oa horizon were taken from opposite corners of each plot in May or early June 2000 (the pretreatment year), 2001 (initial post-treatment year), and 2004 (fourth year post-treatment). This yielded N = 20 per treatment unit and N = 60 for each treatment on each date.

The forest floor was examined for exposure of bare mineral soil and soil strength was determined by penetrometer on each sample date at 20 randomly selected points along one long axis of each sample plot. This yielded N = 200 per treatment unit per date and N = 600 per treatment per date. Soil was judged to be compacted if the soil strength was more than two standard deviations above the mean of the 800 pretreatment samples for that block. Both soil compaction and exposure of bare mineral soil were expressed on a proportional basis.

Each soil sample was air-dried and sieved to remove material >2 mm. Root and particulate organic matter fragments were then removed by hand. Soil pH was determined in a 1/5 soil slurry of 0.01 mol/L $CaCl_2$ (Hendershot and others 1993), available P by the ascorbic acid method (Watanabe and Olsen

1965), available Al^{3+} in 0.5 mol/L K_2SO_4 extracts by the ferron method (Bersillon and others 1980), and exchangeable Ca^{2+} and K^+ in 1 mol/L NaOAc extracts using Orion® ion specific electrodes. Ca:Al ratio was calculated on a molar basis.

Data Analysis

The experiment was a randomized complete block design with study sites as replicate blocks within which the four treatments were allocated randomly to treatment units. As there were time lags between mechanical treatment of units that received only mechanical treatment and those receiving mechanical treatment followed by prescribed fire, and as the prescribed fires appeared to vary in intensity, we considered the four treatments to be independent rather than a 2 x 2 factorial design.

All response variables were tested for normality prior to analysis of variance, and log transformed where necessary to achieve normality. We evaluated treatment responses using one-way analysis of covariance for the randomized complete block design with pre-treatment year conditions as the covariate. Means separation was achieved using least squares estimation with the Bonferroni adjustment for multiple comparisons. The exception to this analysis strategy was the molar Ca:Al ratio, whose exponential distribution defied attempts at normalization. Ca:Al ratio was analyzed by non-parametric analysis of variance using the Savage method, which is designed specifically for exponential distributions. All statistical analyses employed SAS release 8e (Statistical Analysis System 2004).

RESULTS

Soil Physical Properties

During the first growing season after treatment, the proportion of the mineral soil surface exposed ranged from approximately two percent in the control units to approximately 26 percent in the burn-only units (fig. 1, table 1). Mineral soil exposure was significantly greater in units that were burned (with or without mechanical treatment) than in units that were either thinned or untreated. By the fourth growing season after treatment, the magnitude of differences among treatments had decreased, though all three manipulative treatments still had greater mineral soil exposure than was present in the control. The proportion of the soil that was compacted averaged less than seven percent of the treatment units in both the first and fourth growing seasons after treatment (fig. 1, table 1), and there were no significant differences among restoration treatments. The coefficients of variation in soil exposure and compaction averaged 120 percent, but did not vary significantly among treatments or years.

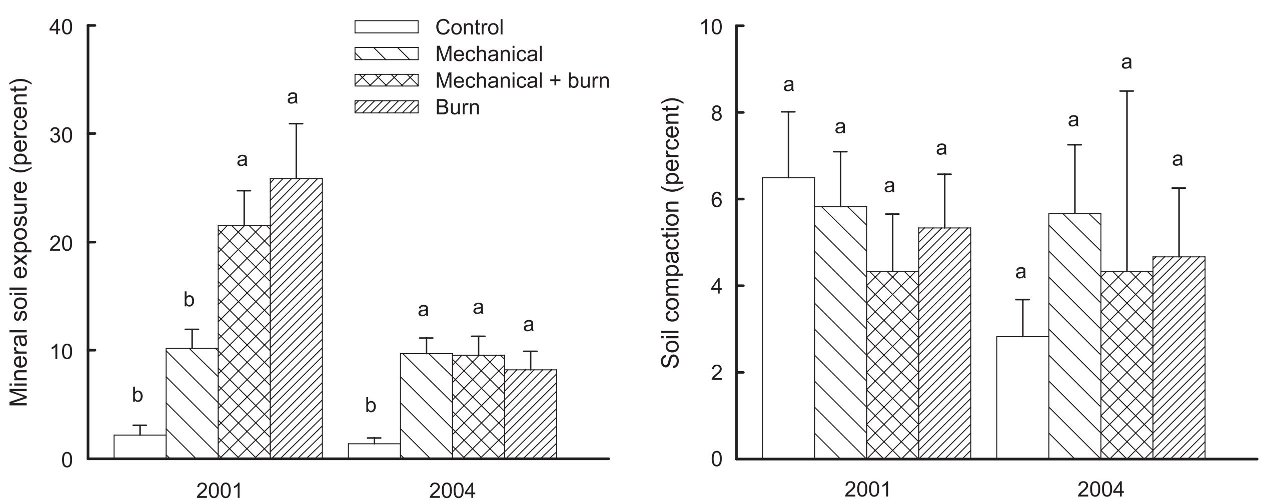

Figure 1—Effects of four ecosystem restoration treatments on the proportion of forest area with mineral soil exposed and the proportion of soil samples exhibiting significant compaction during the first growing season (2001) and the fourth growing season after treatment (2004). Means and standard errors of the means are indicated. Means labeled with the same lowercase letter were not significantly different at p<0.05 following analysis of covariance, with the pretreatment year (2000) as the covariate.

Table 1—Analysis of covariance for the randomized complete block design for the effects of four treatments on soil physical and chemical properties. Pretreatment (2000) conditions were used as the covariates. Shown are the F-statistic and corresponding p for the test of the treatment variance against the treatment-by-block interaction variance

Response parameter	Year	Treatment	Effect
Mineral soil exposure	2001	F = 4.87	p < 0.050
(proportion of area)	2004	F = 5.97	p < 0.032
Soil compaction	2001	F = 0.20	p < 0.895
(proportion of area)	2004	F = 2.49	p < 0.158
Soil pH	2001	F = 2.80	p < 0.013
	2004	F = 1.01	p < 0.045
Available P	2001	F = 0.26	p < 0.851
(µg/kg soil)	2004	F = 5.12	p < 0.044
Available Ca	2001	F = 1.26	p < 0.369
(mg/kg soil)	2004	F = 1.39	p < 0.334
Available Al	2001	F = 6.53	p < 0.026
(mg/kg soil)	2004	F = 0.93	p < 0.482
Available K	2001	F = 2.35	p < 0.172
(mg/kg soil)	2004	F = 0.99	p < 0.357

Soil Chemical Properties

During both years soil pH was significantly greater in the treatment units that were burned than in those thinned or untreated (fig. 2, table 1). The soil pH of the units that received both mechanical treatment and burning did not differ from those given any of the other treatments. During the first post-treatment growing season available P was not affected significantly by any of the treatments, and during the fourth growing season none of the manipulative treatments differed significantly from the control in available P (fig. 2, table 1). However, relative to the thinned units fourth growing season P was 46 percent lower in plots that were burned and 54 percent lower in plots that were burned and thinned.

Although Ca availability varied by as much as 50 percent among treatments, there were no significant effects on Ca availability in either the first or fourth post-treatment growing season (fig. 3, table 1). In contrast, there was a strong and significant effect of the treatments on available Al, with all three manipulative treatments producing significantly lower Al availability than was present in the untreated controls (fig. 3, table 1). The patterns of Ca and Al availability among the four treatments were mirror images (fig. 3).

The molar Ca:Al ratio averaged 0.47 ($\pm$0.04) among the treatment unit groups during the pretreatment year (2000). During the first growing season after fire, the molar Ca:Al ratio was significantly greater than it was during the pretreatment year in the soils of treatments except the control. During the first post-treatment growing season there were significant differences among treatment units (χ^2=41.09, p<0.001) such that treatment units that were burned (either with or without mechanical treatment) had significantly greater Ca:Al ratio than did the thinned units, which in turn had significantly greater Ca:Al ratio than the untreated controls (fig. 4). There were also significant differences in Ca:Al ratio among treatments during the fourth growing season after treatment (χ^2=11.77, p<0.009). During 2004 the Ca:Al ratio of the thin+burn units was still significantly greater than that of the control, but the thinned units and burned units were no longer significantly different from the control (fig. 4).

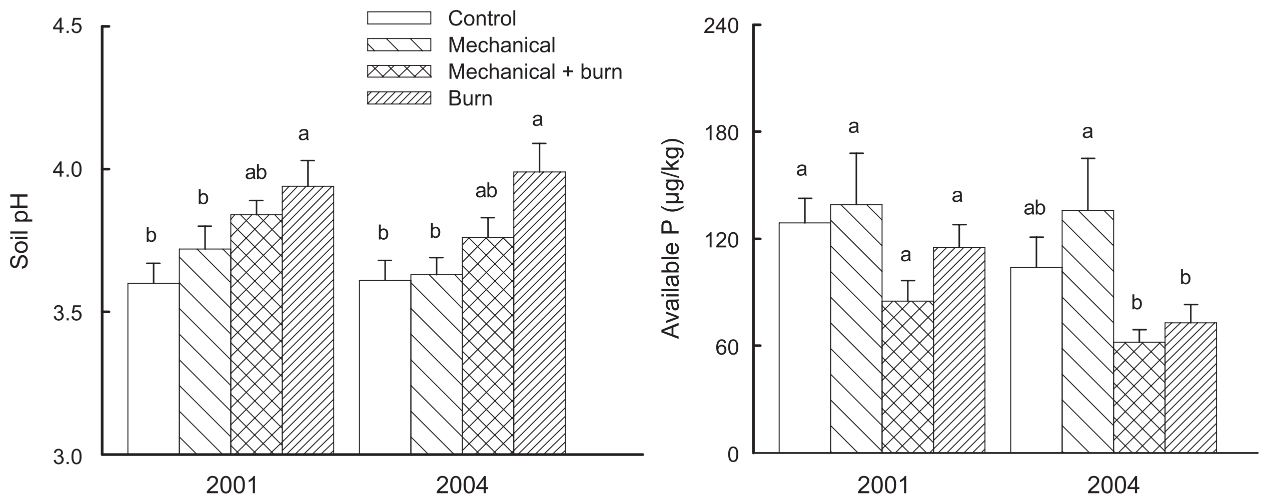

Figure 2—Effects of four ecosystem restoration treatments on soil pH and plant available P (format follows figure 1).

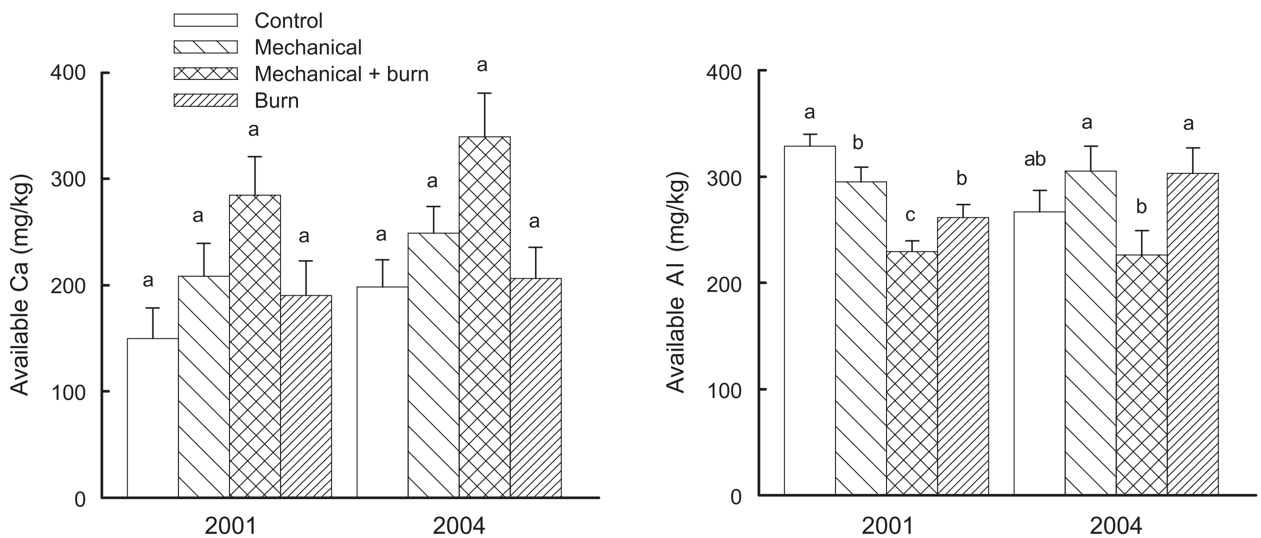

Figure 3—Effects of four ecosystem restoration treatments on extractable Ca and Al (format follows figure 1).

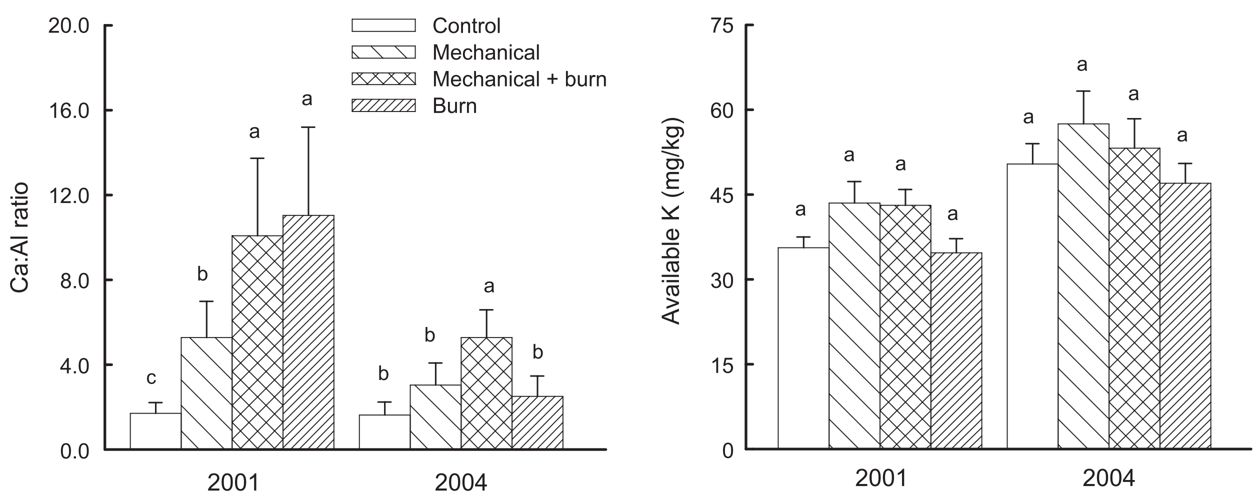

Figure 4—Effects of four ecosystem restoration treatments on molar Ca:Al ratio and extractable K (format follows figure 1).

Available K averaged 39.2 (±0.88) mg K/kg soil during the first growing season after treatment and 52.3 (±2.4) mg K/kg soil during the fourth post-treatment growing season. K availability was not affected significantly by any of the treatments (fig. 4, table 1).

DISCUSSION

Physical disruption of the forest floor and upper mineral soil horizons can produce both acute and chronic impacts on soil nutrient status and subsequent tree growth (Agee 1993). During the first post-treatment growing season, prescribed fire (with or without mechanical treatment) resulted in the mineral soil surface being exposed over an average of 20-30 percent of the area of each burned treatment unit. In contrast, mechanical treatment resulted in approximately 10 percent soil exposure, and this degree of exposure was not significantly different from that of the controls. By the fourth post-treatment growing season, mineral soil was exposed on 8-10 percent in all three treatments. Although this degree of exposure was significantly greater than that observed in the controls (1-2 percent), it did indicate a relatively rapid reestablishment of forest floor cover, at least in the burned areas.

The proportion of the soil exposed by mechanical treatment in these Ohio forests was somewhat lower than that reported after harvesting in other regions. Rummer and others (1997) reported that soil exposure in upland hardwood forests in Alabama averaged 7-25 percent depending on cutting regime and Klepac and others (1999) observed soil exposure averaging 15 percent after mechanical treatment of conifer stands in Washington.

We observed no significant increase in the average or variance of the proportion of ground area with significant soil compaction as the result of fire, mechanical treatment, or the combination. Although it has been demonstrated in western conifer forests that severe and/or repeated burning has the potential to increase soil bulk density, such effects are typically less evident after low intensity fires, such as those typical of prescribed fire in Ohio oak forests (Agee 1993).

Harvesting operations also present the potential for significant effects on bulk density/compaction, especially in areas of heavy vehicle traffic. However, we observed no significant effect, either in average or variance, and Matson and Vitousek (1981) also reported no consistent changes in bulk density as the result of clear-cutting of mixed oak forests in Indiana. Other studies, however, do demonstrate significant effects of harvesting practices on soil compaction (e.g. Berger and others 2004, Rummer and others 1997). The lack of compaction we observed in our study may be the result of the relatively light intensity of the cutting in our Ohio sites. Another contributing factor may have been our random sampling scheme, as we did not single out skid trails when we sampled.

Changes in soil nutrient status as the result of management can have both short and long term effects on revegetation, as nutrients present in the mineral soil after fire are needed both for immediate plant needs and to replenish the nutrients lost from the site during fire or harvesting. In this study, fire alone resulted in an increase in soil pH while mechanical treatment had no significant effect on soil pH. The combination of mechanical treatment and burning produced soil pH that was not significantly different from fire or mechanical treatment alone or from the controls, and this pattern persisted through the fourth post-treatment growing season.

The increase in soil pH after fire we observed was consistent with that observed after single fires (Blankenship and Arthur 1999), multiple fires (Boerner and others 2004), and long term prescribed burning (Eivasi and Bayan 1996) in Midwestern oak forests. However, the lack of effect of mechanical treatment on soil pH in these stands was unexpected, as other studies have demonstrated that thinned stands often have significantly higher soil pH than reference stands. For example, a comparison of stands in Kentucky, Ohio, and Illinois that were experimentally thinned 30+ years before showed that thinned stands had soil pH on average 0.33 units higher than did paired reference stands (Boerner and Sutherland 1997).

We observed no significant effect of fire, mechanical treatment, or their combination on available K^+ at any time and no effect on available P during the first post-treatment growing season. However, by the fourth-post treatment growing season, available P in the burned and thinned+burned treatments was significantly lower than that in the thinned treatments (though none of the three were significantly different from available P in the untreated controls). Long term prescribed burning in a Missouri oak forest also resulted in a decrease of 24-35 percent in available P without a concomitant effect on K^+ (Eivasi and Bayan 1996). It is unclear whether the change in available P is a result of rapid uptake by post-fire regrowth depleting the local pool or the result of changes in P supply from parent material and organic matter.

In a study of the consequences of clear-cutting on mixed oak forests in Virginia, Johnson and others (1985) found that rapid slash decay resulted in increased K^+ but not P in the mineral soil during the growing season after the harvesting. In contrast, Hendrickson and others (1989) reported no change in available K^+ after thinning of northern hardwoods and Frey and others (2003) observed a decrease in available K^+ after harvesting in an Alberta mixed forest. Given the high mobility of K^+ in the soil solution, post-treatment availability may be governed primarily by site- and situation-specific factors such as mineral soil exposure and post-fire precipitation patterns.

As was the case for K^+, we observed no significant effect of our treatments on available Ca^{2+}. This was an unanticipated result, as previous studies in nearby sites had shown significant, positive effects of 1-4 fires on available Ca^{2+} (Boerner and others 2004), and the significant increase we observed in soil pH suggested that Ca^{2+} would also have increased. Although prescribed burning over a longer term does not always result in increased Ca^{2+} in oak forests (e.g. Eivasi and Bayan 1996), shorter term studies typically do observe increases in the availability of Ca^{2+} (Boerner and others 2004). The lack of an effect of mechanical treatment on Ca^{2+} is equally unexpected. In their comparison of thinned and reference oak stands in Ohio, Kentucky, and Illinois, Boerner and Sutherland (1997) found that thinned stands had on average 55 percent greater Ca^{2+} availability than paired reference stands, and a number of studies have also demonstrated increases in Ca^{2+} after clear-cutting (e.g. Frey and others 2003, Hendrickson and others 1989).

Available Al^{3+} did decrease initially as the result of our treatments, but this change did not persist through the fourth post-treatment growing season. The patterns of Ca^{2+} and Al^{3+} among treatments were mirror images, as would be expected by their reciprocal responses to soil pH and base saturation. The Ca:Al molar ratio increased significantly after fire (with or without mechanical treatment), but once again these differences had begun to dissipate by the fourth-growing season after fire. Boerner and others (2004) observed similar post-fire increases in Ca:Al ratio in neighboring sites on similar, acidic parent materials. Based on an extensive literature survey, Cronan and Grigal (1995) concluded that forest decline symptoms were much more likely to develop in European forests after the Ca:Al molar ratio decreased to <2.0. As the pre-treatment Ca:Al ratios in our study sites averaged <2.0 and chronic N deposition continues to contribute to soil acidification in this region (Boerner and others 2004), management practices that have the potential to increase base saturation and Ca:Al ratio should be strongly considered.

MANAGEMENT IMPLICATIONS

Management practices designed to improve ecosystem health and sustainability must adhere to the same first principle as medicine: above all, do no harm. Although we commonly assess the impacts of our management activities in terms of trees, other plants, and animals, the impacts of management on the soil resource is one of the keys to long term sustainability.

The effects on the soil resource of the ecosystem restoration treatments we applied were relatively modest and, for the most part, positive. Although both fire and mechanical treatment resulted in disruption of the forest floor, neither had significant effects on soil compaction. Even the effects on mineral soil exposure were significantly reduced (at least for fire) by the fourth growing-season after fire.

Soil nutrient status was relatively unaffected by mechanical treatment and perhaps modestly improved by fire. Although the effect of the single fires we applied in this study produced effects that were transitory in nature, repeated application of fire at intervals might result in these changes becoming chronic (e.g. Eivasi and Bayan 1996). Given that chronic deposition of N onto these once N-limited ecosystems is unlikely to cease in the foreseeable future, multiple longer term studies of the relationships among fire frequency and forest soils are needed to bring the available database up to even the meager status of the thinning literature.

Studies of thinning at rates similar to the ones used here are uncommon; however, the longer term study of thinning in midwestern oak forests by Boerner and Sutherland (1997) suggests that the reduction in uptake demand that accompanies a reduction in basal area may help retard soil acidification, even in a region with heavy chronic N deposition. This conclusion must, however, be considered preliminary, given the sparseness of the available data and the concerns raised by studies of more intensive harvesting.

The results presented here suggest that modest thinning and low intensity prescribed fire may be applied to eastern oak forests as part of a management or restoration strategy without doing significant damage to the soil resource. Managers should apply the conclusions presented here with caution until longer term, replicated studies in the region confirm them.

ACKNOWLEDGMENTS

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RECLAMATION OF SKID ROADS WITH FIBER MATS AND NATIVE VEGETATION: EFFECTS ON EROSION

Shawn T. Grushecky, David W. McGill, William Grafton, John Edwards, and Lisa Tager[1]

Abstract—A research study was established to test the effectiveness of fiber mats and native seed mixtures in reducing soil erosion from newly-constructed skid roads in the Elk River Watershed in central West Virginia. Twelve road sections of equal grade were paired with a randomly-selected section receiving a fiber mat and native grass seed while the other road section was not treated. Silt fences with sediment traps were constructed at the downslope ends of each road section. Sediments were collected from silt traps three times during the summer of 2005. Road sections with no fiber mulch or seeding averaged 174.1 g/m^2 and those with fiber mulch and seeding average 34.9 g/m^2. Vegetation averaged 17.5 cm in height on fiber mulch treated road sections; no vegetation was observed sections without fiber mulch during the study period. Further research is needed to develop a cost/benefit analysis of employing the road reclamation approach used in this pilot project.

INTRODUCTION

The forestry community has long known that controlling non-point source pollution from silvicultural activities is important. Most states now have forest practice standards or best management practices that require the control of sediments from exposed areas. West Virginia published a set of Forest Practice Standards in 1972, which were the first of their kind in the eastern United States. In 1992, the West Virginia Legislature passed the Logging Sediment Control Act (LSCA). The LSCA mandated that loggers become licensed and certified, notify the West Virginia Division of Forestry about logging operations, and mandated that logging sites be reclaimed within seven days of the completion of operations.

Forest roads, trails, and landings are the primary sources of non-point source pollution, primarily in the form of eroded soil sediments (Egan and others 1996, Kochenderfer and others 1997). Sediments that make their way to a stream channel can be deposited in deeper pools and, once introduced into a stream, can have deleterious affects on both vertebrate and non-vertebrate aquatic wildlife populations. Sedimentation can also affect the natural characteristics (i.e., depth, temperature, width) of the stream itself.

Since landings, forest roads, and skid trails are the largest potential source for sedimentation, it is natural for the forestry community to concentrate their research, education and outreach efforts in this area. This focus is especially justified since Egan and Rowe's 1997 study found that improvements could be made in skid road drainage and that in 2000, LSCA oriented logging inspections found that 11 percent of compliance problems were due to skid/haul road problems (Milauskas 2001). Likewise, a 2001 LSCA evaluation found that 13 percent of compliance problems were due to skid and/or haul roads (Milauskas 2002).

Exposed soils following harvesting operations represent the main potential for erosion. If vegetation is not established quickly, erosion of these exposed surfaces is likely until natural herbaceous and woody vegetation becomes established. The establishment of vegetation on skid roads not only lessens erosion, but it also provides nesting, feeding, and escape habitat for wildlife. After harvesting in West Virginia, skid roads and trails represent approximately 10 percent of the total harvest area (Provencher 2004). Thus,

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vigorous establishment of vegetation on skid roads should be of top priority when timber harvesting sites are reclaimed. Currently in West Virginia, only those skid roads that exceed 15 percent slope, or are within 100 feet of a landing or water crossing must be seeded.

The objective of this pilot project was to document the effectiveness of fiber mats and native vegetation for reducing sediments from skid roads in a high quality watershed in West Virginia. Results from this research project will help refine reclamation techniques so that the impact of sedimentation can be reduced after timber harvesting in West Virginia.

METHODS

This pilot project was initiated in the Upper Elk River Watershed near Webster Springs, West Virginia (fig. 1). The Upper Elk Watershed is a high-quality coldwater system with 16 streams (37 miles) identified under Section 303(d) of the Federal Clean Water Act.

The Elk watershed extends the length of half the state, beginning in the Allegheny Mountains in the east and flowing west to meet the Kanawha River at Charleston, WV, the urbanized and political center of West Virginia. Most of the watershed is under private ownership, divided mainly among three large forest products companies. However, 26 percent of the watershed is publicly owned as part of the Monongahela National Forest. The upper Elk watershed is 95 percent forested and supports some of the highest quality hardwoods in the United States. The quality and quantity of timber in the area leads to a substantial amount of cutting activity in this watershed.

During the spring of 2005, a private timber operator agreed to allow our team to establish this research project within a newly completed harvest unit. Twelve short sections of skid road were identified along two major skid roads from the main landing area. Skid road sections were paired, thus we identified six areas for treatment and six reference road sections within the harvest unit.

Road sections were delineated based on known water-breaks. For example, the start of each section contained pre-established water bars. Sediment catchments were then constructed below the water bar. Sediment catchments consisted of high-quality silt fence staked perpendicular to the road from cut bank to the end of opposite cut bank or fill slope. A 12-inch lip was turf-stapled to the road and served as the sediment trapping area. The total area of the section was calculated based on disturbed skid road section that fell between the sediment trap and the water bar (fig. 2). All skid road sections were chosen so that sediments would flow naturally towards the sediment traps. Slopes ranged from 4 to 36 percent (average = 18 percent) on the selected road sections and were paired based on proximity and slope. Treated areas averaged 16 percent slope, while reference sections had an average slope of 19 percent. Slopes found on both treated and reference sections are above the minimum 15 percent where vegetation establishment is mandated by the WV LSCA.

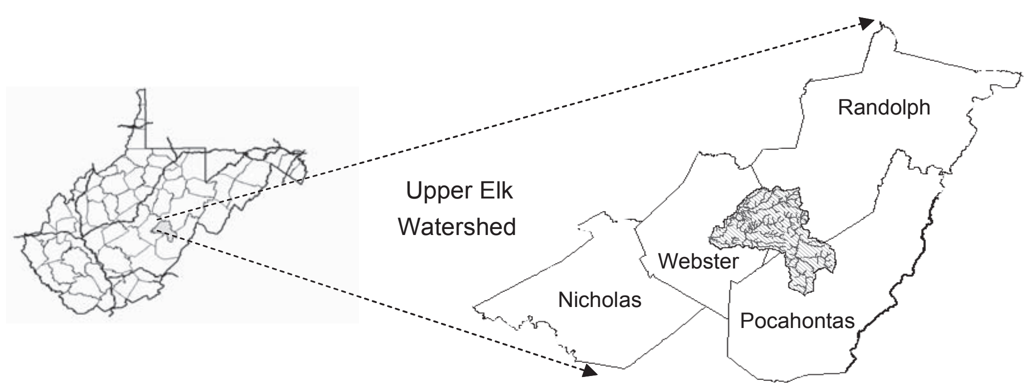

Figure 1—Location of the Upper Elk River Watershed in West Virginia

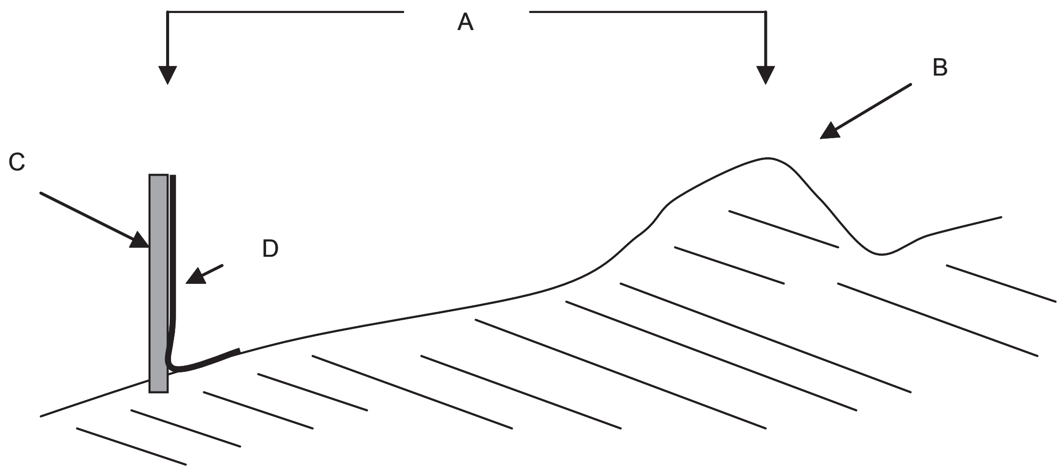

Figure 2—Schematic drawing detailing sediment collection area used on skid roads in the Upper Elk River Watershed in West Virginia. Drawing includes (A) catchment area, (B) water bar, (C) silt fence stake, and (D) silt fence with silt trap at base.

After sediment traps were created, six sections of the paired areas were selected randomly for vegetation treatment. A mixture of native vegetation was chosen for treatments (table 1). Seed was spread manually on the six sections. A high-velocity natural fiber mat purchased from Ernst Conservation Seeds was then unrolled on the section and staked into place. Sediment traps were emptied three times from the period of late June to August, 2005. All collected sediment was placed in labeled bags and returned to a laboratory. Sediments were then oven dried until their mass did not change. Weights were then recorded for use in subsequent analyses. Average vegetation height was also recorded during each sediment collection period.

An analysis of covariance (ANCOVA) was used to test for differences in sediments eroded from skid road sections while adjusting for slope and length. The following model was used (all tests of significance were conducted at an $\alpha = 0.05$ level):

$$Y_{ij} = \mu + \alpha_i + \beta_1 \chi_i + \varepsilon_{ij}$$

where

Y_{ij} = sediments collected per unit area

μ = the overall mean of sediments collected per unit area

α_i = effect of the *i*th treatment group

$\beta_1 \chi_i$ = covariates (slope and section length)

ε_{ij} = random effect that represents all uncontrolled variability

RESULTS

Total sediments displaced within each road section were standardized to g/m^2 by dividing the sum of sediments collected during the three time periods by the associated catchment area. Catchment areas averaged 26.2 m^2 on reference sites and 28.9 m^2 on treated skid road sections. Mean length of catchment area was 7.5 m and 7.9 m on reference and treated areas, respectively. Collected sediments ranged from 5.0 g/m^2 on a treated skid road section to 310.6 g/m^2 on a reference section (table 2). Average sediment per area was 174.1 g/m^{2}on reference sites and 34.9 g/m^2 on treated sites. Vegetation averaged 17.5 cm on treated sites, no vegetation was observed during the sampling period on reference skid road sections.

Table 1—Seed mixture used to reclaim skid trail sections in the Upper Elk River watershed near Webster Springs, WV

Common name	Scientific name	Rate
		kg/ha
Annual winter wheat	*Triticum aestivum* L.	8.9
Little bluestem	*Schizachyrium scoparium*	2.7
Big bluestem	*Andropogon gerardii*	4.5
Side oats gramma	*Bouteloua curtipendula*	2.7
Silky wild rye	*Elymus villosus*	5.8
Creeping red fescue	*Festuca rubra*	6.7

Table 2—Characteristics of skid trails treated in the Upper Elk River watershed near Webster Springs, WV which includes slope, area, total sediments collected, total sediments collected in relation to area, and average vegetation height

Skid trail section	Treatment	Slope	Area	Length	Sediment collected	Sediment/ area	Vegetation height
		percent	*m^2*	*m*	*gm*	*gm/m^2*	*cm*
1	Reference	8	23.6	7.4	2 633	111.7	—
2	Treated	11	50.1	10.9	696	13.9	16.5
3	Reference	4	25.7	7.6	140	5.4	—
4	Treated	14	29.8	9.5	148	5.0	26.2
5	Reference	11	19.5	6.0	2 338	120.1	—
6	Treated	18	18.5	6.7	531	28.7	20.3
7	Reference	26	9.9	4.3	2 590	262.3	—
8	Treated	26	15.4	5.2	961	62.3	17.8
9	Reference	13	26.1	6.6	6 155	236.1	—
10	Treated	11	35.2	8.3	1 135	32.3	13.5
11	Reference	34	52.7	13.3	16 356	310.6	—
12	Treated	36	24.1	6.7	1 614	66.8	10.9

[a] Treated skid trail sections were covered with fiber mulch mats and seeded; reference skid trail sections were not treated.
— = the reference skid trails sections were not treated, thus vegetation height for the reference treatments was not available.

We found a significant difference in sediments collected from treated skid road sections (p=0.0215). Sediments collected on treated skid roads were significantly lower than those collected on reference sections.

DISCUSSION

Forest roads and skid trails are the first access system used in the Appalachian Region to move wood products to market. Soil exposed during harvesting activities, specifically road construction, is known to be the greatest contributor to stream sedimentation (Kochenderfer 1970, Kochenderfer and Aubertin 1975, Patric 1976). Subsequently, practices have been developed that focus on reducing erosion from forest roads, including leaving log slash barriers, seeding fill areas, creating broad-based drainage dips, and daylighting (Kochenderfer 1970), all of which are recommended practices under the WV LSCA.

Most research has shown that sediment levels return to pre-harvest levels within three years of harvest (Hornbeck and Reinhart 1964, Patric 1980, Kochenderfer and others 1997). Since soil exposed during the construction of road systems appears to be the "weak link" when it comes to sediment movement following harvesting, we focused our efforts on reducing its severity. Reductions of the magnitude found in this pilot project indicate that the use of fiber mats and proper re-vegetation of skid roads after harvest has good potential for limiting in-stream sedimentation. It has been found that forest litter and vegetation strips reduce the amount of sediments that actually make it into a stream system (Swift 1986). Therefore, we cannot assume that the reductions we found would mirror those found at streamside. However, keeping sediment from moving from the road systems limits the amount buffered by litter and vegetation surrounding the stream corridor, thus adding to their protective qualities.

Kochenderfer and others (1997) found that the sediment increases following harvest represent a small percentage of the total sediment delivered from a watershed during a 100 year rotation. Therefore, our reductions alone may not significantly reduce stream sedimentation over a typical rotation. However, since most of our study site was in an industrial timber production area, multiple timber harvests will occur in the watershed over the next rotation, all with the potential to increase sediment delivery out of the system. Therefore, sediment reductions of the magnitude found have the potential to significantly reduce sedimentation over a long rotation.

We acknowledge that the effect of the fiber mats used cannot be separated from the impact of the vegetation establishment. However, vegetative growth was quite vigorous on treated skid roads, and the root structure associated with it likely contributed to the reduction in sediments found and will provide extended life to the protected soil as the fiber mats decompose. However, most of the initial reduction in sediments found during this research can likely be attributed to the effects of the fiber matting used. More research is underway in this watershed to determine if seeding alone has a similar impact on sediment reduction.

Likewise, the extra costs associated with the reclamation work done in this pilot project have not been compared to traditional techniques. Expenses associated with BMP establishment can be substantial (Egan 1999), therefore, the cost/benefit relationship of these techniques should be further investigated.

A novel aspect of this pilot project was the use of native vegetation in seeding mixtures. The establishment of native vegetation on skid roads and landings not only controls sedimentation, but it also provides natural habitat for wildlife, while limiting the spread of non-native invasive plants. Current BMP regulations under the WV LSCA do not require the use of native plant species, however, the impacts of choosing natives over exotics and naturalized species should be further investigated.

Regulations, both mandatory and voluntary, have been enacted in West Virginia to control sedimentation. Egan and Rowe (1997) evaluated BMP use after the WV LSCA and found significant increases in compliance levels. However, improvements in haul and skid road drainage practices needed to be improved (Egan and Rowe 1997). Further research is needed to refine techniques and develop a cost/benefit analysis on the feasibility of employing the reclamation approach used in this pilot project.

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IMPACT OF ALTERNATIVE HARVESTING TECHNOLOGIES ON THINNING ENTRY AND OPTIMAL ROTATION AGE FOR EASTERN HARDWOODS

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Abstract—A complete system simulation model is used to integrate alternative logging technologies, stand data, market prices, transportation costs, and economic concerns in a long-term continuous manner to evaluate thinning entry timing and optimal rotation age. Forest Inventory and Analysis (FIA) stand data for the oak/hickory forest type and time and motion study data for 70, 90, and 120 horsepower skidders, a cut-to-length/forwarding system, and a feller buncher/forwarding system were used in this research. Smaller, less expensive skidders allowed commercial thinnings to be scheduled 15-30 years earlier in the life of the stand and resulted in larger cumulative monetary returns to the landowner. Larger, more expensive skidders and expensive mechanized systems such as cut-to-length resulted in delaying thinning entries by as many as 30 years and in less cumulative monetary returns to the landowner. The results should be valuable to landowners, loggers, managers, and decision-makers.

INTRODUCTION

Much of the world's managed forest is for wood production. In order to remain competitive, large corporate or industrial forest owners must manage forests with careful attention to harvesting trees at their optimal financial age. Large and small forest owners must also pay careful attention to the timing of thinning/intermediate treatments so that a thinning/intermediate treatment returns a profit as well as the benefits of releasing the residual trees accelerating their growth into high quality wood products. It has long been known and understood that strategically timed precommercial thinnings (Daggett and others 2002, Jean-Claude Ruel and others 2002), commercial thinnings (Kenefic and others 2005, Opland and others 2002, Wagner and others 2002), crop release treatments (Desmarais and Leak 2005, Phillips and others 2002), shelterwood harvests (Binot and others 2002, Morin and Binot 2002), and variations of improvement/partial cuttings (Barlow and Nowak 2002, Bevilacqua 2002) all serve to release the residual stand from competition and result in accelerated growth and development of higher quality wood products. Additionally, the array of commercially available logging technology has increased in recent years from skidders, small farm tractors, cable yarders, to highly productive and mechanized systems such as cut-to-length and feller-buncher with forwarder systems (LeDoux 2001, 2002). The challenge to the landowner is to match the logging technology available with silvicultural treatments desired so that a profitable operation results. Landowners must also understand how alternative logging technologies impact commercial thinning entry timing, optimal economic rotation age, and related financial yields. In this paper, we use a complete systems simulation model to evaluate the impact of alternative conventional and mechanized logging technologies on commercial entry timing and optimal economic rotation age for an upland oak-hickory stand.

METHODS

Site and Stand Data

In this study, the stand chosen for demonstration is from the oak/hickory forest type and represents substantial acreage (Schnur 1937) in the Central hardwood region. The species mix includes northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), red maple (*Acer rubrum* L.), and hickory [*Carya ovata* (Mill.)] (fig. 1). The average site index of the stand is about 70. The stand is 40 years old and contains 366 trees per acre that are more than 5 inches dbh. The stand has an average tree dbh of 6.15 inches and about 1471.47 cubic feet per acre of merchantable volume. The land is located on gentle-to-moderate slopes (0-39 percent) and ground-based systems can be used for the harvests. It is assumed that new road construction is not required. The stand is located 25 miles from a sawmill/pulpwood mill.

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Logging Technology Evaluated

Three logging systems were used in this simulation (table 1). The first logging technology used in this demonstration was conventional chainsaw felling with cable skidders. The majority of wood harvested in the Eastern United States is extracted with a combination of chainsaw felling and ground-based cable skidding. The 70, 90, and 120 horsepower John Deere® skidders such as the ones used in these simulations are representative of contemporary logging technology and are large enough to handle the size of logs from the thinnings and final harvest (LeDoux 2000). With this system, trees are chainsaw felled, limbed, and topped. The cable skidder then drags the logs to a central landing. The second technology used was a highly mechanized cut-to-length (CTL) system with a forwarder for transporting the wood to the landing.

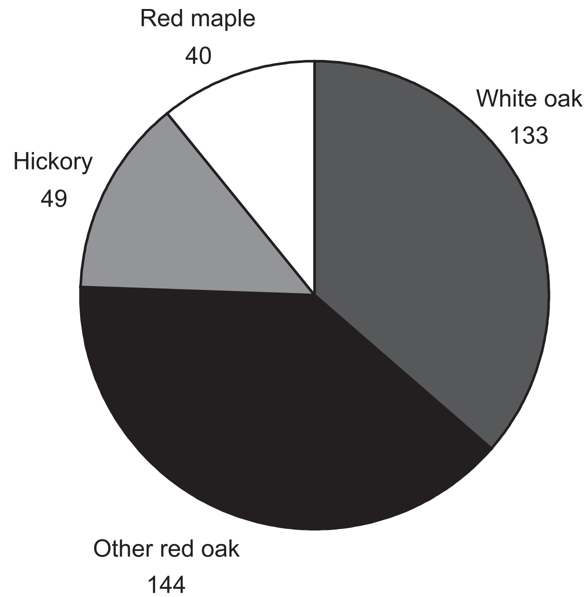

Figure 1—Tree species distribution for oak-hickory stand.

Table 1—Logging technology machine configurations used to simulate the thinnings and final harvest by hourly rate

Logging technology system and description	Machine rate
	$/hour
System 1	
Chainsaw felling with John Deere 440C skidder	59.55
Chainsaw felling with John Deere 540B skidder	65.45
Chainsaw felling with John Deere 640D skidder	81.18
System 2	
Modified John Deere 988 with Peninsula saw head and Valmet 524 forwarder	225.00
System 3	
Timbco 425 feller buncher, chainsaw limbing and topping, and Valmet 524 forwarder	259.17

Cut-to-length systems are expensive, highly productive, requires less personnel in the woods, are safer, and are becoming more popular in harvesting of Eastern hardwoods (LeDoux 2002, LeDoux and Huyler 2001). The CTL system used in this evaluation was a medium-sized modified John Deere 988 with a Peninsula design roller processing saw head and a Valmet 524 forwarder. This CTL system can work efficiently in large or small tracts in thinning and final harvest treatments. This system fells the tree, bucks it into product lengths and piles the sorted wood products into bundles. The piles/bundles are then loaded on the forwarder and transported to a central landing. The third system used was a mechanized feller buncher and forwarding system with chainsaw topping and limbing. Feller bunchers are expensive, highly productive, and safer than chainsaw felling (Bell 2002). The feller buncher cuts the trees at the stump and places them in piles that are later picked up by the forwarder for transport to the landing. A chainsaw is used to limb and top the trees. Feller buncher systems are becoming popular in harvesting applications of Eastern hardwoods (Long 2003). These logging technology configurations were selected because we have robust time and motion data for each, and because they represent contemporary methods being used by loggers to harvest Eastern hardwood stands. All of the above machines are capable of handling the size of logs coming from the thinnings and final harvested simulated. The hourly machine rates used in this study are shown in table 1, as calculated using methods by Miyata (1980). All costs are in 2005 U.S. dollars and reflect new equipment.

Model Used

MANAGE-PC (LeDoux 1986) integrates harvesting technology, silvicultural treatments, market prices, and economics continuously over the life of the stand. The simulation combines discrete and stochastic subroutines. Individual subroutines model harvesting activities, silvicultural treatments, growth and yield projections, market prices, and discounted present net worth (PNW) economic analysis. The model can be used to develop optimal management guidelines for eastern hardwoods. Using the stand data described earlier, MANAGE-PC was used to estimate optimal economic rotation length, volume/production yield estimates, and logging costs for each rotation age. The tree list for the stand and the above logging technology data were used as input to MANAGE-PC and the stand growth and development was projected in 5 year intervals until it reached its optimal economic rotation, that is, the maximization of discounted PNW. At each growth projection interval, the stand was logged, the value of the timber was determined, the stump-to-mill logging cost was computed, and the discounted present net worth was calculated. MANAGE-PC determined the optimal rotation age for the combination of stand and harvesting technology. The average delivered prices for saw logs and pulpwood were estimated from Forest Products Price Bulletins (Ohio Agricultural Statistics Service 2002, Pennsylvania State University 2003, Tennessee Division of Forestry 2003) (table 2).

The stand was thinned once with each logging technology at the earliest entry age that would result in a commercial operation and the residual stand was then projected to its optimal economic rotation. The thinning was an area-wide low thinning that removed all trees below an average diameter at breast height (dbh) of 8 inches to achieve residual stand basal area stocking levels of about 68 square feet per acre. The objective for each thinning treatment was to open up the stand and to accelerate residual tree growth in order to grow quality wood products for the final harvest. The wood harvested was sold as pulpwood and saw logs. The stand was thinned with each logging technology and the residual stands were then projected to their optimal economic rotation.

RESULTS

The simulated growth and yield and economic results are shown in table 3. Using a small, inexpensive skidder such as the John Deere 440C allows a commercial entry into the stand at age 70, optimal economic rotation of age 100, and cumulative PNW of $236.60 per acre. Larger skidders such as the John Deere 540B and 640D delay the commercial entry by 10 and 15 years, respectively, when compared to the smaller John Deere 440C. The 90 and 120 horsepower skidders have optimal economic rotations of 120 and 125 years with cumulative PNW of $159.48 and $136.93 per acre. Using a larger, more expensive 120 horsepower machine delays thinning entry timing by 15 years, extends optimal economic rotation length

Table 2—Delivered prices for saw logs and fuelwood/pulpwood by species

Species	Product			
	Large[a] high-quality saw logs	Medium[b] size and quality saw logs	Small[c] low-quality saw logs	Fuelwood[d]/pulpwood
Red maple	251	192	131	40
White oak	450	279	138	40
Red oak	561	397	225	40
Hickory	210	160	150	40

[a] Minimum small-end diameter ≥ 13 inches, length ≥ 10 feet.
[b] Minimum small-end diameter ≥ 11 inches, length ≥ 8 feet.
[c] Minimum small-end diameter ≥ 10 inches, length ≥ 8 feet.
[d] 89 cubic feet per cord, minimum small-end diameter ≥ 4.0 inches that will not make large, medium, or small saw logs.

Table 3—Simulated results by logging system

Logging system	Chainsaw felling, JD 440 skidding	Chainsaw felling, JD 540 skidding	Chainsaw felling, JD 640 skidding	Modified JD 988 CTL, Valmet 524 forwarder	Timbco 425 feller buncher, chainsaw topping/ delimbing, Valmet 524 forwarder
Thinning age (years)	70	80	85	100	60
Average d.b.h. (inches)	9.77	10.59	10.98	12.17	8.30
Trees cut per acre	141	131	126	113	151
Volume cut per acre (cubic feet)	1,807.58	2,024.14	2,098.35	2,336.26	1,318.77
Mill value ($ per acre)	806.84	951.58	1,001.14	1,240.31	592.71
Logging cost ($ per acre)	631.27	840.28	928.87	1,180.44	549.41
Present net worth[a] (PNW per acre,$)	54.13	23.18	12.37	5.69	19.76
Optimal economic rotation (ORA, years)	100	120	125	125	100
Average d.b.h. at ORA (inches)	12.91	15.39	15.83	15.74	13.43
Trees cut per acre at ORA	127	112	108	103	131
Volume cut per acre at ORA (cubic feet per acre)	3,064.62	3,976.05	4,130.97	3,850.20	3,486.56
Mill value at ORA ($ per acre)	2,409.16	4,195.72	4,516.86	4,332.59	3,156.16
Logging cost at ORA ($ per acre)	489.66	1,054.09	1,023.65	1,878.38	1,189.16
Present net worth at ORA[b] ($ per acre)	182.47	136.30	124.56	87.51	186.98
Cumulative PNW ($ per acre)	236.60	159.48	136.93	93.20	206.74

JD = John Deere; CTL = cut-to-length; PNW = present net worth; ORA = optimal rotation age.
[a] Real discount rate = 4 percent.
[b] Discounted to age 40.

by 25 years, and results in $99.67 per acre less PNW when compared to using a smaller, less expensive 70 horsepower machine. Substantial cumulative monetary returns are available to the landowner by careful selection and matching of skidder size to thinning entry timing.

Using an expensive highly mechanized system such as the CTL/forwarding results in a commercial thinning entry age of 100, an economic optimal rotation of 125 years, and a cumulative PNW of $93.20 per acre. Using CTL/forwarding delays thinning entry timing by 30 years; extends optimal economic rotation by 25 years, and results in $143.40 per acre less PNW than thinning with a 70 horsepower skidder. The reduction in cumulative PNW for the CTL/forwarding system is largely because although this system is very productive, the operating cost of such consumes most of the value of the wood leaving the landowners with less cumulative returns. For example, the commercial entry at age 100 returns a low PNW of $5.69 per acre because the operating cost is $1180.44 per acre, or 95.17 percent of the mill value ($1240.31 per acre) of the wood. Landowners must balance these tradeoffs in managing their woodlots.

The use of an expensive, highly productive feller buncher/chainsaw topping and delimbing/forwarder system results in a commercial thinning entry timing of age 60, optimal economic rotation of age 100, and a cumulative PNW of $203.74 per acre. The age 60 thinning is possible because the feller buncher/forwarding combination is very efficient when felling, piling, and forwarding smaller dbh trees. The feller buncher/forwarding system allows the earliest commercial thinning entry age of 60, optimal economic rotation comparable to using the 70 horsepower skidder, and $113.54 per acre more cumulative PNW return than using a CTL/forwarding system. The cumulative PNW return for the feller buncher system is only $29.86 per acre less than using the smaller John Deere 440C skidder.

CONSIDERATIONS FOR MANAGERS

Landowners can schedule commercial thinning entries into young stands as early as age 60 if they use mechanized feller-buncher/forwarding systems. The use of smaller, less expensive 70 horsepower skidders such as the John Deere 440C allow for commercial thinning entry as early as age 70. These early entries into a stand provide a positive cash flow to the landowner, make wood fiber available to markets earlier in the life of a stand, result in shorter optimal economic rotations, and provide the landowner with larger cumulative monetary returns (PNW). Using larger skidders or expensive mechanized CTL/forwarding systems can delay commercial thinning entry timing by as many as 30 years.

Landowners have some flexibility in scheduling thinnings and in determining optimal economic rotation age. For example, figure 2 shows the PNW revenue curves for the logging technologies simulated. Although the optimal economic rotation for the John Deere 440C and the feller-buncher/forwarding system is the same at 100 years, the cumulative financial yields are slightly improved by using the smaller skidder, but using the feller-buncher/forwarding system would allow scheduling commercial thinnings 10 years earlier than the small skidder. The optimal economic rotation for the CTL/forwarding system and the larger 120 horsepower John Deere 640D skidder is the same at 125 years. However, using the John Deere 640D allows the landowner to schedule a commercial thinning 15 years earlier than using the CTL system. The CTL system requires that the value of the stand be large enough to offset its high operating cost. This forces the landowner to wait until the stand is 100 years old before a commercial thinning can be scheduled. It is interesting to note that for late rotation harvests ≥ about 150 years, the choice of using all logging system technologies simulated will yield similar PNW results with the exception of the CTL/forwarding system.

We only evaluated one stand, three logging technologies, a fixed real interest rate of 4 percent, and fixed market prices with computer simulation. The results reported here are specific to the conditions simulated and to the models used and should not be generally inferred. However, the results suggest that landowners could schedule commercial thinnings earlier in the life of a stand and realize larger cumulative financial returns by careful selection/matching of logging technology to thinning entry timing and following optimal economic harvests.

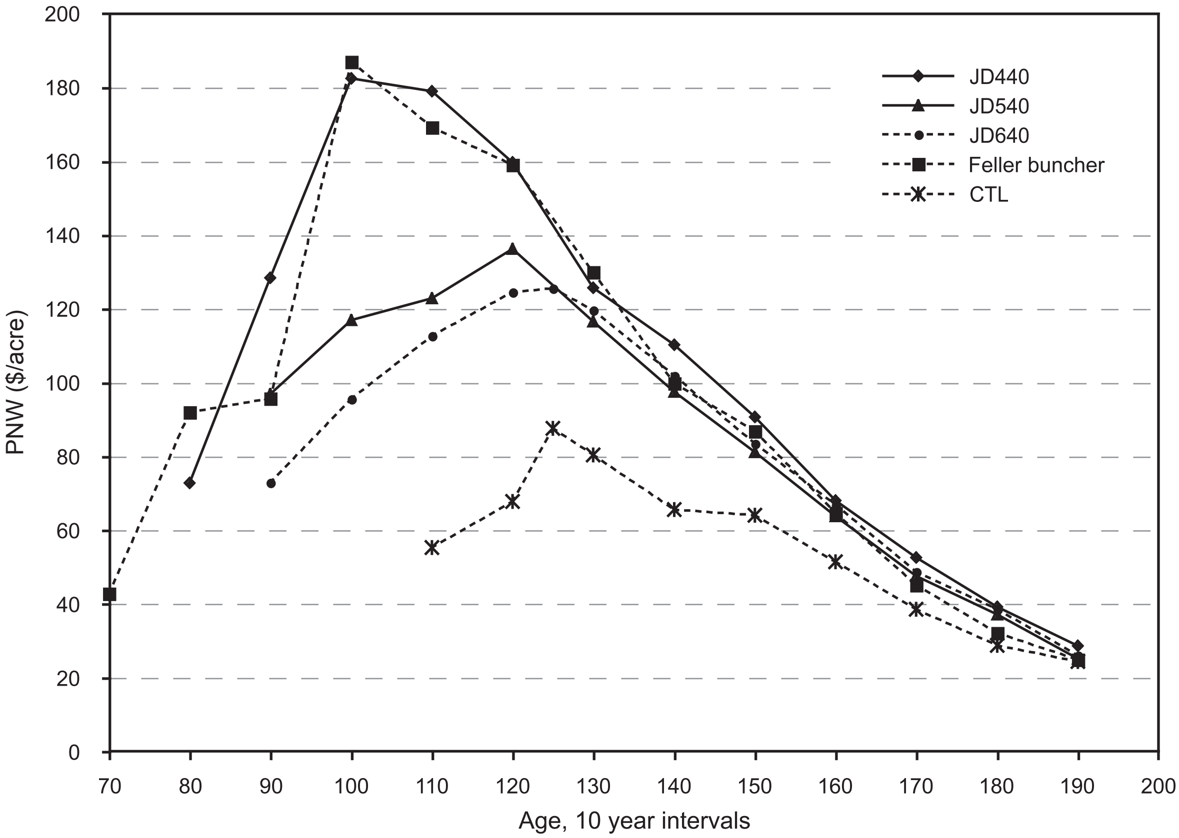

Figure 2—Present net worth (PNW) revenue curves for the oak-hickory stand by logging technology, real interest rate is 4 percent.

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NITROGEN DYNAMICS POST-HARVEST: THE ROLE OF WOODY RESIDUES

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Abstract—The role of woody residues in N dynamics in harvested forests has not been fully elucidated. Woody residues have been found to be an N sink, N source, and N neutral in different studies. To understand the implications of each of these scenarios, post-harvest N dynamics in high- and no- woody residue treatments were modeled for a Douglas-fir ecosystem. Nitrogen mineralization in the combined forest floor, soil (to 15 cm depth), and root pools was 122 and 121, kg N/ha/year, in years 1 and 2 after harvest, independent of treatment. When wood was an N sink, 23 kg N/ha/year could be immobilized annually, and about 80 and 100 percent of the N available from forest floor, soil, and roots remained plant or leaching available in high- and no- woody residue treatments, respectively. When wood was a source of N, an additional 12 kg N/ha/year became available from wood in high residue, and 0 in no residue treatment. When wood was neutral, 100 percent of the N mineralized after harvest was plant and/or leaching available in both treatments. Empirical evidence is still necessary to confirm which scenario operates in various forest ecosystems. Implications of these different scenarios for N-saturated ecosystems of the central Appalachians are that as N sink, woody residues could potentially help decrease N exports as nitrate. As N source, woody residues could contribute to N exports. As neutral, woody residues would allow exports of N as they currently occur. This paper reflects on the dynamics of N and woody residues in the Appalachian hardwood forests and provide hypothetical comparisons between these dynamics in western coniferous forests and eastern hardwood forests.

INTRODUCTION

The role of woody residues in N dynamics in forests is not clear. Some of the obstacles to elucidating this role are the length of time involved in wood decomposition and lack of methods for taking into account changes in wood shape and volume over time (Krankina and others 1999). Wood decomposes over such time frames that chronosequences of pieces of unknown age are the only possibility to examine long-term decomposition of large wood. Age is presumed to be related to stage of decay, and stage of decay is described based on morphological characteristics (Fogel and others 1973). Comparison across species and environments is challenging if not impossible, as different conditions give the same morphological results at different lengths of decay. As wood decays, its original shape changes due to tissue subsidence and loss. Therefore assuming a circular shape of wood regardless of its stage of decay is inaccurate (Krankina and others 1999), but is routinely done and used in calculations of nutrient contents (volume X element concentration). Therefore, woody residues can be an N sink or N source, depending on how volume was calculated (Creed and others 2004). While others are resolving these important and difficult issues, this study was undertaken to better understand the implications of two divergent scenarios for post-harvest N dynamics.

Post-harvest N dynamics is of particular interest because of high rate of N turnover in disturbed and exposed soils, which leads to the formation of nitrate. Nitrate is a mobile anion easily leached to lower soil profiles in the presence of water, and exported to water courses where it is a potentially harmful contaminant (Driscoll and others 2003). Such export in the Douglas-fir forests of the Pacific Northwest further decreases ecosystem levels of a nutrient limiting forest productivity. In the north-eastern and central hardwood forests, some of which exhibit N saturation, N export increases total nitrate outputs to water sources. Nitrogen saturation describes a condition in which ecosystem N demand is lower than available N, and N is routinely exported (Aber and others 1989, 1998; Stoddard 1994). Should woody residues be a sink for N, then leaving branches, tree stumps, and other unwanted wood on sites after forest harvesting may be low-cost yet effective means for lowering the rates of N export and protecting water quality.

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Alternatively, if woody residues after harvest increase N exports by serving as an additional N source, then it may be advantageous to remove them for use for example as biomass-based fuels. Therefore, greater understanding of the implications of woody residues' role in different ecosystems will stimulate research in the direction of uncovering the biogeochemistry of nutrient dynamics with and without woody residues.

To accomplish this task, post-harvest N dynamics were modeled in two ecosystems – a Douglas-fir and a central Appalachian hardwood forest. This paper reflects on the dynamics of N and woody residues, and provides hypothetical comparisons between these dynamics in two ecosystems with widely differing N levels.

METHODS

Data from an extensive post-harvest biomass study in Pacific County, Washington were used for model development. A 40-year-old fertilized Douglas-fir/ western hemlock plantation was harvested in 1999 by cable-logging. The high-residue treatment contained all branches left after bole-only removal. The no-residue treatment contained almost no branches due to operational and manual removal. All residues were sampled including forest floor, buried slash, roots to 30 cm depth, and aboveground slash and large debris where present, and dry-weights and their nutrient concentrations were obtained (Piatek and Terry, unpublished).

The potential net N mineralization was estimated for the forest floor plus top 15 cm of soil (combined) using the equations developed by Yin (1992) for a range of forests growing along an environmental gradient from Massachusetts to Washington. The N processes in these equations are driven by average January and July air temperatures, and N content and mean extractable N of litter and soil. Because data on litterfall N was not available, we estimated this further by averaging the higher of the two Douglas-fir litterfall N values used to develop the model and the total N amount in our forest floor divided by 5 years (assumed length of time that litter had collected on the ground without complete decomposition). Nitrogen mineralization from roots was estimated by using percent N release in field- incubated fine roots of Douglas-fir as reported by Chen and others (2002).

Wood N dynamics for Douglas-fir residues from current harvest (older, mostly decayed woody residues were also present) were estimated according to the two possible and divergent scenarios. First, changes in wood mass from decay stage 1 to decay stage 2 were calculated from a known starting mass of fresh stumps and logging residues (75.2 t/ha; Piatek and Terry, unpublished data) by using an average annual decomposition constant for wood density (0.038; Edmonds and Eglitis 1989) applied for 2 years. Carbon content was estimated by multiplying mass by known C concentration (0.49; Piatek and Terry, unpublished data). The ratio of woody residue C, as calculated after 2 years of decomposition, to the original gave the percent C loss due to respiration alone. Second, to better understand woody residue N dynamics under the scenario of wood being a sink for N, N content was increased to 180 percent 2 years after harvest as described by Edmonds and others (1986), and annual N immobilization rate was calculated as the difference between "final" (after 2 years) and original N content divided by 2. Nitrogen concentration after 2 years was calculated by dividing N content by mass, and percent change by comparing to the original. To estimate possible N dynamics under the scenario of wood acting as N source, N content after 2 years was hypothetically lowered by 10 percent from the original, and N concentration and percent change was calculated as for N immobilization above.

A similar process was followed for a hypothetical Appalachian hardwood stand, using published data. Mass of logging residue used was 10 ton/ha, as reported for large residues only (Grushecky and others 1997). Carbon content was estimated by multiplying mass by 0.49 percent C (as for Douglas-fir). Nitrogen content was estimated by multiplying mass by 0.002 percent N, a value measured in Tucker County, WV 85-year-old hardwood forest (Adams and others 2004). A decomposition constant for yellow birch at 0.217 per year was used to estimate mass loss for 2 years (Creed and others 2004). Using the same procedure as above, N immobilization and "release" rates were obtained.

RESULTS AND DISCUSSION

Post-Harvest Potential N Mineralization Rates

Estimated potential net N mineralization rates from the forest floor, soil to 15 cm depth, and roots at the Douglas-fir site was 122 kg/ha in year 1 and 121 kg/ha in year 2 after harvest. There were no treatment differences, and that was most likely the result of using equations based on air rather than soil temperatures. Microbial processes, such as N mineralization, are driven by soil temperature among other factors, and soil temperatures are expected to be higher in the exposed soils of the no-residue compared to the high-residue treatment; therefore, it is highly likely that N mineralization rates in the no-residue treatment were higher during some parts of the year when soil moisture was not limiting.

Hardwood forests generally have higher rates of N turnover than coniferous forests due to the generally higher N content of leaf as compared to needle litter (Piatek and Allen 2001). Therefore Appalachian hardwood forests, especially under high surface soil temperatures of post-harvest sites, may mineralize at very high rates. In an N-saturated forest of central Appalachia these rates were estimated to be 374 kg N/ha/year (Adams and others 2004).

Post-Harvest Woody Residue Mass, and C and N Content

The Douglas-fir high residue treatment contained 75 tons/ha of fresh woody residues with 36 tons/ha of C, and 230 kg/ha of N with an average N concentration of 0.31 percent (Piatek and Terry, unpublished data). The no-residue treatment had none. After 2 years of decomposition, an estimated 71 tons/ha of wood and 35.5 tons/ha of C were still present in the high residue treatment.

When Douglas-fir wood acted as an N sink, an increase of 180 percent in N content over 2 years resulted in an estimated 92 kg/ha/year of N immobilization (table 1). However, this would only be possible if all woody residues were in direct contact with soil, as they were in the study that reported such an increase (Edmonds and others 1986). The soil is the main source of microbial inoculum for N immobilization

Table 1—Estimated N dynamics post-harvest based on 2 years of mass loss in Douglas-fir and Appalachian hardwood forests [a]

Scenario	Residue mass	C	N	N dynamics	N	Change in percent N
	- - - - - - - - - t/ha	*- - - - - - - - -*		*t/ha/yr*	*percent*	
Douglas-fir post-harvest conditions	75.2	36.9	0.23		0.31	
Wood = N sink	70.8		0.42	0.023[b]	0.59	89
Wood = N source	70.8		0.21	-0.012	0.29	(-) 6
Hardwood forest post-harvest conditions	10.0	4.9	0.02		0.2	
Wood = N sink	6.5		0.036	0.008	0.56	178
Wood = N source	6.5		0.018	-0.001	0.28	39

Wood = N sink represents N dynamics if N mass after 2 years increased 180 percent; Wood = N source represents N dynamics if N mass after 2 years were to decrease by 10 percent.

[a] Post-harvest conditions reflect conditions prior to decomposition.

[b] Estimated N dynamics for all wood in contact with soil was 0.092 t/ha/yr. Here, 25 percent is assumed in contact with soil where immobilization is possible.

in the Pacific Northwest forests as N inputs from atmospheric deposition are minor (Personal communication. 2000. Robert L. Edmonds, Professor, Department of Forest Resources, University of Washington, Seattle, WA 98195-2100). However, large-scale harvesting operations leave large amounts of woody residues that are intertwined with each other in a way that raises pieces at odd angles and often prevents them from lying flat against the soil surface. Woody pieces suspended above ground are assumed to be inert with respect to short-term N dynamics, and 25 percent of all residues present were taken to be in contact with the ground and capable of immobilization. Therefore, the rate of immobilization was adjusted to ¼ of the original estimate to 23 kg/ha/year (table 1).

Using the same procedures as for Douglas-fir, immobilization into hardwood woody residues was estimated at 8 kg N/ha/year. This rate was not further adjusted because the total amount of wood reported after harvest was only 13 percent of the total load of Douglas-fir residues, and individual pieces in a smaller load have greater chances for contact with the soil surface.

When residues acted as an N source, Douglas-fir residues released an estimated 12 kg N/ha/year, while hardwood released 1 kg N/ha/year.

N Immobilization or Release?

With a 90 percent increase in N concentration (a 180 percent increase in N content and including C loss due to respiration), 75 tons/ha of fresh woody residues in a post-harvest Douglas-fir site could potentially immobilize 20 percent of N available from the mineralization in the forest floor, soil, roots, and from atmospheric inputs. Therefore, in the absence of plant uptake, annually 80 percent of the available N could still leach through the soil and be eventually exported from site. By comparison, 10 tons/ha of woody residues in a clearcut in the Appalachian hardwood forest could immobilize only 2 percent of that site's estimated available N, with 98 percent potentially leaching without plant uptake.

When woody residue N dynamics were tested under the source scenario, the Douglas-fir residues contributed an additional 12 kg N/ha/year or almost 10 percent to the mineralization rates from the forest floor-soil-root complex in those treatments where residues were retained. In the no-residue treatments, no additional N would be present. In the Appalachian hardwoods, 1 kg N/ha/year would be added, a trivial proportion of the site's potential net N mineralization.

The large differences between these two sites in the capacity of woody residues to either immobilize or release N are due primarily to the different masses of residues which determined original N content used in these calculations, to wood N concentrations, and potential N mineralization rates from the forest floor-soil-root complex. Also, data accessed and used here for the Appalachian hardwood forest were not as exhaustive and site-specific as for the Douglas-fir forest.

While it may seem unconventional to compare different masses of woody residues, these conditions reflect some of the reality of each ecosystem in terms of growth rates for the species and sites, tree age and size at harvesting, harvesting systems, and wood utilization levels. Representing realistic conditions, given the limitations of data sources, was an objective of this work. At the same time, mass of hardwood residues used in this work included only coarse woody debris of 10 cm and above (Grushecky and others 1997), while the Douglas-fir data included all residues to 0.5 cm in diameter (Piatek and Terry, unpublished data). If mass of hardwood residues was hypothetically set to the same as in the Douglas-fir system (75 ton/ha) and all other parameters remained as in the previous hardwood calculation, then woody residues in the Appalachian hardwoods would be a source of 13 to 16 kg N/ha/year, and immobilization would not be possible.

While the residues' sink activity appeared higher than the source activity for both ecosystems in this modeling exercise, it is important to remember that the sink was estimated based on field data, while the source was somewhat arbitrarily set at 10 percent N release 2 years after harvest. A larger percent release than the one used would increase N release levels from woody residues, but N release would continue to lag behind potential immobilization levels over the same time period due to the smaller N pool for release (original wood N) than for immobilization into wood (the environment).

Woody residues in harvested Douglas-fir forests seem to have a potential capacity to contribute to N dynamics as a sink or a source of N, while woody residues in hardwood forests do not. Given that the Appalachian hardwood forests exhibit some of the highest mineralization rates reported for forested ecosystems, the estimated rates of either mineralization or immobilization by woody residues will not make a significant difference in the overall available N budget, even if residue loads were to increase 7-fold. Only lower rates of N mineralization could increase the relative importance of woody residues' role as an N sink or source.

It has been previously concluded from a review of nutrient dynamics for a range of coniferous forests that woody debris in standing forests plays a minor role in nutrient dynamics (Laiho and Prescott 2004). Estimates for Appalachian forests seem to support these conclusions and expand them into the N-saturated hardwood zone. In the Douglas-fir forests, however, woody residues after harvest appear to be potentially capable of immobilizing about 20 percent of the available N pool, or contribute additional 10 percent, depending on which model is operating. Therefore, for those forests, it will be beneficial to examine in greater detail the biogeochemistry of nutrients in post-harvest woody residues.

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BIOMASS REMOVAL AND ITS EFFECT ON PRODUCTIVITY OF AN ARTIFICIALLY REGENERATED FOREST STAND IN THE MISSOURI OZARKS

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Abstract—Intensive harvesting, which removes a greater proportion of the forest biomass than conventional harvesting and the associated nutrients, may cause a decline in forest productivity. Planted seedling response to three biomass removal levels (1. removal of boles only=OM1, 2. all surface organic matter removed, forest floor not removed=OM2, and 3. removal of all surface vegetation plus forest floor = OM3) was examined in one of the Forest Service Long-Term Soil Productivity (LTSP) research studies located in the Missouri Ozarks. Before harvesting, the study area contained a mature upland oak-hickory (*Quercus*-*Carya* spp.) forest with some oak-pine (*Quercus* spp.-*Pinus echinata* Mill.) communities. Soil nutrient concentrations at one year and eight years later were compared with soil nutrient concentrations in uncut control plots. Survival of red oak, white oak, and shortleaf pine seedlings increased with increasing levels of surface organic matter removal. Mean height for red and white oaks was significantly ($p \leq 0.05$) greater for OM1 and OM2 plots than for OM3 plots. Mean diameter at breast height (dbh) was significantly less for OM1 plots than for OM3 plots. Mean height for shortleaf pine was not significantly affected by biomass removal treatments but dbh was. Overall, measurements of tree growth after nine growing seasons and soil and leaf chemistry indicated that site productivity has not been impaired by the removal of surface organic matter.

INTRODUCTION

Forested ecosystems contain large amounts of nutrients in woody biomass that may exist either as standing material, on the soil surface, or within the soil profile. Logs removed during timber harvesting removes considerable amounts of nutrients and the disturbance caused by the process may sometime later, if not immediately, affect the amount of nutrients left on the site due to increased soil erosion, mineralization, and leaching (Alban and others 1978, Boyle and others 1973, Hornbeck and Kropelin 1982).

Wells and Jorgensen (1979) concluded that because soil nutrient supply and productivity in forests change relatively slowly, biomass-harvesting practices could be selected from rotation to rotation without serious risk of decline in soil productivity. Increasing the amount of biomass removal reduces the quantity of organic residue that would ordinarily be subjected to decomposition and nutrient release. If forest floor temperature and moisture are increased by biomass removals, there could be a nutrient flush from accelerated forest floor decomposition.

Most attempts to predict the effects of organic matter removal on long-term forest productivity have been severely limited by lack of information. An alternative to prediction is to wait 40 to 100 years for the outcome after installing such studies (Wells and Jorgensen 1979). In this paper, data is presented on planted red oak (*Quercus rubra* L.), white oak (*Q. alba* L.) and shortleaf pine (P*inus echinata* Mill.) after nine growing season, which were planted in plots with different levels of surface organic matter removal. The objective of the study was to determine the effect of three levels of surface organic matter removal on the productivity of the site. The study is part of a network of studies in the USDA Forest Service's Long-Term Soil Productivity (LTSP) program that is based on the following rationale (Powers and others 1990):

- Management practices create soil disturbances
- Soil disturbances affect soil and site processes
- Soil and site processes control site productivity

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The research focuses on the impact of soil compaction and organic matter removal on the growth, development, and long-term soil productivity (LTSP) of forested lands in the United States and similar studies established in parts of Canada. Installations are designed to be maintained for at least one rotation.

MATERIALS AND METHODS

Site Description

The site for this study is located in the Carr Creek State Forest in Shannon County, Missouri. The silt loam soils on the site are primarily of the Clarksville series (Loamy-skeletal, mixed mesic Typic Paledults). Initial soil chemical properties of the 0-30 cm depth were: pH (1:1 water) 5.7; total C, 3.3 percent; total N, 0.11 percent; P, 16.9 mg/kg; Ca, 789 mg/kg; and Mg, 61 mg/kg (Ponder and others 2000). Prior to harvest, the site had a well-stocked, mature, second-growth oak (*Quercus* spp.) -hickory (*Carya* spp.) forest with a site index for 50-year-old black oak (*Q. velutina* Lam.) that ranges from 22.5 to 24.3 m (Hahn 1991). Mean annual precipitation and temperature is 112 cm and 13.3º C, respectively (Barnton 1993).

Experimental Design

The LTSP study includes nine treatments derived from combinations of three levels each of organic matter removal and soil compaction. The three levels of organic matter removal included: (1) merchantable tree boles removed, crowns retained, felled understory, and forest floor not removed (OM1), (2) all aboveground living vegetation removed, forest floor retained (OM2), and (3) all surface organic matter removed, exposing mineral soil (OM3). Merchantable boles included trees with diameters at breast height (dbh) of 25 cm or larger. Total biomass dry weight was calculated for individual trees, then plotted against dbh for each tree species, and biomass at each 5-cm diameter class was extrapolated from an eye-fitted curve. Combined with the number of trees per acre, total dry weight of the overstory (> 4 cm) was estimated. Allometric regression equations in the literature in the form Y = a(DBH)**B were developed and compared to these estimates; for white oak and hickory (Clark and others 1985), for black, scarlet, and white oak and hickory (Wiant and others 1977), and black oak (King and Schnell 1972). The three levels of compaction included: (1) no compaction (C1), (2) moderate compaction (C2), and (3) severe compaction (C3). Soil compaction was accomplished by using heavy road construction equipment (Ponder and Mikkelson 1995). Mean bulk density increased to 1.8 g cm^3 compared to 1.3 g cm^3 for the noncompacted treatment. The 3 x 3 factorial arrangement of treatments was replicated 3 times. Three uncut control plots, which were similar in stand history, species composition, and topography to harvested plots, were established as reference plots. Prior to tree harvesting and treatment installation, pre-harvest inventories of the overstory, understory, herbaceous layer, and dead and downed woody material plus biomass and soil sampling were completed. Following treatment installation, 1-0 seedlings of red oak, white oak, and shortleaf pine were planted in rows at a spacing of 3.66 m apart in and between rows at a ratio of 3 oaks of each oak species to one shortleaf pine. A complete description of the site and the LTSP installation are provided elsewhere (Ponder and Mikkelson 1995).

For this report, only the three levels of organic matter removal without compaction and the uncut control plots were used to compare soil nutrient changes and other measurements. For the first 2 years after planting, a 3-foot radius area around seedlings was sprayed annually in the spring with a mixture of glyphosate and simazine to control weeds. Growth responses to weed control are not part of this report.

Seedling survival, height, and diameter were measured after planting and annually thereafter. Diameter at 2.54 cm above the soil surface and diameter at breast height (dbh), when trees reached 1.4 m tall or taller, were measured. Red oak, white oak, current-year shortleaf pine leaves were collected in August of year 8 for nutrient analyses. Soil samples were collected at 10 cm increments from 0 to 30 cm deep both at pre-inventory and during the ninth growing season. To reduce cost for sampling and analyses, only leaves from the OM1 and OM3 treatments and soil from the OM1 and OM3 treatments plus uncut controls were sampled. For soil, data for all depths were combined for each plot, analyzed, and results presented as relative differences between treatments after one year and during the ninth growing season. Leaf samples for each plot were kept separate and analyzed.

Statistical Analyses

The experiment was analyzed as a randomized complete block design. Survival was analyzed using the PROC LIFETEST procedure (Allison 1995). Growth and leaf nutrient data were analyzed using analysis of variance with the PROC GLM procedures in SAS Version 8.2 (SAS Institute, Cary, NC). All statistical tests were performed at the $\alpha = 0.05$ level of significance.

RESULTS AND DISCUSSION

Surface Organic Matter

Boles (OM1) made up approximately 37 percent of the organic matter removed in the OM3 treatment (table 1). Removing all living vegetation (OM2) increased organic matter removal by another 40 percent over removing only merchantable boles (OM1). Removing all living vegetation plus the forest floor (OM3) increased organic removal over OM2 by 23 percent. Considerably lesser amounts of nutrients were removed in the OM1 treatment than in OM2 and OM3 treatments (table 1). Removing boles and crowns more than doubled the amount of nutrients removed from the site, and for some nutrients, such as Ca and Al, the OM2 treatment was three times the OM1 treatment. The amount of Al removed in the OM3 treatment was 10 times higher than in the OM2 treatment. These results indicate that tree branches account for large amounts of the nutrients in a tree. In a study similar to this study, mixed conifers (*P. ponderosa, P. lambertianaover, Abies concolor, Pseudotsuga menziesii,* and *Sequoiadendron giganteum*, boles accounted 80 percent of the above ground organic matter but less than half of the N present above ground biomass (Powers and Fiddler 1997).

Table 1—Estimated biomass and nutrients removed in organic matter removal treatments

	Treatment		
Variable	OM1	OM2	OM3
	- - - - - - - - - - *Mg/ha* - - - - - - - - - -		
Biomass			
Biomass removed	85	176	228
	- - - - - - - - - - - *kg/ha* - - - - - - - - - - -		
Nutrients removed			
Nitrogen	195	540	811
Phosphorus	7	26	48
Potassium	109	256	285
Calcium	774	2303	2819
Magnesium	20	53	81
Manganese	7	18	49
Iron	1	3	18
Zinc	0.5	2	3
Aluminum	2	8	81
Sodium	0.5	1	2
Copper	0.1	0.3	0.6
Boron	0.4	1	1.5

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor.
Values are the mean for 18 trees.

The impact of organic matter removal on major soil chemical properties during the first nine years is presented in table 2 as relative differences between chemical properties of the soil in OM1 and OM3 treatments and the uncut control treatment. Differences between treated plots and uncut control plots show few nutrient declines. Only K and Mg were less for treatments in 2002 than in 1995, nine years after treatment application. The percent soil carbon did not change. Data from seven Coastal plain sites indicated that organic matter removal had negligible impact on the concentration of soil C after 10 years (Powers and others 2004).

Although treating the plots removed large amounts of nutrients, considerable amounts of nutrients remained in the soil. It was estimated that 8,436 kg N/ha remained in the soil on this site following the most severe organic matter removal treatment (OM3). This amount is within the range of 7,561 to 23,286 kg N/ha reported for two other central hardwood sites with site indexes similar to the site index for the present study site (Kaczmarek and others 1995). Soil nitrogen pools on such sites can be large and variable. Nitrogen as well as other soil nutrients released from organic matter on the forest floor in the Missouri Ozarks may be cycled at a very slow rate in midsummer because decomposition is often limited by moisture during that time of the year (Meentenmeyer 1978, White and others 1988). Also contributing to the pool of nutrients that remains after harvesting or organic matter removal is the root biomass which has been estimated to be almost proportional to aboveground biomass (Harris and others 1977). Further, it has been estimated that precipitation, including dustfall, annually adds 7.9, 0.1, 4.0, 5.6, and 0.8 kg/ha of N, P, K, Ca, and Mg, respectively, to the landscape (Foster 1974).

Tree Survival, Height, and Growth

Survival for all seedlings declined with age but increased with increasing organic matter removal (table 3). After nine growing seasons, survival for red oak and white oak was 81, 86, and 94 percent and 79, 82 and 88 percent, respectively, for OM1, OM2, and OM3 treatments. For shortleaf pine, survival ranged from a low of 51 percent for the OM1 treatment to a high of nearly 60 percent for both OM2 and OM3. The better survival associate with increasing organic matter removal may be due to fewer mice and rabbits during the first few years of the study because of less cover for protection and forage in OM2 and OM3

Table 2—Relative differences in some soil chemical properties between treatments at the initiation (1995) of the study and during the ninth growing season (2002)

	Treatment difference from uncut control[a]			
	1995		2002	
Chemical property	OM1	OM3	OM1	OM3
pH	+0.3	+0.3	+0.1	0
Carbon (percent)	+0.9	+0.2	+0.8	+0.2
Nitrogen (percent)	+0.03	+0.03	—[b]	—[b]
Phosphorus (kg/mg)	+4.5	+8.9	+9.2	+2.6
Potassium (kg/mg)	+12.0	+10.6	-72.0	-21.9
Calcium (kg/mg)	+342.5	+363.2	+759.0	+270.0
Magnesium (kg/mg)	+10.6	+18.1	-33.7	-14.3

OM1 = removal of boles only; OM3 = removal of all surface vegetation plus forest floor.

[a] Uncut control plots are three plots that are adjacent to treated plots where soils and timber stand conditions are similar to treated plots before treated plots were harvested. Positive values are higher than values for uncut control and negative values are less than values for uncut control.

[b] Data not available.

Table 3—Percent survival of planted 1-0 red oak, white oak, and shortleaf pine after the second, fifth, and ninth growing season in three organic matter removal treatments

	Treatment		
Year	OM1	OM2	OM3
	- - - - - - - - - - - *percent*[a] - - - - - - - - - - -		
Red oak			
2	83a	89b	97c
5	81a	88b	95b
9	81a	86a	94b
White oak			
2	83a	88ab	93b
5	81a	86ab	92b
9	79a	82a	88b
Shortleaf pine			
2	62a	67b	70b
5	61a	62a	68b
9	51a	60b	61b

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor.

Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).

[a] Percent = number of live trees ÷ number of trees planted x 100.

treatments. Shoot damage, which is typically associated with these predators, was more apparent in OM1 plots. Plastic tree protectors were installed around seedlings soon after planting, but apparently not before a disproportioned number of seedlings in OM1 plots were killed. Also, part of the better survival of trees in OM3 plots may be associated with reduced vegetative competition created early on by forest floor removal that generated better root growth and water and nutrient uptake (Grossnickle and Heikurinen 1989).

Mean height of red oak and white oak declined with increasing organic matter removal level (table 4). After nine growing seasons, red oaks were 40 cm or more taller than white oaks for all treatments. Mean annual growth rates for oaks were similar (fig. 1). The decline in mean annual height growth increment for oaks that occurred in 1998 and in 2000, except for the OM2 treatment for red oak, did not occurred for shortleaf pine. The cause for the decline is not known, but may be related to precipitation. Rainfall data for 1999 and 2000 was 42 and 46 percent lower than from April through August. However, rainfall varied from 0.9 cm during April 2000 to 17 cm during June 2000. We speculate that the three species reacted differently to changes in precipitation, with shortleaf pine less tolerant of spring drought.

The dbh of red and white oaks also decreased with increased levels of organic matter removal (table 4). For red oak, trees in OM2 and OM3 treatments had significantly smaller dbh than trees in the OM1 treatment while white oaks trees with the smallest dbh were in the OM3 treatment. Shortleaf had the smallest mean dbh in the OM1 and OM3 treatments and the largest in the OM2, indicating they performed best in with an intermediate level of organic matter removal.

Table 4—Mean height and diameter at breast height of red oak, white oak, and shortleaf pine after the ninth growing season in three organic matter removal treatments

	Treatment		
Species	OM1	OM2	OM3
	- - - - - - - - *cm* - - - - - - - -		
Height			
Red oak	300.7 (115) a	291.8 (118) a	274.7 (117) b
White oak	256.9 (93) a	246.1 (97) a	233.1 (99) b
Shortleaf pine	470.5 (117) a	474.0 (101) a	455.1 (150) a
	- - - - - - - - *mm* - - - - - - - -		
Diameter (d.b.h.)			
Red oak	26.5 (20) a	24.6 (15) ab	22.4 (15) b
White oak	23.6 (17) a	23.3 (14) a	20.9 (14) b
Shortleaf pine	75.2 (37) a	88.3 (31) b	80.9 (31) ab

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor; d.b.h. = diameter at breast height.
Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).
Numbers in parentheses are standard deviations.

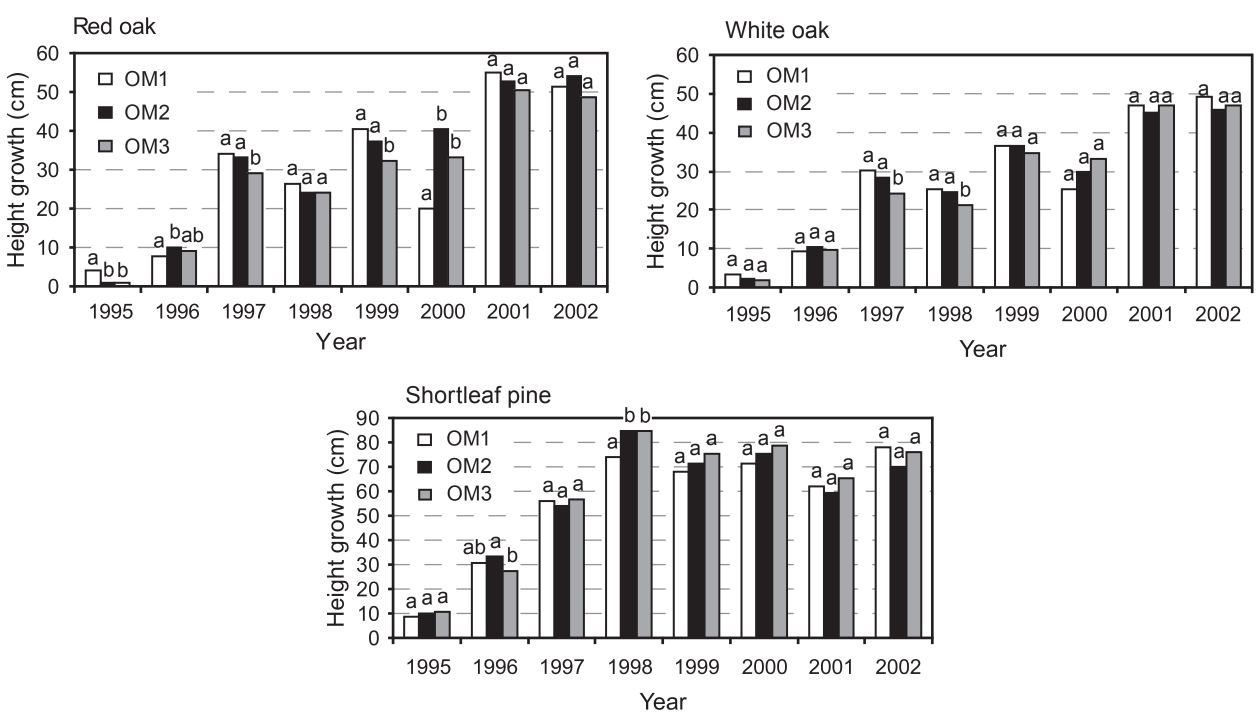

Figure 1—Annual height growth of planted red oak, white oak, and shortleaf pine on plots treated with three levels of organic matter removal including OM1 = all merchantable tree boles removed, OM2 = all aboveground vegetation removed except forest floor, and OM3 = all aboveground vegetation removed plus forest floor exposing mineral soil. Means with the same letters within a year are not significantly different based on Tukey's test at the p<0.05 level.

Much of the reason for species responding differently to organic matter removal levels is likely due to inherent differences in species. Responses by oaks and shortleaf pine in table 4 cannot be explained by leaf nutrient concentrations for 2001 (table 5). Except for differences in P and Mn concentrations for red oak between OM1 and OM3 treatments, differences between treatments for leaf nutrient concentrations were not significant. Neither leaf nutrient concentrations nor relative differences in soil chemical properties (table 2) indicate a decline in site productivity; although, growth of oaks would suggest there was. The overall mean height and dbh measurements after 9 growing seasons shown in table 4 indicate differences between organic matter removal treatments; however, the analysis of variance for the annual growth data graphically shown in figure 1 revealed that except for red oak in 2000, treatment differences for red and white oak growth were not significant after 1999 and were significant for shortleaf pine only in 1996 and 1998. Thus, mean differences in height and diameter after 9 growing seasons can be attributed to growth differences established by trees in the earlier years.

Recently, Powers and others (2004) showed that removing all surface organic matter prior to planting had no general impact on total vegetative production (standing trees plus understory vegetation) at 10 years for two species of conifers. These authors, with caution, also reported that the linear trend developed by the regression suggests that removing surface organic matter reduces productivity more on poorer sites than on better sites. The Missouri Ozarks is among the poorer sites in the Central Hardwood region for the tree species in this study; primarily because occasional summer droughts occur and soils are often cherty and/or shallow plus low in fertility. Despite being unable to compare the productivity of study trees on more productive sites, apparently, even on this site, any detrimental effect that might have existed earlier has disappeared. However, these are early results and caution must be exercised in making conclusions about a study that is planned to continue for 80 to 100 years. In the present study, tree growth rather than total vegetation was measured in response to organic matter removal. Total vegetation production better reflects site potential than just trees growth alone, particularly were tree stocking has not yet reached site carrying capacity.

CONCLUSIONS

Nine growing seasons are a short time period in the life of a forest stand. Results indicated that significant growth differences attributed to organic matter removal treatments were accomplished early in the life of the trees and these differences have been maintained through 9 growing seasons. Hence, later annual growth differences were not significantly different between treatments. Measurements of tree growth and soil and leaf chemistry indicate that site productivity has not been noticeably impaired by the removal of surface organic matter. The greatest impact of treatments on vegetation production can not be fully evaluated until crown closure. Although, the lack of site impairment due to organic matter removal agree with findings reported earlier for another group of LTSP studies (Powers and others 2004), results can not be generalized over the range of sites where other LTSP installations exist because of differences in climate, soils, and tree species. Generalized conclusions may not be possible until data from most of the more than 100 LTSP installations are analyzed.

Table 5—Leaf nutrient concentrations for red oak, white oak, and shortleaf pine during the eighth growing season in the low and high organic matter removal treatments

	Treatment					
	Red oak		White oak		Shortleaf pine	
Nutrient	OM1	OM3	OM1	OM3	OM1	OM3
	- - - - - - - - - - - -	- - - - - -	g/kg	- - - - - -	- - - - - -	- - - - - -
Nitrogen	20.8a	21.5a	19.1a	18.9a	15.0a	14.8a
Phosphorus	1.1a	1.3b	1.0a	1.1a	1.1a	1.1a
Potassium	6.3a	6.2a	5.7a	5.9a	5.3a	5.8a
Calcium	8.9a	8.2a	9.7a	10.0a	2.0a	1.9a
Magnesium	1.9a	1.9a	1.5a	1.3a	0.8a	0.9a
Sulfur	1.2a	1.2a	1.2a	1.2a	0.9a	0.8a
	- - - - - - - - - - - -	- - - - - -	mg/kg	- - - - - -	- - - - - -	- - - - - -
Sodium	37.5a	37.6a	36.7a	33.9a	36.3a	34.8a
Iron	93.2a	87.2a	65.6a	75.4a	68.5a	48.0a
Manganese	1200.3a	962.5b	742.5a	804.9a	305.3a	369.5a
Zinc	35.0a	35.1a	16.7a	16.6a	42.2a	39.9a
Copper	6.3a	6.5a	6.7a	6.6a	5.4a	5.3a
Boron	35.7a	32.6a	47.2a	47.3a	13.9a	14.3a

OM1 = removal of boles only; OM3 = removal of all surface vegetation plus forest floor.
Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).
Each value is the mean of nine samples.

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ATTRIBUTES OF DOWN WOODY MATERIALS IN HARDWOOD FORESTS OF THE EASTERN UNITED STATES

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Abstract—The Forest Inventory and Analysis Program (FIA) of the USDA Forest Service conducts a national inventory of down woody materials (DWM) on forestland in the United States. Estimates of DWM for inventory plots occurring in eastern U.S. hardwood forests facilitate large-scale assessment of hardwood forest fuel loadings and wildlife habitat. Therefore, the objectives of this study were (1) to quantify fuel loadings by National Fire Danger Rating System (NFDRS) hour-class for common hardwood forest types of the eastern U.S., (2) to quantify coarse woody debris (CWD) size distributions for common hardwood forest types of the eastern U.S., (3) and to compare the means of CWD and fine woody debris (FWD) by classes of stand live-tree basal area and stand age for hardwood forests of the eastern U.S. using currently available data from FIA. Results indicate appreciable amounts of forest fuels in eastern hardwood forests, particularly in pure and mixed species forests with oak components. Furthermore, size-class distributions of coarse woody pieces indicate a dearth of large-sized coarse woody debris in eastern hardwood forests. Overall, a large-scale assessment of down woody attributes in hardwood forests of the eastern U.S. contributes to understanding this resource's role in the management of fuels and wildlife habitat of the United States.

INTRODUCTION

Down Woody Materials (DWM) are dead organic materials that accumulate in forests as a result of plant mortality and leaf turnover (Woodall and Williams 2005). The Forest Inventory and Analysis Program (FIA) of the USDA Forest Service conducts a national inventory of down woody materials (DWM) on forest land in the United States. FIA inventories numerous DWM components including fine woody debris, coarse woody debris, litter, duff, slash, live/dead shrubs, and live/dead herbs. Fine woody debris (FWD) are small pieces of woody material typically made up of fallen twigs, branches, and upper tree boles. Coarse woody debris (CWD) is often defined as large pieces of woody material that meet minimum size and decay requirements. Coarse and fine woody debris are often the central focus of forest ecosystem analyses because they serve as important indicators of fire hazards, carbon stocks, and wildlife habitat.

The size specifications of fine and coarse woody debris sampled by the FIA program were selected to match the components defined by the National Fire Danger Rating System (NFDRS). This system divides fine and coarse woody debris into size classes that are equivalent to the fuel-hour class system (1-hour, 10-hour, and 100-hour) used by many fire scientists (Deeming and others 1977). In terms of wildlife habitat, coarse woody debris serves as critical habitat for numerous flora and fauna. CWD provides a diversity (stages of decay, size classes, and species) of habitat for fauna ranging from large mammals to invertebrates (Maser and others 1979, Harmon and others 1986, Bull and others 1997, Carey and Harrington 2001, Moseley and others 2004). Flora utilize the microclimate of moisture, shade, and nutrients provided by CWD for regeneration establishment (Harmon and others 1986, Nordén and others 2004). Because of CWD's importance with regard to biodiversity, nutrient cycling, carbon stocks, and fire risk, wood debris is a leading concern for managed forest ecosystems.

Although coarse and fine woody debris serve as an important indicator of numerous forest ecosystem functions, they have been infrequently investigated in hardwood forests of the eastern U.S. Chojnacky and others (2004) presented the most recent efforts to estimate DWM in forests of the east. However, most

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other previous studies have been at smaller spatial scales and/or were directed at more specific forest types or individual wildlife species (for examples see Ulyshen and others 2004, Pyle and Brown 1999, Rubino and McCarthy 2003, Idol and others 2001, McCarthy and Bailey 1994). Therefore, although numerous studies have contributed information regarding DWM, there is a lack of DWM information at scales exceeding individual states and/or single hardwood forest types.

Given the lack of widespread information regarding the down woody resources in hardwood forests of the eastern United States, our objectives were threefold:

1. To quantify fuel loadings by NFDRS hour-class for common hardwood forest types of the eastern U.S.

2. To quantify CWD size class distributions for common hardwood forest types of the eastern U.S.

3. To compare the means of CWD and FWD by classes of stand live tree basal area and stand age in eastern hardwood forests

METHODS

Data

Inventory data from the USDA Forest Service's FIA program were used to estimate coarse and fine woody debris attributes for hardwood forests of the eastern U.S. Data was collected on 860 plots during 2001-2003 in hardwood forests within the following states (number of plots per state in parentheses): AL (71), AR (43), GA (57), IL (16), IN (12), IA (12), KY (55), LA (26), ME (45), MI (74), MN (96), MO (55), NH (6), NY (46), NC (7), OH (23), PA (74), SC (2), TN (81), VA (14), WI (45) (table 1).

Field Sample Protocols

The FIA program of the USDA Forest Service conducts a 3-phase inventory of forest attributes of the United States (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into approximate 6,000 acre hexagons with at least one permanent plot established in each hexagon. In phase 1 (P1), the population of interest is stratified and plots are assigned to strata for purposes of increasing the precision of estimates. In phase 2 (P2), tree and site attributes are measured for plots established in the 6,000 acre hexagons. Phase 2 plots consist of four 24-foot fixed-radius subplots on which standing trees are inventoried. Data from the phase 2 used in this study included total standing live tree basal area (square feet) per acre and stand age (years) (for more information see NCRS 2003, Bechtold and Patterson 2005).

In phase 3 (P3), a 1/16th subset of P2 plots are measured for forest health indicators, including down woody materials. Data from P3 plots were utilized in this study to estimate down dead tree information. Coarse and fine woody debris are sampled as part of P3 on 24-foot horizontal distance transects radiating from each FIA subplot center at 30, 150, and 270 degrees (Woodall and Williams 2005). FWD (1-, 10-, and 100-hour fuels) were sampled on the 150 degree transect on each subplot. FWD with transect diameters of 0.01 to 0.24 inches and 0.25 to 0.90 inches (1- and 10-hour, respectively) were tallied separately on a 6 foot slope distance transect (14 to 20 feet on the 150 degree transect). FWD with transect diameters of 1.00 to 2.99 inches (100-hour) were tallied on a 10 foot slope distance transect (14 feet to 24 feet on the 150 degree transect). CWD was defined by the FIA program as down logs with a transect diameter ≥ 3 inches and a length ≥ 3 feet. Transect diameter, length, small-end diameter, large-end diameter, decay class, species, evidence of fire, and presence of cavities was collected for every CWD piece encountered on each of the 3 24-foot transects on every forested FIA subplot. Transect diameter was defined as the diameter of a down woody piece at the point of intersection with a sampling transect.

Analysis

Line intersect model-based estimators were used to determine 1-hour, 10-hour, 100-hour, and 1000-hour per acre fuel loading estimates for each inventory plot (Van Wagner 1964, and Brown 1974). To determine

Table 1—Primary species constituents of forest types and forest-type groups used in this study[a]

Forest type and forest-type group[b]	Number of plots	Predominant constituent tree species
Oak/other pine	48	Oaks (*Quercus* spp. L.), pines (*Pinus* spp. L.)
Oak/loblolly	28	Oaks (*Quercus* spp. L.), loblolly pine (*Pinus taeda* L.)
Post oak/blackjack oak	11	Post oak (*Quercus stellata* Wang.), blackjack oak (*Quercus marylandica* Muenchh.)
Chestnut oak	26	Chestnut oak (*Quercus prinus* L.)
White oak/red oak/ hickory	173	White oak (*Quercus alba* L)., red oak (*Quercus rubra* L.), hickory (*Carya* spp.)
White oak	18	White oak (*Quercus alba* L.)
Northern red oak	13	Northern red oak (*Quercus rubra* L.)
Yellow-poplar/white oak/red oak	25	Yellow-poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L)., red oak (*Quercus rubra* L.)
Sweetgum/yellow-poplar	26	Sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.)
Chestnut oak/black oak/scarlet oak	13	Chestnut oak (*Quercus prinus* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.)
Red maple/oak	7	Red maple (*Acer rubrum* L.), oak (*Quercus* spp.)
Mixed upland oaks	63	Upland oaks (*Quercus* spp.)
Sweetgum/nuttall oak/ willow oak	18	Sweetgum (*Liquidambar styraciflua* L.), nuttall oak (*Quercus nuttalli* Palmer), willow oak (*Quercus phellos* L.)
Sweetbay/swamp tupelo/red maple	12	Sweetbay (Magnolia virginiana L.), swamp tupelo (*Nyssa biflora* Walt.), red maple (*Acer rubrum* L.)
Black ash/American elm/red maple	15	Black ash (*Fraxinus nigra* Marsh.), American elm (*Ulmus americana* L.), red maple (*Acer rubrum* L.)
Sugarberry/hackberry/ elm/green ash	20	Sugarberry (*Celtis laevigata* Willd.), hackberry (*Celtis occidentalis* L.), elm (*Ulmus* spp. L.), green ash (*Fraxinus pennsylvanica* Marsh.)
Sugar maple/beech/ yellow birch	138	Sugar maple (*Acer saccharum* Marsh.), beech (*Fagus* spp. L.), yellow birch (Betula alleghaniensis Britt.)
Black cherry	5	Black cherry (*Prunus serotina* Ehrh.)
Hard maple/basswood	16	Hard maple (*Acer* spp. L.), basswood (*Tilia* spp. L.)
Elm/ash/locust	5	Elm (*Ulmus* spp. L.), ash (*Fraxinus* spp. L.), locust (*Gleditsia* spp. L.)
Upland red maple	19	Red maple (*Acer rubrum* L.)
Aspen	67	Aspen (*Populus tremuloides* Michx.)
Paper birch	37	Paper birch (*Betula papyrifera* Marsh.)

[a] Scientific nomenclature follows the USDA National Plants Data Center.
[b] See North Central Research Station (2002); Miles and others (2001).

the number of CWD pieces per acre, de Vries' (1986) line intersect estimation procedures were used (for application see Waddell 2002). For further information regarding the sample protocol and estimation procedures for the DWM sampled by the FIA program, see Woodall and Williams (2005). Means and standard errors were determined for down woody variables by forest type and by classes of stand live-tree basal area and stand age. Forest type was determined by forest typing algorithms currently utilized by the FIA program to fulfill program reporting requirements (table 1). The forest type algorithm assigns forest type and forest type groups according to the preponderance of stocking by individual species (Bechtold and Patterson 2005). Additionally, significant differences among DWM means by classes were evaluated using ANOVA. Ratios of CWD diameter classes were estimated by dividing the number of CWD pieces per acre for a particular size-class by the total number of CWD pieces per acre.

RESULTS

Mean fuel loading estimates for fuel-hour classes varied considerably by hardwood forest type (table 2). For 1-hour fuels, the northern red oak forest type had the highest fuel loadings, approaching 0.6 tons per acre. By contrast, most other forest types had 1-hour fuel loadings between 0.14 and 0.5 tons per acre. For 10-hour fuels, the elm/ash/locust, oak/loblolly, northern red oak, upland red maple, paper birch, and yellow-poplar/white oak/red oak forest types had the highest fuel loadings meeting or exceeding 1.0 tons per acre. On the contrary, levels in the post oak/blackjack oak, red maple/oak, and black ash/American elm/red maple types were at or below 0.5 tons per acre. For 100-hour fuels, oak/loblolly, yellow-poplar/white oak/red oak, sugar maple/beech/yellow birch, black cherry, paper birch, and upland red maple forest types had the highest fuel loadings nearing or exceeding 3 tons per acre. In contrast, loadings in the post oak/blackjack oak, white oak, black ash/American elm/red maple, and elm/ash/locust types were below 1.5 tons per acre. For 1000-hour fuels, the oak/other pine, white oak/red oak/hickory, and upland red maple forest types had the highest fuel loadings nearing or exceeding 20 tons per acre. By contrast, levels in the sweetgum/yellow-poplar, chestnut oak/black oak/scarlet oak, and sweetbay/swamp tupelo/red maple types were less than 2 tons per acre. Finally, the oak/other pines, white oak/red oak/hickory, and upland red maple forest types had the highest levels of total down woody material with loadings higher than 20 tons per acre.

The size distributions off 1000-hour fuels, otherwise termed CWD in broader ecological contexts, were heterogeneous across hardwood forest types of the eastern US (table 3). The distribution of CWD sizes was dominated by small pieces (3.0 to 7.9 inches in diameter) for most forest types. Ninety percent or more of CWD pieces in the post oak/blackjack oak, chestnut oak/black oak/scarlet oak, sweetgum/yellow-poplar, black cherry, and elm/ash/locust forest types fell within the 3 to 7.9 inch diameter range. In most other forest types, 50 to 85 percent of CWD pieces fell within the 3 to 7.9 inch size class. The sweetbay/swamp tupelo/red maple forest type had an average of thirty-three percent of CWD in the 8 to 12.9 inch CWD diameter size class, while most other types had between 10 and 30 percent. Thirteen to 17.9 inch pieces comprised 5 percent or less of CWD in all forest types, while pieces in the largest size class (18.0 and larger) were absent in most types.

Estimates of mean CWD generally increased by class of stand live basal area until a basal area greater than 120 square feet per acre was attained, although ANOVA results indicated no significant difference between class means ($P = 0.167$) (fig. 1). Estimates of mean FWD essentially remained the same across classes of stand live basal area (fig. 1). Trends in estimates of mean CWD by class of stand age were hardly discernable (fig. 2). Maximum mean CWD was attained at an age class of 75 to 99 years, while the minimum mean was for the 100+ age class. Estimates of mean FWD decreased slightly as stands increased in age, although ANOVA results once again indicated a weak relationship ($P = 0.213$).

DISCUSSION

The results indicate that the majority of hardwood forests in the eastern US contain total down woody fuel loadings below 10 tons per acre. The oak/pine, oak/loblolly, white oak/red oak/hickory, and upland red maple forest types contained the highest mean tons-per-acre of total down woody material of all

Table 2—Mean fuel loadings for hardwood forest types in the Eastern United States

Forest type and forest-type group[a]	1-hour	Standard error	10-hour	Standard error	100-hour	Standard error	1,000-hour	Standard error	Total down woody	Standard error
	tons/ acre		*tons/ acre*		*tons/ acre*		*tons/ acre*		*tons/ acre*	
Oak/other pine	0.19	0.02	0.81	0.12	1.92	0.26	18.45	11.3	21.38	11.37
Oak/loblolly	0.22	0.04	1.02	0.15	3.06	0.88	10.94	6.37	15.24	6.53
Post oak/ blackjack oak	0.14	0.04	0.51	0.11	1.24	0.24	2.13	1.18	4.02	1.26
Chestnut oak	0.18	0.02	0.72	0.09	2.23	0.33	3.28	0.55	6.42	0.76
White oak/red oak/hickory	0.21	0.01	0.64	0.04	1.77	0.12	19.21	6.77	21.84	6.76
White oak	0.22	0.03	0.58	0.06	1.22	0.26	8.69	2.69	10.76	2.69
Northern red oak	0.58	0.35	0.98	0.24	2.11	0.50	7.37	4.37	11.04	4.40
Yellow-poplar/ white oak/red oak	0.22	0.03	1.07	0.16	3.92	0.67	2.71	0.58	7.91	1.10
Sweetgum/ yellow-poplar	0.27	0.05	0.75	0.11	2.22	0.41	1.89	0.54	5.07	0.75
Chestnut oak/ black oak/ scarlet oak	0.36	0.13	0.78	0.13	2.62	0.78	1.49	0.42	5.26	1.00
Red maple/oak	0.16	0.05	0.42	0.08	1.49	0.32	3.73	0.72	5.79	0.67
Mixed upland oaks	0.18	0.02	0.86	0.13	1.89	0.28	7.09	4.57	10.04	4.61
Sweetgum/nuttall oak/willow oak	0.23	0.03	0.78	0.16	2.26	0.55	3.26	1.19	6.53	1.41
Sweetbay/swamp tupelo/red maple	0.14	0.06	0.83	0.27	2.48	1.04	1.55	0.65	5.00	1.33
Black ash/ American elm/ red maple	0.17	0.03	0.42	0.09	1.46	0.28	4.29	0.88	6.34	1.08
Sugarberry/ hackberry/elm/ green ash	0.17	0.04	0.89	0.18	2.09	0.38	3.13	1.14	6.29	1.45
Sugar maple/ beech/yellow birch	0.38	0.03	0.94	0.08	2.89	0.23	5.96	1.04	10.17	1.11
Black cherry	0.33	0.15	0.60	0.19	2.99	1.29	5.85	2.97	9.78	3.34
Hard maple/ basswood	0.29	0.05	0.65	0.20	1.82	0.37	7.49	1.75	10.26	2.18
Elm/ash/locust	0.15	0.04	1.52	0.79	1.34	0.68	2.60	1.47	5.61	1.87
Upland red maple	0.44	0.09	1.24	0.40	4.02	1.10	28.12	24.76	33.81	24.71
Aspen	0.15	0.02	0.73	0.12	2.07	0.35	5.21	0.95	8.16	1.12
Paper birch	0.24	0.07	0.97	0.28	3.16	0.48	6.17	1.05	10.55	1.43

[a] See North Central Research Station (2002); Miles and others (2001).

Table 3—Mean ratios of diameter classes of coarse woody debris for hardwood forest types in the Eastern United States

Forest type and forest-type group[a]	3.0 – 7.9	Standard error	8.0 – 12.9	Standard error	13.0 – 17.9	Standard error	18.0 +	Standard error
	inches		*inches*		*inches*		*inches*	
Oak/other pine	0.85	0.04	0.11	0.03	0.01	0	0.03	0.02
Oak/loblolly	0.74	0.07	0.13	0.05	0	0	0.13	0.07
Post oak/ blackjack oak	0.93	0.03	0.07	0.03	0	0	0	0
Chestnut oak	0.82	0.03	0.11	0.03	0.05	0.02	0	0
White oak/red oak/ hickory	0.83	0.02	0.10	0.01	0.02	0	0.05	0.02
White oak	0.68	0.09	0.18	0.07	0.02	0.01	0.12	0.08
Northern red oak	0.73	0.08	0.18	0.05	0	0	0.08	0.08
Yellow-poplar/ white oak/red oak	0.83	0.05	0.13	0.05	0.04	0.02	0	0
Sweetgum/ yellow-poplar	0.89	0.04	0.09	0.04	0.01	0.01	0	0
Chestnut oak/black oak/scarlet oak	0.94	0.03	0.04	0.03	0	0	0.01	0.01
Red maple/oak	0.87	0.05	0.12	0.05	0.01	0.01	0	0
Mixed upland oaks	0.85	0.04	0.08	0.03	0.02	0.01	0.04	0.03
Sweetgum/nuttall oak/willow oak	0.73	0.10	0.10	0.04	0.04	0.03	0.14	0.08
Sweetbay/swamp tupelo/red maple	0.66	0.14	0.33	0.15	0	0	0.05	0.03
Black ash/ American elm/red maple	0.83	0.04	0.16	0.04	0	0	0	0
Sugarberry/ hackberry/elm/ green ash	0.83	0.04	0.15	0.04	0.01	0.001	0	0
Sugar maple/ beech/yellow birch	0.81	0.02	0.15	0.02	0.03	0.01	0.02	0.01
Black cherry	0.94	0.04	0.06	0.04	0	0	0	0
Hard maple/ basswood	0.86	0.03	0.07	0.02	0.03	0.02	0.04	0.03
Elm/ash/locust	0.91	0.01	0.09	0.01	0	0	0	0
Upland red maple	0.83	0.06	0.11	0.04	0.01	0	0.06	0.06
Aspen	0.84	0.02	0.13	0.02	0.01	0.01	0.01	0.01
Paper birch	0.84	0.03	0.14	0.03	0.02	0.01	0	0

Due to rounding, not all ratios will add up to 1 for individual forest types.
[a] See North Central Research Station (2002); Miles and others (2001).

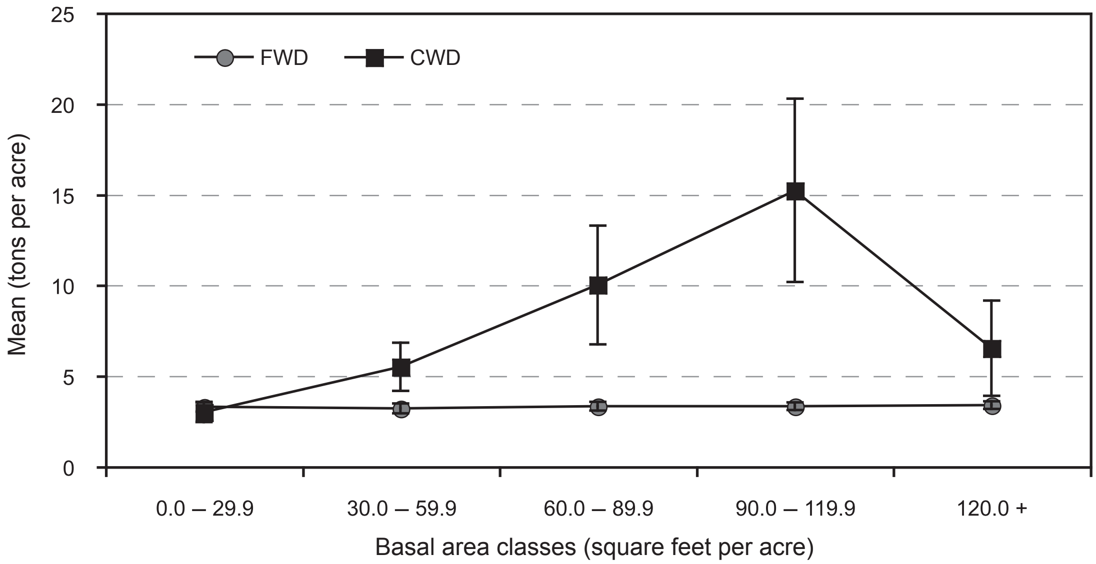

Figure 1—Means and associated standard errors of fine woody debris (FWD) and coarse woody debris (CWD) in hardwood forests across the Eastern U.S. by standing live tree basal area class.

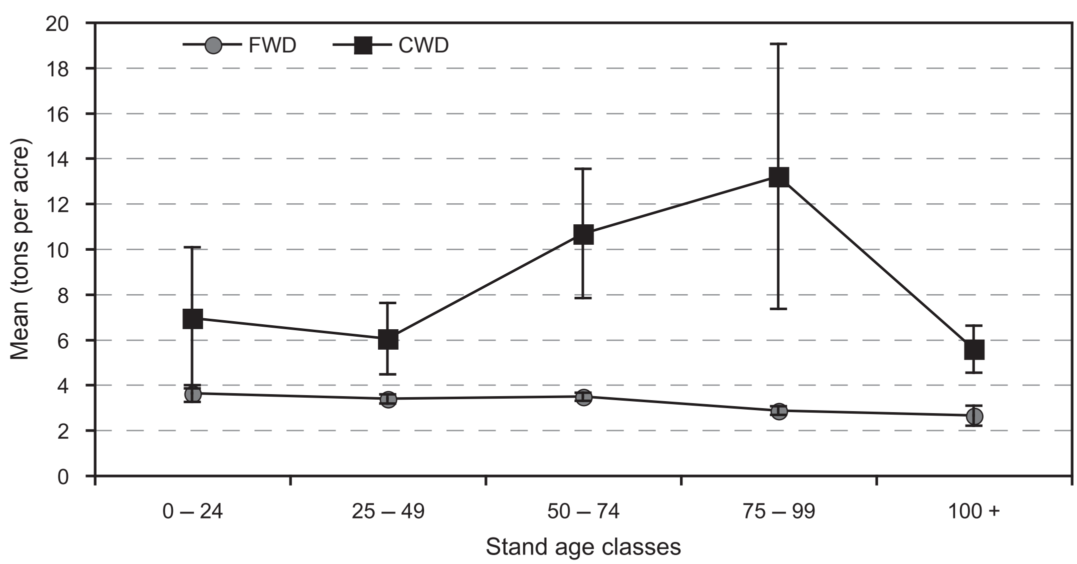

Figure 2—Means and associated standard errors for fine woody debris (FWD) and course woody debris (CWD) by stand age classes (years).

forest type groupings and had larger ratios of CWD to FWD than most other forest types. These forest types are prevalent in the hardwood forests of much of the eastern U.S. Within the context of fuel loadings in forests across the nation, the fire dangers in eastern hardwood forests should be considered low due to the mesic environments and relatively low mean fuel loadings. However, fire dangers might be exceedingly high for local areas due to high fuel loadings (> 50 tons per acre) in isolated areas and regional droughts.

For most hardwood forests, CWD constituted the majority of the total down woody fuel loading. With the exception of upland red maple forest types, forests that had oak species mixtures often had the highest mean CWD. Four out of the top five forest types in terms of highest CWD amounts were oak forest types (oak/other pine, oak/loblolly, white oak/red oak/hickory, white oak) accounting for almost a third of study observations. Eyre (1980) also found unusually high levels of CWD in some eastern oak stands. There may be a number of reasons why mixed species oak forests have higher levels of CWD. First, across much of New England and New York beech bark disease (BBD) mortality has added unnaturally high amounts of CWD to many stands (Gore and Patterson 1986). McGee (1998) estimated that BBD-induced mortality may have increased CWD volumes by as much as 25 percent. Second, forests in the southern U.S. are periodically infested with southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) in varying degrees of severity (Coulson and others 1999). The SPB causes mortality in all pine species often devastating entire softwood stands and resulting in large amounts of down woody material. CWD is particularly prevalent when an SPB attack is followed by windthrow events and a lack of active management (e.g., salvage logging) (Hanula 1993). In the southern states of Georgia, Alabama, Arkansas, and Lousiana where hardwood forests are interspersed and commingled with yellow pine species, SPB could account for much of the accumulation of down woody material. Bragg (2004) noted that in pine-hardwood stands in southern Arkansas, pines contributed more DWM (60 percent) than hardwood species, even though softwoods contributed less than 20 percent of the overstory stem count. Third, high levels of CWD in oak forests may indicate widespread oak tree mortality. Thomas and Boza (1984) and Kessler (1989) suggest that oak forests are in a state of decline highlighted by observed oak forest declines in regions of the south-central US. The high level of CWD in oak forests may be another indicator of their decline. In addition to oak decline, extensive gypsy moth defoliation has caused oak mortality for more than a century in eastern and and north-central forests of North America (Davidson and others 1999).

In terms of wildlife habitat, CWD appears to be prevalent across most hardwood forests in this study. However, we found that most hardwood forests have less than 10 tons per acre of CWD in sizes below 8 inches (transect diameter). Further, very few hardwood forests on average had any CWD pieces greater than 13 inches, a finding supported by McCarthy and Bailey (1994). These results indicate that CWD hardwood forest habitat may provide adequate structural diversity and ecological niches for smaller fauna. Further, the moderate stages of CWD decay indicate no recent widespread mortality events and no immediate loss of CWD habitat. However, the lack of large CWD pieces provides little habitat for larger-sized fauna and may reflect decades of utilization and natural negative exponential stand size-class distributions common (Spetich and others 1999) in eastern hardwood forests.

Relationships between standing tree attributes, such as stand age and density, and total down woody fuel loadings refines understanding of stand dynamics and its role in DWM accumulation. For FWD, we found no relationship with stand age or stand basal area. However, we found increasing CWD amounts with increasing stand age and basal area (except for the highest classes of independent variables). Our findings are similar to Spetich and Guldin (1999) with regards to the accumulation of DWM in southern Arkansas and Northern Louisiana, and the increase of DWM with increasing basal area. Spetich and Guldin (1999) found that accumulation of dead trees was highest in southeast Arkansas, and that increasing volumes corresponded with increasing site productivity—a function of increased biomass corresponding with increased dead wood volume over time. However, Nordén and others (2004) found no correlation between DWM volume and basal area in temperate broadleaved forests in Europe, and suggested that stand age and management, which also affect basal area, may preclude the use of basal area as a predictive variable. Although we found possible relationships between CWD and stand age/density, future studies may need to incorporate variables relating to ownership, climate, physiography, and stand history to further elucidate CWD differences across large-scales.

CONCLUSIONS

We present results of one of the first regional assessments of DWM in hardwood forests of the eastern US. Our estimates of DWM suggest that fuel loadings are not exceedingly high in most hardwood forests and may only pose a fire danger in isolated areas of high fuel loadings in times of drought. Beyond obvious fire danger assessment, our study also suggests: (1) the lack of large CWD pieces indicates a lack of habitat for large fauna, (2) the prevalence of CWD in oak forests may indicate widespread impacts of forest pests and oak decline, (3) weak correlation between total woody fuels and stand age/density indicate the difficulty in predicting DWM attributes for any given hardwood stand, (4) and climatic attributes of temperature and moisture may influence the accumulation of CWD across the diverse hardwood ecosystems of the eastern US. Although DWM may serve as an indicator of fire dangers and habitat, it may also indicate the impacts of forest pests and resulting health of hardwood forests.

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FOREST HEALTH AND PROTECTION

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IMPACT OF THE HEMLOCK WOOLLY ADELGID ON RADIAL GROWTH OF EASTERN HEMLOCK IN PENNSYLVANIA

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Abstract—We evaluated the past 60-70 years of radial growth of old-growth eastern hemlock [*Tsuga canadensis* (L.) Carr] infested with the hemlock woolly adelgid (*Adelges tsugae* Annand) in south-central Pennsylvania. Although undocumented, the initial adelgid infestation may have occurred within the stand in the early 1990s. Increment cores were extracted during May 2003 from lightly infested and severely infested canopy hemlocks. Those hemlocks that were growing more slowly in the decades prior to adelgid infestation ultimately exhibited more severe infestation. This indicates that that slower-growing hemlocks may be inherently more susceptible to the adelgid, or that stressed trees growing on poor sites may be more susceptible. Radial growth of severely infested canopy hemlocks was below normal by the mid-1990s; growth of lightly infested trees began to decline several years later. Severely infested trees exhibited a short-term, spike in growth immediately prior to a precipitous growth decline that eventually lead to mortality.

INTRODUCTION

In eastern North America, the hemlock wooly adelgid (HWA) was introduced into Virginia in the early 1950s (Suoto and others 1996), and has caused mortality of eastern hemlock from New Hampshire to Georgia (Stoetzel 2002). Eastern hemlock has little resistance to this invasive, introduced adelgid, and cannot sprout or refoliate following infestation; hemlocks of all age and size classes may be killed by the adelgid. Presumably, there will be a drastic decrease in eastern hemlock populations and resultant stand composition changes within infested hemlock areas (McClure 1999; Orwig and Foster 1998, 1999).

Severely infested canopy hemlock trees may die within 4 years after the initial infestation by the HWA, or, in contrast, may survive for 10 years after infestation (McClure 1999, Orwig and Foster 1998). In moderately infested stands, suppressed and intermediate canopy trees often experience higher amounts of mortality than dominant and codominant trees, and trees on xeric or stressful sites may exhibit more mortality than trees growing on more mesic sites. Orwig (2002) stated that radial growth of eastern hemlocks declined precipitously in stands heavily infested with the adelgid, but presented only preliminary growth information. Few studies have assessed the effect of the HWA on growth of eastern hemlock, or on the relationship between growth rate and level of infestation. Much remains unknown about the long-term implications of this adelgid on growth of hemlock within forests of eastern North America (Orwig and others 2002, Kizlinski and others 2002). However, dendrochronology (i.e., tree-ring analysis) offers a powerful tool for modeling growth trends and events relating to tree decline and mortality (McClenahen 1995).

The objective of this study was to examine the relationship between infestation by the HWA and radial growth of canopy, old-growth eastern hemlock.

PROCEDURES

Study Area

This study was conducted within the Hemlocks Natural Area (HNA), located within the Ridge and Valley Province of the Susquehanna lowland region in Perry County, PA (40˚15' N, 77˚37' W). The HNA is within the Tuscarora State Forest and encompasses approximately 50 ha of old-growth eastern hemlock in a steep ravine that extends about 2 km in length (Pennsylvania Department of Conservation of Natural Resources, Bureau of Forestry 1998). The area receives approximately 100 cm of annual precipitation,

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has an average annual temperature of 18˚C, and an average temperature of 26˚C from April 1 to August 31 during the growing season. Soils are classified as extremely-stony, sandy-loams that are deep, well drained, and strongly- to extremely-acidic. Stones and rocks 0.5-2 m or more in diameter cover more than 50 percent of the soil surface (U.S. Department of Agriculture, Soil Conservation Service 1986).

By the late 1800s, most old-growth hemlock stands in Pennsylvania had been harvested for their bark that was used for tanning leather; many surviving stands were later cut for lumber. However, the HNA was not logged, and remains one of the few old-growth stands of eastern hemlock in the state. The area has not undergone significant anthropogenic disturbance, and was designated a National Natural Landmark by the National Park Service in 1973. Canopy hemlocks within the stand are several hundred years old; Cook (1982) reported that the oldest hemlock was 448 years old (approximate pith age at 1.4 m in height). Most canopy hemlocks in the stand have a diameter greater than 60 cm dbh; the greatest dbh recorded was 132 cm, and the tallest hemlock was 38 m during the most recent inventory (Pennsylvania Department of Conservation of Natural Resources, Bureau of Forestry 1998).

In addition to eastern hemlock, the HNA contains a cohort of old-growth hardwoods including yellow birch (*Betula alleghaniensis* Britton), sweet birch (*B. lenta* L.), northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), chestnut oak (*Q. prinus* L.), black gum (*Nyssa sylvatica* Marsh), yellow-poplar (*Liriodendron tulipifera* L.), cucumbertree (*Magnolia acuminata* L.), and basswood (*Tilia americana* L.). However, eastern hemlock is the dominant tree species in the HNA, representing 80 percent of the old-growth total basal area (Pennsylvania Department of Conservation of Natural Resources, Bureau of Forestry, unpublished census data). Understory vegetation is very sparse beneath the dense hemlock canopy, with pockets of regeneration occurring mainly within canopy gaps. The understory flora is comprised mainly of birch seedlings, woodfern (*Dryopteris* spp.), and mountain winterberry (*Ilex montana* Torr. and Gray), along with a very few hemlock seedlings. The invasive tree-of-heaven [*Ailanthus altissima* (Mill.) Swingle] seedlings are beginning to colonize canopy gaps.

The natural area has not been actively managed since its inception, in order to allow undisturbed processes of tree mortality, decay, and succession to take place (Pennsylvania Department of Conservation of Natural Resources, Bureau of Forestry 1998). This was a rather simple task until infestation by the adelgid. The date of initial infestation in the HNA is unknown, but local accounts state that visual effects of the adelgid were apparent on the hemlocks by the mid-1990s. As of 2002, the old-growth canopy hemlocks in the natural area were experiencing initial mortality caused by the HWA.

Data Collection and Analysis

During May 2003, increment cores were taken from 20 lightly infested and 20 severely infested, codominant, canopy, old-growth, hemlock trees. Lightly infested trees were those that retained mainly green needles and experienced <25 percent defoliation. Severely infested hemlocks retained very few green needles and experienced >50 percent defoliation; crowns of severely infested trees often had a distinct grayish cast. Most canopy hemlocks in the stand were likely infested at time of sampling.

Two cores were extracted from each tree at dbh, 180˚apart, and parallel with the slope contour. Since Cook (1982), had already cored the hemlocks to the pith in this same stand, we extracted shorter cores containing only the past 60–70 years of growth. Increment cores were air-dried, glued in grooved wooden mounts, sanded with progressively finer grits of sand paper, and buffed with lamb's wool to enhance ring boundaries. Cores were visually cross-dated (Stokes and Smiley 1996) to ensure that each ring was assigned to the correct year, and to help with detection of missing, partial, or false rings. Annual ring widths were measured to the nearest 0.001 mm with a Velmex (East Bloomfield, NY) tree ring-measuring device. Data were organized using the program MeasureJ2X (Voor Tech Consulting, Holderness, NH), and initially evaluated using the quality control program COFECHA (Grissino-Mayer 2001; Holmes 1983, 1985). Cores that did not meet quality control standards were re-measured and data re-evaluated using COFECHA. Growth data from cores that still did not meet standards were not used in further analyses.

Mean annual growth patterns (ca. 1930-2002) of lightly infested trees (36 individual cores from 19 trees) were graphed against the mean growth data from severely infested trees (31 individual cores from 17 trees). A dimensionless ratio was constructed as: (mean annual growth of severely infested trees) ÷ (mean annual growth of lightly infested trees) (Davis and Frontz 2003). This ratio allowed a direct comparison of the difference in growth rates of severely vs. lightly infested trees. Since sampled hemlocks were all codominants, and of approximately the same dbh, conversion of raw ring widths to basal area increment (BAI) (Phipps and Field 1988) was deemed not necessary. In addition, we were interested in growth trends, not absolute growth values.

RESULTS

Local reports indicated that the initial adelgid infestation of hemlock in the HNA probably occurred in the early 1990s. Our results reveal anomalous growth patterns beginning approximately with the 1993 growing season, which supports these observations.

Examination of growth patterns prior to infestation revealed that slower growing hemlocks ultimately became more severely infested by the HWA (in 2003), as compared to trees exhibiting better growth (fig. 1). In addition, the slower growing trees generally did not respond as much to favorable environmental growing conditions as compared to the faster growing trees. This is especially noticeable during periods for favorable growth, such as in 1943 and 1973.

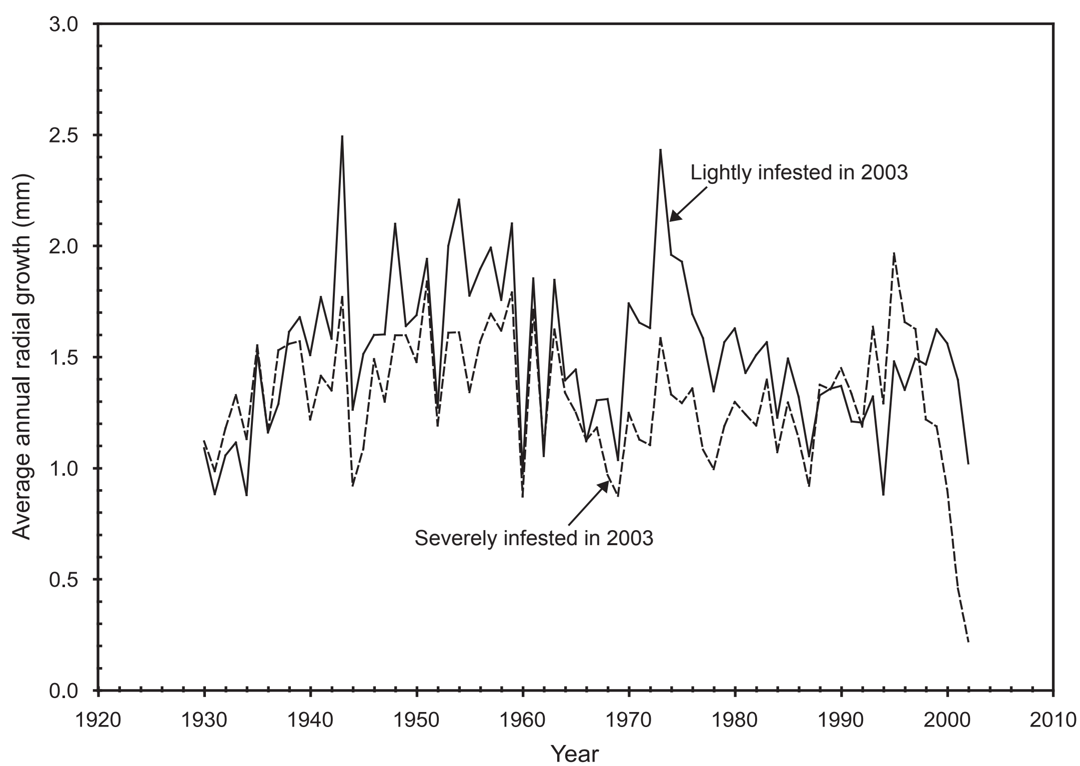

Figure 1—Average annual radial growth (mm) of old-growth eastern hemlock trees within the Hemlocks Natural Area in southcentral Pennsylvania. The solid line indicates growth patterns of trees that were lightly infested (n = 36 cores from 19 trees) at time of sampling in May 2003. Dashed line represents growth patterns of trees that were severely infested (n = 31 cores from 17 trees) at time of sampling.

The calculated ratio (fig. 2), although not illustrating the high frequency variation in annual growth, illustrates even more clearly that trees that became severely infested were growing much slower (ratio < 1.0) during most of the pre-infestation period, as compared to trees that became lightly infested. However, this pattern was not as evident during the early to mid-1930s and 1990s.

Growth patterns of the lightly infested and severely infested trees began to diverge in the early 1990s (figs. 1 and 2). From 1993-1997, growth was greater in the severely infested trees, for the first time since the early 1930s. The calculated ratio illustrates this most dramatically. The ratio noticeably displays the magnitude of the growth decline of the severely infested trees. At the end of the study (May 2003), 7 of the 17 severely infested hemlocks were dead.

DISCUSSION

During the pre-infestation period of 1930-1992, the slower growing hemlocks ultimately became more severely infested by the HWA than did the faster growing trees. The slow growing trees may be located on poor, dry micro-sites within a stand. This may cause increased stress to this shallow-rooted and drought-sensitive species, resulting in less growth before the infestation, as well as more rapid decline following infestation. Orwig and others (2002) reported that hemlock stands on xeric aspects succumb rapidly to infestation, supporting this supposition.

The severely infested hemlocks experienced a sharp increase in growth in 1993, and for the first time since the late 1930s, experienced greater growth rates than did lightly infested hemlocks. Although the reasons for the rapid growth spike are unknown, the increase may be due to growth release due to mortality of adjacent, competing, severely infested trees. In addition, infestation by insects may temporarily stimulate growth of some tree species (Alfaro and Shepherd 1991). Also, increased soil

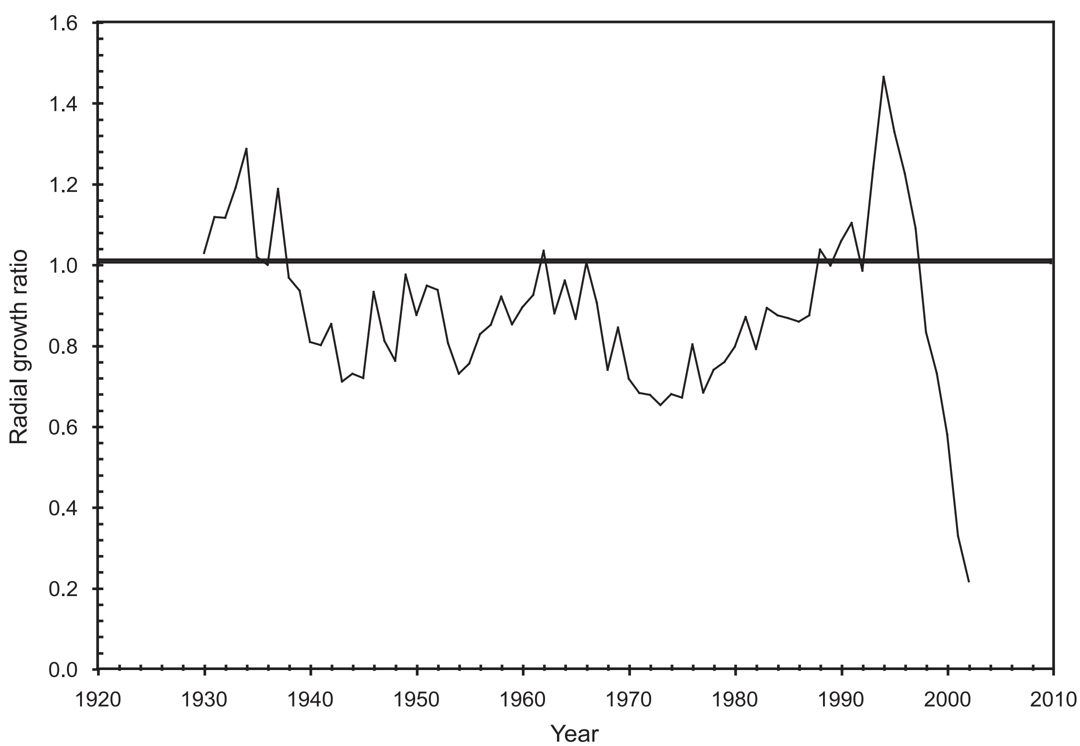

Figure 2—Ratio of average annual radial growth (severely infested:lightly infested) of old-growth eastern hemlock trees within the Hemlocks Natural Area in southcentral Pennsylvania. The horizontal line at 1.0 represents approximately equal growth between trees that were lightly infested (n = 36 cores from 19 trees) vs. trees that were severely infested (n = 31 cores from 17 trees) at time of sampling in May 2003.

nitrogen levels, possibly related to nitrogen in needle-fall from adjacent dying trees (Jenkins and others 1999), may stimulate growth. This growth spike in 1993 further suggests that the adelgid infestation in HNA was well established in 1992, and that the initial infestation likely occurred earlier, before visual symptoms were apparent in the hemlock crowns.

Although faster growing hemlocks became less infested by 2003, radial growth decline was evident within this population beginning around 2000. Duration of infestation ultimately controls the intensity of decline and mortality (Orwig and others 2002), suggesting that these trees will likely continue to decline in following years and succumb to the HWA. Severely infested trees were dying by the end of our study. It took approximately 10 years for mortality to begin in this stand. However, at the current rate of hemlock mortality, most old-growth trees in the HNA may be dead in a few years. This is important, as most old-growth forests on public land in Pennsylvania contain eastern hemlock is a major component of the overstory (www.dcnr.state.pa.us/wrcf/keynotes/summer99/growth.htm). Although small in area, these old-growth hemlock stands are important as watersheds, recreation areas, and various public-use activities. Perhaps more importantly, they serve as a benchmark describing real old-growth conditions. We may have to use such datasets and descriptions in the future, to re-create new stands that will serve as "old-growth" stands for future generations.

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TESTING THE EFFICACY OF TRICLOPYR AND IMAZAPYR USING TWO APPLICATION METHODS FOR CONTROLLING TREE-OF-HEAVEN ALONG A WEST VIRGINIA HIGHWAY

William E. Eck and David W. McGill[1]

Abstract—Tree-of-heaven (*Ailanthus altissima* [Mill.] Swingle) is a non-native invasive plant that is spreading throughout much of the U.S. In this study, efficacy of the herbicides triclopyr and imazapyr was tested using injection and basal bark treatment methods. No treatment was 100 percent effective. Only triclopyr injection was significantly different from other treatments, providing the least control. Both injection and basal spray treatments with imazapyr affected untreated neighbor stems, probably through root connections and/or root leaking.

INTRODUCTION

Originating in Southeast Asia, tree-of-heaven is now found on all continents except Antarctica (Udvardy 1998). In the Americas, tree-of-heaven can now be found from Massachusetts to Oregon and from Toronto to Argentina (Hu 1979). In some locations, it is so common that it appears to be a part of the native flora (Little 1979). It has been present in urban and agricultural settings for quite some time, often growing where no other tree would, but is now spreading into our forests, displacing more desirable native trees.

Possible control methods for tree-of-heaven include manual (hand pulling, digging, girdling), mechanical (chopping, cutting, mowing), burning, grazing, biocontrol, and chemical control (Hoshovsky 1988). Successful control methods for tree-of-heaven will kill both the stems and roots while allowing for the reestablishment of native vegetation on the site (Burch and Zedaker 2003).

Chemical treatments are often performed on tree-of-heaven with differing levels of success. Foliar broadcast applications are effective in defoliating this species. Basal bark application may be used on trees up to six inches in diameter. For larger stems, cut stump treatments, treating fresh-cut stem surfaces with herbicide, may be effective (Randall and Martinelli 1996). A study of chemical control by Burch and Zedaker (2003) was successful in removing existing trees, in preventing resprouting, and allowing for reestablishment of native vegetation on the site. Basal bark treatments with an herbicide combination including picloram (at least 5 percent of the product Tordon K) proved most successful. Treatments of triclopyr ester, imazapyr, and a combination of the two herbicides all controlled *A. altissima* better than cutting alone, but were not as effective as treatments containing picloram.

The quandary is that the label for Tordon K (picloram) reads, “Picloram is a chemical which can travel (seep or leach) through soil and under certain conditions has the potential to contaminate groundwater which may be used for irrigation and drinking purposes.” Because of the potential negative impacts on water and on adjacent trees in high-valued broadleaved stands, it may be advisable to formulate prescriptions that do not include picloram.

With the overall purpose of finding an herbicide treatment that can be used on the invasive tree-of-heaven growing in broadleaved stands in the central Appalachians, we established a study to investigate the efficacy of two commonly used herbicides in combination with two herbicide application methods. The objective of this study was to test the efficacy of triclopyr or imazapyr applied by basal bark treatment or

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stem injection. Our secondary objective was to observe damage to non-target stems that may occur by means of root connections and seepage.

METHODS

Study Site

The study was established in a 0.44 mile long plot centered on the Mile 150 marker along the northbound lane of I-79 in Morgantown, West Virginia. Several benches of shale and sandstone are present along most of this study site. Exposed bedrock-derived soils grade into forest soils on the north end of the site. Tree of heaven is a clonal species, but most of this stand was contiguous and there were no discernable isolated clones.

Herbicides and Application Methods

Imazapyr and triclopyr were the herbicides selected for use in this experiment. These are commonly-used forestry herbicides in many areas of North America, particularly in pine plantations of the Southeastern United States.

Imazapyr inhibits the production of three chain amino acids necessary for plant growth and protein synthesis (Tu and others 2001). Mortality of treated plants is largely dependent on the amount of amino acids they have stored. Roots begin to die soon after application followed by aboveground growth cessation; mortality generally occurs one month after treatment (Cox 1996). Imazapyr is reported to be most effective during axillary budding (post-emergent) (Hanlon and Langeland 2000).

Triclopyr behaves like a synthetic auxin, imitating natural plant hormones (e.g. indoleacetic acid) and causing the growing tips of the plant to elongate, distort, wither, and die (Ware 2000). Triclopyr herbicide symptoms are likely caused by disorganized cell division that leads to vascular damage (WSSA 1994).

In the low volume basal bark treatments used in this study, the lower ten inches of selected tree-of-heaven stems were sprayed until thoroughly wet, including the root collar area, but not to the point of runoff. Garlon 4 (triclopyr ester) and Stalker (imazapyr) were used for each of the two low volume basal bark treatments. Because of the low volume of herbicide that was needed for this study, herbicide was applied with one liter spray bottles. These bottles were calibrated in the lab so that the volume of herbicide mixture used to treat each tree could be estimated.

Stem injections were applied using the EZject® lance. The EZject inserts .22 caliber shells containing solid herbicide through the bark and into the cambium. Injections are applied to the lower ten inches of treated stems. Herbicides used in this method included imazapyr capsules (same active ingredient as Stalker) and triclopyr amine capsules (same active ingredient as Garlon 3A). Triclopyr capsules contain 0.24g active ingredient (0.27g total), and imazapyr contain 0.18g active ingredient (0.24g total). Label recommendations for injection rates are related to the size of the stem to be injected; one capsule per four inches (dbh) of circumference. The number of capsules to be injected was calculated prior to treatment to assure that each stem was injected with the recommended number of capsules.

Treatments and Assessment

During the summer of 2004, 150 tree-of-heaven stems were identified, mapped, and measured for use in this study. Diameter and height measurements were taken to assess treatment differences in efficacy of treatments by size class.

Thirty trees were randomly assigned to each of the four herbicide/application treatments. All treatments were applied on August 4-5, 2004. Treatments included:

1. Low volume basal bark — 20 percent Garlon 4 (61.6 percent triclopyr ester) in Aqumix (BB-T)

2. Low volume basal bark — 8.25 percent Stalker (27.6 percent imazapyr) in Aqumix (BB-I)

3. EZject — triclopyr (44.4 percent triethylamine salt) capsule injection (I-T)

4. EZject — imazapyr (83.5 percent imazapyr) capsule injection (I-I)

Thirty untreated control trees were also randomly chosen. A 2.25m radius buffer was established around each subject tree to diminish the possibility of herbicide translocation between adjacent treatment trees. The two nearest living neighbor trees to each treated stem were marked, regardless of species, to monitor for herbicide translocation.

Treatment stems were revisited in August 2005 (12 months after treatment) and were assigned a four-category efficacy score using the following qualitative ratings:

1. Tree was treated, but with no apparent negative effect on growth or health of the tree

2. Treatment effects evident with partial defoliation or retardation of foliage development

3. Defoliation complete, suckering or sprouting present

4. Defoliation complete, no evidence of suckering

Numerical Methods

All analyses were performed using SAS (SAS 2003). Fisher's LSD and Dunnett's t-test were used as mean separation procedures at the alpha=0.05 significance level. Qualitative ratings of treatment efficacy are ordinal. Although they are used in many disciplines, parametric methods such as ANOVA are inappropriate for analyzing data on an ordinal scale (Munzel and Bandelow 1998). Hence, efficacy ratings for treatment stems were rank-transformed and ranks used as the dependent variable in a single factor analysis of variance (e.g., Iman 1982).

RESULTS AND DISCUSSION

No treatment provided 100 percent control (i.e, both top-kill and no sprouting). A Dunnett test shows that all treatments were significantly different in efficacy from the untreated controls. Table 1 shows the differences between the treatments. LSD failed to show a significant difference between efficacy of basal bark treatment of triclopyr (BB-T) and capsule injections of imazapyr (I-I). These treatments provided the highest level of control. Triclopyr injection (I-T) provided the least control, with treated trees showing little or no effect of herbicide treatment.

Table 1—Differences in level of control between treatments based on mean rank of ratings

Treatment	N	Mean rank of rating
I–I	30	68.3 A
BB–T	30	62.4 BA
BB–I	30	52.7 B
I–T	30	19.3 C

Means with the same letter are not significantly different based on Fisher's LSD.

While imazapyr injections and both basal bark treatments resulted in total defoliation of at least 80 percent of treated stems (table 2), basal bark treatments with imazapyr had a higher proportion of treated stems with root suckering than the others (fig. 1), explaining why it is significantly less effective. A Dunnett test shows that only this treatment had a higher number of sprouts per stem than the untreated control.

Although the control trees were not treated with herbicide, five of them had new suckers. This is not surprising, as clonal growth in tree-of-heaven is often a response to injury or stress to the parent plant (Kowarick 1995). The hot, dry shale slopes of the highway cut on which this study is located, likely provide enough stress to cause some suckering, even in untreated stems. In fact, this site had many stems showing severe basal damage due to downslope soil and rock movement with significant bark and woody tissue damage on the uphill sides of these stems.

Several non-target hardwood stems adjacent to imazapyr treated trees (basal bark and injection treatments) showed obvious signs of herbicide damage, including wilting, prolific axillary budding, and chlorosis and necrosis of foliage. This effect was most common in tree-of-heaven stems (up to 15 feet from the treatment stem), but was also observed in black locust (*Robinia pseudoacacia* L.) and white ash (*Fraxinus americana* L.) up to 48 inches from the treated stem. This is likely the result of root leakage, or root grafting between treated stems and those adjacent. No herbicide damage was observed in stems neighboring triclopyr treated stems.

Table 2—Attributes of treated stems prior to and 12 months following herbicide treatments

Treatment	D.b.h.	Root suckers per acre	D.b.h.	Capsules per stem	Topkill	Stems w/ root suckers
	inches	*number*	*ml/inch*		- - - - - *percent*	- - - - -
Controls	2.97	1,276			0	16.7
BB–T	3.05	4,359	2.76		90	13.3
BB–I	2.95	9,143	3.13		80	40
I–T	3.35	1,063		2.63	3.3	10
T–T	3.13	1,488		2.47	93.3	6.7

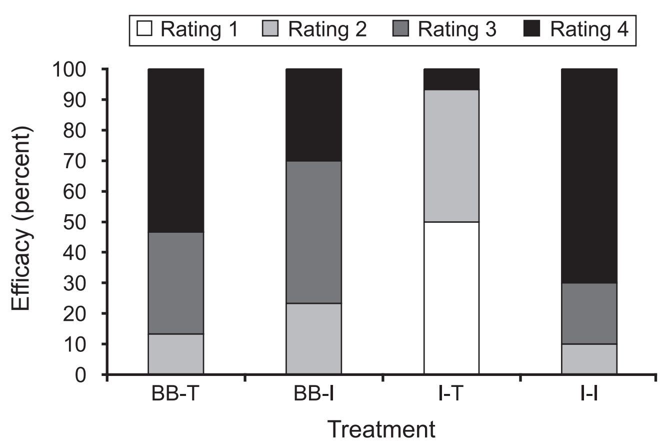

Figure 1—Proportions of trees at each level of control for all treatments.

Damage to untreated trees was not unexpected. In fact, the label for Stalker warns against possible damage to nontarget stems through root uptake. Imazapyr exhibits soil activity (Anderson 1996) and is known to be absorbed through the roots of plants outside of treated areas (USDA 1989). A study by Kochenderfer and others (2001) showed that in a hardwood crop tree release in central West Virginia, imazapyr treatments applied to competing trees adversely affected several crop trees. On one site, 66 percent of the crop trees were killed by imazapyr treatments applied to competing non-crop trees. As in our study, they observed no nontarget herbicide damage in the triclopyr treatments. Herbicide damage to untreated trees caused by imazapyr is of importance as tree-of-heaven is becoming increasingly common in woodlots and forest gaps where incidental damage to other more valuable hardwood trees is undesirable.

While damage to adjacent trees was not unexpected, the spatial extent of damage was, and only two nearest neighbor trees were marked for observation. No design for collecting and quantifying damage to unmarked trees was in place, so results of imazapyr damage are purely observational. More research needs to be conducted on damage to nontarget stems when using imazapyr.

Management Implications

No treatment in this study provided 100 percent control of tree-of-heaven stems by killing both the aboveground and belowground portions of the tree. We recommend against the use of triclopyr injection since this treatment was the least effective. Imazapyr injection was not significantly more effective in control than basal bark treatments with triclopyr. In areas with valuable crop trees or in mixed species stands, it is not advisable to use imazapyr treatments based on this and other studies; in these situations, basal bark treatments with triclopyr should be used. In tree-of-heaven stands where a monoculture has formed, use of imazapyr treatments may be a useful strategy in achieving greater control.

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ABUNDANCE OF *ARMILLARIA* WITHIN OLD-GROWTH EASTERN HEMLOCK STANDS IN SOUTH-CENTRAL PENNSYLVANIA

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Abstract—In early summer 2002, 329 soil-sampling pits were dug within an old-growth, eastern hemlock (*Tsuga canadensis* [L.] Carrière) stand in south-central Pennsylvania recently infested with the hemlock woolly adelgid (*Adelges tsugae* Annand). For comparison, 199 similar pits were dug in an adjacent hardwood stand. Rhizomorphs of *Armillaria* (Fr: Fr) Staude were recovered from 8.5 percent of the sample pits in the old-growth hemlock stand, and from 6.0 percent of the pits within the hardwood stand. Average lengths of rhizomorphs per sample pit were 1.8 and 1.6 cm within the hemlock and hardwood stand, respectively. For only pits that contained rhizomorphs, the average length of rhizomorphs per sample pit was 21.5, and 26.6 cm within the hemlock and hardwood stand, respectively. Based on IGS-1 rDNA sequence data, recovered *Armillaria* were either *A. ostoya* or within the *A. gallica/calvescens/sinapina* group. There were no readily apparent differences in *Armillaria* between the two stands.

INTRODUCTION

Root disease caused by *Armillaria* is one of the major problems on tree species worldwide (Kile and others 1991). Infection by *Armillaria* often occurs on hosts weakened by some predisposing factor that reduces overall vigor, compromising host defenses (Wargo and Harrington 1991). Defoliation caused by insects is one of the most common predisposition factors associated with *Armillaria* infections in eastern North America (Horsley and others 2002, Marcais and Wargo 2000, Twery and others 1990). Eastern hemlock is declining throughout much of its range due to infestations by the introduced hemlock woolly adelgid. Some infested hemlock stands have experienced 95 percent tree mortality in the overstory and 90 percent sapling mortality (Orwig and Foster 1998). However, in some cases hemlock mortality may be restricted to 5 percent in infested stands. The reason for this great range in mortality is unknown, but variability in species of *Armillaria* among infested stands may play a role. *Armillaria* species that are more virulent or aggressive may cause greater mortality to adelgid-stressed hemlocks. In contrast, *Armillaria* species that are predominantly saprophytic, or that infect mainly hardwoods, may cause little mortality in an infested hemlock stand. Thus, correct identification of the species of *Armillaria* in a stressed forest may greatly influence forest management plans and procedures. However, precise identification of *Armillaria* species is often problematic (Perez-Sierra and others 2000).

Confusion has surrounded the taxonomy of the genus *Armillaria* for more than a century (Rishbeth 1982). The genus is probably composed of about 40 species worldwide (Watling and others 1991). In North America, *Armillaria mellea sensu lato* is considered to be comprised of ten genetically isolated, biological species (North American Biological Species, NABS) (Anderson 1986, Anderson and Ullrich 1979, Banik and others 1996, Morrison and others 1985). *A. mellea* is the most divergent North American species of *Armillaria* (Anderson and Stasovski 1992) based not only on phylogenetic data but also on morphology (Bérubé and Dessureault 1988) and the lack of clamp connections (Korhonen 1978). *A. ostoyae* and *A. gemina* are more closely related to one another than to the other species of *Armillaria* (Anderson and Stasovski 1992). The remaining species, *A. sinapina, A. gallica, A. calvescens, A. nabsnona, A. cepistipes,* and NABS X are considered to be closely related to one another (Anderson and Stasovski 1992). These NABS species-group concepts have been generally supported by other research groups (Coetzee and others 2003, Frontz and others 1998, Piercey-Normore and others 1998, Terashima and others 1998).

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However, there has been increased interest in use of molecular techniques to identify *Armillaria* species (Perez-Sierra and others 2000). The most widely used molecular technique for species identification has been RFLP analysis of the IGS-1 region of the rDNA, pioneered by Anderson and Stasovski (1992). They reported that two groups of *Armillaria* (1. *A. gemina*, *A. ostoyae*, and *A. borealis;* and 2. *A. sinapina*, *A. calvescens*, *A. lutea*, *A. cepistipes*, NABS IX, and NABS X) were more closely related to each other than to *A. mellea* and *A. tabescens*. The two groups could be separated from one another, but interrelationships within the groups were unclear.

The objectives of this research were: 1) determine the abundance of *Armillaria* within two different forest stands in south-central Pennsylvania; and 2) to use IGS-1 sequence data to identify species of *Armillaria* within each stand. One stand was an old-growth, eastern hemlock stand recently infested by the hemlock woolly adelgid, in which we were conducting other research. For comparison, a second-growth, mixed-species hardwood stand that abuts the old-growth hemlock stand was also sampled.

MATERIALS AND METHODS

Study Area

The study area (40°15'N, 77°37'W) is within and adjacent to an old-growth stand (Hemlocks Natural Area, HNA), located within a steep ravine in Perry County, PA, U.S.A. (Pennsylvania Department of Conservation of Natural Resources 1998). Soils are classified as extremely-stony, sandy-loam that are deep, well drained, and are extremely- to strongly-acidic; stones and rocks 0.5-2 m or more in diameter cover about 50 percent of the soil surface (U.S. Department of Agriculture, Soil Conservation Service 1986). Many hemlocks in the stand have been dated, and are 400-500 years old (Cook 1982). The hemlocks have been infested by the hemlock woolly adelgid since the mid-1990s, and hemlock mortality has recently occurred. In addition to eastern hemlock, the HNA contains several old-growth hardwood tree species. The most common associated hardwoods include yellow birch (*Betula alleghaniensis* Britton), sweet birch (*Betula lenta* L.), northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), and chestnut oak (*Q. prinus* L.).

Although sample sites were initially established within the old-growth HNA, we wanted to compare *Armillaria* species composition and abundance in an adjacent mixed-species hardwood stand. This hardwood stand abuts the HNA in the same ravine, and was likely originally a hemlock stand. However, this stand had been harvested at various times, and is now a second- or third-growth hardwood stand consisting of northern red oak, white oak (*Q. alba* L.), red maple, sugar maple (*A. saccharum* Marsh.), and black gum (*Nyssa sylvatica* Marsh.), as well as a small percentage of young eastern hemlock trees.

Abundance of Soil-Borne Rhizomorphs

If abundant, soil-borne rhizomorphs would serve as an efficient source of material for isolate collection and species identification. Also, a measure of rhizomorph abundance would allow estimation of potential inoculum pressure from *Armillaria* in a forest stand (Wargo and others 1987). However, due to the extremely rocky nature of the soil in the study area, soil samples could not be collected in a systematic manner. Therefore, in areas where surface soil could be sampled due to lack of rocks, 329 soil-sampling points were randomly established in the old-growth HNA, and 199 points randomly established in the adjacent hardwood stand during the early summer of 2002. Wargo and others (1987) reported that 94 percent of *Armillaria* rhizomorph density was contained in the organic soil horizon (fermentation and humus layers) of the forest floor, as opposed to the underlying mineral soil. Therefore, the unincorporated surface litter was removed at each sampling point, and a 15 x 15 x 15 cm cube of soil, consisting mainly of organic matter, was extracted from the forest floor. At times the lower portion of the samples contained a small amount of the upper mineral horizon.

Samples were placed in plastic bags and returned to the lab where they were evaluated for presence or absence of *Armillaria* rhizomorphs. Abundance (presence or absence) of rhizomorphs in each sample was recorded. When present, the total length of rhizomorphs in the sample was measured to the nearest 0.1 cm. The density of rhizomorphs in each stand was calculated by dividing total rhizomorph length (cm) by number of soil pits. Significant differences ($P = 0.05$) in abundance (percent samples containing rhizomorphs) and density (cm of rhizomorphs per sample) between the two types of stands were evaluated using the two-sample T-test (abundance) and the non-parametric (density) Mann-Whitney test (Zar 1999).

Collection of Isolates for Identification

Initial data from the soil pits revealed that *Armillaria* rhizomorphs were very scarce within the soil of the study area (see Results), and that pit excavation represented an inefficient method to collect isolate material for culturing. Therefore, *Armillaria* rhizomorphs collected from the soil pits were not used for culturing isolates, but only to estimate rhizomorph abundance in the soil. However, during location and excavation of soil pits, we observed that *Armillaria* rhizomorphs commonly occurred on trees, logs, and stumps within the study area. Therefore, during the late summer and fall 2002, and summer 2003, samples of *Armillaria* were collected from tree material during a walk-through the entire study area, including both the HNA and adjacent hardwood stand.

Initial observations revealed very little *Armillaria* on roots and root collars of standing live hemlocks. *Armillaria* was more abundant on roots and root collars of hemlocks that were severely stressed by the hemlock wooly adelgid or that had died from various causes. Therefore, in order to collect a sufficient number of isolates for species identification, sampling was biased towards severely defoliated or dead material. For standing dead trees or snags, bark was removed from the root collar and 2 to 3 large buttress roots were excavated for 1 to 2 m from the trunk with a soil mattock and a soil knife. On stumps and fallen trees, only the root collar was examined. Logs were examined by removing the bark at the butt end.

Armillaria rhizomorphs or mycelial fans were removed from the host material, placed in labeled plastic bags, and returned to the laboratory. Decayed wood was not sampled. A total of 72 samples were collected from standing dead trees, standing live trees, fallen trees or logs, and stumps in the old-growth HNA; 30 similar samples were collected in the adjacent, second-growth hardwood stand. Sample numbers in each stand were related to availability of suitable substrate material.

Isolation Techniques

Rhizomorphs were washed with tap water, surface sterilized with 10 percent Clorox for 5 minutes, rinsed with sterile water, dipped in 95 percent ethanol, flamed, and plated onto 2 percent malt extract agar in Petri plates. Tissue from mycelial fans was directly plated onto malt agar (Maloy 1974, Worrall 1991). Cultures were grown on malt agar in the dark at 23° C within a controlled environment chamber for 4 to 6 weeks.

DNA Extraction, PCR, and Sequencing

Liquid cultures [100ml of liquid MY (20g/L malt extract and 2g/L yeast extract)] were inoculated with 10 1-mm^2 plugs of agar and mycelium (Anderson and Bailey 1989) and shaken at 100 rpm at ambient room temperature in the dark. Mycelia were harvested on cheesecloth, rinsed with sterile distilled water, and frozen in liquid nitrogen (Terashima and others 1998). Template DNA was extracted using the Qiagen DNeasy Plant Mini Kit (QIAGEN Valencia, CA) following the manufacturer's protocol.

The PCR protocol of Harrington and Wingfield (1995) was adapted to amplify the IGS-1 region of the rDNA. Extracted DNA was used as template in the PCR reactions to amplify the IGS-1 region for the unknown isolates (Coetzee and others 2003). Primers LR12R [5'CTGAACGCCTCTAAGTCAGAA3' (Veldman and others 1981)] and O-1 [5'AGTCCTATGGCCGTGGAT3' (Dushesne and Anderson 1990)], were used for amplification of the IGS-1 region (Frontz and others 1998). PCR products were purified before sequencing with a QIAquick PCR Purification Kit (QIAGEN Valencia, CA). Sequences were generated by The Pennsylvania State University Nucleic Acids Facility with the ABI Hitachi 3100 Genetic Analyzer fluorescence-based capillary electrophoresis unit. Approximately 20 to 40 ng of PCR product was used for sequencing. IGS-1 sequences were obtained with primers LR12R (Veldman and others 1981) and O-1 (Dushesne and Anderson 1990).

DNA sequences were edited in DNAstar (DNA Star Inc., Madison WI) using SeqMan II. The forward and reverse sequences were trimmed to remove non-readable sequences, and base calls were made when necessary. Initial identification of the unknown isolates was based on nucleotide similarity with sequences at GenBank, by using the BLAST search function of the database (Coetzee and others 2003). Unknown sequences were aligned with sequences that showed the highest similarity from GenBank. Sequences were aligned in the Megalign program of DNAstar, using the clustal W method, and the alignment was saved as a PAUP file (http://www.sinauer.com/detail.php?id=8060#atitle). The neighbor joining method (using uncorrected p value) was used to generate a tree with *A. nabsnona* defined as the outgroup, since this species falls outside our group of interest (Volk and others 1996). In addition, only six unknown isolates were included in the analysis to eliminate the identical sequences among the unknown isolates that were observed in preliminary distance analyses (data not shown).

RESULTS

Abundance of Soil-Borne Rhizomorphs

There were no statistical differences ($p = 0.05$) in number or length of rhizomorphs collected within the two types of forest stands. Soil-borne *Armillaria* rhizomorphs were recovered from 28 of 329 (8.5 percent) of the sample pits in the old-growth HNA, and from 12 of 199 (6 percent) sample pits within the adjacent hardwood stand. Including soil pits that did not contain rhizomorphs (length = 0 cm), the average lengths (cm) of rhizomorphs per sample pit were 1.8 and 1.6 cm within the HNA and hardwood stand, respectively. When only pits that contained rhizomorphs were analyzed, the average length of rhizomorphs per sample pit was 21.5, and 26.6 cm, within the HNA and hardwood stand, respectively.

Collection of Isolates for Identification

Of the 102 samples collected from trees, 85 (83 percent) yielded positive *Armillaria* cultures. In the HNA, *Armillaria* was recovered from 40 of the 47 (85 percent) old-growth eastern hemlocks sampled; *Armillaria* was also recovered from all three of the dead hemlocks sampled in the hardwood stand. With regard to hardwoods, *Armillaria* was recovered from 23 of the 25 (92 percent) old-growth hardwoods sampled in the HNA, and from 19 of the 27 (70 percent) younger hardwoods sampled in the mixed-hardwood stand.

Within all sampled eastern hemlock trees (n = 50), *Armillaria* was recovered from approximately 86 percent of all trees. Within all sampled hardwood trees (n = 52), *Armillaria* was isolated from approximately 81 percent of the trees. With regard to living or dead trees in both stands, *Armillaria* was recovered from all (n = 31) of the dead hemlocks and 12 of 19 (63 percent) of the living hemlocks. *Armillaria* was recovered from 15 of 23 (65 percent) of the dead hardwoods and 27 of 29 (93 percent) of the living hardwoods.

Species Identification

Of the 85 *Armillaria* isolates obtained from field-collected material, sequence data were usable from 71 of the unknown isolates. Initial BLAST searches revealed that the unknown sequences were similar to either *A. gallica* or *A. ostoyae.* Phylogenetic analysis using neighbor joining trees revealed that unknown sequences were most closely related to two species groups: I) *A. ostoyae/A. gemina* and II) *A. gallica/A. calvescens/A. sinapina/A. cepistipes/* NABS X. Of the 71 sequences, 11 (15 percent) of the unknowns were identified as being in group I, whereas the other 60 (85 percent) were identified as in group II (fig. 1). Species identified as being in group I were most closely related to *A. ostoyae* (fig. 1). However, exact species identifications could not be obtained for unknown isolates within group II based on IGS-1 data.

DISCUSSION

Armillaria rhizomorph abundance and lengths from the 528 soil samples within the study area were very low, variability was high, and distribution of rhizomorphs was not uniform among sample plots. *Armillaria* rhizomorphs were recovered from only 8.5 percent of the sample pits in the old-growth HNA, and 6 percent of the sample pits within the adjacent hardwood stand. In contrast, Wargo and others

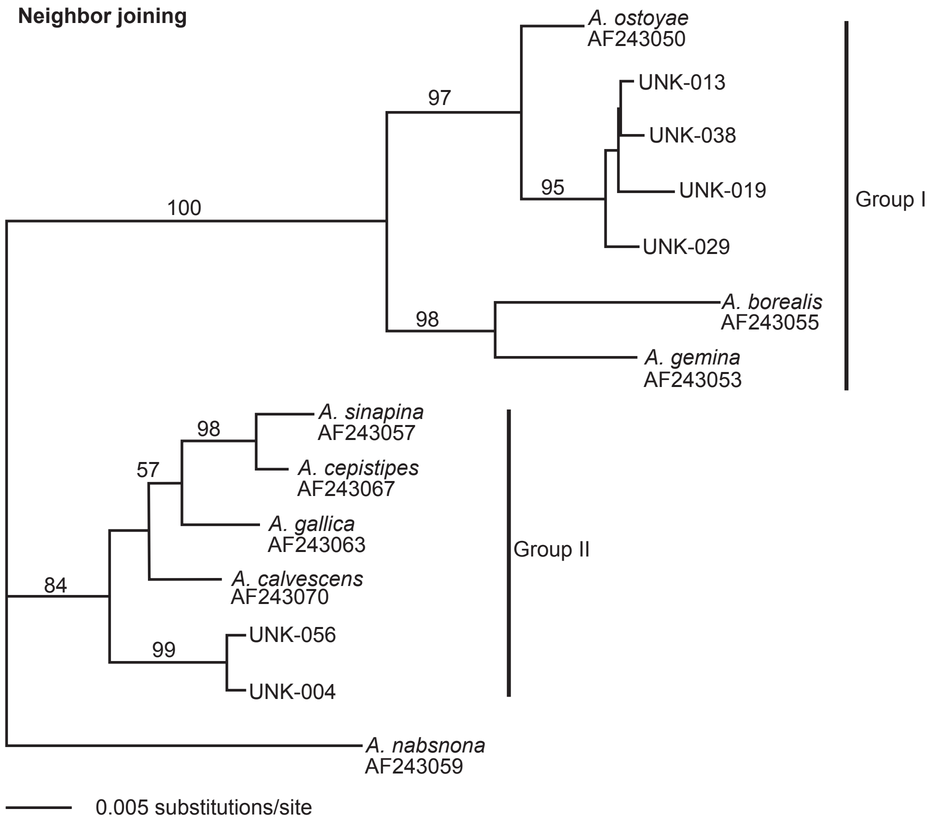

Figure 1—Neighbor-joining tree with 1,000 bootstrap replicates for known and unknown isolates. Horizontal branch length and scale bar correspond to evolutionary distances measured as the proportion of nucleotide substitutions between the sequences. Known isolates are labeled with species names and GenBank accession numbers. *A. nabsnona* was defined as the outgroup. Unknown isolates UNK-013, UNK-019, UNK-029, and UNK-038 are representative of the 11 unknown isolates in group I. Unknown isolates UNK-004 and UNK-056 are representative of the 60 unknown isolates in group II.

(1987) found *Armillaria* rhizomorphs in 95 of 351 (27 percent) of soil pits excavated along a transect in hardwood, transition, and boreal forests that contained declining red spruce (*Picea rubens* Sarg.) in eastern U.S.A. They also reported that rhizomorph density (cm/sample) was 10 times greater in hardwood stands than in transition or boreal stands. Twery and others (1990) also reported high variability in rhizomorph abundance in the soils of mixed oak forests; although comparable data were not given, they reported a direct relationship between rhizomorph abundance and proximity to dead trees, length of time since defoliation, and time of tree death.

The greater abundance of *Armillaria* rhizomorphs found in both of these studies (Twery and others 1990, Wargo and others 1987) may have been related to stand history. Both harvesting and insect defoliation may result in increased numbers of *Armillaria* rhizomorphs in the soil. Stands that have been harvested recently provide abundant dead and dying stumps and roots, food bases that are important for *Armillaria* survival and spread (Pronos and Patton 1978). Since our old-growth stand had not been harvested, and since the adjacent hardwood stand had not been harvested for many decades, it is likely that our stands had less food base. Likewise, the infestation from the hemlock wooly adelgid was just initiating hemlock mortality in our study area, and there were not large numbers of adelgid-killed hemlocks in the stand whose roots would serve as food bases. Although present, dead trees and snags were not common in either stand. It was surprising, however, that both the old-growth hemlock stand and the adjacent hardwood stand had similar numbers of rhizomorphs in spite of differences in stand composition and history.

However, the two stands were contiguous, located in the same steep rocky ravine, and had the same very acidic soil. The lower numbers of rhizomorphs found in this area may be related to the acidic nature of the soil, since some *Armillaria* species may be inhibited by low soil pH (Singh 1983).

In contrast to the limited abundance of *Armillaria* in the soil, as indicated by the limited recovery of *Armillaria* in the soil pits, the fungus was abundant on dead trees and stumps in the two stands, and 83 percent of these samples yielded isolates for identification. Most samples taken were rhizomorphs associated with root collars or roots. Only two samples consisted of mycelial fans, both of which yielded positive *Armillaria* cultures identified as *A. ostoyae*. *Armillaria* was recovered from 86 percent of all eastern hemlocks sampled and from 81 percent of all hardwoods sampled. This was surprising, since rhizomorph production may be greater from hardwood substrates than coniferous substrates (Wargo and others 1987).

Phylogenetic analysis using the neighbor joining method revealed that our unknowns fell within two species groups: I) *A. ostoyae/A. gemina* and II) *A. gallica/A. calvescens/A. sinapina/A. cepistipes/*NABS X. Isolates within group I were more closely related to *A. ostoyae* than *A. gemina*.

The IGS-1 sequences from unknown isolates that cluster within group II are more closely related to each other than to sequences of known isolates from other NABS available in sequence databases (fig. 1). It is therefore unclear what species the unknown isolates in group II may belong to. However, *A. nabsnona, A. cepistipes,* and NABS X can be ruled out due to their limited geographic distribution in northwestern North America (Banik and others 1996, Volk and Burdsall 1993, Volk and others 1996). It also appears that these isolates are more closely related to *A. gallica* and *A. calvescens* than to *A. sinapina* based on the distance analysis and bootstrap values that show *A. sinapina* as being very closely related to *A. cepistipes* (fig. 1). This relationship between *A. sinapina* and *A. cepistipes* was previously reported (Terashima and others 1998). However, true biological species definitions cannot be determined within this group using the IGS-1 region of the DNA, since multilocus phylogenetic methods for determining species boundaries have not yet been completed for *Armillaria*.

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ROTATION LENGTH BASED ON A TIME SERIES ANALYSIS OF TIMBER DEGRADE CAUSED BY OAK BORERS

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Abstract—Recent outbreaks of red oak borer (*Enaphalodes rufulus* Haldeman) are causing unprecedented economic devaluation of red oak timber in many areas of the Ozarks in the Midwestern United States. Managers have few guidelines for coping with this problem in the long-term. Here we present a retrospective analysis of degrade in wood quality and value focused on cumulative degrade caused by oak borers over a period of approximately 80 years. This study is intended to provide managers with guidance on the temporal aspects of changes in wood quality as these are related to timber value and damage from oak borers. A dendrochronological determination of the cumulative number of dated xylem tunnels and wounds, basal area, and stand age was used to assess changes in timber value in a red oak stand. We sampled 31 black (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Meunchh.) along two belt transects in a forest with observable red oak borer activity and canopy dieback near Bixby, Missouri in the Ozark Highlands. Cross-sections were taken along tree boles at one m intervals beginning at one m above the ground. Annual growth increments were cross-dated (Stokes and Smiley 1968) and tree stem initiation dates determined. We identified and determined the year of occurrence of 745 borer wounds on 137 cross sections. We used the cumulative frequency of dated injuries that occurred between 1925 and 2001 as a proxy for the amount of economic degrade that occurred throughout the life of the stand. The cumulative distribution of dated borer wounds and tunnels increased exponentially from the date of stand origin (circa 1925) with a dramatic pulse beginning about 1975. Based on data from this location, the earliest time of harvest for maximum value was about 1975 at a rotation length of about 60 years. After 1975 value either stayed the same or decreased depending on the difference in price between degraded and sound wood. The study provides a new and important approach to assessing temporal changes in red oak borer degrade caused by wood boring beetles.

INTRODUCTION

The numerous large tunnels (approximately 1 cm diameter x 20 cm long) resulting from red oak borer (*Enaphalodes rufulus* Haldeman) outbreaks (Solomon 1995) are causing unprecedented devaluation of red oak timber in many areas of the Ozarks in the Midwestern United States. Managers have few guidelines for coping with timber quality problems due to chronic insect damage (Gansner and Herrick 1982) and changing environmental and forest conditions (Muzika and Guyette 2004). In this paper we present a retrospective analysis focused on cumulative degrade caused by oak borers over a period of approximately 80 years. This analysis provides guidance on temporal aspects of wood quality, rotation age, and forest value due to damage from oak borers, thereby adding more information to the many considerations for optimal rotation length (Brazee and Newman 1999). Site productivity and red oak borer population dynamics vary greatly among sites and regions; therefore, this study's major contribution is to describe a means to assess the temporal dimension of red oak borer degrade in oak stands. We use dendrochronological methods to determine the cumulative number of defects from dated oak borer xylem tunnels and wounds, annual basal area increment at a given age, and stand age, and use these variables to assess changes in timber quality that influence optimum rotation age. The specific objective of this paper is to develop an equation that can be used to estimate the optimal rotation length for the best economic value considering only oak borer damage.

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METHODS

The study area was in the Mark Twain National Forest, near Bixby, Missouri, in the Ozark Highlands. Using two belt transects in a forest with observable red oak borer activity and canopy dieback, we sampled 31 oak trees, with approximately equal numbers from black oak (*Q. velutina* Lam.) and scarlet oak (*Q. coccinea* Meunchh.). Cross-sections were taken along potential saw logs at one m intervals beginning at one m above the ground. Annual growth increments were cross-dated (Stokes and Smiley 1968) and tree stem recruitment dates at 1 m in height. We identified and dated 745 borer wounds on 137 cross-sections. Injuries were identified as borer damage by wound configuration and characteristics (e.g. size, xylem wound shape, holes in bark, excelsior fibers), the presence of borer tunnels and tunnel stain traces, and the occurrence of live larvae in tunnels. Although all borer wounds can be dated, not all borer tunnels on a cross-section are datable. Tunnels constructed within the wood do not elicit a growth response from the dead heartwood or sapwood. However, every borer tunnel has an entrance wound and often an exit wound, and year of entrance and exit were determined when these wounds occurred on the sample cross-sections. Annual basal area increment (BAI) of the trees was estimated for each year by calculating basal area increment from the ring-widths of the trees. The BAI was used as a cumulative measurement of growth and increasing timber volume.

The timing and accumulation of timber quality defects can be estimated over the life of a stand of oak trees from dated borer tunnels and injuries. The cumulative frequency of dated injuries that occurred between 1925 and 2001 is used as a proxy for the amount of degrade that occurred in timber throughout the life of the stand. We developed the assumption that all red oak borer tunnels and injuries reduce the value of timber. We used hypothetical levels of price reduction at three levels for degraded timber. We use the difference in price between timber that has no borer injury and the percent of this price for timber with varying levels of degrade. Admittedly, there are many variables we have not included in this analysis since the objective was to determine optimal rotation length based solely on timber quality degrade by oak borers. For example, the price differential for degraded and non-degraded timber which affects optimum rotation age would vary through time. This variability, although interesting, is difficult to document and we do not address this in our analysis. Additional value may be gained when the stand regenerated or when ingrowth can occur. We did not address these factors due to the limited nature of our study.

We developed an equation for estimating rotation age and tracking value in the stand based on (1) the cumulative amount of wood increasing in the harvest trees each year, (2) the cumulative degrade to this wood by oak borers, and (3) the difference between the value of degraded timber and undamaged timber. This price differential (a constant) determines the magnitude of difference in annual value estimates while the two time series variables (BAI and borer degrade) operate in opposing directions. We developed the equation both theoretically (using known relationships among variables) and empirically by testing the equation against known conditions. We assumed a linear relationship between economic value and the number of oak borer tunnels and wounds.

The output of the derived equation was calculated for three scenarios of market value. We used three levels of market price reduction (as percent of wood that is free of degrade): 25 percent, 50 percent, and 75 percent. The optimal rotation length was determined by the difference in value between degraded lumber versus non-degraded lumber and the rate of degrade accumulation.

RESULTS AND DISCUSSION

The cumulative distribution of dated borer wounds (fig. 1) and tunnels increased generally in an exponential form from the date of stand origin (circa 1925). During the last 20 years of the trees lives major borer damage occurred with increasing frequency in 1982, 1986, 1996, 1998, and 2000. Beginning about 1975 the rate increases from about 3 wounds per year to 23 wounds per year for all cross-sections in the sample. Whether this increase is due to the biology and population dynamics of the red oak borer or to environment factors or both is not known, but this rate precedes abrupt decreases in timber value as predicted below.

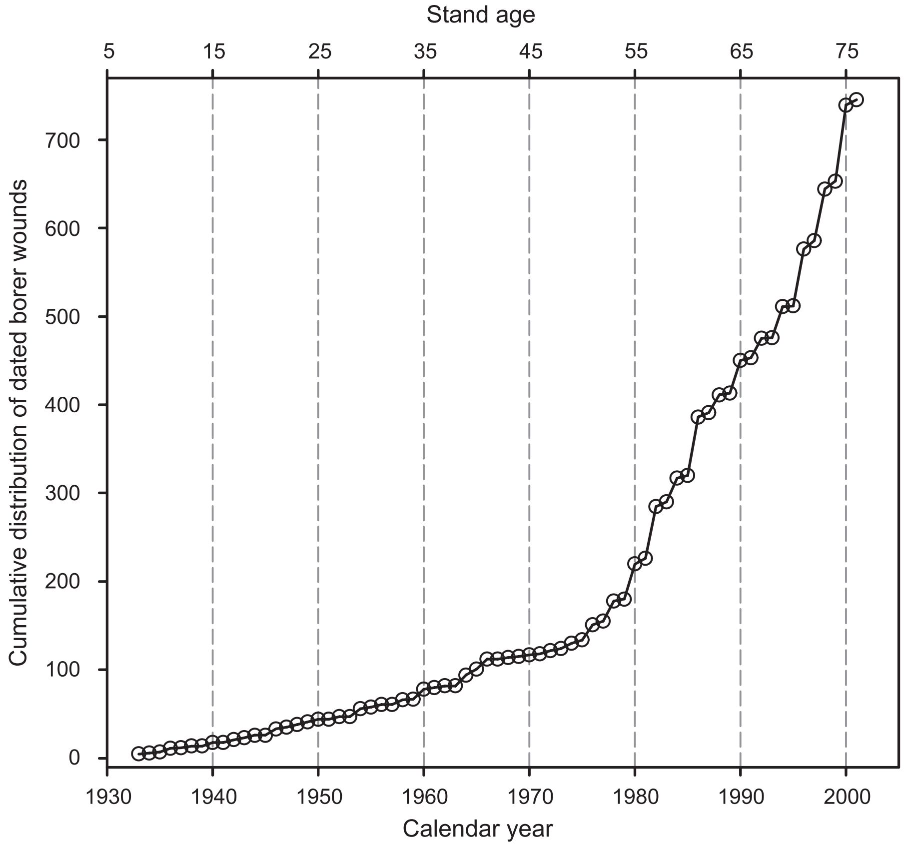

Figure 1—The cumulative distribution of dated borer wounds and tunnels determined from cross sections of 31 red oak trees sampled at 1-m intervals along 10 m of bole. The rate of borer wounding began increasing about 1975.

By comparing estimates of timber degrade (cumulative red oak borer wounds) with stand growth (BAI) we can determine an optimum rotation age for timber value based on different scenarios of likely market value (fig. 2). Timber value estimated from the accumulation of both borer tunnels and increasing basal area of the stand is described by the equation:

$$TV(\%) = PCBAI * \{[(100\text{-}CBORER) + (pd * CBORER)]/100\} \quad (1)$$

where

TV(%) = percent timber value compared to undamaged timber
PCBAI = the cumulative percent increase in basal area
CBORER = cumulative percent borer damage
pd = degraded timber price/non-degrade price

Based on the first abrupt decline in annual estimates of relative value, these scenarios yielded a difference in rotation length of 16 years (table 1). If there is no difference in market value for timber with and without defect (e.g. firewood) then rotation length and value will not be different (Scenario 100%, fig. 2).

CONCLUSIONS

Cumulative indices of red oak borer degrade indicate that stand devaluation often begins one to two or more decades before typical rotation lengths of 65 to 85 years. Also, this devaluation often goes unnoticed until cutting begins. In these stands, once the rate of red oak borer activity increases (in 1975 in this study), increase in stand volume does not offset devaluation due to borer damage under most price scenarios.

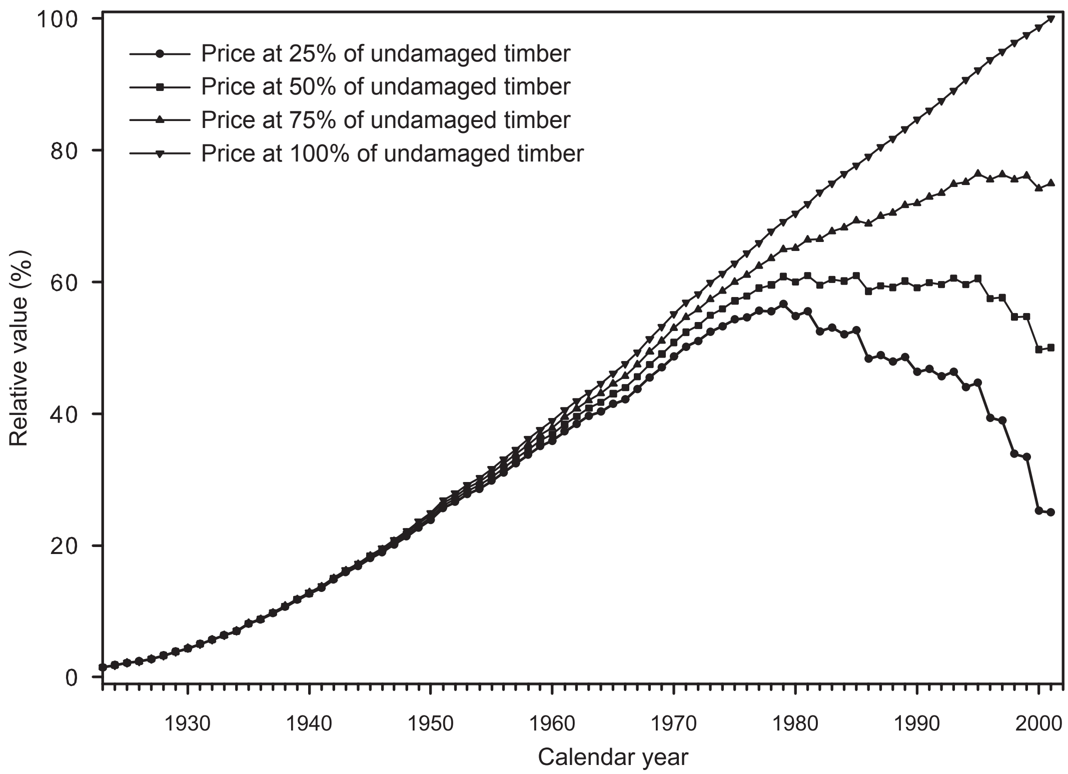

Figure 2—Plots of relative timber value at four levels of time-constant price differential between borer degraded and nondegraded timber. Rotation ages are based on the first abrupt decline in annual estimates of relative value.

Table 1—Rotation age versus market price reduction due to oak borer degrade in a red oak stand

Scenario	Residual value [a]	Harvest date [b]	Constant period [c]	Optimum rotation [d]
75% value reduction	25%	1979	1979-1980	54 years
50% value reduction	50%	1980	1980-1994	55 years
25% value reduction	75%	1995	1994-1999	70 years

[a] Residual value represents degraded timber value divided by non-degraded timber value and multiplied by 100.
[b] Optimum harvest date is defined as the calendar year of increasing value.
[c] Constant period refers to the period when timber value remains the same despite increasing BAI.
[d] Optimum rotation is the length of the rotation based on tree age.

In even aged, low site index red oak stands, where borer outbreaks and populations are high, short rotation intervals of less than 60 years may be optimum if timber quality is a consideration. The optimum rotation length for forests with severely degraded timber quality was 54 years. This study underscores the need to consider insect damage in infested forests when determining optimal rotation length.

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RED OAK DECLINE AND MORTALITY BY ECOLOGICAL LAND TYPE IN THE MISSOURI OZARKS

John M. Kabrick, Zhaofei Fan, and Stephen R. Shifley[1]

Abstract—Oak decline, the precipitous mortality of mature oak trees, has been a chronic problem in xeric oak ecosystems and is reaching unprecedented levels in red oak group (*Quercus* section *Lobatae*) species in the Ozark Highlands. The high rates of mortality are leading to rapid changes in species composition, forest structure, and related changes in fire risk, insect populations, and colonization patterns of root diseases such as Armillaria. Based on intensive analysis of more than 455 half-acre plots of the Missouri Ozark Forest Ecosystem Project (MOFEP), we compared red oak mortality change by ecological land types (ELT) using a multiple comparison test. There were significant differences in red oak mortality between certain ELTs. Using ANCOVA, we found that the abundance of red oak species was a major contributor; stand structure and tree attributes played a marginal role. The result is helpful for interpreting the landscape-scale change of red oak decline and mortality.

Keywords: Ecological land type, mortality, oak decline.

INTRODUCTION

For more than a century, episodes of oak decline periodically have occurred wherever oaks are prominent throughout North America and Europe (Kessler 1989, Starkey and others 1989). Since the 1970's, oak decline has been a common and chronic problem throughout the oak-dominated forests of the Missouri Ozarks (Law and Gott 1987). By 1999, oak decline had become widespread and locally severe on more than 400,000 acres of forests throughout the Interior Highlands of Missouri, Arkansas, and Oklahoma (Heitzman and Guldin 2004, Heitzman and others 2004).

In the Missouri Ozarks, widespread episodes of decline generally have followed periods of drought (Law and Gott 1987, Lawrence and others 2002). Red oak group species (*Quercus* section *Lobatae*) have been particularly susceptible, especially those that are physiologically mature and growing on drought-prone, nutrient-deficient sites such as on ridges or south-facing slopes and on soils that are shallow or rocky (Law and Gott 1987). High mortality of red oak group species in Missouri Ozark forests has been associated with Armillaria root disease (Bruhn and others 2000) and infestation by oak borers and other insect pests (Lawrence and others 2002, Starkey and others 2004).

The high mortality rates associated with oak decline are leading to rapid changes in species composition and forest structure. Where large numbers of red oak group species are declining and dying, they are being replaced by white oak group species (*Quercus* section *Quercus*) and other hardwoods (Kabrick and others 2004). Rapid onset of mortality temporarily increases the density of snags and the volume of coarse woody debris, changing wildfire risk and the behavior of prescribed fire. In some locations, unprecedented numbers of oak borers have infested the dead and dying red oaks (Lawrence and others 2002). In addition to the ecological ramifications, these large outbreaks of wood-boring insects have severely reduced the merchantability of red oak sawtimber.

Because of the significance of oak decline to forest management, we wanted to know whether an ecological classification system was useful for identifying places where the incidence of oak decline and mortality would be greater or have more impact. Ecological classification schemes are used to hierarchically classify forest systems at multiple scales (Bailey 1996). At the finest levels, ecological land

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types (ELTs) are mapped approximately at stand scales, each comprising distinctly different vegetation communities and environmental conditions. In theory, different ELTs can be used to identify where red oak group species are likely to be abundant and where site conditions are likely to hasten the onset of oak decline. We examined the differences in the distribution and the decadal mortality rates of red oak group species to determine how they differ among ecological land types in Missouri Ozark forests.

METHODS

We used data from The Missouri Ozark Forest Ecosystem Project (MOFEP), a long-term study examining the effects of forest management practices on upland forest flora and fauna in oak-dominated forests. MOFEP comprises nine study sites ranging from 312 to 515 ha. Study sites are located within the Current River Oak Forest Breaks or the Current River Oak-Pine Woodland Hills land type association (LTA) in the Ozark Highlands (Kabrick and others 2000, Nigh and Schroeder 2002). The Current River Oak Forest Breaks LTA has narrow ridges and steep side slopes with relief of 90-137 m which exposes the Roubidoux, Gasconade, and Eminence bedrock formations. The Current River Oak-Pine Woodland Hills LTA has broad ridges with relief < 95 m and exposes only the Roubidoux and Gasconade bedrock formations. Within these LTA's at the study area, ten ecological land types have been identified (fig. 1).

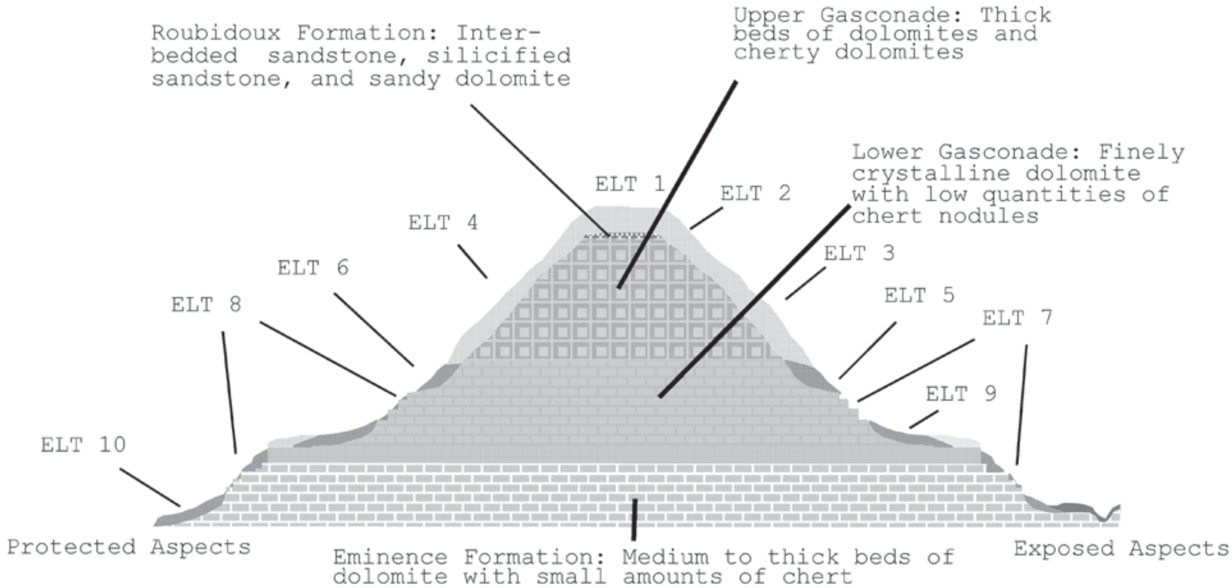
Since the first inventory on MOFEP was initiated in 1990, the 648 0.2-ha permanent plots have been inventoried approximately every three years (completed in 1995, 1998, and 2002) to document the condition of the woody vegetation. Information recorded included: species, size class or dbh for trees > 4 cm dbh, status (e.g., live, dead, den, cut, blow-down), and crown class (Jensen 2000). From this dataset, we examined the fate of all black oaks (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Muenchh.) > 11 cm dbh that were alive during the initial inventory. We examined the fate of black oaks and scarlet oaks because these two species are most susceptible to oak decline (Law and Gott 1987) and together comprise 98 percent of the red oak group basal area in the Missouri Ozarks (Kabrick and others 2004). We also restricted our analysis to a subset of 455 of the 648 vegetation plots that were not harvested as part of MOFEP treatments. We monitored the total basal area (BA), the number of trees per ha (TPH), and quadratic mean diameter (QMD) of 13,176 live black and scarlet oaks through 2002 for each ELT on the nine MOFEP sites. We used Duncan's multiple-range test (SAS® Institute Inc. 2000) to compare mean BA, TPH and QMD among ten ELTs. We incorporated the initial condition (BA, TPH, and QMD of live black and scarlet oaks in year 1990) as covariates, respectively, in analysis of covariance (ANCOVA) to determine whether the detected differences among ELTs resulted from original abundance or were associated with other characteristics.

RESULTS AND DISCUSSION

The cumulative mortality of black oaks and scarlet oaks (BA or TPH) differed significantly ($p < 0.01$) among ELTs (table 1). Two prominent groups of ELTs were identified. The first group (ELTs 1 through 6 and 9) had greater mortality than the second group (ELTs 7, 8, and 10). No significant difference was further identified within groups.

Greater cumulative mortality occurred on ELTs that are droughty and nutrient deficient (fig. 1). For example, ELTs 1 through 3 are located on convex summit and shoulder slope positions and ELT 9 occurs at the convex-shaped ends of structural benches where soil water readily drains to lower slope positions. The soils of these ELTs, as well as those of ELT 5 and 6, contain 35 to > 60 percent cherty gravel or cobbles, diminishing their ability to hold and supply water. Moreover, the soils have low cation exchange capacity and low base saturation, limiting their ability to hold and provide nutrients. Of this group of ELTs, the water and nutrient supply capacities increase gradually from ELT 1 (having lower capacity) to ELT 6 and 9 (having greater capacity). Similarly, there appears to be a corresponding gradient in cumulative basal area of black oaks and scarlet oaks that died (table 1).

In contrast, the second group of ELTs (7, 8, 10), where cumulative mortality was lower, generally have greater water supply capacity, nutrient supply capacity, or both (fig. 1). ELT 10 occurs on silty footslopes



Ecological Land Types	Description
1. Roubidoux/Upper Gasconade Summits	Slopes: < 8 percent; soils: moderately-deep to deep, gravelly or cobbly with low base saturation; overstory: black oak, white oak, scarlet oak, shortleaf pine; ground flora: *Vaccinium* spp.
2. Roubidoux/Upper Gasconade Shoulders	Slopes: 8 - 20 percent; soils: moderately-deep to deep, gravelly or cobbly with low base saturation; overstory: black oak, scarlet oak, shortleaf pine; ground flora: *Vaccinium* spp.
3. Exposed Roubidoux/ Upper Gascondade Backslopes	Slopes: > 20 percent; aspect: 135 - 315 degrees; soils: deep, gravelly or cobbly with low base saturation; overstory: black oak, scarlet oak, white oak, shortleaf pine; ground flora: *Vaccinium* spp., *Desmodium* spp.
4. Protected Roubidoux/ Upper Gascondade Backslopes	Same as ELT 3 except aspect: 315 - 135 degrees; overstory: white oak, black oak, scarlet oak; ground flora: *Vaccinium* spp., *Desmodium* spp., *Smilacena* spp.
5. Exposed Lower Gascondade/Eminence Backslopes	Slopes: > 20 percent; aspect: 135 - 315 degrees; soils: deep, gravelly or cobbly becoming clayey with depth and having moderate base saturation; overstory: white oak, black oak; ground flora: *Vaccinium* spp., *Desmodium* spp.
6. Protected Lower Gascondade/Eminence Backslopes	Same as ELT 5 except aspect: 315 - 135 degrees; soils: deep, gravelly or cobbly with moderate base saturation; overstory: white oak dominates; ground flora: *Cimicifuga* spp., *Desmodium* spp.
7. Exposed Variable-Depth-to Dolomite or Dolomite Glades	Slopes: variable; Aspect: 135 - 315 degrees; soils: depth is variable and outcrops are common or extensive, gravelly or cobbly becoming clayey with depth and having high base saturation; overstory: chinkapin oak, white ash; ground flora: *Smilax* spp., *Tephrosia* spp., *Silphium* spp.
8. Protected Variable-Depth-to Dolomite	Same as ELT 7 except aspect 315 - 135 degrees; soils: clayey with high base saturation, outcrops occur but are not extensive; overstory: sugar maple, white ash, black walnut, chinkapin oak, ground flora: *Cimicifuga* spp. *Lindera* spp., *Smilax* spp.
9. Lower Gasconade/ Eminence Benches and Shoulders	Slopes: < 20 percent; soils: deep, gravelly or cobbly with low base saturation; overstory: black oak, scarlet oak, white oak, shortleaf pine; ground flora: *Vaccinium* spp., *Desmodium* spp.
10. Footslopes	Slopes: 8 - 20 percent; soils: deep, silty with moderate base saturation; overstory: white oak, hickories; ground flora: *Desmodium* spp., *Smilacena* spp.

Figure 1—Upland ecological land types (ELT) of the study area. ELT names include slope aspect (for slopes > 20 percent), bedrock formation, and slope position. Landscape profile identifies the composition of the bedrock formation and illustrates the approximate landscape location for each ELT. Overstory or ground-flora species are either dominant or diagnostic and are listed in order of importance. Detailed descriptions of the ELTs are provided by Nigh and others (2000).

Table 1—Black oak (*Quercus velutina* Lam.) and scarlet oak (*Q. coccinea* Muenchh.) initial abundance and cumulative mortality, determined as basal area, trees per hectare, and quadratic mean diameter for ecological land types on the nine MOFEP sites[a]

	Live black oaks and scarlet oaks at year 1992			Cumulative mortality of black oaks and scarlet oaks during 1992 – 2002		
ELT	BA	TPH	QMD	BA	TPH	QMD
	m²/ha		*cm*	*m²/ha*		*cm*
1	10.7 a	144 abc	31.2 a	2.36 a	34 a	27.8 ab
2	10.6 a	157 abc	30.2 a	1.97 a	36 a	28.0 ab
3	10.1 a	185 a	27.6 ab	1.99 a	33 a	29.1 a
4	10.7 a	146 abc	31.7 a	1.97 a	27 ab	32.7 a
5	9.4 a	171 ab	27.9 ab	1.63 a	31 a	26.3 ab
6	9.0 a	121 cd	31.4 a	1.90 a	31 a	26.9 ab
7	2.4 b	58 e	22.4 c	0.33 b	6 d	25.6 ab
8	3.9 b	82 de	25.7 bc	0.62 b	12 cd	20.7 b
9	9.5 a	135 bc	29.1 ab	1.58 a	23 abc	27.5 ab
10	4.0 b	61 e	30.3 a	0.67 b	15 bcd	26.3 ab
Pr > F	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.16

[a] Abundance and diameter differences among ecological land types were identified with Duncan's multiple-range test. Within columns, values followed by a different letter indicate significant differences ($\alpha = 0.05$).
MOFEP = Missouri Ozark Forest Ecosystem Project; ELT = ecological land type; BA = basal area; TPH = trees per hectare; QMD = quadratic mean diameter.

where water and nutrient supply are relatively high. ELT 8 occurs on lower, north-facing slopes where the underlying dolomite is sufficiently near the soil surface to provide large quantities of the base cations Ca and Mg; however, the bedrock is not too near the surface to restrict root development. The anomaly was ELT 7 because the underlying and outcropping dolomite of this ELT restricts growing space for trees. We also found that the abundance of black oaks and scarlet oaks was considerably lower on this ELT than on the others. This led us to question whether the cumulative oak mortality was related to the abundance or diameter (i.e., a surrogate for tree age) of black oaks and scarlet oaks at the initiation of the study.

We found few differences among ELTs in the QMD of live or dead oaks. When the study was initiated the black and scarlet oaks on ELT 7 were slightly smaller than elsewhere, but the QMD of the black oaks and scarlet oaks that died during the study period was the same as for the other ELTs. This suggests that greater cumulative mortality of some ELTs was not due to the presence of larger (and presumably older) black oaks and scarlet oaks.

However, we found higher cumulative mortality of black oak and scarlet oak was strongly correlated to a greater abundance of these species at the initiation of the study (table 1). ANCOVA indicated that this association was highly significant ($p < 0.01$). After accounting for this abundance effect, we found the cumulative mortality was no longer significantly different among ELTs (BA: $p = 0.86$; TPH: $p = 0.10$) at the 95 percent confidence level (table 2). This suggested that the mortality rate of black oaks and scarlet oaks did not differ proportionally among ELTs.

In combination, these findings provide a new perspective on the oak decline problem. Much like studies reported elsewhere, our findings confirm that there is greater cumulative mortality of black oaks and scarlet oak on sites that are drought prone and nutrient deficient (Heitzman and others 2004, Law and Gott 1987, Lawrence and others 2002). Moreover, they demonstrate that ELTs can be used to identify across the landscape where the cumulative mortality of these species is likely to be greater. However, they also

Table 2—Least square means and standard errors of dead basal area, trees per hectare and quadratic mean diameter of black oaks (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Muenchh.) at year 2002 for each ecological land type adjusted by initial condition at year 1992 in the analysis of covariance

ELT	BA	TPH	QMD
	m²/ha		*cm*
1	1.8 ± 0.3	30 ± 3.8	25.7 ± 2.3
2	1.4 ± 0.2	29 ± 3.6	26.9 ± 2.1
3	1.6 ± 0.2	20 ± 3.5	30.6 ± 1.8
4	1.4 ± 0.2	22 ± 3.2	30.1 ± 1.9
5	1.3 ± 0.2	20 ± 3.7	27.5 ± 2.1
6	1.7 ± 0.2	32 ± 3.5	24.6 ± 2.1
7	1.5 ± 0.3	22 ± 3.8	30.3 ± 2.4
8	1.5 ± 0.3	22 ± 4.0	24.5 ± 2.6
9	1.3 ± 0.2	21 ± 3.5	27.5 ± 2.1
10	1.5 ± 0.2	30 ± 3.6	25.2 ± 1.9
Pr > F	0.86	0.10	0.24

ELT = ecological land type; BA = basal area; TPH = trees per hectare; QMD = quadratic mean diameter.

suggest an alternative pathway leading to accelerated mortality of black oaks and scarlet oaks. Rather than accelerating mortality, the drought-prone and nutrient-deficient site conditions of some of the ELTs may have favored the colonization of black oaks and scarlet oaks following the extensive logging and farming practices during the early 1900s. When young, these species are adapted to poor site conditions (Johnson and others 2002). Consequently, black oaks and scarlet oaks must have been more competitive for growing space, displacing other oaks and other tree species and eventually becoming the dominant species. Because black and scarlet oaks become highly susceptible to oak decline as they mature, the cumulative mortality of these species is higher anywhere that physiologically-mature black oaks and scarlet oaks are more abundant.

Our findings do not discount the role of environmental stress in triggering the onset of oak decline. Episodes closely follow periods of drought (Law and Gott 1987, Lawrence and others 2002, Stringer and others 1989). However, it appears that the water supply differences among ELTs have little impact on the mortality rate of individual black oaks or scarlet oaks. The total number or basal area of dead black and scarlet oaks is higher on ELTs that have more of those species, but the proportion of those trees that die is comparable across all ELTs we examined. Stringer and others (1989) also noted that site moisture regime did not appear to play a role in oak decline in eastern Kentucky. There may be a physiological explanation for why site moisture regime does not appear to be important. Jenkins and Pallardy (1995) suggested that in the Missouri Ozarks, oaks on poorer sites allocate more photosynthate to their roots than oaks on nearby higher quality sites. This mechanism enables oaks on the poorer sites to withstand the deleterious effects of extreme drought as well or better than those on higher quality sites. This may partially explain why the mortality rate of black oaks and scarlet oaks is about the same regardless of ELT.

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HERBICIDE TREATMENTS FOR CONTROLLING INVASIVE BUSH HONEYSUCKLE IN A MATURE HARDWOOD FOREST IN WEST-CENTRAL INDIANA

Ron Rathfon and Keith Ruble[1]

Abstract—Asian bush honeysuckles (*Lonicera maackii* [Rupr.] Maxim*, L. morrowii* Gray, and *L. tartarica* L.) have proved extremely invasive in eastern hardwood forests. In addition to displacing native forest ground flora and associated fauna, these understory shrubs pose a threat to forest regeneration. Effective control strategies need to be developed to incorporate into routine silvicultural prescriptions for affected stands. This study tested ten control treatments in a fully stocked, mature central hardwood forest in central Indiana for efficacy and cost. Treatments included: low volume foliar applications of 4 percent triclopyr (Garlon 3A), 3 percent triclopyr (Garlon 3A) + 1/8 percent imazapyr (Arsenal), and 5 percent glyphosate (Glypro Plus), each applied in both early spring and late fall; full basal bark application of 20 percent triclopyr (Garlon 4) in AX-IT basal oil; streamline basal bark application of 20 percent triclopyr (Garlon 4) in AX-IT basal oil; and cut stump treatments with either picloram + 2,4-D (Pathway) or 20 percent triclopyr (Garlon 4) in AX-IT. Treatment timings were chosen to test effectiveness of herbicide control at a time of year when native vegetation would be least vulnerable to off target damage. Efficacy was tested across four shrub size classes. All but one of the low volume foliar applications were equally effective, controlling 70 to 94 percent of bush honeysuckle shrubs between 2 and 8 feet tall. Triclopyr applied in the fall (Nov. 2) provided only 2 percent control. Both basal bark applications provided inconsistent and poor control. Both cut stump treatments were equally effective on the larger two size classes of shrubs, but efficacy declined on smaller shrubs due to operational difficulties of locating all shrubs in a treatment unit. Depending on bush honeysuckle stand stocking and size distribution, treatment costs ranged from $83 per acre to $383 per acre.

INTRODUCTION

The introduction, promotion, invasion, and ultimate vilification of Asian bush honeysuckles (*Lonicera maackii* [Rupr.] Maxim*, L. morrowii* Gray, and *L. tartarica* L., all herein collectively referred to as BHS names) in North America are well documented (Luken and Thieret 1996). Their ecology and impacts on native forest vegetation in the Central Hardwood Region have been extensively studied (Deering and Vankat 1999, Gorchov and Trisel 2003, Hutchinson and Vankat 1997, and Luken and Mattimiro 1991). These honeysuckles have demonstrated a very plastic physiological and morphological response to varying light levels (Luken and others 1995). They attain their fastest growth rates in full sunlight. BHS growth rates increase in direct proportion to increasing amounts of light following forest canopy disturbances. Timber harvesting in forest stands with significant BHS populations in either the understory or on the edges of the forest will only increase the dominance of BHS in the stand. This may adversely affect forest regeneration and most assuredly will harm the native forest herbaceous and shrub components and the wildlife dependent on them (Gould and Gorchov 2000).

The literature, including websites, is replete with general recommendations for controlling BHS. However, little experimental research specific to BHS control has been published. Silvicultural prescriptions for controlling BHS in forest environments are needed.

The objective of this study was to test the effectiveness of various herbicide delivery methods and specific herbicide combinations commonly used in forestry vegetation management to control different sizes of BHS shrubs in a heavily infested, mature, well-stocked Central Hardwood Forest. Herbicides were applied during the dormant season to minimize damage to native vegetation. Preliminary cost data is also presented.

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METHODS

The 14 acre study site was on rolling topography with 5 to 10 percent slopes and primarily east to southeast aspects. Soils consisted of deep silt loam, between 6.5 and 7.5 feet deep. White oak site index (base age 50 years) was 90 feet (NRCS 2005).

The study was located in a mature, well-stocked hardwood forest, in a Vigo County Park, located east of Terre Haute, in west-central Indiana. Tree stocking ranged from 70 square feet to 190 square feet, averaging 114 square feet per acre of basal area. Dominant tree species included sassafras (*Sassafras albidum* [Nutt.] Nees), black cherry (*Prunus serotina* Ehrh.), and red maple (*Acer rubrum* L.) comprising 22 percent, 19 percent and 17 percent, respectively, of the basal area. Miscellaneous oaks (*Quercus*), ash (*Fraxinus*), elm (*Ulmus*), and yellow-poplar (*Liriodendron tulipifera* L.) comprised the remaining stand stocking.

The experimental design was a completely randomized design with 11 different treatments, each replicated three times, applied to 33 ¼-acre square treatment plots. The application methods were low volume foliar, basal bark, and cut stump herbicide applications. Only hand applications (as opposed to mechanized) were chosen for this study because of the need to test applications appropriate for typical native forest conditions; i.e., heavy tree stocking, relatively rough terrain, poor accessibility by motorized equipment, desire to protect native vegetation, and the limited array of equipment typically available to foresters in the region.

The individual treatments were as follows:

1. Control

Low Volume Foliar:
2. SprTriclo = 4 percent triclopyr (12 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A[2])
3. SprTriclo+Imaz = 3 percent triclopyr (9 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A) + 1/8 percent imazapyr (0.25 lb ae/100 gal), 22.6 percent (2 lb/gal) acid equivalent (Arsenal[3])
4. SprGlyph = 5 percent glyphosate (15 lb ae/100 gal), 30.8 percent (3 lb/gal) acid equivalent (Glypro Plus [see footnote 2])
5. FalTriclo = 4 percent triclopyr (12 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A)
6. FalTriclo+Imaz = 3 percent triclopyr (9 lb ae/100 gal), 31.8 percent (3 lb/gal) acid equivalent (Garlon 3A) + 1/8 percent imazapyr (0.25 lb ae/100 gal), 22.6 percent (2 lb/gal) acid equivalent (Arsenal)
7. FalGlyph = 4 percent glyphosate (12 lb ae/100 gal), 30.8 percent (3 lb/gal) acid equivalent (Glypro Plus)

Basal Bark:
8. FullBas = Full Basal 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gal) acid equivalent [Garlon 4 (see footnote 2)] in AX-IT[4] oil-surfactant low volume basal oil
9. Stream = Streamline 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gallon) acid equivalent (Garlon 4) in AX-IT oil-surfactant low volume basal oil
10. Cut Stump:Pathway = Undiluted picloram, 3 percent acid equivalent + 2,4-D, 20.9 percent acid equivalent, (Pathway [see footnote 2])
11. Triclo+AX-IT = 20 percent triclopyr (0.8 lb ae/gal), 44.3 percent (4 lb/gal) acid equivalent (Garlon 4) in AX-IT oil-surfactant low volume basal oil

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[2] Garlon 3A, Garlon 4, Glypro Plus, and Pathway are registered trade names of Dow AgroSciences.
[3] Arsenal is a registered trade name of BASF Corporation.
[4] AX-IT is a registered trade name of Townsend Chemical.

Foliar herbicides were applied using a hand pump, piston backpack sprayer with an adjustable cone nozzle. Blue dye was added to the herbicide to aide in identifying already-treated areas. Each foliar herbicide treatment was applied in late fall (Nov. 4, 2002) or early spring (Apr. 4 and 10, 2003) to test the feasibility of conducting BHS control operations during periods when native vegetation is dormant but BHS is still photosynthesizing and is possibly capable of absorbing and translocating systemic herbicides through its foliage.

Basal bark herbicide treatments were applied Jan. 7, 2003. Temperatures were below freezing and one-inch of snow was on the ground. The full basal spray was applied with a hand pump diaphragm backpack sprayer, using a cone-jet nozzle. Herbicide was applied from the root collar up the stem to approximately 12 to 15 inches on all sides. The streamline method of basal bark application was applied using a hand-pump, diaphragm backpack sprayer with a 0.0001 inch orifice spray tip that delivers a pencil-lead thick straight stream. Herbicide was sprayed in a 3 inch to 6 inch band, approximately 6 inches from the ground to two sides of the stem. On stems smaller than 1 inch in diameter, herbicide was applied to only one side of the stem.

Cut stump treatments were applied with a two-person crew where one person operated the chainsaw while the second applied herbicide to the stump. The cut stump Pathway treatment was applied on Feb. 13, 2003 using a hand pump piston backpack sprayer, applying herbicide to the cut surface. The cut stump triclo+AX-IT treatment was applied on Jan. 21, 2003 using a diaphragm backpack pump, applying herbicide to the cut surface and to the stump bark. Temperatures were at freezing or below with approximately one inch of snow cover. Treatment application labor time and herbicide volumes were recorded for each treatment plot.

Prior to treatment application, ten 1/385 acre circular subplots were established in each treatment plot. BHS population was determined for each ¼-acre treatment plot by tallying shrubs in the 10-subplot sample by one of the following four size classes:

Class 1 – 0 to 2 feet tall

Class 2 – 2 to 4.5 feet tall

Class 3 – 4.5 to 8 feet tall

Class 4 – over 8 feet tall

Shrub size classes were at first assigned with the aid of a telescoping height pole until field technicians became proficient at assigning classes by ocular estimation.

BHS populations were inventoried in the fall of 2003 and 2004. In the fall of 2003 shrubs were tallied according to 0 percent, 20 percent, 40 percent, 60 percent, 80 percent, 99 percent, and 100 percent damage classes. All damage classes, except 0 percent and 100 percent were subjective estimates of crown percentages showing some form of herbicide damage, i.e., twig, branch death or die back, or leaf necrosis and deformity. The 0 percent class showed no damage while the 100 percent class appeared to be completely dead. Pretreatment, 1st year, and 2nd year BHS populations and efficacy data were determined from sample shrub counts.

Efficacy data was analyzed as the proportion of shrubs dead (100 percent damage class) after the first growing season following treatment. Because proportion data do not usually fit a normal distribution, the proportions were transformed using the following arcsine transformation equation (Zar 1984) prior to statistical analysis:

$$p' = \frac{1}{2}\left[\arcsin\sqrt{\frac{X}{n+1}} + \arcsin\sqrt{\frac{X+1}{n+1}}\right]$$

where

p' = the transformed proportion
X = number of BHS shrubs observed to be dead or assigned to a damage class within a treatment plot
n = total number of BHS shrubs inventoried within a treatment plot.

The transformed efficacy proportion data was then analyzed using a general linear models (GLM) procedure and Duncan's Multiple Range Test (SAS Institute 2001). The control treatment was not included in this analysis since we were most interested in finding the most efficacious treatments and not simply those that were significantly different from doing nothing. Individual treatment data was pooled by herbicide delivery method to compare overall differences between these methods. Treatment data was also pooled by size class to test overall responsiveness of different size BHS to control treatments. The pooled method and size class data were analyzed as factorial combinations of each other in order to test for significant interactions. First year BHS populations were compared to 2nd year populations for each treatment using paired t-tests to show longer-term treatment effects.

RESULTS

The forest understory was dominated by BHS ranging from seedling size to large mature shrubs up to 15 feet tall (table 1). Across all treatment plots, BHS stocking across the full range of sizes averaged 1,596 shrubs per acre. Stocking for shrubs 4.5 feet and taller averaged 519 shrubs per acre. Amur honeysuckle was the most dominant BHS. A small number of patches of Morrow's honeysuckle were interspersed throughout the total BHS population.

Low volume foliar application as an herbicide delivery method on BHS appears to provide better control over a broader range of shrub sizes than basal bark and cut stump methods (fig. 1), with 69 percent, 26 percent, and 26 percent control respectively.

The smallest size class, class 1, sustained significantly lower levels of control (33 percent) than the three larger size classes (fig. 2). This was likely attributable to the difficulty applicators experienced locating and treating shrubs less than two feet in height, especially when they grow amid the dense foliage of the larger shrubs. Many in this size class were simply overlooked.

Significant interactions between herbicide delivery method and height class indicated that individual herbicide delivery methods were best suited to controlling specific BHS shrub sizes (fig. 3). This may be intuitive for anyone with any familiarity with vegetation control methods. Smaller shrubs were most easily treated with foliar applications. Foliar treatments were most effective for size classes 2 and 3. It was impractical to treat the largest shrubs with backpack foliar applications. Basal treatments had overall lower levels of effectiveness across all sizes with marginally better results with size classes 2 and 3 than 1 and 4. Cut stump treatments were effective on shrubs larger than 4.5 feet and ineffectual for smaller shrubs due to the impracticality of trying to find and cut them with a chainsaw.

Low Volume Foliar Treatment Comparisons

Only size class 2 and 3 shrubs were used to determine efficacy of the individual low volume foliar treatments. Because these two size classes responded similarly, their data were combined for analysis and presentation. In year one, for low volume foliar treatments showing acceptable efficacy levels, mean control levels ranged from 70 percent for SprTriclo to 95 percent for SprGlyph (fig. 4). Among the low volume foliar treatments only the FalTriclo treatment was significantly different. All other treatments were equally effective on size class 2 and 3 shrubs. Crown damage greater than 50 percent further reduced BHS overall health and competitiveness in the SprTriclo, SprTriclo+Imaz, FalTriclo+Imaz, and FalGlyph treatments.

Table 1—Asian bush honeysuckle pretreatment shrub inventory by height class for an herbicide trial in an hardwood forest in west-central Indiana

	Size class									
	1 (0 – 2 feet)		2 (2 – 4.5 feet)		3 (4.5 – 8 feet)		4 (8+ feet)		Total (0 – 8+ feet)	
Treatment [a]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	shrubs/acre									
SprTriclo	820	167	974	293	692	558	154	117	2,641	1,087
SprTriclo+Imaz	385	308	731	402	449	126	205	34	1,769	859
SprGlyph	551	257	308	102	205	112	51	34	1,115	500
FalTriclo	423	89	308	22	397	151	179	56	1,308	204
FalTriclo+Imaz	295	239	526	148	385	97	0	—	1,205	260
FalGlyph	282	225	333	191	269	102	90	13	974	423
FullBasal	923	332	474	167	410	237	244	114	2,051	681
Streamline	628	128	500	44	397	144	77	77	1,603	237
CSPathway	936	714	269	212	256	26	282	141	1,744	999
CSTriclo+AX-IT	679	400	423	182	397	172	51	34	1,551	749
Total	592	97	485	67	386	63	133	26	1,596	197

SE = standar error; — = not applicable.
[a] See text for individual treatment definitions.

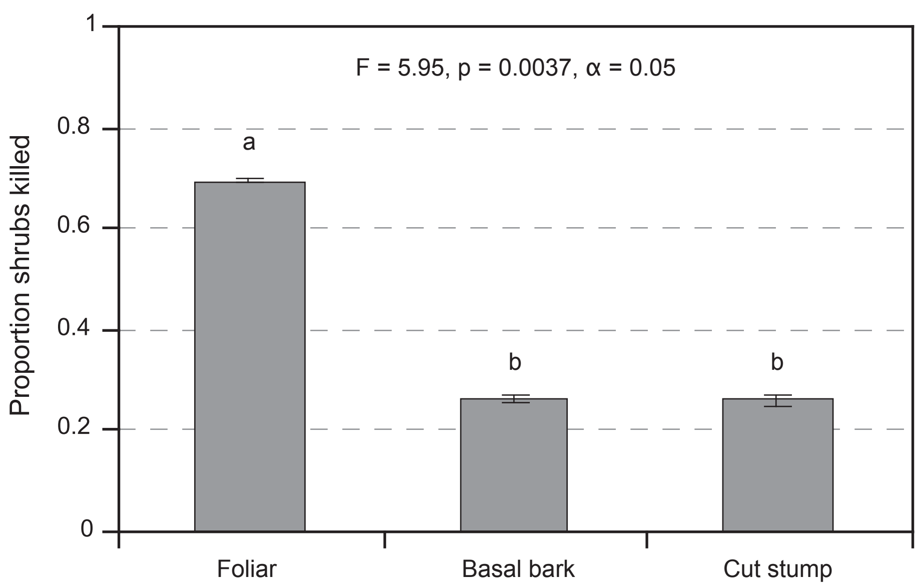

Figure 1—First-year Asian bush honeysuckle control efficacy by method of herbicide delivery in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs across all size classes that are killed by the treatment.

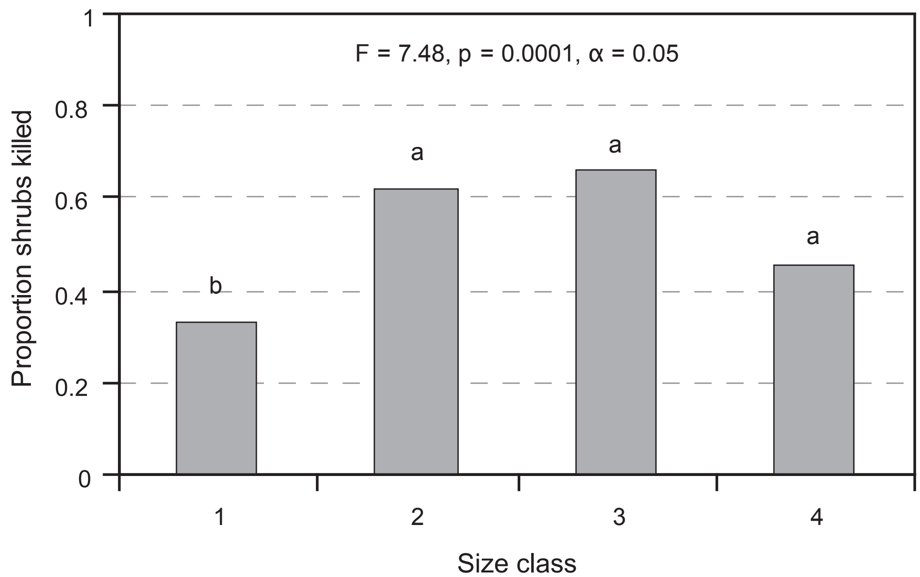

Figure 2—First-year Asian bush honeysuckle control efficacy by size class in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs across all treatments that are killed by the treatment. Size classes are: 1 = 0–2 feet tall, 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

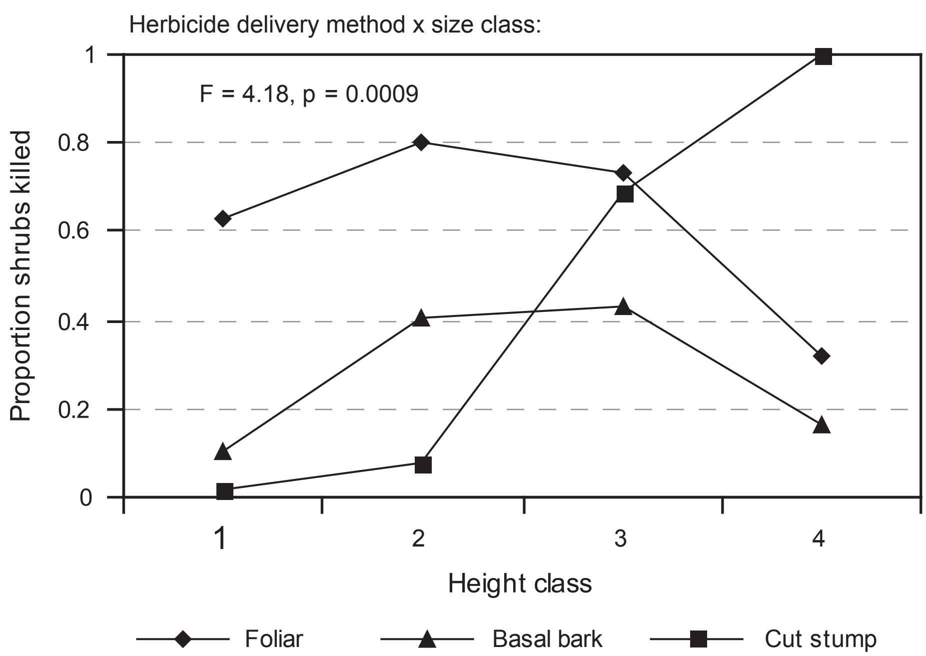

Figure 3—First-year Asian bush honeysuckle control efficacy for herbicide delivery method x height class interaction in a hardwood forest in west-central Indiana. Efficacy is measured as the proportion of shrubs killed by the treatment. Size classes are: 1 = 0–2 feet tall, 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

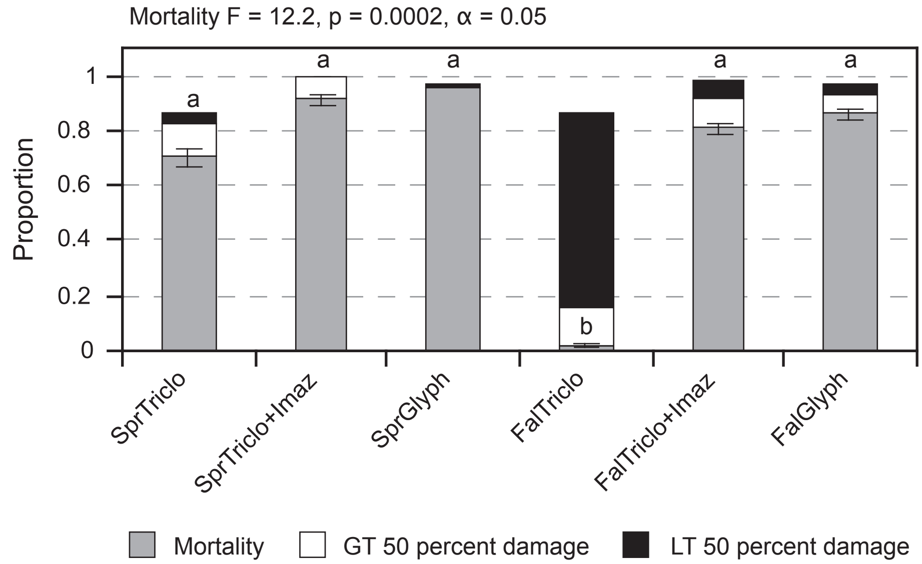

Figure 4—First-year Asian bush honeysuckle control mortality and damage for three low-volume foliar herbicide treatments, each applied in both early spring and early fall, for size classes 2 and 3 (2–8 feet tall) combined in a hardwood forest in west-central Indiana. Mortality and damage are measured as the proportion of shrubs killed or damaged. Damage classes are: GT 50 percent = more than 50 percent of the crown with herbicide-inflicted damage; LT 50 percent = less than 50 percent of the crown with herbicide-inflicted damage, not including shrubs exhibiting no herbicide-related injury.

The FalTriclo treatment was significantly lower than all other treatments with only 2 percent mortality. FalTriclo had no long term effect on any size class of BHS. It, unlike the other herbicides, was apparently not adequately absorbed, translocated, or metabolized by BHS at the lower air temperatures encountered in the early November application to be effective. Air temperatures gradually declined through the last half of October 2002. Nighttime temperatures dropped to 30 °F, 23 °F, and 31 °F for the three successive nights preceding the November 2, 2002 application date, while the daytime highs ranged from 41 to 50 °F. Following treatment application, temperatures remained relatively cool with daytime highs in the mid-40 °F range and nighttime lows ranging from 29 to 42 °F for three successive days. Warmer temperatures followed this through the middle of November. Although leaf abscission did not begin until mid-to-late November, BHS leaf color was just beginning to yellow in early November at this latitude. Most native vegetation was dormant by the treatment application date.

The spring foliar treatment application dates were immediately preceded and followed by daytime highs ranging from 44 to 75 °F and nighttime low temperatures ranging from 61 to 25 °F. BHS shrubs were fully leafed out at this time, while most native woody species were still dormant or were only initiating bud break. A few native herbaceous plants were emerging.

Year 2 BHS inventory data for size classes 2 and 3 combined showed no significant changes from year 1 data for any of the low volume foliar treatments (fig. 5). Resprouting of top-killed BHS was rare to nonexistent in year 2.

Basal Treatment Comparisons

Full basal herbicide applications were most practically used to treat the two larger size classes (classes 3 and 4) considered in this study. This treatment resulted in 15 percent 1st year mortality in size class 4 shrubs and 40 percent 1st year mortality in size class 3 shrubs (fig. 6). In addition to 1st year mortality,

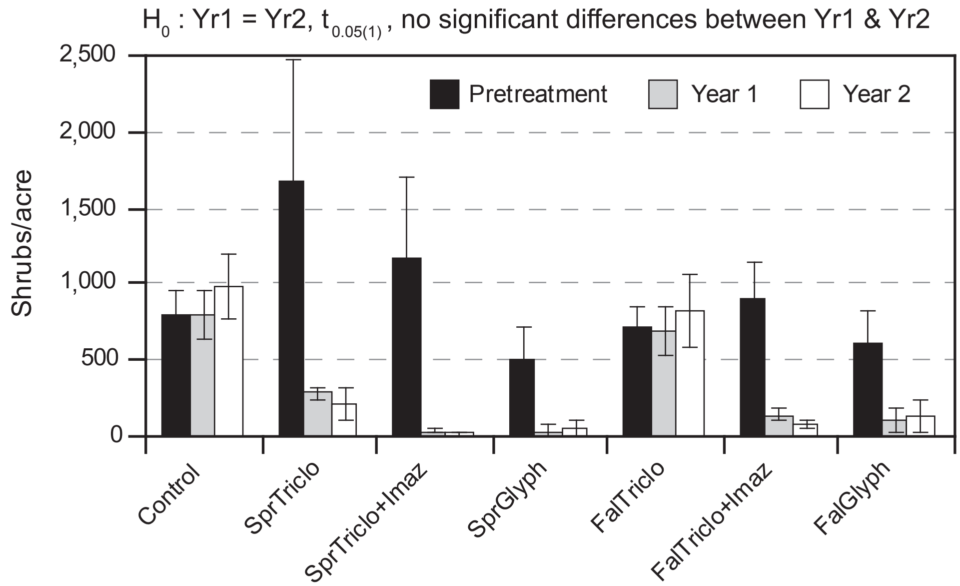

Figure 5—Mean pretreatment, year 1, and year 2 Asian bush honeysuckle populations of size classes 2 and 3 (2–8 feet tall) combined by low-volume foliar herbicide treatments in a west-central Indiana hardwood forest.

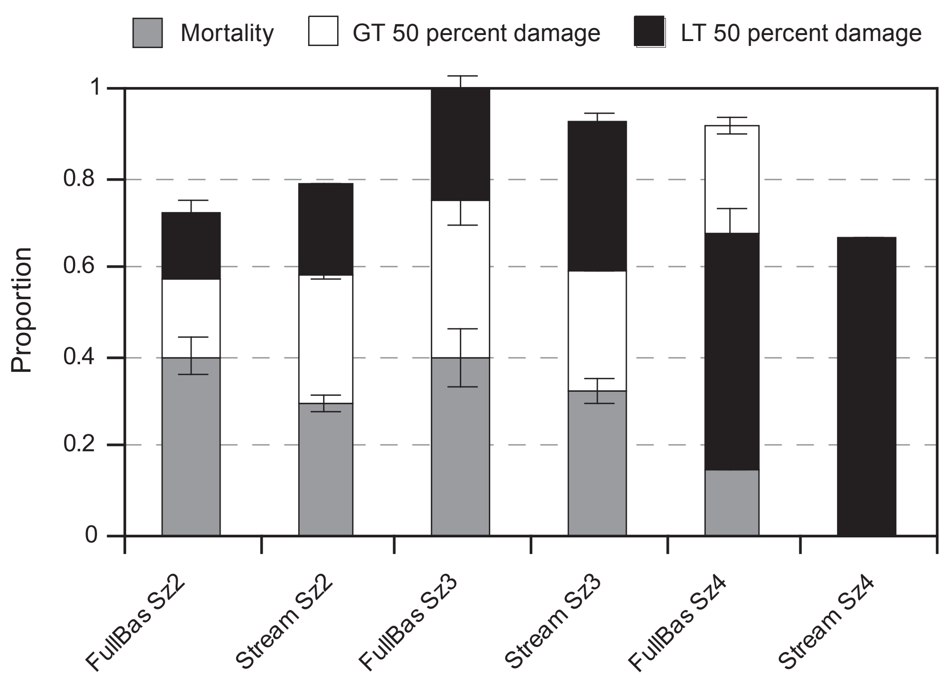

Figure 6—First-year Asian bush honeysuckle control mortality and damage for two basal bark herbicide treatments for size classes 2, 3, and 4 in a west-central Indiana hardwood forest. Mortality and damage are measured as the proportion of shrubs killed or damaged. Damage classes are: GT 50 percent = more than 50 percent of the crown with herbicide-inflicted damage; LT 50 percent = less than 50 percent of the crown with herbicide-inflicted damage, not including shrubs exhibiting no herbicide-related injury. Size classes are: 2 = 2–4.5 feet tall, 3 = 4.5–8 feet tall, 4 = over 8 feet tall.

full basal treatment inflicted greater than 50 percent crown damage to 35 percent and 52 percent of the shrubs in size classes 3 and 4, respectively.

Streamline basal applications were most efficiently used to treat small size classes. Streamline herbicide applications would not be expected to deliver enough herbicide to kill large BHS shrubs. Over 60 percent of class 4 size shrubs experienced light damage (<50 percent crown damage) from this treatment while none experienced heavy damage (>50 percent crown damage) or mortality. However, the streamline treatment did kill 30 percent and 32 percent of shrubs in size classes 2 and 3, respectively. This was not significantly lower than the levels of mortality inflicted by the full basal treatment. In addition, the streamline treatment produced >50 percent crown damage in 28 percent and 27 percent of the shrubs in size classes 2 and 3 respectively. Size class 1 shrubs had much lower efficacy rates for both basal treatments due to the operational difficulty of locating and individually treating such small shrubs.

There were no significant differences between year 1 and year 2 populations for any of the treatment by size class combinations.

Cut Stump Treatment Comparisons

Since cut stump treatments were only practical to apply to larger shrubs, only size classes 3 and 4 were analyzed for efficacy. Furthermore, size classes 3 and 4 were sufficiently similar in their responses to combine them into one class (4.5 - 8+ feet) for analysis.

There were no significant differences in the efficacy between the two cut stump treatments (fig. 7). Both achieved 100 percent control in class 4 size shrubs. Less than 100 percent control was achieved in class 3 shrubs only because of applicator error (both in cutting and applying herbicide). In extremely dense populations of bush honeysuckle, operational scale treatment usually results in less than 100 percent control in the first application.

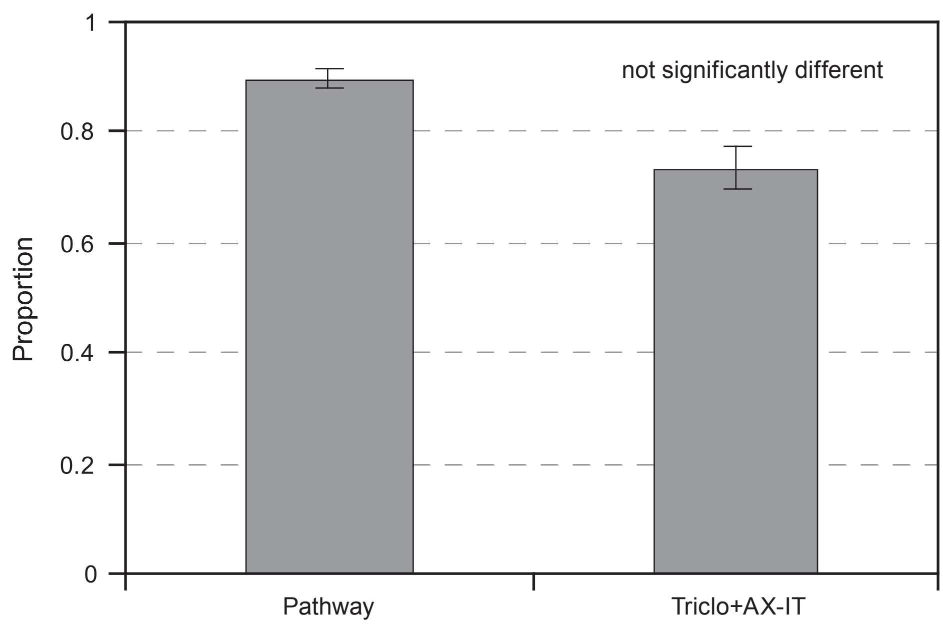

Figure 7—First-year Asian bush honeysuckle control mortality for two cut-stump herbicide treatments for size classes 3 and 4 (4.5–8+ feet tall) combined in a west-central Indiana hardwood forest. Mortality is measured as the proportion of shrubs killed.

Treatment Costs

Table 2 contains treatment labor time, herbicide application rates, and herbicide costs based on product retail prices. Labor costs were not provided as this can vary greatly between applicators. This data should be viewed as preliminary and is presented to provide a range of costs using these methods with the stocking and size distribution of BHS treated in this study. Assuming labor costs of a conservative $25 per hour, total costs ranged from $83 per acre on a low volume foliar glyphosate plot with comparatively lighter BHS stocking (884 BHS per acre less than 4.5 feet tall and 269 BHS per acre greater than 4.5 feet tall) to $383 per acre on a low volume foliar triclopyr plot with very heavy BHS stocking (2,500 BHS per acre less than 4.5 feet tall and 2,192 BHS per acre greater than 4.5 feet tall).

Table 2—Asian bush honeysuckle (BHS) control labor, herbicide application, and herbicide cost rates for an herbicide trial in an hardwood forest in west-central Indiana

Treatment[a]	Plot	BHS < 4.5 feet tall	BHS > 4.5 feet tall	Labor time	Herb. 1 concentr. applied	Herb. 2 concentr. applied	Herb. cost[a]
		- - - - numbers/acre - - - -		hours/acre	- - - gallons/acre - - -		$/acre
SprTriclo	1	962	115	1.5	0.64		47.45
SprTriclo	2	1,885	231	1.3	0.45		33.33
SprTriclo	3	2,538	2,192	10.0	1.80		133.21
SprTriclo+Imaz	1	2,461	962	8.2	1.19	0.050	103.71
SprTriclo+Imaz	2	769	577	5.7	0.78	0.033	68.09
SprTriclo+Imaz	3	115	423	3.4	0.53	0.022	45.99
SprGlyph	1	885	269	2.7	0.53		14.60
SprGlyph	2	1,461	500	3.5	0.62		17.08
SprGlyph	3	231	0	2.4	0.44		12.18
FalTriclo	1	846	385	1.3	0.27		20.17
FalTriclo	2	731	962	5.1	0.96		71.17
FalTriclo	3	615	385	6.5	1.24		92.17
FalTriclo+Imaz	1	1,231	308	2.3	0.27	0.011	23.15
FalTriclo+Imaz	2	808	577	1.3	0.24	0.010	20.95
FalTriclo+Imaz	3	423	269	1.7	0.20	0.008	17.18
FalGlyph	1	1,423	308	7.0	0.88		24.11
FalGlyph	2	77	192	2.7	0.34		9.39
FalGlyph	3	346	577	2.0	0.32		8.82
FullBasal	1	462	269	1.4	0.60		23.25
FullBasal	2	1,923	1,077	3.0	1.20		46.50
FullBasal	3	1,808	615	2.1	0.80		31.00
Streamline	1	1,077	615	2.3	0.42		16.43
Streamline	2	1,000	154	1.2	0.13		4.96
Streamline	3	1,308	654	2.1	0.38		14.57
CSPathway	1	3,038	654	6.5	2.68		21.16
CSPathway	2	500	654	6.3	2.60		20.53
CSPathway	3	77	308	3.5	1.00		7.90
CSTriclo+AX-IT	1	2,154	846	6.1	0.62		23.87
CSTriclo+AX-IT	2	1,000	154	1.7	0.15		5.89
CSTriclo+AX-IT	3	154	346	2.3	0.25		9.61

[a] See text for individual treatment definitions.

CONCLUSIONS

The development of BHS control prescriptions should be based on BHS stocking and size distributions, as well as overall forest stand conditions and management priorities, such as the importance of protecting native vegetation. Low volume foliar treatments were effective across a broad range of BHS shrub sizes up to 8 feet tall. Cut stump treatments were most effective and practical for BHS exceeding 4.5 feet tall.

All low volume foliar herbicide combinations, triclopyr, triclopyr + imazapyr, and glyphosate, were equally effective at controlling two to eight feet tall BHS in both early spring and late fall applications, except triclopyr applied in the late fall, which was completely ineffective. Both basal bark applications of 20 percent triclopyr in AX-IT basal oil provided inconsistent and poor control. The streamline method of basal bark application was nearly as effective as the full basal bark application, however, for BHS up to 8 feet tall. More research is needed to develop effective prescriptions for this potentially valuable method of controlling large BHS. Both cut stump treatments, Pathway and 20 percent triclopyr in AX-IT, were equally effective in controlling BHS taller than 4.5 feet.

Once appropriate herbicide delivery methods are chosen the choice of specific herbicide combinations is largely one of comparative costs and potential risks to native vegetation. For instance, the two cut stump treatment herbicides were comparable to one another in cost and effectiveness, but the triclopyr + AX-IT poses less risk to sensitive native species than does Pathway.

BHS control costs were proportionate to BHS stocking and size distribution. In more lightly stocked BHS stands, control costs were in the range of those associated with timber stand improvement (TSI) in the region and could potentially be done in conjunction with scheduled TSI operations. In heavily stocked BHS stands, costs far exceeded those expected for intensive TSI operations. Mechanization of control applications where they are feasible should reduce costs.

ACKOWLEDGMENTS

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COTTONWOOD LEAF BEETLE CONTROL WITH IMIDACLOPRID SOAKED CUTTINGS

Terry L. Robison and Randall J. Rousseau[1]

Abstract—Dormant, unrooted cuttings from three eastern cottonwood (*Populus deltoides* Marsh.) clones were soaked in either water or one of two concentrations of Admire® 2 Flowable (imidacloprid) insecticide. Half were planted immediately after soaking while the other half were stored for 12 weeks at -2°C prior to planting. Trees from cuttings soaked in either the 0.053 or 0.106 percent imidacloprid solutions were significantly taller at each measurement date and had lower levels of insect feeding than trees from cuttings soaked in water. Insect feeding on shoot terminals was limited almost entirely to the control trees (water soaked). Treatment effects lasted for over 14 weeks, but insect population levels were low at the end of the growing season limiting damage. In a related observational study, imidacloprid treatment effects seemed to carry into June of the second growing season.

INTRODUCTION

Cottonwood leaf beetle (*Chrysomela scripta* F.) is a major defoliator of *Populus* plantations (Abrahamson and others 1977, Burkot and Benjamin 1979, Coyle and others 2005) with preferred clones containing parentage from the Aigeiros or Tacamahaca sections (Caldbeck and others 1978, Harrell and others 1981, Bingaman and Hart 1992). Both cottonwood leaf beetle (CLB) adults and larvae feed on young leaves, with larvae causing the most damage. When population numbers are high, larvae may completely consume young leaves and shoot tips. Because CLB have up to five generations per year (Coyle and others 2005), high population levels can be attained quickly under favorable conditions (Bingaman and Hart 1992) such as warm, extended growing seasons (Mattson and others 2001). Near the confluence of the Mississippi and Ohio Rivers, we have observed intense CLB feeding pressure from bud break throughout the growing season.

Eastern cottonwood makes its most rapid growth during the first three years after planting. Plantations are particularly susceptible to CLB infestations during this period because of the high percentage of succulent leaf and stem tissue (Bingaman and Hart 1992, Coyle and others 2005, Fang and Hart 2000). An artificial defoliation study showed that during the first two growing seasons *Populus* growth and biomass may be reduced by one-third when defoliation reaches 75 percent (Reichenbacker and others 1996). Recent field studies indicate that heavy CLB defoliation (approaching 100 percent) during the first two years resulted in height and diameter growth losses greater than 50 percent (Mattson and others 2001, Coyle and others 2002).

Carbofuran, chlorpyrifos, carbaryl, dimethoate, and various *Bacillus thuringiensis* Berliner (*Bt*) endotoxin formulations have been effective in controlling CLB (Coyle and others 2000). Carbofuran provided long-term control of CLB and other cottonwood pests such as the cottonwood borer (*Plectodera scalatum*) because of its long soil residual and systemic activity. However, this chemical is no longer labeled for use on cottonwood. Carbaryl, chlorpyrifos, and dimethoate are labeled for CLB control, but mounting pressure to further restrict these pesticides may limit their use. *Bt* products (Coyle and others 2000) and carbaryl are highly effective, but their residual activity is low and repeated applications are needed to maintain adequate control levels. Application timing is critical, and often insecticides are applied after substantial damage has occurred. Residual and systemic actions are desirable insecticide traits.

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Studies in the Pacific Northwest indicate Admire® 2 Flowable (imidacloprid), also a systemic insecticide, applied through drip systems was highly effective in reducing population abundance of CLB and aphids [*Phylloxerena popularia* (Pergrande)] (Unpublished data, Douglas Walsh, Department of Entomology, Washington State University, Irrigated Agriculture Research and Extension Center, Prosser WA). These results were used to obtain a supplemental label for Admire® 2 Flowable for use on *Populus* in Oregon and Washington.

Imidacloprid was introduced in the early 1990s as the first chloronicotinyl insecticide. It disrupts an insect's nervous system by acting as a competitive inhibitor at nicotinic acetylcholine receptors (Liu and Casida 1993). It is the most widely used insecticide in the world with various formulations used in over 120 countries on more than 250 crops (Personal communication. 2004. David Rogers, Product Development Manager, Bayer CropScience, Product Development, P.O. Box 12014, Research Triangle Park, NC). The wide acceptance is founded on the effectiveness of the chemical, the safety to its handlers, and its enhanced environmental safety. Studies show imidacloprid undergoes complete biotic degradation in the soil, degradation is enhanced by sunlight, there is little soil accumulation even with repeat applications, and it does not persist in aqueous environments (Krohn and Hellpointner 2002). It is highly toxic to bees and house sparrows; moderately toxic to aquatic invertebrates, upland game birds, and earthworms; and slightly to not toxic to fish and waterfowl (Anon. 2003, Elbert and others 1990, U.S. Environmental Protection Agency 1994).

"Seed-piece" soaking is used for treating sugarcane stalks, *Saccharum* sp., and seed potatoes (*Solanum tuberosum* L.) with imidacloprid prior to planting. In these cases, the sugarcane stem section or potato "seed-piece" serves as the reservoir for the chemical instead of the soil. This method may work similarly with dormant, unrooted cottonwood cuttings. Cost per cutting would be substantially less using this method versus applying imidacloprid directly to the soil. Moreover, potential toxic effects to bees, birds, and fish would be minimized. Because this application method has not been tested previously on cottonwood, we evaluated its use on a sample of operational clones to determine its effectiveness and detect potential harmful effects such as reduced survival. Because storage times for operational cuttings can vary from zero to 25 weeks, we also wanted to test the effects of storage on chemical stability and insect control.

PROCEDURES

The study was located on an unprotected (located between levee and Mississippi River), alluvial site in Pemiscot County, Missouri that was previously in row crops. The soil is Commerce silty clay loam, which is considered excellent for cottonwood growth. Site preparation consisted of disking followed by row marking and sub-soiling at 3.66 m intervals. The experiment was arranged in a factorial design with randomized complete blocks. Cottonwood clones (3 clones), planting dates (2 dates), and Admire® 2 Flowable solution concentrations (3 levels) were the three factors combining for a total of 18 treatments. A nine-tree row plot represented each treatment in each block for a total of 72 plots. A three-tree border planted with untreated cuttings separated plots. Dormant, unrooted cuttings from three MeadWestvaco clones (WV000099, WV000413, and WV000426) were submerged for 17 hours in 0, 0.053, or 0.106 percent Admire® 2 Flowable solutions. To verify stability of the insecticide, one-half of the cuttings were planted immediately after soaking (February 27, 2004), and the other half were planted after approximately 12 weeks of storage at -2°C (May 21). Cuttings were planted at intervals of two feet along the sub-soiled rows.

Insect presence and leaf feeding damage were assessed every seven to 25 days to evaluate treatment effects. Assessment began on May 12 and June 3 for the first and second planting dates, respectively, and lasted through October 6. Total height was measured to the nearest 0.1 m on July 15, September 1, and October 6. CLB presence was recorded using the following categories:

0 = no insects
1 = CLB eggs
2 = 1st instar
3 = 2nd instar
4 = 3rd instar
5 = adult
6 = other feeding insect

Feeding damage was rated on the top eight leaves (LPI 1-8) (Larson and Isebrands 1971) using the following scale (Coyle and others 2002, Fang and Hart 2000):

0 = no feeding on LPI 1-8
1 = light feeding; sample feeding to < 33 percent LPI 1-8 missing
2 = light to moderate feeding; 33-50 percent of LPI 1-8 missing; main leader intact
3 = moderate to heavy feeding; 50-75 percent of LPI 1-8 missing; main leader intact
4 = heavy feeding; > 75 percent of LPI 1-8 missing; main leader and terminal bud heavily damaged or destroyed

Arcsine transformations of individual plot proportions were computed for insect presence, substantial feeding damage (score >2), and terminal damage (score =4) on all survey dates and for end of year survival. Analysis of variance for arcsine transformations and height data were generated using PROC GLM, SAS/STAT software (Version 8.1 of the SAS System for Windows. Copyright ® 1999-2000 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Survival

On October 6, 2004, overall test survival was 92 percent. Significant survival differences were detected for planting date (P<0.01) and clone (P<0.001). Survival for the February 27 planting was 94 percent but dropped to 90 percent for the May 21 planting date. The decrease in survival is more likely related to environmental conditions at the May planting date than to cutting storage conditions. Overall clone survival was 98, 96, and 82 percent for WV000099, WV000413, and, WV000426, respectively. Based on previous experience, the decreased survival for clone WV000426 is an anomaly, and may have resulted from poor handling or improper storage prior to assembling the test. Most important, no differences were detected for survival of any clone at the various Admire® 2 Flowable concentrations (P>0.99), which indicates that the chemical had no detrimental effects on this sample of operational clones at these concentrations.

Height Growth

Height was significantly greater (P<0.001) for trees receiving either Admire® 2 Flowable treatment than control trees at all measurement dates for both planting dates (fig. 1). The 0.053 percent and 0.106 percent treatments did not differ from each other on any measurement date. End-of-season heights for treated trees averaged 30 to 60 cm greater than control trees for the early-planted and late-planted trees, respectively. No second or third order interactions were significant, but heights varied significantly among clones at the final measurement date (P<0.01). Regardless of soaking treatment concentration, WV000099 was taller than the other two clones at each measurement date for each planting date, and the difference became greater later in the season (fig. 2).

CLB Populations and Feeding Damage

Insects first appeared in noteworthy numbers around May 21 on trees planted February 27, approximately one month after bud break (table 1). Initially, insecticide treated plots had fewer trees with CLB than the control plots. In June, CLB levels increased dramatically, and we found CLB on nearly all treated trees and on 79 percent of the control trees during the June 21 survey. The lower CLB presence may have

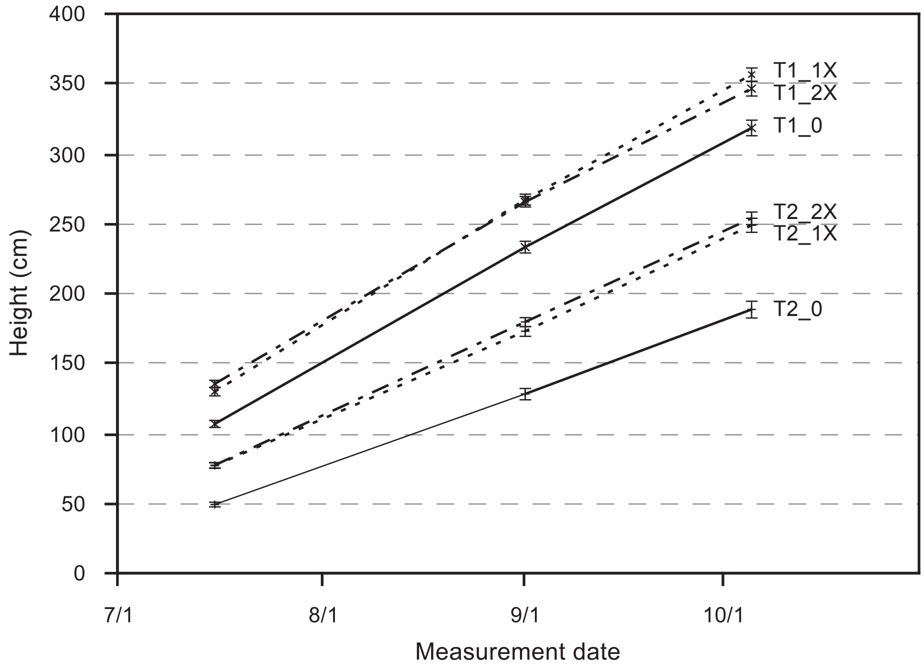

Figure 1—Mean height by planting date (T1 = 2/27/04 top three lines; T2 = 5/21/04 bottom three lines) and Admire® 2 Flowable soaking concentration (0 = 0 percent, 1x = 0.053 percent, 2x = 0.106 percent) for all trees. Bars indicate mean standard error.

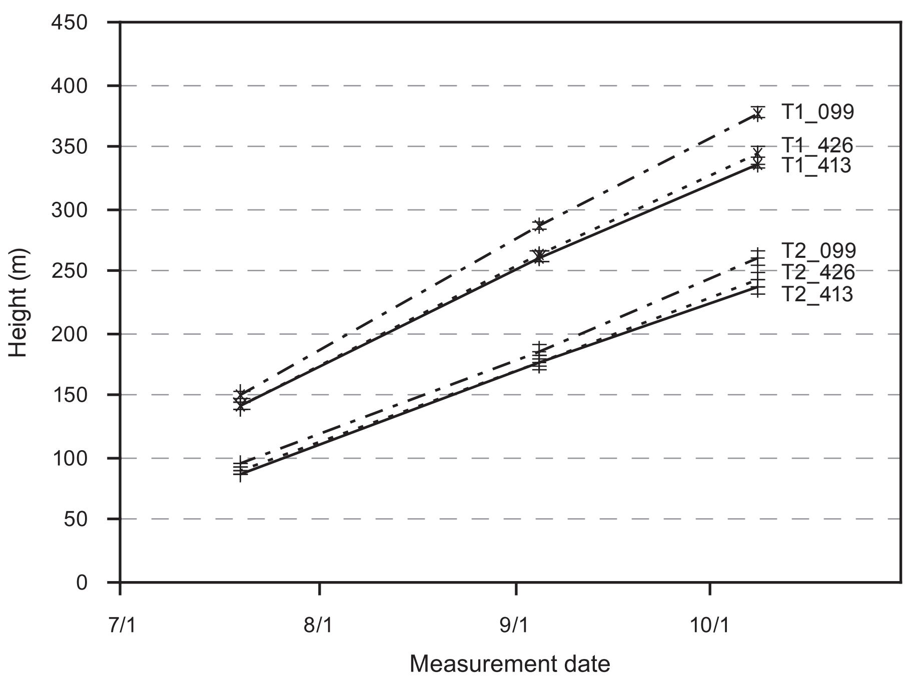

Figure 2—Mean height by planting date (T1 = 2/27/04 top three lines; T2 = 5/21/04 bottom three lines) and clone (WV000413, WV000426, and WV000099). Bars indicate mean standard error.

Table 1—Mean percent trees with leaf–feeding insects, with feeding damage score > 2 (affecting 33 percent of top eight leaves), and with feeding damage score > 4 (terminal shoot damage) for trees treated with either 0 percent, 0.053 percent, or 0.106 percent Admire® 2 Flowable insecticide and planted February 27, 2004 (clones were combined for this analysis)

	Trees with leaf–feeding insects (mean %)			Trees with feeding damage score > 2 (mean %)			Trees with feeding damage score = 4 (%)		
	Admire® 2 Flowable soaking solution concentration								
Date	0	0.053%	0.106%	0	0.053%	0.106%	0	0.053%	0.106%
May 12	1a	0a	0a	1a	0a	0a	0a	0a	0a
May 21	54a	28b	15c	9a	0b	0b	3a	0b	0b
May 26	60a	35b	31b	13a	0b	2b	4a	0b	0b
June 3	60ab	67a	53b	30a	2b	1b	5a	0b	0b
June 10	85a	87a	77a	37a	3b	2b	3a	0b	0b
June 21	79a	97b	99b	100a	94ab	83b	40a	3b	2b
July 6	37a	33a	22b	38a	27ab	12b	5a	0b	0b
July 15				23a	4b	7b	1a	0a	0a
August 4	4a	2a	2a	2a	0a	0a	0	0	0
September 1	35a	39a	31a	0a	1a	0a	0	0	0
September 16	26a	22a	21a	1a	0a	0a	0	0	0

Note: mpty cells indicate data not collected for that variable and date.
For a particular date and variable, means followed by the same letter are not significantly different (0.05) using Tukey's HSD.

resulted from increased terminal damage on control trees resulting in less desirable leaf tissue available to CLB than on the less damaged, treated trees. In early August, levels dropped and remained low until an outbreak of CLB in early September. During the October 6 height measurements, CLB levels were very low and incidence data were not collected.

Cuttings planted May 21 developed quickly with bud break initiating within one week. CLB populations were low on the developing cuttings, but from June 3 to June 21 the percentage of trees with CLB climbed steadily on the control trees to over 80 percent (table 2). Less than 30 percent of the treated trees (either concentration) had CLB at this date. As with the February planted trees, CLB populations then dropped until an outbreak in early September when fewer control trees had CLB than the treated trees.

Substantial feeding damage was defined as occurring when CLB feeding affected more than 33 percent of the top eight leaves (feeding damage scores ≥ 2). Throughout the season, the percent of trees with substantial feeding damage was always greater on control trees than on treated trees for both planting date with the 0.106 percent treatment showing the least damage in most instances. For the trees planted in February, feeding damage on treated trees approached that of the control trees only in late June and early July when CLB populations were the highest (table 1). On June 21, 100 percent of the control trees had feeding damage while 94 percent and 83 percent of the 0.053 percent and 0.106 percent treatment trees, respectively, had damage. Damage to insecticide treated trees planted in May was always much lower than the control trees except late in the year when feeding damage was found on less than 10 percent of trees across treatments (table 2).

Regardless of planting date, very few trees in the 0.053 percent or 0.106 percent treatments had terminal damage (feeding score = 4) indicating that Admire® 2 Flowable nearly eliminated heavy CLB feeding in

Table 2—Mean percent trees with leaf–feeding insects, with feeding damage score > 2 (affecting 33 percent of top eight leaves), and with feeding damage score > 4 (terminal shoot damage) for trees treated with either 0 percent, 0.053 percent, or 0.106 percent Admire® 2 Flowable insecticide and planted May 21, 2004, after 12 weeks of storage at -2 °C (clones were combined for this analysis)

	Trees with leaf–feeding insects (mean %)			Trees with feeding damage score > 2 (mean %)			Trees with feeding damage score = 4 (mean %)		
	Admire® 2 Flowable soaking solution concentration								
Date	0	0.053%	0.106%	0	0.053%	0.106%	0	0.053%	0.106%
June 3	1a	0a	0a	0	0	0			
June 10	30a	5b	2c	5a	0b	0b	0	0	0
June 21	81a	28b	28b	64a	0b	0b	19a	1b	0b
July 6	30a	19a	21a	52a	1b	0b	11a	0b	0b
July 15				29a	1b	0b	6a	0b	0b
August 4	2a	4b	6b	4a	1b	3ab	2a	0b	1ab
September 1	43a	49ab	60b	9a	3b	4b	1a	0a	0a
September 16	31a	16b	16b	13a	3b	4b	3a	0b	0b

Note: empty cells indicate data not collected for that variable and date.
For a particular date and variable, means followed by the same letter are not significantly different (0.05) using Tukey's HSD.

this study (tables 1 and 2). Even during the June 21 survey date when population and feeding levels were high, terminal feeding remained low on treated trees. These observations indicate that imidacloprid is directed to the growing points of the plant and concentrated in the actively growing shoot tips. These data and observations show that imidacloprid does not prevent CLB from colonizing cottonwood leaves. The beetles are often found in large numbers on treated trees, but their feeding activity is limited, especially at the actively growing shoot tips.

Observations

Both Admire® 2 Flowable soaking treatments resulted in reduced feeding damage, especially terminal damage, and increased height growth compared to the control. CLB control lasted at least through July 15 as indicated by the reduced levels of damage and terminal feeding on treated trees compared to the controls. This translates to almost 14 weeks of control from bud break for the first planted trees. Reduced CLB numbers and damage levels throughout the test later in the growing season made it difficult to determine whether CLB control continued longer in this test. In other crops, the length of control is related to application rates, and it may be possible to extend control past 14 weeks using higher solution concentrations (Personal communication. 2004. David Rogers, Product Development Manager, Bayer CropScience, Product Development, P.O. Box 12014, Research Triangle Park, NC). Indeed, trees treated with 0.212 percent Admire® 2 Flowable in an observational trial near Wickliffe, Kentucky had far less CLB damage than controls through June of the second growing season.

Leaves on treated trees appeared glossy compared to control tree leaves especially during the first one-third of the growing season. This appearance was also observed in the observational trial. Bayer CropScience supports this observation indicating that along with the healthier appearance of plants, yield data shows that when compared to other insecticides, Admire® 2 Flowable enhances growth of other crops beyond that attributed to insect control (see www.BayerAdmire.com). In our study, the low to moderate CLB populations during the growing season might imply that the growth enhancement for treated trees could be attributed partially to the insecticide treatments. More detailed studies comparing growth rates using this and other insecticides are needed to determine if this is true for cottonwood.

The effectiveness of soaking treatments regardless of planting date indicates that time in cold storage did not degrade the insecticide once imbibed by the cuttings. Moreover, the first planted cuttings were in the ground for almost two months prior to growth initiation. The chemical apparently was not leached or otherwise degraded during this period. Both of these observations are consistent with manufacturer claims regarding low volatilization, tight soil binding, and slow breakdown in the absence of light. The tight soil binding characteristics seem to be reflected in the binding within the cuttings.

Cost Analysis

Admire® 2 Flowable is an expensive insecticide for forestry use considering the 473 to 976 mL/ha rates currently recommended for cottonwood when applied through drip irrigation or when knifed into the soil. At $153/L, these methods cost $180 to $358/ha for the chemical alone suggesting that it should be used only on high-value plantings such as nurseries. However, the soaking treatment described herein reduces the chemical cost to $2.55/ha using a 0.106 percent solution concentration and the highest uptake rate calculated from pre- and post-soaking cutting weights (21 mL solution per cutting). At a spacing of 3.66 m square, this translates to less than 16.7 mL/ha Admire® 2 Flowable at a cost of $0.0034 per cutting. The cost of handling, including soaking tank development, will increase the actual application cost.

An improved chemical formulation has been released with an expanded label that includes methods described in this paper. The new product formulation, Admire® Pro Systemic Protectant, provides better mixing properties eliminating foaming and tank residue.

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DOWN DEADWOOD DYNAMICS ON A SEVERELY IMPACTED OAK DECLINE SITE

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Abstract—Following a 3-year drought from 1998 to 2000, oak decline symptoms began to appear throughout many parts of the Ozark Highland region of Arkansas and Missouri. Changes in down deadwood that occurred at one site during the oak decline event are described and discussed. In 2000, 24 deadwood measurement plots 0.2025 ha (45 m by 45 m) in size were established. The down deadwood on all plots was remeasured in the spring of 2005. Because 6 plots were burned in March of 2004, changes on only 18 of the 24 plots are considered. In each inventory, all down dead woody material with a diameter of 10 cm or greater was measured on each plot. Changes in volume occurred across the site. Overall, median total volume increased from 15.8 m^3/ha to 22.9 m^3/ha ($p = 0.016$). Down woody material was further divided into decomposition classes 1 through 5, where class 1 represents the least decomposed and class 5 represents the most decomposed material. Decomposition class 1 increased from a median of 0 m^3/ha in 2000 to 0.13 m^3/ha in 2005 ($p = < 0.001$). Class 2 increased from a mean of 2.1 m^3/ha in 2000 to 4.7 m^3/ha in 2005 ($p = 0.013$). There were no significant changes in down deadwood volume for decomposition classes 3, 4, or 5. The number of pieces of down deadwood also increased from a mean of 184 pieces per ha in 2000 to 245 pieces per ha in 2005 ($p = 0.003$). Results show an increase in down deadwood input. However, at this stage increases are generally in the smallest, least decomposed material on this dry and rocky site. The diameters of down deadwood pieces are small because inputs are mostly from branches and small trees. Most large trees that died have remained standing.

INTRODUCTION

Large-scale oak mortality events have likely occurred for as long as there have been oak-dominated forests. Fifty-seven oak mortality events have been recorded in the eastern United States between 1856 and 1986 (Millers and others 1989). These include one in 1959 in the Ozark Mountains of Arkansas (Toole 1960), one in 1980-1981 in northwestern Arkansas (Bassett and others 1982, Mistretta and others 1984), and mortality that occurred in Missouri from 1980 to 1986 (Law and Gott 1987). The current oak decline event in Arkansas and Missouri has severely affected up to 120 000 ha in the Ozark National Forest of Arkansas alone (Starkey and others 2004).

In the Eastern U.S., oak decline is considered a complex set of interactions involving many factors (Wargo and others 1983). Manion (1991) describes it as resulting from the interaction of three major groups of factors: predisposing factors, inciting factors, and contributing factors. Predisposing factors include tree physiologic age and tree density, soil conditions, and topography; inciting factors include drought and defoliating insects; and contributing factors include opportunistic insects (such as some wood boring insects) and diseases, e.g., *Hypoxylon* canker (*Hypoxylon atropunctatum*).

A 3-year drought, an inciting factor of oak decline according to Manion (1991) and Starkey and others (2004), occurred across the Interior Highlands region of Arkansas and Missouri from 1998 to 2000. This, coupled with the fact that it occurred in a forest with high tree density and mature trees, made Arkansas' upland hardwood forests especially vulnerable to oak decline (Oak and others 2004).

An oak decline event of this magnitude has the potential to significantly alter forest structure. One important consequence of such an event is its effect on the amount and quality of coarse woody debris. Living trees complete only a portion of their ecological role by the time they die (Franklin and others 1987). Coarse woody debris from dead and dying trees provides important habitat for forest organisms

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(Cain 1996, Larson 1992, Maser and others 1988, Meyer 1986, Muller and Yan Liu 1991, O'Neill 1967, Thomas and others 1979, Van Lear 1993), provides both habitat and energy for detritivores (Lang and Forman 1978), and serves as a reservoir for nutrients and carbon (Bray and Gorham 1964, Harmon and others 1986, Edmonds 1987, Huston 1996, Lang and Forman 1978, Maser and others 1988).

The amount of living biomass in a dead log may be greater than that in a live tree (Franklin and others 1987). Meyer (1986) lists snags and down wood in Missouri as habitat for 26 bird species, 11 reptiles, 11 mammals, and 9 amphibians. In the Blue Mountains of Oregon and Washington, 39 bird and 23 mammal species use standing dead trees for nest sites and shelter (Thomas and others 1979). At least 98 species of land snails are associated with log habitats in the southeast (Caldwell 1996). In southern hardwood and pine forests, 45 bird species use standing dead trees and 20 bird species that use down woody debris (Lanham and Guynn 1996). In the southeast, at least 23 mammal species use standing dead trees and at least 55 mammal species use down wood (Loeb 1996). Ausmus (1977) found greater organic matter content, nematode density, and root biomass in soil beneath log litter than under leaf litter. Reptiles and amphibians are associated with coarse woody debris, and it has been suggested that their diversity may be linked with the quality and amount of coarse woody debris (Whiles and Grubaugh 1996). Earthworms use deadwood for cover and as a source of food from microbial biomass (Hendrix 1996). Additionally, a study by Barnum and others (1992) found that mice selected logs as the most widely used substrate for travel. However, little is known about inputs of deadwood during a severe oak decline event.

Initially, all 24 plots in this study were intended to be part of one replication of a large, periodic, prescribed fire study. However, by the summer of 2001 oak decline symptoms were evident at the site (Spetich 2004), and the site became the center of a local patch of severe oak decline covering hundreds of hectares in northwestern Pope County, AR. At that point, this site was designated for a long-term case study of oak decline forest dynamics. Although this meant the temporary loss of one replication of the original study, it provided a serendipitous opportunity to examine oak decline dynamics using detailed early data.

The objective of this phase of the study was to examine the dynamics of down deadwood from 2000 to 2005. The study's long-term objective is to compare stand dynamics among areas treated with a growing-season prescribed fire, a dormant-season prescribed fire, and a control area.

STUDY SITE

The study site is a 32-ha area in an upland oak-hickory (*Quercus-Carya* spp.) stand that was approximately 75 years old in 2005. It is located in the Boston Mountains of Arkansas, part of the southern lobe of the Central Hardwood Region (Merritt 1980). The Boston Mountains are the highest and most southern member of the Ozark Plateau Physiographic Province (Croneis 1930). They form a band 48 to 64 km wide and 320 km long from northcentral Arkansas westward into eastern Oklahoma. Elevations range from about 275 m in the valley bottoms to 760 m at the highest point. The plateau is sharply dissected. Most ridges are flat to gently rolling and generally are less than 0.8 km wide. Mountainsides are alternating steep simple slopes and gently sloping benches. Vegetation across the landscape is a forest matrix with non-forest inclusions.

More specifically, the study site is located in the northwestern corner of Pope County, approximately 3 km southeast of Sand Gap, Arkansas. The stand is dominated by oak and hickory and has become the center of a local patch of oak decline. In August 2000, mean basal area for all standing trees was 25.9 m^2/ha, and there were 417 standing trees/ha of which 1.8 m^2/ha of basal area and 53 trees/ha were standing dead trees. Stocking was 88 percent.

METHODS

The study site was located in the fall of 1999. Twenty-four deadwood measurement plots were established with permanent plot markers during the winter of 2000. Each plot was 45 m by 45 m in size (0.2025-ha).

Down deadwood in the plots was measured in September of 2000 and remeasured in the spring of 2005. Because 6 plots were burned in March of 2004, changes on only 18 of the 24 plots are considered here. Electronic data recorders were used to record measurement data in the field.

In each of the 24 plots, all dead and down coarse woody debris ≥10 cm in diameter was measured (fig. 1). Each section was measured for length and midpoint diameter. Decomposition class of each section (hereafter referred to as a piece) was also recorded and classified into one of five decomposition classes (table 1). The length and midpoint diameter of each piece of down wood ≥10 cm in diameter within each plot were measured to the nearest 0.1 m and 1.0 cm, respectively. The formula for the volume of a cylinder was used to calculate the volume of each piece from the piece's measured length and midpoint diameter.

The data were analyzed using paired t-tests to compare 2000 plot values with 2005 plot values. In cases where the normality test failed, a Wilcoxon signed rank test was performed to compare median values.

RESULTS AND DISCUSSION

Total volume of down deadwood increased from a median value of 15.8 m^3/ha in 2000 to 22.9 m^3/ha in 2005 ($p=0.016$). However, only two of the decomposition classes showed statistically different volumes in 2000 and 2005. Decomposition class 1 increased from a median of 0 m^3/ha in 2000 to 0.13 m^3/ha in 2005 ($p=<0.001$). Class 2 more than doubled from a mean of 2.1 m^3/ha in 2000 to 4.7 m^3/ha in 2005 ($p=0.013$). There were no statistically significant changes in down deadwood decomposition classes 3, 4, or 5. However, mean values of both class 3 and 4 appeared to increase (fig. 2).

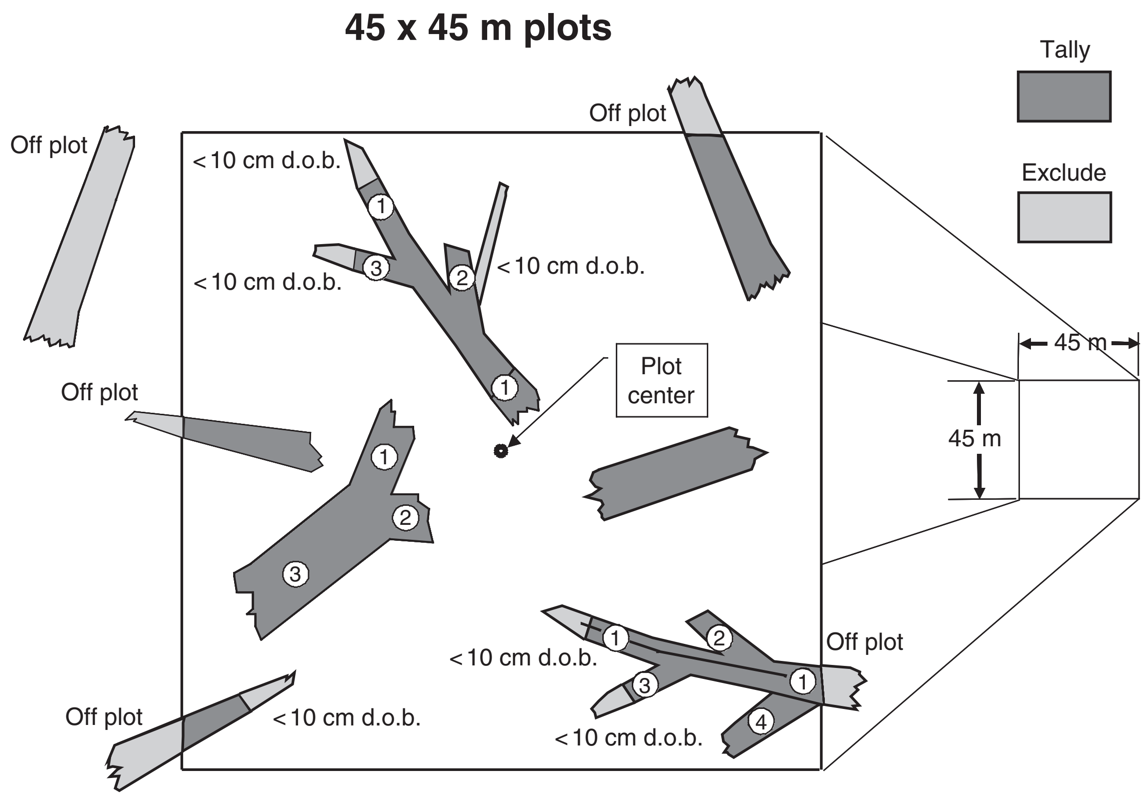

Figure 1—Layout of 0.02025 ha down deadwood measurement plot. Numbers indicate a section measured as one piece. All deadwood pieces ≥10 cm in diameter were measured for total length and midpoint diameter.

Table 1—Decomposition classes for down deadwood

Attribute	Decomposition class 1	2	3	4	5
Bark	Intact	Intact	Trace to absent	Absent	Absent
Twigs > 3 cm	Present	Absent	Absent	Absent	Absent
Texture	Intact	Intact, sapwood partly soft	Hard, solid interior, possible evidence of exterior decay	Soft, blocky pieces	Soft and powdery
Shape	Round	Round	Round	Round to oval	Oval
Color of wood	Original	Original	Original to faded	Original to faded	Heavily faded
Portion of log on ground	Log elevated on support points	Log elevated on support points	Log near or on ground	All of log on ground	All of log on ground

Numbers 1 through 5 indicate codes used for decomposition classes where class 1 is least decomposed and class 5 is most decomposed.
Adapted from Cline and others (1980) and Maser and others (1979).

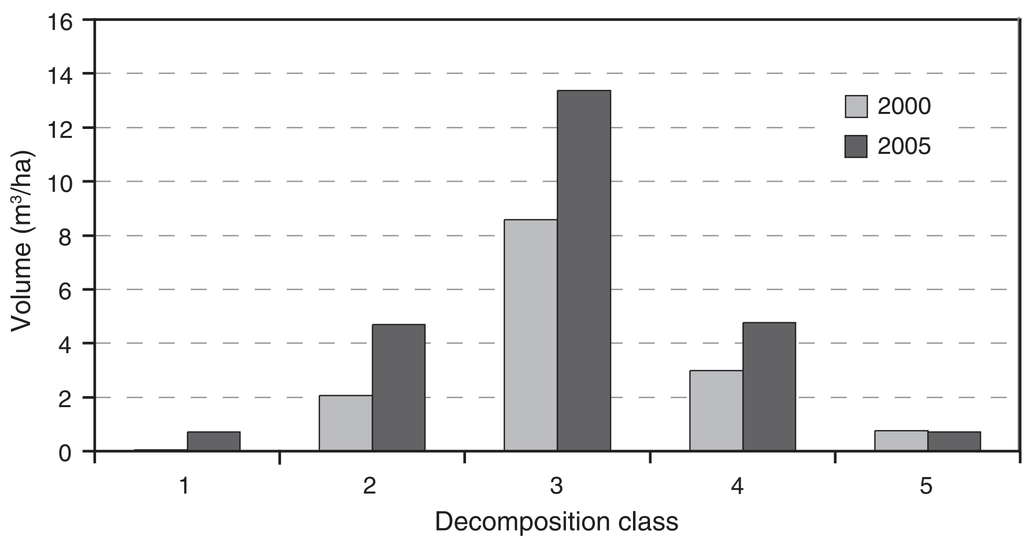

Figure 2—Mean volume of down deadwood by decomposition class (see table 1) and year for the down deadwood study in the Boston Mountains in Arkansas, n = 18.

Decomposition class 3 constituted the greatest proportion of down deadwood in both years. This is consistent with findings of other studies (Spetich and others 1999). One identifying characteristic of decomposition class 3 deadwood is lack of bark. Bark is often shed while the tree is standing or soon after the tree falls. Both Van Lear (1993) and Harmon and others (1986) suggest that when down wood loses bark early it dries quickly and may become case hardened, slowing the decay process. Additionally, fissures and excavations that develop in decomposition class 4 and 5 materials increase the total surface area and accelerate the rate of decay (Maser and others 1988).

In comparison, the average down deadwood volume for second-growth Central Hardwood forests is 20 m^3/ha (Spetich and others 1999). The mean values at the Arkansas site are below this value in 2000 and above it in 2005. As standing dead trees continue to fall, they will continue to add to down deadwood volume. Decomposition of these large woody materials progresses slowly. For example, MacMillian (1981) estimates that the average oak log takes 75 years to decay to 1/10 of initial density (density in grams dry weight per cubic cm fresh volume). Inputs of the relatively large stems of standing dead trees (up to 84 cm) at this oak decline site will likely provide nutrients, structure, and wildlife habitat for many years.

The number of pieces of down deadwood increased from a mean of 184 pieces per ha in 2000 to 245 pieces per ha in 2005 ($p = 0.003$). In both years the majority of pieces were in the smallest diameter classes, decreasing in number exponentially with increasing diameter (fig. 3). The negative exponential distribution of the number of pieces of down deadwood by diameter class is likely linked to a negative exponential diameter distribution of live trees. In 2005 the largest increase in the number of pieces per ha was in the smallest diameter class. Small-diameter wood is likely to lose its structural integrity sooner than are large pieces.

The volume of down deadwood per ha also decreased with increasing diameter, but not as quickly as did number of pieces per ha (fig. 4). In 2005 the largest increase was in the smallest diameter class. However, there was also a small increase in two larger diameter classes, 55 cm and 65 cm, due to a few fallen trees. The diameters of down deadwood pieces are generally small because inputs are mostly fallen branches

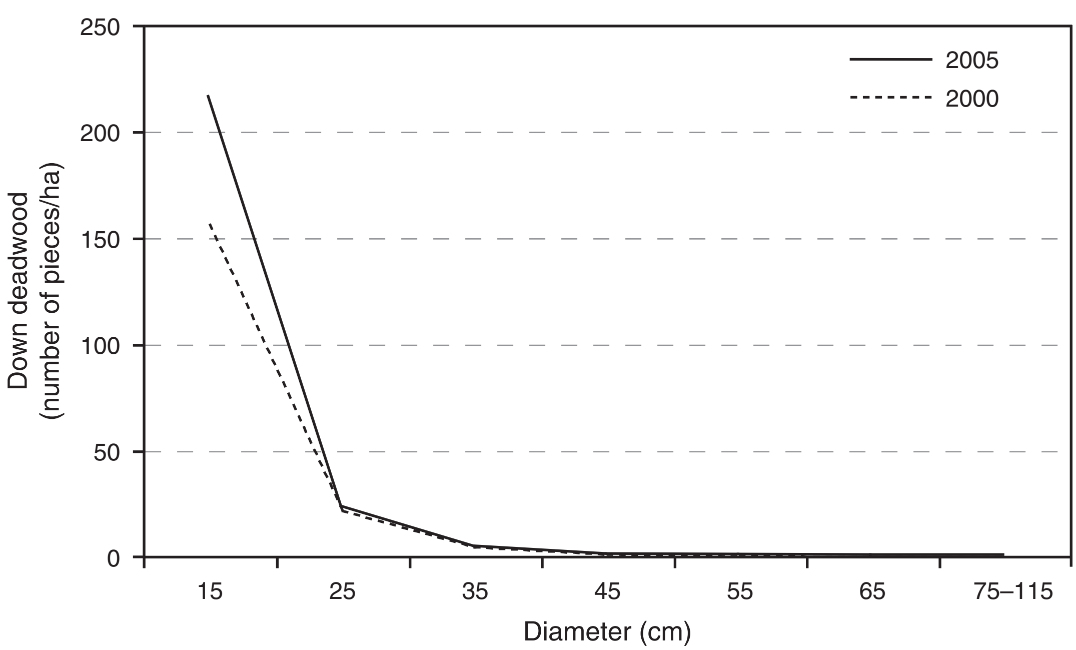

Figure 3—Number of down deadwood pieces per ha by 10-cm diameter class and year for the down deadwood study in the Boston Mountains in Arkansas, n=18.

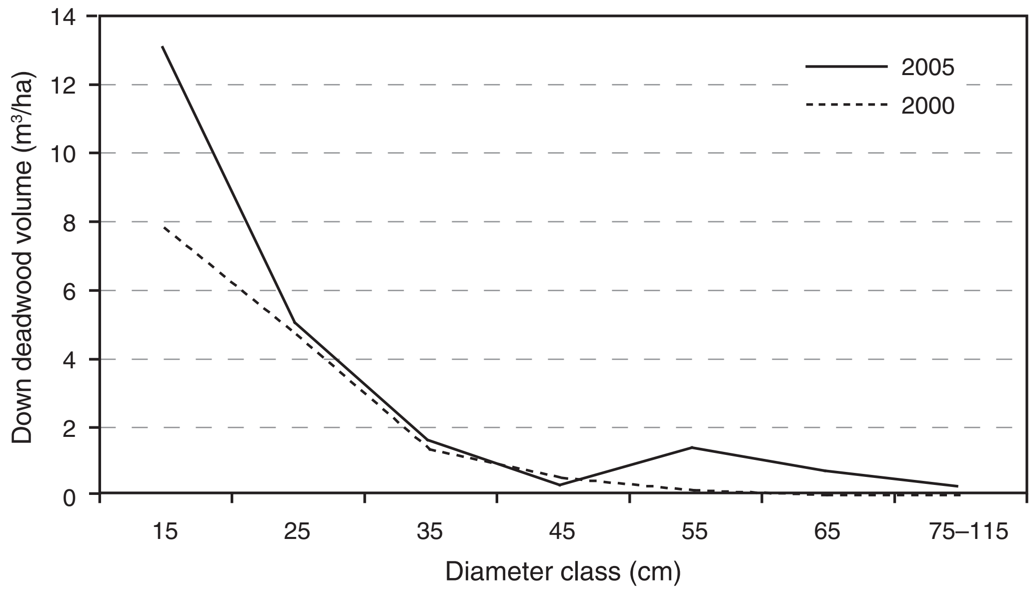

Figure 4—Down deadwood volume by 10-cm diameter class and year for the down deadwood study in the Boston Mountains in Arkansas, n = 18.

and fallen main stems of small trees. Although the 2005 overstory inventory was not completed by the time this paper was written, visual observations indicate that main stems of most large trees that died over the last 5 years remained standing.

Results show an increase in down deadwood input. However, at this stage increases are generally in the smallest, least decomposed material on this dry and rocky site. As main stems of the large dead standing trees fall they will continue to add to down deadwood for many years, likely changing the structure and dynamics of the down deadwood pool.

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DEFOLIATION AND OAK MORTALITY IN SOUTHERN NEW ENGLAND

Jeffrey S. Ward[1]

Abstract—Crown class and diameter of 4088 upland oaks have been monitored at 10-year intervals since 1927. Plots had three episodes of moderate to heavy defoliation: 1961-1964, 1971-1972, and 1981. Primary defoliators were gypsy moth, canker worm, and elm spanworm. Mortality peaked during the period of 1957-1967 when there were three years of defoliation. Mortality was higher for white oaks than red oaks, and higher for lower canopy trees than for upper canopy trees. Since the end of the multi-year defoliations in 1972, mortality rates for both species groups and all crown classes have fallen to pre-defoliation levels. Mortality was related to tree vigor for red oaks with higher mortality for slower growing trees. The longer term impact of multi-year defoliation events in oak dominated forests is to accelerate mortality of less vigorous oaks in the lower canopy and slower growing trees in the upper canopy.

INTRODUCTION

Gypsy moth (*Lymantria dispar*) has spread to at least seventeen eastern states since its accidental introduction outside of Boston in the late 1800's (Morin and others 2005). Gypsy moth is well established on the eastern and northern portions of the central hardwood region. Although the national "Slow the Spread" program has greatly reduced the rate of expansion (Sharov and others 2002), gypsy moth will probably be found throughout the region before 2050.

Gypsy moth has a wide host range (Liebhold and others 1995). However, increased mortality and reduced growth of oak (*Quercus* spp.) species have accounted for most of the economic and ecological damage caused by this alien pest. Mortality is usually highest for smaller trees in the lower canopy (suppressed and intermediate crown classes) than for larger trees (Brown and others 1979, Campbell and Sloan 1977, Kegg 1973, but see Stalter and Serrao 1983). Much of the mortality following defoliation has been attributed to secondary agents, such as twolined chestnut borer (*Agrilus bilineatus*) and shoestring root rot (*Armillaria mellea*), that attack weakened trees (Baker 1941, Dunbar and Stephens 1975).

The short term impacts of gypsy moth defoliation are well-documented. Oak diameter growth decreases by 30-60 percent during outbreaks (Baker 1941, Brown and others 1979, Campbell and Garlo 1982, Muzika and Liebhold 1999). Earlier studies noted that diameter growth and tree health recovered 2-10 years after heavy defoliation (Campbell and Garlo 1982, Campbell and Sloan 1977, Muzika and Liebhold 1999).

The objectives of this study were: (1) document the effect of multi-year defoliations on oak mortality and diameter growth, (2) analyze how mortality was influenced by crown and vigor classes, and (3) examine the longer term impacts (20+ years) of multi-year defoliations on mortality and growth of upland oaks.

STUDY AREAS

Study plots were the Cabin (40 acres), Cox (50 acres), and Reeves Tracts (40 acres) in Meshomasic State Forest, Connecticut. Most of the land was cleared for pasture or cultivation by the mid-1800's. The current forests developed following farm abandonment and cessation of charcoal cutting in the early 1900's. The forests were estimated to be 20 to 40-years-old in 1927 (Hicock and others 1931).

Stand composition and structures are typical of most second-growth forests, not only in central Connecticut, but of much of the eastern extension of the central hardwood forest. Upland oaks are predominant in the upper canopy. Upland oaks have accounted for more than half the upper canopy basal

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area since the first inventory (Ward and others 1999). The mean diameter of upper canopy trees increased from five inches in 1927 to over fourteen inches in 1997. Maple (*Acer* spp.) and birch (*Betula* spp.) are predominant in the lower canopy.

The plots are on the western edge of the Eastern Highlands of Connecticut, a region of metamorphic rocks and glaciated soils. The topography of the plots is gently rolling with elevations ranging from 300 to 550 feet above mean sea level. Soils are very stony to extremely stony, fine sandy loams derived from granite, gneiss, and schist glacial tills, and are acidic to strongly acidic (pH 4.5-6.0). The area is in the northern temperate climate zone with average annual precipitation of 44 inches.

Defoliation

The plots were subjected to three episodes of defoliation between 1961-1982. The guidelines of Gottschalk (1993) were used to describe defoliation severity in this paper: light (< 30 percent), moderate (30-60 percent), and heavy (> 60 percent). Aerial surveys indicated moderate to heavy defoliation of Cox, Cabin, and Reeves during 1961-1963 by gypsy moth and canker worm (*Paleacrita vernata*). The plots were heavily defoliated by gypsy moth and elm spanworm (*Ennomos subsignarius*) during 1971-1972. All plots were once again heavily defoliated by gypsy moth in 1981. Only Cabin was lightly defoliated in 1982. The duration of each defoliation episode decreased over time, but defoliation intensity was greatest in 1981. A fourth gypsy moth infestation began in 1989, but was limited by the gypsy moth fungus (*Entomophaga maimaiga*).

PROCEDURES

Field Measurements

The study plots were established in 1927. Each plot had six to fourteen transects, and each transect had ten to twenty transect segments (66 by 16.5 feet). Transects were spaced 264 feet apart. Transect centerlines were permanently located by stakes at two chain intervals. Trees were mapped on transect segments. During each inventory, the species, diameter, and crown class of each tree was recorded. Minimum dbh (diameter at 4.5 feet) was 0.6 inches in 1927 and 1937; since 1957 the minimum dbh has been 0.5 inches. The plots were not inventoried in 1947. Individual trees were matched with data from previous inventories using their location, species, and diameter. To increase the sample size of larger stems, the transect width was increased to 33 feet in 1957 for all stems with diameters of at least ten inches. These larger trees in the outer strips were measured and mapped concurrently with the stems in the inner, original strips. More complete details of the plots and sampling can be found in Ward and others (1999).

Data Analysis

Preliminary analysis following defoliation episodes found survival and growth differed between the white oak subgenera (*Leucobalanus*) and the red oak subgenera (*Erythrobalanus*). Species in the *Leucobalanus* subgenera include white (*Quercus alba*) and chestnut oak (*Q. prinus*). Species in *Erythrobalanus* subgenera include northern red (*Q. rubra*), black (*Q. velutina*), and scarlet oak (*Q. coccinea*). In the analysis and discussion that follows, these groups will be referred to as the white oak and red oak groups, respectively.

To allow direct comparisons of mortality rates in this study and other published studies, mortality rates were converted to 10-year values. Differences in mortality rates among periods (intersurvey intervals) were tested using procedures by Neter and others (1982, p 325-329). Analysis of variance was used to examine influence of species group, crown class, and periods on diameter growth. Tukey's HSD test was used to determine whether diameter growth differed among periods and species group for each crown class. Differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Before Defoliation

Mortality rates for upper canopy trees (dominant and codominant crown classes) were lower than mortality rates for lower canopy trees (intermediate and suppressed) during the thirty-years before multiple years of defoliation (table 1). During this period, mortality of upper canopy trees averaged less than 5 percent per decade compared with more than 60 percent per decade for suppressed oaks.

Table 1—Mortality rates of oaks in southern New England by survey period and crown class at beginning of period

Species group and period	Crown class at beginning of period[a]			
	Dominant	Codominant	Intermediate	Suppressed
	Mortality rate (percent per decade)			
Red oaks				
1937–57	3a	5b	26a	60b[b]
1957–67	11b[b]	44c[b]	79b	78c[b]
1967–77	12b	35c	43a	69bc
1977–87	5a	4ab	24a	33a
1987–97	2a	2ab	31a	54b
White oaks				
1927–37	1a	4a	18a	61b
1937–57	2a	11a	31a	71b
1957–67	55c	76b	84b	89c
1967–77	10b	13a	33a	46ab
1977–87	5ab	5a	31a	33a
1987–97	0a	3a	9a	60b
	Sample size			
Red oaks				
1927–37	325	238	361	562
1937–57	239	230	233	353
1957–67	540	144	81	167
1967–77	514	74	14	35
1977–87	424	101	21	21
1987–97	382	140	29	72
White oaks				
1927–37	151	165	336	1,032
1937–57	98	136	196	625
1957–67	161	88	56	167
1967–77	78	15	9	26
1977–87	64	22	16	66
1987–97	53	29	11	113

[a] Column values for a given species group and crown class with the same letter were not significantly different at $p \leq 0.05$.
[b] Red oak and white oak mortality were significantly different at $p \leq 0.05$.

Similar mortality rates (converted to 10-year basis) were found in other stands that were not defoliated. In New York, mortality of northern red oak between ages 24-64 years varied by crown class; 5 percent for dominant and codominant trees, 33 percent for intermediate trees, and 70 percent for suppressed trees (Lorimer 1981). Another study in New York and Massachusetts found mortality of 21-41 year-old upper canopy trees was 3-4 percent compared with 55-59 percent for suppressed trees (Lorimer 1984). In West Virginia, mortality was much higher for intermediate than codominant or dominant 55-year-old northern red oaks (Trimble 1974).

Before defoliation, mortality rates of upper canopy trees did not significantly differ between the white and red oak groups (table 1). Diameter growth of red oaks was significantly greater than for white oaks within a given crown class, except for suppressed trees between 1927-1937 (table 2). Average annual diameter growth of red oaks between 1927-1957 was 0.17 inches compared with 0.12 inches for upper canopy white oaks.

During the Period of Multi-Year Defoliations

The three consecutive years of moderate to heavy defoliation, 1961-1963, were the first known defoliation episodes on these plots. Mortality rates increased significantly during this period (table 1). Significant increases were noted for both the red oak and white oak groups, and for all crown classes. Mortality of dominant and codominant white oaks increased to 55 and 76 percent, respectively. This was significantly higher than the mortality rates of dominant and codominant red oaks. Mortality of all dominant and codominant red oaks remained higher than pre-defoliation levels during 1967-77 when there were two consecutive years of defoliation. Interestingly, mortality of codominant white oaks decreased to values similar to, and not significantly different from, pre-defoliation values.

Table 2— Annual diameter growth of oaks in southern New England by period and crown class at beginning of period

Species group and period	Crown class at beginning of period[a]			
	Dominant	Codominant	Intermediate[b]	Suppressed
	inches per decade			
Red oaks				
1927–37	0.24d[b]	0.15d[b]	0.09a[b]	0.04a
1937–57	0.17c[b]	0.11bc[b]	0.08a[b]	0.06a[b]
1957–67	0.12a[b]	0.07a	0.05a	0.04a
1967–77	0.11a[b]	0.08ab	0.07a	0.07a
1977–87	0.14b	0.10abc	0.07a	0.05a
1987–97	0.15bc	0.12c	0.10a	0.03a
White oaks				
1927–37	0.18d	0.12b	0.07a	0.03a
1937–57	0.10abc	0.08a	0.04a	0.02a
1957–67	0.08a	0.06a	0.01a	0.03a
1967–77	0.09ab	0.05a	0.02a	0.04a
1977–87	0.12bc	0.09ab	0.04a	0.04a
1987–97	0.13c	0.11ab	0.05a	0.02a

[a] Column values for a given species group and crown class with the same letter were not significantly different at $p \leq 0.05$.
[b] Red oak and white oak diameter growth were significantly different at $p \leq 0.05$.

Mortality differed among species during 1957-1967 (table 3). Red oaks (northern red, black, and scarlet) in the dominant crown class had lower mortality rates during this period than white and chestnut oaks. In the codominant crown class, mortality of northern red and scarlet oak were lower than for white and chestnut oak. Northern red and black oaks in the suppressed crown class had lower mortality than white oak. Thus, when crown class is included as a factor, the red oak group had lower mortality than the white oak group.

Other studies differ on relative mortality rates among species during and immediately following defoliation (table 4). Because these studies did not present mortality rates by crown position for individual species and because mortality is much higher for trees in the lower canopy than for trees in the upper canopy, the observed differences in species mortality rates in other studies may reflect the proportion of each species that was in lower canopy in each study.

Diameter growth of upper canopy red oaks, but not white oaks, decreased during the initial period of defoliation (table 2). Growth rates for dominant and codominant red oaks decreased by 30 and 35 percent, respectively. Red oak diameter growth during the pre-defoliation period (1937-1957) was 23-30 percent lower than the previous period (1927-1937). Multi-year defoliations reduced oak (primarily black oak) diameter growth by 32-40 percent (Brown and others 1979). Other studies found diameter growth reductions for both red and white oaks following defoliation (Campbell and Garlo 1982, Muzika and Liebhold 1999).

Mortality rates of lower canopy (intermediate and suppressed) oaks increased during the initial period of defoliation (table 1). Mortality rates were similar to pre-defoliation values during the second period of defoliation. Other studies have also reported higher mortality for lower canopy oaks (Brown and others 1979, Campbell and Sloan 1977, Kegg 1971). It should be recalled that mortality of suppressed oaks was high prior to defoliation (table 1), and it is likely that defoliation merely accelerated demise of this crown class. Surprisingly, multi-year defoliations did not have a significant impact on diameter growth of lower canopy trees (table 2). This may be because mortality was higher for the slowest growing trees (table 5).

Table 3—Mortality rates between 1957–67 of oaks in southern New England by species and crown class in 1957

	Crown class in 1957[a]			
Species	Dominant	Codominant	Intermediate	Suppressed
	Mortality rate (percent per decade)			
Northern red oak	10a	38a	77a	79a
Black oak	12a	53ab	82a	76a
Scarlet oak	13a	44a	82a	87ab
White oak	40b	72b	83a	92b
Chestnut oak	67c	82b	90a	80ab
	Sample size			
Northern red oak	303	72	53	94
Black oak	133	45	17	58
Scarlet oak	104	27	11	15
White oak	70	50	46	132
Chestnut oak	91	38	10	35

[a] Column values for a given species group and crown class with the same letter were not significantly different at $p \leq 0.05$.

Table 4—Summary of previous research on mortality rates of oak species following gypsy moth defoliation

Study	CHO	WHO	BLO	SCO	NRO	State
Kegg (1971)	11	38	16	39	36	NJ
Kegg (1973)	66	84	48	27	41	NJ
Dunbar and Stephens (1975)	80	42	27	33	32	CT
Campbell and Sloan (1977)	—	42	48	35	16	MA
Stalter and Serrao (1983)	0	1	4	—	46	NJ
Fosbroke and Hicks (1989)	44	35	46	57	31	PA
Herrick and Gansner (1987)	23	23	33	28	14	PA
Average	37	38	32	37	31	
Median	34	38	33	34	32	

CHO = chestnut oak; WHO = white oak; BLO = black oak; SCO = scarlet oak; NRO = northern red oak; NJ = New Jersey; CT = Connecticut; MA = Massachusetts; PA = Pennsylvania.
— = not applicable.

Table 5—Mortality rates between 1957–67 of oaks in southern New England by diameter growth and crown class immediately before multi-year defoliations[a]

Species group	Annual growth	Crown class at beginning of period[b]			
		Dominant	Codominant	Intermediate	Suppressed
		- - - - - - - -	*percent per decade*	- - - - - - - -	
Red oaks					
	≤ 0.05	—	60b	96b	94b
	0.05 – 0.10	35c[c]	58b[c]	75a	84b
	0.10 – 0.15	13b[c]	35a	50a	38a
	> 0.15	4a[c]	16a	—	—
White oaks					
	≤ 0.05		82ab	90a	95a
	0.05 – 0.10	66a	85b	70a	88a
	0.10 – 0.15	55a	56a	—	—
	> 0.15	44a	—	—	—

— = not applicable.
[a] Diameter growth was the average of the 1937–57 period.
[b] Column values for a given species group and crown class with the same letter were not significantly different at $p \leq 0.05$.
[c] Red oak and white oak mortality were significantly different at $p < 0.05$.

As was noted above, diameter growth of red oaks was higher than for white oaks prior to the period of multi-year defoliations (table 2). Thus, higher mortality of white oaks following defoliation may be related to lower vigor, more than to the ability of white oaks to successfully recover from (cope with) multiple defoliations. Mortality was higher for oaks with poor crowns than for those with good crowns (Campbell and Sloan 1977, Gansner and Herrick 1984).

For red oaks, but not white oaks, tree vigor was a good predictor of upper canopy tree mortality between 1957-1967 (table 5). Red oaks with annual diameter growth of at least 0.1 inch had lower mortality rates during the period of multi-year defoliations than slower growing trees (table 2). For example, mortality was 16 percent for codominant red oaks that had annual diameter growth of 0.15 inch compared with 60 percent for codominant red oaks that had annual diameter growth of less than 0.05.

After Defoliations

Although there was heavy defoliation in 1981, there have been no sequential years of defoliation since 1971-1972. The defoliation in 1981 did not induce the higher mortality of the earlier, multi-year defoliations (table 2). Indeed, mortality rates for both red and white oaks during 1977-1987 fell to values similar to, or lower than, those before the first defoliations in the 1960's.

Mortality continued to decrease during the next ten years, 1987-1997, except for both red and white oaks in the suppressed crown class. Many of the oaks in the suppressed crown class became established in the canopy gaps formed following the mortality pulse during the 1960's. The increased mortality between 1987-1997 can probably be attributed to competition from the more shade tolerant maple and birch that became established at the same time.

Diameter growth quickly recovered following the end of multi-year defoliations. Diameter growth of codominant red and white oaks during 1987-1997 were similar to, or higher than, growth before 1957-1967 (table 2). Following multi-year defoliations, diameter growth of red and white oaks recovered to eighty percent of pre-defoliation levels within two years of defoliation episodes (Campbell and Garlo 1982), and full recovery was noted after 10 years (Campbell and Sloan 1977). Other studies have also noted oak stands are capable of quickly recovering once defoliation severity and frequency have subsided (Feicht and others 1993, Gansner and others 1983, Muzika and Liebhold 1999).

Stand basal area of oaks has increased steadily since 1927, except during the periods of multi-year defoliations (Ward and others 1999). The decrease in basal area between 1957-1967 was evenly distributed among lower canopy oaks and upper canopy white oaks. Basal area of upper canopy red oaks increased slightly during this period. The longer term impacts of multi-year defoliations have been to nearly eliminate lower canopy oaks (both red and white oaks) and to reduce the proportion of white oaks relative to red oaks. Because mortality of upper canopy red oaks was less than that for to white oaks, and because the diameter growth of surviving red oaks increased once defoliations ceased, total oak basal area is now higher than before the period of multi-year defoliations.

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FIRE

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SURVIVAL OF STRIPED MAPLE FOLLOWING SPRING PRESCRIBED FIRES IN PENNSYLVANIA

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Abstract—Survival of striped maple (*Acer pensylvanicum* L.) was assessed after three spring prescribed fires in Pennsylvania mixed oak (*Quercus* spp.) stands. Portions of two stands were prescribe-burned in spring 2002 and the part of a third in spring 2004. Following the fires, each stand was divided into burned and unburned units. Striped maple sapling counts were done one and three growing seasons after the fires in both units of each stand to determine whether the fires had reduced the density of stems. In all stands, fire initially reduced density of striped maple by 25 to 50 percent. Delayed mortality pushed this rate to over 90 percent in two of the stands. These data suggest that prescribed fire appears to be a viable means of controlling striped maple in mixed oak forests.

INTRODUCTION

There is growing appreciation and understanding of the important role periodic, low-intensity, surface fires played in the historic dominance of mixed oak (*Quercus* spp.) forests throughout the eastern North America, including the mid-Atlantic region (Abrams 1992, Brose and others 2001, Yaussy 2000). This fire regime was largely the result of American Indian burning practices and, in conjunction with other environmental factors, helped perpetuate mixed oak forests on a wide variety of soils, especially mesic upland sites. The advent of effective fire control policies and practices ended the periodic surface fire regime of the mid-Atlantic region, like they did in the Southeast and the Interior West. However, unlike those other regions, the lack of fire did not translate into an increased loading of hazardous fuels that contributed to catastrophic, stand-replacing wildfires. Rather, the cessation of periodic surface fires in the mid-Atlantic region led to a new forest succession pathway; one in which fire-sensitive, shade-tolerant shrubs and trees invade and eventually impede successful oak regeneration in mixed oak forests.

One beneficiary of the cessation of periodic surface fires is striped maple (*Acer pensylvanicum* L.). Striped maple is a small- to medium-sized, shade tolerant tree found from Nova Scotia west to the Great Lakes region and south along the Appalachian Mountains to North Carolina (Gabriel and Walters 1990). Within that range, it generally occurs in northern hardwood forests and is most common on cool, moist slopes. However, it is being found more frequently and abundantly in mixed oak forests, an environment from which it was historically absent or sparse.

Striped maple is not a long-lived tree, about 40 years, but can subsist as a small seedling for another 40 years (Hibbs 1979). It is a rather prolific seeder and, in conjunction with its seedling banking strategy, can develop high density populations in forests. When such populations develop, striped maple becomes a serious silvicultural problem as it casts a dense shade on the forest floor that impedes oak seedling survival and growth. In Pennsylvania, striped maple is considered the most troublesome woody interference that precludes successful oak regeneration (Personal communication. 2005. Gary Rutherford, Silviculture Section Chief, Pennsylvania Bureau of Forestry, P.O. Box 403, Rothrock Lane, Huntington, PA 16652).

Glyphosate-containing herbicides are often used to control striped maple when its density becomes an obstacle to forest regeneration (Horsley and Bjorkbom 1983, Marquis and others 1992). However, there are times and places when herbicide use is not possible so there is growing interest in using prescribed fire as an alternative control method. Striped maple exhibits several attributes that suggest it is quite sensitive

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to fire. Striped maple bark is quite thin, regardless of stem diameter, its root collar (the location of dormant buds) is relatively high in the litter layer, and its root system is small and shallow. Striped maple leaves also emerge earlier in the spring than many other species. As a result, root carbohydrate reserves are depleted earlier thus rendering striped maple susceptible to surface fires for a longer period of time.

Surprisingly, there is little published literature on the effects of fire on striped maple. Swan (1970) compared burned and unburned northern hardwood stands in southern New York. He found unburned sites to have five times more striped maple than those that had been burned. Unfortunately, fire behavior was unknown and pre-fire striped maple density between stands was not documented. Conversely, Collins and Carson (2003) reported that striped maple was a strong sprouter following prescribed fires in West Virginia and actually benefited from them. Again, fire behavior was poorly described.

The objective of this study was to determine whether striped maple densities increased or decreased following prescribed burning. Understanding this aspect of striped maple ecology will help foresters deal more effectively with the species when it poses a regeneration obstacle.

METHODS

Study Sites

This study was conducted on three Pennsylvania State Forests (Bald Eagle, Clear Creek, and Moshannon) between 2002 and 2005. The Bald Eagle State Forest is located in eastern Centre County in the Ridge and Valley region of central Pennsylvania. The study site was a 10-acre stand situated at the bottom of an 18-percent, north-facing slope. Elevation was approximately 1400 feet. Soil was a stony loam (Typic Fragidult) formed from sandstone alluvium (Braker 1981). Consequently, it was moderately acidic, fertile, and well drained. Severe gypsy moth (*Lymantria dispar* L.) defoliation had occurred there in the late 1980s and early 1990s, resulting in substantial overstory mortality and salvage logging occurred shortly thereafter. The remaining overstory trees resembled a shelterwood stand and relative density, i.e., stocking, was 50 percent as per SILVAH criteria (Marquis and others 1992). Common canopy species were chestnut oak (*Quercus prinus* L.), northern red oak (*Q. rubra* L.), and red maple (*A. rubrum* L.). A dense sapling layer of striped maple, sweet birch (*Betula lenta* L.), red maple, and witch-hazel (*Hamamelis virginiana* L.) was present. The forest floor contained abundant late low blueberry (*Vaccinum angustifolium* Ait.), black huckleberry (*Gaylussacia baccata* (Wang.) K. Koch.), mountain laurel (*Kalmia latifolia* L.), and seedlings of several hardwood species, especially chestnut and northern red oak.

The Clear Creek State Forest is located in northern Jefferson County on the Allegheny Plateau region of northwestern Pennsylvania. The study site was an 8-acre stand found at midslope of a 5-percent, east-facing hill. Elevation was approximately 1800 feet. Soil was a loam (Typic Dystrochept) formed in place by the weathering of sandstone and shale parent material (Zarichansky 1964). Consequently, it was moderately acidic, fertile, and well drained. The stand had only experienced light gypsy moth defoliation with little attendant overstory mortality (relative density was 100-percent). Dominant canopy species included northern red oak, sugar maple (*A. saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), and yellow-poplar (*Liriodendron tulipifera* L.). The sapling layer was quite dense and consisted almost entirely of striped maple with a few American beech (*Fagus grandifolia* Ehrh.). The regeneration layer was dense with northern red oak seedlings because of a bumper acorn crop in fall 2001. Otherwise there were few hardwood seedlings and some scattered pockets of hay-scented fern [*Dennstaedtia punctilobula* (Michx.) Moore] comprised the herbaceous community on the forest floor.

The Moshannon State Forest is located in northern Clearfield County in the Allegheny Mountians region of north-central Pennsylvania. The study site was a 12-acre stand situated on an upperslope bench with a northwest aspect and slope of 2 percent. Elevation was approximately 2100 feet. Soil was a loam (Typic Fragiudult) formed in place by the weathering of sandstone and shale parent material (Hallowich 1988). Consequently, it was moderately acidic, fertile, and moderately drained. The stand had experienced light to moderate gypsy moth defoliation and mortality but relative density was nearly 100 percent. Dominant canopy species included northern red oak, sugar maple, black cherry, and yellow-poplar. The sapling layer was quite dense and consisted almost entirely of striped maple with a few American beech. The regeneration layer was dense with northern red oak seedlings due to a bumper acorn crop in fall 2001. Otherwise there were few hardwood seedlings and some scattered pockets of hay-scented fern comprised the herbaceous community on the forest floor.

The Prescribed Fires

The objective of all three fires was to remove the sapling layer that was competing with the oak regeneration. Personnel of the Pennsylvania Bureau of Forestry conducted the prescribed burns on April 19, 2002 at Clear Creek State Forest, May 23, 2002 at Bald Eagle State Forest, and May 3, 2004 at Moshannon State Forest. Fuel, weather, and fire behavior data are presented in table 1. Fires were lit by hand with drip torches in a strip-headfire pattern commencing at the downwind or uphill side of each burn unit. The Clear Creek fire barely burned as it had only compacted leaf litter as a fuel. Observed flame lengths were only a few inches. Conversely, the Bald Eagle fire produced flame lengths of four to eight feet because that site had an abundance of ericaceous shrubs for fuel. The Moshannon burn displayed widely varying fire behavior. Some areas barely burned due to a paucity of fuel while other areas produced enough heat to damage and kill overstory trees. Leaf expansion of the striped maples was as follows; Clear Creek – swollen buds, Bald Eagle – fully expanded, Moshannon – half expanded.

Study Design and Sampling Procedures

Because the Bald Eagle and Clear Creek fires occurred with little advance notice to us, collecting pre-burn data was not possible. However, approximately 50 percent of each stand was excluded from the fires, thus providing a valid source of data for evaluating the effect of the fires on striped maple survival. Ten to twelve 1/40 acre circular plots were systematically located in each burn and control unit to ensure uniform coverage of the area. In these plots, all saplings (five feet tall to six inches dbh) were identified to species and tallied as alive, i.e., not top-killed by the fires, dead, or sprouting. Inventories were conducted in fall 2002 and 2004 (one and three growing seasons post-burn) at the Bald Eagle and Clear Creek stands and in spring 2005 (one growing season post-burn) at the Moshannon site.

Table 1—Environmental conditions and fire behavior at the time of the prescribed fires

Fuel and weather data	Bald Eagle	Clear Creek	Moshannon
Burn date	May 23, 2002	April 19, 2002	May 3, 2004
Time of burn	13:00–15:00	11:00–12:00	14:00–15:00
Burn size (acres)	5	4	6
Aspect	N	E	NW
Slope (percent)	18	5	2
Slope position	Lower 1/3	Middle 1/3	Upper 1/3
Air temperature (F)	72–78	65–67	71–74
Rel. Humidity (percent)	23–27	35–40	42–48
Wind direction	West	West	West
Wind speed (miles per hour)	1–3	1–2	2–5
Cloud cover (percent)	0	0	25
Fuel model	6	8	8
Fuel description	Heath shrubs	Compact litter	Litter, slash
Fuel moisture (percent)	10	15	16
Flame length (feet)	4–8	< 0.5	0.5–3
Rate-of-spread (feet per minute)	3–6	1–2	1–4

Statistical Analysis

A randomized complete block design was used to test for differences in the number of living, dead, and sprouting striped maples between treatments. Each stand was considered a block to account for differences in site quality, fire behavior, and degree of leaf expansion. Burned and unburned were the treatments and the number of living, dead, and sprouting striped maples was the dependant variable. Analysis of variance with the Student-Keuls mean separation test (SAS 2002) was used to determine whether there were any differences in the number of living, dead, and sprouting striped maple between treatments. Residuals were analyzed to ensure ANOVA assumptions were met and alpha was 0.05 for all tests.

RESULTS

The mean density (stems per acre) of the striped maple understories varied among stands but was reasonably equivalent between treatments within each stand (fig. 1). Moshannon had the most striped maple, 1466, while Bald Eagle and Clear Creek had 700 and 913, respectively. Striped maple densities were equal between the burned and unburned treatments at all sites. Bald Eagle had striped maple densities of 709 and 691 stems per acre in the burned and unburned portions while Moshannon had 1400 and 1533 and Clear Creek had 871 and 754, respectively, for their burned and unburned portions.

There were clear differences between the burn and unburned treatments after the first post-burn growing season (fig. 2). In the unburned treatment, virtually all the striped maple saplings were alive. Conversely, the burn treatment, regardless of the study stand, always had more dead and sprouting striped maples and fewer living ones than the unburned plots. Densities of dead, sprouting, and alive striped maple were 548, 331, and 46 stems per acre, respectively, in the burn treatment while the corresponding unburned densities were 11 dead, 23 sprouting, and 961 alive. Striped maple density data were available for the third post-burn growing season (2004) from the Bald Eagle and Clear Creek stands. Again, the burned portions had more dead, sprouting, and alive striped maple saplings than the unburned portions.

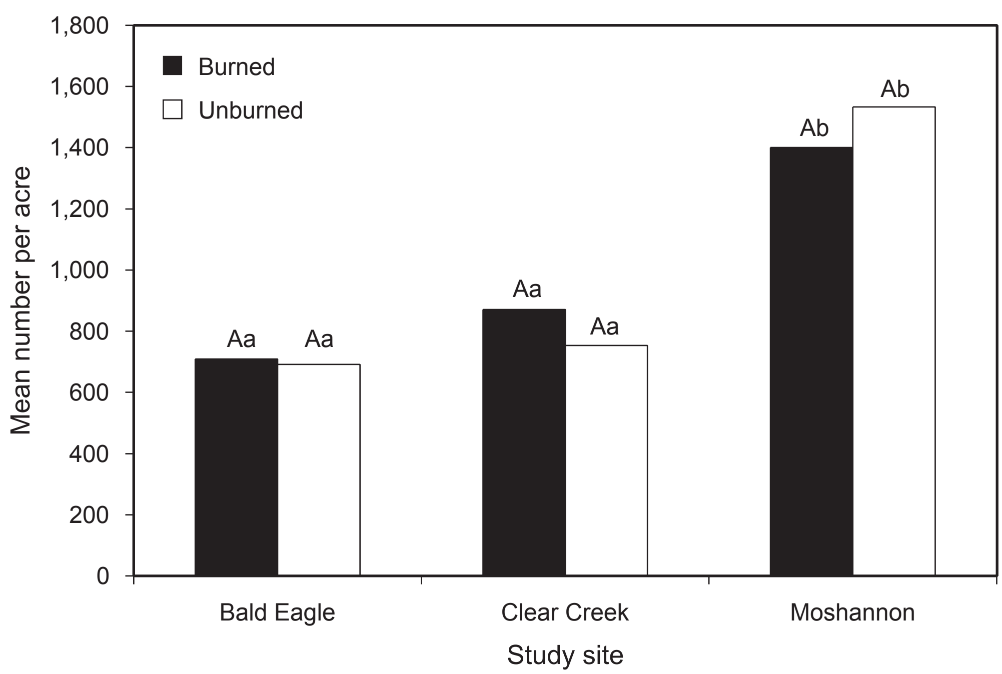

Figure 1—Mean number of striped maple saplings per acre at the three sites at the beginning of the study. Columns with the same uppercase letter are not significantly different at the 0.05 level for that stand. Columns with the same lowercase letter are not significantly different at the 0.05 level for that treatment.

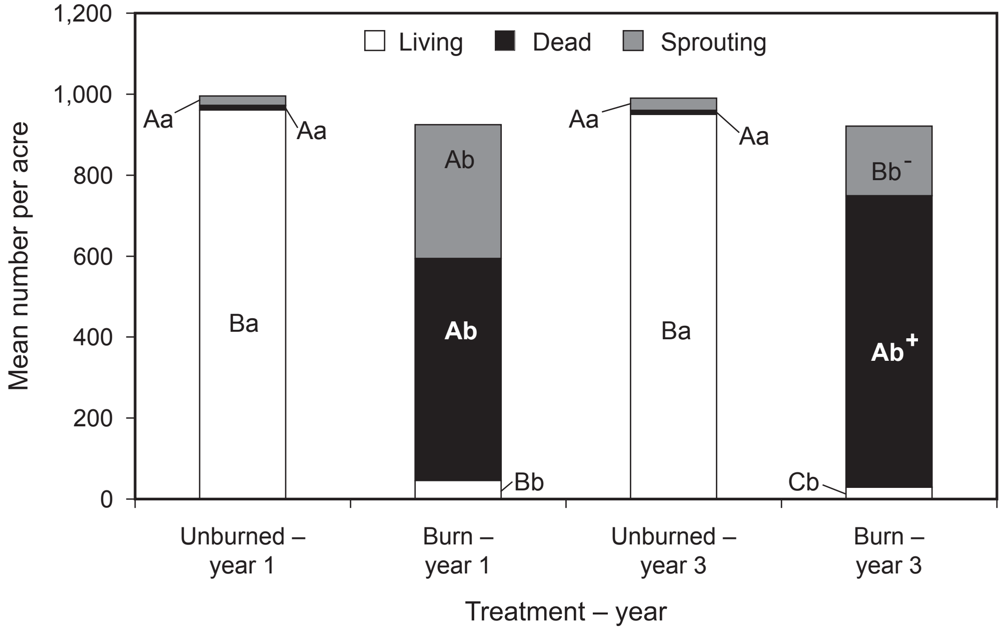

Figure 2—Mean number of living, dead, and sprouting striped maple saplings by treatment and year. Different uppercase letters within a column indicate significant differences at the 0.05 level. Different lowercase letters indicate significant differences between treatments within the same year at the 0.05 level. The plus (+) and minus (-) superscripts in the Burn–YR3 column indicate a significant increase and decrease, respectively, from the Burn–YR1 column.

Comparing the first- and third-year data, the mean number of dead striped maples in the burned portions increased from 548 in 2002 to 717 saplings per acre in 2004 (fig. 2). This additional mortality appears to have come from previously sprouted stems as those densities declined from 331 in 2002 to 172 in 2004. The number of living striped maples in the burned units did not significantly decrease from 2002 to 2004 nor did any of the striped maple densities in the unburned portions change during that period.

DISCUSSION

One obstacle to using more prescribed fire in the mixed oak forests of the eastern states is the lack of knowledge regarding fire effects on important competing hardwoods. Striped maple certainly falls under that heading as evidenced by the contradictory results reported in the few fire studies that included the species. This study helps clarify the picture, at least in term of spring fires.

Striped maple is extremely sensitive to spring fires, regardless of fireline intensity. Its paper-thin bark offers little or no protection against fire as even the small flames at Clear Creek top-killed over 80 percent of the saplings. The slightly more intense fire at Moshannon pushed the top-kill rate to over 93 percent and less than 5 percent of the striped maple at Bald Eagle was not top-killed. In fact, striped maples surviving the fire at Bald Eagle were only able to do so if they were growing in protected microsites that precluded burning.

Not only were striped maples easily top-killed, substantial numbers of rootstocks were also killed by fire. Over 50 percent of the striped maples at Bald Eagle and Clear Creek failed to sprout the first year after the fires. This was apparently due to the fires being able to scorch the root collars, thereby killing the dormant basal buds. While this was not unexpected at Bald Eagle given its relatively high fireline intensity, it was surprising at Clear Creek where the fire barely burned. In fact, after that fire all the striped maples expanded their leaves as if there had been no fire. However within a few weeks, they began wilting in large numbers. Apparently the fire was sufficient to girdle these saplings and prevent carbohydrate and water flow through the cambial tissue. Given the sensitivity to fire displayed by striped maple in this study, it probably was not the major component of the understory when periodic surface fires occurred that it is now in the absence of fire.

It is unclear why there was delayed mortality at Bald Eagle and Clear Creek. Both stands showed an increase in the number of dead striped maples in the burn units from 2002 to 2004. The intervening two growing seasons were exceptionally cool and wet leading to a major outbreak of anthracnose. This foliar pathogen may have caused the additional mortality because many of the dead stems were sprouts close to the ground. *Armillaria mellea* Vahl., a root pathogen, may also be the causal agent as this fungus is ubiquitous in eastern forest soils and routinely attacks trees weakened by a stress. Whatever the mechanism was, between it and the fires, over 80 percent of the striped maple saplings were dead within three years after the fires.

From this study, it appears that prescribed fire is another means to control striped maples when they become a silvicultural obstacle. Fire can be used in lieu of herbicides when the latter is not feasible due to policy constraints or site restrictions, i.e., too steep or rocky for equipment, striped maple is too tall, it's a drought year, etc. Or fire and herbicides can be used in tandem with fire initially removing some stems and spot application of herbicide finishing the job.

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FUELS CONSUMPTION AND NITROGEN LOSS FOLLOWING PRESCRIBED FIRE: A COMPARISON OF PRESCRIPTION TYPES IN THE SOUTHERN APPALACHIANS

Barton D. Clinton and James M. Vose[1]

Abstract—Prescribed burning is frequently used as a tool for restoration of plant communities, wildlife habitat improvement, and site preparation. We compared and contrasted the effects of four burning prescriptions on forest floor and fine fuels consumption, and nitrogen loss. The burning treatments included dry (DU) and mesic (MU) understory burns, stand replacement (SR) burning, and fell and burn (FB) site preparation. On all sites, forest floor was sampled before and immediately after burning. It was separated into woody fuels (< 7.5 cm in diameter), the Oi layer (litter), and the Oa + Oe layer (fermentation plus humus), and dry weight and nitrogen content of each component was determined. Tiles with heat-sensitive chalk and paint were used to estimate flame intensity at 30 cm above the forest floor. Mean peak flame temperatures ranged from 700 ºC for the FB treatment to 169 ºC for the MU burn. Except in the FB treatment, which had a substantial amount of woody mass on the forest floor as a result of felling overstory trees and shrubs, the majority of pre-burn mass and nitrogen was contained in the humus layer. Following burning, mass loss ranged from 88 Mg ha^{-1} (90 percent wood, 10 percent litter, < 5 percent humus) on the FB treatment to 5 Mg ha^{-1} (5 percent wood, 55 percent litter, 40 percent humus) on the MU burns. Nitrogen losses followed similar patterns – 292 kg ha^{-1} (70 percent from wood, 28 percent litter, <5 percent humus) on the FB to 30 kg ha^{-1} (65 percent from wood, 35 percent litter, <5 percent humus) on the SR site. High-intensity ground fires may result in greater losses of site nutrients, and this may have negative short- and long-term consequences.

INTRODUCTION

In many ecosystems, fire is used as a management tool to enhance and protect overall stand health and productivity by reducing fuel loadings, thereby reducing the threat of catastrophic fire (Sanders and Van Lear 1987, Van Lear and Waldrop 1989). Prescribed fire can also be used to reduce competition that affects commercially desirable tree species and improve habitat for terrestrial wildlife (Cooper 1971). The use of fire to accomplish these goals is considered an attractive alternative to mechanical techniques of stand improvement, primarily because of reduced costs (Cooper 1971, Abercrombie and Sims 1986). The continued (and expanded) use of prescribed fire in the southern Appalachians and elsewhere has raised interest in its effects on ecosystem integrity. Scientists are especially interested in determining how fire influences losses of key plant nutrients such as nitrogen (N). Although total N pools are frequently in greater supply than is needed for plant growth, N is commonly a limiting nutrient to forest productivity (Keeney 1980, Vitousek and others 1982) because most is in unavailable organic forms (Vose 2000). Total ecosystem nitrogen may decrease in forested systems following fire (Neary and others 1984, Rapp 1990) due to volatilization of nitrogen stored in coarse and fine fuels, or to increased leaching of released NO_3 from the system, or to both of these causes (Knoepp and Swank 1993). In contrast, increases in total N following burning can result from a combination of increased abundance of symbiotic and non-symbiotic N-fixers. Similarly, N availability often increases due to increased N mineralization and decreased plant uptake (DeBano 1991).

Nitrogen losses during and following prescribed fire in southern forests range from 20 kg ha^{-1} for low-intensity understory burns (Kodama and Van Lear 1980) to >400 kg ha^{-1} for high-intensity site preparation burns in heavy fuels (Vose and Swank 1993, Clinton and others 1996). The significance of

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these losses depends on inherent site productivity and the magnitude and duration of changes in N pools and cycling rates (Wells and Morris 1982, Vitousek and Matson 1985). In pine-hardwood ecosystems in the southern Appalachians, Knoepp and Swank (1993) found that net soil N mineralization increased immediately following cutting and burning and remained higher than that in control plots for about 2 years. Similarly, Dudley and Lajtha (1993) found N availability increased following prescribed fire in a sandplain grassland and remained higher than pretreatment levels for 3 years. Increased N mineralization rates can offset total N losses from fire; however, the degree to which N losses are ameliorated depends on the magnitude and source (i.e., forest floor vs. wood) of N losses and subsequent N recovery. In southern Appalachian hardwood ecosystems, forest floor losses are particularly important because release of N from the forest floor provides approximately 50 percent of the total available N (Monk and Day 1988). Our objective in this paper is to describe and compare variation in woody and fine fuels mass consumption and N losses across a range of prescribed fire types.

METHODS

Study Site Descriptions

Sites represented in this comparison span 15 years of fire research under a variety of conditions and objectives. To simplify the comparison we assigned each treatment to one of four categories: (1) fell and burn (FB) site preparation, (2) stand replacement (SR) burning, (3) understory burning on dry sites (DU), and (4) understory burning on moist sites (MU). The fell and burn site preparation treatment was developed by Abercrombie and Sims (1986) for pine-hardwood ecosystems in the mountainous region of South Carolina. As the treatment was originally conceived, merchantable products were to be removed and all other vegetation felled in the spring after leaf-out; then a mid-summer burn would be used to consume slash and sprouting vegetation. On our FB sites no products were removed and all vegetation was cut by chainsaw during the summer of 1990. Cut vegetation cured for 44 to 90 days before burning, and sites were burned in early fall with a hand-set fire that produced a high-intensity but low-severity fire (Ottmar and Vihnanek 1991). Average fuel moisture (for all size classes) at the time of burning varied from 28 percent to 37 percent (Swift and others 1993, Vose and Swank 1993). The FB study sites were located on the Wayah Ranger District of the Nantahala National Forest in western North Carolina (Clinton and others 1993, Elliott and Vose 1993, Knoepp and Swank 1993, Swift and others 1993, Vose and Swank 1993, Clinton and others 1996, Elliott and others 2002). Pretreatment stand age was approximately 80 years (Swift and others 1993), and average basal area and density (stems >10 cm in diameter at breast height (d.b.h.)) were 14.8 $m^2 ha^{-1}$ and 461 stems ha^{-1}, respectively (Vose and Swank 1993). Sites were selected as replicates and had similar pre-treatment vegetation structure, topographic position, aspect, and soil type (Swift and others 1993).

The SR burn was located on the Wayah Ranger District of the Nantahala National Forest in western North Carolina and was part of the Wine Spring Creek Ecosystem Management Project (Swank and others 1994, Vose and others 1999). The site consisted of an overstory in various stages of decline that ranged from dead pines and heavy fuels on the upper slope positions to degraded (dead and dying) mixed pine-hardwood overstory on the mid-slopes. The area was approximately 150 ha, had a southeast aspect, ranged in elevation from 1000 to 1300 m (3,300 to 4,300 feet), and had slopes ranging from 35 to 60 percent. Mean annual temperature is 10.4 ºC (50 oF) and annual precipitation is approximately 1900 mm (75 inches). The stand replacement prescription fire was set in late April by helicopter using a combination of heli-torch and ping-pong balls (potassium permanganate). See table 1 for additional site descriptions.

The DU study sites were located in north Georgia on the Cohutta and Tallulah Ranger Districts of the Chattahoochee National Forest and in southeast Tennessee on the Ocoee Ranger District of the Cherokee National Forest (see Hubbard and others 2004). These sites were part of the USDA Forest Service Large-Scale Watershed Restoration Project. All sites had about 50 percent of the stand basal area in yellow pine, consisting of one or more of pitch pine (*Pinus rigida*), Table Mountain pine (*P. pungens*), Virginia pine (*P. virginiana*), loblolly pine (*P. taeda*), and shortleaf pine (*P. echinata*). Sites were burned in the late winter or early spring season with a mix of hand-set and helicopter-set ignitions.

Table 1—Site descriptions for the four burn types. Helicopter-set burns were ignited by a combination of heli-torch and ping-pong balls (potassium permanganate). Hand-set fires were set with handheld drip torches. Temperature is mean peak flame temperature at 30 cm above the forest floor. "Preburn woody fuels" is material on the forest floor

Burn type	Timing	Ignition type	Elevation	Preburn woody fuels	Mean temperature	Temperature range
			m	*kg ha^{-1}*	*°C*	
FB (1)	Late summer	Hand	750 – 1000 (2,460 – 3,280)	183 717 (163,912)	712 (1,314)	276 – 800+ (529 – 1,470+)
SR (1)	Early spring	Helo	1000 – 1300 (3,280 – 4,260)	15 773 (14,073)	560 (1,040)	80 – 800+ (176 – 1,470+)
DU (2)	Late winter	Helo/hand	350 – 900 (1,150 – 3,000)	15 000 (13,383)	238 (478)	52 – 700 (126 – 1,292)
MU (3)	Late winter	Helo/hand	350 – 1200 (1,150 – 4,000)	3 400[a] (3,033)	169 (336)	80 – 276 (176 – 529)

FB = fell and burn; SR = stand replacement; DU = dry understory; MU = mesic understory.
Values in parentheses under "Burn type" represent the number of studies included for each type.
Values in parentheses under "Elevation," "Preburn Woody Fuels," "Mean Temp," and "Temperature Range" are standard English equivalents in feet, lbs ac^{-1}, and degrees Fahrenheit, respectively.
[a] Value is for woody fuels < 7.5 cm (3 inches) diameter.

The MU study sites were (1) a high-elevation site in western North Carolina on the Wayah Ranger District of the Nantahala National Forest and (2) an approximately 300-ha south-facing watershed on the Tallulah Ranger District of the Chattahoochee National Forest in northeast Georgia. The sites were mixed hardwood with a small yellow pine component and scattered to continuous understory of *Rhododendron maximum* and *Kalmia latifolia*. Aspects ranged from south-facing at the low-elevation site to east-facing at the high-elevation site. A combination of hand-set and helicopter-set ignition was employed (table 1).

Forest Floor

On each site, 10 by 20 m plots were established to characterize vegetation and other processes associated with studies examining a range of ecosystem responses that are not reported here. Forest floor mass was measured for each site before and immediately after burning. Forest floor samples were collected from four locations in each 10 by 20 m plot by cutting and removing all material in a randomly located square (0.1 m^2) sampling frame. Forest floor was separated into small woody material (<7.5 cm diameter), Oi (litter), and Oe+Oa (fermentation and humus) layers. Pre- and post-burn coarse wood (>7.5 cm) mass was quantified on each 10 by 20 m plot using pre and post diameters and estimates of specific weight for the range of observed decay classes. Coarse wood amount was not estimated on the MU sites. Forest floor samples were dried at 70 ºC to a constant weight. Forest floor mass estimates were not ash free corrected; however, care was taken during sampling to minimize mineral soil contamination. Each sample was completely ground through a 1 mm mesh, homogenized, and subsampled for nutrient determination. Percent N was determined using a Perkin-Elmer 2400 CHN elemental analyzer. Estimates of N pools for each forest floor component were made by multiplying percent N times mass.

Fire Characterization

We used heat sensitive chalk and paint (Omega Engineering, Inc.) coated 10 cm by 20 cm tiles to characterize the temperature of the burns. On the day before the burn, we suspended the temperature tiles

30 cm above the forest floor co-located with forest floor subplots (four tiles per plot). Each tile could detect 30 temperature thresholds ranging from 52 ºC to 900 ºC.

Data Summary and Analysis

Comparisons were made between prescription types for pre- and post-burn mass and N pools. Statistical differences in pre- and post-burn N concentrations in wood, litter, and humus were evaluated for each site at the 0.05 level with analysis of variance (PROC ANOVA, SAS Inst. 1994). Since most the data used in this paper were derived from retrospective watershed scale studies, we have limited our analyses to descriptive statistics and qualitative comparisons of fuels consumption and N losses. While this approach limits the ability to make inferences about responses in other watersheds and burning treatments, the long-term and integrative nature of watershed scale studies has long been recognized as a powerful approach for understanding ecosystem responses to disturbance (Swank and Vose 1997).

RESULTS AND DISCUSSION

Pre-Burn Conditions

Total pre-burn mass was substantially greater (3- to 8-fold) on the FB compared with the SR, MU, and DU burn sites, due primarily to the felled woody material (fig. 1a), and to a lesser extent the additional leaf litter from felled material. Mass of woody fuels on SR sites was generally similar to that on DU sites, but mass of woody fuels on the MU sites was considerably less. Forest floor mass, separated into Oi (litter) and Oa + Oe (fermentation and humus), varied among study sites. Litter was greatest on the FB sites and least on the MU sites, whereas humus amounts were greater on the DU sites and least on the SR site (fig. 1a). The lower amount of litter humus on the MU sites is likely due in part to faster decomposition rates on those more productive sites. In contrast, slower decomposition on the DU sites most likely resulted in greater litter and humus accumulation. There were scattered live fuels on all sites in the form of the evergreen shrubs mountain laurel (*Kalmia latifolia*), primarily on the driest sites, and rosebay rhododendron (*Rhododendron maximum*) on the moist sites, as well as various deciduous ericaceous species. Both evergreen shrub species are sclerophyllous, producing foliage high in waxy compounds that increase flammability (Hough 1969). Under the right conditions, these species can act as fuel ladders in these ecosystems (Waldrop and Brose 1999).

Pre-burn N concentrations in woody and fine fuels are shown in table 2. Typically, woody material has a low N concentration relative to litter and humus but can represent a substantial pool of site N on sites with heavy woody fuels (Harmon and others 1986, Vogt and others 1995). The highest N concentrations, and typically the largest N pools, are typically in the humus layer. In southern Appalachian ecosystems, as much as 50 percent of the total plant available N is provided by the forest floor, much of it by the humus layer (Monk and Day 1988). On our study sites, the humus layer accounted for 40, 74, 76, and 86 percent of total pre-burn N on the FB, SR, MU, and DU sites, respectively (fig. 1b). Although pre-burn humus N concentrations were greater on the MU sites than on the DU sites, there was substantially more humus mass on the DU sites contributing to the greater amount of total N in that layer.

Fire Characteristics

Fire intensity varied across burn types, with the greatest mean peak flame temperatures occurring on the FB treatment (table 1). The range in flame temperatures varied considerably among burn types (table 1). Heavy, dried fuels on the FB site contributed to a greater mean peak flame temperature. Variation in mean peak flame temperature and maximum temperature may be explained by timing and ignition source. For example, in the case of heli-torch or ping-pong balls, fire intensity increases with decreasing placement density. That is, the wider apart the burn initiation points the more room the fire has to run before encountering burned areas, which can result in more intense fires.

Fuels Consumption

Consumption of woody and fine fuels varied among burn treatments and was greatest on the FB treatment. Total fuels consumption ranked FB>DU>SR>MU with the majority of consumption coming from the

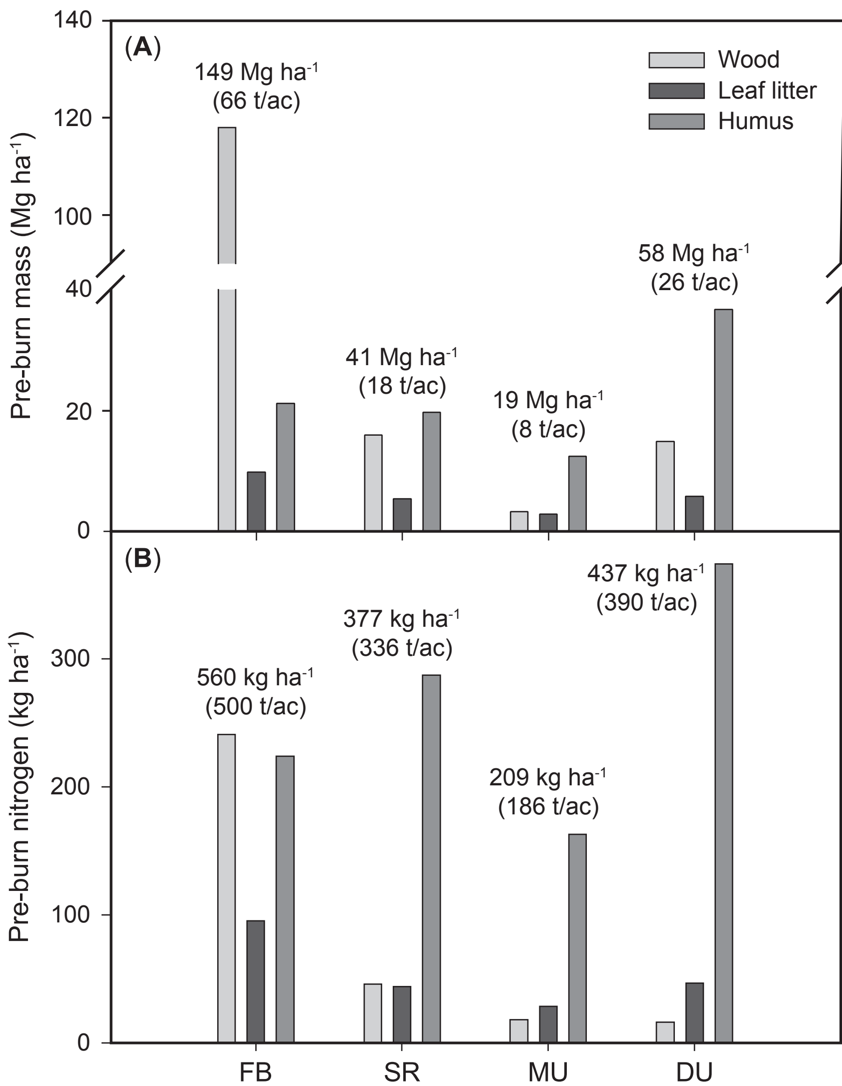

Figure 1—Pre-burn mass (A) and total nitrogen (B) by prescription and material type. Values within each panel represent site totals. Values in parentheses are standard English equivalents. Wood for mesic understory is fine woody fuels < 7.5 cm (3 inches) in diameter only.

Table 2—Nitrogen concentrations in percent for wood, litter, and humus before and after burning by site[ab]

Site	Wood	Litter	Humus
	- - - - - - - - - - - - - - - -	*percent*	- - - - - - - - - - - - - - - -
FB			
Pre N	0.25 n.a.	0.89 n.a.	0.95 n.a.
Post N	0.36 n.a.	1.13 n.a.	1.00 n.a.
SR			
Pre N	0.54[a] (0.03)	0.97[a] (0.03)	1.48[a] (0.06)
Post N	0.50[a] (0.06)	1.10[a] (0.10)	1.56[a] (0.04)
MU			
Pre N	0.45[a] (0.03)	0.77[a] (0.02)	1.14[a] (0.02)
Post N	0.51[a] (0.02)	1.07[b] (0.03)	1.22[a] (0.01)
DU			
Pre N	0.40[a] (0.01)	0.76[a] (0.01)	1.10[a] (0.02)
Post N	0.38[a] (0.02)	0.93[b] (0.02)	1.00[a] (0.02)

FB = fell and burn; SR = stand replacement; MU = moist understory burn; DU = dry understory burn.
[a] Values in parentheses are standard errors.
[b] Means within material type and site with the same superscript are not significantly different at the 0.05 level

wood component on the FB and SR sites and from the litter component on the MU and DU sites. Wood (almost 80 Mg ha^{-1}) made up nearly 90 percent of the total mass lost on the FB sites, whereas <5 Mg ha^{-1} of wood was consumed on each of the other sites (fig. 2a). Of the total mass of 6 Mg ha^{-1} consumed on the SR site, almost 65 percent was woody material, whereas on the DU and MU sites approximately 20 percent and 10 percent, respectively, was woody material, although total mass loss was similar on those three sites (fig. 2b). Differences in proportional consumption (i.e., wood vs. litter vs. humus) between the SR, DU, and MU sites was primarily due to the amount of humus consumed. Very similar amounts of humus were consumed on the FB, DU, and MU sites, while the SR site lost a smaller amount of humus. All burns were characterized as having high intensity and low severity, which is essential for minimizing humus consumption and the resulting loss of site nutrients. Although total pre-burn mass of wood was very similar to total pre-burn mass of humus on the SR site, the quick burn resulted in minimal humus consumption. Shorter fire residence times reduce the likelihood that significant losses of site nutrients will occur through humus consumption.

Nitrogen Losses

The greatest loss N during burning occurred on the FB site. Before burning, the amounts of N in woody material and humus on that site were roughly equal. However, most of the mass loss came from the woody component, and, although N concentrations were low, total N losses were great (fig. 3a). Similarly, most of the N loss on the SR site came from the woody component, although the total amount lost was an order of magnitude less. More importantly, the majority of the N lost from the MU and DU sites (50 and 65 percent, respectively) came from the humus layer. Even though more mass was lost from the litter layer on those sites, higher N concentrations in the humus layer resulted in a greater proportion of total site N lost from that layer (figs. 3a, 3b). Total amounts were low relative to the extreme condition found on the FB site but the loss of N from the humus layer can have immediate and long-term consequences for site productivity.

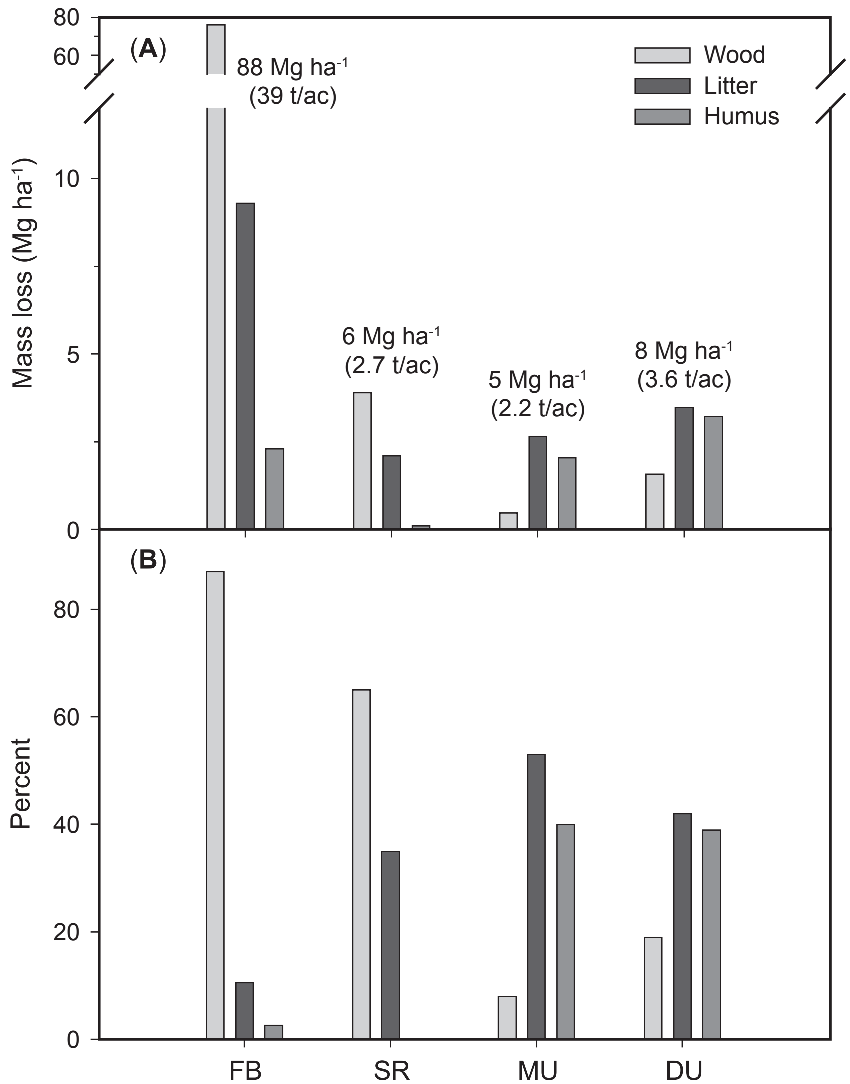

Figure 2—Mass consumption (A, in Mg ha^{-1}) following burning and percent of total loss (B) by site and material type. Values in (A) represent total loss for each site. Values in parentheses are standard English equivalents.

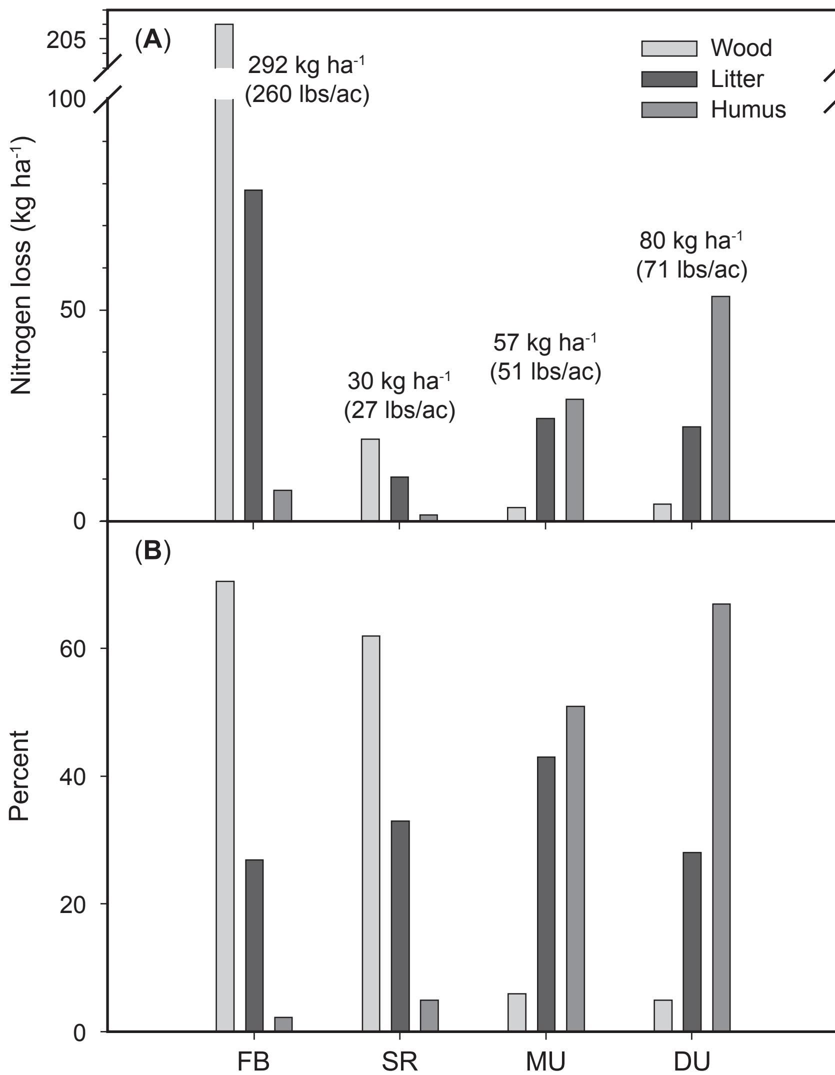

Figure 3—Nitrogen losses (kg ha^{-1}) (A) and percent of total loss (B) by prescription and material type. Values in panel (A) represent total loss for each site. Values in parentheses are standard English equivalents.

Implications for Management

Fire managers cannot control fire weather but they can control ignition timing and type, and consequently fire intensity. Under all site conditions, the longer a prescribed fire persists in one place the more intense the fire and the more likely there will be significant consumption of the humus layer. Minimizing consumption of the humus layer has important implications for long-term site productivity, as this layer is typically the largest reservoir of available site nutrients in these ecosystems. This is particularly important during the post-burn recovery period when young woody and herbaceous seedlings are becoming re-established (Clinton and Vose 2000). Although the short-term loss of site nutrients, particularly nitrogen, is inevitable during burning, prescribed burning can enhance overall site quality and productivity over the long-term by stimulating nitrogen cycling processes. The significance of N losses and time required for recovery and enhancement of N cycling processes varies considerably by ecosystem type and the severity and intensity of the prescribed fire. For example, when total site N pools are small, as was the case on the MU sites, any loss of N — and especially any loss from the humus layer — can represent a substantial fraction of the pre-burn total and increase the risk of negative impacts. Burning under such conditions requires careful planning in order to not compromise near-term site recovery or long-term site productivity.

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INITIAL EFFECTS OF PRESCRIBED BURNING AND THINNING ON PLANT COMMUNITIES IN THE SOUTHEAST MISSOURI OZARKS

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Abstract—A study examining the effectiveness of prescribed fire and thinning as fuel reduction tools was initiated in the southeast Missouri Ozarks in 2001. Vegetation plots were established throughout 12 stands in each of 3 replicate blocks to monitor the effects of fire, thinning, and a combination of fire and thinning on the overstory, understory, and ground flora communities. The study was stratified across north facing slopes, south facing slopes, and ridge tops to discern the influence of topographic position on the treatments and on the resulting vegetation. Prior to treatment, overstory communities in all topographic positions were dominated by black oak (*Quercus velutina* Lam.) and white oak (*Q. alba* L.), and had relatively low diversity and evenness. Understory woody vegetation was dominated by red maple (*Acer rubrum* L.) on northern slopes, white oak (*Q. alba* L.) on ridges, and sassafras (*Sassafras albidum* [Nutt.] Nees) on southern slopes. Immediate and marked changes in the vegetative structure and species composition resulted from the initial burn, thinning, and combined treatments. Burning caused shifts in dominance by physiognomic group, with forbs, grasses, and sedges increasing, while woody tree, vine, and shrub species decreased. Thinning did not significantly affect physiognomic composition in the first year following treatment, and thinned plots were very similar to controls. Topographic position appeared to have more influence on ground flora composition than treatment in the first two years of the study. Continued monitoring may provide insight into the viability of using prescribed fire and thinning for ecosystem restoration in addition to fuel reduction.

INTRODUCTION

The Ozark Highlands region of southeast Missouri is an area of densely forested and rugged terrain. While pre-settlement forest conditions in the topographically variable Ozarks probably ranged from openings to completely closed canopies (Nigh 1992), many researchers believe the forests of the Ozark Highlands were predominantly open-canopy shortleaf pine (*Pinus echinata* Mill.) and oak (*Quercus* sp.) maintained by frequent low-intensity surface fires (Bielmann and Brenner 1951, Ladd 1991, Nelson 1997). Reconstructions of fire frequency in the upper Current River watershed, in the Ozark Highlands, indicated a mean fire interval (MFI) of 15.8 years for the period 1581-1700, 8.9 for 1700-1820, and 3.7 for 1820-1940 (Guyette and Dey 1997). After the establishment of national forests in the area and the enforcement of fire suppression policies, the MFI for Missouri is estimated to be 715 years (Westin 1992). While wildfires still occur in the Ozarks, the average area burned by each fire has been reduced at least 90 percent.

The history of logging in the Ozarks is similar to that seen elsewhere in the Central Hardwoods region. Much of the Ozarks was completely cutover in the late 19th century (Cunningham and Hauser 1989). The second-growth forests regenerated primarily from stump sprouting and are dominated by oak and hickory species. As a result, the shortleaf pine and oak-pine forest types in the Missouri Ozarks have been reduced from an estimated 6.6 million acres (Liming 1946) to approximately 400,000 acres (Cunningham and Hauser 1989). Consequently, fuels in the understory shifted from primarily pine litter and woody debris to hardwood litter and woody debris. Furthermore, litter accumulations and dense canopies have led to conditions unfavorable for the regeneration of oak and shortleaf pine (Stambaugh 2001).

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As the land becomes increasingly populated and fragmented and fuels accumulate, the risk of a devastating fire event increases exponentially (Guyette and others 2002). Though the Ozarks have a long history of periodic low-intensity surface fires, the accumulation of fuels over the past several decades reduces the predictability of fire behavior in these forests. Thus, there is a pressing need for information on potential fuel reduction methods for these forests, and a need for ecological evaluation of such methods to ensure long-term sustainability of the ecosystem. In 2001 a study was initiated in the Missouri Ozarks to investigate the potential of prescribed burning for fuel reduction in thinned and unthinned oak-hickory forests. The specific objective of the work presented here was to document initial effects of these treatments on the resident plant communities.

Study Area

The study area is located in the Black River Hills Oak-Pine Woodland/Forest Hills land type association (LTA) of the Current River Hills subsection of the Ozark Highlands section (Nigh and others 2000). The Black River Oak-Pine Woodland/Forest Hills LTA is characterized by hilly topography with steep slopes and occupies much of the Black River basin. Soils are mainly cherty, low-base soils associated with Roubidoux and Gasconade geologic formations (Nigh and Schroeder 2002). Two of the three study blocks are located in Clearwater Conservation Area, while another is located in Dickens Valley Conservation Area. Both areas are near Ellington, MO and managed by the Missouri Department of Conservation.

METHODS

Study Design and Site Selection

The study uses a split-plot experimental design. The variables include fire (2 levels), thinning (2 levels), and topographic position (3 types). The combinations of prescribed fire/thinning, prescribed fire/no thinning, no fire/thinning, and no fire/no thinning (control) were repeated across three topographic positions (protected backslope, ridge top, and exposed backslope) to form one study block. Control treatments were randomly located either on the east or west side of the block such that the prescribed fire treatment could be applied to the six burned plots as a single unit.

The study block design was replicated at three sites located within the Black River Hills LTA, with each block (replicate) containing 12 treatment plots. Stands were selected to represent mature, upland oak-hickory forests of the Missouri Ozarks. Stands chosen met the criteria of having a stand age of at least 50 years, an overstory dominated by oaks and hickories, and no evidence of fire or other major disturbance within the past 30 years. Three blocks of stands that met all of the criteria were identified, hereafter designated as Blocks 1, 2 and 3.

Fuel Reduction Treatments

Thinning operations were conducted using a mark-leave method during the growing season prior to the first burn. Stocking was reduced to ~40 square feet per acre (~3.7 m^2/ha). Preference for leave-trees was given to the most vigorous individuals of more fire tolerant species such as white oak, post oak (*Q. stellata* Wangenh.), and shortleaf pine. Non-commercial trees were felled by hand, and all slash was left on-site and broken down with chainsaws.

Prescribed burns were conducted by the Missouri Department of Conservation utilizing the ring fire method. The burns were conducted in spring 2003 before full leaf-out had occurred. One plot (Block 3, Ridge, Burn) that was to be treated with prescribed fire was not burned in 2003 due to time and weather constraints, and was dropped from first-year analyses. Flame lengths did not vary greatly between burn-only and burn-thin treatments except where slash piles occurred. Flame lengths varied from 0.5 to 1 foot in backing fires and 1 to 4 feet in head fires. At slash piles, flame lengths ranged from 5 to 40 feet, averaging between 10 and 15 feet (Kolaks and others 2004).

Vegetation Sampling

Permanent vegetation subplots were installed during the summer of 2001. Pre-treatment sampling was conducted May-August, 2001, and post-treatment sampling was conducted May-July, 2003. The size, shape, and configuration of each stand required a modified transect method for sampling three types of subplots: woody regeneration, overstory, and ground flora.

Woody regeneration subplots—Within each plot, 15 circular woody regeneration subplots (0.001 ha) were randomly located along a transect. Three of these subplots also serve as a plot center for 0.1 ha overstory subplots. In addition, five regeneration subplots were randomly placed within each 0.1 ha overstory subplot, for a total of 30 woody regeneration subplots per plot. All live woody stems <4 cm dbh rooted within these subplots were identified to species and tallied by 30 cm height classes. For multiple-stemmed woody species, each stem was tallied and height measured on only the tallest stem.

Overstory subplots—Within each 0.1 ha subplot, all live overstory trees greater than 4 cm dbh were identified to species, dbh measured, tagged, numbered, and location recorded. In post-treatment years, these tagged trees were assigned codes indicating mortality, root suckering, fire damage, and crown position characteristics.

Ground flora subplots—For the sampling of ground flora, one 1 m^2 quadrat was located in association with each of the 15 woody regeneration subplots established along the plot transect. Within each 0.1 ha overstory subplot, five additional 1 m^2 quadrats were also randomly located. Within each quadrat, all live herbaceous plants and woody regeneration (<4 cm dbh) rooted within the quadrat frame were identified to species and cover was estimated to the nearest 1 percent. Site characteristics were collected at each quadrat by measuring percent slope, aspect, and crown cover (densitometer reading), and estimating percentages of bare soil, leaf litter coverage, exposed rock, and downed dead woody material.

Statistical analyses—An ANOVA model was developed to include the three replicate sites, three aspect classes, and four levels of treatment. Using SAS, PROC GLM and PROC MIXED were used to test for differences between pre- and post-treatment plant community characteristics such as species richness (number of species per 30 m^2), diversity, and evenness. ANOVA was also used to analyze treatment effects on the proportional cover by physiognomic group, using an angular transformation to improve normality and homogeneity of variance (Beers and others 1966):

$$y = \sin^{-1} (\sqrt{x}) \qquad (1)$$

Importance values (relative frequency + relative abundance) of individual species were used to examine which species increased or decreased greater than 10 percent following treatment, and also to determine new and missing species following treatment.

Diversity was calculated using the Shannon diversity index (Shannon and Weaver 1949, Magurran 1988):

$$H' = -\sum_{i=1}^{St} p_i \log_e p_i \qquad (2)$$

Evenness was calculated using Pielou's formula (Pielou 1975):

$$J' = \frac{H'}{H'_{\max}} = \frac{H'}{\log_e S} \qquad (3)$$

RESULTS

Overstory

Stand structure—Prior to treatment all study plots were fully stocked stands dominated by oak and hickory species. Across all plots, pre-treatment trees per acre (TPA) ranged from 241.6 to 485.8, with a mean of 357.4. Basal area (BA) ranged from 79.5 square foot per acre to 146.2 square foot per acre (7.4 to 13.7 m^2/ha), with a mean of 107.4 square foot per acre (10.0). Stands were on average 95 percent fully stocked with a range in stocking of 71.5 to 129.2 percent. In general, protected backslopes had the highest values for all three stand structure characteristics.

Thinning removed an average of 101.8 trees per acre and 57.7 square foot per acre BA, while stocking decreased an average of 59.1 percent. Burn-thin plots exhibited the greatest decreases in all three stand characteristics, followed by thin-only plots and burn-only plots. Although TPA, BA, and percent stocking decreased following treatment, burn-only plots were more similar to control plots following treatment than thin or burn-thin plots (table 1).

Species composition—Both before and after treatment, the composition of the overstory across all plots was dominated by the same species in terms of number of individuals: hickory sp. (*Carya* sp.), flowering dogwood (*Cornus florida* L.), white oak, black oak, and black gum (*Nyssa sylvatica* Marshall). In terms of relative BA, differences after treatment reflected the effect of thinning: shortleaf pine, scarlet oak (*Q. coccinea* Muenchh.), and post oak all had greater proportional abundance following thinning.

On protected slopes, hickory, dogwood, and black gum, represented much less of the proportional basal area following all treatments (when compared to pre-treatment levels), while scarlet oak, black oak, and white oak increased in mean relative basal area. On ridges and exposed slopes, similar patterns occurred, but with greater post oak and shortleaf pine presence in the post-treatment composition. The effect of thinning and/or burning on overstory species composition in the first year was primarily the reduction of small diameter dogwoods, black gums, and hickories.

Ground Flora

Species richness—Pre-treatment plot richness ranged from 20 to 91, with a mean of 36.5 species across all plots. Following treatment, mean plot richness was 36.8 and ranged from 20 to 87 species. The overall ANOVA model was not significant, and no significant differences in richness due to the main effects of treatment were found (table 2). Most of the variability in richness was due to differences among replicate blocks. Tests of the differences between least square means (LSMeans) indicated a significantly higher richness on exposed slopes than protected slopes following treatment (P=0.0437).

Table 1—Mean trees per acre (TPA), basal area (BA), and percent stocking by site, aspect, and treatment

Site, aspect, and treatment	Pre-treatment 2001			Post-treatment 2003			Percent change between years		
	TPA	BA	Stocking	TPA	BA	Stocking	TPA	BA	Stocking
		ft^2/ac	*percent*		ft^2/ac	*percent*		ft^2/ac	*percent*
Site 1	341	105	92	187	77	65	-45	-26	-29
Site 2	380	109	99	174	70	61	-54	-36	-38
Site 3	351	108	95	208	78	67	-41	-27	-29
Protected	367.4	110.4	96.8	184.1	76.2	64.4	-50	-31	-33
Ridge	348.9	105.8	94.1	188.3	75.8	65.1	-46	-28	-31
Exposed	356.1	105.9	94.2	196.2	73.6	63.9	-45	-31	-32
Control	350.6	107.3	94.7	329.0	107.9	94.4	-6	1	-0
Burn	333.2	94.3	84.7	246.9	89.3	77.5	-26	-5	-9
Harvest	338.3	112.3	97.3	94.7	54.0	44.9	-72	-52	-54
Harvest-burn	370.7	105.1	94.1	60.0	39.7	32.5	-84	-62	-65

Table 2—Results of analysis of variance tests conducted for post-treatment ground flora plant community characteristics, including analysis of difference scores (post-treatment minus pre-treatment)

	P-value									
Post-treatment	Overall	Site	Aspect	Harvest	Aspect x harvest	Burn	Aspect x burn	Harvest x burn	Aspect x harvest x burn	Site x aspect	Significant differences[abcd]
Richness (n = 34)	0.1053	0.0268								0.0462	None
Abundance (n = 35)	<.0001			0.0001		<.0001		0.0001			**ab ac ad af ag ah aj ak al bc be** bg **bi** ce ch **ci cj** cl **de di ef eg eh ej ek el fi** gh **gi** gj gl **hi ij ik il**
Diversity (n = 34)	0.0028		0.0049			0.0008	0.0146			0.0107	**ab ad ae af ag ah ai aj ak al bc cd** ce **cf cg ch** ci **cj** ck **cl**
Evenness (n = 35)	0.0259		0.0284			0.0024	0.0253				**ab ad** ae af **ag ah ai** aj ak **al** bc **cd** cg **ch** ci **cl** el jl kl
Differences											
Richness (n = 35)	0.3352	0.0129									cj
Abundance (n = 35)	0.0007	0.0439	0.0248	0.003		0.0002		0.0002			**ab ac ad af** ag **ah** aj ak **al be** bg **bi** bj bk **ce** cg ch **ci** cj ck **de di ef** eg eh ej ek **el fi** gi **hi** ij ik **il**
Diversity (n = 35)	0.1114					0.0024					ab ad al bc be bi bj bk cd **cl** de dg di dj dk el gl il jl kl
Evenness (n = 35)	0.1206					0.0074					ab ad **al** bc be bg bi **bj** bk cl di dj el fl gl il **jl** kl

[a] All letter combinations imply a significant difference between aspect and treatment combinations as follows: a = protected, control; b = protected, burn; c = protected, thin; d = protected burn-thin; e = ridge, control; f = ridge, burn; g = ridge, thin; h = ridge, burn-thin; i = exposed, control; j = exposed, burn; k = exposed, thin; l = exposed, burn-thin.
[b] Letters in bold indicate significance at the 0.01 level, all others significant at the 0.05 level.
[c] Only significant sources of type III SS in the model are indicated.
[d] Significant differences based on tests of least square means for effect aspect x harvest x burn Pr>|t| for H0: LSMean(i) = LSMean(j).

Diversity and evenness—Prior to treatment, diversity values ranged from 2.0 to 3.5 (mean = 2.5). Pre-treatment diversity differed significantly by block and aspect. While not significantly different from each other, ridges and exposed slopes tended to have higher mean diversity than protected slopes. Following treatment, diversity values ranged from 2.1 to 3.5 (mean = 2.6. Significant variability in diversity existed due primarily to the effects of burning (P=0.0008) and aspect (P=0.0049) (table 2). Mean diversity was highest on burn-thin plots, followed by burn plots, thin plots, and controls. Mean diversity scores on protected control and protected thin plots were significantly lower than those of all other aspect and treatment combinations.

LSMeans tests of differences showed significantly greater increases in diversity on protected plots versus ridge plots (P=0.0280). The highest increases in diversity occurred on burn-thin plots in all landscape positions, followed by burned plots, controls, and thinned plots.

Evenness (J') differed significantly before treatment among the three aspect classes. Mean evenness on protected plots was significantly lower than on ridge (P=0.0308) and exposed (P=0.0244) plots prior to treatment. A comparison of the LSMeans also indicated that exposed plots with a burn-thin prescription had significantly lower evenness prior to treatment than exposed control plots (P=0.0109) and exposed burn-only plots (P=0.0145).

Following treatment, burned plots had significantly higher mean evenness than unburned plots (P=0.0024). Mean evenness on burn-thin plots was significantly higher than those on control (P=0.0015) and thin (P=0.0029) plots. Mean evenness increased across all aspects, with evenness increasing more substantially on protected slopes. Mean evenness increased the most on burn-thin plots, followed by burn-only, thin-only, and controls. Only thin and burn-thin plots were significantly different than controls in mean evenness following treatment.

Species responses—The burn-only and burn-thin treatments tended to increase the abundance of *Carex* sp. and *Panicum* sp.; both genera increased by at least 10 percent in mean importance value on all aspects with these treatments, though their overall relative abundance remained small. *Desmodium*, the most ubiquitous herbaceous genera prior to treatment, was generally reduced by burning, with the exception of ridge burn plots. Scarlet oak seedlings were eliminated entirely following treatment on burn plots on all landscape positions, and on burn-thin plots in protected positions.

In the post-treatment sample, three species occurred despite being absent prior to treatment: *Ambrosia artemisifolia* (ragweed), *Erechtites hieracium* (fireweed) and *Phytolacca americana* (pokeweed). All are weedy annual forbs commonly found in Missouri on recently disturbed sites, and were found only on treated plots in this study. There were no annual forbs found in the pre-treatment sample.

In general, burning affected the cover and frequency of woody species in the ground flora layer more than herbaceous species, increasing sassafras and sumac species while decreasing scarlet oak, American hazel (*Corylus americana* Walt.), Carolina buckthorn *(Rhamnus caroliniana* Walt.), white oak, eastern redbud (*Cercis canadensis* L.), flowering dogwood, black gum, red maple, black oak, bush honeysuckle (*Lonicera flava* Sims.), Virginia creeper (*Parthenocissus quinquefolia* L.), persimmon (*Diospyros virginiana* L.), and *Vaccinium* sp. These species responded similarly to both the burn-only and burn-thin treatments. Thin-only plots exhibited increases in woody species such as black gum, *Vaccinium* sp., *Vitis* sp., flowering dogwood, and Virginia creeper, and decreased cover and frequency of sassafras, red maple, black oak, white oak, and persimmon.

Compositional changes—Ground flora species were grouped physiognomically: perennial native forbs (including herbaceous vines and ferns), annual native forbs, graminoids (grasses and sedges), legumes, woody tree species, woody vines, and shrubs. Proportional abundance of each physiognomic group was examined for each aspect and treatment through mean relative cover, and LSMeans tests revealed statistical differences between pre- and post-treatment ground flora physiognomic composition.

Regenerating tree species decreased in burn-only plots in all landscape positions, and woody vines, graminoids, perennial forbs, and annual forbs increased following treatment. Shrub abundance decreased substantially on ridges, decreased slightly on exposed slopes, and increased slightly on protected slopes. Legumes increased substantially on ridges (fig. 1), decreased slightly on exposed slopes (fig. 2), and remained stable on protected slopes (fig. 3).

Slight decreases in abundance of regenerating tree species, very slight decreases in shrubs, and slight increases in woody vines occurred in thin-only plots in all landscape positions exhibited. In general, physiognomic composition did not shift as dramatically in thin-only plots following treatment as burned plots, and thinned plots were more similar to controls than to other treatments.

Burn-thin plots in all landscape positions showed decreased proportional abundance of regenerating tree species and legumes, and increased abundance of graminoids, perennial forbs, and annual forbs following treatment. Woody vines increased substantially on exposed slopes, increased slightly on protected slopes, and decreased slightly on ridges. Shrubs increased slightly on protected slopes, decreased on exposed slopes, and remained stable on ridges.

SUMMARY AND CONCLUSIONS

All fuel reduction treatments significantly reduced ground flora abundance on every landscape position. Landscape position did seem to mitigate some of the effects of treatment, as ridges were generally less affected by the treatments than both protected and exposed slopes. Thinning consistently impacted the ground flora layer less than the burn and burn-thin treatments in terms of species composition. Annual forbs such as fireweed and pokeweed were prolific on burn-only and burn-thin plots across all aspects. Diversity increased more on protected slopes with these treatments than on any other aspect-treatment

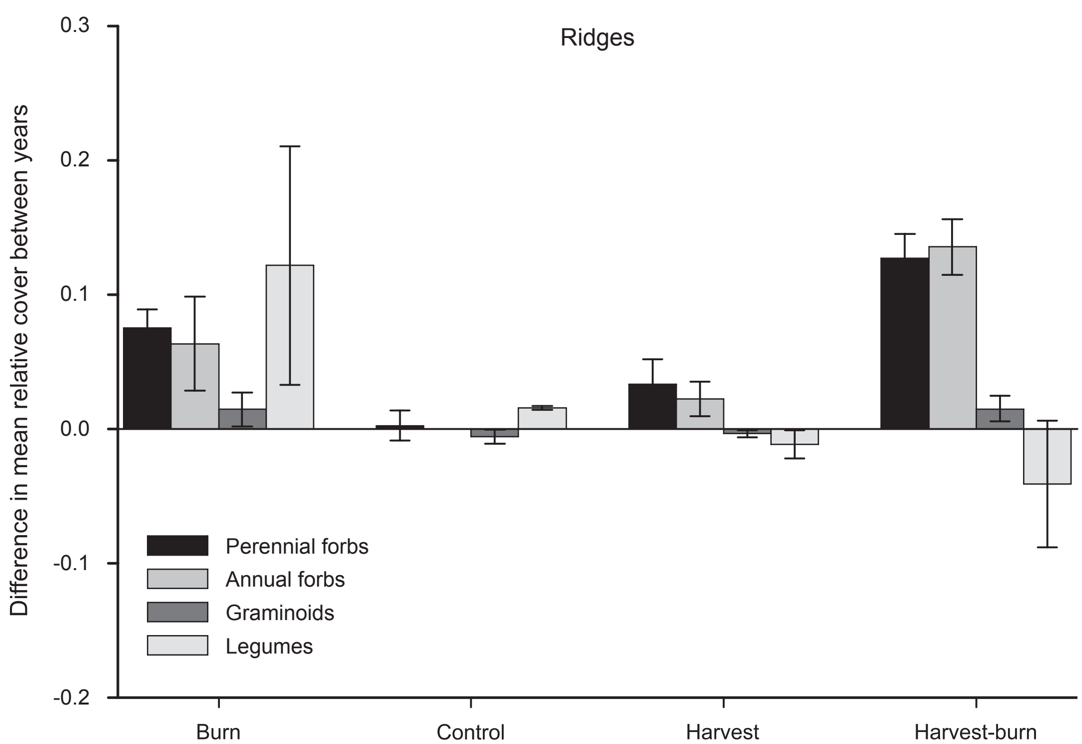

Figure 1—Differences in mean relative cover (post-pre) of herbaceous physiognomic groups on ridges, by treatment.

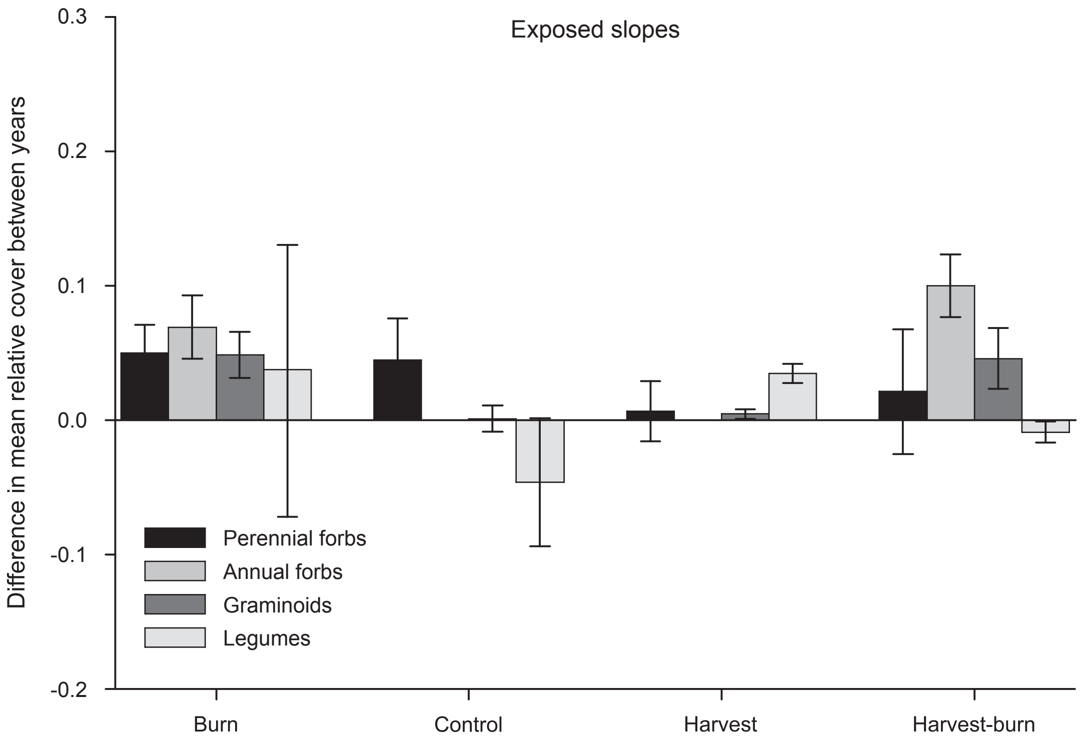

Figure 2—Differences in mean relative cover (post-pre) of herbaceous physiognomic groups on exposed slopes, by treatment.

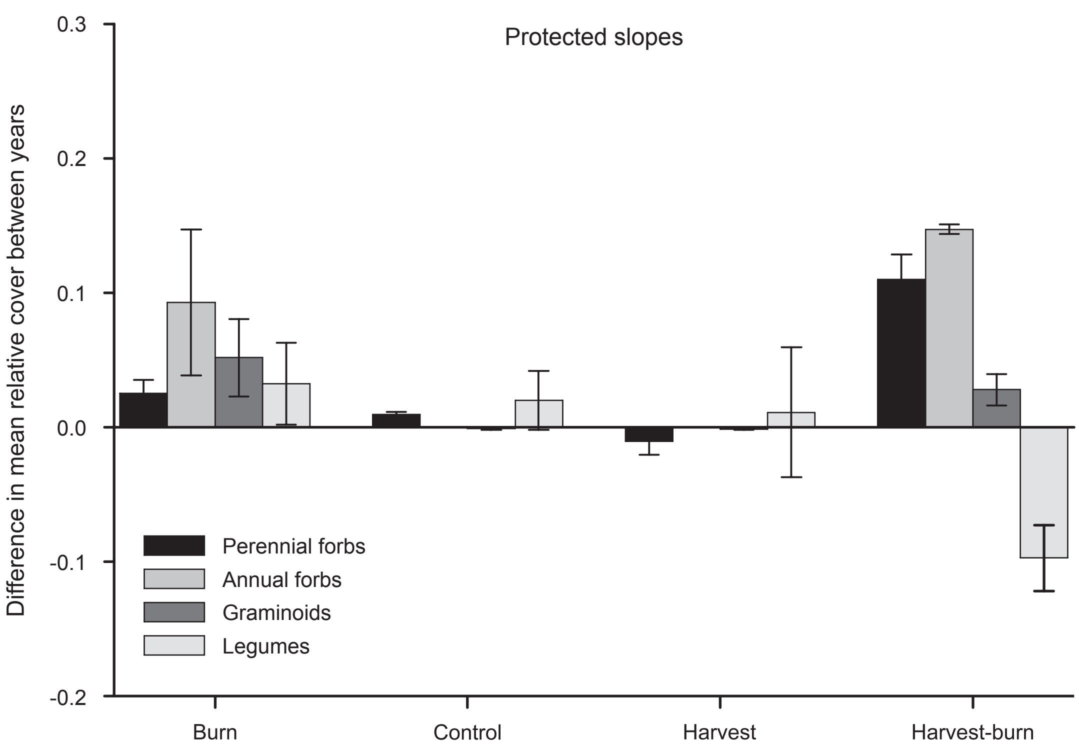

Figure 3—Differences in mean relative cover (post-pre) of herbaceous physiognomic groups on protected slopes, by treatment.

combination. Legumes increased the most on burn-only plots, while they decreased the most on burn-thin plots. It is important to note that these findings may be very short-lived, and may capture only the immediate response to these treatments.

The study is scheduled to continue until at least 2007, and a second prescribed burn and vegetation sampling was conducted in 2005. Monitoring of the herbaceous plots will continue, and vegetation data will continue to be linked with fire behavior and fuel loading data as the plots continue to change following treatments. In addition, woody regeneration and overstory plots will provide information on overstory mortality and regenerative capacity following these treatments.

Implications for findings thus far suggest there is a substantial interaction among all treatment types with topographic position. Careful consideration of treatments, particularly those utilizing prescribed fire, must consider topographic position.

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EFFECTS OF LANDSCAPE POSITION AND SEASON OF BURN ON FIRE TEMPERATURE IN SOUTHERN OHIO'S MIXED OAK FORESTS

Doug J. Schwemlein and Roger A. Williams[1]

Abstract—The use of fire to maintain and restore oak (*Quercus* spp.) ecosystems is becoming an increasingly accepted silvicultural tool; however, specific management recommendations have been slow to develop as past studies have shown mixed results. By examining fire temperature in response to landscape position and season of burn, we attempted to offer increased insight into the use of prescribed fire to effectively regenerate oak. Prescribed burns were performed in 2004 in two oak forests that encompassed 96 and 170 ha. One forest was burned late-March and the other was burned early-November. Eight areas that represented the four aspects and two slope positions (upper and lower) were marked out within each forest and replicated. Fire temperature was measured using temperature-sensitive paint applied to aluminum tags (pyrometer) at three different heights above the forest floor. Six pyrometers were placed in each area, providing a total of 192 sets of temperature/height data. Pre-burn fuel conditions were characterized around each temperature gauge. Temperature readings as indicated by temperature-sensitive paint were recorded immediately after each burn. Fall burns were significantly hotter than spring burns at all aspects and slope positions. This same trend was recorded at the different height readings, indicating longer flame lengths during the fall burn. This paper discusses how fire reacts to landscape position and season of burn, and how these factors may be used to more successfully implement prescribed fire for oak management objectives.

INTRODUCTION

Over the past fifty years many stands once dominated by oak have been slowly replaced by more mesophytic species, especially red maple (*Acer rubrum*) (Heiligmann and Norland 1985, Lorimer 1993). These declining oak-dominated, second-growth forests of today are believed to have originated after years of widespread, high intensity fires swept through old-growth logging slash. However, the historical disturbance regime also consisted of more frequent, low intensity fire (Brose and others 2001), ignited naturally by lighting, but mainly by indigenous peoples and early settlers (Kimmerer and Lake 2001). It seems inevitable that without replicating this historical fire regime, oaks will continue to decline because of the increasing difficulty in regenerating the genus (Clark 1993).

In recent years the use of prescribed fire as a means to maintain or restore oak forests has gained attention as studies have indicated the potential effectiveness of this management tool (Arthur and others 1998, Brose and others 1999). The ubiquitous nature of oak regeneration failure throughout its eastern range requires that an equally universal management technique must be developed and implemented if forest managers are to maintain and restore oak forests. Although it seems clear that fire can increase oak regeneration success, the analysis of more specific data about fire will increase its effectiveness as a management tool. For instance, if higher fire intensity, of which temperature is large part, is more effective in promoting oak regeneration, then detailed knowledge about fire temperature variability across a multitude of landscape positions would be very useful. The objective of this study was to examine how fire temperature is affected by landscape position, aspect, and season of burn. These results are the first phase of a continuing study that will evaluate the differential sprouting response of oak and red maple following fire.

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SITE DESCRIPTION

The two study sites are located 24 km apart in the unglaciated hill country of southern Ohio. The regional topography is characterized by deeply dissected terrain of the Allegheny Plateau, which creates a gradient of moisture regimes and subsequent microclimates across the landscape. Forest composition and structure consist primarily of mixed-oak, sawtimber size stands. Both sites are located within Ohio state forests with similar geologic, topographic, and climatic characteristics, and accordingly, very similar vegetation.

The spring burn site is a 96 ha tract located in Richland Furnace State Forest (39°10'N, 82°36'W), in Jackson County, Ohio. Soils consist mainly of deep, well drained to moderately well drained silt loams of the Rigley-Rarden-Clymer association, formed in colluvium and residuum from sandstone and shale. The climate of Jackson County is characterized by mean annual precipitation of 105.36 cm and a mean annual temperature of 11°C. Average daily maximum and minimum temperatures in January are 4.3°C and -5.7°C respectively, and average daily maximum and minimum temperatures in July are 30°C and 15.5°C respectively (United States Department of Agriculture 1985).

The fall burn site is a 170 ha tract located in Tar Hollow State Forest (39°22'N, 82°45'W), in Ross County, Ohio. Soils in this area are deep to very deep, moderately well drained to well drained soils of Cruze-Shelocta-Brownville association, derived from shale, siltstone, and sandstone. The climate of Ross County is characterized by mean annual precipitation of 98.50 cm with a fairly even annual distribution. The mean annual temperature is 11.6°C, with January average daily maximum and minimum temperatures being 3.7°C and -7.7°C respectively, and July average daily maximum and minimum temperatures being 30°C and 16.8°C respectively (United States Department of Agriculture 2003).

SAMPLE DESIGN

This study was the first phase of a continuing study that will evaluate the differential sprouting response of oak and red maple following fire. Because the overall objective was to evaluate the response of individual sample trees to fire, the experimental design consisted accordingly of individual observations surrounding those sample trees.

Prior to the burns at each site, two areas were identified that represent northeast (NE) (360°-90°), southeast (SE) (90°-180°), southwest (SW) (180°-270°), and northwest (NW) (270°-360°) aspects. In addition, two areas were chosen at each aspect that represent slope position: upper and lower. These landscape positions were defined with the upper slope being the upper 33 percent of the slope and lower slope being the lower 33 percent of the slope. The two sample areas in each aspect and slope position were placed in different locations within each site for replication. This provided for the following sample design:

(2 areas) X (4 aspects) X (2 slope positions) X (2 sites) = 32 areas

Fire temperature measurement was achieved by placing six pyrometers throughout each area. With six temperature gauges at 32 areas, the following sample size was achieved:

N = (6 pyrometers) X (32 areas) = 192

Each pyrometer then became the center of a circular 0.005 hectare plot for purposes of characterizing fuel. This characterization was performed by placing fuel into fuel-type categories defined as: (1) coarse woody debris being small to large logs, (2) fine woody debris being twig, branch and bark material, (3) woody vegetation, and (4) herbaceous vegetation. The percent coverage of each of these fuel types on each plot was determined by ocular estimation and recorded. The litter depth was defined as the depth to mineral soil, and was measured at the base of each pyrometer.

The temperature gauges consisted of three aluminum tags painted with temperature-sensitive paint (Tempilaq®), and attached to a metal pin that was then inserted into the ground (Blankenship and Arthur

1999, Boerner and others 2000, Cole and others 1992). The three aluminum tags were attached to each pin at 0 cm, 20 cm, and 40 cm above the ground. On each tag, 10 temperature-sensitive paints were applied, each with a different melting point from 79°C to 538°C, as a means to record the fire temperature at different heights. The aluminum tags were then covered with aluminum foil to protect the paint from moisture, ash, and charring damage. Soon after the burns were completed, the aluminum tags were collected, and the temperature indicated by the melted paint was recorded.

Fire Implementation

The Ohio Division of Forestry conducted both the spring and fall burns with the dual intention of reducing fuel, in accordance with the national fire plan, and to promote oak regeneration. Both burn areas were fully enclosed by either roads or bulldozed fire lines. Ignition consisted of first backfiring a buffer or blackline of approximately 30 m around the perimeter of the burn area. The interior of the burn compartment was then lit using both manual and aerial internal ignitions.

The spring burn in Richland Furnace State Forest was conducted at approximately 10:00 a.m. on March 26, 2004. Weather conditions were partly cloudy with a relative humidity and air temperature of 46 percent and 21°C respectively, and southwesterly winds of 14.5 km per hour. The fall burn at Tar Hollow State Forest was implemented at approximately 10:00 a.m. on November 10, 2004. Weather conditions were partly cloudy with a relative humidity and air temperature of 35 percent and 16°C respectively, and southwesterly winds of 7.9 km per hour. Fuel moisture levels were not measured prior to the fires; however both sites had recently received light precipitation.

RESULTS

The prescribed fires burned both sites almost completely, leaving only small patches of each area unburned. However, due to these unburned areas several samples were discarded, reducing the spring burn sample size from 96 to 92, and the fall burn sample size from 96 to 90.

Fuel characterization yielded fairly homogeneous pre-burn fuel levels between the spring and fall sites (table 1). Litter depths across sites did not differ significantly, with a spring site depth of 4.5202 cm and a fall site depth of 4.5159 cm. Similarly, little difference was measured in the fuel-type categories across the two sites with coarse, woody and herbaceous fuels not differing significantly; however, a significant difference was found between mean fine woody debris percentages, with a spring site mean of 9.7917 percent cover and a fall site mean of 12.604 percent cover.

The pyrometers indicated a significantly higher temperature in the fall burn than in the spring (table 2). The average total temperature, which consisted of all samples combined, was 117°C for the spring burn and 167°C for fall burn. This difference between burns was similar when temperatures were examined at

Table 1—Mean fuel characteristics of two forest sites in southern Ohio used in this study

	Burn season (site)	
Fuel characteristics	Spring	Fall
Litter depth (cm)	4.52 a	4.52 a
Coarse woody debris cover (percent)	8.23 a	9.48 a
Fine woody debris cover (percent)	9.79 a	12.60 b
Woody vegetation (percent)	25.26 a	23.65 a
Herbaceous vegetation (percent)	13.81 a	12.53 a

Means followed by the same small case letter are not significantly different across sites (Duncan's MRT, p = 0.05).

Table 2—Mean fire temperatures by burning season of two forest sites in southern Ohio used in this study

Temperature/location	Burn season (site)			
	N	Spring	N	Fall
		°C		*°C*
Average total temperature	92	117 a	90	167 b
Average temperature at 0 cm	92	176 a	90	233 b
Average temperature at 20 cm	92	107 a	90	166 b
Average temperature at 40 cm	92	68 a	90	101 b

N = sample size.
Means followed by the same small case letter are not significantly different across sites (Duncan's MRT, $p = 0.05$).

the three temperature height locations. Mean ground level temperatures for spring versus fall burns were 176°C and 233°C, mean temperatures at 20 cm were 107°C and 166°C, and mean temperatures at 40 cm were 68°C and 101°C respectively. The significantly higher temperatures recorded at 40 cm during the fall burn indicate that fall burn flame heights were greater. These higher flame heights were also confirmed by observing higher scorch heights on surrounding trees. Fire temperature and height were found to have a negative relationship at both the spring and fall burn sites, with ground level temperatures being the highest and the 40 cm temperatures being the lowest.

The fall burn also resulted in higher temperatures when measurements were further evaluated by aspect, height, and burn season (table 3). For each temperature location: total average temperature, average temperatures at 0 cm, average temperature at 20 cm, and average temperature at 40 cm, the NE and NW aspects were slightly higher for the fall burn than for the spring burn; however SE and SW aspects were all significantly higher for the fall burn. In addition to burning hotter, the fall burn had a more variable temperature range than the spring burn, with average total spring temperatures ranging from 89°C to 141°C, a difference of only 52°C, while average total fall temperatures ranged from 96°C to 207°C, a difference of 111°C. For both burns the SE aspects achieved the highest temperatures for all temperature locations, except for the 20 cm location during the fall burn where the SW aspect temperatures were highest. SW aspects showed the second highest temperatures across both sites, NW aspects were the third highest, and NE aspects indicated the lowest temperatures.

Fire temperatures were higher on upper slope positions for both spring and fall burns (table 4). Spring burn values across all temperature height locations were higher on upper slope positions than lower slope positions, with the average total temperature ranging from 103°C on lower slopes to 132°C on upper slopes, a difference of 29°C; however only the difference at the 0 cm temperature location was found to be significant. Fall burn values across all temperature locations were significantly higher on upper slopes than lower slopes, with the average total temperature ranging from 103°C on lower slopes to 199°C on upper slopes, a difference of 96°C. Temperature differences between season of burn were higher across both slope positions and all temperature locations for the fall burn. Upper slope positions for the fall burn were significantly higher than upper slope positions for the spring burn across all temperature locations. Lower slope position temperatures were higher for the fall burn, with the exception of the 20 cm temperature location, but these differences were not significant.

Mean temperature values grouped according to slope position and aspect show significantly higher fall burn temperatures (table 5). The mean temperatures also duplicate the positive relationship between slope elevation and temperature, as in table 4. Upper slopes with SE and SW aspects achieved the highest

Table 3—Mean fire temperatures by burning season and aspect of two forest sites in southern Ohio used in this study

Temperature/location	Aspect	N	Burn season (site) Spring	N	Fall
			°C		*°C*
Average total temperature	NE	29	89 aA	22	96 aA
	SE	29	141 bA	22	207 aB
	SW	11	124 abA	24	203 aB
	NW	21	120 abA	25	155 bA
Average temperature at 0 cm	NE	29	156 aA	21	165 aA
	SE	29	207 aA	22	278 bB
	SW	11	169 aA	24	257 bB
	NW	21	165 aA	25	227 bB
Average temperature at 20 cm	NE	29	77 aA	21	95 aA
	SE	29	125 aA	22	198 bB
	SW	11	125 aA	24	207 bB
	NW	21	113 aA	25	158 bA
Average temperature at 40 cm	NE	29	35 aA	21	29 aA
	SE	29	89 aA	22	145 bB
	SW	11	79 aA	24	144 bB
	NW	21	80 aA	25	81 cA

N = sample size.
Means followed by the same small case letter are not significantly different across aspects; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, p = 0.05).

temperatures for both spring and fall burns, while lower slopes with NW and NE aspects experienced lowest temperatures.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Fire intensity has been shown to be one of the key factors in encouraging competitive oak regeneration (Arthur and others 1998, Brose and others 1999), with oak regeneration success often displaying a positive relationship with fire intensity. Because landscape position, season of burn and fuel characteristics can determine fire intensity, more knowledge about these interactions could help to fine-tune the use of prescribed fire as a management tool.

Other studies have suggested that spring burns are most effective in achieving medium to high intensity burns (Brose and others 1999), due to the occurrence of more days with favorable weather conditions such as high temperature, low humidity, and sunshine. Our findings at Richland Furnace and Tar Hollow, however, showed that higher fire intensity was reached during the fall burn. With weather conditions, fuel quantities, and site characteristics being similar between the spring and fall burns studied here, the more intense fall burn can perhaps be explained by the superior quality of leaf litter in the fall burn. Leaves had freshly fallen prior to the November fire, whereas by spring much of the fall litter would be expected to degrade somewhat. However, contrary to expectations, the results showed nearly identical litter depths at the two sites, suggesting that leaf litter quality rather than leaf litter quantity influenced fire temperature.

Table 4—Mean fire temperatures by burning season and slope position of two forest sites in southern Ohio used in this study

Temperature/location	Slope position	Burn season (site)			
		N	Spring	N	Fall
			°C		*°C*
Average total temperature	Upper	43	132 aA	46	199 aB
	Lower	47	103 aA	46	103 bA
Average temperature at 0 cm	Upper	43	198 aA	46	198 aB
	Lower	47	156 bA	46	156 bA
Average temperature at 20 cm	Upper	43	119 aA	46	119 aB
	Lower	47	96 aA	46	96 bB
Average temperature at 40 cm	Upper	43	79 aA	46	79 aB
	Lower	47	58 aA	46	58 bA

N = sample size.
Means followed by the same small case letter are not significantly different across slope positions; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, $p = 0.05$).

Fall burns may also be preferable to spring burns for oak regeneration due to differences in post-burn nutrient utilization by trees. The historical forest conditions in which oak remained dominant are thought to have been nitrogen limiting, and through chronic atmospheric deposition, species with higher nitrogen requirements can now outcompete oak (Boerner and Brinkman 2003). These competitors are likely to receive a surge of recycled nutrients after a spring burn to facilitate vigorous sprouting. However, after a fall burn, many of these nutrients would be lost to leaching and runoff while the trees are dormant. Boerner and Brinkman also state that when mean fire temperatures exceed 200°C, direct volatilization of nitrogen becomes significant, which would also help to favor oak because of its adaptation to poorer site conditions. This volatilization would have been greater during the fall burn where temperatures frequently reached or exceeded 200°C, while during the spring burn 200°C was rarely reached.

Our results also clearly show that fire intensity is directly related to slope position and aspect. Measurements on the upper slopes of both spring and fall sites displayed higher temperatures than on lower slopes. Measurements on SE and SW aspects showed significantly higher temperatures than on NW and NE slopes across both sites. This relationship between aspect and fire temperature has important management implications if achieving moderate to high intensity fire is the goal. Because oak regeneration success, or oak competition failure, has been shown to increase with fire intensity (Arthur and others 1998, Brose and others 1999), then it may only be practical to maintain or restore oak on the SE and SW aspects where fire intensity will be high enough to have the desired effect. On NW and NE aspects where fire intensity is likely to be low, repeated burns or alternative silvicultural treatments may be necessary to promote oak. Historically, oak may have been able to dominate these productive, mesic sites due to a more frequent and intense fire regime which, due to safety precautions, today's forest managers are unable to duplicate with prescribed fire.

Table 5—Mean fire temperatures grouped according to slope position and aspect by burning season for two forest sites in southern Ohio used in this study

Temperature/location	Slope position	Aspect	N	Burn season (site) Spring	N	Fall
				°C		*°C*
Average total temperature	Upper	NE	16	91 aA	13	135 aA
		SE	13	175 aB	9	223 bB
		SW	3	115 aAB	13	229 bB
		NW	11	146 aAB	11	219 bB
	Lower	NE	13	87 aA	8	33 aA
		SE	16	112 aA	13	196 bB
		SW	8	128 aA	11	172 aB
		NW	10	91 aA	14	105 aC
Average temperature at 0 cm	Upper	NE	16	184 aA	13	219 aA
		SE	13	228 aA	9	297 bB
		SW	3	186 aA	13	290 bB
		NW	11	187 aA	11	290 bB
	Lower	NE	13	121 aA	8	78 aA
		SE	16	191 aA	13	264 bB
		SW	8	163 aA	11	218 aB
		NW	10	142 aA	14	177 aB
Average temperature at 20 cm	Upper	NE	16	72 aA	13	130 aA
		SE	13	166 aB	9	217 aB
		SW	3	79 aA	13	228 bB
		NW	11	144 aAB	11	226 bB
	Lower	NE	13	84 aA	8	40 aA
		SE	16	92 aA	13	184 bB
		SW	8	142 aA	11	183 aB
		NW	10	79 aA	14	105 aA
Average temperature at 40 cm	Upper	NE	16	18 aA	13	58 aA
		SE	13	132 aB	9	155 aB
		SW	3	79 aB	13	169 aB
		NW	11	107 aAB	11	141 aB
	Lower	NE	13	56 aA	8	0
		SE	16	54 aA	13	138 bB
		SW	8	79 aA	11	114 aB
		NW	10	33 aA	14	50 aA

N = sample size.
Means followed by the same small case letter are not significantly different across aspects within slope positions; means followed by the same uppercase letter are not significantly different between burn seasons (Duncan's MRT, $p = 0.05$).

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FOREST FUELS AND LANDSCAPE-LEVEL FIRE RISK ASSESSMENT OF THE OZARK HIGHLANDS, MISSOURI

Michael C. Stambaugh, Richard P. Guyette, and Daniel C. Dey[1]

Abstract—In this paper we describe a fire risk assessment of the Ozark Highlands. Fire risk is rated using information on ignition potential and fuel hazard. Fuel loading, a component of the fire hazard module, is weakly predicted ($r^2 = 0.19$) by site- and landscape-level attributes. Fuel loading does not significantly differ between Ozark ecological landtypes. Drought and exposure are related to fuel moisture content. Drought is particularly important to the Ozark fire regime and fire risk as it is related to both ignitions and fuels.

INTRODUCTION

In recent decades much attention has centered on the occurrence of wildfires and the concomitant changes in vegetation, climate, and human population. Despite over 15,000 fires occurring annually in the Central Hardwoods Region (National Fire Occurrence Database 2001), little work has been done to assess fire risk. The high number of fire events and relatively low level of concern supports the widely recognized fact that the region's fire risk is much lower than that of western states. Although unrealized, extreme drought conditions enhance the potential for high fire risk in the Central Hardwoods.

The importance of fire risk information lies in understanding its spatial and temporal variability, knowledge that can be used for a variety of purposes. Managers can prioritize areas for fuel reduction treatment and integrate fire risk into regional fire plans. Community and rural fire district managers can use fire risk information to improve protection and response to fires (Winter and Fried 2001). Forest harvesting schedules can be planned and optimized to reduce fuel hazard (Englin and others 2000).

OZARK FIRE REGIME

For over 400 years the fire regime of the Ozark Highlands has been influenced by humans (Guyette and Dey 2000, Guyette and Spetich 2003). The historic frequency of burning was largely a result of changing human population and culture (Guyette and others 2002). Today, human ignitions represent over 98 percent of the total ignitions (1980-2003; Missouri Department of Conservation fire data) and their number is highly correlated to drought. Arson is the largest cause of human ignitions. Year to year changes in number of acres burned are correlated (r = .61) between state lands and the Mark Twain National Forest suggesting a larger scale influence on fire occurrence (data: Westin 1992, National Fire Occurrence Database 2001, USFS Missouri fire records unpublished data). Previous studies have characterized the dynamics of surface fires and vegetation in the Ozarks (Jenkins 1997, Batek and others 1999, Kolaks 2004, Nigh 2004). Mean fire size in the Ozark Highlands is about 31 acres and 54,502 acres burn annually on average (1939-2003: Missouri Department of Conservation data, Westin 1992). Before European settlement, 250,000 acre fires were estimated to have occurred at least once per century in the Current River watershed (Guyette and Kabrick 2002)-an area that represents about 8 percent of the Missouri Ozark Highlands. Even larger fires occurred during extreme drought years [e.g., 1780 (Guyette and others 2002)]. Due primarily to fire suppression, average annual fire size in Missouri has decreased exponentially from about 100 acres to 15 acres during the period 1939 to 2001.

FIRE RISK MODEL

A fire risk model is being developed from current and historic fire records to provide information for fire preparedness and prevention (USDA and others 2002). Fire risk is defined as the probability of a fire

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of a specified severity happening during a given period, in a given area (Preisler and others 2004). Fire risk assessments provide a means for quantifying fire risk and prioritizing fire management activities on multiple spatial scales (Haight and others 2004). Multiple approaches have been taken to assess fire risk including theory-based functions (Prestemon and others 2002), analysis of satellite imagery (Maselli and others 2003), and landscape simulation models (Shang and others 2004). For the Ozarks, a large set of landscape-level data makes possible an index modeling approach for fire risk assessment. Fire risk indices are used to classify a landscape into incremental levels (e.g., low to high). The model is based on two modules: ignition potential and fuel hazard (fig. 1). Ignition potential is rated using data on human population, topographic roughness, roads, and suppression potential. Similarly, fuel hazard is estimated from data on fuel loading, fuel moisture, vegetation, precipitation, land-use, and multiple topographic

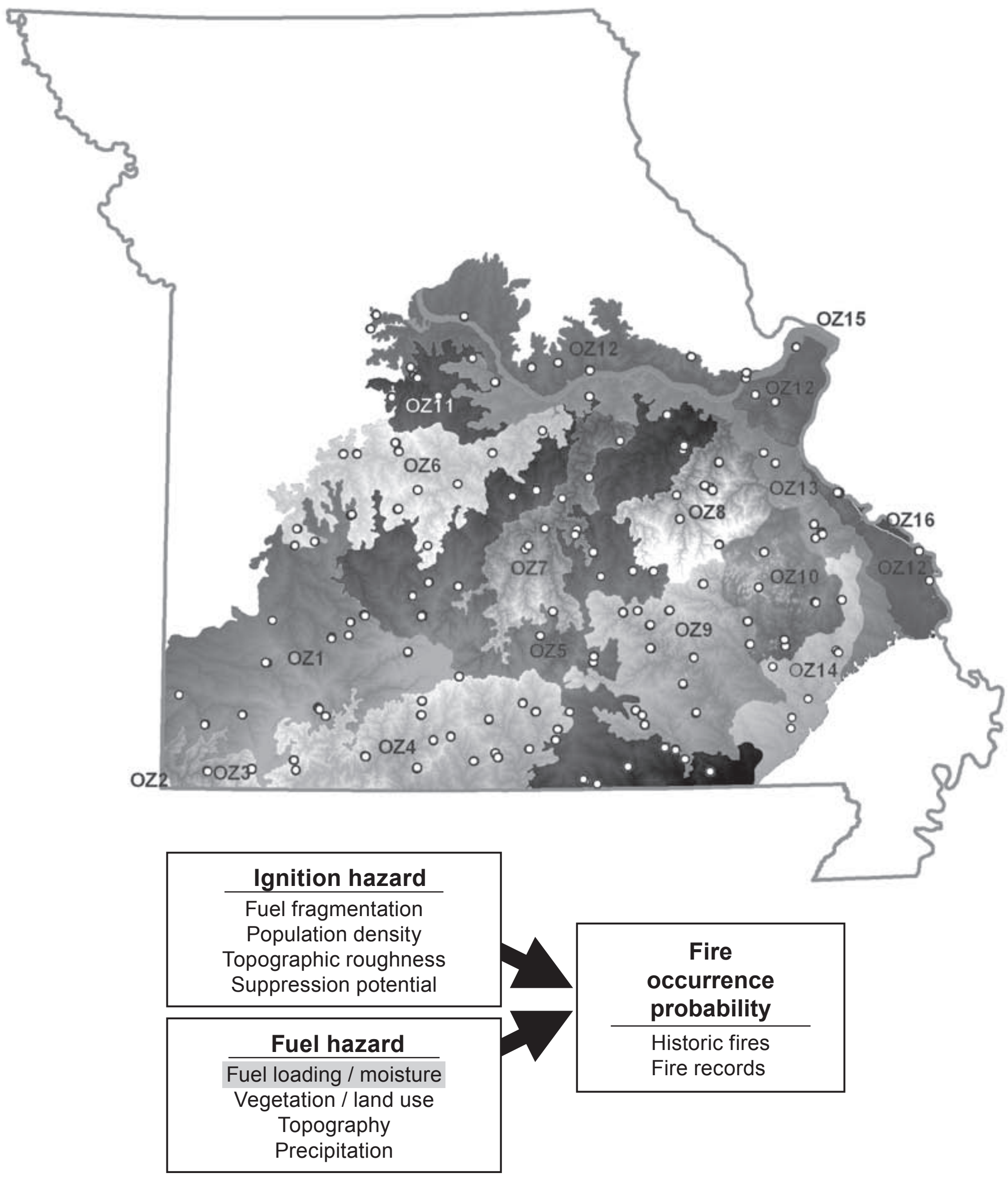

Figure 1—(Top) The Ozark Highlands section of Missouri with 16 ecological subsections. Subsection names are given in table 1. Small circles are locations of fuel loading plots (n = 1030). (Bottom) Conceptual model showing integration of fuel loading and moisture data into the fuel hazard module of the fire risk assessment model.

features. In our model, fuel loading is based on a region-wide collection of fuels data, which is unlike many models that do not include empirical fuel loading data.

In this paper, we describe results of the Ozark Highland region-wide fuel measurements. Fuel data and relationships will be used in the development of the fuel hazard module for the assessment of fire risk. The objective of this paper is to describe the regional fuel variability and discuss its relevance and use in fire risk assessment.

METHODS

Fuel Loading

Utilizing ESRI® ArcGIS™ v 9.1 (Environmental Systems Research Institute 2005), ecological subsections (Nigh and Schroeder 2002) were identified within the Ozark Highlands section of Missouri (fig. 1). One hundred fifty-nine fuel transect locations were randomly placed within 17 subsections. The number of transects per subsection was weighted by subsection area. Transect locations were moved to the nearest forested public property ownership within the same subsection. Ownerships included state conservation areas, national forest lands, and state and county parks. Transects consisted of multiple fuel loading plots using methods described by Brown (1974) with modification. Transects were randomly located within forested areas. Transect bearings were randomly chosen from a predetermined bearing range that ensured crossing landforms and that varied in location, topography, and vegetation. Three to ten fuel plots were sampled per transect depending on forested area and landform. A total of 1,030 fuel loading plots were sampled across the region, and their locations were recorded by a GPS and entered into a GIS. Data were collected from July 2004 through June 2005, a period of highly variable drought conditions.

Fuels were tallied and measured in four size classes (0.0-0.25 inch (1-hour), 0.26-1.0 inch (10-hour), 1.01-3.0 inch (100-hour), and > 3 inch (1000-hour)). No differentiation was made between solid and rotten 1000-hour fuels. Fuel loading constants, specific gravities, and squared average-quadratic-mean diameters are unavailable for most tree species in the Central Hardwoods Region. Thus, constants for fuel calculations were derived from several sources (Brown 1974, Adams and Owens 2001) including field measurements of fuels. At each plot we collected data on species composition, elevation, slope, aspect, slope shape and position, basal area, percent ground cover (leaves, needles, herbaceous plants, bare soil), estimate of down dead wood, number of snags > 3 inches dbh, small diameter stem density, moisture content of 1000-hour fuel, and evidence of past fire. Moisture content of 1000-hour fuels was measured with a Protimeter® hand-held moisture meter on stems at least 3 inches in diameter and 1 foot above the forest floor. Additional GIS data were spatially joined to the plot data. These data included elevation, precipitation, topographic roughness (Guyette and Dey 2000), land-use, vegetation, and geographic coordinates (decimal degrees, UTM, Zone 15N). Spatial trends in litter loading were examined using ArcGIS™.

Fuel loading data were summarized by ecological subsection and tested for normality using the Shapiro-Wilk test (SAS/STAT 2002). Fuel loading data were modeled for the purpose of predicting region-wide fuel variation. Combinations of fuel variables were developed from the original litter and time-lag class fuel data, and a model was constructed describing fuel variation using multiple regression. We chose the simplest model whose relevance could be verified both statistically and biologically.

Litter and Moisture

In mixed hardwood forests of the Ozark Highlands, much of the energy released during fires results from combustion of litter (i.e. leaves, needles, twigs,) and 1-hour fuels (Kolaks 2004). For this reason, emphasis is placed on the litter layer for the purpose of evaluating risk and understanding landscape variation in litter loading. We measured litter depth (cm) at 3 points at each fuel loading plot (n = 3,090). In a separate experiment we measured litter loading using randomly placed 0.5 m^2 clip plots located in the Current River Hills (Guyette and others 2003, 112 plots) and Outer Ozark Border subsections (51 plots). Litter collection was completed within a two day period so that sampling time and date had minimal effect on moisture content. Litter was placed in sealed plastic bags, weighed at field moisture content, and then dried at 60° C until weight became constant. Percent moisture content was calculated by dividing the weight of water in the litter by the oven-dried weight of the litter and then multiplying by 100. Repeated collections (September 2004, March 2005, June 2005) were made at clip plots located in the Outer Ozark Border for the purpose of understanding within year temporal changes in loading and moisture. Regression analysis was used to develop equations that relate litter loading and moisture content to landscape variables. Both litter and 1000-hour fuel moisture contents were correlated against monthly divisional Palmer Drought Severity Index data (Palmer 1965, National Climate Data Center 1994). As drought conditions increase, it is hypothesized that the differentiation in litter moisture by solar exposure is lessened.

RESULTS AND DISCUSSION

Fuel Loading

Total fuel loading averaged 4.5 tons per acre and ranged from 0.1 to 70.3 for all Ozark plots (table 1). Mean 1-hour and mean 10-hour fuel loading were similar among all Ozark subsections. Trend analysis indicated a small decrease in 1-hour and 10-hour fuel loading along a north to south Ozark gradient, and geographic location was a significant variable in predicting total fuel loading (see below). None of the fuel time-lag classes were normally distributed ($p < 0.0001$) (figs. 2 and 3). High variability existed in 1000-hour fuel loading with the majority of plots having no 1000-hour fuels and 51 plots having over 15 tons per acre. The majority of plots with high 1000-hour fuel loading (>15 tons per acre) had usual levels of tree mortality; however, many of the highest loadings (e.g., > 50 tons per acre) resulted from forest management activities and windthrow disturbance. Fuel loadings between time-lag classes are correlated because larger fuels are typically connected to and provide smaller fuels.

Multiple regression analysis of landscape variables on plot fuel loading resulted in a four variable model ($r^2 = 0.19$, $p < 0.0001$, all variables and intercept significant, $p < 0.0001$):

$$FUEL = -417.33 + (1.76^{*}10^{-5})^{*}tri + 0.08^{*}elev + 0.07^{*}ba - (5.48^{*}10^{-12})geo$$

where

FUEL = litter depth (cm)*[log(tons of 1-hour fuel]+log(tons of 10-hour fuel)+log(tons of 100-hour fuel)
tri = an index of topographic roughness (Guyette and Dey 2000)
elev = elevation in m
ba = basal area
geo = (-1* y UTM coordinate)*(x UTM coordinate)

Although significant, the fuel model explains a low percentage of fuel variation, suggesting that little regional variability in fuel loading exists. In a separate study within the Current River Hills subsection no significant differences were found in fuel loading between forest types (Personal communication. 2005. Keith Grabner, Community Ecologist, USGS Columbia Environmental Research Station, 4200 New Haven Rd., Columbia, MO 65201). Model variables, spatial fuel loading trends, and fuel statistics support that both large- and small-scale factors influence fuel variation within the Ozark Highlands.

Litter and Moisture

Decomposition causes total forest litter depth to decrease between litter fall events. However, our measurements of litter loading showed erratic changes in litter depths between the three collection dates likely due to the high spatial variability in litter within small extents (e.g., 3 m) and the movement of litter by wind (e.g., leaves). Fifty-nine percent of the plots decreased in litter loading from September 2004 (pre-leaf fall) to March 2005 (post-leaf fall) and 61 percent increased from March 2005 to June 2005. Maximum litter loading occurred when basal area was approximately 150 square feet per acre and decreased as basal areas deviated both above and below this stand density.

Table 1—Summary of fuel loading for Missouri Ozark Highlands ecological subsections

Ozark ecological subsections	Subsection code	Fuel transects, (plots)	Fuel loading (tons per acre)														
			1 hour			10 hours			100 hours			1,000 hours			Total		
			mean	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*
Springfield Plain	OZ1	19 (115)	0.1	0.1	0 – 0.6	0.3	0.1	0 – 0.7	1.1	1.2	0 – 8.8	2.9	6.2	0 – 36.9	4.4	6.4	0.1 – 36.8
Elk River Hills	OZ3	2 (14)	0.1	0.1	0 – 0.4	0.3	0.1	0.1 – 0.5	1.5	0.7	0.4 – 2.8	4.5	5.1	0 – 15.6	6.4	5.7	1.1 – 18.8
White River Hills	OZ4	17 (112)	0.1	0.1	0 – 0.4	0.3	0.2	0 – 1.0	1.2	1.0	0 – 4.9	2.3	4.7	0 – 25.4	4.0	5.1	0.2 – 31.0
Central Plateau	OZ5	26 (158)	0.1	0.1	0 – 0.3	0.2	0.2	0 – 1.3	1.1	0.8	0 – 6.2	3.5	7.2	0 – 51.2	5.0	7.4	0.1 – 53.4
Osage River Hills	OZ6	14 (94)	0.1	0.1	0 – 0.4	0.2	0.2	0 – 1.5	1.1	1.2	0 – 8.8	7.6	8.0	0 – 68.9	3.7	8.3	0.1 – 70.3
Gasconade River Hills	OZ7	11 (68)	0.1	0.1	0 – 0.4	0.2	0.1	0 – 0.6	0.8	0.8	0 – 4.2	3.1	5.8	0 – 26.0	4.2	5.6	0.1 – 27.1
Meramec River Hills	OZ8	8 (53)	0.1	0.1	0 – 0.3	0.3	0.1	0 – 0.5	1.1	1.0	0 – 6.2	4.0	6.5	0 – 30.8	5.4	6.5	0.3 – 32.6
Current River Hills	OZ9	15 (112)	0.1	0.1	0 – 0.4	0.2	0.1	0 – 1.5	1.3	0.9	0 – 6.2	4.1	6.1	0 – 29.3	5.8	6.6	0.3 – 31.8
St. Francious Knobs and Basins	OZ10	6 (37)	0.1	0.1	0 – 0.2	0.3	0.2	0 – 0.4	0.9	0.6	0 – 2.9	1.7	2.9	0 – 12.7	2.8	3.2	0.1 – 15.9
Prairie Ozark Border	OZ11	5 (31)	0.1	0.1	0 – 0.4	0.3	0.2	0 – 1.1	0.8	0.6	0 – 2.2	2.5	6.7	0 – 36.5	3.8	6.8	0.2 – 38.0
Outer Ozark Border	OZ12	16 (106)	0.1	0.1	0 – 0.4	0.2	0.2	0 – 0.9	1.1	0.7	0 – 3.3	4.3	8.2	0 – 44.9	5.8	8.4	0.1 – 47.1
Inner Ozark Border	OZ13	11 (73)	0.1	0.1	0 – 0.3	0.3	0.1	0 – 0.9	0.7	0.7	0 – 4.0	1.8	3.6	0 – 24.4	2.9	4.0	0.1 – 28.7
Black River Ozark Border	OZ14	7 (46)	0.1	0.1	0 – 0.3	0.2	0.1	0 – 0.5	0.8	0.6	0 – 3.0	2.1	4.1	0 – 23.6	3.2	4.3	0.1 – 24.9
Missouri River Alluvial Plain	OZ15	1 (5)	0.2	0.1	0.1 – 0.3	0.3	0.1	0 – 0.4	1.6	0.7	0.7 – 2.6	15.1	13.4	0 – 36.4	17.1	13.5	1.1 – 37.6
Mississippi River Alluvial Plain	OZ16	1 (6)	0.1	0.04	0.1 – 0.2	0.2	0.1	0 – 0.3	0.5	0.4	0 – 1.1	1.0	2.2	0 – 5.9	1.8	2.1	0.3 – 6.5
All (Ozark Highlands Section)			0.1	0.1	0 – 0.6	0.3	0.2	0 – 1.5	1.0	0.9	0 – 8.8	3.1	6.5	0 – 68.9	4.5	6.7	0 – 70.3

Source: Nigh and Schroeder (2002).
s.d. = standard deviation.

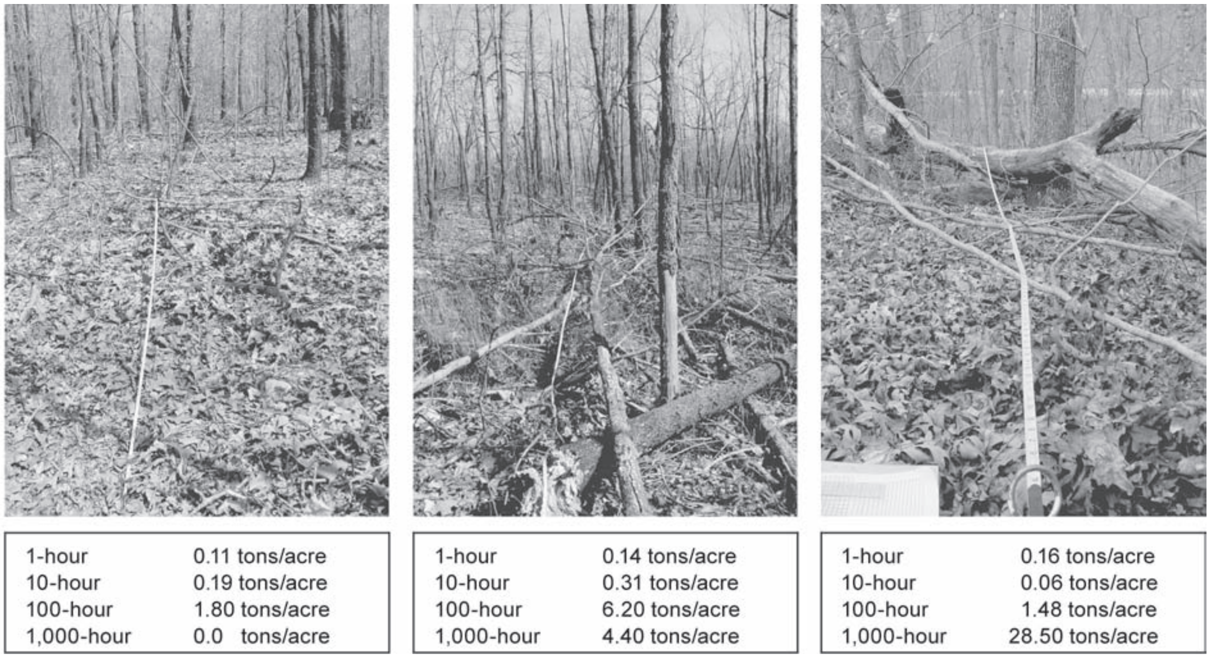

Figure 2—Three examples of fuel loading illustrating the physical variability of the four time-lag fuel classes.

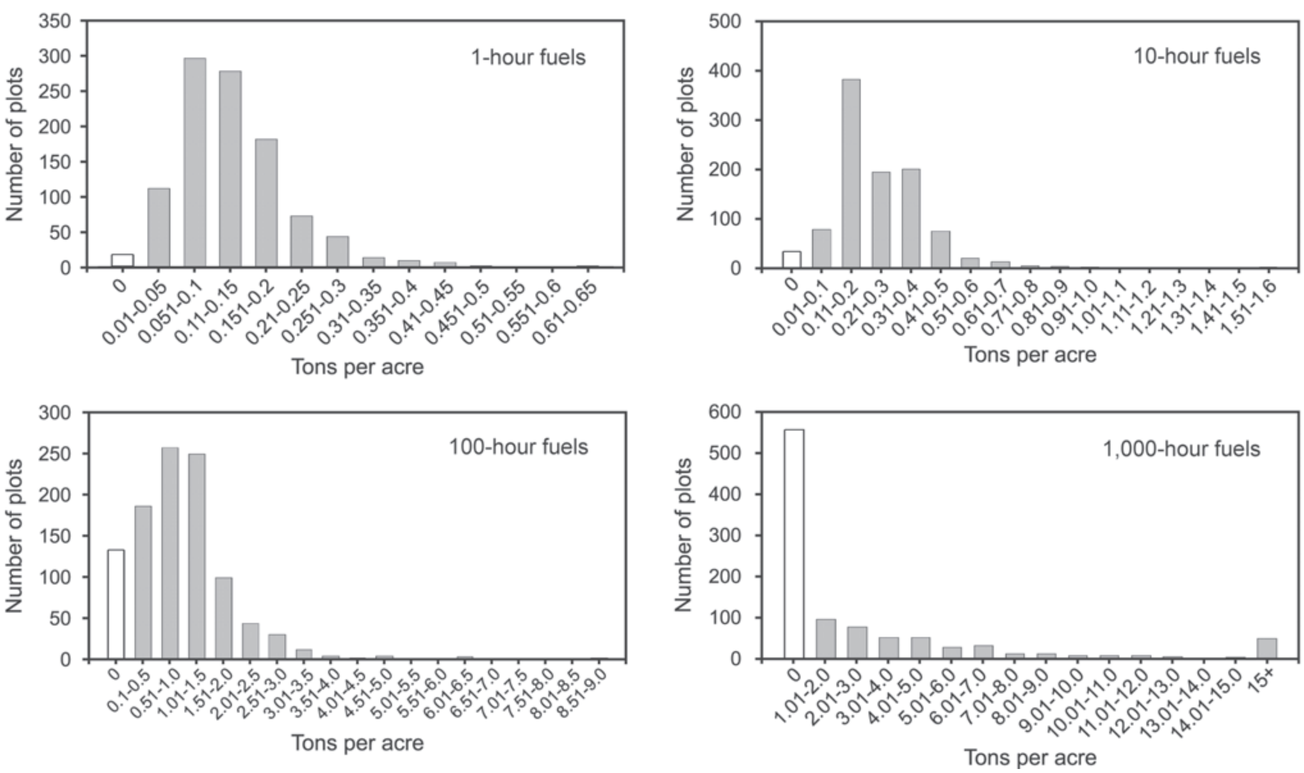

Figure 3—Histograms of the four fuel time-lag classes. Scales of x- and y-axes differ between graphs.

Percent moisture content (PMC) of litter was a function of solar exposure. Differences in PMC were greatest when conditions were slightly wet (PDSI = 1.0 - 1.99). The equation describing PMC of litter during incipient wet (0.5 - 0.99) conditions is:

$$PMC = 63.2 - 18.4^{*}\left(exposure\right)\left(r^2 = 0.43, p < 0.01\right)$$

where
exposure = COS(3.1415/180*(180-aspect))+1.

During wetter conditions no relationship existed between PMC and solar exposure, and during drier conditions the differentiation in PMC is lessened (fig. 4). During mild droughts (PDSI = -1.95) PMCs, regardless of exposure (i.e., aspect), became nearly equal or "undifferentiated dry". This is similarly true during extreme wet conditions when PMCs are "undifferentiated wet" by exposure. Assessment of the equation's predictive ability in modeling the spatial patterns in PMC during various PDSI conditions would be valuable, however requires additional collections during wet and dry extremes.

Drought has been an important component of the Ozark fire regime for centuries, even during the recent period (1940 to present) of fire suppression. Drought influences multiple components of the Ozark fire regime including the number of acres burned, average fire size, fire severity (percent trees scarred), and number of arson fires (Guyette and others, in press). Understanding the effects of drought on ignition potential and fuel hazard would be valuable, particularly for the assessment of fire risk.

Both fire hazard and ignition potential can be better understood from the conditions of litter. For hazard, litter is the key fuel type facilitating surface fire propagation. Even during rare crown fire events, fires are initiated from surface fires that burn litter. Likewise, litter is likely the primary material for initial ignitions regardless of fire cause. As drought increases, the area for potential ignitions is increased because more area of the landscape contains dry fuels. During droughts (PDSI < 0) moisture contents of 1000-hour fuels were at levels below the common fuel moisture prescription range (e.g., 17-20 percent) (fig. 5) which indicates conditions of increased fire danger.

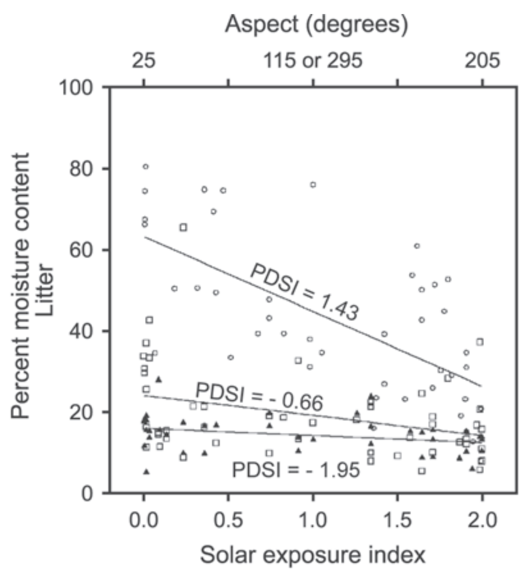

Figure 4—The relationship between percent moisture content of litter and solar exposure index for three Palmer Drought Severity Index (PDSI) values. Solar exposure variable is significant in all models ($p \leq 0.05$).

CONCLUSIONS

Information about fire regimes in deciduous forests is needed in order to adequately assess fire risk. Although wildfires rarely threaten lives and homes in the Ozarks and Central Hardwoods region, the potential exists and is increased during droughts. During drought and dry weather, "undifferentiated dry" litter and low moisture content of 1000-hour fuels increase fuel hazard and ignition potential. Forests of greatest fuel loading are those of high elevation, greatest basal area, and highest topographic roughness that occur in the southeast portion of the Ozark Highlands region.

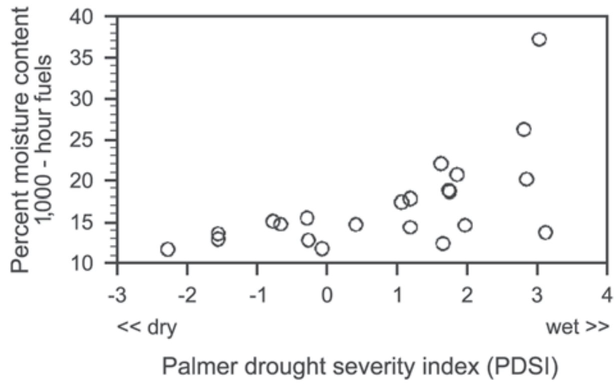

Figure 5—The relationship between 1,000-hour fuel moisture and Palmer Drought Severity Indices. Data were collected throughout the Missouri Ozark Highlands during the period July 2004 to July 2005.

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MANAGEMENT AND FOREST RESOURCES

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THE IMPACT OF THINNING AND FERTILIZATION TREATMENTS ON SUGAR CONCENTRATION, VOLUME, AND TOTAL SUGAR OF SILVER MAPLE SAP

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Abstract—This study examined the influence of thinning and fertilization on sap sugar concentration (SSC) and sap volume of silver maple (*Acer saccharinum* L.) in southern Illinois. The two study sites were originally planted in 1990 as a biomass production study and contain 12 provenances, and four clones from each provenance. Data was collected in 2001, 2002, and 2003. In 2001 thinning treatments were applied at Thunderstorm Road and in 2002 fertilization treatments were applied at Chautauqua Bottoms. Differences in SSC (both sites), sap volume, and total sugar (SSC*sap volume) (Thunderstorm Road only), were found among clones within provenances using a nested analysis of variance. Main effects of thinning and fertilization positively influenced sap characteristics. The significant positive effect of thinning on sap characteristics was most pronounced in sap volume production which was more than doubled compared to unthinned controls. Thinning effects became insignificant after two years.

INTRODUCTION

The season for maple syrup production is in the winter when temperatures oscillate above and below the freezing point, inducing sap flow (Heiligmann and others 1996b). Production of maple syrup starts with the selection of healthy and vigorous maple trees of at least 25cm to 30cm in diameter at breast height (dbh) to tap. There are thirteen native North American maple species, of which sugar maple (*Acer saccharum* Marsh.) and black maple (*A. nigrum* Michx.) are the preferred species utilized for maple syrup production. Red maple (*A. rubrum* L.) is also utilized for maple syrup production and on occasion, especially in Canada, silver maple (*A. saccharinum* L.) which tends to have lower sap sugar concentration (SSC) and a shorter collection season has been used (Heiligmann and Winch 1996).

Sugar maple is the dominant tree species used in maple syrup production because of its relative abundance, and its ability to produce large quantities of sap with high (averaging 2 to 2.5 percent) SSC (Larsson and Jaciw 1967). Sugar maple does not tolerate extreme wet or dry sites (Heiligmann and Winch 1996) and tends to be relatively slow growing. It takes approximately 40 to 60 years for a sugar maple to reach a tappable size, whereas a silver maple can grow to a tappable size in 10 to 20 years (Heiligmann and Winch 1996).

Silver maple, unlike sugar maple, can be readily clonally propagated (Preece and others 1991) which is an advantageous attribute to multiply desirable genotypes. Additionally, silver maple thrive in riparian conditions, stream banks, flood prone areas, and can also be found in dry upland areas. Silver maple is among the fastest growing eastern hardwood tree species (Gabriel 1990). A study done by Kriebel (1989) indicated that SSC among sugar maple grafted clones was relatively consistent over the years. Therefore, potential to select for silver maple trees with desirable sap characteristics may exist. In a previous study, silver maple trees produced a mean SSC of 1.71 percent that was within the expected range reported in other regions (Crum and others 2004). Silver maple SSC has been shown to be positively related to total sap volume and basal area. In addition, silver maple SSC has been shown to be consistent from year-to-year (Keeley 2000). Selecting silver maple trees with desirable SSC may include relatively high total sap volume production. This could allow landowners to choose vigorous, fast-growing maple genotypes, with high SSC and volume outputs for their own use.

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There is a paucity of information about the impact of cultural practices on sap production from silver maple trees. Cultural practices such as thinning can be useful in improving productivity (Heligmann and others 1996a). Past fertilization research on sugar maple trees has shown both positive and negative effects (Heligmann and others 1996a). This current research sought to determine if sap characteristics (SSC, sap volume, and total sugar) of silver maple trees growing on an upland site and a bottomland site were influenced by cultural practices of thinning and fertilization.

METHODS

Study Area

Chautauqua Bottoms and Thunderstorm Road are the two sites used in this study. Chautauqua Bottoms is a lowland site located directly south of Chautauqua road 1.6 km (1 mile) west of Southern Illinois University Carbondale (SIUC). It is bordered by 15 to 20 m of grassland and is within 25 m of a creek. It sits in a relatively low flat area that is prone to spring flooding events. The soil composition is Belknap silt loam, a poorly drained soil. The Thunderstorm Road site, an upland area, is located adjacent to Thunderstorm Road, 2.4 km (1.5 miles) southwest of SIUC. The soil composition is a gently sloping Hosmer silt loam, a moderately well-drained soil.

In 1990, silver maple trees were planted and treated as part of a biomass production study replicated at each site. Thirteen provenances of silver maple from seed sources across the native range were propagated by tissue culture and established in a randomized complete block design on each site (fig. 1). Four clones from each provenance were planted on 1.5 by 1.5 m spacing in three-tree clonal plots randomly arranged in four rows within each of 10 blocks. Each site was established with two border rows of silver maple trees surrounding the plantation to minimize a potential edge effect.

In 1993, half the trees, 5 northern blocks at each site were harvested and allowed to coppice. In 1995, all ten blocks at both sites were harvested and the stumps were left to coppice. At Chautauqua Bottoms, the trees remained untouched from that time, until utilized for this study in 2001. At Thunderstorm Road in 1996, one year after coppicing, ramets within three-tree clonal plots were randomly chosen to be either thinned to one stem, two stems, or left unthinned for another study. This site was then left untouched until the onset of this study.

Field Procedures

Thinning treatments were applied to the planting at Thunderstorm Road after the 2001 sap collection but before the 2002 growing season to determine if there was an effect on sap sugar concentration and sap volume of tapped silver maple. In two randomly chosen experimental blocks, one tree of the three-tree clonal plots, typically the tree with least total dbh or vigor was removed, leaving a maximum of two trees per plot. Additionally, any remaining multi-stemmed trees were thinned to either one (usually the largest stem) or two stems. Double-stemmed trees were left in cases where the attachment of the largest coppiced stem to the stump appeared to be somewhat incomplete and potentially prone to breaking. Trees in two other blocks were left unthinned as a control.

Trees at Chautauqua Bottoms were utilized to examine the effect of fertilization on sap sugar concentration of tapped silver maple. Fertilizer was applied, to three randomly chosen blocks at Chautauqua Bottoms after the 2002 tapping season in late spring before leaf out. For each of the four rows of trees, 13.95 kg per 88 m2 (31 pounds per 978 square feet) of 12:12:12 ($N:P_2O_5:K_2O$) fertilizer was applied using a drop spreader. In blocks 2, 3, and 5, fertilizer was applied between the first and second row and between the third and fourth rows of each block. In this way, trees received fertilizer along one side only of the row that they were in. Trees in two other blocks (blocks 1 and 4) were left as non-fertilized controls. The five blocks used in the fertilizer study at Chautauqua Bottoms were all similarly thinned following the 2001 collection season in the spring prior to leaf-out. This was done to reduce competition and severe stress of the closely-spaced trees but not to test thinning as a cultural treatment. The least vigorous tree out of each three-tree clonal plot was removed. Additionally, multi-stemmed ramets were thinned to either one or two of the largest stems.

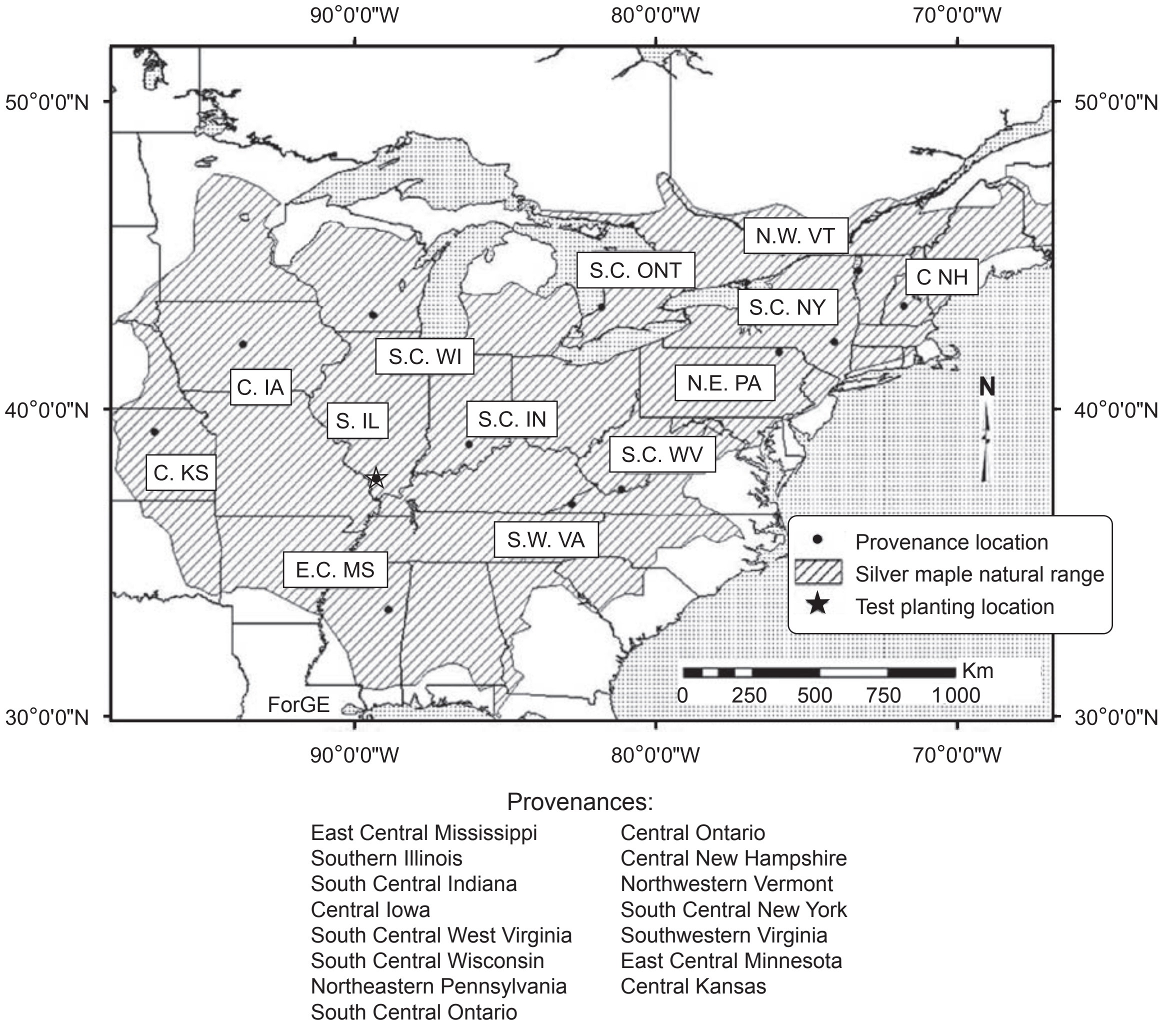

Figure 1—Delineation of the natural range (Gabriel, 1990; Keeley 2000) of silver maple, with general locations of provenances marked. Plantation locations in Illinois are marked by a star.

Trees were tapped as described below at both sites to collect silver maple sap in the winters of 2001, 2002 and 2003. At both sites, one tree, without any major defect or damage usually possessing the largest diameter stem at breast height, was selected to be tapped from each one of the clonal plots within the blocks used in this study.

Tapping procedures differed by site. At Thunderstorm Road upland there was one tap installed per tree. Tapping of the trees was done using a cordless power drill with a 7.9 mm in diameter drill bit. Holes were drilled 3.8 cm deep with a slight upward slope. Tree Saver food grade nylon spiles, (Sugar Bush Supplies Co. Mason, MI) were then hammered into the holes using a rubber mallet. These spiles have a smaller diameter of 7.9 mm and allow the tree to heal-over tapholes more quickly than more traditionally-sized spiles with diameters of 11.1 mm (Perkins 1999).

At Chautauqua Bottoms there was also one tap installed per tree. However, the more traditional 11.1 mm drill bit size was used to accommodate spiles as used in previous studies (Keeley 2000). These spiles were made from Fisher brand 1.5 ml micro-centrifuge tubes that were cut in half and hammered into the tree. A small piece of tubing was used to facilitate sap sample collections for SSC described below.

Sap volume (ml) was not collected at the Chautauqua Bottoms lowland site because of the relatively small-sized and multi-stemmed trees. Sap volume was collected at Thunderstorm Road upland site by running polyethylene tubing from the spile end to 19 liter plastic food-grade buckets or 3.8 L (1 gallon) plastic jugs. Collection containers were decided on based on the sap volume production expectation for each tree. Throughout the collection season, from mid-January to early March, buckets and jugs were periodically checked for sap volume production when the temperatures were conducive for sap flow.

Each year from 2001 to 2003, approximately 190 trees at Thunderstorm Road and 240 at Chautauqua Bottoms were tapped. The 2001 collection period started on January 22 and went to February 12. At both sites there were four SSC collections and eight sap volume collections at Thunderstorm Road. In 2002, the collection season was from January 18 to March 27 with four SSC collections and four sap volume collections at Thunderstorm Road and three SSC collections at Chautauqua Bottoms. The 2003 collection season was from February 3 to March 5 and at both sites there were four SSC collections and at Thunderstorm Road only one sap volume collection because of sap leaking around many of the spiles early in the season resulting in inaccurate measurements. Consequently trees were re-tapped in mid-season and only one volume collection was performed in 2003. This study was designed to test for sap parameter differences among cultural treatments over a major portion of the sap production seasons over each of 3 years. The study was not intended to cover the entire sap production season of each year and therefore may underestimate total sap volume. Sap volume (ml) was determined from the 3.8 L jugs by was pouring the contents into a graduated cylinder and the volume was recorded to the nearest 1.0 ml, sap volume in buckets was determined by measuring sap depth to the nearest 0.1 cm using a ruler. The bucket depth to volume conversion was determined by calibrating the buckets with known volumes of water and measuring depth, producing a linear regression equation ($y=0.0017x$, $p<0.0001$, $R2=0.99$).

Laboratory Procedures

SSC samples were collected from each tree directly from the tubing with 1.5 ml polypropylene microcentrifuge tubes (Fisher Scientific Pittsburg, PA) while sap was actively flowing. The sap samples were brought back to the lab, refrigerated (1.1º C to 4.4º C), and analyzed within 48 hours using a temperature compensated hand-held refractometer (Fisher Scientific Pittsburgh, PA). The refractometer was initially calibrated and periodically recalibrated to 0.0 degrees Brix using distilled water. Sap sugar concentration was determined by placing a drop of sap from sample tubes onto the lens of the refractometer, exposing it to fluorescent light, and reading the scale to the nearest tenth of a degree. The lens was cleaned between each sample.

Data Analysis

Because there was only 33 percent survival of provenance 13 from central Ontario, it was omitted from data analysis at both sites. Additionally, at Chautauqua Bottoms, one clone from provenance 12 from south-central Ontario and 2 clones from provenance 20, central Kansas were omitted from analyses because of low survival. A logarithmic transformation of the SSC data was performed to normalize the data. Mean SSC and total sap volume for each tree over each tapping season was used as sample values in the analyses of variances.

To test for a thinning effect at Thunderstorm Road, a nested analysis of variance was used to determine if sap parameters of SSC, sap volume, and total sugar (in grams, computed as a product of SSC and sap volume) differed between trees receiving the thinning treatments testing for the main effects of thinning, provenance, clone, and a thinned*provenance interaction at the alpha=0.05 level. To test for a fertilization effect at Chautauqua Bottoms, a nested analysis of variance was used to determine if SSC differed among trees receiving the fertilization treatments testing for the main effects of fertilization, provenance, clone, and a fertilization*provenance interaction at the alpha=0.05 level. Testing for sap characteristic differences among provenance and clones was not the focus of this study. However, these effects were included in the statistical model to account for variance when testing for fertilization and thinning effects.

RESULTS

Thunderstorm Road

Thinning—SSC did not differ in 2001, the season before thinning (table 1) for those trees in blocks slated to be thinned and blocks that would be left unthinned (p=0.1047). In 2002, one growing season after the thinning treatment, trees in thinned blocks had greater SSC (p=0.0465), averaging 4 percent more then those in unthinned blocks. However, in 2003, two seasons after treatment, differences in SSC between thinned and unthinned blocks were no longer apparent (p=0.1470). For each year, there were significant differences in SSC among provenances and among clones but there were no significant provenance*thinning interactions.

Sap volume did not differ in 2001 prior to thinning (table 1) between trees in blocks that would be thinned and those in blocks that would be left unthinned (p=0.4122). The sap volume of the thinned blocks, one growing season after treatment in 2002 was greater (p<0.0001), averaging nearly 2.4 times that of the mean sap volume of the unthinned blocks. By 2003, there were no longer differences in sap volume between thinned and unthinned blocks. As was the case for SSC, each year there were significant differences in sap volume among provenances and among clones but there were no significant provenance*thinning interactions.

Total sugar did not differ (p=0.6098) in 2001 between trees in blocks that would be thinned and trees in blocks that would be left unthinned (table 1). In 2002, after treatment, trees in thinned blocks had more than double (p<0.0001) the total sugar compared to trees in unthinned blocks. In 2003, total sugar did not differ between trees in thinned blocks and unthinned blocks (p=0.1944). Each year there were significant differences in total sugar among clones and there were no significant provenance*thinning interactions. There were differences in total sugar among provenances for 2001 and 2002 but not for 2003.

Chautauqua Bottoms

Fertilization—SSC was 1.47 percent (2001) and 1.41 percent (2002), prior to fertilization treatment. This SSC was lower (p=0.0078 and p=0.0056, respectively) in blocks randomly chosen to be fertilized than in the control blocks which had a SSC of 1.52 percent (2001) and 1.47 percent (2002). In 2003, after treatment, mean SSC for fertilized trees (1.59 percent) was somewhat higher than for unfertilized trees (1.53 percent) but the difference was not statistically significant (p=0.1672). Each year there were

Table 1—Mean sap sugar concentration, sap volume, and total sugar between thinned and unthinned blocks prior to treatment in 2001, and after treatment in 2002, and 2003 for silver maple at Thunderstorm Road

Sap characteristics	Year	Significant effect	Thinned treatment	Unthinned treatment
SSC (percent)	2001 (Pretreatment)	ns	1.50	1.58
	2002 (Posttreatment)	*	1.41	1.36
	2003 (Posttreatment)	ns	1.57	1.53
Sap volume (ml)	2001 (Pretreatment)	ns	1016	1155
	2002 (Posttreatment)	*	2687	1138
	2003 (Posttreatment)	ns	551	390
Total sugar (g)	2001 (Pretreatment)	ns	17.56	20.79
	2002 (Posttreatment)	*	42.51	18.75
	2003 (Posttreatment)	ns	10.22	7.01

SSC = Sap sugar concentration; ns = Not significant; * = Significant at the alpha = 0.05 level.

significant differences in SSC among provenances and among clones but there were no significant provenance*fertilization interactions.

DISCUSSION

Thinning

In 2001, prior to the thinning treatments at Thunderstorm Road, SSC in blocks designated to be thinned (1.50 percent) and not thinned controls (1.58 percent) was not significantly different. From 2001 to 2002, plantation-wide mean SSC dropped 11 percent, which may have been related to year-to-year fluctuations in environmental conditions. Year-to-year variation in SSC was noted in several studies (Taylor 1956, Kriebel 1960, Marvin and others 1967). In 2002, after treatment, thinned blocks had significantly greater SSC than unthinned blocks. Stone and Christenson, (1974) found that thinning significantly increased growth by 73 percent among young sugar maple when compared to unthinned sugar maple stands. Thinning can be used to remove unhealthy or undesirable trees, allowing more resources to be available for the remaining trees (Heiligmann and others 1996a).

The significant benefit of thinning on sap characteristics was short-term, being present for only for one year after treatment. A benefit in the following year was not detected perhaps because of the shortened tapping season from leaking taps and subsequent retapping. However, even after thinning, trees in this planting were closely spaced with narrow crowns which rapidly filled in canopy gaps. Perhaps a more intensive thinning which would free-up more space and resources would have longer lasting effects on residual trees. The design and management history of this plantation was not conducive for maximizing maple syrup production.

Fertilization

Chautauqua Bottoms was used to test for the impact of fertilizer on sap performance. Fertilization of sugar maple has been shown to increase foliar concentrations of N, P, Ca, and Mg, as well as increasing radial growth from 45 percent to 90 percent (Moore and others 2000). In contrast, fertilizer had no positive effect on growth of young sugar maple (Stone and Christenson 1974). In the current study, fertilization tended to increase SSC of trees in blocks that had been performing poorly to levels similar to trees in blocks that had been exhibiting greater SSC.

The temperature fluctuations in Southern Illinois were conducive to maple sap flow in the winter maple syrup production season. Differences found among clones and provenances indicate that selection for superior trees should not only occur at the provenance level but also at the clonal level for increased gains in desirable characteristics such as SSC, sap volume, and total sugar (Keeley 2000, Zaczek and others 2003, Crum 2005). Silver maple provenances and clones showed fertilization and thinning treatments had a positive but short-term impact on SSC. Thinning also positively influenced sap volume and total sugar of the residual trees.

Compared to sugar maple, silver maple may have greater potential for use in new plantings because of its fast growth and ease in vegetative propagation. Considerable variability in silver maple sap characteristics among cultural treatments, clones, and provenances suggest that gains in maple syrup production in the region could be achieved through selection and stand management.

Additional research on native silver and sugar maple trees over time would be necessary to better document performance potential under different management regimes on specific sites. More investigations into the effects of cultural practices on sap sugar parameters over longer amounts of time, as well as on larger, more mature maple trees of both species is warranted. Also, further research would be necessary on the performances of provenances and clones when used in new plantings on a variety of sites.

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ALTERNATIVE SILVICULTURAL PRACTICES IN APPALACHIAN FOREST ECOSYSTEMS: IMPLICATIONS FOR SPECIES DIVERSITY, ECOSYSTEM RESILIENCE, AND COMMERCIAL TIMBER PRODUCTION

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Abstract—Increasing demands for timber and non-timber forest products often conflict with demands to maintain biodiversity and ecosystem processes. To examine tradeoffs between these goals, we implemented six alternative management systems using a stand-level, replicated experiment. The treatments included four silvicultural regeneration methods designed to sustain timber production, one commercial harvest without regard for future stand values, and a no harvest control. Our goal was to determine effects of management alternatives on multiple system components, including biodiversity, medicinal plants, timber production, terrestrial amphibians, soil disturbance, invasive exotic plants, soil and leaf litter invertebrates, leaf litter decomposition rates and nutrient flux. Plant species richness increased with increasing canopy disturbance, through colonization both by shade-intolerant native species and by exotic species. We detected several species of medicinal plants. Oak regeneration depended more on site quality than treatment. Terrestrial salamander populations declined precipitously on all treatments subjected to canopy disturbance. Although initial soil loss was reduced by using treatments that retained higher levels of basal area in the stand, over a complete rotation, the effects of repeated entries are likely to cause greater soil loss than a clearcut and greater impacts on salamanders.

INTRODUCTION

The Silviculture and Biodiversity in Southern Appalachian Forests study was designed to address the conflict between increasing pressures to harvest commodities and pressures to restrict harvests in order to achieve recreation and conservation goals. This conflict may be seen in local efforts to prevent clearcutting on National Forests. We hoped to be able to provide reliable information about the costs and benefits of different management strategies for both commodity and non-commodity components of the forest.

We approached this study with three points in mind: (1) Managers need to know the costs and benefits of each management practice in relation to alternatives. (2) Randomly assigned experimental manipulations are needed to differentiate between real effects and artifacts of site peculiarities. Although chronosequence studies can contribute valuable information, the confounding relationships that exist between site conditions and management techniques severely limit the inferences that can be drawn. (3) Although short-term trends can be informative, these initial responses may or may not reflect longer-term trends. We designed this study to extend over a complete rotation (80-100 years). In this paper, of course, we are limited to reporting only preliminary results.

Our major objective was to compare the short- and long-term effects of alternate forest management techniques. A key benchmark of success was long-term maintenance of oak dominance. Oak stands have high timber value, high value for many game and non-game species of wildlife, and were common in

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much of the immediate pre-European settlement forests in the central and southern Appalachians. For this reason, the alternatives we chose to study include only those that have been used successfully or are currently being promoted as techniques for oak regeneration.

METHODS

We established 5 replications in the George Washington and Jefferson National Forest, in Virginia, and 2 on MeadWestvaco Corporation's Wildlife and Ecosystem Research Forest in West Virginia. Harvests occurred between 1994 and 1998 with all harvesting treatments implemented at approximately the same time at each location. Six treatments 2 ha in size were included in each installation: (See Wender 2000, Hood 2001, and Knapp and others 2003 for details of prescriptions.)

1. Control: no silvicultural activity within the stand

2. Group selection system: two or three groups, each from 0.1-0.25 ha, were made in each area. All stems in the group cut were felled. Additionally, a timber stand improvement cut that removed poor quality trees from the lower crown classes was implemented in the areas between harvest groups.

3. Shelterwood system: 11-14 m^2/ha of main canopy basal area was retained following the initial cut.

4. Commercial clearcut: 5-10 m^2/ha of basal area was retained during the harvest. The residual stand was typically unmerchantable poletimber or sawtimber cull trees.

5. Leave-tree system: 25-50 trees/ha (approximately 5 m^2 of BA/ha) were left to remain throughout the rotation, thus creating a two-aged structure. Residual trees were selected based on good form, dominant or codominant crown position, and species desirability (oaks and other commercial species).

6. Silvicultural clearcut: removal of all stems >5 cm DBH, creating an even-aged structure. Non-merchantable stems were felled and left on the ground.

Quantitative data on overstory, midstory, and understory vegetations were collected from permanently marked plots arrayed in a nested design of 24 x 24 m tree, 6 x 6 m shrub, and 1 x 1 m herbaceous plots. In each treatment, 3 sets of nested plots were established. A 24 m x 24 m "tree plot" was established where height and diameter of all trees was measured. The tree plot was divided into sixteen 6 m x 6 m "shrub plots". Three of the shrub plots were randomly selected and height of all woody vegetation less than 1.3 m tall was measured. The shrub plots were then divided into 1 m x 1 m "herbaceous plots". Nine of the herbaceous plots were randomly selected and inventoried for all vascular plants. Vascular plant species were also inventoried in each 2 ha treatment plot using complete walk-throughs twice per growing season. Pretreatment data was collected for one year prior to treatment at each site. Post treatment data was collected at 1 year and five years following harvest.

We sampled actively foraging salamanders using night-time area-constrained searches (Harpole and Haas 1999) only during or after rain events (Feder and Londos 1984). We established a grid of nine 2 x 15 m transects per treatment plot and sampled a subset of these per plot per year.

RESULTS

Species richness of woody and herbaceous plants 1-year post-treatment was higher in plots with canopy disturbance (Wender 2000). Considering individual species, there was almost no loss of herbaceous plant species in response to harvest (Wender 2000, Hood 2001). Increases in exotic species richness were dramatic on harvested sites, averaging more than 10 new species per treatment plot. (Preharvest levels averaged less than 1 per plot.) Some of these were introduced through the seed mixes used to revegetate skid trails. The increase in exotics varied significantly among our sites, suggesting that landscape context may play a large role in the probability of a site being invaded.

To test the effects of harvesting on understory plant community structure, we analyzed plant community dissimilarity using Jaccard's distance. We expected the naturally patchy plant community to become more homogenous or uniform after harvest, leading to a post-harvest decline in Jaccard's distance. We found both positive and negative slopes, depending on the harvest treatment applied, suggesting that the different treatments may have very different effects on community structure, some increasing and some decreasing homogeneity.

Although our sites are relatively dry, unsuitable to some medicinal plants such as ginseng (*Panax quinquefolius* L.), we identified 30 species of plants known to be used for medicinal purposes. Several of the medicinal plants appeared to respond positively to harvest in the short-term, but at least one species showed a more than 40 percent decline in cover 1-year post-treatment (unpublished data).

The effects of harvesting on oak regeneration were compared among sites and among treatments. Oak regeneration dominance (relative density of dominant and codominant oak regeneration) varied by site, but did not vary by silvicultural treatment; all treatments resulted in relatively low numbers (Lorber 2003). Advanced oak regeneration was not abundant at any of the sites prior to harvest. Oak regeneration dominance four years after harvest varied by site, with successful regeneration of oak only on the lowest quality site (SI 60). In contrast, on the intermediate and higher quality sites (SI 70-80), oak has not regenerated successfully and is being replaced by other species such as black cherry (*Prunus serotina* Ehrhart.), yellow-poplar (*Liriodendron tulipifera* L.), and cucumber magnolia (*Magnolia acuminata* L.). Oaks will likely make up a smaller proportion of the trees in the future stands compared to the parent stands. The biggest losses in oak importance occurred on the intermediate and high quality sites. Therefore, the silvicultural treatments used here were not enough to overcome the site specific limitations to successful oak regeneration. Multiple linear regression analysis was used to identify the factors controlling oak regeneration at a smaller scale. The most important variables were those that described the oak stump sprouting potential, the understory and overstory oak component in the pre-harvest stand, post-harvest light and soil nitrogen levels.

In the period 1-4 years post-treatment, none of the harvest treatments differed significantly from the silvicultural clearcut in the relative abundance of salamanders (Harpole and Haas 1999, Knapp and others 2003). Even though only approximately 20 percent of the canopy in the group selection harvest was disturbed, salamander abundance on these plots declined to less than 50 percent of the preharvest population (Knapp and others 2003).

Although 1-year post-treatment clearcuts showed the highest level of estimated soil loss, projected over a 100-year rotation the group selection harvest showed the highest level. Over the rotation, group selection was projected to increase erosion 108 percent over the control while a clearcut would increase erosion only 38 percent (Hood and others 2002).

DISCUSSION

When land managers consider eliminating clearcutting, they should evaluate the costs and benefits of alternative management practices. Although there has been concern that clearcutting harms understory plant and animal communities (e.g., Ash 1988, Duffy and Meier 1992; Petranka and others 1993, 1994), our short-term evidence does not show an advantage of other regeneration techniques. We found almost no loss of herbaceous plant diversity in any of the treatments. However, if local plant extinctions were to occur, we might expect these during the period of low light penetration that occurs 4-20 years after harvest, rather than in the first year post-harvest. Our data support previous studies showing that salamander populations decline drastically following clearcuts. However, the same response was found on all treatments subjected to canopy removal, so there is no advantage to switching to alternate techniques.

We also found little evidence that regeneration techniques that retain some canopy reduce soil loss over the long run compared to clearcuts, because most of the erosion originates from roads and skid trails.

USLE estimates of soil erosion in each treatment indicate that erosion rates decline rapidly vegetation grows following disturbance. However, because of the multiple entries and increased number of skid trails required in the group selection system, projections over a 100-year rotation indicate that the group selection treatment showed the highest soil loss, and the shelterwood was no different from the clearcut.

Our preliminary results suggest that there may be some effects of harvest treatment on herbaceous plant community structure and resilience and we hope to be able to study this further. We will also need to collect more intensive data in order to compare the effects of harvest treatments on plants used in the medicinal plant trade.

Because oak dominance often declines following clearcutting, alternative regeneration systems are frequently recommended to regenerate these intermediate shade tolerant species. However, we found that the different regeneration treatments had little effect on oak regeneration. Site quality determined whether oaks would persist or be replaced by other species. Without substantial amounts of oak advanced regeneration prior to harvest, oak dominance will likely decrease following harvest on all but the lowest quality sites.

Considerations of uneven- and some even-aged regeneration methods often fail to account for the multiple stand entries required by these methods (e.g. group selection and shelterwood). The disturbance created by harvesting does cause declines in populations of salamanders and some medicinal plants and results in soil loss. Repeating these disturbances frequently, or spreading them across a larger portion of the landscape, may actually result in detrimental effects much greater than those of a clearcut. In conclusion, we hope our work will illustrate how the choice of management techniques results in different tradeoffs in the short and long terms and how the effects will vary based on initial site characteristics.

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FOREST CERTIFICATION AND NONINDUSTRIAL PRIVATE FOREST LANDOWNERS: WHO WILL CONSIDER CERTIFYING AND WHY?

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Abstract—As forest certification has grown as a tool to foster sustainable forest management, questions have arisen about the potential and suitability of forest certification for nonindustrial private forest (NIPF) ownerships (Lindström and others 1999, Newsome and others 2003, Rosenberger and Huff 2001, and Vlosky, 2000). This ownership category is particularly important in the central hardwood region where it comprises the majority of the forest land and contributes the greater part of the region's annual hardwood removal. Little is known of whom among this diverse and sizable group will adopt forest certification on their lands, and why. NIPF owners in western Tennessee were surveyed to evaluate their awareness, acceptance, and perceived benefits of forest certification. Only 2.9 percent of the owners were familiar or very familiar with forest certification. Even so, over eight in ten indicated a willingness to consider it. The type of landowner who would most likely consider certifying their forest can be profiled. These landowners were typically well educated, new at forest ownership, and had received information or advice about their forest land. They would certify for both monetary and non-monetary reasons.

INTRODUCTION

Most consumers are vaguely familiar with the concept of an objective third party certifying products to assure a high standard, or consistency, in product quality. The certification label that is affixed to electrical appliances by the Underwriters Laboratory, thereby assuring that appliances meet or exceed standards of quality and safety, is an example (Maser and Smith 2001). Certification has evolved in a number of industrial sectors including automobiles, chemicals, footwear, apparel, and fisheries (Sasser 2001). Forest certification is a relatively new development and deals not with the product, but with the practice of forestry, growth of the product, harvesting of the product, and ecological impacts associated with harvesting of the product (Klingberg 2003). Forest certification is gaining widespread attention by a variety of stakeholders including environmentalist, policy makers, professional foresters, social activists, loggers, and the general public (Mater 1999, Viana and others 1996).

The situation for forest certification in the United States is somewhat unique when compared to the global picture because such a large percentage of the total forest area in the U.S. is under nonindustrial private forest (NIPF) ownership. NIPF forests have traditionally filled an important position in U.S. wood production, a role that has become even more crucial with the decline in timber harvesting on public lands. However, the understanding of certification among this ownership class in the United States is low (Lindström and others 1999).

Many of the major retail outlets of wood and paper products have announced policies that recognize and give preference to certified wood products (Rana and others 2003). Some companies, in order to satisfy the minimum content guidelines required for paper and other wood products, are requiring greater percentage of certified wood in their inventory (American Tree Farm System 2005). These policies are in turn changing the wood procurement policies of the solidwood and pulpwood processing facilities. As a result of these concerns, stakeholders are beginning to debate the necessity of implementing forest certification on NIPFs. This ownership group is particularly important in Tennessee, where it comprises 79 percent of the state's 14.4 million acres. Moreover, these forests contribute more than 84 percent of the state's annual hardwood removal volume (Schweitzer 2000). In time, market forces could require large-scale certification, and the needs and preferences of NIPF landowners must be taken into consideration

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to ensure their participation. A viable certification system cannot be shaped without this knowledge (Lindström and others 1999).

The project reported in this paper was designed to assess awareness, acceptance, and perceived benefits regarding forest certification of NIPF landowners in west Tennessee, and to develop a profile of who would consider certifying, and why. The information is important if viable certification programs are to be developed and implemented for this ownership category.

STUDY AREA

This study focuses on West Tennessee and includes 9 counties within the 18 county Forest Inventory and Analysis West Tennessee Region. The 9 counties were selected as they represent 70 percent of the total forest area in the region (Schweitzer 2000). Because compiling and mailing to landowner populations is costly, three counties were randomly selected from the list of nine for survey purposes (Carroll, Hardeman, and Weakley counties). The three counties include 564,300 acres of total forest land (223,369 ha).

METHODS

Mail surveys were utilized for data collection to allow for coverage of large geographical area in a cost effective manner. The original database of landowners was obtained from the Tennessee State Division of Property Assessment. Only landowners controlling 40 acres or more of forest land were surveyed. A 50 percent random sample was drawn from the landowner list for the three counties. Duplicate names, trusts, businesses, partnerships, and saw and pulp mill ownerships were removed. After these reductions, the final mail sample became 1,153.

The survey instrument provided questions about owners and ownership characteristics. A draft version of the survey questionnaire was developed and pre-tested with two separate audiences. First, the questionnaire was sent to professional foresters for comment. Next, the survey was provided to NIPF landowners who were active in their County Forestry Association (outside the study counties). These individuals were asked to complete the survey, and to make suggested improvements for simplification or clarification. The questionnaire was refined based on feedback received.

In August 2004, postcards were mailed to the 1,153 landowners notifying them of the project and the intent of the research. Questionnaires and cover letters were mailed two weeks later. Landowners were assured that the information would be kept confidential. A reminder postcard was mailed, followed by a second questionnaire to the non-respondents. Another reminder postcard was mailed. The Dillman tailored design method was followed as closely as possible (Dillman 2000). The respondents were given the opportunity to receive a summary of the results for participating in the study. One hundred and three of the questionnaires were determined ineligible, bringing the eligible target population to 1,050. The final response rate was 50.7 percent. Telephone surveys were conducted to test for non-response bias. Using the Wilcoxon rank sum two sample test, none of the variables for the non-respondents showed a significant difference ($\alpha = 0.05$) between the respondents. Overall, these results reduced the concern for non-response bias.

DATA ANALYSIS

The survey consisted of 22 questions having a total of 78 response variables. After reading a definition of forest certification, participants were asked a binary (yes/no) question of their willingness to consider certification. This became the prominent dependent variable from which the demographic and attitudinal variables were examined. Chi-square tests were used to examine relationships between variables when data were ordinal scale and Spearman's correlation when data were interval. Results were reported as significant when $p \leq .05$.

RESULTS AND DISCUSSION

A series of questions with categorical responses were given to investigate landowner's familiarity with: (1) certification, (2) trustworthiness of objective third-party certifiers, (3) expected benefits of certifying, and (4) reasons for certifying. Only 2.9 percent of the respondents indicated they were familiar or very familiar with forest certification and 80.0 percent were not at all familiar. Familiarity with certification was not significantly related to willingness to consider certification.

Landowners were asked to read the following definition of forest certification and answer the questions that followed:

> "Forest certification means that forests are managed in a sustainable manner and that trees are harvested with environmentally sound practices. These management practices are certified by objective third parties. Landowner participation is voluntary."

Participants were asked to indicate their level of trust for five groups as "potential third party certifiers" (table 1). Landowners were most trusting of the state division of forestry, followed by consulting foresters, and were least trusting of environmental organizations.

Four major certification systems are the most active in the United States: Green Tag, Sustainable Forestry Initiative (SFI), American Tree Farm System (ATF), and Forest Stewardship Council (FSC). Landowners showed very little familiarity with any of these systems. The percent of respondents indicating either "familiar or very familiar" was: Green Tag (1.6), SFI (3.8), ATF (3.2), and FSC (2.8). Familiarity with any of the certification systems was not significantly related with willingness to consider certification.

To assess the perceived benefits of certification, a series of statements related to what certification could accomplish were given. All participants (including those that would not consider certification) were asked to indicate their level of agreement or disagreement with each perceived benefit (table 2). Seven of ten believed that certification would improve forest management; six of ten felt that it would both increase their profits from tree farming and that it would satisfy consumers that their wood purchases were supporting good forestry. Less than half of the respondents felt that certification would: lessen the need for forestry regulation, give recognition for the good forestry that they were already practicing, or be necessary for U.S. timber growers to complete in the international market.

When the perceived benefits of certification were linked with only those landowners who would consider certification, a highly significant relationship existed between all variables. In other words, landowners

Table 1—Rating of trustworthiness of objective third party forest certifiers by NIPF landowners

Third party certifier	Mean[a]	Mean[b]
State division of forestry	4.03	4.12
Consulting foresters	3.54	3.62
Landowner associations	3.21	3.34
Forest Industry	2.70	2.77
Environmental organizations	2.31	2.38

NIPF = nonindustrial private forest.
[a] Among all respondents (1 = not trustworthy; 5 = very trustworthy).
[b] Among respondents willing to consider certification (1 = not trustworthy; 5 = very trustworthy).

with willingness to consider certification felt strongly that certification would accomplish all of the potential benefits ($P<.0001$).

Landowners were asked whether or not they would consider certification, and 81.2 percent indicated that they “would.” Those indicating affirmative were then asked the importance of six different reasons (both monetary and non-monetary) for why they would consider certification. The top three reasons landowners chose for certifying their forest were: (1) if it made their forest more healthy, (2) if it improved wildlife habitat, or (3) if it saved money by reducing the likelihood of future regulation. Ninety-two percent indicated that improving forest health was either important or very important, 84.8 percent stated improving wildlife habitat, and 84.0 percent claimed reducing regulation for the same. The lowest response was 62.8 percent, whereby participants thought that gaining access to additional markets was an important or very important reason (table 3).

Table 2—Perceived benefits of forest certification among all NIPF landowners

Perceived benefits	Respondents indicating “agree or strongly agree”
	percent
Certification will improve forest management	69.8
Certification will increase my profits in tree farming	61.0
Certification will satisfy consumers that their wood purchases are supporting good forestry	59.6
Certification will lessen the need for forestry regulation	42.9
Certification will give me recognition for the good forestry that I am already practicing	48.1
Certification will be necessary for U.S. timber growers to compete in the international market	33.0

NIPF = nonindustrial private forest.

Table 3—Reasons why landowners would consider certifying their forest land

Utility category	Reason for certifying	Respondents indicating “agree or strongly agree”	Overall rank
		percent	
Nonmonetary	If it helped protect the environment	81.2	4
	If it improved wildlife habitat	84.8	2
	If it made my forest more healthy	92.0	1
Monetary	If my wood products could be sold for a higher price	75.9	5
	If it gained me access to additional wood markets not normally available	62.8	6
	If it saved me money by reducing the likelihood of future regulation	84.0	3

Neither age of the landowners, nor the size of forest ownership, were significantly related to willingness to consider certification. However, more highly educated landowners (χ^2= 25.95, P<.0001), new owners (χ^2=74.74, P=.0036), and those who had received information or advice about their forest land (χ^2= 14.34, P<.0002) were more likely to consider certification.

Among the variables significantly related to a landowner's willingness to consider certification, tenure (the variable that classifies them as "new" to land ownership), and advice (the variable indicating they have received forestry advice or information) are perhaps the most prominent. Unlike the other variables that are significantly related to willingness to consider certification, these two variables can be captured from tax assessor records and professional foresters' lists. Doing so would allow targeting educational programs to landowners with characteristics favorable toward certification. With 16 percent of the forest properties anticipated to change ownership in the next 15 years, an increase in the number of new owners is likely. This suggests that forest certification among NIPF owners has the potential to be expanded.

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THE IMPORTANCE AND DISTRIBUTION OF HICKORY ACROSS VIRGINIA

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Abstract—The importance and role of hickory (*Carya* spp.) in the Oak-Hickory forest community complex has been studied over the last 70 years and questioned by several investigators. Until recently, there were virtually no species-level landscape-scale studies that accurately defined the role of hickory in these systems. Data from the USDA Forest Service, Forest Inventory and Analysis Program, were used to describe the distribution and compositional status of several hickory species across Virginia. Oak-Hickory was the predominant forest-type group in Virginia, covering 3 859 500 ha and accounting for 78 430 000 m^2 of basal area. A total of 1 880 live hickory trees (d.b.h. ≥ 12.7 cm) occurred and were measured on 51 percent of plots. Across all plots in the study, the average basal area of hickory was 1.2 m^2 ha^{-1}. On plots where hickory was present, basal area was 2.4 m^2 ha^{-1}. Mockernut (*Carya tomentosa* (Poir.) Nutt.) and pignut (*C. glabra* (Mill.) Sweet) hickory were the most prevalent hickory species measured. Mockernut (basal area = 0.5 m^2 ha^{-1}) and pignut (basal area = 0.5 m^2 ha^{-1}) were tallied on 29 and 30 percent of plots, respectively. Shagbark (*C. ovata* (Mill.) K. Koch) and bitternut (*C. cordiformis* (Wangenh.) K. Koch) hickory were also tallied, but they occurred less frequently. Hickory ranked in the top three species, by importance value, on 25 percent of all plots. This study sheds new light on the importance and species-level distribution of hickory in the Oak-Hickory forest complex at the landscape scale.

INTRODUCTION

The Oak-Hickory complex is the largest forest vegetation association in the Eastern United States. This association covers approximately 32 869 000 ha from Virginia and Kentucky to East Texas and Oklahoma, with an additional 21 016 000 ha in the northeastern and north central States (Smith and others 2004). Currently it covers approximately 3 859 500 ha (60 percent) of all forest land in Virginia. Although the complex is typically more prevalent in the Piedmont, the Coastal Plain has also been characterized as potentially an Oak-Hickory climax (Oosting 1956, Vankat 1979). Others (DeWitt and Ware 1979, Ware 1992) have found that the vegetation of the Coastal Plain of Virginia is strongly similar to the southern mixed hardwood forest described by Quarterman and Keever (1962).

The composition of the vegetation of western Virginia is much like that of the Oak-Chestnut association defined by Braun (1950). Braun maintained that the vegetation of central Virginia belonged to the Oak-Pine forest complex. However, both she and Barrett (1962) noted a similarity between the Oak-Hickory of the East and the same association in the central region of the Eastern United States. Greller (1988) modified Braun's classification of the Piedmont vegetation to Oak-Pine-Hickory. Kuchler (1964) classified the Piedmont forest as Oak-Hickory-Pine, specifically acknowledging a difference between Oak-Hickory regions with and without a pine component.

The dominant genus in the Oak-Hickory association is oak (*Quercus*) and the binomial nomenclature suggests that hickory is second in dominance. However, some investigators have questioned whether hickory is of high enough importance to justify classifying large areas of the Eastern United States as Oak-Hickory. Monk and others (1990) concluded that hickory was not of great enough importance in oak-dominated forests to justify classifying large portions of eastern North America as such. Other studies have confirmed the lack of quantitative evidence for an Oak-Hickory type, especially on the Coastal Plain of Virginia (DeWitt and Ware 1979). Ware (1992) also concluded that hickory was of relatively low importance in the Piedmont of Virginia. In contrast, several studies found hickory to be of relatively high

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importance in Virginia, particularly in the northern part of the Piedmont, and in the central part of the Blue Ridge Mountains (Farrell and Ware 1991, Johnson and Ware 1982).

Quite often, studies of vegetation composition are limited in scale, and plot selection is therefore subjective and preferential. Preferential sampling emphasizes forest stands with unique characteristics, such as mature forests, or stands that have unusual features, such as rare species. In contrast, our approach utilized plots distributed systematically across Virginia. This allowed for the study of a wide range of stands across a variety of conditions and captured the most common stand conditions influencing vegetation across Virginia.

The objectives of this study were to describe the current distribution and importance of hickory at the landscape scale across Virginia, and evaluate the temporal dynamics of hickory.

METHODS

The study area was the State of Virginia. The land area of the State is 10 255 000 ha and approximately 62 percent of this is forested (6 412 000 ha). Virginia is bounded on the west by a mountainous region, which includes the Blue Ridge, the Ridge and Valley, and the Appalachian Plateaus. To the east of these mountains is the Piedmont, which ranges from rolling hills in the west to several nearly level basins in the east. The easternmost part of the State lies on the Coastal Plain, which extends inland approximately 200 km from the coast and is defined by the eastern Atlantic shoreline and the rolling and dissected area where it meets the Piedmont to the west (Fenneman 1938). The elevation in Virginia ranges from sea level to just over 1737 m on Mount Rogers in the George Washington and Jefferson National Forest. Because of this wide range of topography, the State was divided into five regions that approximate the various physiographic provinces found in Virginia (fig.1).

Data for this study came from the forest survey conducted in Virginia between 1997 and 2001 by the USDA Forest Service, Southern Research Station, Forest Inventory and Analysis (FIA) program. Surveys such as this have been conducted since the early 1930's, under the direction of several legislative acts. The survey mission was to estimate forest area, timber volume, growth, removals, and mortality.

The survey used a two-phase sampling scheme on a hexagonal grid system to derive forest statistics (USDA 2004). Phase I consisted of photo-interpretation for the determination of forest area. Phase II consisted of measurements on sample plots to determine individual tree and forest stand parameters, with an intensity of one plot per 2430 ha. The plot design employed a fixed-plot composed of four circular subplots with a radius of 7.3 m spaced 37 m apart. The total sample area of these four subplots was 0.07 ha. Only live trees 12.7 cm in d.b.h. were included in the study.

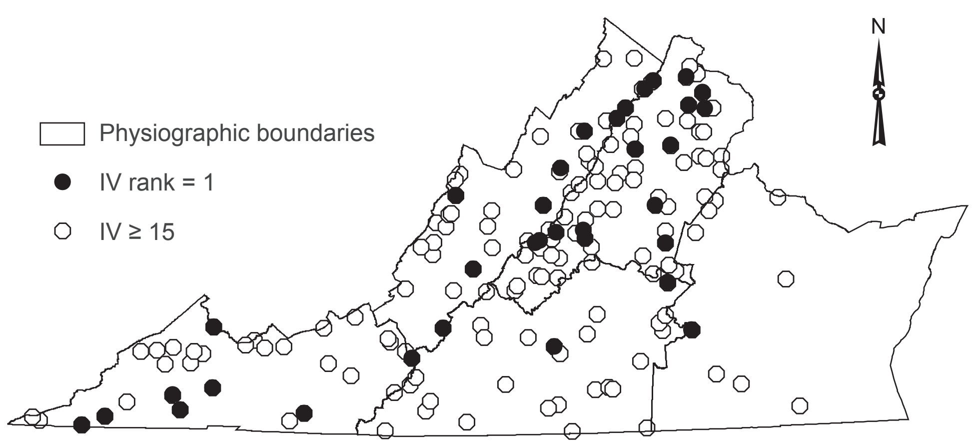

Figure 1—Plots where hickory ranked first in importance value (IV) or had an IV of ≥ 15.

The total plot population was post-stratified based upon the following criteria: (1) each plot was internally homogeneous regarding stand size and forest type, (2) the plots were not artificially regenerated, (3) the plots showed no evidence of cutting since the previous survey (5-10 years previously), and (4) the plots were classified as either pole-size, or timber-size stands. Out of 3,037 forested plots, 1,168 met these requirements. The Coastal Plain was represented by 194 plots, the Piedmont by 416 plots, and the Mountains by 558 plots (table 1). The 2001 survey represents the first time that hickory data were collected by specific species in the FIA program in Virginia. Therefore, survey-to-survey comparisons of hickory importance can only be done at the genus level. Additionally, sample design differences between surveys preclude rigorous analysis of temporal trends.

Basal area for genus and species was calculated for all plots. Given that trees are not distributed homogenously across the landscape, and therefore the plots, this can result in a standard deviation that equals, or exceeds the mean. Relative density (density of species or genus / total density in stems ha^{-1}) and relative dominance (basal area of species or genus / total basal area in m^2 ha^{-1}) were calculated and the mean of these two yielded relative importance values (IV), modified after Curtis and McIntosh (1951), for each genus and species on each plot. Unless otherwise noted, taxonomic nomenclature follows Little (1979). FIA includes red hickory (*C. ovalis* (Wangenh.) Sarg.) with pignut hickory.

Main effects of physiographic province and stand age were examined statistically using separate analysis of variance tests (ANOVA) via the general linear models procedure in SAS (SAS Institute Inc. 1999). Unless otherwise noted, all tests were considered to be significant at the 0.05 level.

RESULTS

At the genus level, hickory was tallied on 596 plots, or 51 percent of all plots, ranking third in frequency (table 2). Average basal area of hickory across all plots was 1.2 m^2 ha^{-1}, and average density was 24 stems ha^{-1}. Oak was the most prevalent genus. It occurred on 86 percent of all plots and had an average basal area of 9.5 m^2 ha^{-1} and an average density of 146 stems ha^{-1}. Maples (*Acer*) were the second most prevalent, occurring on 72 percent of all plots. This genus had an average basal area and density of 2.3 m^2 ha^{-1} and 53 stems ha^{-1}, respectively.

Dominance of hickory varied significantly between physiographic provinces (F = 13.6, $p < 0.0001$). In the northern portion of the Piedmont, 66 percent of all plots had hickory. This area also had the highest average basal area of hickory, 1.9 m^2 ha^{-1}, as well as the highest average density, 38 stems ha^{-1}. In contrast, the Coastal Plain had the least hickory, with only 30 percent of plots having hickory and an average basal area of 0.6 m^2 ha^{-1}. Basal area of hickory also varied significantly by stand age (F = 7.15, $p < 0.0001$). Stands 25-50 years old had an average basal area of 0.9 m^2 ha^{-1}, while basal area averaged 1.4 m^2 ha^{-1} in stands > 50 years old.

Table 1—Average basal area and density for Virginia, by major physiographic province (for trees ≥ 12.7 cm d.b.h.)

Region	n (plots)	Basal area			Density		
		Avg	Min	Max	Avg	Min	Max
		- - - - - m^2 ha^{-1} - - - - -			- - - - - - stems ha^{-1} - - - - - -		
Coastal Plain	194	26.4	1.3	56.2	474.2	59.5	1 293.7
Southern Piedmont	174	22.7	4.7	47.3	448.3	148.7	921.9
Northern Piedmont	242	23.2	4.5	50.5	382.7	74.4	877.3
Northern Mountains	299	21.8	2.1	39.9	415.1	119.0	847.6
Southern Mountains	259	23.8	3.0	55.4	430.5	104.1	803.0
All regions	1,168	23.4	1.3	56.2	426.6	59.5	1 293.7

Table 2—Average basal area m²/ha⁻¹ for the top 15 genera by major physiographic province for Virginia (for trees ≥ 12.7 cm d.b.h.)

		Region											
		Coastal Plain		Southern Piedmont		Northern Piedmont		Northern Mountains		Southern Mountains		All regions	
Genus	n (plots)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Quercus	999	5.7	6.2	7.6	7.4	8.9	8.1	13.3	7.2	10.0	8.1	9.5	7.9
Pinus	573	7.5	8.8	3.5	5.8	2.0	4.5	2.4	4.3	1.0	2.8	3.0	5.7
Liriodendron	578	2.5	4.4	4.0	5.4	4.6	6.0	0.8	2.4	3.2	5.3	2.9	5.0
Acer	837	3.3	5.4	2.0	2.6	1.6	2.7	1.8	3.0	3.1	3.5	2.3	3.6
Carya	596	0.6	1.4	1.3	2.0	1.9	2.8	0.9	1.8	1.3	2.0	1.2	2.1
Liquidambar	232	2.6	3.8	1.2	2.7	0.5	1.7	0.0	0.0	0.0	0.2	0.7	2.2
Nyssa	403	1.2	4.0	0.3	0.7	0.4	0.8	0.4	1.0	0.4	0.9	0.5	1.8
Fraxinus	227	0.5	1.9	0.3	1.0	0.6	1.6	0.3	1.0	0.5	1.5	0.4	1.4
Fagus	160	0.8	2.5	0.3	1.3	0.5	1.7	0.0	0.1	0.5	1.6	0.4	1.6
Betula	183	0.1	0.4	0.4	1.7	0.4	1.3	0.4	1.2	0.5	1.6	0.4	1.4
Robinia	173	0.0	0.3	0.1	0.6	0.3	1.0	0.3	1.1	0.5	1.3	0.3	1.0
Oxydendrum	218	0.1	0.3	0.5	0.9	0.0	0.3	0.1	0.4	0.5	0.9	0.2	0.7
Tilia	76	0.0	0.0	0.0	0.1	0.1	0.8	0.3	1.1	0.4	1.5	0.2	1.0
Juniperus	109	0.1	0.3	0.1	0.5	0.4	1.4	0.1	1.1	0.1	0.8	0.2	0.9
Prunus	126	0.1	0.4	0.1	0.4	0.2	0.6	0.1	0.7	0.3	1.4	0.2	0.8

SD = standard deviation.

Across the State, hickory ranked first, based on IV, on 34 plots (3 percent of all plots) (fig. 1). It ranked second on 125 plots (11 percent), and third on 134 plots (12 percent). Almost one-half of the plots where hickory ranked first were in the northern Piedmont (table 3), especially the north-western portion (fig.1). Hickory did not rank first in IV on any plot in the Coastal Plain. Oaks had the highest IV in 604 plots (52 percent), and the second and third highest IV in 186 (16 percent), and 88 (8 percent) plots, respectively.

Pignut hickory was the most frequently occurring hickory species, having been tallied on 351 plots. Mockernut was second, occurring on 340 plots. Both pignut and mockernut averaged 0.5 m^2 ha^{-1} of basal area across all plots. In contrast, both shagbark and bitternut averaged 0.1 m^2 ha^{-1} of basal area (table 4). Of the 94 species of trees tallied across all plots, 51 were leading dominants on at least one plot. Chestnut oak (*Quercus prinus* L.), yellow-poplar (*Liriodendron tulipifera* L.), and white oak (*Quercus alba* L.) were the leading dominants in 241 (21 percent), 190 (16 percent), and 133 (11 percent) plots, respectively (table 5). Mockernut, pignut, bitternut, and shagbark hickory, ranked first in 16 (1 percent), 13 (1 percent), 3 (< 1 percent), and 0 plots, respectively.

The distribution of the individual hickory species varied by physiographic province. Both pignut and mockernut hickory were most abundant in the northern Piedmont, while shagbark tended to be more abundant in the southern part of the mountains. Bitternut hickory was nearly equally distributed between the Mountains and the northern Piedmont. Pignut hickory reached its highest average basal area of 0.9 m^2 ha^{-1} in the northern Piedmont.

Mockernut hickory ranked first on four plots in the northern Piedmont and on five in the southern Piedmont and was the only hickory to rank first on a plot on the Coastal Plain. Pignut hickory ranked first on six plots in the northern Piedmont and on four in the northern Mountains. Bitternut hickory ranked

Table 3—Importance value rankings for genera ranking third or greater in at least 30 plots across Virginia, by major physiographic province (for trees ≥ 12.7 cm d.b.h.)

	Region														
	Coastal Plain			Southern Piedmont			Northern Piedmont			Northern Mountains			Southern Mountains		
	IV rank														
Genus	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	number of plots														
Quercus	57	37	20	77	26	17	108	43	28	223	44	11	139	36	12
Acer	21	31	25	11	31	25	13	23	41	24	65	53	31	77	55
Pinus	57	38	16	28	26	19	19	27	13	22	79	29	9	25	11
Liriodendron	20	15	25	37	22	29	52	43	22	7	11	15	37	32	25
Carya	0	8	15	3	24	13	15	42	35	8	34	36	8	17	35
Liquidambar	19	31	30	6	14	13	4	10	6	0	0	0	0	0	0
Nyssa	6	4	9	0	5	7	0	5	15	1	20	44	0	2	9
Fraxinus	4	3	6	3	2	5	4	8	12	2	4	6	4	6	10
Betula	0	2	1	3	2	1	5	9	9	2	7	18	6	4	9
Oxydendrum	0	1	3	0	8	8	1	1	0	0	3	5	0	16	30
Fagus	4	8	8	1	3	3	4	5	7	0	0	0	4	8	4
Robinia	0	0	1	1	2	1	5	1	3	3	4	6	4	7	10
Juniperus	0	1	1	1	1	2	4	10	5	2	2	1	2	2	2
Tsuga	0	0	0	0	0	0	1	0	0	0	6	10	3	4	7
Prunus	0	0	3	0	1	2	1	2	5	2	1	4	1	6	2

IV = importance value.

first on one plot in the northern part of the Piedmont and first on two plots in the Mountains. Shagbark hickory did not rank first on any plot across the State, but ranked second on four plots.

DISCUSSION

Because this study was based on sample plots that were systematically located, with minimal post-stratification, the data represent the current status of vegetation across the landscape and emphasize characteristics of the common types of vegetation across Virginia. This is a departure from most vegetation studies in which a small area with unique characteristics is selected and studied. Such select studies are important but they do not portray the average state of vegetation across a large area.

Most of the forests of Virginia, and, therefore, our plot population, have experienced varying degrees of disturbance since settlement in the 1600s (Williams 1989). Since pine (*Pinus*) and yellow-poplar were both of relatively high importance in the survey data, it is likely that a large proportion of the plots were early to mid-successional. Additionally, the high frequency of pine, especially loblolly pine (*P. taeda* L.), suggests that some plots may have been artificially regenerated. However, some plantations were likely too old and broken up to be identified as such during data collection.

Stands on the Coastal Plain were predominately Oak-Pine, with relatively little hickory present. This agrees closely with Dewitt and Ware (1979) who found that none of the hickory species were of a high dominance in stands on the Coastal Plain.

Our data also showed that stands in the Mountains and Piedmont, and especially the northern Piedmont, had more hickory than those on the Coastal Plain. Farrell and Ware (1991) found the same to be true of

Table 4—Top 35 species for basal area, Virginia (for trees ≥ 12.7 cm d.b.h.)

Common name	Scientific name	n (plots)	Basal area Avg	Basal area SD
			- - m^2 ha^{-1} - -	
Chestnut oak	*Quercus prinus* L.	518	3.41	5.60
Yellow-poplar	*Liriodendron tulipifera* L.	578	2.87	4.96
White oak	*Q. alba* L.	555	2.13	3.67
Red maple	*Acer rubrum* L.	773	1.95	3.34
Northern red oak	*Q. rubra* L.	477	1.55	3.26
Loblolly pine	*Pinus taeda* L.	157	1.18	4.28
Scarlet oak	*Q. coccinea* Muenchh.	354	0.97	2.19
Virginia pine	*P. virginiana* Mill.	277	0.88	2.75
Black oak	*Q. velutina* Lam.	380	0.85	1.93
Sweetgum	*Liquidambar styraciflua* L.	232	0.72	2.21
Pignut hickory	*Carya glabra* (Mill.) Sweet	351	0.52	1.24
Mockernut hickory	*C. tomentosa* (Poir.) Nutt.	340	0.50	1.30
Eastern white pine	*P. strobes* L.	144	0.46	1.97
American beech	*Fagus grandifolia* Ehrh.	160	0.40	1.58
Blackgum	*Nyssa sylvatica* L.	379	0.39	1.10
White ash	*Fraxinus americana* L.	173	0.33	1.23
Southern red oak	*Q. falcata* var. *falcata* Ell.	154	0.33	1.62
Sugar maple	*Acer saccharum* Marsh.	131	0.30	1.34
Black locust	*Robinia pseudoacacia* L.	173	0.27	0.99
Sweet birch	*Betula lenta* L.	153	0.26	0.99
Sourwood	*Oxydendrum arboreum* (L.) DC.	218	0.23	0.66
Pitch pine	*P. rigida* Mill.	102	0.21	1.06
Shortleaf pine	*P. echinata* Mill.	86	0.19	1.39
American basswood	*Tilia americana* L.	76	0.17	0.98
Black cherry	*Prunus serotina* Ehrh.	121	0.16	0.83
Eastern redcedar	*Juniperus virginiana* L.	109	0.16	0.94
Eastern hemlock	*Tsuga canadensis* (L.) Carr.	64	0.16	1.17
American sycamore	*Platanus occidentallis* L.	53	0.12	0.87
Green ash	*Fraxinus pennsylvanica* Marsh.	59	0.11	0.77
Shagbark hickory	*Carya ovata* (Mill.) K. Koch	90	0.10	0.45
Bitternut hickory	*C. cordiformis* (Wangenh.) K. Koch	55	0.10	0.63
Cucumbertree	*Magnolia acuminata* L.	82	0.09	0.50
Willow oak	*Q. phellos* L.	42	0.09	0.74
American holly	*Ilex opaca* Ait.	89	0.07	0.40
Sassafras	*Sassafras albidum* (Nutt.) Nees	73	0.07	0.49

SD = standard deviation.

Table 5—Importance value rankings for species ranking third or greater in at least 10 plots across Virginia, by major physiographic province (for trees ≥ 12.7 cm d.b.h.)

	Region														
	Coastal Plain			Southern Piedmont			Northern Piedmont			Northern Mountains			Southern Mountains		
	IV rank														
Species	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	number of plots														
Chestnut oak	3	0	0	21	7	6	31	7	11	123	52	28	63	38	19
Red maple	21	32	25	16	23	22	12	23	23	19	27	34	28	46	30
Yellow-poplar	25	12	17	42	24	20	63	33	15	12	9	7	48	25	17
White oak	30	12	9	31	17	15	36	31	18	26	27	19	10	15	13
Northern red oak	1	4	2	2	3	10	9	20	12	24	34	29	15	18	16
Scarlet oak	0	5	6	2	13	3	3	10	9	19	32	26	17	13	17
Virginia pine	7	13	6	18	9	11	18	14	8	4	12	11	2	4	4
Sweetgum	20	34	19	7	11	13	6	7	4	0	0	0	0	0	0
Black oak	2	5	5	0	2	5	5	8	8	6	19	20	6	11	15
Loblolly pine	53	29	15	5	3	2	2	2	1	0	0	0	0	0	0
Mockernut hickory	1	1	5	5	8	10	4	13	17	3	3	8	3	2	10
Pignut hickory	0	3	5	0	3	5	6	10	22	4	5	15	3	3	8
Blackgum	2	1	6	0	4	5	0	3	10	4	9	21	0	4	1
White pine	0	0	0	2	3	1	3	3	3	16	12	13	5	6	2
White ash	1	1	2	2	2	1	4	9	13	4	3	0	4	6	9
American beech	7	5	8	2	3	1	6	7	4	0	0	0	8	5	4
Sourwood	0	2	1	0	9	8	2	0	0	0	1	2	1	8	20
Sweet birch	0	0	0	0	0	1	4	5	11	3	4	9	5	3	7
Sugar maple	0	0	0	0	0	1	0	0	1	8	6	2	10	10	11
Southern red oak	3	4	14	1	3	6	4	3	8	0	0	0	0	0	0
Black locust	0	0	1	1	1	2	5	1	2	4	3	3	6	8	5
Pitch pine	0	0	0	0	1	0	0	0	0	5	13	14	0	2	7
Eastern redcedar	0	1	0	1	1	0	8	6	2	2	3	2	3	1	2

IV = importance value.

the northern Piedmont, especially sites located on geologic belts of Triassic age. In that study, hickory seemed to be associated with soils of high Ca and Mg. We found that in the Mountains, plots where hickory ranked first or had an IV of ≥ 15 tended to cluster along the Blue Ridge (fig.1). On plots in the Shenandoah National Park, Stephenson and others (1991) found that hickory ranked third for IV. Additionally, Johnson and Ware (1982) found hickory to be of rather high importance in the central Blue Ridge. They surmised that hickory was playing a major role in the replacement of American chestnut (*Castanea dentata* Mill.) in this area.

That hickory was correlated with stand age is not surprising, given that it is a late-successional species (Burns and Honkala 1990). A cursory examination of data for stands > 75 years old showed that hickory was nearly equal in relative dominance to pine, yellow-poplar, and maple. While basal area was correlated with stand age and physiographic province, there is the possibility that these two independent variables are correlated, as stands in the Mountains and in the northwestern portion of the Piedmont tend to be older than stands elsewhere.

The question of whether hickory is important enough to be carried in the binomial name is a complex issue. Several complicating factors should be considered. First, it must be ascertained whether the classification system being used is based on current vegetation or some potential vegetation scheme. Braun (1950) visualized how the forest vegetation would appear after the erosion cycle was complete, and Kuchler's (1964) work was based on potential natural vegetation. Both maintained hickory as an indicator in the type name. Also, much of the work on the eastern forest types and associations has been done post-chestnut blight. Prior to the blight, much of what is now called Oak-Hickory was classified as Oak-Chestnut-Yellow-poplar (Shantz and Zon 1924). While oak has proliferated in the absence of American chestnut, it is doubtful that all species have stabilized completely in filling the vacated niche.

Second, forest typing and classification systems are complex and subjective. Baker (1950) outlines a number of problems: (1) type boundaries may be vague, (2) extensive unlisted or unrecognized mixtures of species may occur, (3) some types are judged too unimportant, or local, to be worthy of recognition, and (4) it is difficult to judge whether a type is a phase of another type because of a shift in the ranking of species importance. In addition, existing guides and manuals do not explain fully how to assign type names to sample data. Workers are thus left with much flexibility in deciding on classifications of their data.

Third, classification schemes at the macro level cannot address all the variations found in ecosystems at the micro level. By necessity, they have to be collapsed into a manageable naming system. Some of the questions raised by the hickory issue most likely are due to the process of taking forest stands of a highly variable and complex nature and arbitrarily placing them into predetermined forest types. However, classifications for the macro scale have to be simpler than those for the micro scale in order to be manageable and useful.

Our data suggest that hickory is present in sufficient numbers to be maintained as a component in the binomial naming convention, at least for the Mountains and northern Piedmont. This is especially true when the importance values of the hickories at the landscape scale, and trends through time are considered. Over the past 20 years, the density of hickory has remained fairly stable, and there have been small increases (10-15 percent) in volume. Other species, however, have not remained quite so constant. Both Virginia pine and shortleaf pine have been losing ground in Virginia over the past several decades. Over just the last 20 years, Virginia pine volume has decreased by 24 percent and that of shortleaf by 35 percent (Thompson and Johnson 1992). Perhaps the hickories are not as widespread or dominant as believed and the Oak-Hickory type name has become a catch-all assigned to all of the forest stands that are highly variable in species composition. However, a suitable replacement has not been suggested.

Braun (1950) recognized that Oak-Hickory communities occur throughout the deciduous forest and surmised that rather than one, there are three: (1) Ozarkian Oak-Hickory, (2) Piedmont (or eastern) Oak-Hickory, and (3) white oak. She suggested that their distribution was bimodal, being centered both in the Ozarks and in the Piedmont. She believed that the best development of the Oak-Hickory forest type was found in the Ozark upland. Future work comparing the importance of hickory in the structure and composition of the Ozark forests with those in the Piedmont will further clarify the role of hickory in the eastern deciduous forest. Follow-up studies that investigate the seedlings and saplings of this area will provide insight into the future composition of these forests. Furthermore, a closer examination of the Blue Ridge and the Piedmont of Virginia may provide further information regarding the forces that drive the distribution and importance of hickory.

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THE PAST, PRESENT, AND FUTURE OF INDIANA'S OAK FORESTS

Stephen R. Shifley and Christopher W. Woodall[1]

Abstract—Regenerating mesic oak forests to retain oaks and control competitors such as sugar maple and yellow-poplar is one of the most vexing silvicultural problems in the Midwest. We use nearly 50 years of state-wide inventory data to examine forest change in Indiana with emphasis on species composition, forest size structure, snags and coarse woody debris. Over the past five decades the area of Indiana timberland increased slightly from 4 to 4.4 million acres; over that same period the volume of growing stock timber more than doubled from 2.6 to 6.9 billion cubic feet. Fifteen percent of all trees on timberland are now sugar maple and no single oak species ranks in the top 12 species in terms of total number of trees. Yet red oak species as a group have more volume than any other species group and they dominate the largest diameter classes. Contemporary forests still bear the legacy of the wave of timber harvesting and land clearing that altered most Indiana forests a century ago. Extensive timber harvesting in the late 1800s and early 1900s followed by periodic burning and grazing created an environment favorable for the establishment of oaks and hickories. Over the past 50 years most forest disturbances have been smaller in scale and intensity, and the conversion from oak to maple and yellow-poplar has been relentless and pervasive. Over time we expect the volume of oak biomass in snags and coarse woody debris to increase. These trends will take decades to alter if that is deemed desirable.

INTRODUCTION

Difficulty regenerating oaks (*Quercus* spp.) on mesic sites in the Central Hardwood Region is a widely documented and long-standing silvicultural problem (e.g. Dey 2002, Johnson and others 2002). Shifts in species composition for mature oak forests and associated oak regeneration difficulties were topics during the first Central Hardwood Forest Conference 30 year ago (Johnson 1976, Rudolf and Lemmien 1976, Schlesinger 1976). Many of those same issues still persist. Now, with the advantage of hindsight and five decades of accumulated forest inventory data, we decided to examine how extensive the impacts of the "oak regeneration problem" have been, and how rapidly forest composition and structure have changed as a consequence.

Forest statistics for Indiana provide an opportunity to explore these questions. Modern statistical inventories of Indiana's forests began in 1950 and were repeated in 1967, 1986, 1998, and 2003. These records give us the opportunity to trace changes in the oak resource in total and for specific components including regeneration, established trees, snags, and down woody material.

The forest composition and size structure in Indiana (and throughout the Central Hardwood Region) are dynamic and a product of past disturbances. Fifty years ago forests in Indiana were dominated by oaks (U.S. Forest Service 1953), but the original land surveys prior to widespread European emigration indicated a more balanced mix of oak and beech-maple forest (Lindsey 1997). The wave of European settlement brought widespread logging. In 1899 Indiana was the largest producer of lumber in the United States; more than 1 billion feet of lumber were produced (Parker 1997). The lumber soon played out, however, and Indiana was left with a highly disturbed and relatively young forest resource that regenerated under the influence of frequent fire, widespread grazing, farming, and farm abandonment. These disturbances favored the accumulation of oak reproduction more so than American beech (*Fagus grandifolia* Ehrh.), maple (*Acer* spp.), yellow-poplar (*Liriodendron tulipifera* L.) and other associates. With reductions in large-scale clearcutting, wildfire and woodland grazing in the mid 20th century, mesic species such as sugar maple, American beech and yellow-poplar regenerated with notably greater success

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than oaks--even on sites that previously supported a vigorous oak overstory. Maple and beech were well adapted to the shaded understory of existing oak forests, and in the absence of periodic fires the fast-growing yellow-poplar was able to out-compete oaks and increase in dominance.

Indiana's forest resources are dynamic and still responding to the wave of harvesting and other disturbances that occurred in the late 1800's and early 1900's. The current trajectory away from dominance by oaks represents a long, slow change that has implications for biodiversity, wildlife, recreation, and the forest products industry. In this paper we analyze current Indiana state-wide forest conditions along with 50 years of past inventory results to measure the magnitude and rate of changes in species composition and forest size structure, for oak, maple, beech, yellow-poplar and other dominant species in Indiana forests.

The goal of this study is to broadly assess the current status and possible future of oaks in Indiana. Specifically,

1. We estimate the degree to which oaks have occupied and/or currently occupied Indiana's forests when viewed in terms of regeneration, standing live trees of various sizes classes, snags, and coarse woody debris.

2. We use historic forest inventory data to estimate the rate and trajectory of oak forest change and address implications for the future.

METHODS

Data were drawn from U.S. Forest Service state-wide inventories conducted in cooperation with the Indiana Division of Forestry. Published inventories are available for 1950, 1967, 1986, 1998, and 2003. (U.S. Forest Service 1953; Spencer 1969; Spencer and others 1990; Schmidt and others 2000; Woodall and others 2004; Woodall and others, in press). Data for inventory years 1986, 1998, and 2003 are also available on-line (http://www.ncrs2.fs.fed.us/4801/FIADB/index.htm) and can be used to create custom queries and tabulations (Miles 2001).

The surveys varied somewhat in sample design, but they provide compatible estimates of forest area over time. They also provide compatible estimates of the number and volume of trees by species and by tree or stand size class. However, methods used to estimate forest cover type changed significantly from 1950 to 1968, and again from 1998 to 2003. Consequently, changes in area by forest cover type are not meaningful over these intervals. Analyses track changes in forest conditions over time and are derived from tables in published reports or retrievals from the Mapmaker software. Mapmaker is a web-based data retrieval application that simplifies access and summary of the state-wide inventory data collected by the Forest Inventory and Analysis program of the U.S. Forest Service.

Some results are reported by species group. The most abundant species in the white oak group are white oak (*Q. alba* L), chestnut oak (*Q. prinus* L.), chinkapin oak (*Q. muehlenbergii* Engelm.), and bur oak (*Q. macrocarpa* Michx.). The most abundant species in the red oak group are black oak (*Q. velutina* Lam.), northern red oak (*Q. rubra* L.), pin oak (*Q. palustris* Muenchh.), scarlet oak (*Q. coccinea* Muenchh.), and shingle oak (*Q. imbricaria* Michx.). The maple-beech species group is and upland group comprised of sugar maple (*A. saccharum* Marsh.), black maple (*A. nigrum* Michx. f.), and American beech. In some summaries the hard maple species (sugar and black maple) are distinguished from soft maple species comprised primarily of red maple (*A. rubrum* L.) and silver maple (*A. saccharinum* L.).

RESULTS AND DISCUSSION

Concern about the oak resource in Indiana has usually focused on poor oak regeneration and the associated shifts in species composition over time. However, when examined by size class or life stage, some parts of the oak resource are thriving while others are in decline. In this section we address the oak resource in terms of seedlings, saplings, mature trees, snags, and coarse woody debris (CWD). The available long term inventory information addresses the live tree component and permits a more detailed analysis of those components. Information about snags and CWD is of more recent origin. Before addressing the oak resource *per se*, we start with an overview of general forest trends in Indiana's forests over the past five decades.

Timberland area in Indiana is approximately 4.4 million acres or 19 percent of Indiana's land area. The area of timberland in Indiana increased by nearly 10 percent from 1950 to 2003. Over the same period the volume of growing stock on timberland increased by more that 2.5 times from 2.6 to 7.5 billion cubic feet; the proportional increase was slightly greater if expressed in board feet (fig. 1). This increase in volume is in large measure due to the maturing of the forest resource. Between 1950 and 2003 the proportion of all timberland in the sawtimber size class (i.e. stands where the overstory trees are predominantly > 11 inches d.b.h.) increased from 52 to 73 percent (fig. 2).

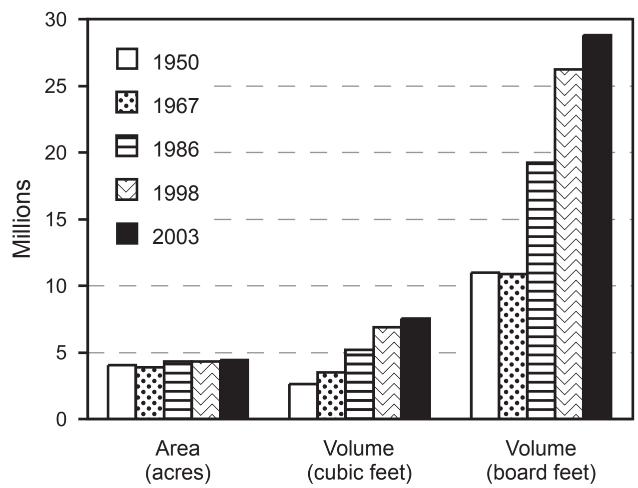

Figure 1—Timberland area and volume of growing stock by inventory year, 1950–2003, Indiana.

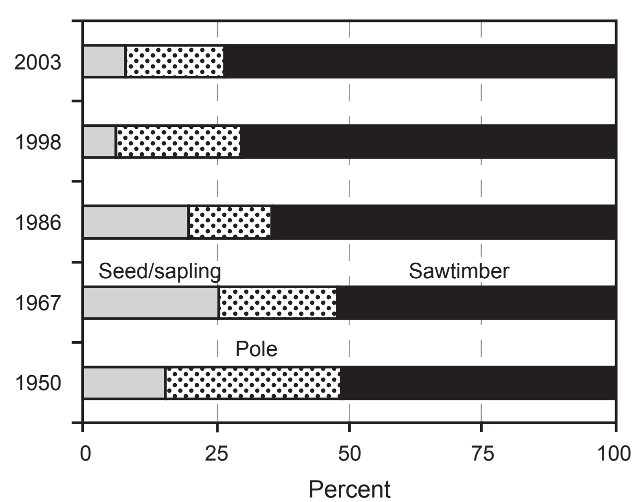

Figure 2—Area of timberland by stand size class, 1950–2003, Indiana.

These trends are indicative of a forest resource that is maturing and where disturbances to the main canopy are either infrequent or of low intensity (e.g. harvest by individual tree selection).

Over a period of 50 years, changes in area by forest cover type normally would be indicative of broad changes in species composition. However, changes in forest cover type definitions at subsequent inventory periods have limited our ability to track this variable over time. In the 1950 inventory, 44 percent of the forest area was classified as mixed hardwoods, a category that was not used in subsequent inventories. From 1968 to 1998 the area of oak-hickory forest decreased by 800,000 acres and the area of maple-beech forest increased by 900,000 acres, a trend that is indicative of a slow but persistent shift in forest composition (fig. 3). In 1998 the area of maple-beech forest exceeded the area of oak-hickory forest by more than 100,000 acres. But due to a change in the forest cover-typing algorithm associated with nation-wide standardization of inventory procedures, the 2003 inventory appears to show a 1 million acre increase in the oak-hickory cover type relative to 1998 and a corresponding 700,000 acre decrease in the maple-beech cover type. However, closer examination of individual species dynamics confirms that the changes in forest type between 1998 and 2003 are principally the result of changes in the forest cover type algorithms, not vast shifts in the forest species composition. This is borne out in the presentation of species composition by size class that follows.

The species composition of the seedling and sapling size classes is indicative of regeneration success in recent decades. In 2003, the proportion of oaks in the seedling and sapling size classes lagged well behind that of maple and beech (fig. 4). Even yellow-poplar, a shade intolerant species, is approximately as common in the small tree size classes as the entire white oak or red oak groups.

For pole-size and larger trees (≥ 5 inches d.b.h.), sugar maple still dominates with 11 percent of all trees (table 1), but they are small relative oaks and yellow-poplar. This is evident in the distribution of the corresponding volume by species (fig. 5) which gives greater weight to large trees. The largest diameter classes are still dominated by oaks. Moreover, in the 36 years between 1967 and 2003 there were gradual shifts in the number of trees by d.b.h. class (fig. 6). For trees less than 14 inches d.b.h., there was a notable decrease in the proportion of red and white oaks and a corresponding increase in the proportion of maples and beech. The proportion of yellow-poplars increased across all d.b.h. classes, undoubtedly due in part to its relatively rapid d.b.h. growth rate. Trees in the red and white oak groups still comprise 40 to 50 percent

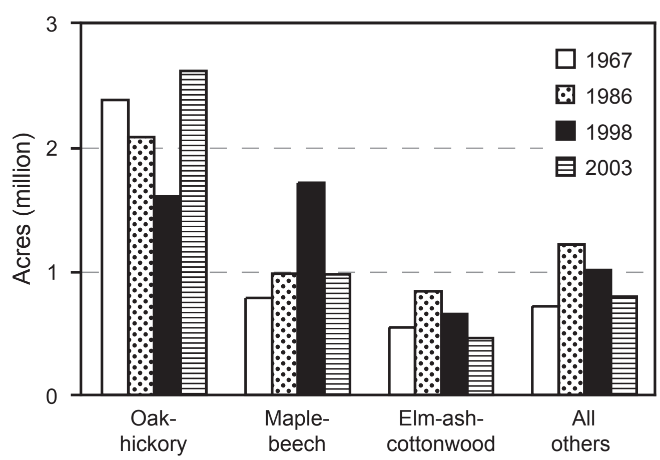

Figure 3—Area by forest-cover type, 1967–2003, Indiana. The dramatic changes in area by cover type between 1998 and 2003 are the result of changes in the forest-cover type definitions, and not due to a sudden reversal of long-term trends in oak-hickory and maple-beech forest-cover type area.

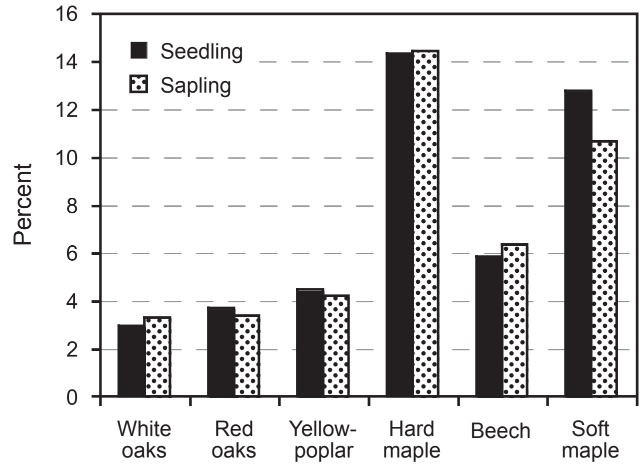

Figure 4—Relative abundance of seedlings and saplings by species group, 2003, Indiana.

Table 1—Relative frequency of growing-stock trees on timberland for trees 5 inches d.b.h. and larger. In 2003 there were an estimated 577 million such trees in Indiana (fifty-eight other species each occurred with a frequency of 1 percent or less)

Species and rank	Scientific name	Frequency	Cumulative frequency
		- - - - - - - percent	- - - - - - -
1. Sugar maple	*Acer saccharinum* Marsh.	11	11
2. Yellow-poplar	*Liriodendron tulipifera* L.	7	18
3. White ash	*Fraxinus americana* L.	6	23
4. White oak	*Quercus alba* L.	5	28
5. Black cherry	*Prunus serotina* Ehrh.	5	33
6. Sassafras	*Sassafras albidum* (Nutt.) Nees	4	37
7. American elm	*Ulmus americana* L.	4	41
8. Red maple	*Acer rubrum* L.	4	45
9. Black oak	*Q. velutina* Lam.	4	49
10. Eastern redcedar	*Juniperus virginiana* L.	4	52
11. Shagbark hickory	*Carya ovata* (Mill.) K. Koch	3	56
12. Black walnut	*Juglans nigra* L.	3	59
13. Pignut hickory	*C. glabra* (Mill.) Sweet	3	63
14. Northern red oak	*Q. rubra* L.	3	65
15. Silver maple	*A. saccharinum* L.	2	67
16. American beech	*Fagus grandifolia* Ehrh.	2	69
17. Slippery elm	*U. rubra* Muhl.	2	71
18. Green ash	*Fraxinus pennsylvanica* Marsh.	2	73
19. Bitternut hickory	*C. cordiformis* (Wangenh.) K. Koch	2	75
20. Hackberry	*Celtis occidentalis* L.	2	77
21. Sycamore	*Platanus occidentalis* L.	2	79

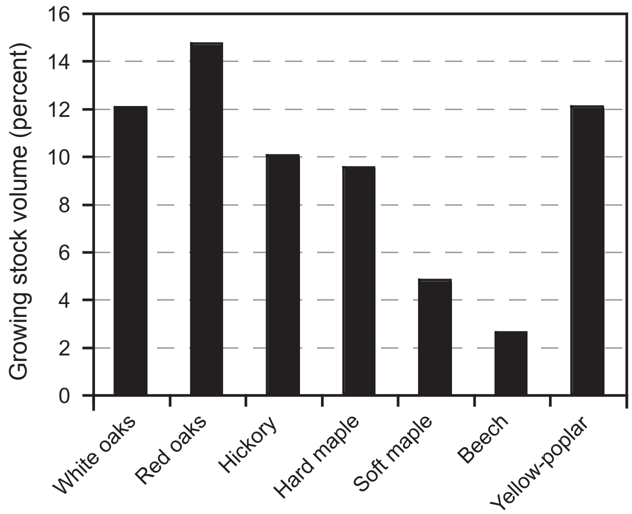

Figure 5—Percent growing-stock volume on timberland by species group, 2003, Indiana.

of all trees 25 inches d.b.h. and larger, but the temporal trend in figure 5 indicates that oak dominance in larger size classes will decrease over time as it already has for smaller trees.

Another way to gauge change in species composition over time is to plot the proportion of species by d.b.h. class in a line graph format (fig. 7A). In 1967 the proportion (or the total number) of red oaks and of number of white oaks each exceeded that of maple and beech for diameter classes larger than about eight inches d.b.h.. By 2003, the proportion of maples and beech increased in smaller d.b.h. classes and the point of intersection increased to approximately 13 inches d.b.h. (fig. 7B).

Shifts in the relative dominance of tree species are indicated by changes in volume over the last 17 years. Although white oak volume increased by 100 million cubic feet between 1986 and 2003, and red oak increased by 300 million cubic feet, yellow-poplar and sugar maple had the greater percentage increases in volume (fig. 8).

This shift in species composition and volume is caused in part to long-term patterns of disturbance and regeneration that favor maples and beech regeneration more than oaks. Removals play a role in this dynamic. In the 1986, 1998, and 2003 inventories, the rate of removals as a percent of growth for the red and white oak groups was nearly double that reported for sugar maple and beech. The proportion of removals for the white oak group ranged from 51 to 127 percent of white oak net growth (i.e., growth adjusted for mortality but prior to removals). Although in absolute terms the average annual removals of maple and beech increased from 16 million to 50 million cubic feet from 1986 to 2003, the rate of removals as a proportion of the rapidly increasing net growth for those species decreased from 39 to 24 percent.

The pulse of oaks that have increased in size and age to dominate much of the overstory of Indiana's forests will continue on as snags and eventually as down wood. About 1 in 8 snags (12 percent) is an oak (fig. 9). But due to the relatively large size of the oaks, they constitute an even greater proportion of large snags and of total snag volume. Oaks currently constitute about 9 percent of down coarse woody debris volume (fig. 10), a percentage that is likely to increase in coming decades as large oaks (live and snags) fall to the forest floor. A huge volume of oak biomass will eventually reach the forest floor and dominate that component of the forest ecosystem in much the same way oaks have dominated the forest overstory for decades.

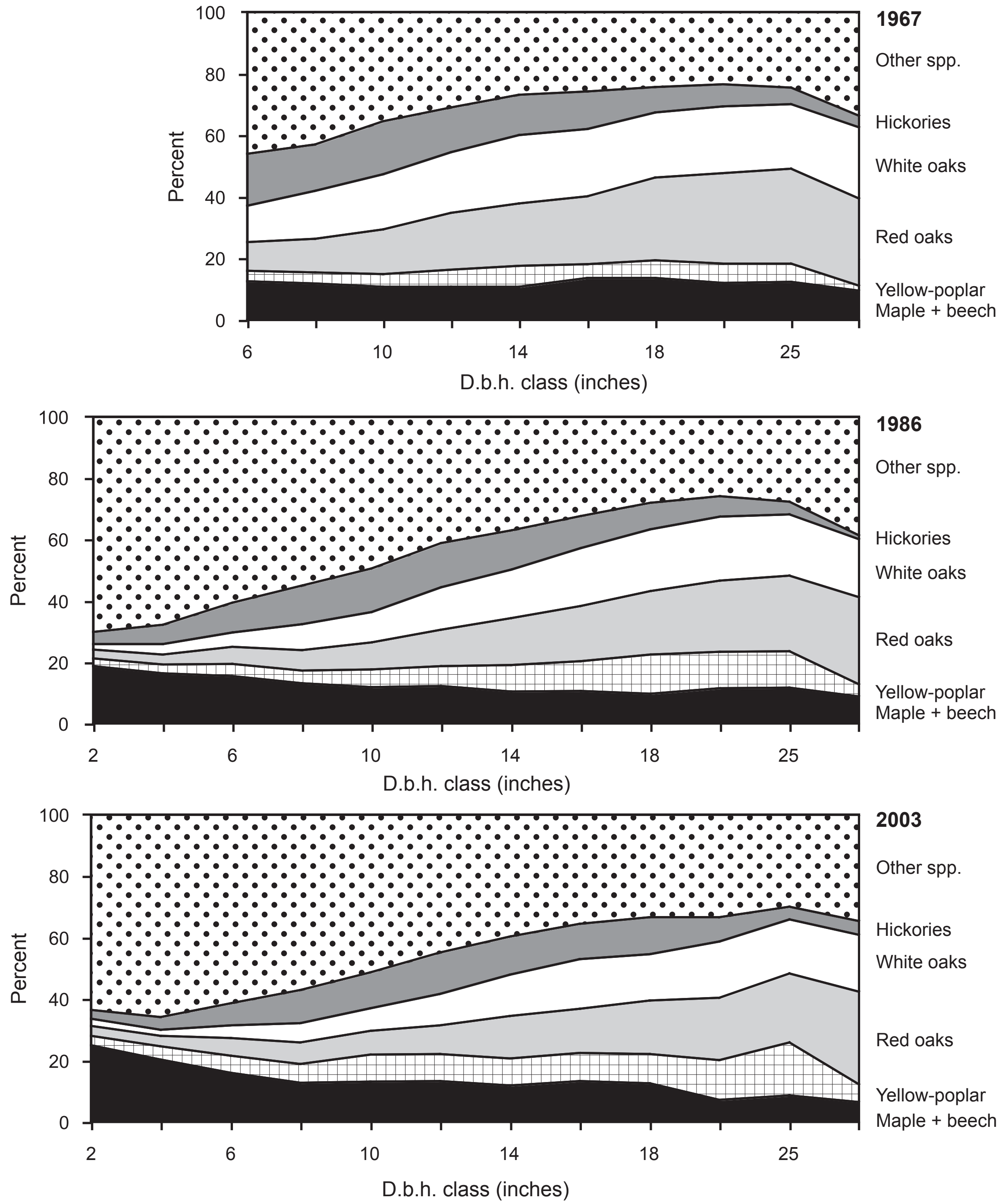

Figure 6—Proportion of growing-stock trees on timberland by diameter class, 1967, 1986, and 2003, Indiana. For this figure the maple group is comprised of sugar and black maples.

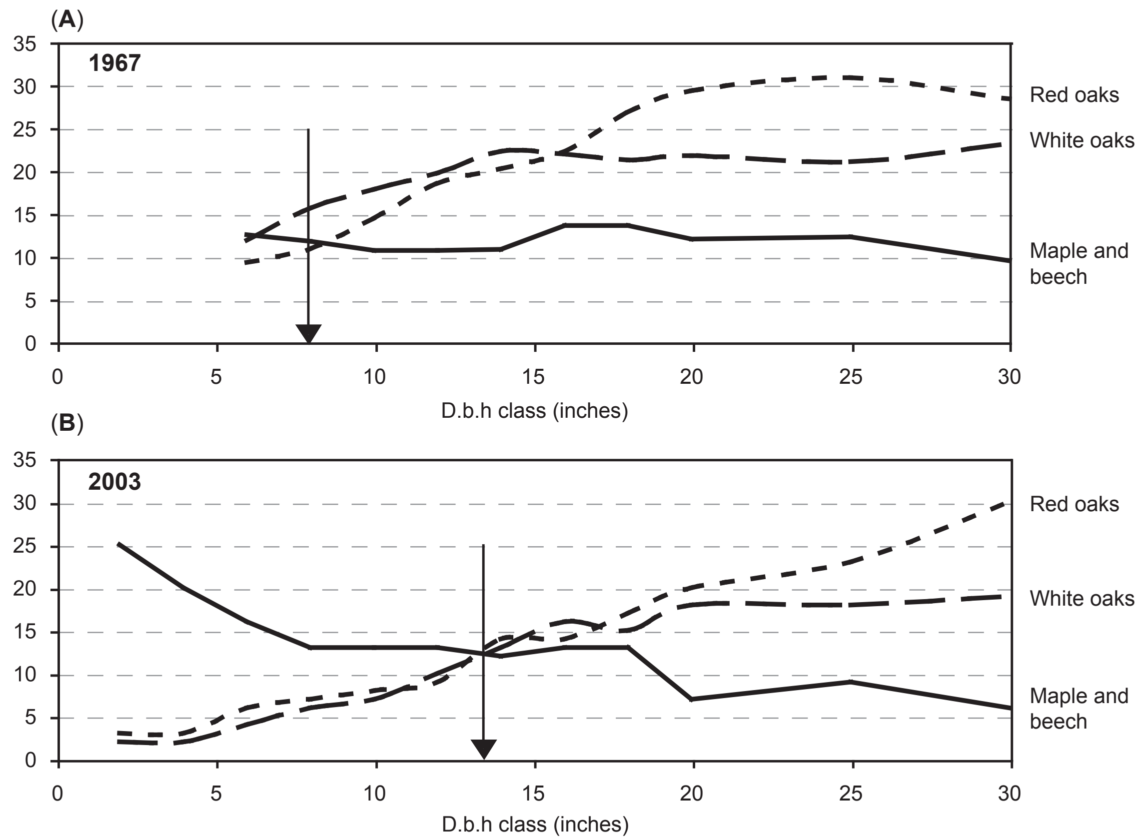

Figure 7—Changes in the size distribution of trees in the red oak, white oak, and maple-beech species groups, 1967 (A) to 2003 (B), Indiana. For this figure the maple group is comprised of sugar and black maples.

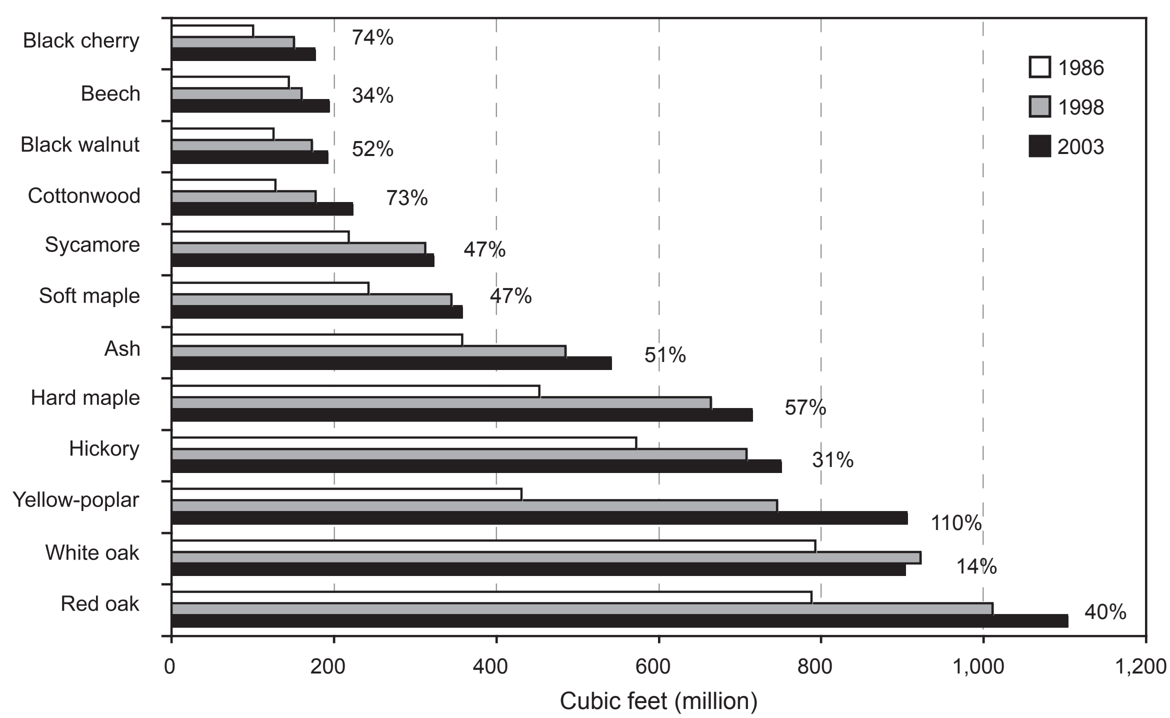

Figure 8—Net volume by species or species group, 1986–2003. The percentages shown on the graph indicate percent increase in volume from 1986 to 2003, Indiana.

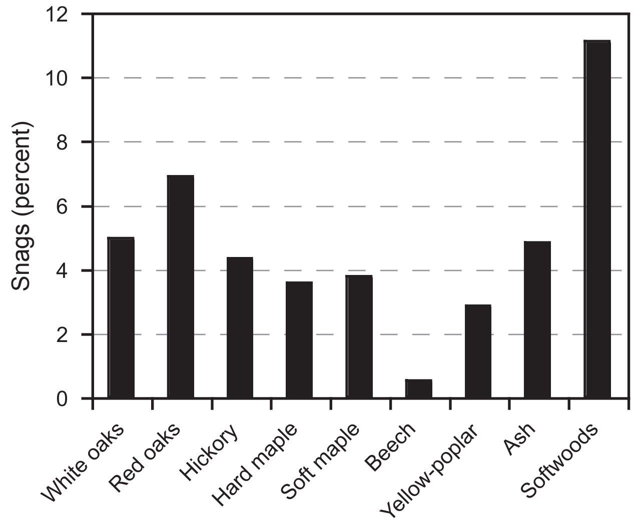

Figure 9—Proportion of snags (standing dead trees) by species group for growing stock trees, 2003, Indiana. The ash group includes all *Fraxinus* spp. No other individual species exceeded 2 percent, but all other species combined accounted for 57 percent of snags.

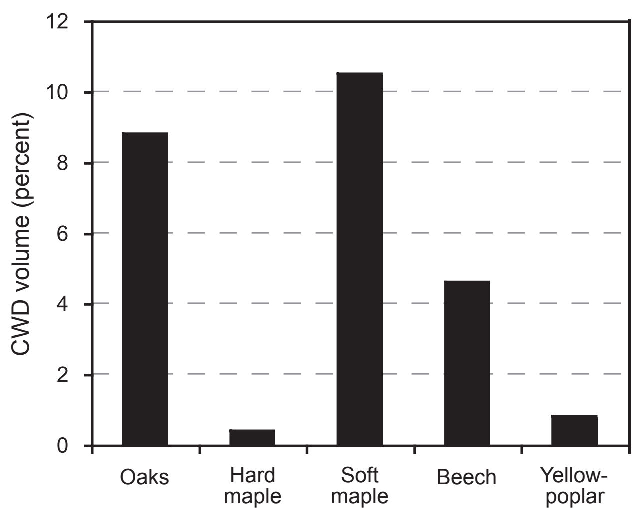

Figure 10—Proportion of coarse woody debris volume by species group, 2003, Indiana.

CONCLUSIONS

Forest disturbance patterns in Indiana 60 to 100 years ago created a pulse of oak regeneration that is gradually increasing in size and age. Over the past 50 years oaks have dominated the overstory in the majority of Indiana's upland forests. Those maturing oaks are increasingly being replaced by a newer pulse of maple, beech, yellow-poplar, and other mesophytes. Oak dominance in live trees will decline in coming decades and the oak biomass will dominate the snag and coarse woody debris components of the ecosystem. Change in tree species composition is a slow process. The current forest species composition and size structure was 50 to 100 years in the making and was the product of large-scale ecosystem disturbances. These, current trends will take decades to alter, if that is deemed desirable.

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SITE CLASSIFICATION

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Daniel Cassidy
University of Georgia

ECOSYSTEM CLASSIFICATION AND SUCCESSION IN THE CENTRAL TILL PLAIN OF INDIANA

Benjamin J. Dolan and George R. Parker[1]

Abstract—Successional trends at a site level scale in the Bluffton Till Plain of Indiana were studied using an ecological classification system (ECS) as a framework to determine whether the current and potential future overstory canopies of several ecological land type phases (ELTP) differed from one another. The Bluffton Till Plain ECS stratifies the subsection into 3 ecological landtypes (ELT) and 12 ecological landtype phases. However, forest canopy composition and successional changes can best be described with three separate groups: (1) mesic upland swells and slopes, (2) upland despressions, and (3) bottomlands. Potential future composition was inferred from midstory communities, assuming no large-scale disturbance would occur. Mesic upland and hill slope sites, which were currently dominated by *Quercus* and *Carya* species, will eventually become dominated by *Acer saccharum* based on its dominance in the midstory. Wet depressional sites on the till plain were currently dominated by *Quercus macrocarpa* and *Quercus bicolor*, but these species were absent from the understory. *Ulmus americana* was the most abundant midstory species at these sites, but *Acer saccharinum* was more likely to become the dominant overstory species because of pathogens restricting the growth of *Ulmus* sp. Bottomland forests were comprised of mixed species communities, with *Acer saccharum* dominant in the understory of mesic sites, but absent from annually flooded sites, where *Acer saccharinum* was dominant. In the absence of future disturbances, *Acer saccharum* is expected to become the dominant woody species in all but the wettest sites of the Bluffton Till Plain.

INTRODUCTION

The Bluffton Till Plain Subsection, within the broader Central Till Plain Section, is typically viewed as having a uniform *Acer-Fagus* climax community throughout its extent, although various successional stages have been described, including oak-hickory forests (Braun 1950). Part of this accepted understanding comes from the relatively homogeneous landscape, which is comprised of a relatively flat till plain with minor changes in elevation derived from glacial moraines and eskers (Schneider 1966). At the regional scale, the uniform topography precludes large compositional differences usually found in topographically diverse regions where differences in slope aspect and position result in varied moisture regimes (Abella and others 2003; Carter and others 1999, 2002; Hutto and others 1999; McNab and others 1999; Hix and Pearcy 1997; Van Kley 1993; Spies and Barnes 1985).

Acer-Fagus forests are typically described as having overstory canopies comprised of at least 50 percent *Fagus grandifolia* Ehrh. and *Acer saccharum* Marsh., while the remaining species are varied and randomly distributed throughout the canopy (Lindsey and others 1965, Petty and Jackson 1966). And though *Quercus-Carya* forests are found within the region, they are typically described as long-term, transitional phases that will eventually succeed to *Acer-Fagus* dominance (Petty and Jackson 1966). Recent evidence suggests that the spatial scale at which the *Acer-Fagus* forest association is used does not capture the variety of successional pathways that may occur within forests of the Bluffton and Central Till Plains. Most studies addressing succession have focused on midstory composition at entire stand levels, where *Acer saccharum* is wide-spread; yet study at finer scales has shown that at the site level, this species, along with other late-successional species, develops a patchy distribution potentially corresponding to site conditions (Aldrich and others 2004, Ward and Parker 1989, Parker and others 1985).

A newly developed ecological classification system (ECS) of the Bluffton Till Plain Subsection allows study of successional trends at the site level, by relating sites with similar environmental conditions determined

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through physiography and soil differences (Dolan and Parker 2005). The Bluffton Till Plain ECS, based on the USDA Forest Service Hierarchy of Ecosystem Units (Cleland and others 1997), stratifies the subsection into 3 ecological landtypes (ELT) and 12 ecological landtype phases (ELTP). The ELTP represents site level differences, while the ELT more closely approximates stand level differences. The ECS classifies sites at the ELT level into slopes, upland till plain, and bottomlands (table 1). These ELTs are further divided into more specific ELTPs, for which the current overstory canopies are described. Future overstory composition based on midstory species abundance has not been completely demonstrated.

The goal of this study was to determine whether successional trends differ among sites using the Bluffton Till Plain ECS to identify site conditions and stratify the landscape. The succession of species is inferred from the composition of midstory communities, a method used by Peet and Loucks (1977), and followed by Host and others (1987) and Van Kley (1993), among others. It was hypothesized that evidence of late-successional species aggregation and thus potential overstory community differences across the *Acer-Fagus* complex would be detected at the ELTP level.

METHODS

Study Area

This research was concentrated in the Bluffton Till Plain Subsection of east-central Indiana (fig. 1). The broader Central Till Plain Section, including the Bluffton Till Plain Subsection, is formed of Wisonsinan till (Homoya and others 1984). Although topographically homogenous, it is divided into three subsections,

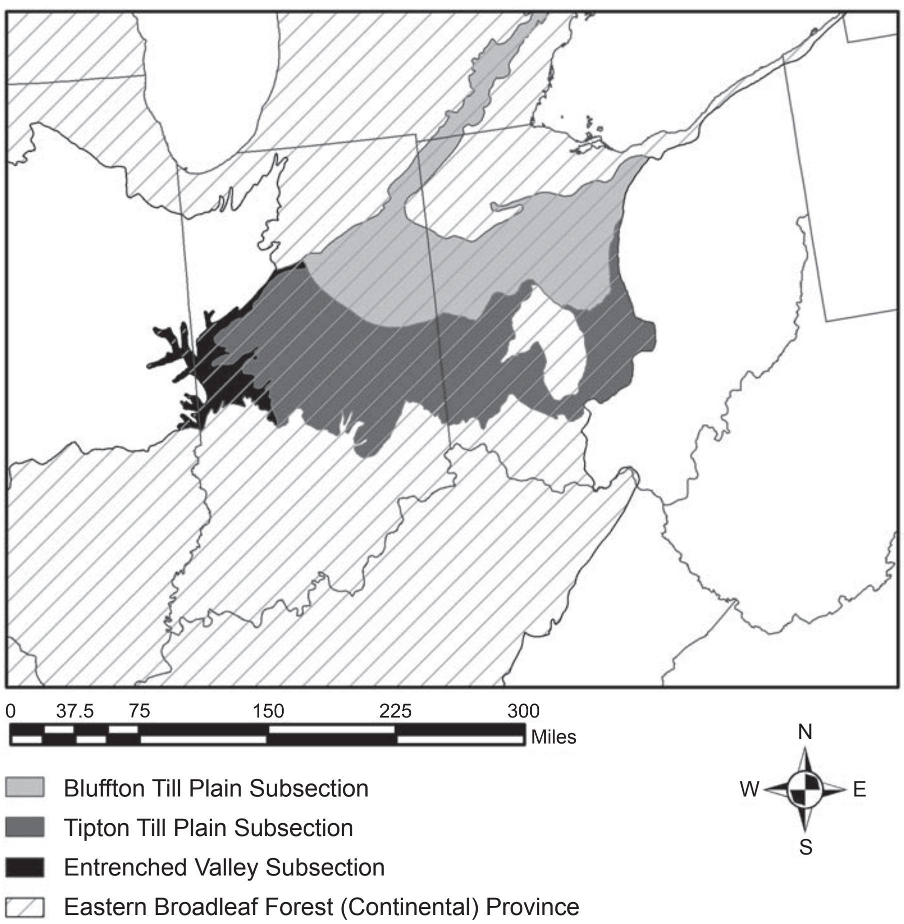

Figure 1—Central Till Plains Section of the Eastern Broadleaf Forest (Continental) Province. Research was concentrated in the western portion of Bluffton Till Plain Subsection, located in east-central Indiana.

Table 1—Ecological classification system of the Bluffton Till Plain Subsection, Central Till Plain section of Indiana

ELT	ELTP	Short name	Landscape position	Drain	Surface horizon textures	Diagnostic soil features
1	1	Mesic slope	Slopes ~42-50% Length: 29-34 m	W	Loam	Calcareous depth: 61-84 cm E-horizon depth: 3-6 cm
1	2	Mesic slope (eroded)	Short slopes ~40-60% Length: 18-26 m	W	Loam	Calcareous depth: 23-39 cm E-horizon depth: 5-13 cm
1	3	Mesic upper slope	Convex slopes ~28-40% Length: 23-30 m	MW	Silt loam to sandy loam	Calcareous depth: 58-102 cm E-horizon depth: 6-10 cm
2	4	MW drained mesic upland swell	Upland swells ~42-48 m to nearest depression	MW to SP	Silt loam	A-horizon: 12-14 cm deep E-horizon: ~20 cm wide Calcareous: 81 cm
2	5	SP drained mesic upland swell	Upland swells ~36-38 m to nearest depression	SP	Silt loam	A-horizon: 13-16 cm deep E-horizon: ~12-15 cm wide Calcareous: 65-73 cm
2	6	Wet-mesic upland	Transition between swell and swale 17-22 m to swell or swale	SP	Silt loam to silty clay loam	A-horizon: 19-25 cm deep E-horizon: ~0-7 cm wide Calcareous: 96-124 cm
2	7	Upland depression	Upland depressions ~37-44 m to nearest swell	P	Clay loam	A-horizon: 17-21 cm deep No E-horizon B-horizon texture: clay Calcareous: > 145 cm
2	8	Flooded upland depression	Upland depressions; permanently or ephemerally flooded	P to VP	Clay loam	A-horizon: 15-20 cm deep No E-horizon B-horizon texture: clay Calcareous: > 145 cm
3	9	Small stream bottom	Small stream bottoms and toeslopes	W to SP	Loam to sandy loam	A-horizon: 16-24 cm deep E-horizon: coarse textures only Calcareous: 78-134 cm
3	10	Mesic bottomland	Large stream and river bottoms ~50 m from stream	W	Loam to sandy loam	A-horizon: 33-50 cm deep No E-horizon
3	11	Adjacent bottomland	Large stream and river bottoms; adjacent to stream	W	Loam, silty clay loam, and sandy loam	A-horizon: 15-18 cm deep No E-horizon

ELT = ecological landtypes; ELTP = ecological landtype phases; W = well-drained; MW = moderately well-drained; SP = somewhat poorly-drained; P = poorly drained; VP = very poorly drained.

differentiated by soil texture and physiography. The Bluffton Till Plain Subsection, which encompasses the northeastern one-third of Indiana's Central Till Plain, differs from the other subsections because of its clayey soil texture and slow water percolation (Homoya and others 1984, Keys and others 1998). The soils of the region are poorly drained clay loams of the Blount-Pewamo and Morley-Blount-Pewamo Associations (Indiana Soil Survey Staff 1982). Loamy soils of the Fox-Genessee-Eel Association are found in the floodplains of major rivers (Indiana Soil Survey Staff 1982).

The Bluffton Till Plain was entirely forested prior to European settlement (Gordon 1936), but is now highly fragmented because of clearing for agricultural production. And though forest cover has been increasing across Indiana, forest cover of the Bluffton Till Plain remains at approximately 8.5 percent (Schmidt and others 2000). Typically, the remaining forests are limited to distinct woodlots, previously left on the landscape as sources of fuelwood or as a consequence of poor agricultural conditions.

Site Selection

Fifty three sites were located within mature and undisturbed woodlands across the subsection within Indiana and western Ohio. Forest were determined to be mature and undisturbed if they had closed canopies with saw-timber sized trees, and relatively open understories and no signs or known history of disturbance from logging or land clearing. Forest smaller than 15 acres (6 ha) were not sampled to reduce edge effects.

Landscape Stratification

Data for this analysis was collected concurrently with data used to create the Bluffton Till Plain ECS (Dolan and Parker 2005). As such, a preliminary physiographic classification was constructed following guidelines established by Bailey (1996) and Barnes and others (1982). The classification was based upon landform components typical of upland till plains, including convex swells and concave depressions. Additionally, hill slope and floodplain components were incorporated to capture the various ecosystems located along the till plain escarpment and the bottomlands of major and minor streams of the Bluffton Till Plain. The preliminary classification was used to stratify each forest and select sample sites that displayed representative characteristics of the forest. Each observed landform component was sampled with at least two replicates in each forest. Data from the 2003 field season were then used to construct an ecological classification, incorporating information from herbaceous plant species, physiographic location, and soil conditions. Data collected during the 2002 field season were subsequently classified according to the ECS. All sample sites classified according to the ECS were used in the current study to explore succession through differences in overstory and midstory composition.

Sampling

Data collection began in late May and ran through early August during the 2002 and 2003 summer field seasons. Sampling was completed by the end of the first week in August each year. Several physiographic landforms were sampled in each of the woodlands using a pair of 10 x 15 m subplots. Subplots were located adjacent to each other in an orientation that best captured the landform. Typically, subplots on the upland till plain were oriented to create a 15 x 20 m plot, while subplots along hill slopes and along rivers or creeks were oriented to create a 10 x 30 m plot that followed the slope contour.

Trees greater than 5 cm diameter at breast height (dbh) were identified by species and measured to the nearest 0.1 cm dbh within each 10 x 15 m subplot. Abiotic factors, including soil and physiographic characteristics, were also sampled in order to classy sites by ecological landtype.

Data Preparation

Plots were removed from the data set if the pair of subplots were classified in different ELTPs, or they represented a transition between ELTPs. Subplot data were then summed to provide plot level data. Canopy trees greater than 5 cm dbh were partitioned into two layers: overstory trees with diameters greater than or equal to 15 cm, and midstory trees with diameters between 5 cm and 15 cm. Basal area and density of the overstory and midstory species were calculated and converted to per hectare values.

Basal area and density were then used to calculate the following values for the overstory and midstory layers:

Relative Density (RD): The density of each species within a plot divided by the total density of all species in the plot.
Relative Basal Area (RBA): The basal area of each species within a plot divided by the total basal area of all species in the plot.
Importance Value (IV): (RD+RBA)/2

Data Analysis

Differences between the density of overstory and midstory species at the ELTP level were compared using pairwise Multiple Response Permutation Procedures (MRPP). MRPP is a nonparametric, multivariate procedure used to test the null hypothesis of no difference between two groups. Because MRPP is nonparametric, it does not require distributional assumptions; however, sample units must be independent. The test provides a measure of group separation with a significance value, much like a parametric T-test. A matrix was constructed to summarize the results of pairwise comparisons for the each of the two layers, but only significant differences are presented. A Bonferonni corrected p-value was used to determine whether significant differences existed between ELTPs. An experiment-wise alpha level of 0.15 was used to maintain statistical power, as suggested by Chandler (1995).

Successional trends were determined within each ELTP by comparing the species' IVs between the overstory and midstory layers. The differences between mean IVs of each species were tested using non-parametric Mann-Whitney U tests. Post-hoc pairwise comparisons of statistically different means were completed with Duncan's multiple range tests on ranked data.

RESULTS AND DISCUSSION

Plots were classified into the Bluffton Till Plain according to their vegetation, soil, and physiographic characteristics. The composition of woody species in the 11 ELTPs can be grouped into 3 main categories to describe successional trends: mesic upland plains and slopes, upland depressions, and bottomlands. The overstory canopy of the mesic upland plains and slopes, ELTPs 1-6, had similar subcanopy compositions with no statistically significant differences based on MRPP comparisons (table 2). Within each of these

Table 2—Matrix of p-values from the pairwise MRPP analyis of midstory and overstory communities[a]

ELTP	1	2	3	4	5	6	7	8	9	10	11
1		0.265	0.408	0.187	0.193	0.039	0.021	**0.000**	**0.002**	0.290	**0.000**
2	0.007		0.683	0.120	0.269	0.125	0.004	**0.000**	**0.001**	0.084	**0.000**
3	0.048	0.593		0.415	0.483	0.065	0.012	**0.000**	**0.002**	0.100	**0.000**
4	0.006	0.282	0.402		0.390	0.006	0.003	**0.000**	**0.000**	0.064	**0.000**
5	**0.003**	0.497	0.713	0.970		0.117	0.048	**0.000**	**0.000**	0.192	**0.000**
6	0.004	0.090	0.568	0.082	0.097		0.249	**0.000**	**0.003**	0.250	**0.000**
7	0.040	0.005	0.085	0.014	0.008	0.758		**0.000**	0.052	0.392	**0.000**
8	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**		**0.000**	**0.001**	**0.000**
9	0.019	**0.000**	0.011	**0.000**	**0.000**	0.023	0.147	**0.001**		0.062	0.238
10	0.013	**0.000**	**0.002**	**0.000**	**0.000**	**0.002**	0.009	**0.001**	0.300		0.013
11	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.294	0.072	

MRPP = Multiresponse Permutation Procedures; ELTP = ecological landtype phases.
[a] Bold values indicate statistically significant differences between a pair of plant communities. Midstory comparisons are presented in the upper right half of the matrix, and overstory comparisons are in the lower left half.

ELTPs, the importance of *Acer saccharum* was significantly higher in the midstory layer than in the overstory layer (table 3). The importance of early successional species such as *Quercus alba* L., *Quercus rubra* L., and *Carya* Nutt. was generally smaller in the midstory, with the overstory canopy having a significantly higher IV in most cases across the six ELTPs. The difference between the overstory IVs and midstory IVs was statistically significant for *Acer saccharum*, *Quercus alba*, and *Quercus rubra* for all six ELTPs, indicating a potential change in future overstory composition as early successional species are replaced by *Acer saccharum* in these mesic sites.

The exception to this shift in species composition is ELTP 1. The mesic slopes of ELTP 1 had an overstory currently dominated by *Acer saccharum* and *Fagus grandifolia*. The number of early successional species was low in the overstory, while *Acer saccharum* and *Fagus grandifolia* remained dominant in the midstory layer. Both of these species appeared to have the ability to retain dominance in this ELTP, indicating no future shift in species composition.

Fagus grandifolia was not a major component of the midstory of the other mesic upland ELTPs, although its dominance tended to be higher than that of the early successional species such as *Quercus* and *Carya* spp. Braun (1950) suggested that *F. grandifolia* may become more dominant after an initial period of dominance by *Acer saccharum*, citing a compositionally similar forest of the adjacent Tipton Till Plain (Freisner and Ek 1944), though much of the future relationship between importance of *Acer saccharum* and *Fagus grandifolia* may depend on changes in tree fall gaps (Poulson and Platt 1996). Regardless, the successional trends of the mesic upland plain and slope ELTPs tended to conform to the *Acer-Fagus* community described by Braun (1950).

Additional supporting evidence of this trend in the Bluffton Till Plain can be found in an intensively studied old-growth woodland in the southwest corner of the subsection, where species composition has had a moderate increase in the density of *Fagus grandifolia* from 1926-1986 (Aldrich and others 2003). This suggests that, although not dominant, Fagus grandifolia is a growing component of the forest. It has been estimated that by 2070, this particular old-growth forest will be dominated by both *Fagus grandifolia* and *Acer saccharum* (Spetich 1995), with other forests of the Central Hardwood Region following similar patterns based on subcanopy compositions (Rubino and McCarthy 2003, Shotola and others 1992). The mesic upland forests of the Bluffton Till Plain are no exception, and with no major disturbance, mesic upland forests studied for this research will eventually have overstory compositions dominated by *Acer saccharum* and *Fagus grandifolia*.

In contrast to mesic sites, depressional sites of the upland till plain, ELTPs 7 and 8, were comprised of different species, although succession followed a similar path from *Quercus* dominance to *Acer* dominance. *Quercus* species, particularly *Q. bicolor* Willd. and *Q. macrocarpa* Michx., were dominant in the overstory of ELTPs 7 and 8, while the midstory was more variable with compositional differences between the two ELTPs (table 3). Neither the overstory nor midstory of ELTP 7 was compositionally different from the mesic uplands and slopes based on the MRPP analysis, but both were significantly different for ELTP 8 (table 2). The midstory composition of ELTP 7 resembled the midstory of the mesic upland sites with *Acer saccharum* dominating, while the midstory of ELTP 8 was dominated by *Ulmus americana* L. Although *Ulmus americana* has been restricted to the subcanopy because of Dutch elm disease and phloem necrosis; it has been suggested that because it can reproduce in large numbers, it may eventually develop its own resistance to the diseases (Parker and Leopold 1983). It is impossible to determine from this study whether this will happen. Nonetheless, *Ulmus americana* was a significantly more dominant midstory species, and its dominance will likely affect successional changes in the flooded depressions. Eventually succession may lead to overstory dominance by the second most important species in this ELTP, *Acer saccharinum* L., as larger *Quercus* species senesce. Succession in the upland depressions may be slowed by competition from structurally limited *Ulmus americana*.

Table 3—Average indicator value of selected species for the midstory and overstory in each of the ELTPs

Species	ELTP 1		ELTP 2		ELTP 3		ELTP 4		ELTP 5		ELTP 6		ELTP 7		ELTP 8		ELTP 9		ELTP 10		ELTP 11	
	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr	Mid	Ovr
Acer negundo	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	16	3	0	1	21	22
A. rubrum	0	0	0	0	3	1	1	1	0	1	0	0	1	1	5	4	0	0	0	0	0	0
A. saccharum	**48**	**26**	**53**	**15**	**57**	**17**	**64**	**21**	**53**	**16**	**41**	**14**	**32**	**15**	2	2	18	5	**37**	**4**	6	3
A. saccharinum	0	0	0	0	0	0	0	0	0	0	0	0	3	3	13	19	0	0	0	0	5	7
A. glabra	5	2	3	0	1	0	0	1	1	1	7	1	**5**	**1**	0	1	**20**	**1**	2	2	16	4
Carpinus caroliniana	0	0	1	0	1	0	0	0	0	0	5	0	**12**	**0**	0	0	7	1	2	0	0	0
C. cordiforis	**0**	**5**	1	0	1	5	0	1	1	1	**0**	**6**	3	3	0	0	3	7	1	0	0	0
C. glabra	0	2	0	3	**0**	**6**	2	4	3	9	1	2	1	2	0	2	0	0	0	0	0	0
C. ovata	0	1	5	4	3	6	**0**	**9**	3	6	4	13	**1**	**9**	2	5	1	0	0	1	1	0
C. occidentalis	0	3	0	0	2	3	0	0	0	1	1	2	3	1	0	0	12	13	0	1	7	13
Fagus grandifolia	9	14	0	5	3	2	9	7	5	3	1	2	5	4	0	1	4	1	1	0	0	1
F. americana	0	0	2	4	0	2	**0**	**5**	0	4	0	5	0	3	0	1	0	0	0	0	0	0
F. pennsylvanica	2	0	0	1	0	2	0	2	0	0	**0**	**4**	1	6	3	5	0	4	0	1	1	4
F. quadrangulata	2	1	1	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0
Juglans nigra	**0**	**3**	0	1	0	2	0	0	0	1	**0**	**5**	0	3	0	0	0	18	0	3	1	4
Liriodendron tulipifera	**0**	**5**	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	4	9	25	0	2
Ostrya virginiana	**13**	**1**	22	3	**16**	**0**	10	0	**10**	**0**	**14**	**1**	3	0	0	0	0	0	4	0	1	0
Platanus occidentalis	0	0	0	3	0	1	0	0	0	0	0	1	0	0	0	0	0	6	**0**	**10**	**0**	**15**
Populus deltoides	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	1	0	2	0	7	0	6
Prunus serotina	2	1	0	2	4	4	2	2	6	5	1	1	3	0	1	0	0	0	2	0	1	0
Quercus alba	**0**	**7**	**0**	**20**	**0**	**11**	**0**	**21**	**1**	**23**	**0**	**10**	**0**	**5**	0	2	0	0	0	0	0	1
Q. bicolor	1	0	0	0	0	0	0	2	0	0	**0**	**2**	**0**	**2**	**1**	**22**	0	0	0	0	0	1
Q. macrocarpa	0	0	0	1	0	0	0	0	0	0	**0**	**2**	0	11	**0**	**10**	0	4	0	4	0	1
Q. rubra	**2**	**8**	**2**	**22**	**1**	**22**	**0**	**15**	**1**	**17**	**0**	**14**	4	10	0	4	0	3	0	3	0	0
Tilia americana	2	4	**1**	**10**	3	7	3	2	1	3	5	5	2	6	5	0	0	4	0	0	3	2
Ulmus americana	6	5	3	2	2	1	7	1	12	3	**13**	**2**	18	6	**56**	**9**	16	12	25	14	28	7
U. rubra	**0**	**2**	0	1	0	0	1	0	0	0	2	1	1	3	0	0	1	2	2	1	1	0

Mid = midstory; Ovr = overstory; ELTP = ecological landtype phases.
[a] Bold values indicate significantly different means ($p < 0.05$) for Mann-Whitney U tests comparing midstory and overstory IVs within an ELTP.

The differences between successional pathways of the depressional sites of ELTP 7 and ELTP 8 reflect how the composition of species is affected by microenvironment and competition for resources (Beatty 1984). The difference in flooding regime of these two ELTPs affects composition by excluding *Acer saccharum* only on the wettest sites of ELTP 8. Although this is not a new finding, it has implications for the generalized composition of forests across the Bluffton Till Plain subsection, which is typically characterized by the dominance of *Fagus grandifolia* and *Acer saccharum* in the late seral forest community. Though ecological landtype phases have not yet been mapped for the Bluffton Till Plain, soil surveys suggest that Pewamo soils, which are strongly correlated to ELTP 8 (Dolan and Parker 2005), account for approximately 28 percent of the upland ELT (Indiana Soil Survey Staff 1982). Thus the Bluffton Till Plain may have a larger component of wetter site species, like *Acer saccharinum* and *Ulmus americana*, than the *Fagus grandifolia-Acer saccharum* complex would suggest, should the region be covered by contiguous forest.

In addition to *Acer saccharinum*, *Ulmus americana* was prolific and dominated the subcanopy of ELTP 8, though its dominance in any ELTP is doubtful at this point as a consequence of Dutch elm disease and phloem necrosis. Yet the reintroduction of a resistant elm, either through scientific or natural processes, is not impossible. Naturally occurring, disease tolerant individuals have been identified and propagated for nursery use, and genetically improved species have also been developed. As these tolerant varieties are planted across the region, it is possible for them to spread into the native forests, establishing a strong component of future overstory trees. Suitable out-planting sites should include those where elm is currently a dominant midstory species, as in ELTPs 7 and 8.

The third category of successional trends, the bottomland ELTPs (ELTP 9-11), had overstory canopy compositions that were more variable than those of the upland sites, with no single species dominating any ELTP (table 3). Results of the MRPP show that the overstory composition of these sites were significantly different from the upland sites, and that ELTPs 9 and 11 had significantly different midstory compositions. The overstory of ELTP 9 was composed of mesic site species, including *Ulmus americana*, *Celtis occidentalis* L., *Juglans nigra* L., and *Carya cordiformis* (Wangenh.) K. Koch, with minor components of *Quercus rubra*, *Quercus macrocarpa*, *Liriodendron tulipifera* L., and *Acer saccharum*. ELTP 10 was comprised of many of the same species, but had a much greater proportion of *Liriodendron tulipifera*, and more *Populus deltoids* Bartr. ex Marsh. ELTP 11, on the other hand, had a typical riparian community composed of *Acer negundo* L., *Acer saccharinum*, *Aesculus glabra* Willd., *Celtis occidentalis*, *Juglans nigra*, *Populus deltoides*, and *Ulmus americana*.

Though the overstory canopy of the bottomland ELTPs presented a variety of species compositions, the midstory canopies were more similar, especially those of ELTP 9 and 11. Co-dominant species common to both ELTPs included *Ulmus americana*, *Aesculus glabra*, *Acer negundo*, and *Celtis occidentalis*. Additionally, ELTP 9 had a large component of *Acer saccharum* in the midstory. Because *Acer saccharum* does not tolerate flooding (White 1973), it is unlikely to become a major component of bottomland overstory canopy. Thus the mixed canopy will likely remain in these bottomland ELTPs.

The third bottomland community, ELTP 10, differed from ELTPs 9 and 11 because of the large proportion of *Acer saccharum* in the midstory. Although ELTP 10 is susceptible to flooding, it is generally less prone because of the greater distance to a river or stream (Dolan and Parker 2005). The midstory of ELTP 10 most closely resembled that of upland depression ELTP 7, with *Acer saccharum* and *Ulmus americana* dominanting. ELTP 10 differed in its abundance of *Liriodendron tulipifera* in the subcanopy and seedling layers.

CONCLUSION

Forest canopy composition and successional changes can best be described with three separate groups: (1) mesic upland swells and slopes, (2) upland depressions, and (3) bottomlands. The overstory composition of the mesic upland swells and slopes are expected to become more similar as succession leads to canopies dominated by *Acer saccharum*, a common pattern within mesic forests of the Eastern Broadleaf Forest Province (Rubino and McCarthy 2003, Van Kley 1993, Hix and Pearcy 1997, Spetich and Parker 1998). Bottomlands and upland depressions of the Bluffton Till Plain are expected to remain compositionally separate through succession, largely as a result of wetter conditions that exclude mesic species such as *Acer saccharum* and *Fagus grandifolia*.

This research provides baseline data for potential natural vegetation in the absence of major disturbance. The response of vegetation to disturbances such as fire and harvesting within ELTs and ELTPs need to be further investigated.

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FOREST CONSERVATION IN THE CUMBERLAND PLATEAU AND MOUNTAINS: ASSESSING DISTRIBUTION AND STRUCTURE OF LANDFORM FOREST ASSOCIATIONS

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Abstract—Mixed mesophytic forests within the Cumberland Plateau and Mountains in Tennessee and Kentucky are among the most diverse in North America; however, these forests have been impacted by changes in land use. To define future ecological conditions for this region, current and potential forest land cover and stand structure are compared using remote sensing imagery and descriptions of remnant and historical forest associations. While potential forest cover was greater than current natural forest cover across all landform forest associations, the upland deciduous forests in the Plateau were reduced to less than half of their potential. Across all natural forest-cover classes, fewer large forest patches were found under current conditions than in the projection of potential forest cover. Upland deciduous forests in the Plateau, along with mesic deciduous forests in the Mountains and Plateau regions of the Northern Cumberlands Project Area, possess younger stands with smaller trees than observed from indicators of old-growth condition.

INTRODUCTION

Landscape ecology provides a new paradigm for conservation management with its inherent recognition of the importance of spatial context for natural preserves (Liu and Taylor 2002, With 2005). This study applies the first steps of a landscape approach to a region of the Cumberland Mountains and Plateau in Kentucky and Tennessee. This region, labeled the Northern Cumberlands Project Area (NCPA), contains approximately 1 million ha and includes mixed mesophytic forests (Braun 1950, Hinkle and others 1993, Runkle 1996) that are among the most diverse temperate forests in North America and are viewed as requiring critical habitat protection and restoration (Ricketts and others 1999). Yet within the Cumberland Plateau in Tennessee, few old-growth forests remain and 72 percent of timberland is in non-industrial private forest land ownership (Schweitzer 2000). Since the diversity of canopy species and forest associations across the Cumberland Mountains and Plateau prevents any single reserve from supporting the entire flora, a regional approach is necessary to conserve these forests (Schmalzer 1989).

The landscape approach presented in this study compares the current conditions of forests within the NCPA with a description of long-term goals, as expressed by the concept of desired future conditions. The ecological component of desired future conditions, which we refer to as desired ecological conditions, provides managers with benchmarks to maintain ecological systems (Landres and others 1999). The landscape approach in this study quantifies the desired ecological conditions of the NCPA and characterizes current conditions of a landscape using the same measures of ecological condition.

While this approach has been refined and revised during its application, additional methodological details on The Nature Conservancy's landscape approach are provided in Druckenbrod and Dale (2004).

Predictive vegetation mapping serves a central role in defining desired ecological conditions in this study. Since little quantitative information exists on the regional distribution of forest associations or their stand structure and composition prior to extensive human land use, this study uses predictive vegetation mapping to characterize the relationships of forest associations to landforms using rules based upon historical and scientific studies of forests from this region. These relationships are possible because forest

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composition and productivity of the region are controlled by available soil moisture, which is influenced by slope and aspect of landforms (Franzmeier and others 1969, Smalley 1982, Hinkle and others 1993).

METHODS

The NCPA extends from 35°30' to 37° and incorporates areas from two distinct ecoregions: the Cumberland Mountains and the Cumberland Plateau. The Cumberland Mountains are underlain by shale, sandstone, siltstone, and coal and feature an elevation range greater than 600 m with peaks extending above 1000 m. The Cumberland Plateau contains a greater abundance of sandstone and is generally less dissected than the Cumberland Mountains with elevations generally between 350 to 600 m (Griffith and others 1995); however, the Plateau becomes more dissected northward within the NCPA (Smalley 1982). The majority of the NCPA is within the Cumberland Plateau Climate Division within Tennessee, which from 1931 to 2000 had annual temperature of 13.6 ± 0.8 °C (standard deviation) and mean annual precipitation of 140.8 ± 19.5 cm (National Climatic Data Center 2002).

Current Ecological Conditions

Current ecological conditions within the NCPA were determined using classifications of land cover from Landsat Enhanced Thematic Mapper (ETM) imagery from 2000 to 2002. Both leaf-on and leaf-off imagery were mosaicked over the project area at 30 m resolution. While Landsat imagery provides a spatially-explicit depiction of forest cover, it is typically not able to resolve detailed floristic differences and hence ancillary information is often useful (Franklin 1995). The Cumberland Plateau and Mountains regions of the NCPA were stratified following ecoregional boundaries (Omernik 1987, Griffith and others 1995), which accounted for the variation in geology and relief within the study area. An unsupervised classification using an ISODATA clustering algorithm produced 25 land-cover classes for each ecoregion. These classes were aggregated into eight classes for the Plateau and Mountains based upon qualitative field surveys across both ecoregions in September 2004. Coarse forest classes consisted of evergreen, mixed, and deciduous land covers. Other land-cover classes identified included pasture/non-forest, cleared, transitional, urban, and water. Transitional cover incorporated areas that changed from forest cover to non-forest cover during the timeframe of the Landsat ETM scenes. Urban and water land covers were superimposed using GAP data (Jennings and Scott 1997). Pasture/non-forest land cover was only classified within the Plateau region of the NCPA.

Landform forest associations were generated by combining coarse forest classes with landforms, which were defined using a rule-based method (Biasi and others 2001). The landform method, which delineates a region into landforms based upon landscape position, slope, aspect, and a moisture index, had been previously applied to the entire Cumberland Plateau and Mountains using a 90 m digital elevation model (DEM) along with expert opinions from regional ecologists. These same rules were re-applied to the Plateau and Mountains ecoregions within the NCPA using 30 m DEM to generate landforms consistent with the resolution of the land-cover data.

The combination of land cover and landform defining each landform forest association were used to classify current as well as potential forest cover. Dominant species composition of canopy trees for each landform forest association was determined through a literature review of historical, ecological, and forestry studies in the Cumberland Plateau and Mountains that related particular species to landforms.

The distribution and composition of landform forest associations were evaluated using Forest Inventory and Analysis (FIA) survey plots (Alerich and others 2004). Four surveys (or panels) conducted from 2001 to 2004 were available for analysis. Landform forest associations and other land-cover types were independently evaluated by the FIA Southern Regional Office (Knoxville, TN). FIA forest types were matched to landform forest associations using descriptions of dominant canopy species. Only FIA plots that were completely within forest cover were used. On the ground, each FIA plot contains four subplots, and classification was considered successful only if at least two subplots correctly matched their respective land-cover classifications. FIA data also enabled estimates of current forest composition and structure across the Plateau and Mountains portions of the NCPA. Forest composition and structure was expressed using attributes of the forest canopy for all trees ≥ 12.7 cm DBH including stand age, density, basal area, basal area by species, and number of large trees (> 0.75 m DBH).

Desired Ecological Conditions

A projection of potential natural forest cover was examined for both the Mountains and Plateau regions to discern how forest extent and spatial pattern would change under potential natural forest cover and to inform desired ecological conditions of land cover within the NCPA. In this projection, anthropogenic land cover was replaced with natural forest cover based on landform forest associations. Potential natural forest cover was assigned using the dominant coarse forest cover (either deciduous, mixed, and evergreen) from eight neighboring pixels along with the topographic status of the landform to determine whether the landform forest association in each location was xeric, upland, or mesic. The projection replaced pasture/non-forest, cleared, urban, upland evergreen, and transitional land covers with natural forest covers based on landform forest associations. Upland evergreen, which reflects plantations on the Plateau, was reassigned to either upland deciduous or upland mixed forest associations in this projection.

Comparing Current and Desired Ecological Conditions

The extent and spatial pattern of current land cover was compared with the projected potential natural forest cover using Fragstats (McGarigal and Marks 1995). Indicators of forest pattern were evaluated using measures of area, number of patches, mean patch size, median patch size, and core area. Forest pattern analyses were conducted both for the entire landscape as well as by ownership categories within the landscape consisting of public, large private, and small private lands. Public lands included lands owned at the federal, state, and local levels. The boundaries of large private lands were provided by The Nature Conservancy using tax records of all ownerships greater than 200 ha. Large private lands included public lands where forest resources were privately owned. Remaining lands in the NCPA were considered as small private ownership.

The structure and composition of the current natural forest covers were also compared to estimates of potential structure and composition from old-growth forests specific to each landform forest association as ascertained from the literature review of historical, ecological, and forestry studies. This comparison quantified the gap between current forests and potential values of forest structure and composition. Estimates of old-growth stand age were defined using the range of maximum ages for characteristic canopy species within each landform forest association.

RESULTS

Consistency with FIA Plots within NCPA

All FIA plots in forest cover were matched with specific landform forest associations. Upland evergreen forest cover in the Plateau region was matched with the USFS loblolly pine forest type. A total of 180 FIA plots were located within the Cumberland Plateau region of the NCPA and 46 within the Cumberland Mountains region. The overall consistency between forest/non-forest land uses reported for FIA plots and forest/non-forest land-cover classes for the Plateau was 94 percent and for the Mountains was 100 percent; however, the consistency between the FIA plots and land-cover classification was reduced to 45 percent for the Plateau and 67 percent for the Mountains when individual landform forest associations were considered. Mesic deciduous forests and non-forest categories were most accurately represented by the land-cover classes in both the Plateau and Mountains. Upland deciduous forest land cover in the Plateau was most often incorrectly associated with mesic deciduous forest land cover.

Current Land Cover

The Cumberland Plateau region of the NCPA encompasses 896,124 ha with mesic mixed and mesic deciduous forests comprising the most prevalent land-cover classes within this region. Mean patch area, core area, and mean core area per patch were also greatest for these two landform forest associations. Median patch areas were consistently less than mean values, reflecting the negative exponential distribution of patch areas with few large patches within the NCPA. Similarly, median core areas reflected the absence of core areas on at least half of the forest patches. Anthropogenic land cover accounted for a total of 23.7 percent of the Plateau region with extensive transitional and cleared land covers.

Considering the Plateau by ownership category, across all land-cover classes 23 percent was in public ownership, 21 percent in large private ownership, and 56 percent in small private ownership. Compared with its overall extent within the Plateau, public ownership contained proportionally greater amounts of natural forest cover in mesic evergreen, xeric mixed, and xeric evergreen forests but less cover in upland deciduous forests. Conversely, large private ownership had proportionally more cover in mesic deciduous, upland deciduous, and upland mixed forests but less cover in xeric forests. Small private ownerships contained the greatest amounts of mesic deciduous, mesic mixed, and upland deciduous forest classes but also had proportionally less cover in xeric forests. For natural forest-cover classes, mean patch area and core area per patch were smaller in small private ownerships. Within anthropogenic land-cover classes, small private ownership had the greatest amounts of anthropogenic land cover with proportionally more cover in cleared, pasture/non-forest, and urban land covers. Public land ownership had proportionally less transitional, cleared, pasture/non-forest, and urban land-cover classes but greater amounts of upland evergreen.

The Cumberland Mountains region encompasses a smaller portion of the NCPA (172,125 ha) than the Plateau, but mesic deciduous and xeric deciduous forests were the most prevalent land-cover classes within this region. Mean patch area, core area, and mean core area per patch was also greatest for mesic deciduous and xeric deciduous forests. Anthropogenic land covers accounted for 12.9 percent of the Mountains region with most cover in transitional and cleared classes.

By ownership class, 20 percent of the Mountains region was within public ownership, 56 percent in large private ownership, and 24 percent in small private ownership. Public and large private ownerships had proportionally greater amounts of natural cover mesic deciduous and xeric deciduous forests, but less in mesic evergreen and xeric evergreen forests than expected from their overall extents. In contrast, small private ownership had proportionally less cover in mesic deciduous and xeric deciduous forests, but greater cover in mesic mixed, mesic evergreen, and xeric evergreen forests. Mean patch area and core area were typically smaller within small private ownership than public or large private ownership. Small private ownership also had proportionally greater anthropogenic cover in transitional and cleared classes as well as the preponderance of urban classes. Public and large private ownerships both contained proportionally less transitional, cleared, and urban covers. Mean patch area and core area of urban cover in small private ownership were greater than in other anthropogenic cover classes or ownership categories.

Potential Forest Cover

Within the Plateau region, upland deciduous forests became the second most prevalent natural forest cover. Combined with mesic deciduous and mesic mixed, these landform forest associations encompassed 73 percent of the region and had the largest mean patch areas, core areas, and mean core areas. Mesic evergreen, xeric mixed, and xeric evergreen were the least extensive natural forest covers and also had the smallest patch areas, core areas, and mean core areas. Potentially, 70 percent of all upland deciduous forest cover was within small private ownership. Small private ownership also featured the largest mean patch area for upland deciduous forests. Similar to current conditions, public ownership had the potential for proportionally greater cover in mesic evergreen, xeric mixed, and xeric evergreen forests.

In the Mountains region, mesic deciduous and xeric deciduous forests remained the most prevalent natural forest covers, encompassing approximately 74 percent of the region. These two cover types also had the largest mean patch areas, core areas, and mean core areas. Large private ownership held potentially the greatest amount of each natural forest cover while small private ownership featured the smallest mean patch area and mean core area.

Comparing Current and Potential Forest Cover

While potential forest cover was greater than current natural forest cover across all landform forest associations in the Plateau, the greatest increase was with upland deciduous forests, which showed an order of magnitude increase in area compared with other forests. This landform forest association extends over less than half (42.0 percent) of its potential area across all ownerships (224,578 ha) but is most reduced within small private ownership, followed by large private ownership. The percent covers of all natural forests except upland mixed forests had the greatest reduction from their potential cover values in small private ownership. Xeric evergreen forests were also greatly reduced from their potential area, occupying only 57.0 percent currently across all ownerships and 53.7 percent within small private ownership; however, the total potential area of this landform forest association (8,416 ha) was least extensive of all natural forest cover classes in the Plateau.

In the Mountains region, all landform forest associations were at least at 75 percent of their potential area across all ownerships. The percent of forest covers currently within small private ownership also showed greater reduction from their potential forest covers than public or large private ownership in the Mountains. Similar to the Plateau, xeric evergreen forests showed the least current cover relative to their potential cover, particularly within small private ownership but was also the least extensive natural forest cover in the Mountains region. Median patch areas in the Mountains region were also consistently less than mean values in both current and the potential forest cover projection.

Current and Potential Forest Structure

Sufficient numbers of forested FIA plots existed to approximate current forest structure for three landform forest associations: mesic deciduous forests in the Plateau (73 plots), upland deciduous forests in the Plateau (28 plots), mesic deciduous forests in the Mountains (27 plots). Mesic deciduous forests in both the Plateau and Mountains regions were on average younger with reduced basal area and number of large trees (> 0.75 m DBH) than estimates of potential old-growth structure for mixed mesophytic forest types. Mesic deciduous forests did have densities of live trees and snags that were comparable to old-growth structure. The relative basal area for mesic deciduous forests in the Plateau was dominated by white oak, chestnut oak, yellow poplar, and red maple; however, characteristic mixed mesophytic species including sugar maple, northern red oak, American basswood, and beech were also present.

Upland deciduous forests in the Plateau were also younger than estimates of dry – mesic oak forests for the southern Appalachians. Current structure was also reduced with respect to live tree density and snag density, but not basal area. However, the old – growth estimates were determined using lower minimum diameters of 10.1 and 7.6 instead of 12.7 cm DBH. The species composition by relative basal area was dominated by oak species and red maple.

DISCUSSION

The consistency of landform forest associations with forest types reported for FIA plots is similar to other studies comparing remote sensing imagery with FIA data (Huang and others 2001, Ohmann and Gregory 2002). While classifications of vegetation associations are inherent abstractions of gradients in environmental variables and species distribution, a portion of this error likely arises from the comparison of forest associations independently derived from FIA and Landsat data. These errors include differences in definitions of land-cover classes, image registration and plot location errors, differences in Landsat imagery resolution and FIA plot size, and temporal lags between data collection (McRoberts and others 2002, Ohmann and Gregory 2002). FIA defines forest and land-cover classes using a combination of land-cover and field-based observations of land use (McRoberts and others 2002, Alerich 2004), while Landsat imagery is only capable of assessing land cover. The time difference between Landsat imagery (2000-2002) and FIA surveys (2001-2004) is particularly important in the context of a pine back beetle outbreak that occurred on the Plateau from 1999 through 2001. As a result, this classification is most appropriate for interpreting forest cover and determining management actions at regional, not local, scales (Huang and others 2001, Ohmann and Gregory 2002).

Recognizing the overall importance of forest habitat, desired ecological conditions for land cover in the NCPA should seek to maximize the amount of natural forest cover. Currently, forests in the Mountains and Plateau regions generally extend over the vast majority of their potential area. This finding suggests that large amounts of suitable land cover exist within the NCPA. However, the upland deciduous forests in the Plateau clearly have the largest gap from their potential forest cover, by possessing both the smallest percent of potential forest cover as well as the greatest amount of unrealized forest area. Upland deciduous forests are a conspicuous, underrepresented landform forest association and should be included as a component of a management strategy aimed at maintaining the regional ecological processes within the NCPA.

Xeric evergreen forests in the Plateau and Mountains regions also show large gaps from their potential forest covers, although their potential area is at least an order of magnitude smaller than upland deciduous forests. Their limited extent within this region limits a landscape approach from assessing their ecological condition as accurately as more widespread forest associations. Generally, few FIA plots were located within xeric evergreen forests, which prevented estimates of forest structure and composition. While there is a possibility that xeric evergreen communities are a successional stage within this region (Hinkle 1993) that reflect past land uses, this community type likely represents a unique habitat within this region (Haney and Lydic 1999).

Although most landform forest associations show relatively high proportions of cover across the NCPA when compared with their potential, this measure of desired ecological condition does not alone express the entire condition of these ecological systems. The structure and composition of these landform forest associations are also central to a characterization of desired ecological condition. The indicators for old-growth stand structure developed by Martin (1992) provide a useful set of desired ecological conditions to assess the current stand structure of mesic forests within the NCPA. Overall, in both the Mountains and Plateau regions, the current stand structure of these mesic deciduous forests indicates that they are generally younger, with smaller trees. The density and composition of the current mesic deciduous forests in the Plateau are instead more similar to the second-growth stands surveyed by Schmalzer (1989) within the NCPA. This difference suggests that these forests are in intermediate stages of stand development.

CONCLUSIONS

By applying a landscape approach to the conservation of forests within the Cumberland Plateau and Mountains, this study was able to assess the gap between current and desired ecological conditions for the Plateau and Mountains. The greatest gaps were observed in upland deciduous forests in the Plateau and xeric evergreen forests in the Plateau and Mountains, particularly within small private ownership. Three extensive landform forest associations, including upland deciduous forests in the Plateau, also displayed gaps in stand structure with current stands consistently containing younger trees of smaller diameter than those in old-growth condition.

While the NCPA remains in a largely forested land cover, the pronounced gaps in forest structure suggest the need for regional forest management and conservation to improve forest structure across the NCPA. These improvements would include incentives to encourage larger trees, greater expanses of upland deciduous forest and xeric evergreen forests, and more large patches of contiguous forest. The implementation of new management prescriptions will require diverse expertise to understand the socio-economic and silvicultural realities of this landscape. Although certain ecological components of this landscape may never again achieve regional prominence (e.g., American chestnut) and human land use will remain an important component within this landscape, these results provide scientific guidance for improving the forests of the Cumberland Plateau and Mountains toward a suite of desired ecological conditions through the application of new regional conservation initiatives.

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INFLUENCE OF LANDFORM AND SOIL CHARACTERISTICS ON CANOPY AND GROUND-FLORA COMPOSITION AND STRUCTURE OF FIRST- AND SECOND-ORDER HEADWATER RIPARIAN FORESTS IN UNGLACIATED OHIO

Kathryn L. Holmes, P. Charles Goebel, and David M. Hix[1]

Abstract—In the Southern Unglaciated Allegheny Plateau Ecoregion of southeastern Ohio, we characterized the distribution of canopy and ground-flora species relative to physiographic and soil characteristics of riparian forests associated with first and second-order streams. Although vegetation patterns are highly variable, analyses indicated that vegetation is ordered along a complex environmental gradient running from the streamside to the base of the adjacent hillslope, and are strongly related to specific landforms and to soil characteristics. Specifically, the canopies of the floodplains are dominated by *Liriodendron tulipifera*, *Fraxinus pennsylvanica*, and *Platanus occidentalis*, while those of the lower slopes are dominated by *Quercus velutina*, *Quercus coccinea*, and *Nyssa sylvatica*. *Arisaema triphyllum*, *Lindera benzoin*, and *Polystichum acrostichoides* dominated the ground-flora of the floodplains, while *Smilax glauca*, *Polygonatum biflorum*, and *Vaccinium stamineum* dominated the ground-flora of the adjacent lower slopes. This information will be useful for developing field indicators of riparian extent and vegetative reference conditions.

INTRODUCTION

Headwater streams are important landscape components, often forming over 70 percent of the entire stream channel system of forested watersheds (Meyer and Wallace 2001). Riparian forests associated with headwater streams are critical to overall landscape health and resource productivity, as they promote many ecosystem linkages between headwater streams and adjacent upland areas (Ilhardt and others 2000). Some of these important linkages include: providing habitat for many plant and animal species that promotes overall biodiversity (Goebel and others 2003a); providing nutrients in the form of allochonthous materials that maintain aquatic food webs (Goebel and others 2003b); and, the cycling of nutrients (especially nitrogen) at multiple scales (Naiman and Decamps 1997).

Our conceptual basis of the factors that regulate the composition, structure and function of headwater riparian areas, however, is often predicated upon research conducted in higher-order stream systems. Landforms, which are fairly easy to distinguish in the field along streams and rivers, have been shown to be surrogates of the predominant hydrogeomorphic processes operating in stream valleys. They provide a framework to investigate the influence of these processes on the composition and structure of riparian areas (Bendix and Hupp 2000). Because most research elucidating landform-vegetation relationships has occurred along higher-order streams, research conducted along small headwater streams is especially needed, especially in the Central Hardwoods Region.

The objective of this study was to examine the distribution of overstory and ground-flora species in relation to landforms and soils of riparian forests along first- and second-order streams of unglaciated southeastern Ohio. This information will be useful when developing more ecologically based management options and restoration programs for headwater riparian areas of the region.

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STUDY AREA

The Southern Unglaciated Allegheny Plateau Ecoregion portion of Ohio (fig. 1) is a maturely dissected plateau with moderate to steep slopes, narrow ridgetops, rock outcrops, and narrow stream valleys with elevations ranging from 195 to 322 m above sea level (Keys and others 1994). Geology of the study area consists of inter-bedded sedimentary bedrock of shale, siltstone, limestone, and coal lain down in the shallow seas of the Mississippian, Pennsylvanian, and Permian periods. In general, floodplains along first- and second-order streams are narrow and gently sloping, and typically grade into relatively steep hillslopes. Soils are moderately acidic with surface layers that are moderately to well-drained loams or silt loams, and with subsoils comprised of silty clays, loamy clays, or clays (Keys and others 1994).

The climate of the area is humid continental. Winters are relatively cold, while summers are generally warm; mean daily temperatures are 0°C and 21°C, respectively. Average annual precipitation is 98 cm, half of which falls during the growing season (Keys and others 1994).

METHODS

Sampling Design

We sampled the vegetation associated with floodplain and lower slope landforms along first- and second-order streams at 42 sites dominated by mature second-growth forests (> 70 years old) distributed across the Wayne National Forest (fig. 1). At each site, we established a transect perpendicular to streamflow, from the stream across the floodplain and on to the lower slope. In each case, at least two 500-m^2 circular plots with eight nested 2-m^2 rectangular ground-flora sample quadrats were located on each adjoining landform (floodplain and lower slope). In total, we sampled 118 500-m^2 canopy plots and 944 2-m^2 ground-flora quadrats.

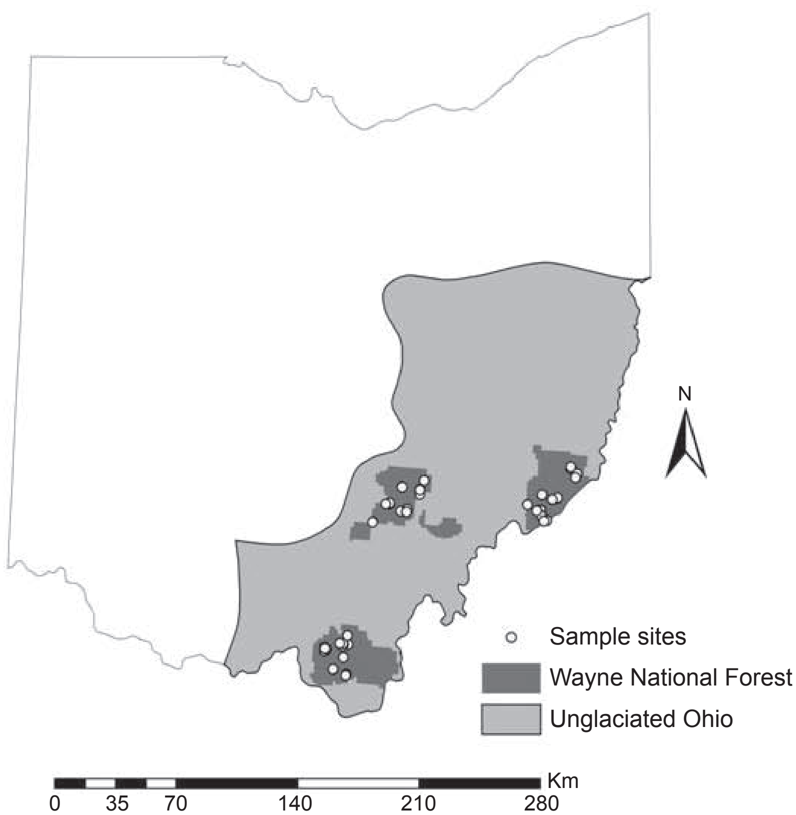

Figure 1—Headwater stream sample sites in the Wayne National Forest, southeastern Ohio.

Field Methods

On each canopy plot, the species, dbh (diameter at breast height; 1.37 m) of all dominant, codominant and intermediate trees were recorded. Percent cover of ground-flora vegetation (vascular plants < 1 m tall, including pteridophytes, graminoids, forbs, woody vines, and shrubs) was estimated visually for each ground-flora species in a quadrat using the following cover class codes: 1, < 1 percent; 2, 1-5 percent; 3, 6-10 percent; 4, 11-20 percent; 5, 21-40 percent; 6, 41-70 percent; and 7, 71-100 percent. Nomenclature and lifeform categories follow Gleason and Cronquist (1991).

In addition to the canopy and ground-flora measurements, physiographic and soil characteristics were measured at the center of each plot. Variables measured included landform, aspect, slope steepness (percent), depth to mottling, and thickness, texture, and pH of the A and of the B horizons.

Data Analysis

Prior to analysis, each canopy tree and ground-flora species was classified according to its wetland indicator status (obligate wetland, facultative wetland, facultative, facultative upland, or obligate upland) (U.S. Fish and Wildlife Service 1988) and ground-flora species were classified by functional lifeform guild (annual forb, perennial forb, graminoid, pteridophytes, woody vine, woody seedling, or woody shrub). Importance values (IV; sum of relative density and relative dominance [basal area] divided by 2) were calculated for each canopy species. For the ground-flora species, the midpoint value of each cover class was substituted for the numerical cover class code and mean percent cover for each species and lifeform guild (e.g., cover of all graminoid species combined, cover of all perennial forb species combined, etc.) was calculated.

Dufrene and Legendre's (1997) Indicator Analysis within PC-ORD (McCune and Mefford 1995) software was used to test for differences in species composition between the two landforms. These analyses use Monte Carlo permutation procedures to test the association of each species with each landform, and generate a p-value that is the proportion of randomized trials in the permutation procedure with an indicator value equal to or exceeding the observed indicator value (Dufrene and Legendre 1997). We also summarized canopy and ground-flora diversity using a variety of measures, including: (1) species richness (S), or the number of species present within a 1 m x 2 m plot; (2) Shannon's index (H'; $H' = S * \ln(r_i)$ where r_i is the relative importance of the i^{th} species; Ludwig and Reynolds 1988); and (3) an evenness ratio (E; $E = H'/\ln(S)$; Ludwig and Reynolds 1988). T-tests were used to determine if there were differences in species richness, species diversity, and evenness of the canopy and ground-flora vegetation between the floodplain and adjacent lower slope landforms. Similarly, we used a series of t-tests to test for differences between landforms with respect to the different compositional and structural characteristics of the canopy and ground-flora described above, as well as with the physiographic and soil characteristics.

To examine the relationships between the canopy and ground-flora layers and environmental factors, we used canonical correspondence analysis (CCA), a direct gradient analysis ordination that is constrained by multiple regression of the environmental factors (ter Braak and Šmilauer 1997). Eight environmental factors were used in the CCA: landform, aspect, slope steepness (percent), thickness of the A and B horizons, texture of the A and B horizons, and depth to mottling. Percent data were standardized by square root arcsine transformation prior to analysis. Monte Carlo simulations (using 1000 iterations) were used to test the significance of the gradient as represented by each canonical axis.

RESULTS

Canopy Composition and Structure

Indicator analysis revealed that the floodplain landforms are dominated by white oak (*Quercus alba* L.), yellow-poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), northern red oak (*Q. rubra* L.), and American sycamore (*Platanus occidentalis* L.), while the adjacent lower slopes are dominated by mixed-oaks (especially white oak), sugar maple (*Acer saccharum* Marsh.), and yellow-poplar (table 1). Although the composition of the landforms is different, we observed no differences in species richness, evenness, or diversity (t-test, $P > 0.05$, fig. 2), or in importance values of these species when they were grouped into functional guilds based on wetland indicator status (t-test, $P > 0.05$, fig. 3), between the floodplains (FP) or adjacent lower slopes (SL).

Table 1—Mean importance values (± 1 standard error) for canopy species of flood plain and lower slope landforms associated with headwater streams in southeastern Ohio

Species	Code	Flood plain	Lower slope
Acer rubrum	AcRu	1.47 ± 0.89	3.04 ± 0.91
A. saccharum	AcSa	4.37 ± 1.69	8.36 ± 2.09
Aesclus octandra	AeOc	1.76 ± 1.31	0.17 ± 0.17
Carya cordiformis	CaCo	0.85 ± 0.85	0.55 ± 0.29
C. glabra	CaGl	2.91 ± 1.78	3.66 ± 1.05
C. laciniosa	CaLa	0 ± 0	0.32 ± 0.18
C. ovata	CaOv	1.23 ± 0.69	1.57 ± 0.51
C. tomentosa	CaTo	0.37 ± 0.37	1.43 ± 0.44
Fagus grandifolia	FaGr	9.9 ± 3.71	5.76 ± 1.48
Fraxinus americana	FrAm	0.89 ± 0.61	0.81 ± 0.45
Fraxinus pennsylvanica	FrPe	4.33 ± 1.81	1.06 ± 0.42
Juglans nigra	JuNi	1.81 ± 0.82	0.52 ± 0.29
Lirodendron tulipfera	LiTu	15.64 ± 4.75	6.42 ± 2.07
Nyssa sylvatica	NySy	0 ± 0	0.54 ± 0.22
Platanus occidentalis	PlOc	5.43 ± 3.75	0 ± 0
Prunus serotina	PrSe	0.42 ± 0.42	0.67 ± 0.3
Quercus alba	QuAl	29.19 ± 7.26	32.79 ± 4.55
Q. coccinea	QuCo	0 ± 0	5.33 ± 1.79
Q. prinus	QuPr	0.99 ± 0.72	5.82 ± 1.66
Q. rubra	QuRu	7.74 ± 2.78	12.06 ± 2.02
Q. velutina	QuVe	0.6 ± 0.6	6.99 ± 2.08
Tilia americana	TiAm	4.99 ± 2.25	0.65 ± 0.34
Ulmus americana	UlAm	1.74 ± 1.12	0 ± 0
U. rubra	UlRu	1.43 ± 1	0.57 ± 0.4

Canonical correspondence analysis (CCA) reveal significant relationships ($P < 0.05$) between canopy composition and physiographic and soil factors (fig. 4). Specifically, the first two axes of the CCA explain 10 percent of the total variation and show the strong influence that landform (FP, SL), with facultative wetland species (e.g., American sycamore and green ash, *Fraxinus pennsylvanica* Marsh.) associated with floodplains. CCA also reveals that certain soil characteristics are also important factors influencing the distribution of overstory species, e.g., thickness of the B horizon (Tb) and texture of the A horizon (Xa). Floodplains are characterized by higher sand content and have thinner A and B horizons than adjacent lower slopes.

Ground-Flora Composition and Structure

Indicator analysis suggests there are differences in the composition of the ground-flora with jack-in-the-pulpit (*Arisaema triphyllum* [L.] Schott), spicebush (*Lindera benzoin* [L.] Blume), and Christmas fern (*Polystichum acrostichoides* [Michx.] Schott) dominating the ground-flora of floodplains, while cat greenbrier (*Smilax glauca* Walt.), smooth Solomon's seal (*Polygonatum biflorum* [Walt.] Ell.), and deerberry (*Vaccinium stamineum* L.) characterize the ground-flora of adjacent lower slopes. Corresponding with these compositional differences, floodplains have significantly higher species richness (fig. 5), percent cover of forbs and pteridophytes (fig. 6), and facultative wetland and facultative species (fig. 7) than lower slopes (t-test, $P < 0.05$).

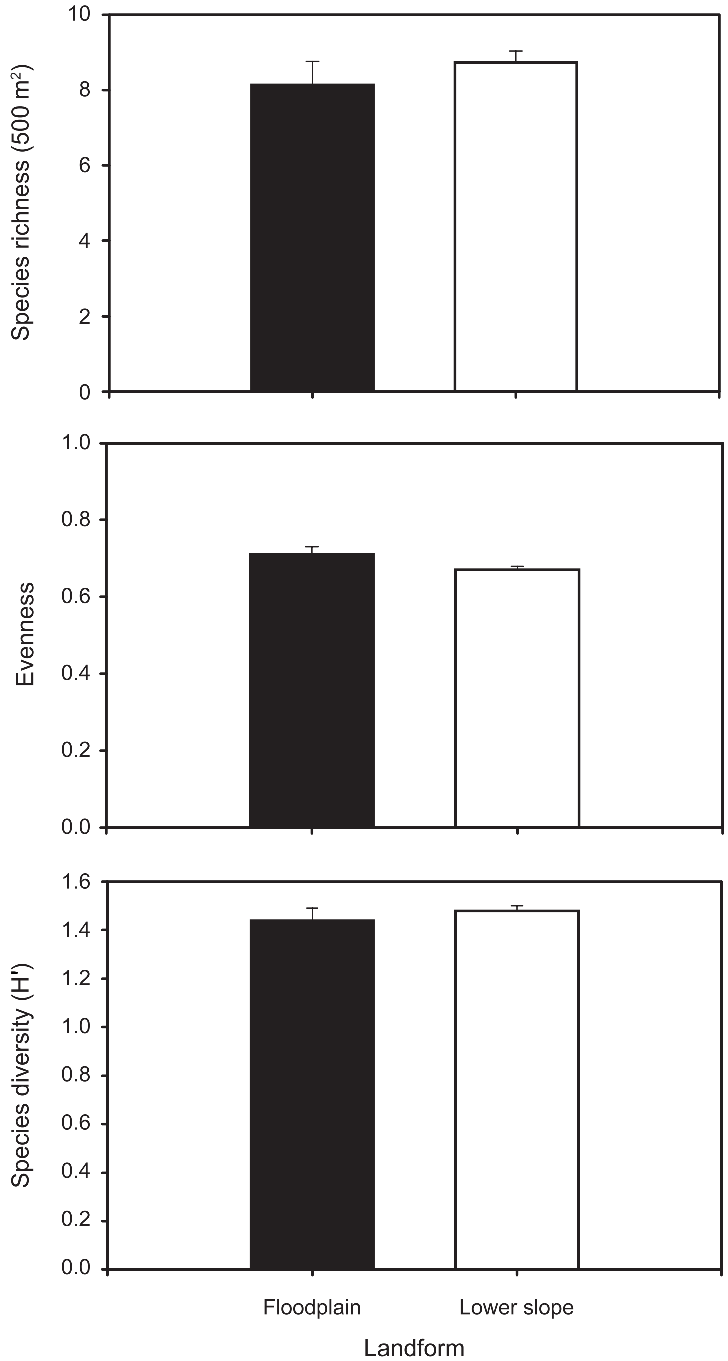

Figure 2—Canopy richness, evenness, and diversity (H') of flood plain and lower slope landforms along headwater streams in the Wayne National Forest, southeastern Ohio.

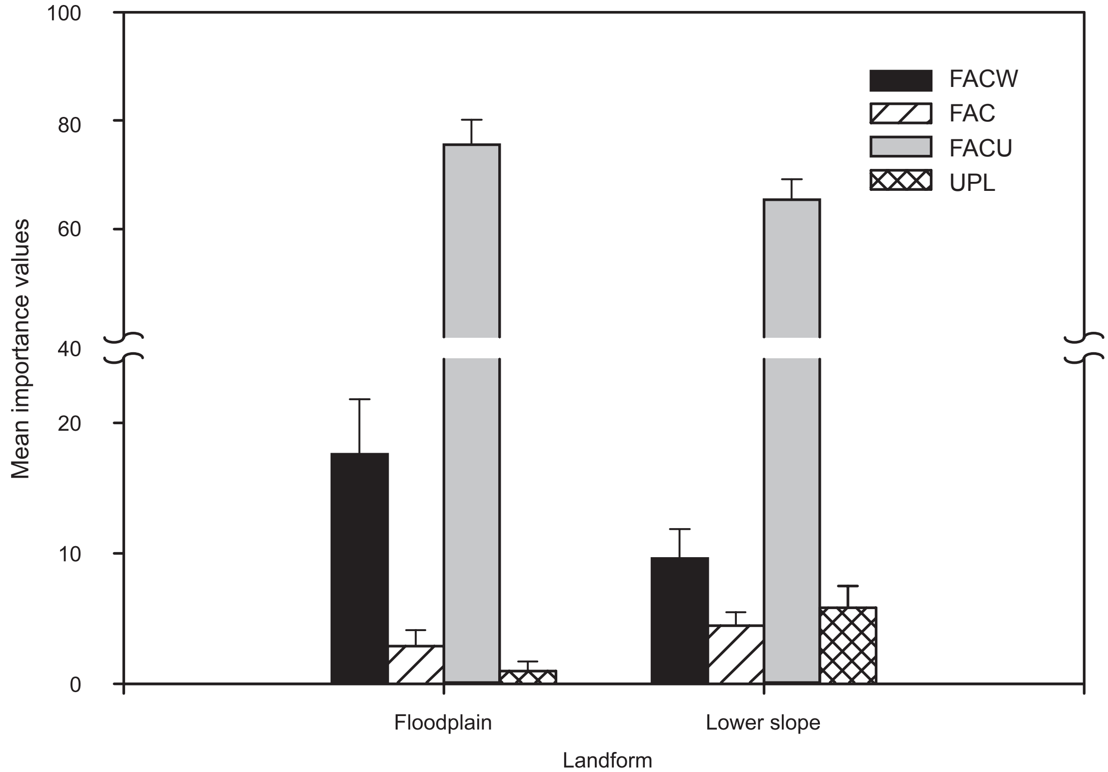

Figure 3—Canopy importance values by wetland indicator status of flood plain and lower slope landforms along headwater streams in the Wayne National Forest, southeastern Ohio.

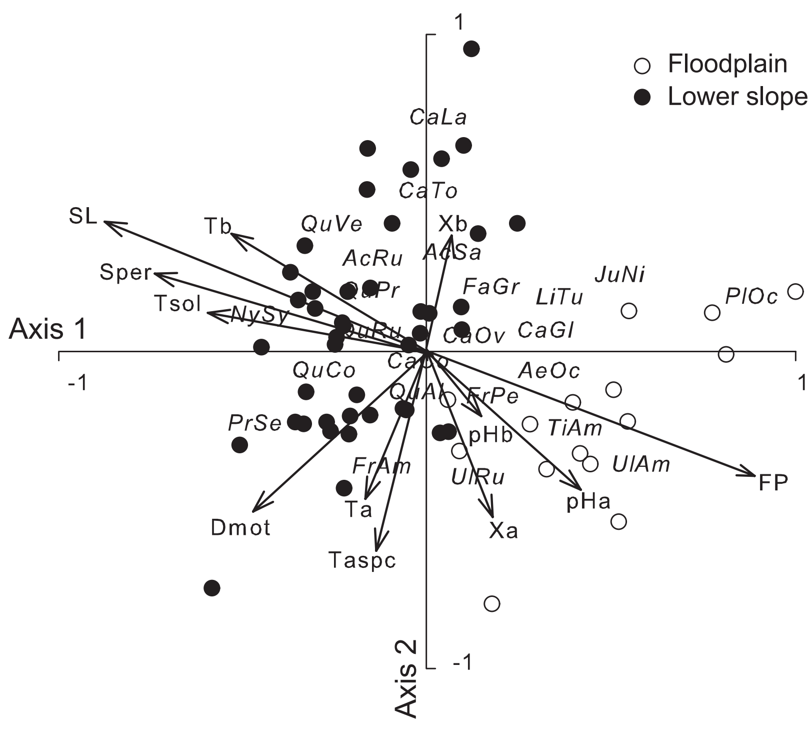

Figure 4—Canonical correspondence analysis relating canopy species to physiographic and soil characteristics of headwater streams in the Wayne National Forest, southeastern Ohio.

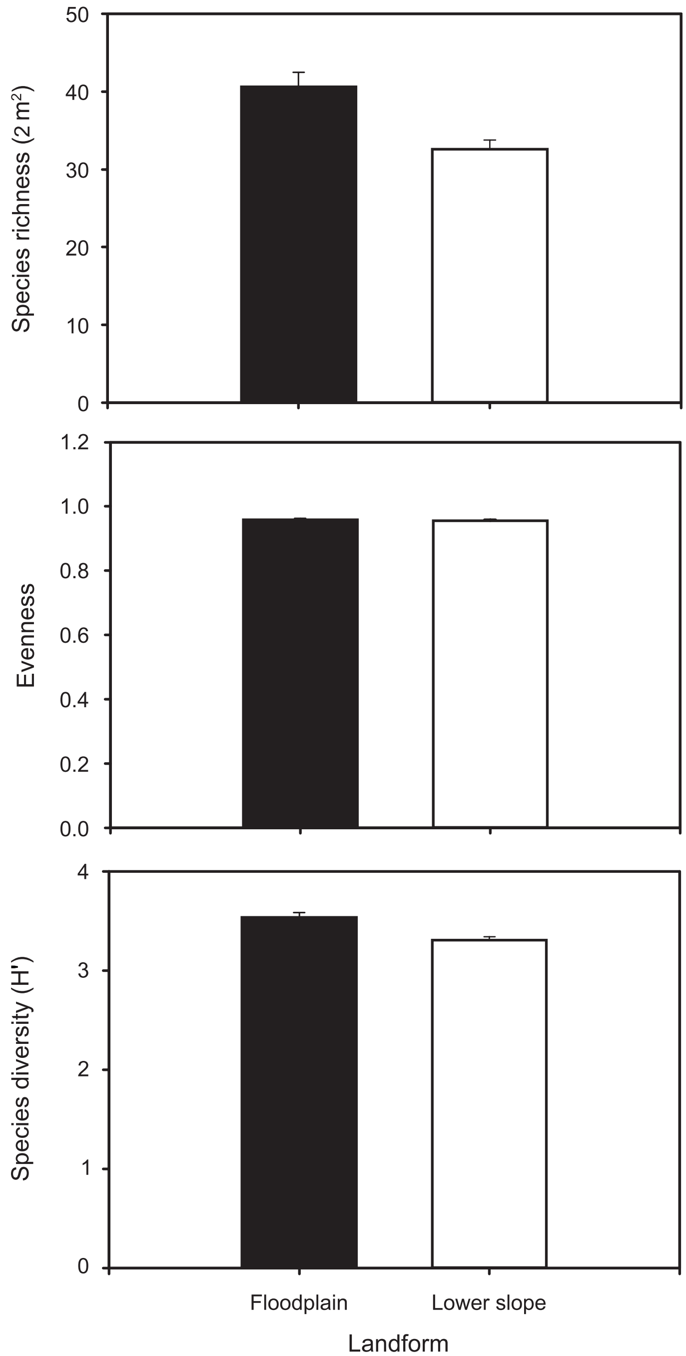

Figure 5—Ground-flora richness, evenness, and diversity (H') of flood plain and lower slope landforms along headwater streams in the Wayne National Forest, southeastern Ohio.

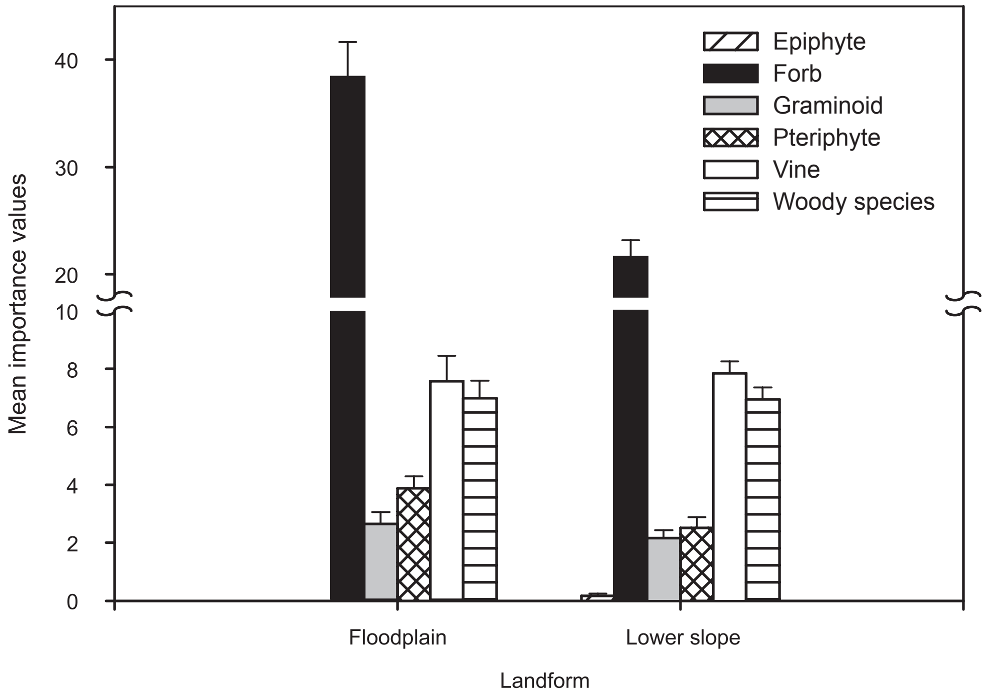

Figure 6—Ground-flora relative abundance by functional life form guild of flood plain and lower slope landforms along headwater streams in the Wayne National Forest, southeastern Ohio.

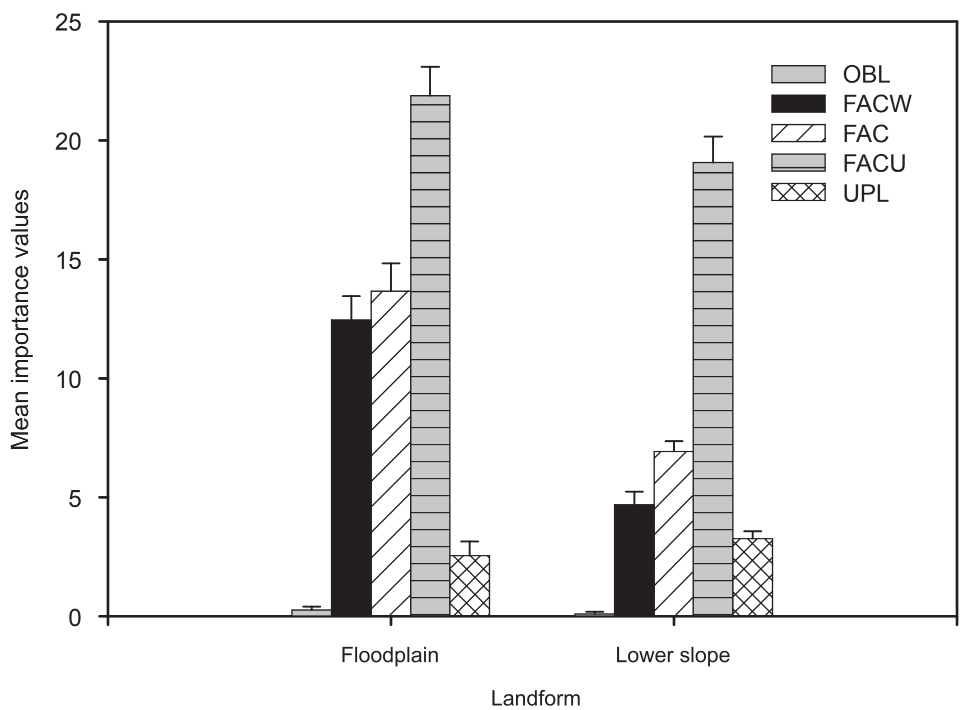

Figure 7—Ground-flora relative abundance by wetland indicator status of flood plain and lower slope landforms along headwater streams in the Wayne National Forest, southeastern Ohio.

Canonical correspondence analysis relating the ground-flora to environmental factors also reveal significant relationships ($P < 0.05$) between ground-flora composition and physiographic and soil factors, with the first two canonical axes explaining 14.2 percent of the variation associated with the ground-flora dataset (fig. 8). CCA shows the differences in the ground-flora communities with floodplains clearly grouped on the left side of the ordination and lower slopes on the right side (fig. 8). Only those species determined to be significant indicators (Dufrene and Legendre 1996) are included in figure 8. As with the canopy CCA, those species found on the floodplain landforms are associated with soils characterized by higher sand content and higher pH of the A and B horizons (fig. 8).

DISCUSSION

Across the eastern United States, there is an increasing need to restore the structure and function of headwater riparian areas. However, in many areas including the Central Hardwoods Region, effective riparian restoration methods often remain undefined (Ilhardt and others 2000). As headwater riparian areas have been recognized as critical components of forested watersheds, they also are increasingly considered to be functional ecotones rather than narrow buffers or corridors along streams and rivers in the landscape (Ilhardt and others 2000). Hence, more detailed characterizations of riparian areas are needed, including more specific information on how environmental factors influence the composition and structure of the plant communities and methods to identify the extent of these forests across the landscape (Gregory 1999, Goebel and others 2003a).

In mature second-growth headwater riparian forests of unglaciated southeastern Ohio, we found distinct differences in vegetation composition between floodplains and lower slopes of headwater streams, as others have found for higher-order streams (e.g., Hupp and Osterkamp 1996, Pabst and Spies 1998). These differences are likely in response to different hydrogeomorphic conditions (as represented by the landforms we studied) which promote unique environmental conditions and plant communities. The result is that although we did not detect any significant differences in species richness or diversity, there were

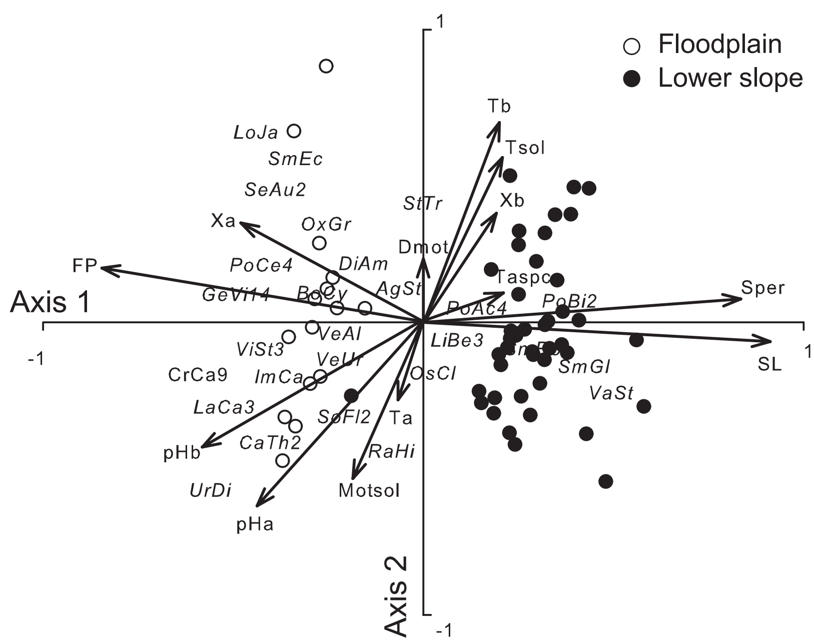

Figure 8—Canonical correspondence analysis relating ground-flora species to physiographic and soil characteristics of headwater streams in the Wayne National Forest, southeastern Ohio. Species codes are listed in table 2.

Table 2—Ground-flora species and species codes in the ground-flora CCA of headwater streams in southeastern Ohio

Code	Species
AgSt	*Agrimonia striata*
AmBr2	*Amphicarpaea bracteata*
ArTr	*Arisaema triphyllum*
BoCy	*Boehmeria cylindrica*
CaTh2	*Caulophyllum thalictroides*
CiLu	*Crcaea lutetiana*
CrCa9	*Cryptotaenia canadensis*
DiAm	*Diarrhena americana*
GeVi14	*Geum virginianum*
ImCa	*Impatiens capensis*
IrCr	*Iris cristata*
LaCa3	*Laportea canadensis*
LiBe3	*Lindera benzoin*
LoJa	*Lonicera japonica*
MoCl	*Monarda clinopodia*
OsCl	*Osmorhiza claytonii*
OxGr	*Oxalis gracilis*
PhDi5	*Phlox divartica*
PiPu2	*Pilea pumila*
PoAc4	*Polystichum acrostichoides*
PoBi2	*Polygonatum biflorum*
PoCe4	*Polygonum caespitosum*
PoRe2	*Polemonium reptans*
PoVi2	*Polygonum virginianum*
RaHi	*Ranunculus hispidus*
RoMu	*Rosa multiflora*
SeTe3	*Sedum ternatum*
SmEc	*Smilax ecirrata*
SmGl	*S. glauca*
SmHi	*S. hispidus*
SmRo	*S. rotundifolia*
SoFl2	*Solidago flexicaulis*
StTr	*Sphagnum subsecundum*
UrDi	*Urtica dioica*
VaSt	*Vaccinum stamineum*
VeAl	*Verbesina alternifolia*
VeUr	*Verbena urticifolia*
ViSt3	*Viola striata*

CCA = canonical correspondence analysis.

differences in canopy composition -- the floodplains are characterized by white oak, American beech, American sycamore, yellow-poplar, and green ash while the lower slopes are dominated by sugar maple and mixed-oaks.

While the differences observed in canopy composition among the different headwater streams were small, we did observe significant differences in the composition and structure of the ground-flora between the different landforms. Unlike the Pacific Northwest where canopy closure was found to be an important factor regulating the ground-flora composition and structure of headwater streams (Pabst and Spies 1998), the headwater streams we examined in southeastern Ohio all are dominated by dense forest cover (Personal observation). This suggests that the differences in ground-flora composition we observed appear to be associated with differences in landforms and the flow regimes associated with the headwater stream valleys. The result is that the floodplain landforms are characterized by more facultative wetland and facultative species than are the lower slopes. These patterns are similar to those suggested by the results of the CCA which shows that the vegetation along these small stream valleys is ordered along a gradient of decreasing soil moisture and increasing moisture stress from the streamside into the uplands in these headwater areas.

Currently, riparian management zones (RMZs) in the eastern United States that are based upon the functional extent of a riparian zone are being developed and implemented as alternatives to a "one-size-fits-all" approach (Ilhardt and others 2000). However, most of this work is being conducted along higher-order streams in large watersheds. Clear agreements on how to handle small tributary systems do not exist among environmental regulators, forest policy makers, and forest managers. One of the few existing constraints in managing these areas is that they must be managed in compliance with laws such as the Clean Water Act (1977), Pollution Prevention Act (1990), and many state laws designed to protect wetlands [e.g., Michigan Natural Resources and Environmental Protection Act (1994)]. In order to improve Best Management Practices, more detailed investigations into the specific role of landforms on the structure and function of riparian areas along headwater streams should be undertaken. With a better understanding of these areas, especially vegetation-landform relationships, it should be possible to come up with proper guidelines to protect both the functions and values of headwater riparian areas.

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A MULTI-CRITERIA GIS ANALYSIS FOR RANKING POTENTIAL RESTORATION AREAS IN THE FRAGMENTED KASKASKIA RIVER WATERSHED BOTTOMLAND HARDWOOD FOREST

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Abstract—Land-use conversion to agriculture in the fertile Kaskaskia River floodplain of southwestern Illinois has increased fragmentation and decreased interior forest habitat available for nesting migratory songbirds. A GIS-based Multi-Criteria Evaluation (MCE) was used to create a ranking of private landholdings in Clinton and Washington counties, Illinois, according to forest restoration potential. Study area incorporated individual land parcels whose centers fell within a study-defined 1 mile floodplain buffer of the lower Kaskaskia and its tributaries. Decision criteria included landscape metrics assumed to affect suitability of a riparian forest for migratory bird habitat. The ArcView 3.2 MCE extension standardized, weighted and combined nine GIS layers: "available" agricultural land; forest cover gaps; edge density metric; proximity to river; 200 m corridor area; total forest core area metric; fringe core area; distance to primary core value; and primary core area. The resulting ranking not only prioritizes parcels but also associates GIS map output with land registry data, thereby facilitating outreach to individual landowners.

INTRODUCTION

Forest fragmentation, parcelization, and land-use conversion are complex phenomena that result from society's increasing demands on the natural landscape (Tyrell and Dunning 2000). Results from a previous Illinois study (Blake and Karr 1987) support the conclusion that forest-interior breeding Neotropical migratory birds are most likely to be adversely affected by fragmentation and isolation of forest habitat. The process of habitat fragmentation occurs when a large, fairly contiguous tract of vegetation is subdivided and converted to other vegetation types or land-use regimens such that only scattered fragments or patches of the original remain (Faaborg and others 1993). Statistics compiled by Thompson (2000) on the level of fragmentation in the central hardwood region of the Midwest indicate a highly variable landscape with percent forest cover ranging from 1 to 82 percent. Small patches (mean = 21 km^2, median = 1 km^2) dominate the distribution of central hardwood remnants, although a few very large patches do persist (Thompson 2000).

The Kaskaskia River Watershed in southwestern Illinois is representative of the region's few remaining large patches of bottomland hardwood forest. The Kaskaskia basin's 136,000 acres contain Illinois' largest contiguous forest block: a 7,000 acre tract that reaches widths of up to two miles and is predominantly composed of bottomland hardwoods and flatwoods typical of the South (IDNR 2001). Within the expanse of this remnant forest resides one of the largest breeding bird communities of rare, local, and declining species characteristic of Illinois floodplain forests including: Red-shouldered hawk (Buteo lineatus Gmelin), Red-headed woodpecker (Melanerpes erythrocephalus Linn.), Yellow-billed Cuckoo (Coccyzus americanus Linn.), and Cerulean warbler (Dendroica cerulea Wilson). Kaskaskia River Corridor (KRC) species inventories rank its breeding bird densities among the highest in the state, surpassed only by floodplain forests in extreme southern Illinois (Unpublished field notes. Scott Robinson. 1997. Professor and Professional Scientist, Center for Wildlife Ecology, Illinois Natural History Survey, 607 East Peabody Drive, MC-652, Champaign, IL 61820). In addition, the north-south orientation of the KRC leads to intensive seasonal use by migratory waterfowl and songbirds (IDNR 2000). Land-use conversion to

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agriculture has increased forest fragmentation throughout the watershed, thereby decreasing the amount of nesting habitat available for forest-interior dependent bird species.

Recognizing the ecological significance of the KRC, the U.S. Fish and Wildlife Service (FWS) proposed the establishment of a 10,240 acre National Wildlife Refuge along a stretch of the lower river in 1992. Land acquisition was to be on a willing-seller or donor basis only with compensation methods that included: fee title acquisition, leasing of land, or purchase of easements (NASDA 1997). Most of the land under consideration was in private ownership, and the majority of landowners rejected the idea of government acquisition at that time. In response, the FWS agreed to support the formation of a broad-based stakeholder committee that was charged with developing a cooperative stewardship plan to protect KRC resources while allowing private ownership to continue (NASDA 1997). The outcome of these efforts, together with additional input from the region's Southwestern Illinois Resource Conservation and Development, Inc. (SWI RC&D), was a resource protection strategy both private and voluntary.

At present, the bottomland forests and wetlands of the KRC remain uniquely positioned for restoration efforts (SWI RC&D 2002). Specific habitat recommendations made by SWI RC&D include: (1) maintenance of existing forest corridors and significant forest blocks that are being threatened by urban sprawl, agriculture, and general land conversion; and (2) reduction of bottomland hardwood forest fragmentation with special consideration given to developing additional, large contiguous forested tracts (SWI RC&D 2002). The ongoing SWI RC&D Hole in the Doughnut Land Conservation Program has prepared a geo-referenced database that delineates privately owned land parcels and remaining forest cover in the KRC.

A need exists for an objective, systematic approach to rank the suitability of individual parcels for conservation or restoration of bottomland forest habitat in the KRC. The purpose of the present study is to develop a parcel ranking using a Multi-Criteria Evaluation (MCE) in a Geographic Information Systems (GIS) environment that incorporates landscape metrics and riparian forest habitat spatial criteria. This information will be of immediate use to KRC landowners and will have application to similar forested watersheds located in fragmented, agriculturally dominated landscapes across the Midwest.

PREVIOUS WORK AND PRESENT OUTLOOK

Saab's (1999) analysis of bird-habitat relationships in remnant riparian forests indicates that the surrounding landscape matrix is a more important predictor of avian species occurrence and distribution than structural features of either micro or macro-habitat. The development and accessibility of GIS technology and its ability to manage, manipulate, and interpret spatially referenced data (Russell and others 1997) has facilitated integrated management response to habitat fragmentation at the landscape scale.

A growing body of literature exists that describes using GIS to delineate and quantify fragmentation within forest and riparian habitat. Vogelmann (1995) assessed pattern, extent, and rate of forest fragmentation in southern New England. A negative correlation found between a forest continuity index, derived from the natural logarithms of forest area-to-perimeter ratios, and human population density demonstrated that forest fragmentation increases as human population density increases. A similar study by Fuller (2001) quantified changes in forest area and spatial patterns of fragmentation using a set of four landscape metrics (a fragmentation index, center-versus-neighbors, perimeter-to-area ratio, and the square pixel metric) from eleven watersheds in a rapidly developing northeastern Virginia county.

An earlier pilot study by Ripple and colleagues (1991) tested the feasibility of measuring forest landscape patterns using GIS and a set of spatial statistics that included: a fragmentation index (sensitive to the abundance of patches and the amount of nonfragmented contiguous natural forest); matrix contiguity (natural forested land); interior habitat; and total managed patch edge (clearcut areas). In a similar study, Gustafson and Parker (1994) proposed use of a quantitative fragmentation index to evaluate alternative landscape designs in an Indiana agricultural landscape. The Gustafson-Parker metric was termed a "proximity index" (PX), which quantified the spatial context of a habitat patch in relation to its neighbors. The authors concluded that the spatial distribution of PX values across a landscape could reveal how organisms with specific movement scales perceive the effective fragmentation of the landscape.

Schumaker (1996) modified the concept of a landscape pattern index from one of fragmentation to one of cohesion. An index of patch cohesion was found to be the most effective predictor of habitat connectivity and wildlife dispersal success in old growth forests of the Pacific Northwest (Schumaker 1996). Tinker and colleagues (1998) compared the relative effects of clearcutting and road building on the forest landscape-scale fragmentation patterns of 12 national forest watersheds using a set of pattern metrics and Version 2 of the FRAGSTATS spatial analysis program. FRAGSTATS V. 3 (McGarigal and others 2002) is used by the present study for computation of landscape metrics that quantify the spatial configuration of the study area.

In addition to the ability to delineate and quantify habitat, a GIS approach has been applied to select and rank the potential suitability of sites for restoration or conservation of riparian vegetation. For example, areas deemed of critical importance for establishment of riparian buffer zones were identified along portions of the Iowa River channel by combining a digitized land cover map and GIS thematic layers of soils, hydrology, and areas of potential nonpoint source pollution (Narumalani and others 1997). Russell and colleagues (1997) used GIS to select sites in a California watershed for riparian wetland preservation or restoration. Potential sites were identified by overlaying a digitized land cover map with a "wetness potential" index derived from USGS digital elevation models. Sites were ranked for preservation or restoration of riparian wetland vegetation according to criteria reflecting area size and proximity to existing riparian areas (Russell and others 1997). Wright and Tanimoto (1998) incorporated GIS data layers reflecting factors of habitat diversity, land ownership, and development risk into an acquisition priority methodology for privately owned land parcels within a national recreation area. Carver and colleagues (2004) developed a GIS-based decision-support model for generating tree species planting recommendations based on site characteristics in the Cache River Basin of southern Illinois. This model can serve as a tool for landowners and managers interested in restoring riparian forests or creating managed forested buffer strips.

Recent studies have demonstrated that MCE techniques integrated into a raster GIS environment can be used to combine several spatial criteria into a single land-use suitability index or map. Caselton and Carver (2000) employed MCE to optimize land-use allocations within a rapidly urbanizing Illinois county. Villa and colleagues (2002) used MCE to systematize a marine protected area zoning plan assigning areas to different uses and different levels of protection.

The objective of the present study is to develop a ranking of candidate parcels for reforestation efforts in the KRC based on habitat suitability criteria for migratory songbirds. Gaps in riparian forest cover are deemed candidates for reforestation if such efforts will reduce forest edge while increasing forest core area. An important feature of this study is the association of private land ownership tabular data and digitized land parcel boundaries within a multi-criteria GIS decision-support framework.

METHODS

Study Area

The study area included a segment of the lower KRC, traversing portions of Clinton and Washington Counties between Carlyle Lake and the town of Fayetteville in southwestern Illinois (fig. 1). The analysis focused on a 200 m corridor (100 m buffer) of the Kaskaskia and its tributaries as an optimal width for migratory bird occurrence (see Keller and others 1993).

Figure 1—Lower Kaskaskia River Corridor study area in Clinton and Washington Counties, IL.

Data Layer Development

Spatial land-cover data were assembled to assess current vegetation and land use in the KRC. Study area land-cover data were reclassified as necessary into categories of forestland, available agriculture, and unavailable, urbanized land. Geospatial analysis was conducted primarily in raster format using ArcGIS 8.2 and 9.0 (ESRI 2002). Access to digitized maps of the KRC delineating the boundaries of privately owned land parcels was provided by SWI RC&D's GIS Resource Center. Spatial data included county parcel information developed in ArcGIS shapefile format with Parcel Identification Number (P.I.N.), landowner registry, as well as geographic projection reference information. Land parcels were included in the MCE analysis if parcel centers were within the study-defined 1 mile floodplain buffer. FRAGSTATS, V. 3 (McGarigal and others 2002) was selected for computation of landscape metrics necessary for parcel prioritization. An Excel table conversion was used to make FRAGSTATS tabular output compatible with ArcGIS tables.

Multi-criteria analysis--Eastman and colleagues (1995) defined a criterion as a basis for decision that can be measured and evaluated. A multi-criteria analysis is a form of spatial decision support. In this case, GIS data layers or maps were prepared for each of nine criteria and subsequently aggregated. A Weighted Linear Combination technique for determination of spatial suitability (S) of riparian forest habitat in which $S = \Sigma W_i X_i$ (where W_i equals the weight of the ith criterion and X_i equals the score of the ith criterion) was applied. As the selected criteria were measured on different scales, a simple Linear Scale Transformation standardization procedure was adopted (Malczewski 1999, Voogd 1983). The ArcView 3.2 MCE extension standardized, weighted, and combined the nine criteria layers: "available" agricultural land acres; "doughnut hole" gap acres; edge density metric; proximity to river value; 200m corridor acres; total forest core area metric; fringe core area acres; distance to primary core value; and primary core area acres. Because the Multi Criteria Evaluation tool was only available as an extension in the ArcView 3.2 and 3.3 versions, the weighting and ranking of each individual criterion was completed using ArcView. The outputs were saved as shapefiles for further analysis using the ArcGIS 9.0 format. The output produced by the Ranking Method procedure was a tabulated ranking of land parcels in order of restoration potential importance. Parcels containing gaps whose reforestation would create the greatest impact on increasing forest interior area while decreasing the amount of forest edge were ranked highest.

OUTCOME AND APPLICATIONS

Visual results of the methodology are presented in figure 2. The final aggregate GIS map layer provides a color-scale corresponding to restoration potential ranking. The pattern that emerges from initial review of the output image is a ranking that favors reforestation of larger tracts with greater proximity to the river. Parcel size, ownership data, and ranking score are included in the attribute table associated with this final aggregate map that depicts both suitability and digitized land parcel boundaries.

The next phase of the analysis will be to compare existing land-cover conditions with alternative scenarios based on the top 1 percent and top 3 percent of ranked parcels having their forest-cover gaps reforested. A related study to assess landowner interest and knowledge of conservation easements and other incentives to facilitate desired land-use changes has been initiated.

The immediate application of study findings is to provide an ecological rationale translated to ownership boundary for Southwestern Illinois RC&D, Inc.'s Hole-in-the-Doughnut Land Conservation Program. Several broader implications can be drawn from the outcome: the linking of prioritized maps with digital plat maps and landowner addresses can provide a powerful tool for land management agencies and public-private partnerships seeking to: (1) identify high-priority land holdings; (2) automate sample selection for follow-up social science surveys of landowners; or (3) gauge interest for land swaps, sales, or application of incentive-based conservation practices such as conservation easements and enrollment in state and federal conservation reserve programs. The results of this study and similar efforts (Caselton and Carver 2000, Villa and others 2002) further indicate that the MCE technique combined with GIS can assist land-use planners make objective, systematic choices regarding allocation in a variety of contexts.

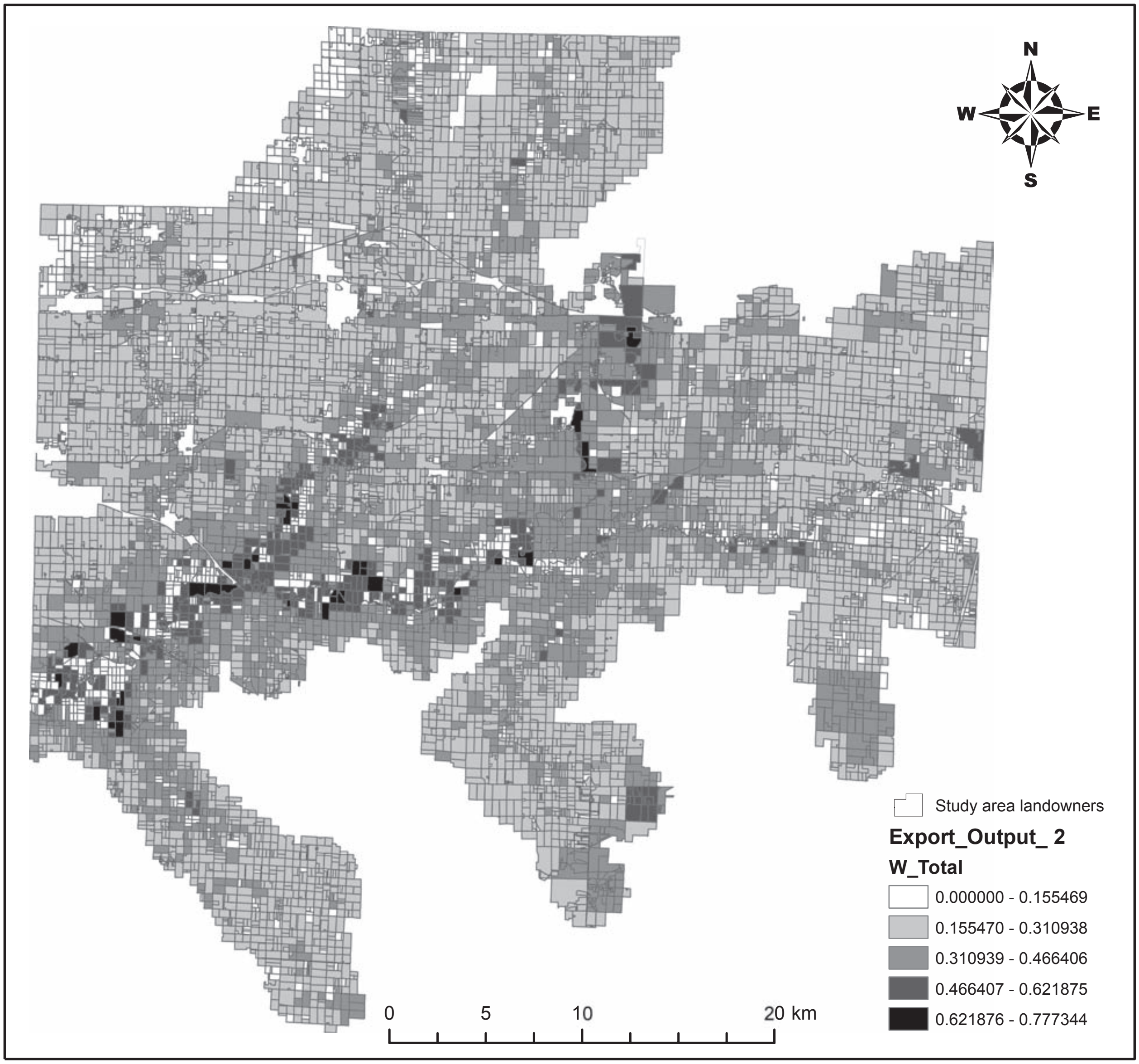

Figure 2—Final aggregate GIS map layer illustrating forest restoration ranking scale overlaid on parcel boundaries map.

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ABORTED YELLOW-POPLAR GEOGRAPHIC SEED SOURCE TEST SERVES TO VERIFY PRODUCTIVITY ON CUMBERLAND PLATEAU UNDULATING SANDSTONE UPLANDS: 42-YEAR RESULTS

Glendon W. Smalley and Elliot D. Olgivie[1]

Abstract—This study was designed to evaluated the extent of geographic variation among yellow-poplars (*Liriodendron tulipifera* L.) from four southern seed sources—Sewanee, TN, Oxford, MS, Birmingham, AL, and Gloster, MS. The Sewanee and Birmingham sources represented the Cumberland Plateau and the Oxford and Gloster sources represented the Gulf Coastal Plain. Originally, out-plantings were made at five mid-South locations. All five out-plantings survived through age 3; four survived through age 6; and only two (those at Sewanee-one on the Plateau escarpment and one on top of the Plateau) were alive at age 10. At that time, the parent study was terminated, but the two outplantings at Sewanee were maintained. The planting on the escarpment was abandoned after age 20. In this paper, we summarize the growth of the planting on top of the Plateau through age 42. Diameter, total height, basal area, and cubic volume of poplars from the two Plateau sources were significantly larger than those from the two Coastal Plain sources. These differences were evident by age 15 and continued to age 42. Site index of the two Plateau sources was significantly larger than the SI for the two Coastal Plain sources at ages 20 and 42. Site index of the local Sewanee source was 84 at age 20 and 89 at age 42 bracketing the estimated value of 85 for Landtype-1 in the Mid-Cumberland Plateau land classification guide. Planting of yellow-poplars grown from a local seed source provides a management alternative to natural mixed hardwoods or conversion to pine on the undulating sandstone uplands on top of the Plateau.

INTRODUCTION

The parent study was initiated by Roger M. Krinard of the Southern Hardwoods Laboratory at Stoneville, MS. to evaluate the extent of geographic variation among yellow-poplars from four southern seed sources—Sewanee, TN, Oxford, MS, Birmingham, AL, and Gloster, MS (table 1). The Sewanee and Birmingham sources represented the Cumberland Plateau and the Oxford and Gloster sources represented the Gulf Coastal Plain. Originally, out-plantings were made at five mid-South locations. All five out-plantings survived through age 3; four survived through age 6 (Farmer and others 1970); and only two (those at Sewanee) were alive at age 10.

About this time, Southern Station geneticists reached the consensus that this approach (gathering seed from a group of mother trees into a composite sample for outplanting) was not an appropriate way to test the effect of location and the parent study was abandoned. However, the two outplantings at Sewanee were maintained as examples of what could be expected from planting yellow-poplar on selected sites as one of many options to improve degraded Plateau hardwood forests. Eight-year data from these two out-plantings were reported by Russell and others (1970); ten-year data by Smalley and Pierce (1972); fifteen-year data by Russell (1977), and 20-year data by Smalley (1982b).

The two Sewanee out-plantings were established in cutover upland hardwood stands in the spring 1961 on land owned by the University of the South.[2] One out-planting was aligned along benches on the upper escarpment of the Plateau (Landtype 16, Smalley 1982a). Elevation ranged from 1,500 to 1,650 feet. Slope ranged from 5 to 15 percent to the northwest, but the overall slope of the escarpment was about

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[2] Study installed by scientists stationed at the Silviculture Laboratory, formerly maintained at Sewanee, TN, by the Southern Forest Experiment Station, USDA, Forest Service, in cooperation with the University of the South.

Table 1—Location, physiographic province, latitude, and elevation of the yellow-poplar seed source

Location	Parent trees	N latitude	Elevation
	number		*feet*
University of the South Domain, Sewanee, TN (Cumberland Plateau)	10	35°30'	1,500 – 1,800
Tallahatchie Experimental Forest Oxford, MS (Coastal Plain)	9	34°30'	200 – 400
Flat Top Experimental Forest Birmingham, AL (Cumberland Plateau)	20	33°30'	400 – 600
Homochitto National Forest Gloster, MS (Coastal Plain)	20	31°30'	100 – 200

40 percent. Soils developed in bouldery colluvium from sandstone, siltstone, and shale. Typical soils are Jefferson (fine-loamy, siliceous, semi-active, mesic Typic Hapludults) and Bouldin (loamy skeletal, siliceous, semi-active, mesic Typic Paleudults) (U.S. Department of Agriculture, Natural Resources Conservation Service 2004). In 1961, the area supported a typical mixed mesophytic forest with a rich herbaceous flora (Hinkle and others 1993) . A harvest in 1956 removed overmature and defective trees. This out-planting was abandoned after age 20 because of severe competition from natural hardwoods. These cool upper escarpment slopes are the most productive Plateau sites with an estimated site index of 100 for natural stands of yellow-poplar (Smalley 1982a).

The second out-planting was on an undulating sandstone upland on top of the Plateau (Landtype 1, Smalley 1982a) that slopes to the east at a 4 percent gradient. Elevation is 1,850 feet. Soils developed in loamy residuum from sandstone, siltstone, and shale. Typical soils were the moderately deep Lily and the deep Lonewood (fine-loamy, siliceous, semi-active, mesic Typic Hapludults) (U.S. Department of Agriculture, Natural Resources Conservation Service 2004). Most merchantable trees had been cut for ties or sawlogs about 1958. When the seed source test was begun, overstory trees were mostly scarlet oak (*Quercus coccinea* Muenchh.) and chestnut oak (*Q. prinus* L.) with some black oaks (Q. *Velutina* Lam.), white oaks (*Q. alba* L.), and hickories (*Carya* spp.). The moderately dense understory consisted of oaks, hickories, flowering dogwood (*Cornus florida* L.), sourwood (*Oxydendron arboreum* [L] DC), blackgum (*Nyssa sylvatica* Marshall var. *sylvatica*), and vacciniums (*Vaccinium* spp). Landtype 1 has an estimated site index of 85 for natural stands of yellow-poplar (Smalley 1982a). Two large poplars near the out-planting indicated a site index of 75 to 80, but both had sustained damage from ice. This out-planting was remeasured in the winter of 2003 at age 42 since planting.[3]

METHODS

Study Design and Analysis

The four seed sources were replicated four times in a randomized block design. Each plot was 55 feet square and contained 121 planting spots arranged in 11 rows of 11 spots at a spacing of 5 x 5 feet.

[3] The inventory at age 42 was conducted as an independent study by Olgilvie in partial fulfillment of the requirements for the degree of Bachelor of Science in Natural Resources, 2003.

Survival and growth measurements were confined to the central 49 trees. Study plots were arranged in a 4-plot x 4-plot square with each block of four plots laid out on the contour.

Growth differences attributable to seed source were tested by analysis of variance. Degrees of freedom and the associated sums of squares for seed sources were partitioned orthogonally. Significance is reported at the 0.05 level of probability.

Seed and Seedlings

Seed from the four sources was collected from 9 to 20 trees that had average or better form and growth, and represented several stands at each collection area (table 1). Seedlings were grown at the Tennessee Valley Authority nursery near Norris, TN. They were lifted, graded, and planted in late March 1961.

Site Preparation

The site was prepared between October 1960 and March 1961 by basal spraying all hardwoods 2 inches dbh with the low-volatile ester of 2,4,5-T (1.8 kg acid equavalent) at the rate of 1 gal. of ester per 25 gallons of diesel oil.[4] Hardwoods >2 inches dbh were deadened by applying herbicide in frills. Study plots were weeded and cleaned several times in the first decade.

Thinnings

Study plots were precommercially thinned after the eighth and tenth growing seasons to provide more growing space and maintain reasonably uniform spacing. Half of the trees were left after each thinning. Thus the density was reduced to one-fourth of the original number of trees and the residual spacing was 10 x 10 feet. Three kinds of trees were cut regardless of stand or crown position; those damaged by falling hardwood snags, those with low forks, and those infected with fusarium cankers. Additional trees in all size classes were cut when needed to achieve reasonably uniform spacing. All cut trees were left on the ground.

Calculation of Yield and Site Index

Yield in cubic feet was calculated at ages 10 (after thinning), 15, 20, and 42 using a tree volume regression for total stem volume, outside bark, all sizes of trees, developed for natural grown trees in the Southern Appalachian Mountains of Georgia, North Carolina, Tennessee, and Virginia (Beck 1963). No attempt was made to calculate board-foot volume at age 42 since only about one-fourth of the trees were ≥10.6 inches dbh. Some Gloster and Oxford plots had no trees of sawlog size.

At plantation ages 20, and 42, site index was calculated for each plot based on the average height of the tallest 50 percent of the trees (minimum of 3; maximum of 5) and age from seed. Since no site index equations have been developed for yellow-poplar plantations or natural stands on the Cumberland Plateau, we used an average of the estimates from three site index curves for natural stands: Southern Appalachian Mountains (Beck 1962), Piedmont of Virginia and the Carolinas, (Beck 1962), and Central Appalachians (Schlaegel and others 1969). Estimates of site index for stands younger than 20 years are subject to substantial error due to the variability of growth in early years,

RESULTS

Survival

Survival of trees from all sources was 93 percent or better after eight years (table 2). There were no significant differences in survival (arcsin transformation) among seed sources at age 8 before the first thinning. Statistical analysis of survival after the two thinnings has little meaning. Several poplars in two Sewanee plots (blocks III and IV) were cut or broken off when the road bordering the study plots on the north was graded and widened by the county highway department. A Gloster plot in block II) and a

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[4] The registration of 2,4,5-T for forestry purposes was cancelled in 1979 by the Environmental Protection Agency.

Table 2—Stand characteristics of yellow-poplars by seed source and plantation age

Plantation age	Seed source			
	Sewanee, TN	Oxford, MS	Birmingham, AL	Gloster, MS
	Survival			
	percent			
8[a]	92.9	93.9	96.4	94.4
10[b]	92.9	93.9	94.9	94.4
15	96.9	100	100	100
20	93.5	100	100	98.4
42	67	60	77	48
	Diameter at breast height			
	inches			
10[c]	2.3	1.9	2.5	2.3
15	4.1	3.2b	4.1a	3.4b
20	5.1a	4.0b	5.2a	4.2b
42	8.9a	7.2b	9.1a	7.9b
	Total height			
	feet			
10[c]	22.1	18.1	24.8	23.2
15	36.4a	29.6b	37.3a	33.4b
20	48a	39b	49a	42b
42	75a	62b	80a	66b
	Basal area			
	square feet per acre			
10[c]	15.8a	10.6b	17.1a	15.0b
15	50.2a	31.0b	47.0a	35.6b
20	76.5a	50.3b	76.4a	54.7b
42	129.0a	73.0b	162.0a	74.0b
	Volume			
	cubic feet per acre			
10[c]	178	96	213	171
15	903a	462b	871	604b
20	1,774a	1,003b	1,814a	1,177b
42	5,333a	2,163b	6,418a	2,365b
	Site index			
	base age 50 years from seed[d]			
20	84a	76b	89a	79b
42	90a	74b	99a	77b

[a] Before first thinning.
[b] Before second thinning.
[c] After second thinning.
[d] Based on mean height of the tallest 50 percent of trees on each plot; average of three site index equations.
In each row, means followed by the same letter are not significantly different ($p = 0.05$).

Birmingham plot in block I sustained no damage. Consequently, survival of the local Sewanee source dropped from 97 to 94 percent between ages 15 and 20. Otherwise, very few trees died naturally between the second thinning at age 10 and age 20. By age 42, survival was 76 percent for the Birmingham source, 65 percent for the Sewanee source, 59 percent for the Oxford source, and 49 percent for the Gloster source.

Diameter Breast Height

Diameter was first measured at plantation age 10 prior to the second thinning and subsequently after the thinning at ages 10, 15, 20, and 42 (table 2). Tenth-year dbh (before thinning) averaged 2.1 inches and ranged from 1.8 to 2.3 among seed sources. The second thinning increased the mean dbh of trees from individual sources 0.1 to 0.2 inches. Mean dbh at age 15 was 3.7 inches and ranged from 3.2 to 4.1; at age 20 it averaged 4.6 inches and ranged from 4.0 to 5.2; and at age 42 it averaged 8.3 inches and ranged from 7.2 to 9.1. Diameters of poplars from Plateau sources were significantly larger than those from Coastal Plain sources at ages 15, 20, and 42.

Basal Area

Basal area (BA) was determined at ages 10, 15, 20, and 42 (table 2). Tenth-year BA before thinning averaged 21.6 square feet per acre and ranged from 15.3 to 25.2 among seed sources. The second thinning decreased BA an average of 7.0 square feet. Mean BA at age 15 was 41.0 square feet per acre and ranged from 31.0 to 50.2; at age 20 mean BA was 64.5 square feet per acre and ranged from 50.3 to 76.5; and at age 42 mean BA was 108 square feet per acre and ranged from 73 to 162. Basal area of poplars from Plateau sources was significantly larger than the BA of those from Coastal Plain sources at ages 10, 15, 20, and 42.

Total Height

Height (H) was measured after planting, annually for 8 years, and at ages 10, 15, 20, and 42 (table 2). At age 5, average H was 8.8 feet and ranged from 7.2 to 10.5 among seed sources. At age 8, H averaged 15.8 feet and ranged from 13.2 to 18.0. The first thinning increased the average H of the residuals 1.4 feet. At age 10, H averaged 21.4 feet and ranged from 17.5 to 23.7. At age 15, H averaged 34.2 feet and ranged from 29.6 to 37.3. At age 20, H averaged 44 feet and ranged from 39 to 49. At age 42, H averaged 71 feet and ranged from 62 to 80. Since age 15, trees from Plateau sources were significantly taller than those from Coastal Plain sources.

Site Index

Site index (SI) at age 20 averaged 80 and ranged from 76 to 89 among seed sources (table 2). Mean SI of the Plateau sources was 86 (Sewanee—84; Birmingham—89). Site index at age 42 averaged 94 and ranged from 74 to 99. Mean SI of the Plateau sources was 94 (Sewanee—90; Birmingham—99). Site indices of Plateau sources were significantly greater than those of Coastal Plain sources at both ages.

Cubic Volume

Cubic volume (CV) was determined at ages 10, 15, 20, and 42 (table 2), Tenth-year CV after the second thinning averaged 174 cubic feet per acre and ranged from 96 to 213 among seed sources. There were no significant differences among seed sources. By age 15, mean CV had quadrupled to 711 cubic feet per acre and ranged from 462 to 903. Cubic volume double during the next quinquennium to 1,440 cubic feet per acre and ranged from 1,003 to 1,814. At age 42, CV averaged 4,070 cubic feet per acre and ranged from 2,163 to 6,418. Cubic volumes of poplars from Plateau sources were significantly larger than the CV of those from Coastal Plain sources at ages 15, 20, and 42. At age 42, CV of Birmingham trees averaged over 1,000 cubic feet more than the CV of Sewanee trees. This difference is probably due to the slightly better survival of Birmingham trees—77 percent vs 67 percent. Survival of trees in the Sewanee block II plot was only 50 percent. Remember that several trees in the Sewanee plot (blocks III and IV) were cut or broken during road construction between ages 15 and 20. The calculated CVs for the Sewanee and Birmingham, sources translate to mean annual increments of 127 and 153 cubic feet, respectively.

DISCUSSION AND CONCLUSIONS

The 5 x 5 foot initial spacing was too close for this fast-growing species even if the study was planned to be short-term. It was definitely too close for operational plantings. Wider plantings would postpone thinning until most of the trees were of merchantable size. However, wider spacings would necessitate more aggressive site preparation or weedings or cleanings. From a research view point, a wider spacing would require bigger plots and bigger plots would mean scattered locations in order to insure reasonable similarity of site.

Variation in foliation dates, observed informally throughout the first 15 years of the study, followed a consistent pattern and was similar to the pattern observed in Ohio (Funk 1958) and North Carolina (Sluder 1960). Trees from southern sources foliated earlier than those from more northern sources, even among the narrow range of 4° of latitude represented in this study. This reaction may be related to the genetic differences in dormancy. New growth on Gloster and Oxford trees was frozen several times by late spring freezes. Birmingham trees did not suffered as much damage as Oxford trees although the Birmingham collection site is 1° of latitude south of the Oxford site. However, the Birmingham site is slightly higher in elevation than the Oxford site. Periodic death of new leaves and shoots may be partially responsible for the poorer growth of Coastal Plain trees compared with those from the Cumberland Plateau.

Diameter breast height, total tree height, basal area, and cubic foot volume of yellow-poplars from the two Plateau sources were significantly larger than those from the two Coastal Plain sources. These differences were evident by plantation age 15 and continued to age 42.

Elsewhere in Tennessee,Thor (1976) found significant differences in height and diameter of poplars after fifteen years for different elevational sources from TN, GA, NC, and SC. In general, high-elevation sources grew slower than low-elevation sources. Significant differences were found only on two relatively uniform planting sites. Results from three more variable sites were inconclusive. All out-plantings were on former agricultural land and each contained four of six seed sources.

A comparison of the calculated CVs with Beck and Della Bianca's (1981) tabular values was not possible. The lowest site index shown in their table 39 was 80 and the SI of Oxford and Gloster sources were 74 and 77, respectively. Cells in their table 39 for combinations of SI and BA at total age 43 for the Sewanee and Birmingham sources contained no values, i.e., they were outside the range of their data base.

Mean SI increased between plantation ages 20 and 42, suggesting that the height/age relation of these trees is different than the ones used to develop the three SI equation. Site index of the local Sewanee source was 84 at age 20 which is very close to the estimated valueof 85 for Landtype-1 on the Mid-Cumberland Plateau (Smalley 1982a) where it exceeds that for all other naturally grown species. At age 42, SI was 89. Site index of the Birmingham source was 89 at age 20 and 99 at age 42. Kuers (2007) reported an estimated SI of 76 for planted yellow-poplar (seed source unknown; seedlings obtained from Tennessee Division of Forestry Nursery at Pinson, TN) at plantation age 24 following whole-tree chipping on a similar site (LT-1). On top of the Plateau, only well-drained hollows (LT-16, Smalley 1982a) are more productive for yellow-poplar. There is no reason to change the published site index (85) of natural stands of yellow-poplar growing on undulating sandstone uplands in the land classification guides for the Mid- or the Southern Cumberland Plateau regions (Smalley 1979, 1982a) based on this study.

Planting of yellow-poplars grown from a local seed source provides a management alternative to natural mixed hardwoods or conversion to pine on these undulating sandstone uplands of the Cumberland Plateau. However, control of competing vegetation will be necessary to insure a successful stand (Kuers 2007, McGee 1977, Russell 1977).

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WILDLIFE

Moderator:

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A METHOD OF QUANTIFYING FOREST VERTICAL STRUCTURE FOR THE PURPOSE OF EVALUATING BAT HABITAT

Marne M. Avina, Roger A. Williams, and Stanley D. Gehrt[1]

Abstract—Changes in forest structure due to silvicultural implementations can significantly impact bat activity and the use of forest resources. Forest biomass, or clutter, is a forest attribute that one, has a direct influence on bat activity, and two, is modified during any type of harvesting. It is necessary to measure the amount of clutter present to adequately evaluate current bat habitat use as well as the subsequent impacts of forest management practices. A method was developed in this study that determines the amount of crown volume (m^3/ha) that exists vertically within a forest at 1-3 m, 3-6 m, 6-9 m, 9-12 m, and 12+ m. It is based on several measurements of tree height and width, conical crown shapes, and geometric proportionality. This method provides an alternative way to measure clutter in a forest setting.

INTRODUCTION

Bats (Order Chiroptera) have high species diversity and specialized feeding ecologies that, coupled with their flight ability, is unparalleled among mammals (Altringham 1996, Kunz 1982). Second only to rodents (Order Rodentia) in representing the greatest number of mammalian species in North America, bats fill a number of unique ecological niches including nocturnal predators, pollinators, and seed dispersers (Altringham 1996, Arnett 2003, Fenton 2001). They have evolved into a unique order consisting of over 1000 living species, which, over the past two decades, has spawned a surge of interest in these flying mammals (Altringham 1996, Fenton 2001).

This interest derives from not only the captivating ecology of bats, but also to documented and suspected population declines of numerous species. Population declines, attributed to loss of habitat, pollution, and other anthropogenic-related causes, have led to several listings of bat species as endangered or threatened, therefore making them a higher priority for both public and private landowners (Miller and others 2003). Although significant strides have been taken in a positive direction, bats remain one of the most complex and difficult groups of wildlife to study (Fenton 1997, Hayes 2003). There are numerous areas where information is lacking (Arnett 2003, Barclay and Brigham 1996). One of these areas deals with understanding how bats respond to forest management practices and how these practices influence habitat relationships of bats (Arnett 2003, Fenton 2001, Lacki 1996, Marcot 1996). In Ohio, all thirteen bat species rely on forests to satisfy at least one life history requirement, but the majority use forests to meet their entire habitat needs during their active phase of the year (Fenton 1997, Miller and others 2003). For example, bats are often found roosting in tree cavities, among the foliage, in crevices between rocks, under exfoliating bark, in hollow trees, and other protected, secretive places (Knopf 1996). Thus, forest management practices may have profound effects on their population status and distribution.

The structural complexity of a forest, such as the amount of clutter (e.g., tree trunks, branches) significantly influences the foraging activity of bats, which in turn influences the presence of bats in that forest. Owen and others (2004) found that bat species segregated themselves among forests with high and low densities of clutter. These habitat preferences may be derived from high insect populations or perhaps more importantly, the species-specific capabilities (Krusic and Neefus 1996, Owen and others 2004). For example, different species of bats have different wing designs which are characterized as wing aspect ratios (Fenton 2001). These aspect ratios are believed to influence flight capabilities as well

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as energetically and mechanically limit where a certain species can forage (Norberg 1981). If a bat has a low aspect ratio, their wings are short and broad. These bats typically forage in denser habitats where their wings allow them to be highly maneuverable (Aldridge and Rautenbach 1987, Fenton 2001, Nowak 1994). These dense habitats also enable the high frequency echolocation calls emitted by these species to be more effective. A bat with a high aspect ratio has long, narrow wings which enables it to fly faster, but with limited maneuverability. Bats with high aspect ratios are generally found foraging in open areas exhibiting low frequency calls that will travel greater distances (Fenton 2001).

It is apparent that clutter is an aspect of all forests that can produce varied levels of bat activity depending on its density. Owen and others (2004) found that the closely spaced trees and high densities of certain forests can be a hindrance to flying bats by impeding detection and capture of prey. Too much clutter may also increase the risk of predation by obstructing a clear path of escape (Campbell and others 1996, Vonhof and Barclay 1996). When determining the effects of forest harvesting on bat activity, it is necessary to measure the amount of clutter present in an adequate and precise manner.

This study presents the first attempted use of this method to quantify forest clutter from the ground upwards through the canopy. Other studies have used a variety of methods to assess clutter. Veilleux and others (2003) defined percent clutter above and below roost trees as the amount of woody material and foliage that broke an imaginary horizontal plane. Kalcounis and Brigham (1995) assigned habitats values one to four, with four being the most cluttered. Broders and others (2004) characterized habitat in one of three clutter categories based on the horizontal distance to the nearest tree. Other studies have simulated clutter in artificial environments (Arlettaz and others 2001, Sleep and Brigham 2003) to determine the effects of varying levels of clutter on foraging bats. The method presented in this study provides a quantitative measurement of clutter (m^3) at various heights by directly measuring the trees present. It is the hope of the authors that this method may prove to be more useful that the previous assessments of clutter. This method is a part of a larger study examining two different shelterwood harvests, combined with fall and spring burns 3–5 years post harvest, on oak regeneration and forest structure changes on bat communities.

METHODS

Data from ten plots, located within the Richland Furnace State Forest, Jackson County, Ohio, were evaluated for the purpose of this paper. Richland Furnace State Forest lies within the unglaciated hill country of southern Ohio where the regional topography is characterized by deeply dissected terrain of the Allegheny Plateau (Kerr 1985). This creates a gradient of moisture regimes and subsequent microclimates across the landscape (Kerr 1985). Table 1 displays the characteristics of the forest used in this study. The forest was dominated by upland oak-hickory, which accounted for an average of 88.2 percent of the total basal area on the ten plots. The remainder comprised of typical upland hardwood species mix (table 2). Slopes ranged from 10–24 percent with an average of 16 percent. Aspects averaged southeast (157^{o} azimuth) and ranged from northeast (43^{o} azimuth) to southwest (268^{o} azimuth).

Table 1—Data summary from 10 plots (n = 10) of the forest used for this study in Richland Furnace State Forest, Jackson County, OH

Variable	Mean	Standard deviation	Minimum	Maximum
Trees/ha	280.30	78.91	173.00	395.00
Average d.b.h. (cm)	30.88	2.61	27.80	36.50
Basal area (m^2/ha)	26.90	5.86	19.10	36.90
Slope (percent)	15.70	4.95	10.00	24.00
Aspect (degrees azimuth)	157.30	68.77	43.00	268.00

Table 2—List of species present in 10 plots measured in Richland Furnace State Forest, Jackson County, OH

Upland oak	Hickory	Mixed hardwoods	Noncommercial
Quercus alba	*Carya glabra*	*Acer saccharum*	*Amelanchier species*
Q. coccinea	*C. laciniosa*	*A. rubrum*	*Carpinus caroliniana*
Q. prinus	*C. tomentosa*	*Fagus grandifolia*	*Corylus americana*
Q. rubra		*Fraxinus americana*	*Hamamelis virginiana*
Q. velutina		*F. pennsylvanica*	*Lindera benzoin*
		Liriodendron tulipifera	*Ostrya virginiana*
		Nyssa sylvatica	*Sassafras albidum*
		Populus grandidentata	*Viburnum species*
		Prunus serotina	
		Ulmus americana	
		U. rubra	

The ten plots were stratified to measure the overstory (trees greater than or equal to 10 cm dbh), saplings (trees greater than or equal to 1.4 m height and less than 10 cm dbh), and large seedlings (trees 0.3 to 1.3 m height). Overstory, sapling, and large seedling plots were circular and circumscribed about the same center. Overstory, sapling, and large seedling plots were 0.08 ha, 0.04 ha, and 0.02 ha in size. On all woody stems, total height, height to the base of the live crown, maximum crown diameter, and the diameter at a right angle to the axis of the maximum diameter, were measured to the nearest 0.15 m and recorded by species. Crown diameters were measured with a linear tape from dripline to dripline. Height measurements with taken with a clinometer. Field measurement were recorded in English units and later converted to metric for analysis.

RESULTS AND DISCUSSION

The volume (V) of a cone was used to estimate the crown volume, which has been used successfully in other studies (Karlik and McKay 2002):

$$V = (1/3)(\pi)(H)(D/2)^2 \tag{1}$$

However, for this study we assumed crown shape to be split into two cones, with the cone base being shared and defined at the crown midpoint. It was assumed that the crown midpoint occurred halfway between the height to the base of the live crown (HL) and the total height of the tree (TH). Accordingly, the measured crown diameter was assumed to be measured at the crown midpoint (fig. 1). These assumptions do not affect the calculation of the total crown volume using the standard cone volume equation. The geometric mean of the maximum crown diameter and the diameter at a right angle to the axis of the maximum diameter was used to determine crown diameter (D) in the cone volume calculations. Cone height (H) was determined as the difference between TH and HL.

Zones of vertical forest clutter that have typically been defined at 0–3 m, 3–6 m, 6–9 m, 9–12 m, and 12+ m upwards through the forest canopy were used for this study (Personal communication. Debbie Scott, Graduate Associate, Ohio State University, 2021 Coffey Road, Columbus, OH 43201). An algorithm using the cone volume equations and the relationship of proportionality was developed to determine how much of the crown volume of a particular tree resided in each of the defined clutter layers. For purpose of illustration, we will give an example of a tree whose total height lies within the 6–9 m strata and live crown base lies within the 0–3 m strata (fig. 2).

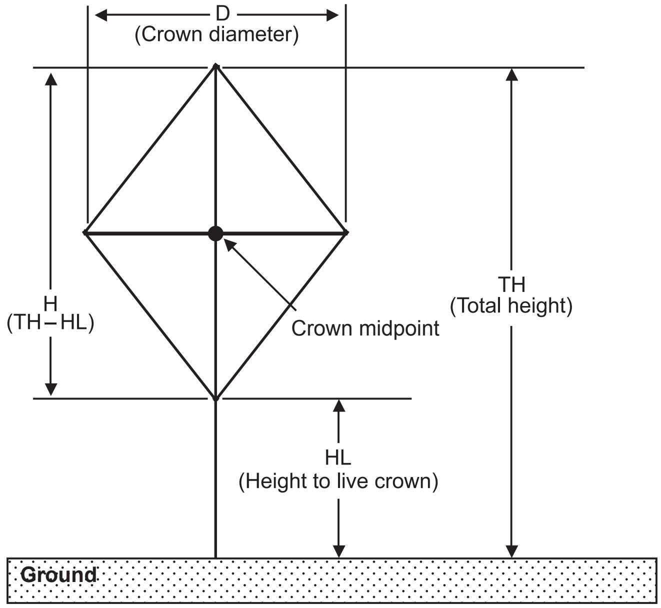

Figure 1—Variables and assumptions used in the estimation of total crown volume and the volume that exists in the various vertical strata.

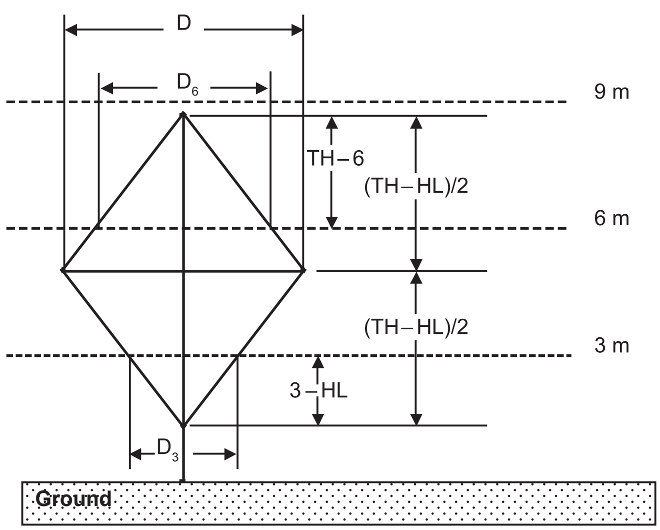

Figure 2—An example of a tree that has a crown that occupies the 0-3 m, 3-6 m, and 6-9 m strata in a forest and the corresponding crown dimensions used in the volume per strata estimations.

To determine how much of the total crown volume resides within the 6–9 m strata we need to estimate the crown diameter that occurs at the 6 m height using the geometric rule of proportionality. The height of the cone at 6 m and above becomes:

$$TH - 6 \tag{2}$$

And the height of the cone beginning at the midpoint becomes:

$$(TH - HL)/2 \tag{3}$$

Using the rule of proportionality, we can solve for the crown diameter at 6 m (D_6):

$$D/[(TH - HL)/2] = D_6/(TH - 6) \tag{4}$$

Solving for D_6:

$$D_6 = [D(TH - 6)]/[(TH - HL)/2] \tag{5}$$

We now can substitute the appropriate values into the cone equation to determine the crown volume within the 6–9 m strata:

$$V_{6\text{-}9} = (1/3)(\pi)(TH - 6)\{[(D(TH - 6)]/[(TH - HL)/2)]/2\}^2 \tag{6}$$

where

$V_{6\text{-}9}$ = the cubic meter crown volume of the tree within the 6–9 m strata

In a similar procedure, we now find the volume of the cone that has its base at the 3 m point and extends downward into the 0–3 m strata. The height of the cone at the 3 m and below is:

$$3 - HL \tag{7}$$

and the height of the cone from the midpoint downward is:

$$(TH - HL)/2 \tag{8}$$

The diameter of the cone at 3 m (D_3) becomes:

$$D/[(TH - HL)/2] = D3/(3 - HL) \tag{9}$$

Solving for D_3:

$$D_3 = [D(3 - HL)]/[(TH - HL)/2] \tag{10}$$

We now can substitute the appropriate values into the cone equation to determine the crown volume within the 0–3 m strata:

$$V_{0\text{-}3} = (1/3)(\pi)(3 - HL)\{[(D(3 - HL)]/[(TH - HL)/2)]/2\}^2 \tag{11}$$

To find the remaining volume that lies within the 3–6 m strata, we subtract $V_{0\text{-}3}$ and $V_{6\text{-}9}$ from the total crown volume:

$$V = [(1/3)(\pi)(H)(D/2)^2] - (V_{0\text{-}3} + V_{6\text{-}9}) \tag{12}$$

The volume determined for each strata were summed on a plot to determine the total cubic meter volume per hectare. The algorithms were developed for each possible strata possibility and placed into a Statistical Analysis Systems program (SAS 2003) to calculate volumes per hectare by strata for all plots.

Table 3 provides a summary of volume data calculated for the ten plots. Figure 3 gives the crown volume strata by plot through the 9–12 m strata. Because the 12+ m stratum includes the crowns of the overstory trees, these volumes are comparatively much higher and are displayed in figure 4.

Table 3—Crown volume (m³/ha) data by vertical strata collected from 10 plots (n = 10) in the Richland Furnace State Forest, Jackson County, OH

Crown volume strata	Mean	Standard deviation	Minimum	Maximum
0 – 3 m	758.25	289.73	396.07	1,172.87
3 – 6 m	1,636.67	659.42	938.89	2,508.91
6 – 9 m	1,425.89	1,139.50	65.64	3,807.26
9 – 12 m	1,659.30	869.87	442.12	3,507.36
12 + m	40,735.52	6,701.29	31,586.26	50,445.54

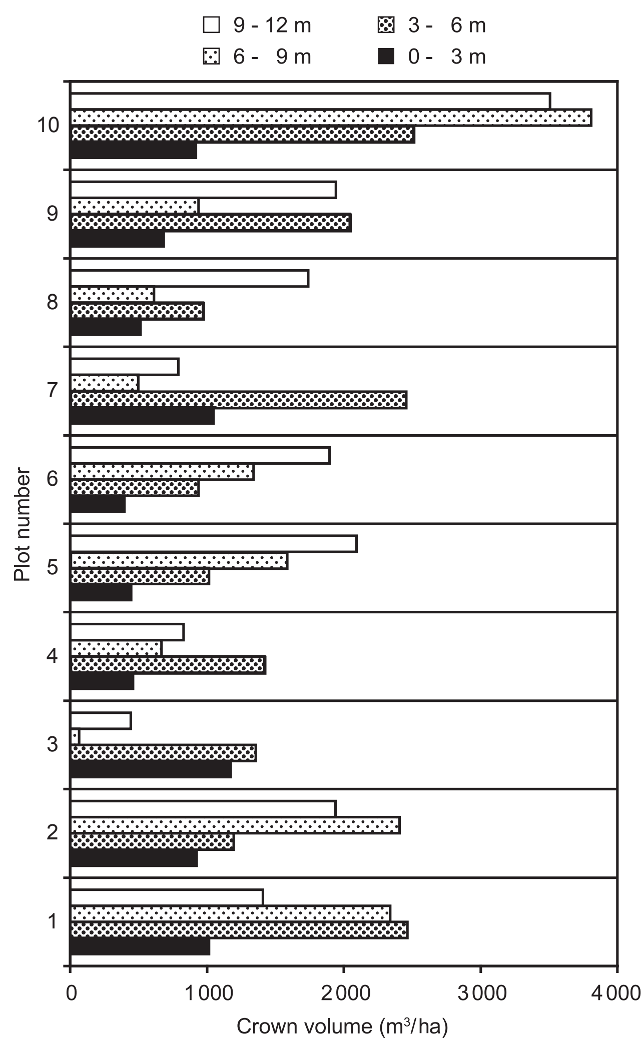

Figure 3—Crown volume (m³/ha) per strata up to 12 m determined the conical algorithmic method for the Richland Furnace State Forest, Jackson County, OH.

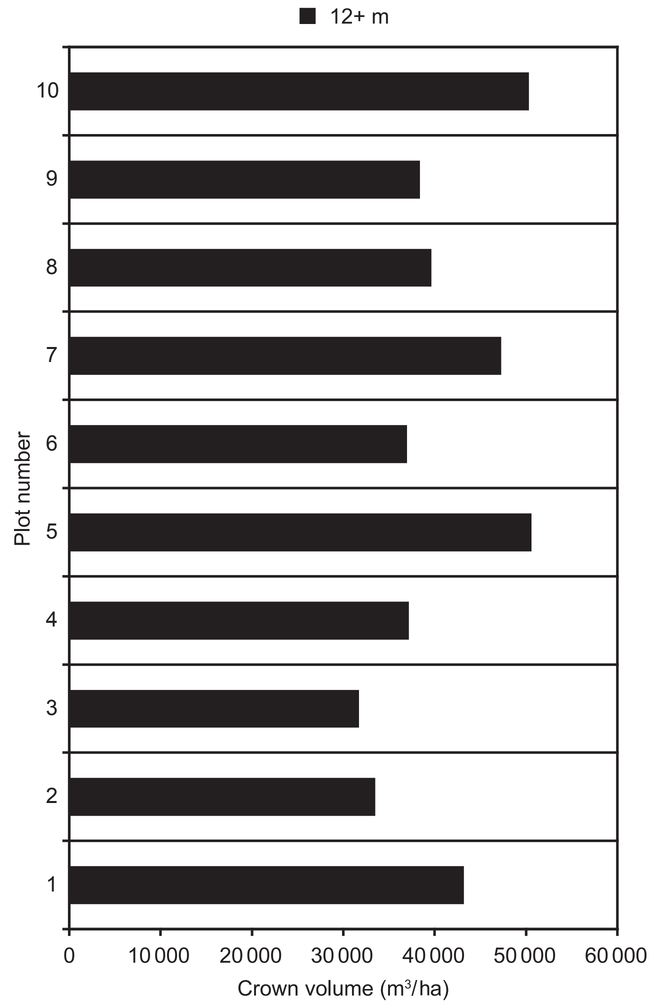

Figure 4—Crown volume (m^3/ha) for the 12+ m strata determined the conical algorithmic method for the Richland Furnace State Forest, Jackson County, OH.

CONCLUSIONS

This method provides a quantitative approach to estimating the amount of clutter that occurs within a forest, enabling a more rigorous application of statistical analysis. The measurement of three features of the tree—total height, height to the base of the live crown, and crown diameter—are measurements that could be taken in standard inventories. This method will be used to quantify the amount of clutter present before and after two shelterwood harvests of varying intensity levels. The results will then be correlated with the mean number of bat passes per intensity level to determine how changes in forest structure influenced bat activity.

We hope to test our assumptions and methods later in this study by felling trees and determining the amount of crown biomass within each stratum, relating it to predicted volumes.

ACKNOWLEDGMENTS

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DEVELOPING MANAGEMENT GUIDELINES FOR CERULEAN WARBLER BREEDING HABITAT

Paul B. Hamel and Kenneth V. Rosenberg[1]

Abstract—Recovery activities for species of conservation concern may be directed to acquire and protect habitats known to contain the species, or to produce suitable habitats or locations suspected to be capable of supporting populations of the species. Management of those habitats ultimately becomes necessary, especially where production of additional habitats is deemed necessary. The Cerulean Warbler Technical Group (CWTG) is working to maintain current Cerulean Warbler (*Dendroica cerulea* (Wilson), Aves: Parulidae) populations and ultimately to double them within the Partners in Flight North American Conservation Plan. This species' population has declined as much as 70 percent since 1965, as measured by our only rangewide yardstick of breeding distribution and trends, the Breeding Bird Survey. These birds were listed as Vulnerable in the prestigious Threatened Birds of the World in 2004. Previously a candidate species under provisions of the U.S. Endangered Species Act (ESA), a petition to list them as Threatened under ESA was lodged in 2000. Ongoing CWTG research activities address three fronts in development of guidelines for habitat management: response of breeding populations to controlled manipulations of existing stands for vegetation management, distribution of the birds among Society of American Foresters' Forest Cover Types, and suggestion of specific practices to improve habitat suitability of particular stands. These practices will vary geographically throughout the species' range, but will focus on common structural elements (e.g., patchy emergent tree canopies) that occur in a variety of forest types. Work on breeding habitats indicates that silvicultural manipulation of the vegetation ultimately will become an important management tool for the species. The studies are, however, in their early stages, permitting us to suggest possible guidelines and illustrate possible objectives and potential consequences. We are not yet in position to specify outcomes of application of particular prescriptions with defined confidence limits.

INTRODUCTION

Why should forest managers in the Central Hardwoods Region care about a songbird, the Cerulean Warbler, that spends only part of the year on their land? Answering this question is the purpose of this paper. We will present a compelling rationale for managing forests for this species, review what is known of its behavioral habitat use and relate this to discussion of silvicultural activities to produce habitat, and suggest methods of evaluating the success of such prescriptions. We will address the important question whether management objectives should be designed for nongame birds, such as Cerulean Warbler, or whether management objectives should be designed to produce specific wood products, and the birds' response to their application subsequently monitored.

Current knowledge of Cerulean Warblers is limited, and it is important that the available management information be assembled into a single, cohesive source that can be distributed to land managers throughout the range of the species. Preliminary guidelines can be developed on the basis of current knowledge and future manipulative studies. We suggest such guidelines here, for consideration in management planning processes for federal as well as state forestry and wildlife agencies. Private landowners may wish to use this information as well. Experience gained through testing the effectiveness of these guidelines will improve our approach to conserving the species.

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METHODS

The Songbird in Question

Cerulean Warbler, a neotropical migratory songbird weighing about 9 gm, is accorded official conservation status in at least 13 states and provinces principally because its population has persistently declined (Link and Sauer 2002). Reasons for the decline are not fully known and may include changes in land use, in forest structure or composition, or in climate of breeding habitats; factors affecting the nonbreeding grounds; or events during migration (Robbins and others 1992). Designated a Vulnerable species by the International Union for the Conservation of Nature and Natural Resources (Birdlife International 2004), the species is listed as one of conservation concern by the U.S. Fish and Wildlife Service (Ruley 2000, Williams 2002). Partners in Flight has identified it as a first priority for conservation efforts throughout its range (Rich and others 2004). NatureServe, however, ranks it as apparently secure globally (G4) (http://www.natureserve.org/explorer, [Date accessed March 20, 2006]).

Migration, south during July-October and north during March-May, and nonbreeding residency in South America, August-March, occupy most of the annual cycle. Breeding occurs during April-August, and the breeding range coincides closely with the Central Hardwoods Region (fig. 1). Breeding habitat includes a great variety of hardwood forests in sawtimber stages of development. Thus, managers of mature hardwood forests in the Central Hardwoods Region are the primary stewards of the reproductive potential of these birds. Furthermore, areas in the most dependably occupied part of the breeding range (Baldy 2005) are

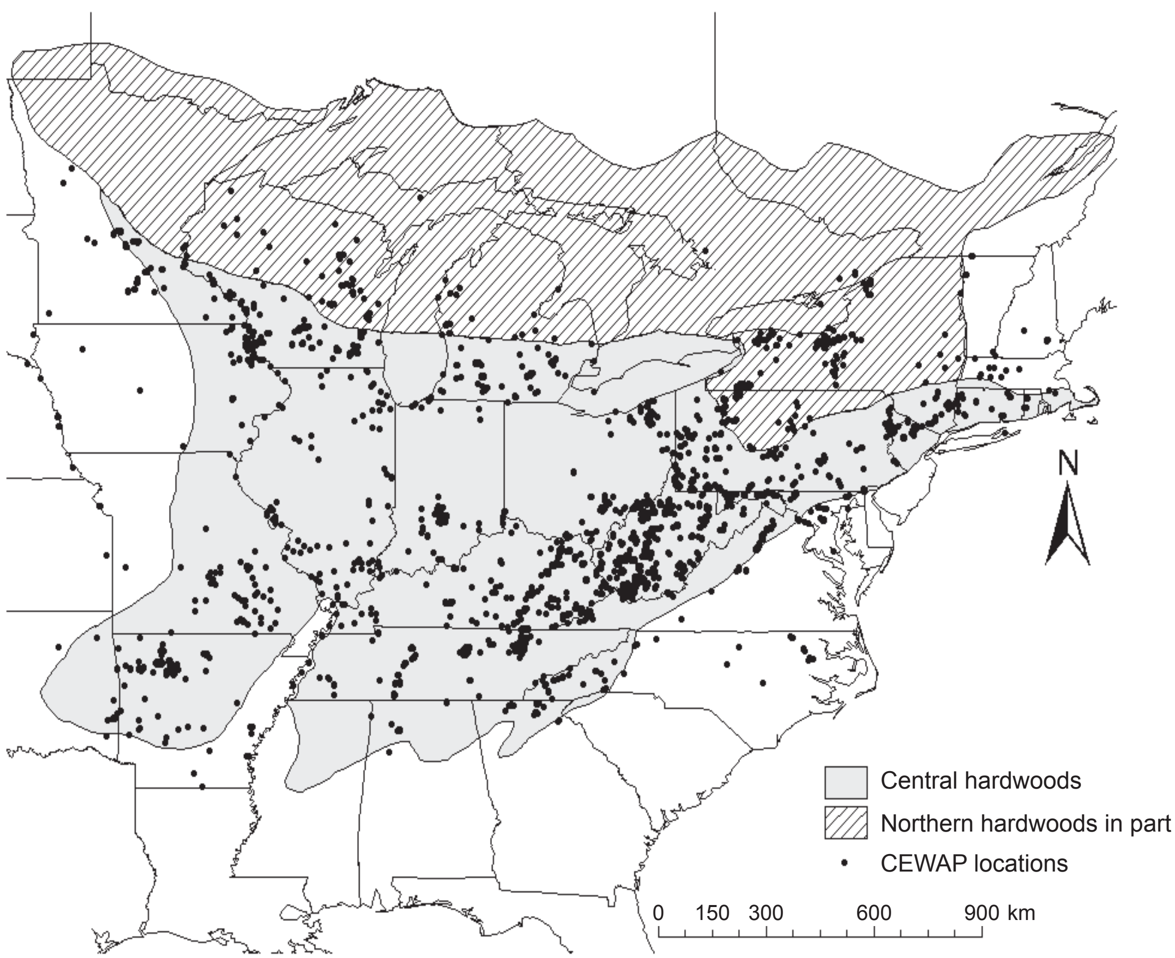

Figure 1—Breeding range of Cerulean Warbler as identified by the Cerulean Warbler Atlas Project (CEWAP; Rosenberg and others 2000), with outline of Central Hardwoods Region after Fralish (2003) and Pijut (2003).

also areas in which intensive coal extraction by mountaintop removal-valley fill methods is practiced, further emphasizing the importance of management of Central Hardwoods breeding habitats (Weakland and Wood 2005).

Cerulean Warbler Technical Group

The Cerulean Warbler Technical Group (CWTG) was formed in 2001 to inform conservation actions directed toward these birds. Founders of this *ad hoc* group recognized an opportunity to take a proactive approach to Cerulean Warbler conservation. They initiated a broad-based forum to exchange technically sound information about the birds. Members seek to preempt contentious and unproductive interactions that might otherwise result were the species to be listed under ESA. "By seizing the initiative and bringing a number of key stakeholders and technical experts together, the CWTG seeks to keep the focus on developing meaningful conservation solutions through sound science, clear communication, and trust" (Hamel and others 2004). With membership from seven nations, numerous states and provinces, international and national conservation and land management agencies and consortia, as well as timber companies, this effort encompasses the entire international range of the species (Hamel and others 2004). Current concern over effects of mountaintop removal-valley fill coal extraction on Cerulean Warblers (see Wood and Edwards 2001) suggests that the CWTG will be an efficacious forum to address issues of bird conservation and energy production. To better understand habitat distribution and management response of Cerulean Warbler in the central portion of the range, the CWTG has initiated a large-scale, replicated experiment in which the effects on the species of timber harvest to reduce canopy will be evaluated. An explicit CWTG goal is to develop forest management guidelines compatible with industry needs as well as with conservation goals to maintain and increase Cerulean Warbler populations.

Methods Used in the Review

We have compiled information presented in Hamel (2000a, 2000b), the Cerulean Warbler Atlas Project (CEWAP; Rosenberg and others 2000), and published and unpublished subsequent materials. We present the results of our review in a series of descriptions of habitat at several hierarchical scales from rangewide to nestsite. From these descriptions of habitat we infer treatments that may produce such habitats and suggest these as potential silvicultural practices that may produce habitat for the species.

HABITAT ASSOCIATIONS OF CERULEAN WARBLERS

Few publications specifically address relationships between silvicultural activities and Cerulean Warbler habitats. Kahl and others (1985) long ago suggested a vector of habitat conditions believed suitable for the birds in Missouri. Rodewald (2004) and Stoleson (2004) presented results of analyses of the birds' response to certain silvicultural practices in the Central Hardwoods Region. The Missouri Department of Conservation (2005) produced a short list of beneficial and detrimental practices for the species as part of a series on Best Management Practices. Hamel (2005) identified elements of a silvicultural prescription through analysis of observations of behavioral habitat use in the Lower Mississippi Alluvial Valley (LMAV). Hamel and others (2005) applied some of that prescription to an Arkansas site.

Scale Description

Cerulean Warbler response to habitat varies across the breeding range (Rosenberg and others 2000) for unknown reasons, and this suggests that management guidelines also will need to vary geographically. We present a sequence of habitat descriptions at successively finer scales. Similarities and differences identified in literature and unpublished studies can be viewed at regional, physiographic, forest type, topographic, edaphic, successional stage, tree species and size, nest vicinity, and nest microsite scales.

Breeding rangewide and regional—Cerulean Warblers breed in deciduous forests of eastern North America (fig. 1). The majority of populations today, as historically, occur in the Central Hardwoods Forest Region. Within this range, the species' association with tracts of different sizes is not consistent (fig. 2; Hamel 2000b). Across the Southeast and on the western edge of the range, the species is found predominantly in very large tracts. In the Midwest the species appears to use tracts of widely varying

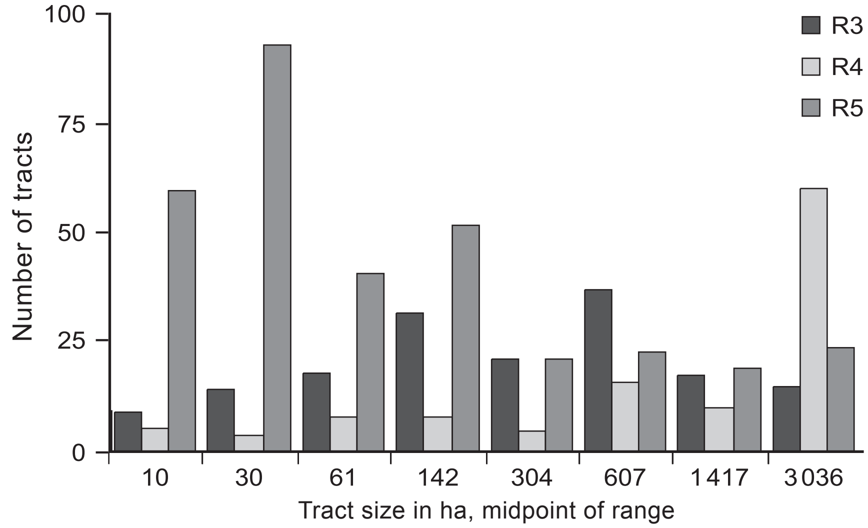

Figure 2—Distribution of Cerulean Warblers by size of tract, from Cerulean Warbler Atlas Project (Rosenberg and others 2000). R3 (Midwest), R4 (Southeast), and R5 (Northeast) correspond to states of the named regions of the U.S. Fish and Wildlife Service. Graph shows differences among parts of the range in the relative frequency of occupancy of tracts of different sizes.

sizes. In the Northeast a large proportion of sites identified in CEWAP were of modest size, while West Virginia birds occurred at lower density in small tracts (Weakland and Wood 2005). No data exist on demographic responses to different tract sizes. Why the species varies in its distribution among tract sizes across its range is not known; variation in Brown-headed Cowbird [*Molothrus ater* (Boddaert)] brood parasitism may be associated with it (Chace and others 2005).

Physiographic regions—The northern Cumberland and Allegheny Plateaus of the Mixed Mesophytic Region of the Central Hardwoods Forest (Fralish 2003) harbor 70 percent of the breeding population. Breeding also occurs in several other Regions, principally in those Sections that form part of the Central Hardwoods Forest. We believe the wider distribution results from association with Central Hardwoods Forest types as they occur in these Regions. The greater abundance in the northern Allegheny and Cumberland Plateaus results from the more continuous distribution of these forest types there.

Forest type—The Cerulean Warbler has repeatedly been identified as having a wide habitat distribution among mesic deciduous forest types within its geographic range (Hamel 2000b). Of 49 hardwood forest cover types in the East (Eyre 1980), Cerulean Warblers have nested in the nominate tree species of 33. However, this does not imply use of those forest types without preference throughout the range. In contrast, the species is often restricted to a few forest types, types that may differ from region to region. In a local area, the distribution is often bi-modal, with birds occurring in bottomland situations and on ridgetops, but not between. In the CEWAP report, numerous state summaries mention oaks and hickories and/or sycamore and cottonwood as the dominant tree species at occupied sites. Reports from different areas may conflict. For example, Stoleson (2004) reports Cerulean Warbler aversion to the black cherry-maple (*Prunus serotina* Ehrhart-*Acer* L. sp.) type in Pennsylvania, while Nicholson (2004) finds black cherry to be among the most frequent nest trees in eastern Tennessee. Our inference from this distribution is that the birds use situations of higher than average local fertility on mesic but neither xeric nor very hydric sites.

Elevation and aspect—Edaphic factors include elevations, topographic situations, aspect, and soil types. Cerulean Warblers nest at a wide range of elevations—almost the full range of elevations in the states in which they occur (Rosenberg and others 2000). Aspect has been evaluated in several studies. Bosworth's (2003) West Virginia results agree with Nicholson's (2004) demonstration in Tennessee that nest sites were on more mesic north-facing slopes than expected based on random point locations in the same plots (χ^2, 5 df, = 36, P < 0.0001). As with forest type and topographic situation, use of a wide variety of elevations across the range is the result of occurrence in different restricted subsets of elevations within individual localities.

Topographic situations—Cerulean Warbler breeding habitat includes upland and bottomland situations, apparently without preference (fig. 3). Some recent work suggests that the birds are partial to areas of local relief and areas of higher than average local elevation, from natural levees close to riverbanks (Castrale and others 1987, Robbins and others 1998), to ridgetops (Weakland and Wood 2005). The birds have access to upland as well as LMAV bottomland habitats at Meeman Shelby Forest State Park, Shelby Co., Tennessee. In the uplands there, they are often found at the edge of a bluff or crest of a saddle and seldom on side slopes. They occur only in the highest floodplain sites at the toe of the bluff at the edge of the floodplain (Hamel, P.B. Unpublished observation. Author can be reached at USDA Forest Service, Center for Bottomland Hardwoods Research, Stoneville, MS 38776).

Spatial distribution within stands—Barg and others (2005) show that individual male Cerulean Warblers concentrate their activities in specific core areas within their territories. Cerulean Warblers are frequently considered to be associated with forest canopy gaps. Nicholson (2004) found this for nest sites in east Tennessee. One carefully controlled test of this hypothesis compared nest to nearest gap distances with distances to nearest gap from randomly selected points in the same LMAV stands. Significant differences existed among stands in average distance to gap, but not between nest-gap and point-gap distances (Hamel 2005). Gap size criteria were not the same in these studies, however. Hunter and others (2001), Rodewald (2004), Stoleson (2004), and Wood and others (2005) associate the birds with canopy disturbance; Jones (2000), working in Ontario, does not.

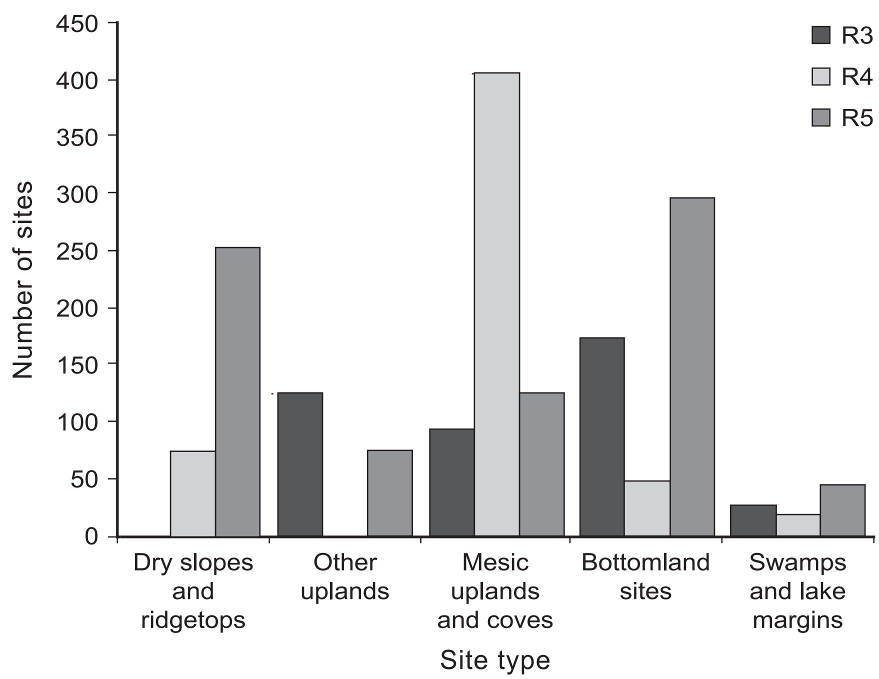

Figure 3—Distribution of Cerulean Warblers by broad site classes, from Cerulean Warbler Atlas Project (Rosenberg and others 2000). R3 (Midwest), R4 (Southeast), and R5 (Northeast) correspond to states of the named regions of the U.S. Fish and Wildlife Service. Graph shows differences among parts of the range in the relative frequency of occupancy of tracts on different site types.

Successional stage—Although the breeding distribution of the species includes many hardwood forest types, it is not so variable in its association with tree size. Cerulean Warblers breed in areas with large trees. One evaluation of tree size association of breeding territories (Robbins and others 1992) demonstrated that in upland as well as bottomland situations in Tennessee, males chose as song perches trees of larger than expected diameter compared to trees in their territories. The territories were located in areas of larger than expected tree diameters compared to the surrounding stand. The stands in their turn were composed of trees of larger than expected diameter compared to the regional norm. It is clear that the birds occur in stands in later successional stages, stands that have achieved mature sawtimber stature.

Tree species—From tree species selected by Cerulean Warblers, particularly for nesting (fig. 4), we can infer what silvicultural practices may be useful. The many species selected include both shade tolerant and shade intolerant trees. The list includes species across a wide range of flood and drought tolerance. The inference is that, within a stand of suitable forest type and size in a suitably forested landscape, the birds will use early successional species such as black locust (*Robinia pseudo-acacia* L.), eastern cottonwood (*Populus deltoides* Marshall), or yellow-poplar (*Liriodendron tulipifera* L.) when those trees achieve large stature. As these stands age and become dominated by large individuals of later successional oaks (*Quercus* L. sp.), hickories (*Carya* Nuttall sp.), and maples, the birds will continue to use such stands.

Tree size—From its description (Wilson 1811), Cerulean Warbler has been associated with large trees (Oliarnyk and Robertson 1996). Further, the birds are purported to use "tall trees." In the LMAV, Cerulean Warblers choose nest trees that are tall relative to heights expected from trees of their species and diameter based on norms derived from Forest Inventory Data sets (P.B. Hamel, unpublished ms). Mean height of 67 nest trees was 100 percent (± 3.9 percent S.E.) of the maximum height expected for a tree of that species

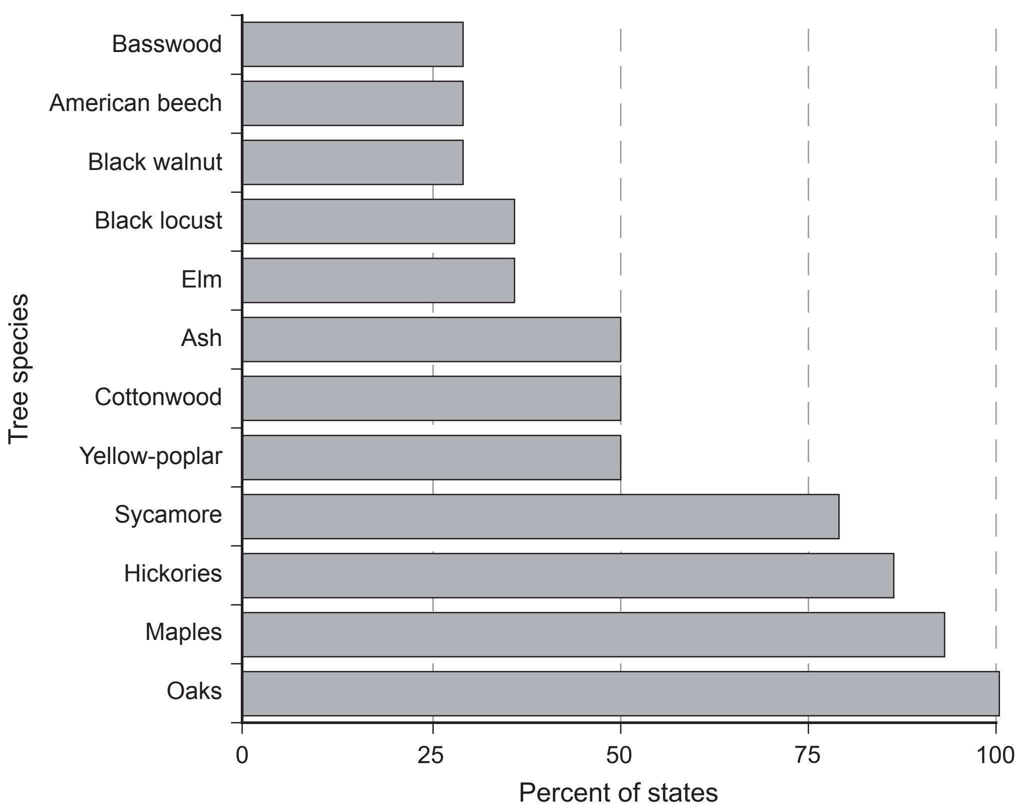

Figure 4—Tree species listed as dominant components of overstory in the Cerulean Warbler Atlas Project, grouped by state (from Rosenberg and others 2000).

and diameter recorded in the LMAV in the most recent Forest Inventory data set. This suggests that Cerulean Warblers prefer to nest in trees that are relatively tall for their diameters.

Nest site—Typically, Cerulean Warblers choose to place their small cup nest on the surface of a branch high in the canopy, closer to the outer edge of the canopy than to the bole. Often, the length of the branch on which the nest is placed approximates the radius of an open-grown tree of that species and diameter (Hamel 2005). This suggests that nest trees have experienced full sunlight on at least that side for some portion of their life. Often, the nest is placed at or near a fork in the nest branch; frequently a small cluster of leaves either of the nest tree or of vines on the nest branch provide some cover over the nest site.

Vertical distribution of vegetation near nests—Heterogeneous vertical distribution of vegetation in stands may be the common thread in understanding breeding habitat. Numerous authors indicate this is so and attribute it to stand structure (Hamel 2005, Jones and Robertson 2001), to topography (Bosworth 2003, Nicholson 2004, Wood and others 2005), or both. Existing methods to measure this structure are either too crude (James and Shugart 1970), or inapplicable at relevant heights (Mills and others 1991). Jones and others (2001) and Weakland and Wood (2005) use optical methods that are promising but imprecise. Describing how to produce this structure may be easier than measuring it.

Development of Management Prescriptions: Alternative Approaches

We challenge the management and silvicultural community generally to consider how objectives for a songbird can become incorporated into silvicultural practice at a regional scale. Cerulean Warbler, as Rodewald (2004) observed, is a species whose future population trajectory may profoundly affect forest management activities in Central Hardwoods. How, then, are we to identify appropriate management prescriptions for this bird? Potential silvicultural prescriptions for Cerulean Warbler habitat can be (1) inferred from habitat characteristics measured on breeding locations, (2) specified as techniques required to produce conditions identified from behavioral habitat selection, or (3) assessed from comparative responses of populations to management operations.

Habitat preference inferred from observed habitat use—The first two techniques lead to specification of management objectives with particular Cerulean Warbler outcomes anticipated. Where the inferences of quality habitat are correct, properly translated into silvicultural practices, and applied in such a way that the inferred habitat is produced, these practices constitute management for the species.

Starting from the premise that required habitat can be specified, the first two techniques build a prescription from the individual tree up. Kahl and others (1985) specify ranges observed at known sites of occurrence for canopy cover (total 85-90 percent, not <65 percent), density of large (>30 cm in d.b.h.) stems (100-125/ha, not <50 or >150), and tall canopy (>18 m), with modest density of shrubs (2100-2800 stems/ha, not <1030), moderate number of dead stems 2.5-10 cm in d,b,h,/ha (50-100/ha, not >175), and a subcanopy cover slightly less than that of the canopy (total 65-70 percent, not <45 percent). These values suggest a stand stocking percent of 65-80 (Ginrich 1967). Presumably a stand in one of the proper forest types, on a mesic site, which met these criteria would be a candidate stand to support Cerulean Warblers in Missouri, and perhaps in other areas.

Studies in Pennsylvania by Rodewald (2004) and by Stoleson (2004), and in West Virginia by Wood and others (2005), identified the silvicultural technique associated with the history of the stands in which the birds occurred. Stoleson (2004) reported that the shelterwood cut with prescribed burning treatments commonly used to manage oak stands resulted in higher abundance and frequency of Cerulean Warbler occurrence than did other treatments. Rodewald (2004) addressed the effects of forest management at the landscape scale. The birds in her Pennsylvania study area were positively associated both with high proportion of forest area within 1km and with nearness to recent forest harvest. Wood and others (2005) reported that Cerulean Warbler use of two-age stands harvested 15-18 years previously was greater than use of clearcut stands of similar age. The results of Kahl and others (1985), Rodewald (2004), Stoleson (2004), and Wood and others (2005) are testable hypotheses of silvicultural prescriptions.

Hamel (2005) designed a prescription around the trees selected by the birds. It combines (1) large, tall sawtimber trees from which males can broadcast their songs, with (2) suitable long-limbed trees in which nests might be placed. The tall sawtimber trees may be of shade-tolerant or more likely shade-intolerant species, and well-spaced in the stand. In the close vicinity of these trees should be favored the development of potential nest trees: large, long-limbed midstory trees of shade-intolerant, or more likely shade-tolerant, species. The prescription is based on extensive work in the LMAV. Implications of the prescription for other species and resources are secondary to the intent of producing habitat specifically for Cerulean Warbler. Difficulties with the prescription lie in the many assumptions involved in determining "required" habitat elements. Hamel and others (2005) are conducting an experimental test of this prescription in an unreplicated study.

Evaluation of alternative standard silvicultural practices—The third technique for establishing a prescription is to evaluate Cerulean response to alternative stand structures that result from standard silvicultural practices. This is the approach taken in the large-scale CWTG experiment, which is contrasting treatments that differ largely in the degree of canopy cover retained following harvest. The treatment with the strongest positive Cerulean Warbler response is inferred to produce the best habitat for the birds from among the alternatives tested. Alternatives that appear to be good candidates are treatments designed to produce large sawtimber trees with spreading crowns, in the vicinity of intermediate midstory crowns. The series of thinning treatments identified in the CWTG experiment appear to be appropriate to produce variants of this structure, provided they do not too greatly reduce either regeneration of canopy species or maintenance of shade-tolerant midstory. The application of standard treatments has the advantage that implications of these treatments for the production of other benefits from the forest are known. Thus, these practices are likely to be applied by landowners. However, unless the treatments are designed with sensitivity to the behavioral ecology of the species, this approach runs the risk of failing to produce good habitat without leading to an explanation for its own failure. On the other hand, silvicultural practices based exclusively on behavioral ecology of the Cerulean Warbler will never be implemented by landowners unless they are economically viable and silviculturally practicable.

Management Risks: Our Caveat

This is a review of existing data from which hypotheses about desired forest conditions can be derived. Virtually none of it represents validated, completed experimental tests of manipulations designed to produce hypothesized habitat conditions. For this reason it is likely that these hypotheses are not entirely accurate, and that the proposed silvicultural treatments will produce habitats that only approximate those chosen by Cerulean Warblers or observed to be used by Cerulean Warblers in the past. We therefore propose the guidelines as a specific, testable set of predictions of what is habitat for Cerulean Warblers and how it can be produced. We believe firmly that by making such predictions we can accelerate the process by which a silvicultural prescription for the birds can be developed. We are further convinced that sufficient time exists in which to test and improve the prescription and to compare the results of a prescription directed toward producing habitat specifically for the species to the results of prescriptions designed for other objectives and applied to habitats in which the birds occur. The ultimate conservation of the species is an achievable goal. We are further aware that factors external to any property may intervene to compromise tests of silvicultural prescriptions applied to that property. Such external factors include (1) climate variations that reduce or enhance the probability of occurrence of the birds on that property during the test, (2) land use changes in the local and regional landscape that may alter the relative proportion of forest above or below threshold values for "fragmented forest" landscapes, (3) catastrophic events occurring during migration, and (4) events occurring to nonbreeding habitats in South America and stopover habitats in Central America and North America that may affect survival, and hence abundance, of the birds. Despite the existence of such risks, however, we are dedicated to the ideal of effective stewardship of Cerulean Warbler habitats, stewardship that can likely be achieved most appropriately with respected tools of silviculture.

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RUFFED GROUSE (*BONASA UMBELLUS*) USE OF STANDS HARVESTED VIA ALTERNATIVE REGENERATION METHODS IN THE SOUTHERN APPALACHIANS

Benjamin C. Jones and Craig A. Harper[1]

Abstract—Ruffed grouse (*Bonasa umbellus* L.) habitat use was studied in the mountains of western North Carolina. In 1997, 9 stands on the study site were harvested via alternative regeneration methods, including shelterwood, irregular shelterwood, and group selection. From 1999–2004, 276 grouse were radio tagged and monitored, resulting in over 7,000 location estimates. Habitat use differed from availability in all seasons. Preferred habitats included gated forest roads, 3–20-year old mixed-oak, late rotation mixed-oak, and mature mesic hardwoods. Shelterwood and two-aged stands created by irregular shelterwood were among habitats preferred in fall, winter, and spring. Group selections were among habitats preferred by broods in summer. Use of alternative regeneration stands began 3 years after harvest and continued through study completion (6 years post-harvest). Hardwood stem density in alternative regeneration stands was within the range recommended for ruffed grouse habitat. With proper implementation, alternative regeneration methods can create quality ruffed grouse habitat in the Appalachian region.

INTRODUCTION

Ruffed grouse (hereafter grouse) are forest-dwelling gamebirds distributed across southern Canada, the northern United States, and southward through the Appalachian Mountains. Although forest types vary across their range, a common characteristic of optimal grouse habitat is dense woody cover with >17000 woody stems/ha (Gullion 1984). Suitable conditions are often found in young (i.e., 5–20-year-old) forests created by timber harvest or natural disturbance; however, various age classes are used as biological activities and food availability change through the year (Gullion 1977, Kubisiak and others 1980).

Silvicultural prescriptions that intersperse age classes are a cornerstone of grouse habitat management. In the Great Lakes states, buds of mature aspen (*Populus tremuloides, P. grandidentata* Michaux) provide an important winter food source while regenerating stands afford cover (Svoboda and Gullion 1972). Over a typical 40-year aspen rotation, a patchwork of small clearcuts implemented at 10-year intervals meets both requirements in close proximity (Gullion 1977). In the central and southern Appalachians (CSA), interspersion of forest types and age classes is especially important as grouse use diverse food sources (i.e., hard and soft mast, and herbaceous plants) in the absence of aspen (Whitaker 2003). Although clearcutting is generally recommended as a grouse habitat management practice, public land managers in the CSA are interested in use of esthetic alternatives to clearcutting. In addition to esthetics, methods such as shelterwood, irregular shelterwood, and group selection may be used to influence species composition, hard mast production, and herbaceous communities (Beck 1986, Dale and others 1995, Loftis 1990, Miller and Schuler 1995, Stringer 2002, Wender and others 1999). Although alternative regeneration methods may have implications for habitat management, little information exists regarding grouse use of these stands. In the mid-1990s, the Southern Research Station began monitoring ecological impacts of alternative regeneration methods on Wine Spring Creek Ecosystem Management Area, (WSC). Initiated in 1999, this study represented the wildlife focus for Phase II of the overall WSC project. Ruffed grouse ecology data were collected through summer, 2004.

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STUDY SITE

Wine Spring Creek Ecosystem Management Area (WSC) is within Nantahala National Forest in Macon County, North Carolina. The area is in the Blue Ridge Physiographic Province and is part of the southern Nantahala Mountain Range. Elevation ranges from 915 m to 1644 m. Terrain is characterized by long, steep ridges with perpendicular secondary ridges that connect upper elevations to narrow valley floors (Whitaker 1956). Mean annual temperature is 10.4 ºC, and mean annual precipitation is 160 cm (National Oceanic and Atmospheric Administration). The area was predominantly forested with <1 percent coverage in permanent openings. The United States Department of Agriculture, Forest Service purchased WSC in 1912 after it was logged. Since then, forest management practices included salvage harvest of blight-killed American chestnut (*Castanea dentata* Marsh.), thinning, clearcutting, and diameter-limit cutting (McNab and Browning 1993).

PROCEDURES

Habitat Delineation

Habitats were classified by a combination of vegetative community type and stand age. Communities were stratified into 3 classes (xeric, subxeric, and mesic) defined by elevation, landform, soil moisture, and soil thickness (McNab and Browning 1993; table 1). Xeric communities were on high elevation, steep, south and west aspects characterized by thin, dry soils. Tree species included, scarlet oak (*Quercus coccinea* Muenchh.), black oak (*Q. velutina* Lam.), pitch pine (*Pinus rigida* Mill.) and chestnut oak (*Q. prinus* L.) in the overstory with ericaceous plants including huckleberry (*Gaylussacia baccata* Wangenh.), lowbush blueberry (*Vaccinium vacillans* L.), and mountain laurel (*Kalmia latifolia* L.) in the understory.

Subxeric communities were at middle elevations and upper elevations on less exposed aspects. Soil characteristics were between xeric and mesic, or subxeric and submesic (Whitaker 1956). Overstory was dominated by chestnut oak, white oak (*Q. alba* L.), hickory (*Carya* spp.), northern red oak (*Q. rubra* L.), red maple (*Acer rubrum* L.), and yellow-poplar (*Liriodendron tulipifera* L.). Ericaceous understory

Table 1—Forest stand associations, understory characteristics, and corresponding USDA Forest Service and Society of American Foresters codes for land classifications used to define ruffed grouse habitats on Wine Spring Creek Ecosystem Management Area, Macon County, NC 1999–2004

Land class	Moisture	Forest associations	Understory	USFS	SAF
Xeric	Xeric	Scarlet oak	> 75% ericaceous	59	NA
	Xeric	Pitch pine–oak	> 75% ericaceous	15	45
	Xeric	Chestnut oak–scarlet oak	50 – 75% ericaceous	60	NA
	Subxeric	Chestnut oak	50 – 75% ericaceous	52	44
Subxeric	Subxeric	Chestnut oak	25 – 50% ericaceous	52	44
	Subxeric	White oak–red oak–hickory	25 – 50% ericaceous	55	52
	Subxeric	Northern red oak	Herbaceous	53	55
	Submesic	Yellow-poplar–white, red oak	Herbaceous	56	59
Mesic	Submesic	Yellow-poplar	Herbaceous	50	57
	Submesic	Sugar maple–beech–yellow birch	Herbaceous	81	25
	Submesic	Basswood–yellow buckeye	Herbaceous	41	26
	Mesic	Hemlock	75 – 100% rhododendron	8	23

USFS = USDA Forest Service; SAF = Society of American Forests.
Adapted from McNab and Browning (1992).

occupied 25–50 percent groundcover on drier microsites whereas herbaceous plants occupied more mesic sites within this category.

Mesic communities occurred on north and east aspects, on lower slopes, and in sheltered coves. Stands were comprised of yellow poplar, eastern hemlock (*Tsuga Canadensis* L.), northern hardwoods, including sugar maple (*A. saccharum* L.), American beech (*Fagus grandifolia* Ehrh.), and yellow birch (*Betula alleghaniensis* Britton), and mixed mesophytic obligates, including American basswood (*Tilia Americana* L.) and yellow buckeye (*Aesculus octandra* Marsh.). Understory was herbaceous except where rhododendron (*Rhododendron maximum* L.) inhibited groundcover. Sites with 75–100 percent cover in rhododendron were placed in a separate habitat classification (RHODO).

An additional land class included gated forest roads (ROAD). Forest roads were defined by a width of 5m from road center on each side. The 10-m width included two gravel tracks separated by herbaceous vegetation and the adjacent berm maintained by mowing. Management of roads included an initial planting of orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.) and white-dutch clover (*Trifolium repens* L.) maintained by annual or biennial mowing.

Stand ages were determined by years since harvest or stand establishment in five categories deemed important to ruffed grouse (0–5, 6–20, 21–39, 40–80, >80 years). Forest roads and RHODO were not assigned age categories because their structural characteristics were similar across age classes.

Alternative regeneration stands were harvested 1996–1997. Target residual basal area for shelterwood stands was 9.0 m^2/ha. Mean size of shelterwoods was 5.56 ha ($\pm$ 0.42 SE, n = 3). Grouse habitat use data were collected prior to removal of residual overstory. Irregular shelterwood was used to create two-aged stands with target residual basal areas of 5.0 m^2/ha. Mean size of two-aged stands was 4.68 ha ($\pm$ 0.18 SE, n = 3). Group selection was implemented in 3 stands with 4–9 groups/stand. Mean stand size was 14.3 ha ($\pm$ 4.70 SE) and mean group size was 0.36 ha ($\pm$ 0.05 SE). On average, within-stand groups were 65.7 m apart ($\pm$ 7.83 SE). All shelterwood, two-aged, and group selection stands were on subxeric sites. Because these were the only harvests implemented after 1996, alternative regeneration exclusively represented the subxeric, 0–5-year habitat type (SUBXER1). Clearcuts on WSC (n = 44) were harvested in the late 1980s and early 1990s and represented the 6–20-year age class. Most clearcuts were on subxeric sites (SUBXER2) and ranged from 1.3 to 24.6 ha.

Subxeric oak and mixed oak-hickory in the >80 year age class (SUBXER5) made up the greatest proportion of the study area (31.7 percent; table 2). Early successional habitats in the 6–20-year age class (XERIC2 and SUBXER2) occupied 9.3 percent. The 6–20-year, and 21–39-year age classes were not represented on mesic sites. There were 52.6 km of gated forest roads (1.1 percent of total area).

Capture and Telemetry

Grouse were captured using intercept traps (Liscinsky and Bailey 1955, Gullion 1965) during two annual periods, late August–early November, and early March–early April, 1999–2003. Birds were weighed, leg-banded, fitted with 12-g necklace-style radiotransmitters (Advanced Telemetry Systems, Isanti, Minnesota) and released at capture sites after processing. Radiotagged birds (n = 276) were located $\geq$2 times per week from permanent telemetry stations. Telemetry accuracy was assessed by mean grouse location error ellipse (1.9 ha $\pm$ 0.06 SE) and bearing error on test beacons ($\pm$ 6.53°).

Home Range and Habitat Use

The ArcView 3.2 Animal Movement Extension (Environmental Systems Research Institute Inc., Redlands, CA; Hooge and Eichenlaub 1997) was used to calculate fixed kernel home ranges (Worton 1989). Estimates were based on 75 percent kernel contours to define central portions of a home range and exclude “occasional sallies” (Burt 1943, Seaman and others 1999). Home ranges were overlain on a Geographic Information System (GIS) created for the area using color infrared aerial photographs, 1:24,000 U.S. Geologic Survey 7.5-minute quadrangles, U.S. Forest Service Continuous Inventory of

Table 2—Stand age, land class, resultant ruffed grouse habitat type and study area coverage on Wine Spring Creek Ecosystem Management Area, Macon County, NC, 1999–2004

Age	Land class	Habitat	Coverage
years			*percent*
0 – 5	Subxeric	SUBXER1	1
6 – 20	Subxeric	SUBXER2	8
21 – 39	Subxeric	SUBXER3	2
40 – 80	Subxeric	SUBXER4	3
> 80	Subxeric	SUBXER5	32
6 – 20	Xeric	XERIC2	1
40 – 80	Xeric	XERIC4	2
> 80	Xeric	XERIC5	12
40 – 80	Mesic	MESIC4	10
> 80	Mesic	MESIC5	9
NA	Mesic	RHODO	20
NA	Roads	ROAD	1

NA = not applicable.

Stand Condition (CISC), and ground truthing. The proportion of habitats within grouse home ranges represented habitat use. Home ranges were estimated for each of 4, 91-day seasons defined by plant phenology and grouse biology. Fall (17 September–14 December) was a period of food abundance and dispersal among juveniles. Winter (15 December–16 March) was defined by minimal food resources and physiological stress. Spring (17 March–15 June) coincided with vegetation green-up and breeding activity. In summer, telemetry efforts were focused on females with broods. Brood hens were located 2–3 times daily from hatch to 5 weeks post-hatch. Across seasons, mean locations/home range was 27 (3.1 SE).

Habitat use was compared to availability at the study area scale with compositional analysis (Aebischer and others 1993). Compositional analysis calculates pair-wise differences in use versus availability for corresponding habitat log-ratios. These differences are then used to rank habitats by relative preference and allow testing for between-rank significance ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Seasonal Habitat Use

Seasonal home ranges ($n = 172$) were estimated for 85 individuals. Habitat use differed from availability during all seasons ($P < 0.001$). Females tended to use greater diversity of forest types and ages compared to males. Top-ranked habitats for females included SUBXER1, SUBXER2, SUBXER5, and ROAD during brooding; SUBXER1, SUBXER2, SUBXER5, RHODO, ROAD, and XERIC5 in winter; and SUBXER1, SUBXER2, RHODO, ROAD, and MESIC4 during fall and spring. There were no between-type differences, indicating these habitats were interchangeable in their rank status. Top-ranked habitats for males included SUBXER2 and ROAD in fall and winter, and ROAD in spring.

Use of shelterwood and two-aged stands was indicated by inclusion of SUBXER1 among habitats preferred by females in fall, winter, and spring. Stands harvested via alternative regeneration techniques were restricted to the southern third of the study site; nonetheless, 22 grouse (7 juvenile female, 1 adult female, 7 juvenile male, 7 adult male) included shelterwood and two-aged stands in their home ranges. Use began 3 years after harvest and increased through the study's conclusion at 6 years post-harvest. Group selections were important brood habitats in summer, though they were not used extensively in fall, winter, and early spring.

Across seasons, female grouse used a diversity of early successional and mature stands and roads, while males centered activity in 6–20 year-old subxeric hardwoods and adjacent roads. Association of ruffed grouse with early seral stages is well documented (Dessecker and McAuley 2001); however, interspersion of forest types and age classes ultimately determines habitat quality (Bump and others 1947, Berner and Gysel 1969, Gullion 1972, Kubisiak 1985). In the Appalachians, interspersion is especially important, as grouse must optimize the balance between energy gain and predation risk. Nutritional constraints posed by reproduction may cause females to spend greater time in foraging habitats, while males opt for cover (Whitaker 2003). The use of diverse forest types by female grouse on WSC supports this contention.

Shelterwood and Two-Age

Grouse first utilize regenerating stands for cover after midstory stems are naturally thinned to approximately 37,000 total woody stems/ha (Gullion 1984). Grouse use on WSC indicated conditions were suitable at 3 years post-harvest when density of woody stems <5.0 cm dbh and >1 m tall was 38,269 stems/ha in shelterwood and 49,117 stems/ha in two-age (Elliott and Knoepp 2005). Stand age at first use was similar to oak-hickory clearcuts in Ohio (Stoll and others 1999), but sooner than 7 years post-clearcut in Pennsylvania mixed oak (Storm and others 2003) and Wisconsin aspen (McCaffery and others 1996).

Reports of regenerating stem densities following shelterwood, irregular shelterwood, and group selection in the Appalachians are within the optimal grouse habitat range of 17,000–37,000 woody stems/ha and similar to stem densities found in clearcuts (Beck 1986, Loftis 1983, Miller and Schuler 1995, Weigel and Parker 1995). An advantage of shelterwood and irregular shelterwood over clearcutting is retention of mature mast producers, especially oaks, for some time after harvest. Following clearcutting, there is a 25–40-year time lag in seed production, requiring grouse to forage and seek cover in different areas. With shelterwood and irregular shelterwood, hard mast and cover are available within the same stand creating optimal foraging conditions. Considering overwood retention time, benefits will be longer lasting in two-aged stands created by irregular shelterwood. Increased growing space also may result in greater acorn production by residuals (Stringer 2002). In a West Virginia two-aged stand, Miller and Schuler (1995) also noted regeneration of additional species important to wildlife, including American hornbeam (*Carpinus caroliniana* Walt.), flowering dogwood (*Cornus florida* L.), pin cherry (*Prunus pennsylvanica* L.), serviceberry (*Amalanchier arbororea* Michx.), and wild grape (*Vitis* spp). These species also were noted in WSC harvest units and grouse use of shelterwood and two-aged stands likely resulted from a combination of desirable midstory structure and food availability.

Group Selection

In summer, SUBXER1, SUBXER2, and SUBXER5 were among habitats used by broods, creating an apparent contradiction with use of both late rotation and early successional areas. Closer examination of stand conditions revealed why broods showed similar use of these habitat types. During the mid-1980's an extensive drought in the southeastern United States resulted in increased overstory tree mortality and canopy gap formation (Clinton and others 1993). These canopy openings promoted localized patches of early successional structure attractive to grouse broods (Jones 2005). Similar conditions were found in 0–5-year-old group selection, and brooding females were often associated with both types of forest openings.

Regarding forest management for grouse, a concern is that group selection creates isolated pockets of habitat. A potential solution may be to thin between groups within a stand. Thinning can soften edge effects and provide improved habitat conditions and connectivity between groups. Groups themselves also may serve as travel corridors. If positioned appropriately on the landscape, groups can provide patches of cover connecting otherwise disjunct habitats.

CONCLUSIONS

Various aspects of shelterwood, irregular shelterwood, and group selection have utility in creating grouse habitat in the Appalachians. Perhaps the greatest benefit is flexibility in management options with these methods. Depending on objectives, managers can influence conditions by adjusting percent canopy cover and species retention. For plans concentrating on grouse habitat (and other wildlife in general), retention of mature trees in both the white and red oak families will decrease probability of mast crop failure in a given year. Retention of other trees and shrubs including flowering dogwood, black gum (*Nyssa sylvatica* Marsh.), serviceberry, pin and black cherry (*Prunus serotina* Ehrh., *P. pensylvanica* L.), and witch hazel (*Hamamelis virginiana* L.) can prove beneficial without negatively impacting growth of commercial species (Miller and Schuler 1995). In addition, alternative regeneration methods can promote oak regeneration ensuring hard mast production in the future stand. As an esthetic alternative to clearcutting, shelterwood, irregular shelterwood, and group selection also may provide opportunities to regenerate mature stands that would not be possible via traditional clearcutting.

Topography of the Appalachians creates diverse vegetation communities defined by changes in soil type, thickness, and moisture (Whitaker 1956). With heterogeneity in soil characteristics, various communities and associated ecotones often occur in close proximity, presenting unique opportunities to intersperse forest types. The greatest diversity often occurs on midslope transition zones between xeric uplands and mesic lower slopes (Berner and Gysel 1969, McNab and Browning 1993). By placing timber harvests on midslope positions, managers can take advantage of diverse food sources while creating early successional cover in close proximity. Timber harvest on midslopes also can create corridors between upper and lower elevation habitats and connect disjunct patches. Management activities designed to intersperse forest types and age classes may prove most beneficial to ruffed grouse in the Appalachians.

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EFFECTS OF LONG-TERM PRESCRIBED FIRE ON SMALL MAMMAL POPULATION DYNAMICS AND MOVEMENT IN AN OAK BARRENS COMMUNITY IN TENNESSEE – PRELIMINARY RESULTS

Rebecca L. Stratton and Wayne K. Clatterbuck[1]

Abstract—Restoration and maintenance of structure and composition of flora and fauna communities associated with frequent fire is a common management goal. However, few studies have been conducted on the effects of prescribed fire on small mammal communities. To study the effects of fire frequency on small mammal population dynamics, small mammals were live-trapped using a mark-recapture method pre- and immediately post-burning across three replicates of three treatments (annual, periodic, and control) on an oak barrens site at the University of Tennessee Forestry Experiment Station near Tullahoma, TN. The plots were initially established in 1962 as part of long-term fire ecology and stand dynamics studies. The annual burn plots have been burned continuously since 1963 and periodic burn plots have been burned every 5 years since 1964. Each treatment block (0.73 ha) contains 24 stations with 2 Sherman traps placed on a 10 m spaced 8x3 grid. Each block was trapped for 16 days, totaling 6915 trap nights per trapping period. Early results indicate fire frequency alters small mammal species abundance, occurrence, and movements. Captures throughout the plots total 147 individuals with 531 total captures encompassing 9 species. Species abundance and occurrence are highest in the periodic plots. The predominant species found across all plots is the white-footed mouse (*Peromyscus leucopus*) followed by the pine vole (*Microtus pinetorum*). One semi-arboreal species, the golden mouse (*Peromyscus nuttalli*), is found only in periodic plots. Small mammal movements between plots were minimal. Although long-term burning clearly affects stand structure and small mammal population dynamics, more work needs to be done on population dynamics and movements of small mammals under different disturbance regimes.

INTRODUCTION

The restoration and maintenance of historically pyric communities with prescribed fire has become a common management tool. Restoration of these communities is generally easily attained, however many managers have difficulty maintaining these restored systems (Boerner 1981, Glitzenstein and others 1995). Little is known about proper fire frequency, intensity, and scale in the eastern deciduous forest that commonly burns on greater than 5-year burning regime. In addition, research is difficult due to the time involved to perform the research. Similarly, little is known about population dynamics of small mammals in restored pyric communities. Many studies have looked at changes in populations as a result of single fires (Ford and others 1999, Kirkland and others 1996, Krefting and Ahlgren 1974, Lunney and others 1987, Monroe and others 2004, Keyser and others 2001, Sullivan and Boateng 1996, Tester 1965). The objectives of this study were to assess small mammal population dynamics between sites with different fire regimes by evaluating species abundance, species occurrence, and movements between plots immediately before and after a low intensity annual prescribed fire.

SITE

This study is located on 7.3 ha of the University of Tennessee Highland Rim Forestry Experiment Station near Tullahoma, TN. The station is 348 ha situated on the Eastern Highland Rim at the eastern edge of the Interior Low Plateaus Province in middle Tennessee. Although the Highland Rim is characterized by rolling hills and wide valleys, the barrens are a flat plain furrowed by ravines with many streams. The climate is warm and humid with hot summers and cool winters ranging from -2.7 to 5.6°C in January and 19.1°C to 31°C in July. Precipitation averages 11.2 cm in January to 12.8 cm in July with an average

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annual precipitation of 146 cm (Phillips and others 2000). The site is classified as “oak barrens” with a long history of frequent low intensity fires prior to the establishment of this study. The “oak barrens” ecosystem is characterized by a low basal area and low quality predominantly oak overstory, with little to no midstory or understory, and a prairie-like grass and forb herbaceous layer. The primary species found in the overstory are post oak (*Quercus stellata*), southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), and blackjack oak (*Q. marilandica*).

PROCEDURES

The plots for this study were established in 1962 as part of long-term fire ecology and stand dynamics studies and have been burned continuously since 1963. The study contains three replications of three late-winter/early-spring prescribed fire frequency treatments (annual, 5-year periodic, and control). The periodic plots are currently in the third growing season since burning. Each treatment block is approximately 0.73 ha and they occur adjacent to each other with no buffers. The treatment blocks offer three distinctly different habitat structure types. The annual burn plots are an oak savanna with a few large overstory trees, a less than .5 m tall grass-herbaceous mix understory and no midstory with little litter or duff. The five-year periodic plots represent old-field succession with less canopy cover than the annual plots and a 1.5 to 2 m tall woody-herbaceous mix dense understory and little midstory with moderate litter and duff. The control plots represent a closed canopy stratified mix of midstory and overstory trees with more litter and duff and very little herbaceous understory. The amount of litter or duff was a consequence of frequency of burning.

Small mammal sampling using mark-recapture live trapping was conducted immediately pre- and post-treatment during the spring of 2005. Each treatment block contained 24 stations with 2 Sherman traps per station. The traps were spaced 10 m apart on an 8x3 grid with a 20 m outer buffer. Each block was trapped for 16 days, totaling 6915 trap nights per trapping period. All treatment blocks were trapped at the same time to reduce error due to movement and to allow for monitoring of movements between plots. Small mammal movement was calculated as total recaptures from a previously recorded block. All captures were individually ear-tagged. Minimal tag loss was observed in this study. Small mammal home-ranges of the species usually ranges in size from approximately .08 to 10 acres (Burt and Grossenheider 1980). Therefore, we assume any movements in or out of the annual burn plots greater than that found pre-treatment is a direct result of treatment.

Pitfall traps are the preferred methodology for sampling shrews. The protocol of our small mammal capture permit did not allow the use of pitfall traps. Although some shrews were captured in the Sherman traps, they were not tagged. Thus, we were not able to determine recapture rate of shrews.

RESULTS AND DISCUSSION

Species Abundance and Occurrence

We caught 147 individuals with 531 total captures (384 recaptures) encompassing 9 species across all plots, however not all species were present in each treatment. The two most abundant species trapped in all treatment plots for both pre- and post-burn plots were white-footed mouse (*Peromyscus leucopus*) and pine vole (*Microtus pinetorum*). *P. leucopus* and *M. pinetorum* accounted for the largest percent of total captures on annual treatments for both pre- and post-burn trapping periods (table 1). Percent of total recaptures for the periodic burn treatment was 75 percent pre-burn and 79 percent post-burn (table 1). The lowest percentages of *P. leucopus* and *M. pinetorum* total captures were in the control treatment, accounting for 65 percent of pre-burn and 63 percent of post-burn captures (table 1).

Southern flying squirrel (*Glaucomys volans*) and short-tail shrew (*Blarina brevicauda*) were both found primarily in the control treatment (table 1). Similarly, other species were found to be treatment specific or only found in two of the three treatments. Two species, hispid cotton rat (*Sigmodon hispidus*) and meadow jumping mouse (*Zapus hudsonius*), were found only and infrequently in periodic plots. The golden mouse (*Peromyscus nuttalli*), a semi-arboreal species, was present only in the periodic treatment

Table 1—Percent of total captures by treatments and all treatments combined for pre-burn and post-burn trapping periods following the annual burn treatment, UT Highland Rim Forestry Experiment Station, Tullahoma, TN, 2005[a]

Taxa	Annual Pre (n = 49)	Annual Post (n = 68)	Periodic Pre (n = 125)	Periodic Post (n = 174)	Control Pre (n = 31)	Control Post (n = 84)	Combined Pre (n = 205)	Combined Post (n = 326)
	- - - - - -	- - - - - -	- - - - - -	*percent*	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Blarina brevicauda short-tail shrew	4	0	2	1	7	12	3	4
Tamias striatus eastern chipmunk	0	0	0	5	0	1	0	3
Sciurus carolinensis eastern gray squirrel	0	1	0	0	0	4	0	1
Glaucomys volans Southern flying squirrel	4	4	1	2	29	20	6	8
Peromyscus leucopus white-fooded mouse	74	84	49	32	61	48	57	47
Ochrotomys nuttalli golden mouse	0	0	10	10	0	0	6	7
Sigmodon hispidus hispid cotton rat	0	0	8	6	0	0	5	1
Microtus pinetorum pine vole	18	9	30	43	3	14	23	28
Zapus hudsonius meadow jumping mouse	0	0	0	2	0	0	0	1
Total percent	100	100	100	100	100	100	100	100

n = total number of captures by trapping period and treatment.
[a] Area represented by each treatment is for three replicates totalling 2.2 ha.

plots and accounted for 10 percent of the total captures for that treatment (table 1). Eastern chipmunk (*Tamias striatus*) was trapped primarily in the periodic treatment and was infrequently found in the control treatments. Eastern gray squirrel (*Sciurus carolinensis*) was sporadically captured in the control and annual treatment plots.

The total number of species caught was the greatest in the periodic treatment with 7 total species. The annual treatment plots supported 6 species, while the control treatment was the lowest with 4 species.

Movements

Little movement occurred as a result of annual burning (table 2). Total movement across all plots was 39 of 384 recaptures. There were 16 pre-treatment captures and 23 post-treatment captures recorded. Movements into the annual burn treatment were 5 captures pre-burn and 7 captures post-burn. The periodic burn treatment movements were 9 captures pre-burn and 8 captures post-burn. The pre-burn/post-burn movements in the control treatment were 2 and 8 captures. Because *B. brevicauda* was not tagged, movement for this species is unknown.

Table 2—Small mammal movements by treatments and all treatments combined for recaptured mammals from pre-burn and post-burn trapping periods, UT Highland Rim Forestry Experiment Station, Tullahoma, TN, 2005[a]

Treatment	Number moved	
	Pre-burn	Post-burn
Annual	5	7
Periodic	9	8
Control	2	8
Combined	16	23

[a] Area represented by each treatment is for three replicates totalling 2.2 ha.

Annual Burn Treatment

The annual burn treatment shows no evidence of small mammal mortality or increased movements after a single annual late-winter low intensity burn, similar to numerous comparable studies (Ford and others 1999, Penn and others 2003, Simon and others 2002, Thompson and others 1989). However, our data suggests that for this area, different long-term fire disturbance regimes appear to be the proximate causal factor determining small mammal population dynamics and available habitat. Annual burning creates an oak-savanna, limiting food and cover availability thus lowering the carrying capacity and the species able to adapt. Most food resources are produced and destroyed annually. There is little to no litter or duff and the herbaceous vegetation is sparse with high amounts of bare ground thus limiting cover. The lack of a shrub layer and limited food resources explains the high amount of generalist small mammals present, such as *P. leucopus*.

Control Treatment

Lack of disturbance in the control treatment creates a habitat with a closed canopy habitat and little midstory. This provides better habit for later successional species but appears to have fewer available resources and a lower carrying capacity than the burn plots. Available food resources are primarily hard mast from the overstory. The litter and duff are high. The lack of shrub layer and closed canopy explain the majority of generalist species and the presence of highly arboreal species.

Periodic Burn Treatment

Periodic burning clearly promotes the greatest abundance and occurrence. These plots have very low canopy cover and very high herbaceous and shrub cover creating a better early successional small mammal habitat. Food resources and available cover are high. The shrub layer promotes *O. nuttalli*, a semi-arboreal species, and *S. hispidus* and *Z. hudsonius*, species preferring old field succession habit. Although not burned during the sample year, i.e. 3 years since last burn, these plots burn with much higher intensity because of greater fuel loading. It would therefore be assumed that the small mammal population within in these plots would fluctuate depending on the availability and quality habitat created by year(s) since burning, available food and cover.

CONCLUSION

Low intensity annual prescribed fire appears to bear little immediate effect on small mammal population dynamics and movements but the long-term effect of fire intensity and frequency appears to greatly alter available habitat. Species abundance, occurrence, and movements varied little between pre-burn and post burn trapping periods. Although little research has been done on the change in population dynamics since this study began, it is evident that fire frequency and intensity play important roles in shaping small mammal habitat and population dynamics. The species abundance and occurrence differences between treatments appear to be a direct result of the different habitat types created by fire. This study shows small mammal abundance and occurrence are highest with periodic burning. The early and old-field succession habitat associated with periodic burning provided habitats preferred by most small mammals in this study. Although small mammal abundance and occurrence are highest with periodic burning, future studies are needed to evaluate the effectiveness of different burning regimes and other forms of disturbance on creating comparable structural diversity and plant diversity. To provide a broad spectrum of habitats for early to late successional species on a landscape, multiple fire frequencies ranging from frequent to no burning in a mosaic pattern are required.

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FOREST MANAGEMENT TO IMPROVE BREEDING HABITAT FOR PRIORITY SONGBIRDS IN UPLAND OAK-HICKORY FORESTS

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Abstract—Oak (*Quercus* spp.)-hickory (*Carya* spp.) forests in the Central Hardwoods Region often have closed canopies with restricted crowns and relatively sparse understory and midstory vegetation, potentially limiting their quality as breeding habitat for Neotropical migratory songbirds. Tennessee National Wildlife Refuge (TNWR) used timber harvest in upland hardwood forests in 2001 to improve songbird breeding habitat quality by promoting spatial and compositional heterogeneity in canopy, midstory, understory, and ground cover vegetation. We assessed the short-term (1-4 years post-treatment) responses of forest vegetation and avian populations within treatment and control units to make recommendations for adaptive management. By four years post-harvest, treatment units had reduced canopy closure levels and increased ground layer and understory vegetation diversity and density, compared with control units. We detected corresponding increases in territory densities of early-successional songbirds in the treated units. Effects on mature forest-interior songbirds were mixed: some target species responded positively, some showed no apparent response, and some species appeared to be negatively affected in the short term.

INTRODUCTION

Conservation and management of breeding habitat for forest songbirds is necessary because many of these species have experienced long-term population declines (Sauer and others 2004). Forest-dependent songbird populations have been negatively affected by the loss and degradation of breeding, wintering, and migratory stopover habitats (Robinson and others 1995, Sherry and Holmes 1995). Forest management to improve breeding habitat quality for priority songbird species may contribute to regional conservation objectives (Franzreb and others 2000). However, our knowledge of how to manage forests for songbirds requiring mature forests is incomplete (Cooper and others 2000). Tennessee National Wildlife Refuge (TNWR) implemented an experimental silvicultural prescription in upland oak-hickory forests to improve habitat quality for priority songbirds. In this paper we describe TNWR's management concept and provide an overview of the strategies used to develop, implement, monitor, and evaluate the management prescription. We present preliminary results to illustrate key points, but data analysis and evaluation are ongoing and will be presented at a later date.

BACKGROUND

Past land-use practices have affected the suitability of Central Hardwood forests as breeding habitats for migratory songbirds. Upland hardwood forests in the Central Hardwood Region were extensively clearcut and burned 80-120 years ago (Hicks 1998). Subsequent second-growth upland oak-hickory forests often regenerated into densely stocked even-aged stands that differ structurally from late-seral stage forests by having closed canopies with restricted crowns and low structural heterogeneity in ground-layer, understory, and midstory vegetation (Dickson and others 1995, Singer and Lorimer 1997). Consequently, second-growth upland oak-hickory stands may be sub-optimal breeding habitats for songbird species that prefer structurally-complex forests (Ford and others 2000).

The U.S. Fish and Wildlife Service (USFWS) is the principal federal agency responsible for protecting and enhancing migratory bird populations and their habitats. Within the Central Hardwoods Region, the

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maintenance of viable Neotropical migratory bird populations is a management priority (U.S. Fish and Wildlife Service 1996, Fitzgerald 2003). To achieve broad-scale songbird conservation, regional priority bird species and habitats are determined by the Partners in Flight prioritization process (Carter and others 2000), and then locally managed within 'focus areas' that have high potential to support sustainable source populations (Donovan and others 2000, Fitzgerald 2003, Pulliam 1988). Bird populations respond to local-scale (nest site or forest stand) and landscape-scale habitat characteristics (Freemark and others 1995, Morse and Robinson 1999). Forested public lands (>70 percent forest cover in 10 km radius) of appropriate habitat structure may support source populations of Neotropical migratory birds (Donovan and others 2000, Martin 1992, Robinson and others 1995). Thus, local management to improve forest habitat quality for priority migratory songbirds may be critical to landscape-scale bird conservation. Based on forest type, landscape context, and avian community composition, TNWR has been identified as a focus area for forest songbird conservation and habitat restoration (U.S. Fish and Wildlife Service 1996, Ford and others 2000, Fitzgerald 2003).

In 1996, USFWS biologists and foresters evaluated upland hardwood forest habitats at TNWR and concluded they were deficient in canopy openings and understory and midstory vegetation (U.S. Fish and Wildlife Service 1996). The USFWS assessment team recommended that upland hardwood forests on TNWR be managed with timber harvest to improve habitat structure for priority Neoptropical migratory songbirds (U.S. Fish and Wildlife Service 1996). In response, TNWR developed a new forest management plan that explicitly identified the conservation of regional-priority forest songbirds as the primary forest management goal (Wheat and Martin 2000). Specifically, TNWR wanted to manage upland hardwood forests to provide optimal forest structure for nesting and foraging habitat for breeding nongame migratory birds, with an emphasis on the highest priority forest-interior Neotropical migratory species occurring on the refuge (table 1). The decision to manage at the local-scale (e.g., forest stand) for species that were of regional conservation concern fits within the Partners in Flight conservation framework (Donovan and others 2000).

The highest priority forest songbirds that breed in the Central Hardwoods Region have diverse habitat requirements but generally prefer forest tracts exhibiting heterogeneous canopies with multiple openings, large (>50 cm diameter) trees with mature spreading crowns, and patches of dense midstory and ground-layer vegetation (Ford and others 2000). Because forests on TNWR were deficient in these habitat characteristics, TNWR hypothesized that priority songbirds and other wildlife species would benefit from forest management that converted even-aged stands into more structurally complex stands containing multiple canopy layers, larger trees, and canopy gaps, while maintaining other features such as cavity trees, snags, and soft mast producing species (Haveri and Carey 2000, Wheat and Martin 2000).

TNWR developed an experimental silvicultural prescription intended to accelerate the development of the desired habitat characteristics. TNWR's prescription called for harvesting single trees and small groups of trees to create a variety of canopy gap sizes and to release large, vigorous canopy dominants from competition (Carey 2003, Franklin and others 1997). Thinning closed-canopied stands to various stem and canopy densities can increase the availability of light, moisture, and nutrients, and thus stimulate canopy tree stem and crown growth (Pedersen and Howard 2004, Singer and Lorimer 1997). The increased resource availability in canopy gaps can also promote ground-layer herbaceous and woody growth, and facilitate the development of understory and midstory shrubs and trees. Timber harvest can create certain characteristics quickly, such as canopy gaps and increased ground layer vegetative density and diversity, whereas characteristics such as larger trees and larger crowns typically take decades to develop following management (Singer and Lorimer 1997, Smith and others 1997). TNWR recognized that the canopy openings created by the initial timber harvest would eventually close as the surrounding vegetation responded to the increased resource availability. TWNR therefore planned to reassess the forest habitat conditions 15 years post harvest, and if necessary, implement a revised silvicultural prescription to address any continuing habitat deficiencies.

Table 1—Partners in Flight prioritization scores, habitat associations, and mean territory densities for select birds breeding during 2005 (4 years after timber harvest) within ~20-ha control and harvest units at Tennessee National Wildlife Refuge, Henry County, TN

					Territory density (per 40 ha)			
		PIF	Action	Habitat	Control[d]		Harvest[e]	
Species	Scientific name	score[a]	code[b]	association[c]	Mean	SE	Mean	SE
Cerulean warbler[f]	*Dendroica cerulea*	19	IM	M/L	0	0	0	0
Worm-eating warbler[f]	*Helmitheros vermivorus*	18	MA	M/L	4.6	1.9	6.4	1.4
Kentucky warbler[f]	*Oporornis formosus*	18	MA	M/L	0	0	10.4	1.4
Wood thrush[f]	*Hylocichla mustelina*	16	MA	M/L	8.9	5.0	3.1	1.4
Yellow-breasted chat	*Icteria virens*	16	MA	E	0	0	14.1	1.3
Acadian flycatcher	*Empidonax virescens*	16	PR	M/L	21.6	1.4	17.4	1.3
Yellow-throated vireo	*Vireo flavifrons*	16	PR	M/L	5.5	2.1	10.7	0.9
White-eyed vireo	*V. griseus*	15	MA	E	0.5	0.5	18.5	1.8
Eastern wood-pewee	*Contopus virens*	15	MA	M/L	20.4	1.2	21.1	1.3
Yellow-billed cuckoo	*Coccyzus americanus*	15	MA	M/L	2.3	1.7	2.5	0.8
Eastern towhee	*Pipilo erythropthalmus*	15	MA	E	0.9	0.9	11.6	2.8
Indigo bunting	*Passerina cyanea*	14	PR	E	0.2	0.2	33.7	2.3

PIF = Partners in Flight; SE = standard error.
[a] From the Partners in Flight Species Assessment Database (http://www.rmbo.org/pif/pifdb.html), range is 5 through 25.
[b] From the Partners in Flight Species Assessment Database: IM = high regional threat and population decline, conservation action needed to prevent extirpation; MA = moderate regional threats and moderate-to-large population declines, management or conservation action needed to stabilize populations of reverse threats; PR = species of continental but not regional concern, long-term planning needed to ensure sustainable populations.
[c] Habitat association: E = early successional forest; M/L = mid- to late-successional forest.
[d] ~20-ha control (n = 4).
[e] Harvest (n = 8).
[f] Species managed at Tennessee National Wildlife Refuge.

At the forest stand scale, characteristics such as foliage height diversity and volume, vegetative species composition, and stand successional stage can influence avian populations (Cody 1985, MacArthur and MacArthur 1961, Martin 1992). Avian species diversity and population densities typically increase with increasing habitat complexity (Cody 1985). Timber harvest (and subsequent vegetative growth and succession) alters stand structure and vegetative species composition, and therefore affects the availability of songbird foraging and nesting substrates, as well as the abundance and composition of food resources and predator communities (Thompson and others 1995). Potential effects include changes in avian community composition, species relative abundances, and nest, fledgling, and adult survival rates. Because managers can influence avian populations through the silvicultural manipulation of forest habitat characteristics, Partners in Flight recommends using silviculture to promote songbird conservation (Ford and others 2000). However, specific techniques for proactively managing upland forested habitats for priority songbird species are not well developed. Several recent studies have evaluated forest songbird response to selection cutting for commodity production or other values in eastern hardwood forests (Annand and Thompson 1997; Gram and others 2003; Jobes and others 2004; Robinson and Robinson 1999, 2001; Rodewald and Smith 1998). The results from these studies were not sufficient for predicting the response of the avian community to TNWR's experimental silvicultural prescription because of differences in stand and site conditions, harvest objectives, and harvesting strategies. Recent reviews recommend evaluating novel silvicultural prescriptions that may affect priority species by conducting manipulative experiments within an adaptive management framework (Sallabanks and others 2000, Thompson and others 2000a).

Adaptive management is a process in which scientists and resource managers collaborate to gain reliable knowledge that is relevant to natural resource management issues (Lancia and others 1996, Romesburg 1981). In this process, habitat or population objectives are identified, management strategies based on those objectives are implemented, responses are monitored, and management strategies are revised following the evaluation of the monitoring data. When conducted using manipulations and statistically valid experimental designs (i.e., using controls, replication, and randomization), adaptive management can establish cause-and-effect relationships between management activities and habitat and/or population change and thus indicate the degree of management's effectiveness (Block and others 2001, Hurlbert 1984). The USFWS recognizes the value of this approach and has explicitly identified adaptive management as a strategy for refining management and conservation actions that affect migratory birds and their habitats (U.S. Fish and Wildlife Service 2004).

TNWR's forest management plan called for several upland hardwood forest stands to be treated with their silvicultural prescription. TNWR recognized that several critical assumptions were untested, and that their prescription was not certain to produce the desired habitat conditions or avian population responses. Indeed, there was potential that the degree of treatment-related habitat alteration could have unintended or adverse effects on some focal species and/or non-target members of the avian community. Because the proposed management would significantly alter avian habitats, research and monitoring were needed to assess the efficacy of this management prescription before the treatment was implemented at a broader scale. Consequently, the TNWR, The University of Tennessee, and the National Wild Turkey Federation initiated a large-scale manipulative experiment designed to address these management uncertainties within an adaptive management framework.

Our goal was to provide a comprehensive evaluation of the short-term (≤ 4 years post-harvest) effects of the silvicultural prescription on forest habitat characteristics and songbird populations. Our primary objective was to determine if the short-term effects of this silvicultural prescription resulted in improved breeding habitat conditions for target forest-interior species that require structurally-complex hardwood forests. Additional objectives were to determine the short-term effects on non-migratory songbirds, on migratory songbirds preferring undisturbed forests, and on songbirds preferring early-successional vegetation. To achieve our objectives we measured several indicators of breeding habitat quality, and compared these between treatment and control units both before and after treatment. The measured response variables were nest-site and stand-level habitat characteristics, avian population densities, avian community composition, Brown-headed Cowbird (*Molothrus ater*) brood parasitism rates, nest survival rates, realized brood sizes (number of fledglings per successful nest), and post-fledging juvenile survival rates (for Wood Thrushes only).

MANAGEMENT AND MONITORING

Study Area

We conducted this study in western Tennessee in the Big Sandy Unit of the 20,784-ha TNWR. The refuge is located primarily within the Western Highland Rim of the Central Hardwoods Region (fig. 1). The local landscape (10-km radius) around our study area was ~83 percent forested.

Upland oak-hickory forests covered ~6,070 ha of TNWR. Common canopy tree species included white oak (*Quercus alba*), chestnut oak (*Q. montana*), post oak (*Q. stellata*), southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), mockernut hickory (*Carya tomentosa*), pignut hickory (*C. glabra*), and yellow poplar (*Liriodendron tulipifera*). Common understory and midstory species included blackgum (*Nyssa sylvatica*), sourwood (*Oxydendrum arboretum*), eastern hophornbeam (*Ostrya virginiana*), flowering dogwood (*Cornus florida*), sassafras (*Sassafras albidum*), and black cherry (*Prunus serotina*).

Forest Management

TNWR's forest plan outlined actions necessary to achieve their forest management objectives, including an iterative cycle of forest inventories, prescriptions, and implementations that are periodically

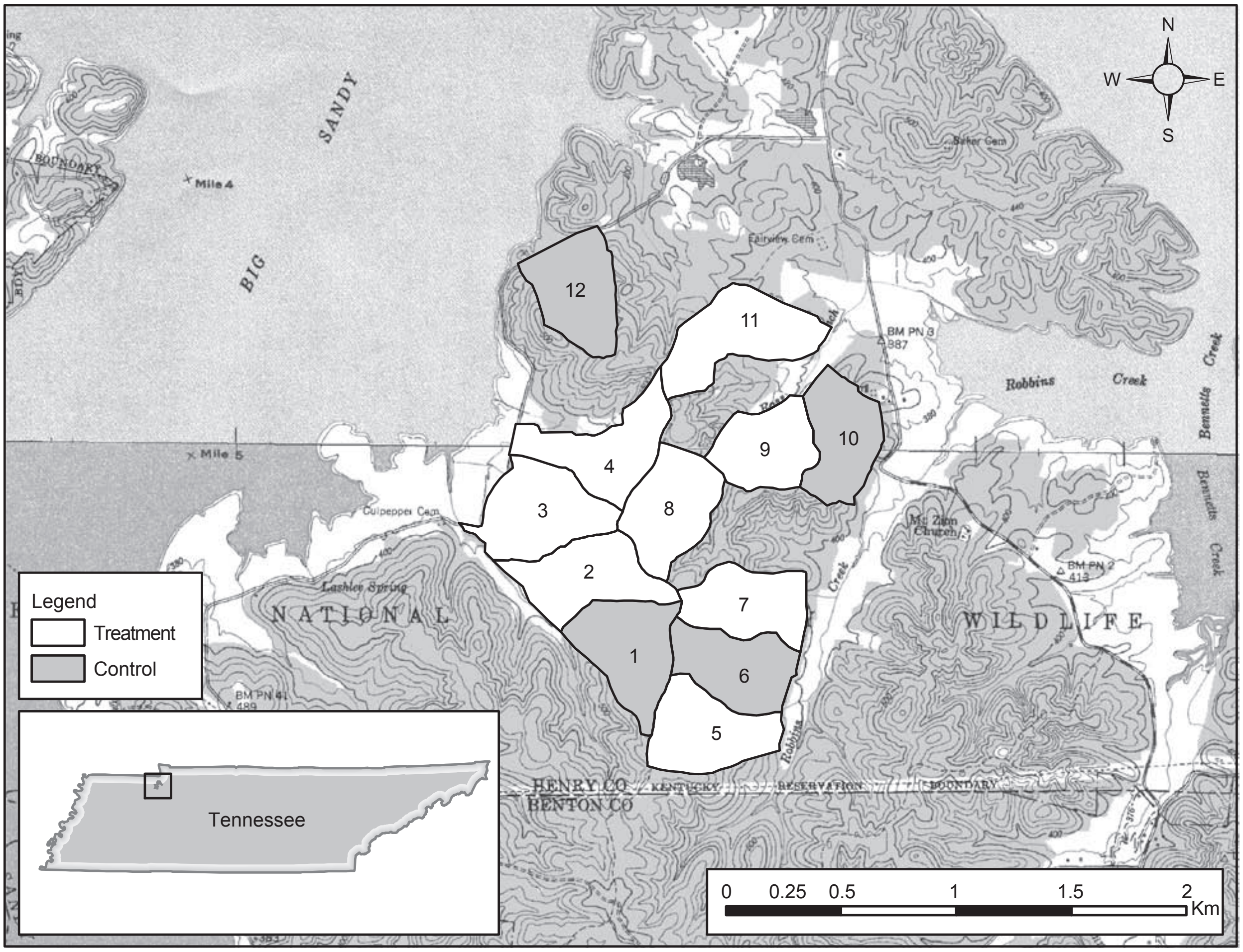

Figure 1—Map of study sites in the Tennessee National Wildlife Refuge, Henry County, TN.

monitored and evaluated (Wheat and Martin 2000). The forest management plan divided TNWR into 15 compartments (~250-350 ha), each of which is to be inventoried once during every 15-year period and subsequently treated with silvicultural prescriptions if the desired habitat conditions are absent.

TNWR staff inventoried one ~350-ha compartment during 2000. The compartment inventory indicated the mature hardwood stands were 70-120 years old and dominated by white oak and chestnut oak (both species comprised 65-79 percent of total saw-timber volume). These even-aged stands exhibited tightly packed canopies (82-89 percent cover) with restricted crown widths (average radius of crown spread for dominant and co-dominant trees was ≤6 m), and few emergent trees. Midstory cover ranged from 41-89 percent, but typically consisted of a single thin layer rather than a deep vertical stratum. Understory cover ranged from 22-40 percent. TNWR staff concluded that these inventory results generally supported the conclusions of the 1996 forest review, and subsequently developed a silvicultural prescription to increase forest structural complexity.

To improve habitat quality for priority songbirds, TNWR decided to reduce canopy closure to 40 percent within a series of evenly distributed 0.4-ha blocks, together comprising 25 percent of the compartment area, and to reduce canopy closure to 70 percent in the surrounding forest matrix (fig. 2). TNWR staff used data from the inventory to determine the reduction in dominant and co-dominant trees required to achieve desired canopy closure levels. They converted canopy cover to square meters per hectare and determined the average crown area of dominant and co-dominant trees, and used this information to determine the number of dominant and co-dominant trees to mark for removal per hectare.

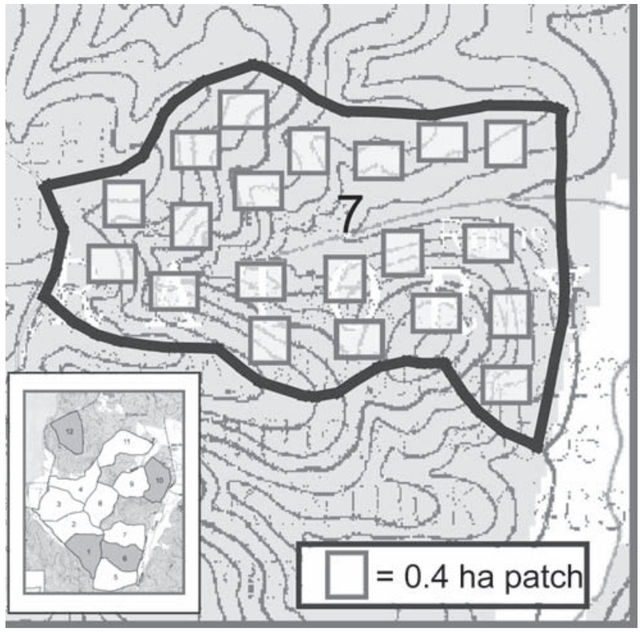

Figure 2—Schematic representation of timber harvest strategy used in research units at Tennessee National Wildlife Refuge. Canopy cover was thinned to 40 percent within the 0.4-ha patches, and to 70 percent elsewhere across the unit.

The timber harvest strategy was intended to control canopy closure levels by harvesting single trees and small groups of trees. The harvest was specifically intended to release selected residual trees from competition to allow them to increase in diameter and crown size, as well as to create canopy gaps for sunlight penetration to stimulate ground-level, understory, and midstory development. The combination of heavy (40 percent canopy closure) and light thinnings (70 percent canopy closure) were intended to reduce the overall average canopy closure to 60 percent while providing a variety of gap sizes and increased heterogeneity across harvested units. The 0.4-ha blocks were not clearcut; rather, they generally contained multiple gaps as well as large canopy trees that were released from competition to facilitate their development into canopy dominants and potential future emergents. Timber selected for removal were species comprising >50 percent of the stand, trees competing with desirable trees, co-dominant and suppressed trees not expected to respond well to release, and exotic species. Co-dominants were selected for removal before dominants, when possible, but trees were selected across all size classes. Retained trees included vigorous dominant canopy trees (i.e., potential emergents), cavity and den trees, snags, soft-mast producing species, and uncommon species. Midstory and understory species were generally retained, although trees likely to create a heavy shade-tolerant midstory (e.g., eastern hophornbeam) were selected for removal (Wheat and Martin 2000). Marked trees were harvested commercially following Forestry Best Management Practices guidelines.

Management Assumptions

Implicit within TNWR's management strategy were the following assumptions:

1. Silviculture could create the desired habitat conditions. TNWR assumed the prescribed levels and arrangements of canopy and stem thinnings were sufficient to stimulate appropriate vegetative growth. The 15-year management cycle will allow TNWR to implement silvicultural adjustments as necessary.

2. Management would improve target avian species vital rates and population densities. Although avian population objectives were not specified, if TNWR's management improved habitat quality, this would

increase carrying capacity, adult survival rates, and/or reproductive success for target species in treatment units (Van Horne 1983).

3. Management would benefit most priority avian species. Managing habitat characteristics for multiple species presents a complex problem because species often have specific or conflicting habitat requirements (Thompson and others 2000b). TNWR assumed the prescription would create sufficient diversity to meet the requirements of most priority species, without resulting in unacceptable declines in vital rates or densities of non-target members of the avian community.

Evaluation

We used a randomized complete block design to evaluate the effects of the silvicultural prescription on the measured response variables. Based on compartment inventory data, twelve ~20-ha research units were assigned to four blocks that exhibited similar mixtures of stands and site conditions. The three research units within each block were then randomly assigned either selective harvest (n = 8) or no-harvest (control; n = 4) treatments (fig. 1). The treatments in two of these research units were not randomly assigned: unit 9 was assigned a selective harvest treatment because several years of pre-harvest avian demography data had been collected at this site, and unit 12 was added as a no-harvest control in an adjacent management compartment to complete one of the blocks. The timber harvest treatment was identical to the actual silvicultural prescription called for in the forest management plan. We collected pre-treatment data on all units during 2001. Timber harvest was implemented in late 2001, and post-treatment data were collected during the 2002-2005 breeding seasons. The study was not designed to test the effects of sub-treatments (e.g., 40 vs. 70 percent canopy closure), rather, we looked at the research unit-level responses of the treatment on avian habitat and populations, and thus the research unit is our experimental unit (n = 12).

Stand-level and nest-site habitat characteristics—To quantify forest habitat characteristics, we established 7 (n = 84 total) randomly located 0.04-ha permanent vegetation plots in each research unit. We sampled vegetation in each plot during July annually 2002-2005 following standard habitat evaluation protocols (James and Shugart 1970, Martin and others 1997). We used similar protocols to measure habitat characteristics at nest sites (n > 600 nests) annually 2001-2005.

Avian use and population densities—To facilitate accurate mapping of bird locations, we established permanent 50 x 75 m marked grid networks across each research unit. Between 15 May and 30 June 2001-2005, we conducted breeding bird surveys following standard territory mapping protocols (Robbins 1970, Bibby and others 2000). We used the territory mapping data to determine breeding bird population densities and community composition for each research unit.

Nest monitoring—We searched each research unit for nests of all songbird species annually 2001-2005 (Martin and Geupel 1993). Nests were monitored every 1-4 d to determine (1) the date of nest termination, (2) nest fate (fledged or failed), (3) realized brood size (4) cause of failure (depredated, abandoned, weather), and (5) the number of Brown-headed Cowbird eggs, nestlings, and fledglings.

Post-fledging juvenile Wood Thrush movements and survival—During 2004 and 2005, we placed radio-transmitters on Wood Thrush (*Hylocichla mustelina*) nestlings on days 9-12 of the nestling period, and on recent fledglings captured by hand. We located radio-marked juvenile Wood Thrushes daily to determine home range sizes, habitat use, and survival rates.

DISCUSSION

Our study was designed to evaluate the short-term (1-4 years post-harvest) effects of this silvicultural prescription. In this time frame, timber harvest was expected to significantly change some forest habitat characteristics such as the size of canopy gaps, and the percent cover and composition of understory vegetation, and to have corresponding effects on the avian community. Some desired future forest conditions, such as increased midstory coverage, and the development of larger trees will take longer

(>10 years) to become manifested. The population densities and demographic characteristics of songbird species will likely change through time as the vegetation in the treatment units continues to respond to the harvest. Nonetheless, we believe data gathered in the first 4 years after treatment is relevant to conservation planning because it will serve as a baseline standard for comparison, because it will help predict future habitat and avian responses, and because TNWR's 15-year management cycle will create similar conditions on >25 percent of their forests at any given time.

TNWR's forest management was designed to create canopy gaps and expedite the development of habitat characteristics (including canopy gaps, larger trees, and increased structural complexity in ground-layer, understory, and midstory vegetation) typical of late-seral stage forests. Our preliminary results indicated the silvicultural treatments reduced average basal area from 29 to 21 m^2/ha in treatment units. This corresponded to a reduction in average canopy cover from 90 to 65 percent across the treatment units. Other preliminary results indicated that by 4 years post-harvest the ground-level vegetation changed from being sparse (15 percent cover) with high percentages of exposed leaf litter (80 percent cover) in control units to being dense (55 percent cover) with increased percent cover of poison ivy (*Toxicodendron radicans*), grape (*Vitis* spp.), and blackberry (*Rubus* spp.) in treatment units. Similarly, horizontal vegetation density in the understory layer increased in treatment units (Thatcher, unpublished data). Thus, in the short term (4 years post-harvest), the silvicultural prescription met stated objectives of reducing canopy closure and increasing understory and ground layer vegetation density.

TNWR's prescription promoted ground-layer and understory growth, created a variety of gap sizes, and retained uncut or sparsely cut areas near streams and along steep slopes, thus increasing vegetative structural complexity and the diversity of microhabitat conditions within harvested units. We detected greater avian species richness in harvest units, with increases in territory densities of early-successional forest specialists (table 1) corresponding with the increased cover of ground layer and understory vegetation (Thatcher, unpublished data). These results were expected given the known positive relationship between vegetative complexity and avian species diversity (Cody 1985, MacArthur and MacArthur 1961). The timber harvest appeared to have mixed effects on the territory densities of some priority mid- to late-successional forest songbirds (table 1). Though the full anticipated benefits of the prescription for target species did not have time to develop, increases in population densities of high priority species such as the Kentucky Warbler (*Oporornis formosus*) provide preliminary evidence that TNWR's prescription is achieving some of the management objectives in the short-term.

The analyses and evaluation of the habitat and avian population data are ongoing. Ultimately, we will compare avian population parameters (e.g., community composition and diversity, population densities, brood parasitism rates, nest survival rates, and fledgling habitat use and survival rates) between treatment and control units, and relate differences in these parameters to changes in habitat attributes caused by the timber harvest. By quantifying multiple parameters related to avian habitat quality and by relating these to management-caused changes in habitat characteristics, our analysis should indicate if the short-term (1-4 years post-harvest) effects of this silvicultural prescription result in improved breeding habitat conditions for target forest-dependent songbirds. Importantly, our assessment will also consider the short-term effects of management on non-target members of the avian community (Franzreb and others 2000). Because researchers and managers initiated this project together, we were able to implement the prescription as a large-scale manipulative experiment (Cooper and others 2000, Marzluff and others 2000). Thus, our inferences should be stronger and more relevant to avian conservation because we used a sound experimental design, measured relevant population parameters, and used manipulations that reflect realistic forest management practices conducted at operational scales (Sallabanks and others 2000, Thompson and others 2000a).

TNWR's mission as a wildlife refuge allowed them to focus their silvicultural prescription specifically on wildlife habitat improvement without constraints such as wood fiber production influencing their timber harvesting strategies. Certain commercial silvicultural prescriptions are compatible with some avian conservation objectives. However, timber harvest prescriptions designed specifically for forest songbird populations may retain or enhance different habitat attributes than prescriptions primarily intended for production-based objectives, and are therefore more likely to be beneficial to target species. Having merchantable timber facilitated the full implementation of TNWR's prescription despite limited refuge budgets. Nonetheless, the economic consequences of commercial timber harvesting on TNWR were not priorities.

Traditional uneven-aged silviculture is generally considered inappropriate for managing oak forests because of concerns regarding high-grading and the potential for oak regeneration failure and compositional shifts to shade-tolerant species (Lorimer 1993). However, the prescription at TNWR was non-traditional (Franklin and others 1997, Mitchell and Beese 2002). For instance, large vigorous trees were retained to improve songbird habitat quality, not to prepare them for future harvest. Similarly, the goal of the prescription was to increase structural heterogeneity, not to create a balanced uneven-aged diameter distribution for sustained yield. In addition, oak regeneration is less problematic on relatively xeric poor-to-medium quality sites like many found at TNWR (Larsen and others 1999). For example, oak-hickory stands in Missouri managed with a partial cutting strategy experienced no significant shift in canopy composition to shade-tolerant species (Loewenstein and others 2000). At TNWR, shade-tolerant maples (*Acer* spp.) are relatively uncommon, and the predominant shade-tolerant species (e.g., blackgum, sourwood, flowering dogwood) are generally relegated to the subcanopy. For these reasons, TNWR staff believed their silvicultural prescription was unlikely to compromise overall oak dominance of future stands. Nonetheless, active monitoring of post-treatment vegetative responses will allow them to make modifications to this experimental prescription as necessary.

CONCLUSION

TNWR's willingness to develop and implement an experimental silvicultural prescription for priority forest songbirds represents a significant shift from traditional National Wildlife Refuge management objectives, and has important implications for regional songbird conservation. Although much remains unknown regarding the most appropriate methods for proactively managing breeding habitats for priority forest-interior songbirds, many unresolved questions can only be addressed with forest manipulations and research. The continuing population declines evident in many migratory songbird species indicate that past conservation efforts have not been completely effective. By implementing and evaluating novel forest management prescriptions within an adaptive management framework, we may improve the efficacy of our management efforts and better ensure that we meet our avian conservation goals.

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KENTUCKY HUNTER PERCEPTIONS OF HARVEST REGULATIONS AND THEIR EFFECTS ON WHITE-TAILED DEER POPULATIONS

Kara W. Throgmorton, Jean C. Mangun, and Andrew D. Carver[1]

Abstract—Previous research indicates that avid hunters in Kentucky are dissatisfied with size of Kentucky white-tailed deer (*Odocoileus virginianus*) and are hunting out-of-state as a result. The purpose of this study is to characterize the extent of this behavior and to identify other hunter concerns. A qualitative research approach was selected using personal interviews and a series of facilitated focus groups. Analysis of transcripts revealed emerging themes or categories of hunter concerns that emphasized aspects of stewardship, trust, and the regulatory environment. Findings of this study highlight perceptions about management policies concerning knowledge, influence, and funding that exist among groups of avid Kentucky hunters. Moreover, qualities of successful collaborative or participatory decision-making that involves an agency and stakeholders were found to be weak or altogether absent in this context. We suggest that an immediate need exists for state agency personnel to develop methods that disseminate information about regulations and management decisions in a more consistent and meaningful manner. As the generalizability of this study to other regions is limited, suggested future research would involve a statewide or regional survey to determine whether perceptions of avid hunters reflect those of the general hunter population.

INTRODUCTION

Responsive wildlife management requires not only understanding the resource base but also involving stakeholders in the process. Understanding human values, attitudes, and opinions assigned to wildlife species is essential. Over the past several years, wildlife managers, policymakers and planners have more widely applied a human dimensions approach to management and resource allocation decisions (Robertson and Butler 2001). However, stakeholder dissatisfaction with management decisions most frequently can be attributed to a disjuncture between managers' perceptions of stakeholder perspectives and how a particular group values wildlife. Studies in the United States and Australia have shown such discrepancies can potentially lead to poorly chosen or unsuccessful wildlife management programs (Miller and McGee 2001).

A perennial issue in the wildlife management community is the continued decline in hunting participation and associated license sales. Several studies (Clark and others 2004, Mangun and others 1996, Memood and others 2003, Miller and Vaske 2003) have addressed the declining levels of participation in consumptive recreational uses of wildlife in the United States. The literature on hunting outlines several contributing factors such as changing social norms and lack of opportunity. Changes in demographics such as an aging population and increasing levels of education can also influence participation trends. The assertion made by Manfredo and others (1998) that the art of managing wildlife could be significantly improved with solid information about the publics being served seems to be particularly pertinent to the situation now facing hunters and hunting.

Deer hunting remains a highly valued tradition throughout the central hardwood region despite smaller numbers of participants. Although the recreational aspects of hunting are widely understood, many differing stakeholder opinions on deer herd management exist. Concerns over declining license sales, combined with the fact that controlled harvest remains a critical component of deer population control in the region, make understanding public perceptions important when determining best management options. It is proposed that avid hunters, such as highly experienced members of organized hunt clubs, can play a key role as a source of information on which to base decisions about season length and other regulations.

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Previous research (Newman and others 2004) has suggested that avid Kentucky hunters are dissatisfied with the size of Kentucky white-tailed deer (*Odocoileus virginianus* Zimmermann) and are hunting out-of-state as a result. Understanding hunter perceptions of harvest regulation effects on white-tailed deer population composition offers an opportunity to enhance our limited applications of the human dimensions approach and to research the topic of hunter knowledge, attitudes, and opinions of natural resource management in general. The purpose of this study is to characterize the extent of out-of-state hunting by avid Kentucky hunters and to identify hunter concerns about deer hunting. A qualitative research approach is selected using in-depth personal interviews and a series of facilitated focus groups. On-going analysis of transcripts has revealed emerging categories or themes of hunter concern that emphasize aspects of stewardship, trust, and the regulatory environment. The projected goal of this study is to develop a better explanation or model of how avid Kentucky hunters assess the efficacy of various firearm and season regulations in terms of deer herd management.

Regulations and Hunting Participation

Hunting is not merely a tool for the management of wildlife populations; it is also a culturally important recreation activity. From a recreation resource perspective, satisfying hunting experiences represent important byproducts of wildlife management. Research on hunter satisfaction primarily has focused on individual factors not under direct management control. Miller and Vaske (2003) propose that research on hunting participation should focus on situational constraints that are within the control of management agencies.

The impact of regulatory changes, which can potentially constrain harvest success or hunting opportunity, on the hunting experience has received lesser amounts of attention in the literature (Fulton and Manfredo 2004). Fulton and Manfredo (2004) suggest that regulations might not negatively affect satisfaction levels—even though others have documented that when regulations are perceived to negatively impact big game harvest opportunities, satisfaction with the hunting experience decreases as well as the intention to participate. Miller and Graefe (2001) further highlight the important relationship between harvest success and satisfaction with deer management programs. The complex relationship between regulations, overall satisfaction and intent to participate, therefore, warrants further examination.

Focus Group Objectives

Perceptions of avid Kentucky resident deer hunters were explored using personal interview and facilitated focus group techniques. Through group discussions, hunters were able to collectively share and discuss their individual experiences describing a wide range of stakeholder interests and concerns. Avid hunters were defined for purposes of our study as an adult member of a private hunt club organization with at least 5 years of hunting experience. These individuals were selected to discuss hunting regulations and their effects on the basis of Bryan's (1977) observation that the recreation specialist seeks a resource setting that allows for predictability and manipulation, a degree of control allowing the differentiation of skill and luck. Avid hunters were seen as activity specialists who would have distinct preferences concerning the management and regulation of their sport.

Facilitated focus groups conducted with volunteer Kentucky hunters were designed to meet the following objectives: (1) to assess the amount of knowledge avid hunters have about wildlife management strategies and hunting regulations; (2) to identify what sources hunters have for information concerning the status of game populations in Kentucky; (3) to identify hunter estimates of the number of active hunters in Kentucky; (4) to identify the states (outside Kentucky) that avid Kentucky hunters choose to hunt in and why; (5) to identify avid hunters' impression of the deer population in Kentucky and if there is a perceived difference between the Kentucky and Illinois deer herds and why; and, (6) to identify what avid Kentucky hunters would like to recommend to managers and policymakers. Preliminary findings from these focus group sessions will be reported here.

METHODS

Data Collection

Before beginning the qualitative portion of this research, a brief, quantitative survey instrument was developed to characterize the subject pool and to identify potential volunteers for subsequent interviews and focus groups. Questionnaires were distributed to members of hunt clubs at social gatherings in western Kentucky during late summer-fall 2004. Out of 60 questionnaires distributed, 35 were returned and usable.

Hunters who indicated on the initial contact questionnaire their willingness to participate further were contacted by mail and phone. Three facilitated focus group sessions with three different sets of 6 to 8 hunters were conducted at eating establishments familiar to participants. Focus group protocol as outlined by Krueger and Casey (2000) was followed.

Data Analysis

Descriptive statistics were used to summarize data from the initial contact survey. Subsequent personal interview and focus group session tape recordings were transcribed verbatim for analysis. Transcripts were analyzed according to the Strauss and Corbin (1990) grounded theory process. Data that represented specific phenomena were labeled as categories. After the initial coding, axial coding was performed. (Axial coding links subcategories with categories, and also further explains these with the addition of properties. Properties are the ideas associated with categories or subcategories. A property is simply the range of ideas associated with specific phenomenon).

After completion of the coding process, combined data from the three focus group sessions were organized into tables in which each category was listed, followed by subcategories and their properties and dimensions as necessary. Each category and subcategory was supported by direct participant quotes.

PRELIMINARY FINDINGS AND RECOMMENDATIONS

Quantitative Data

Table 1 provides a summary of respondent attributes from the initial contact survey. The subject pool, contacted at hunt club social events, contained a surprisingly high percentage of females (31 percent). The distribution of hunters by years of hunting produced a mean of 34 years experience. The majority of respondents reported hunting with some combination of firearms and compound bow (77 percent). The high participation levels of these avid hunters were reflected in the fact that they reported having purchased licenses in 18 different states and Canada over the past two years. Although significant out-of-state activity did occur, only one hunter reported not also having purchased a Kentucky resident license during the same time period.

Qualitative Data

Analysis of focus group discussion transcripts revealed three emergent categories of Kentucky deer hunter perceptions and concerns. These categories were classified as themes of stewardship, trust, and the regulatory environment (table 2). Selected supporting quotations from focus group discussion transcripts were provided in the appendix. The stewardship category included concerns over the number and sex of deer taken, the reduced availability of public hunting areas, and a perceived lack of recognition for the stewardship role of hunters. The trust category included concerns over the influence of the auto insurance lobby on hunting regulations, competency of state government officials, and interactions with authoritarian conservation officers. The regulatory environment category consisted of concerns over fees, regulations, and season length. For example, a quote obtained from a focus group session that would illustrate hunter satisfaction with existing season length was as follows: *"A 10-day season was more than adequate; if they can't kill a deer with a gun in 10 days they've got no business hunting."*

Preliminary findings of this study gave voice to a wider slate of issues than our original study focus. Avid Kentucky hunters were concerned about harvest take and season length (*"Where I hunt [Kentucky] the deer numbers are way down in the last 5 to 6 years from killing too many antler-less deer, in my*

Table 1—Characteristics of Kentucky hunter subject pool for focus group discussions (m = 35)

Attribute	Category	Percent
Gender	Male	68.6
	Female	31.4
Hunting experience (years)	5 to 20	17.1
	21 to 35	37.1
	36 to 50	37.1
	51 or more	8.6
Harvest method	Rifle and/or shotgun	22.9
	Rifle or shotgun and bow	31.4
	Rifle, shotgun, bow, and other	45.7
States where hunting license purchased (past 2 years)	KY only	28.6
	KY and IL	17.1
	KY and at least two other States	48.6
	KY, at least two others, and Canada	2.9
	FL only	2.9

Table 2—Findings from focus group discussions

Category	Subcategory	Property
Stewardship	Herd size	Taking too many doe-to-buck ratio
	Opportunity	More land gone private
	Recognition	Hunters should be recognized as conservationists
Trust	Auto insurance lobby	Auto insurance lobby affects regulations
	State government	Lack of knowledge and experience dealing with hunting and fishing issues
		Wildlife funds re-appropriated
	Conservation officials	Too authoritarian
Regulatory environment	Not satisfactory	Fees
		Vendors
		Variation of regulations and license fees by State
	Satisfactory	Existing gun season length

opinion."). However, they also addressed issues of government competency, use of authority, lobbying group influence, and funding (*"You need to get the politicians out of fish & wildlife. They control the fish & wildlife here in the state of Kentucky. They take the money; they do others things with it. They probate so much for fish & wildlife each year to work with, that's why they [fish and wildlife] don't have the money to buy land. Need to get them [politicians] out of it."*). Participating hunters did not feel that adequate avenues of communication existed between themselves and managers or policymakers. We conclude that, from the stakeholders' perspective, qualities of successful collaborative or participatory decision-making efforts are weak or altogether absent in this context. Additional sources of information are being identified to enhance the credibility of our interpretations. For example, the next phase of this study will involve personal interviews with hunter advocates and agency personnel.

Recommendations

Interpretive, qualitative research techniques, while relatively new in application to natural resource management, can provide managers with richer detail than more familiar quantitative research methods (Davenport and Anderson 2005). The qualitative research approach adopted here has revealed unanticipated topics of hunter concern, in particular, the influence of the auto insurance lobby. We suggest that an immediate need exists for Kentucky state agency personnel to develop methods that disseminate information about hunting regulation formulation and management decisions in a more consistent and meaningful manner. Although the findings of this study may not be generalizable to a larger population because of the small, homogeneous sample of avid hunters and the context-specific nature of their discussions, it does provide direction for subsequent study. Suggested future research should involve a statewide or regional survey to determine whether the perceptions and concerns of this group of avid hunters reflect those of the general hunter population.

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Appendix—Focus group supporting quotations, listed by category

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Stewardship

Herd size - taking too many
- "I mean for a big deer in Kentucky to make it past three and half, he has been doing some hiding."
- "You might see one of us in an open field, but you better be able to shoot a deer running, 'cause when he comes out of that timber, he is not going to stop especially if he hears guns cracking."

Herd size - doe-to-buck ratio
- "Buck to doe ratio needs to be no more than two does per buck otherwise the deer don't travel."
- "The regulations we impose on our members are our own rules; no shooting does with fawns, and bucks must be 3 ½ years or older; these are what we do on our private lease."

Trust

Auto insurance lobby - lobby affects regulations
- "They also cater to the insurance lobby to gather statistics to dictate how many deer we kill in the state."
- "Kentucky insurance companies control legislation, they get legislation passed to determine what kind of harvest they take on deer."

State government - lack of knowledge; funds re-appropriated
- "The first thing I would ask the legislator, if he knew anything at all about hunting and fishing. If he told me no, I would tell him to get off the seat and get somebody that does know."
- "Like in Kentucky, Fish and Wildlife use to be self-supporting and still is, but used to have a fund that was there, that if they had to buy property. The government passed a law that they would take the funds and use it where they wanted to."

Conservation officials - too authoritarian
- "That is the way it operates now and if they want to take your vehicle, they can take your vehicle if they want to take your shotgun, they can take your shotgun, your 4- wheeler."
- "The hunter is the one that pays their salary. I mean the Fish and Wildlife officers, some of them, the majority of them are good people. Some of them feel like they put that badge on and they have more authority. More than they need really."

Regulatory environment

Not satisfactory – fees, license vendors, variation of regulations and license fees by State
- "Every State you go to they require you [to buy] different license to hunt in different States. Each State regulates different prices."
- "I think all States that border each other (or even if they don't border each other) should charge each non-resident according to what they charged themselves."
- "I don't think that any State should allow hunting licenses to be sold through a vendor."

Satisfactory - 10-day gun season length
- "Everybody has their own way of hunting, but I think 10 days with a high powered rifle is more than adequate enough."
- "A 10 day season was more than adequate; if they can't kill a deer with a gun in 10 days they've got no business hunting."

AGROFORESTRY

Moderator:

Adam Taylor
University of Tennessee

ESTABLISHMENT OF UPLAND AND BOTTOMLAND AGROFORESTRY PLANTATIONS IN TENNESSEE AND MISSISSIPPI

David M. Casey, Scott E. Schlarbaum, John T. Ammons, Fred L. Allen, Donald G. Hodges, William G. Minser, III, Arnold M. Saxton, Jason S. Maxedon, Chad Pope, and Chris R. Graves[1]

Abstract—The feasibility of alley cropping was studied across seven different study sites in western Tennessee and northern Mississippi. Open-pollinated progenies were collected from eleven oak species and black walnut and grown under nursery protocols designed to produce high-quality seedlings in one year. Four bottomland studies and three upland studies were established in 2003. Soybeans were planted between the tree rows on three sites. In the spring, two bottomland sites were naturally flooded, while the other bottomland studies experienced soil saturation, but did not flood. First year survival on bottomland sites (35-90 percent) was affected by flood intensity and revealed species differences in tolerance. Survival was positively related to initial root diameter and first-order lateral roots. Each bottomland site had an overall negative height growth due to dieback. Survival (90-97 percent) and height growth (-16.8 to 6.2cm) were generally good in the upland studies. Soybean production was lower overall than the previous year due to tree planting.

INTRODUCTION

Current reforestation (Reed 1983) efforts in the southern United States, particularly on bottomland sites, are greater than ever before (King and Keeland 1999). Generally, low soybean prices and the marginal nature of some farmlands, on former bottomland forest sites have now prompted landowners to consider reforesting the field. Additionally, the growing need for protection of surface water quality and wildlife habitat restoration are other important reasons for reforestation (King and Keeland 1999).

Alley cropping is a form of agroforestry that may represent a viable alternative for landowners wishing to gain the benefits of reforestation, while maintaining a short-term income from row crops. Hodge and others (1999) broadly defined alley cropping as "the planting of rows of trees and/or shrubs (single or multiple) at wide spacing, creating alleyways within which agricultural crops or horticultural crops are produced."

Reforestation strategies using artificial regeneration usually employ small, e.g. 30 to 60 cm tall, bare-root seedlings of unspecified seed sources that can require intensive competition control for establishment success. From an economic standpoint, the high initial investment of artificial regeneration followed by no immediate financial return usually precludes much, if any, subsequent site maintenance to encourage success (Stanturf and others 2001). To reduce post planting management, seedling quality is an important factor in survival and growth (Kormanik and others 1995). Seed source is another consideration, as use of seedlings from unknown seed sources can affect survival and productivity (Post and others 2003).

This study was conducted to determine the feasibility of alley cropping as a means of reforestation in western Tennessee and northern Mississippi using locally adapted, quality-improved seedlings. Specific objectives were: (1) Analyze first-year seedling survival and growth for differences among species and

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half-sibling genetic families; and (2) Report the initial costs of alley cropping in terms of establishment and reduced crop yield.

PROCEDURES

Seed Collection and Handling

Open-pollinated, half-sibling families (families) were collected from individual trees of various oak species and black walnut in the Lower Mississippi Alluvial Plain and East Gulf Coastal Plain of Tennessee and Mississippi in the Fall of 2001 and kept separate by mother tree (table 1). The acorns were subjected to a flotation test for viability. The floating acorns were discarded, and the sinking acorns were kept for planting. Acorns were placed again in plastic bags and stored in refrigeration. Black walnuts were dehusked and stored in refrigeration. Family identity was maintained throughout seed collection and handling procedures. Seed was then sorted into an incomplete block experimental design with two replications for nursery sowing.

Nursery Sowing and Management

Acorns and black walnuts were hand sown in December 2001 at the Georgia Forestry Commission's Flint River Nursery near Montezuma, Georgia. Each block was sown with 180 acorns or black walnuts of the same family. Families were replicated with the exception of southern red oak, Nuttall oak and Shumard oak families. The resulting seedlings were grown according to protocols developed by the USDA Forest Service's Institute for Tree Root Biology (Kormanik and others 1994). Lifting occurred in early February 2003 with a Fobra™ machine lifter that was set to undercut at a depth of 30 cm. The bare-root seedlings were transported to east Tennessee and placed in cold storage at the Tennessee Division of Forestry's East Tennessee State Nursery until growth characteristics were evaluated.

Nursery Measurements

After lifting, a uniquely numbered tag was attached to each seedling and lateral roots were pruned to 10-15 cm. Family identity and experimental design information were recorded for each seedling. Stem height and root collar diameter (RCD) at the soil line were measured. First-order lateral roots greater than 1 mm

Table 1—Species and number of families per species used in the study

Species		Families per species
		number
Quercus nigra L.	Water oak	54
Q. pagoda Raf.	Cherrybark oak	28
Q. nuttallii Palmer	Nuttall oak	13
Q. phellos L.	Willow oak	54
Q. shumardii Buckl.	Shumard oak	5
Q. michauxii Nutt.	Swamp chestnut oak	4
Q. macrocarpa Michx.	Bur oak	2
Q. velutina Lam.	Black oak	7
Q. falcate Michx.	Southern red oak	8
Q. palustris Muenchh.	Pin oak	6
Juglans nigra L.	Black walnut	9
Quercus rubra L.	Northern red oak	21
Q. alba L.	White oak	12

in diameter were counted on the seedlings, except for the black walnut seedlings as the majority of root resources are concentrated in the tap root. Measurements were recorded for each seedling.

Planting Sites and Design

There were four bottomland and three upland sites selected for establishment of this study. Wallace Johnston Tree Farm has two bottomland study sites (WJ–S – 10 ha) and (WJ–N – 2 ha) near Hickory Flat, MS. The 4 ha U.S. Fish and Wildlife Service Lower Hatchie National Wildlife Refuge bottomland study site (LH–CL) is located next to Champion Lake in the Refuge. Also in this Refuge, a 2 ha upland site (LH-UP) was planted. The Tennessee Wildlife Resources Agency's Moss Island Wildlife Management Area contained one bottomland study site (MI) that is approximately 4 ha. The Strawberry Plain Audubon Center study (AC) consists of a 4 ha upland site, located near Holly Springs, MS. The Pat Estes Tree Farm study site (PE) is a 0.5 ha upland site located near Big Sandy, Tennessee. Detailed information on each site can be found in Casey (2004).

Seedlings that appeared to be visually greater than the family mean were sorted into an incomplete block experimental design with single tree plots. Bottomland blocks contained nine or twelve seedlings and upland blocks contained five or twenty four seedlings (table 2). Each block received species according to species availability and silvicultural characteristics. On bottomland sites, blocks were divided into two moisture regimes ("wet" or "dry") by observing ponded water or topographic highs and lows. The dry blocks received a mixture of the less flood tolerant species, while the wet blocks received the more flood tolerant species (Casey 2004). All species were planted in 2003 in an alley cropping design (Hodge and others 1999) except for white oak, which was planted in 2004. In the tree rows, there were three seedlings across the width (10 m) with a 2 meter buffer between the outer seedlings and the crop row (10 m), except

Table 2—Species and families per species of experimental materials at each site

Site	Seedlings	Blocks	Seedlings/block	Species	
Wallace Johnston Tree Farm - Southern field	4,210	354	12	Water oak Cherrybark oak Shumard oak	Nuttall oak Willow oak Swamp chestnut oak
Wallace Johnston Tree Farm - Northern field	826	69	12	Water oak Cherrybark oak Shumard oak	Willow oak Swamp chestnut oak
FWS Lower Hatchie NWR - Champion Lake	1,404	156	9	Water oak Cherrybark oak Shumard oak	Willow oak Nuttall oak
TWRA Moss Island WMA	1,730	144	12	Water oak Cherrybark oak Swamp chestnut oak	Willow oak Nuttall oak Bur oak
Strawberry Plains Audubon Center	780	43	24	Black oak Pin oak White oak	Southern red oak Black walnut
FWS Lower Hatchie NWR - Upland	508	43	24	Black oak Pin oak White oak	Southern red oak Black walnut
Pat Estes Tree Farm	300	60	5	Northern red oak	

at the Pat Estes site, which was designed on a 3 meter tree spacing. Gasoline-powered hand augers with 20 cm bits were used to drill 30 cm deep holes, and the seedlings were planted by hand. Studies were then mapped by tag number.

Planting occured in March and April of 2003 and were observed in May 2003, with the exception of the LH-CL and MI sites (table 2). Tree damage occurred on these bottomland sites due to backwater flooding in late May and early June, and was observed in June. Seedlings that died back were clipped down to the live portion of the stem at all sites. All sites were visited in November, 2003 to record live height and survival.

Soybeans were planted on the WJ–S, LH–CL, and LH–UP sites in May and June. A browntop millet (*Panicum ramosum* L.) and sunflower (*Helianthus annuus* L.) mixture was planted as the crop on the AC study site. Crop rows on other sites were not planted due to flooding and other reasons (Casey 2004). The LH–CL and LH-UP sites were converted to a no-tillage management for the 2003 crop.

Economics

Available financial records were collected from farmers regarding the costs and revenues of farming the sites in recent years and the first year of alley cropping. Costs associated with seedling establishment (design layout, seedlings, and labor) were calculated. Financial information was gathered only on sites producing a soybean crop for the 2003 growing season. Financial information was pooled and estimates were created for the average cost of alley cropping establishment and first year crop production on these sites.

Statistical Analyses

Analyses on survival and first year height growth were conducted. The data were analyzed using the statistical software SAS version 9.1 (SAS 2002-2003). A mixed model was used to analyze the data with two treatment factors, species and family, with covariates. Analysis of variance (ANOVA) was used to detect significant differences in survival and first year growth among species. Pearson correlations were calculated among nursery seedling traits. Fisher's Protected Least Significant Difference (LSD) test was used to identify significant differences among species and families. P-value and mean separation were derived from rank transformed data and estimates are derived from untransformed data. Stepwise variable selection was used to select covariates from site and seedling variables for each ANOVA. An error level of 0.05 was selected to show significance for all statistical procedures.

RESULTS

Bottomland Tree Establishment and Growth

Correlation coefficients among initial seedling measurements ranged between 0.43 and 0.71 for all species. The correlation between FOLR and RCD was the strongest in cherrybark oak (0.71) and water oak (0.69). The FOLR – height correlation was the highest in bur oak (0.64); and the RCD-height correlation was strongest in water oak (0.71) and cherrybark oak (0.65).

Overall seedling survival ranged from 90 to 35 percent across sites (table 3). Survival differed significantly among species at all sites (table 3). Dieback occurred over all bottomland sites, followed by a resumption of height growth. Height growth averaged –16 cm, -14 cm, -52 cm, and –62 cm for WJ-S, WJ-N, LH-CL, and MI, respectively. Height growth differed among species at all sites (table 4).

Upland Tree Establishment and Growth

Correlation values of seedling measurements ranged between 0.12 and 0.75 across all species. The correlation between FOLR and RCD was the strongest for southern red oak. The FOLR – height relationship was not the strongest relationship for any species, and the RCD – height correlation was strongest for black walnut (only correlation calculated), white oak (only correlation calculated), pin oak, northern red oak, and black oak.

Table 3—Survival estimates (percent) for bottomland species by site

Species	Wallace Johnston Tree Farm - Southern Field[a]		Wallace Johnston Tree Farm - Northern Field[a]		FWS Lower Hatchie NWR - Champion Lake[a]		TWRA Moss Island	
Cherrybark oak	82.8	D[b]	85.5	BC	70.8	B	25.2	CD
Bur oak	NA		NA		NA		58.2	A
Swamp chestnut oak	90.8	BC	92.0	AB	NA		41.6	B
Water oak	84.6	CD	79.1	C	67.8	B	22.3	D
Nuttall oak	90.8	B	NA		88.4	A	65.8	A
Willow oak	97.8	A	96.8	A	87.3	A	33.7	BC
Shumard oak	87.4	BC	86.2	BC	73.6	AB	NA	
P-value	< 0.0001		< 0.0001		< 0.0001		<0.0001	
Observations	4,069		783		1,345		1,621	

FWS = U.S. Fish and Wildlife Service.
NWR = National Wildlife Refuge.
TWRA = Tennessee Wildlife Resource Agency.
[a] p-value and mean separation derived from rank transformed data; estimates are derived from untransformed data.
[b] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha = 0.05 level.

Table 4—Height growth measurements for bottomland species by site

Species	Wallace Johnston Tree Farm - Southern Field		Wallace Johnston Tree Farm - Northern Field		FWS Lower Hatchie NWR - Champion Lake[a]		TWRA Moss Island	
Cherrybark oak	-11.7	B[b]	-12.3	B	-36.6	A	-59.0	A
Bur oak	NA		NA		NA		-53.8	A
Swamp chestnut oak	-0.3	A	-0.9	A	NA		-56.7	A
Water oak	-25.3	D	-25.8	C	-70.6	C	-77.1	B
Nuttall oak	-2.3	A	NA		-42.0	A	-49.0	A
Willow oak	-14.6	C	-11.2	B	-59.6	B	-75.1	B
Shumard oak	-9.1	B	-6.9	AB	-62.3	ABC	NA	
P-value	< 0.0001		< 0.0001		< 0.0001		< 0.0001	
Observations	3,344		637		985		536	

FWS = U.S. Fish and Wildlife Service.
NWR = National Wildlife Refuge.
TWRA = Tennessee Wildlife Resource Agency.
[a] P-value and mean separation derived from rank transformed data; estimates are derived from untransformed data.
[b] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha = 0.05 level.

Seedling survival was 97, 93, and 90 percent for AC, LH -UP, and PE, respectively. Survival was different among species for all sites where multiple species were planted (table 5). Height growth was positive on two of upland sites, averaging 1.5, 6.2, and –16.8 cm for AC, LH–UP, and PE, respectively (table 6). Height growth differed significantly between species at the AC site, but not at the LH-UP site. Northern red oak growth was negative at the Pat Estes site due to dieback.

Economics

Planting stock cost was $0.65 per seedling, assuming a 40 percent cull rate, and at approximately 160 seedlings per acre resulted in $104 per acre. Groundcover seed for tree rows (browntop millet) was $18 per acre. Tree row tillage and groundcover planting was $20 per acre. Tree planting, without an

Table 5—Survival estimates (percent) for the three upland study sites

Species	Strawberry Plains Audubon Center[a]		FWS Lower Hatchie NWR - Upland Site[a]		Pat Estes Tree Farm[a]
Black walnut	96.1	AB[b]	89.9	B	NA
White oak	NA		NA		NA
Southern red oak	98.0	A	91.8	B	NA
Pin oak	94.2	B	98.3	A	NA
Northern red oak	NA		NA		91.2
Black oak	99.9	A	90.2	B	NA
P-value	0.0106		0.007		NA
Observations	617		474		299

FWS = U.S. Fish and Wildlife Service.
[a] P-value and mean separation derived from rank transformed data; estimates are derived from untransformed data.
[b] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha = 0.05 level.

Table 6—Height growth measurements for species by site for the upland studies

Species	Strawberry Plains Audubon Center		FWS Lower Hatchie NWR - Upland Site		Pat Estes Tree Farm
Black walnut	-11.1	B[a]	1.7	B	NA
White oak	NA		NA		NA
Southern red oak	2.6	A	5.2	AB	NA
Pin oak	3.2	A	5.7	AB	NA
Northern red oak	NA		NA		-16.8
Black oak	4.7	A	9.1	A	NA
P-value	< 0.0001		0.1569		NA
Observations	561		422		258

FWS = U.S. Fish and Wildlife Service.
[a] Mean separation by Fisher's protected least significant difference tests (LSD). Means followed by the same letter are not significantly different at the alpha = 0.05 level.

experimental design, was $60 per acre with augers. This results in total tree establishment costs of $212 per acre for auger planting.

Tillage, planting, and seed costs were a total of $45 per acre of soybeans. Glyphosate, including application, cost $17.50 per acre. Harvesting costs were $25 per acre. Soybean production prior to alley cropping and with alley cropping was approximately 30 and 25 bushels per acre, respectively. Prices averaged $5.71 (5 year average) per bushel for $171.30 per acre of gross profit prior to alley cropping and $142.75 with alley cropping. The net profit was $83.80 per acre for soybean production prior to alley cropping and $55.25 per acre with alley cropping. Soybeans were planted on approximately 60 percent of the acreage in the alley cropping designs. The net loss, compared to full soybean production, for the establishment year of alley cropping these sites was -$51.65 per acre for auger planted seedlings and -$67.65 to -$79.65 per acre if the seedlings were machine planted.

The WJ–S site produced approximately 300 bushels of soybeans. The LH–CL and LH–UP sites produced approximately 175 and 85 bushels, respectively. Average yields for the WJ–S, LH–CL, and LH–UP sites in previous years were 875, 300, and 150 bushels, respectively. The average yield prior to alley cropping was 30 bushels per acre and 25 bushels per acre with alley cropping. The sunflower/millet crop on the AC site was not harvested for production.

DISCUSSION

Seedling Quality

Seedling quality, as defined by height, RCD, and FOLR, has been cited as a critical factor in outplanted survival and growth (Kormanik and others 1995). Studies have suggested that only 40 to 60 percent of nursery seedlings are acceptable planting stock (Clark and others 2000). Planted seedling quality in this study was 4 to 55 percent greater than the sample mean for all bottomland studies, and 10 to 48 percent higher than the sample mean for upland studies, indicating that the planted seedlings were of acceptable quality (data not shown).

The seedlings were visually selected for quality. Pearson correlation analyses showed that there was no single correlation, e.g. FOLR-RCD, that represented the highest R-value for all species in bottomland plantings (data not shown). As any single characteristic increased in value, there was a concurrent increase in other characteristics. Therefore using a combination of visually assessed characteristics, rather than any one specific characteristic, is effective in selecting the highest quality seedlings. The upland plantings, however, show that the height-RCD correlation was generally the strongest relationship, although characteristics still increased in value in concert (data not shown). Visually assessing using RCD was the fastest method for selecting the highest quality seedlings in upland species, as opposed to assessing a combination of characteristics.

Although the seedling quality was excellent, dieback occurred primarily in the bottomland species. The dieback may be related to the relatively long time between lifting and planting (almost 2 months) and the manipulations of root-pruning and measuring, which caused the seedlings to be taken in and out of storage several times. The relatively thin lateral roots of willow and water oaks particularly did not respond well to the planting delay and manipulations.

Bottomland Plantings

The scale of flooding on all bottomland sites was significant and impacted all plantations to varying degrees. Bottomland flooding is not an anomaly in this region (Stanturf and Gardiner 2000) and presents the most challenging aspect to seedling survival in reforestation efforts (Williams and others 1993). In this study, the WJ–S and WJ–N sites experienced relatively good survival rates (88 and 90 percent, respectively) while the two sites with significantly greater flooding, LH–CL and MI, had lower survival rates (79 and 35 percent, respectively). The most apparent cause for the decrease in average survival among sites is the differing severities of stress induced by flooding. Survival decreased as flood depth increased from soil saturation with some ponding (WJ-S and WJ-N sites), to 7 feet of floodwater (LH–CL), and finally to 12 feet of floodwater on the MI site. Duration of flooding was not collected in a manner for analysis, but it is likely that the duration of flooding may be the overriding factor in seedling performance rather than flood depth.

Upland Plantings

Survival on upland sites was generally high (90–100 percent) and differed only slightly among species. There was a trend in which seedlings (excluding pin oak) had better survival on the AC site, perhaps due to a higher water table on the AC site than the LH-UP site.

Height growth differences among species occurred only on the AC site, where black walnut had a substantial amount of dieback. The northern red oak on PE experienced dieback, possibly because of the late planting date and deteriorating condition of the seedlings, e.g. somewhat drier roots.

Crop Production and Economics

A 40 percent reduction in cropland due to alley cropping was significant to farmers, but this amount could be reduced through different alley cropping designs. Three tree rows were planted next to each other, instead of single rows, in order to shorten the length of time needed for reforestation. In addition to the reduction in cropland, a yield loss of 10 bushels per acre was reported, but only at the WJ-S site. The reduction in soybean yields is not due to competition with seedlings during the first year of growth, but could be related to the groundcover treatments. Ditches were not created on this site, as in previous years, due to the alley cropping design, and may have caused some water logging during the growing season, thereby reducing soybean yields.

Auger planting 160 high-quality seedlings per acre (total acreage) along with proper groundcover establishment averaged a one-time cost of $212 per acre (total acreage); significantly greater than planting conventional-sized seedlings with a dibble bar.

Crop production, based on five year prices of soybeans, yielded a profit of $55.25 per acre (total acreage). The net loss of $51.65 per acre lost to alley cropping, is considerable, but significantly less than if the entire field was planted in trees and no crops were produced. Crop production in subsequent years will not have the initial costs of alley cropping to detract from the overall profit. The sunflower/millet crop on the AC site was not harvested for production, and soybeans were planted the previous year so the effect of alley cropping cannot be quantified for this site.

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A PRELIMINARY ECONOMIC ANALYSIS OF SILVOPASTURE IN MISSOURI'S OZARK FORESTS

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Abstract—In 2002, a silvopasture practice was established at the University of Missouri Wurdack Farm located in the Ozark Region of Southern Missouri. With approximately 260 acres dedicated to livestock and forage production and 940 acres of timber, the Wurdack Farm is representative of the open pasture and upland hardwood forest mix commonly found in the Missouri Ozark Region. A total of 25 acres of pole-size white oak located on north-facing slopes were thinned by a contract logger. Selected forages were established as a treatment. Based on the cost to establish silvopasture in the study area, it is estimated that the additional cost to establish silvopasture over improved pasture would range from $121.74 to $635.92 per acre with additional revenue potential from future timber harvests of $354.08 per acre.

INTRODUCTION

According to the most recent forest inventory, Missouri has approximately 15 million acres of forested land, 71 percent of which is a predominately oak-hickory mix (Leatherberry and Treiman 2002). Of the 15 million forested acres, 12 million acres are privately owned (Leatherberry and Treiman 2002). In addition to the available forest resource, Missouri is the second largest producer of cattle in the US, producing 6.5 percent of the nation's beef cows and 5.5 percent of the nation's calf crop in 2003 (Missouri Agricultural Statistics Service 2004). Because of the abundance of privately owned forestland, the prevalence of livestock based agriculture, and the limited amount of forest land under management, silvopasture seems to be a possible option through which Missouri farmers can realize value and have an incentive to manage forested lands.

The negative aspects of unmanaged forest grazing are well documented (Bezkorowajnyj and others 1993, Chandler 1940, Dewitt 1989, Patric and Helvey 1986). Yet, in a survey conducted by Hershey (1991) of four rural Missouri counties, 68 percent of the woodlands were used for grazing. It is important at this point that a significant conceptual misunderstanding be overcome; silvopasture and unmanaged forest grazing are two dichotomous approaches to mixing livestock and trees. Garrett and others (2004) emphasized that the silvopasture practice is intensively managed to integrate production of trees with forage and livestock, and should be viewed as an artificial agroecosystem. Allowing livestock access to woodlands, or forests, without a plan for concurrent production of each component, is likely to have negative consequences to the forest resource while providing limited benefits to the livestock.

However, the benefits of the interactions between the livestock and the trees using silvopasture technology are very well documented (Clason and Sharrow 2000, Lawrence and others 1992, Zinkhan and Mercer 1997). The synergy that exists between a well-managed silvopasture practice includes benefits such as increasing seasonal grazing land, reduction in heat stress on livestock, and improved forest management.

From an economic standpoint, silvopastoral practices can provide both long- and short-term financial benefits on land that might otherwise be considered "non-productive". These documented financial benefits include increased net present value (NPV) (Dangerfield and Harwell 1990; Husak and Grado 2001, 2002); increased annual equivalents including annual equivalent income (AEI) or annual equivalent land value (AELV) (Dangerfield and Harwell 1990; Grado and others 1998, 2001); improved cash flow (Dangerfield and Harwell 1990); and higher rates of return (Dangerfield and Harwell 1990, Lundgren and others 1983).

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Financial, or economic, studies on silvopasture in hardwood stands are not well documented (Zinkhan and Mercer 1997). Most, if not all, silvopasture economic studies have been conducted in the southern pine regions of the United States. Yet, one particular study of silvopasture in hardwood stands showed that the "multiple use management" approach of silvopasture could more than double the expected NPV over managing for livestock only (Standiford and Howitt 1993).

THE WURDACK STUDY

The Hugo Wurdack Farm is a University of Missouri Research Farm located in the heart of the Missouri Ozark Region. It is representative of the typical open pasture and upland hardwood forest mix, with approximately 260 acres dedicated to livestock and forage production and 940 acres in timber. The upland hardwood forest consists predominately of white oak (*Quercus alba* L.), black oak (*Q. veluntina* L.), red oak (*Q. rubra* L.), black walnut (*Juglans nigra* L.), and flowering dogwood (*Cornus florida* L.).

In 2002, a silvopasture study was designed and established to quantify the economic and biophysical effects of hardwood silvopasture in Missouri. The study was designed to identify interactions between the cattle and trees, determine the costs and benefits associated with converting upland hardwood forests to a silvopastoral system, and develop a demonstration site that could be viewed by the public.

One of the impacts of cattle integrated with trees that is being assessed is the value of timber improvement as a result of the integration. Cost and benefit analysis is focused on identifying the most cost effective way to establish the silvopasture practice.

Study Design

The original silvopasture study consisted of five replications in a randomized complete block design. Each replication totaled 6.25 acres of forested land located on north- to northeast-facing slopes and 2.5 acres of open pasture. On the forested land, four treatments per replication were imposed. The treatments included 2.5 acres that were thinned, planted with select forages, and fenced for grazing; 1.25 acres that were thinned, planted with select forages and were not to be grazed; 1.25 acres that were thinned, not planted with select forages and not to be grazed; and 1.25 acres used as a control that were not thinned, not planted with select forages, and not to be used for grazing (table 1). The selected forages included Kentucky 31 tall fescue (*Festuca arundinacea*), red clover (*Trifolium pratense* L), and Marion lespedeza (*Lespedeza striata*). In 2005, an additional treatment was added to better enable analysis of the effects of forages and livestock on tree growth. This increased the total size of each replication to ten acres (7.5 acres of forested treatments and

Table 1—Summary of treatments used on the Wurdack silvopasture study for each of the five forested replications

	Description			
Treatment	Size	Thinned	Select forages[a]	Grazed
	acres			
1 (control)	1.25	No	No	No
2	1.25	Yes	No	No
3	1.25	Yes	Yes	No
4	2.5	Yes	Yes	Yes
5[b]	1.25	Yes	No	Yes

[a] Select forages include Kentucky 31 tall fescue (*Festuca arundinacea*), red clover (*Trifolium pratense* L.), and Marion lespedeza (*Lespedeza striata*).
[b] Treatment 5 was added in July 2005 in the area originally designated for treatment 1. A new control (treatment 1) was established at that time.

2.5 acres of open pasture). The newly added treatment, treatment 5, is a thinning treatment to the previously mentioned control area, where cattle would be placed, but no forages established. New control areas were also created. These new control areas are not to be thinned, grazed, or have soil amendments applied.

Thinning in 2002-2003 was completed by a local logger who was contracted through a competitive bidding process. Thinning was applied to treatments 2, 3, and 4. Removal of additional woody material was achieved by University of Missouri Center for Agroforestry (UMCA) personnel and graduate students. The thinning was designed to allow 50 percent sunlight to reach the forest floor and discriminated against the red oak and black oak (in response to their showing general decline), leaving predominately the white oak.

Treatment 5 (table 1), which was added in 2005, employed an alternate method of thinning from that of 2002-2003. This method required injection of herbicide directly into the unwanted trees on the stump. The designated trees were hacked with a hatchet and undiluted Garlon 3A was squirted into the wound. Similar to the first thinning, white oaks were favored as leave, or crop, trees.

Soil samples were taken after the original thinning was conducted and, along with other analyses, soil pH was determined to average approximately 4.3. Pelletized lime was added to the original forested treatment areas at a rate of five tons ENM (effective neutralizing material) per acre. The open pasture treatments were limed at a rate of one ton per acre. Fertilizer was also added to the four original forested treatment areas at a rate of 450 pounds per acre of 0-150-75 NPK (Nitrogen-Phosphorous-Potassium). No fertilizer was applied to the open pasture treatments.

Selected forages were established in Treatments 3 and 4. For the grass component, the fescue was seeded at a rate of 34 pounds of pure live seed (PLS) per acre. For the legume component of the forage, red clover was sown at a rate of 2 pounds PLS per acre and Marion lespedeza was sown at a rate of 7 pounds PLS per acre.

A single strand electric fence and mobile water systems were added to Treatment 4 which was to be grazed. A total of 20,000 linear feet of fencing was used to fence paddocks and create access lanes between scattered paddocks.

PRELIMINARY ECONOMIC FINDINGS

Establishing silvopasture in an existing hardwood stand is comprised of four cost categories: 1) the cost of thinning the tree stand, 2) the cost of amending the soil for grass establishment, 3) the cost of establishing improved forages, and 4) the cost of fencing and watering systems. In this study, the cost of establishing improved forages and the cost of fencing and watering systems were considered to be constant across both the silvopasture and the open pasture treatments. Therefore, this economic analysis focuses on the additional costs resulting from thinnings and increased soil amendments required to add pasture to timbered areas, as well as the additional revenue potential from the managed tree stand.

Cost of Thinning and Clearing

There were many factors that affected the cost of thinning the original study plots. First, because the study was to be used as a demonstration, special emphasis was placed on aesthetics and minimizing tree damage from logging operations—costs that would not be incurred by a typical landowner interested in establishing a silvopasture program. Part of the logging contract also included keeping detailed records of the quality and quantity of material that was removed from the 25 acres that were commercially thinned. One bid was submitted from a local logger for $150 per acre. Trees to be left were marked by UMCA personnel. Approximately 67 trees per acre were left of various diameters from pole-size to 18 inches dbh (average dbh across species and treatments 4 and 5 was 10.3 inches in spring 2003). Average residual basal area for treatment 4 was 45 square feet per acre. Average residual basal area of dominant and co-dominant species on treatment 5 was 87 square feet per acre.

Following commercial thinning on a particular plot, tops, limbs and non-commercial trees were removed and either carried off site or chipped. This was prescribed to improve the immediate aesthetics of the site and allow for seeding and soil amendments to be more successfully applied. A total of 1032 man hours were used to clear the original study site. For this economic analysis, standard labor rates of $10 per hour and equipment usage rates of $20 per hour for the tractors (Plain and others 2004) and an estimated $10 per hour for the Gator vehicles were applied. Table 2 shows per acre costs and revenue for thinning and clearing the silvopasture study.

Other costs associated with thinning and clearing on the original 25 acres included a $10 cost for chainsaw oil, fuel costs of $199.64, and stump spraying at a cost of $625. The stump spraying cost included the cost of the Garlon 3A and the labor, and was subcontracted to the logger who was conducting the thinning. Net cost for the thinning and clearing of the original 25 acres was estimated at $567.92 per acre.

The thinning costs for Treatment 5 were considerably lower (table 2). Although there was no income from a commercial thin, aesthetics were not emphasized. The major costs for the "hack and squirt" thinning method using Garlon 3A included labor and chemicals. Flagging and deadening the trees that were to be thinned on the 6.25 acres used for Treatment 5 took approximately 17.8 hours. Total chemical used was 8310 ml of Garlon 3A at a cost of $0.02/ml. Thinning on the Treatment 5 area cost a total of $53.74 per acre.

Liming Costs

Within the forested areas, soil pH was measured at 4.3 immediately following the thinning. It was determined that these areas would require 5 tons ENM of lime per acre to bring the pH level up to 6.4. Open pasture treatments were given 1 ton per acre. Pelletized lime was used to speed up the process of incorporating the lime into the soil profile and quickly raise the pH for the purpose of forage establishment. However, pelletized lime is considerably more expensive than standard lime with a cost of $65 per ton; but, a ton of pelletized lime is equivalent to four tons of common agricultural lime. Common agricultural lime

Table 2—Summary of per-acre costs for two methods of thinning in preparation for the establishment of silvopasture on the Wurdack farm

Methods of thinning	Costs per acre
	dollars
Thinning and clearing (method 1)	
Commercial thin[a] revenue	150.00
Labor (41.28 hours $acre^{-1}$)	-412.80
Tractor and implements (15.28 hours $acre^{-1}$)	-255.60
Fuel (gas and diesel)	-7.98
Miscellaneous (repairs, chainsaw oil)	-16.54
Stump spraying (labor, chemical)	-25.00
Total	**-567.92**
Treatment 5 thinning (method 2)	
Labor (flagging, chemical thinning; 2.84 hours $acre^{-1}$)	-28.48
Chemical (Garlon 3A)	-25.26
Total	**-53.74**

[a] Commercial thin revenue reflects the amount received for the thinning conducted in 2002–03.

ranges from $8 - $17 per ton delivered and applied (Plain and others 2004). The difference in cost for the silvopasture treatments as compared to open grass paddocks is estimated at $68.00 per acre for this site.

Benefits from the Managed Trees

The Woodsman's Ideal Growth projection System (TWIGS) (Gale and Yaussey 2002) was used to estimate the value of the trees remaining after the commercial thinning conducted in 2002 and 2003. A plot sample list of crop trees for each Treatment 4 replication was used in the TWIGS model. Species and dbh were based on measurements taken from all Treatment 4 crop tree sample plots. Pulp wood values and sawlog values per species were based on the Missouri Quarterly Market Report (Missouri Department of Conservation 2003). The pulpwood value used was $4 per cord. Sawlog values were $195 mbf for white oak, $180 mbf for black oak, $145 mbf for post oak, and $200 mbf for red oak.

Growth projections are made in 10-year increments from 2003 through 2063 using a white oak site index of 65. A real discount rate of four percent is used for financial analysis. All replications of Treatment 4 (the silvopasture treatment) are aggregated for the model. Trees reaching 17 inches dbh or larger were subject to select removal (commercially thinned within the model) throughout the analysis period, and all trees are removed in 2063. Although regeneration is not discussed in this paper, it is an important part of the Wurdack Study. The initial goal of study is to create a sustainable agroecosystem through a new form of forest management, of which, regeneration must be an integral part. However, the current economic analysis from the TWIGS model only follows the trees that were present on the site at the time of the thinning and silvopasture creation. New containerized white oak seedlings have since been established to help meet the long-term objectives of the Wurdack Silvopasture Study but are not discussed.

According to the values used in the TWIGS model, it is estimated that the net present value (NPV) of the crop trees left on all Treatment 4 areas is $354.08 per acre (table 3).

DISCUSSION

The costs described above (table 2) reflect the additional costs a landowner might incur when establishing a silvopasture practice in an existing hardwood forest setting. Based on the four cost categories listed, these additional costs would be for thinning and any additional soil amendments required on forested lands, above those normally applied in establishing pasture to lands not previously forested.

Table 3—Summary of future timber yields and net present values based on simulations using the Central States TWIGS growth-and-yield model

Year	Saw-log volume bdft/value ($) acre^{-1}	Pulpwood volume cords/value ($) acre^{-1}	Total value in year of harvest	Net present value[a]
			- - - - - - dollars acre^{-1}	*- - - - - -*
2033	3,109/$580	0.8/$3.26	583.26	179.84
2043	2,413/$468.60	0.4/$1.44	470.03	97.90
2063[b]	4,116/$802.66	0.1/$0.46	803.11	76.34
Total net present value of timber harvests				**354.08**

[a] Real rate of 4 percent used to discount the future harvests back to 2003.
[b] All of the original trees were harvested and the residual value of the stand in 2063 is $1,094.31 acre^{-1} which represents the accumulation of planted and natural regeneration. The residual stand contains 5,653 board feet of saw logs valued at $1,091.96 acre^{-1}, 0.6 cords of pulpwood valued at $2.35 acre^{-1}.

As the study was being established, no separate records were kept for cost per treatment, therefore treatment costs are extrapolated from the total costs. Admittedly, this may not show the marginal cost differences within certain cost areas. For example, it may take more time to spread fertilizer on forested land as compared to open pasture. However, it is assumed that those differences are small.

As mentioned, two methods of thinning were used. A labor intensive thinning and clearing method following a commercial thinning represents the top end of the cost range at $567.92 per acre. Whereas, the "hack and squirt" thinning method represents the low end of the cost range at $53.74 per acre.

Liming costs were also higher on the forested land. This may not always be the case; however, for this particular site, additional lime was needed to quickly increase soil pH. The additional lime cost was $68.00 per acre.

Therefore, it can be concluded that the additional costs for establishing silvopasture when compared to establishing open pasture can range from $121.74 to $635.92 per acre. All or part of these costs can be offset by future timber harvests with an NPV of $354.08 per acre.

The Wurdack study was designed with emphasis on demonstration and analysis of tree/livestock interactions. Many of the actual costs in establishing Treatment 4 were substantially higher than a typical landowner would face. For example, clearing limbs and understory trees from the site for aesthetics was done at a substantial cost; however, this process was necessary to increase the demonstration value of the study. Although this method may not be recommended, some landowners may consider this alternative.

Treatment 5 offered a more practical cost estimate for landowners. Although a commercial thinning was not conducted on Treatment 5, and no revenue was generated at the time of establishment, the total cost to thin the site was less than ten percent of the total cost on the other treatments. The most likely recommendation may be a commercial thinning followed by a "hack and squirt" thinning of the residual, non-crop trees, that would be removed as a part of creating the desirable 50 percent light environment for forage growth.

Continued research on the silvopasture study site will determine the growth response of the trees and the forage, as well as the benefits to the livestock of partially shaded pasture areas. These additional benefits from silvopasture will also have a positive effect on the returns to the practice. The study will look at the costs and benefits of alternative regeneration methods including natural regeneration and the use of superior seedlings. At this time the projected NPV makes it likely that the silvopasture practice can be conducted with positive economic returns to a farm. Yet, as with any economic analysis, returns will be very dependent on the early cost of establishment. The intermediate management will determine the longevity, or sustainability, of the practice.

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EPICORMIC RESPONSE WHEN CONVERTING HARDWOOD FORESTS TO A SILVOPASTURE

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Abstract—Scientists at the University of Missouri Center for Agroforestry are researching the impacts on upland oak forests associated with the creation of a silvopasture practice. An initial concern was that the low residual stocking might negatively impact log quality due to epicormic branch development. Trees were thinned leaving only dominants, resulting in a residual basal area of 45 square feet per acre. Epicormic branch count over a two year time span is presented for the two major species present following thinning. Of the 230 white oak (*Quercus alba* L.) and 67 black oak (*Q. veluntina* Lam.) measured in 2005 from treatments thinned during winter 2002-2003, 87 and 92 percent, respectively, remained free of epicormic branches on their first 16 foot log. Therefore, current recommendations to create a silvopasture practice by thinning existing hardwood forests should emphasize leaving trees that do not currently have, or show evidence of, epicormic branches.

INTRODUCTION

Silvopasture is one of five agroforestry practices that promotes good resource stewardship through alternative combinations of forest management and farming practices (Garrett and others 2000, Garrett and others 2004). The silvopasture practice integrates forest and forage management to achieve increases in livestock productivity and provide for greater economic opportunity. This practice differs significantly from the traditional practice of allowing livestock indiscriminant access to the woods. The negative aspects (including impacts on forest regeneration and soils) of unmanaged/continuous forest grazing have been well documented (Bezkorowajnyj and others 1993, Chandler 1940, DenUyl and others 1938, Hawley and Stickel 1948, Patric and Helvey 1986).

However, practices of integrating livestock and forage management have been shown to produce benefits including reduced heat stress and an increase in acreage of seasonal grazing land (Clason and Sharrow 2000, Zinkhan and Mercer 1997). Silvopasture may be an alternative to overgrazing woodlots by incorporating rotational or management intensive grazing practices. Management intensive grazing moves livestock when their impact on pasture forages is such that overall pasture productivity and animal gain drops. This integrated approach to production of forage, livestock and timber has been successfully demonstrated under conifer systems (Zinkhan and Mercer 1997), yet application in hardwood regions of the United States has been widely viewed as being negative, and little research has been conducted.

Lin and others (1999) identified several cool-season grasses and legumes that have been shown to either maintain or improve their productivity under 50 percent shade. Older studies on range management and the suitability of forests for producing forages have also identified that 50 percent light or shade as a threshold point needed for the production of adequate forage under forested conditions (DenUyl and others 1938, Ehrenreich and Crosby 1960). Many studies in eastern hardwood forests have shown that 50 percent of the basal area of hardwood forests needs to be removed in order to increase light levels at the forest floor to 35 percent to 50 percent of full sunlight (Marquis 1988, Dey and Parker 1996, Sander 1979). Based on crown cover, basal area, tree diameter relationships developed by Law and others (1994), they determined that 50 percent crown cover might be achieved by reducing basal areas to approximately 20 to 40 square-feet per acre for tree diameters ranging from 3 to 30 inches, respectively.

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This paper is focused on how thinning an existing forest, as would be done during stand conversion to the silvopasture practice, impacts epicormic branch development following conversion. This is important because epicormic branches reduce hardwood log grades and thereby lower their associated values (Brinkman 1955). In general, studies have identified white oak as highly susceptible to the development of epicormic branching as a result of heavy thinnings (Smith 1966, Trimble and Seegrist 1973, Ward 1966). The change in numbers of epicormic branches are presented for black oak (*Q. veluntina* Lam.) and white oak (*Q. alba* L.) logs as a result of thinning to a residual basal area of 47 square feet per acre.

STUDY LOCATION, CONDITION AND DESIGN

The study site is located in South Central Missouri on the University of Missouri Wurdack Farm, which is adjacent to the Meramec River, near Cook Station, Missouri. The farm comprises approximately 260 acres of pastures and forage production fields and 940 acres of upland hardwood forest. The silvopasture study consist of approximately 50.0 acres of the Wurdack Farm of which 37.5 acres is forested and 12.5 acres is open improved pasture. All of the silvopasture study is located in Crawford county (Section 36, Township 36N, Range 5W).

Pre- and Post-Thinning Conditions

Study stands were principally white oak, post oak (*Q. stellata* Wangenh.), black oak and northern red oak (*Q. rubra* L.). Additional understory species were present, such as flowering dogwood (*Cornus florida*) and redbud (*Cercis Canadensis*). The average pre-harvest diameters at breast height (dbh) of the white oak and post oak averaged approximately 8 inches, with dominant and co-dominant white oak ranging from 7 to 17 inches and post oak ranging from 7 to 12 inches in diameter. The northern red oak and black oak averaged 13 inches dbh with the dominant and co-dominant northern red oak ranging from 9 to 23 inches and the black oak 8 to 21 inches. Across all replicates, basal area prior to thinning averaged 112 square feet per acre.

Before treatments were implemented the number of commercial trees measured across all replicates, and within the species groups of white oak, northern red oak, post oak and black walnut (*Juglans nigra* L.), totaled 902 (table 1). Following application of the thinning treatment, count of trees in the sample plots was reduced by 64 percent to only 329 trees.

Table 1—Number of trees measured and mean diameter at breast height (d.b.h.) in 2003, by species and treatment

Species (common name)	Pre-treatment—all plots tree count	Treatment	Post-treatment—all plots by treatment tree count	D.b.h. 2003
				inches
White oak	602	Thin	155	10.66
		No thin	75	9.94
Black oak	195	Thin	37	11.97
		No thin	30	10.54
Post oak	76	Thin	21	9.53
		No thin	4	11.75
Northern red oak	23	Thin	1	13.50
		No thin	4	12.05
Black walnut	6	Thin	2	13.20
		No thin	0	—

— = not applicable.

Average dbh for residual white oak and post oak was 10.66 and 9.53 inches, respectively (table 1). Black oak averaged 11.97 inches dbh. For all thinned treatments (2, 3 and 4) residual basal area averaged 45 square feet per acre, down from a pre-thin basal area of 112 square feet per acre. By comparison, average basal area of dominant and codominant trees on the control treatments was 87 square feet per acre.

Areas used for this study were fertilized and limed in order to adjust soil fertility to favor the growing of forages. Fertility adjustments were made in the spring of 2003 based on soil tests conducted by the University of Missouri Soil Testing Lab in Columbia, Missouri. Initial pH measurements averaged 4.3 and each treatment received 5 tons of pelletized lime per acre, as well as 450 pounds of 0-150-75 NPK (Nitrogen-Phosphorous-Potassium) fertilizer per acre. Additionally, those treatments with forages were broadcast seeded with Kentucky 31 tall fescue (*Festuca arundinacea*), red clover (*Trifolium pratense* L), and Marion lespedeza (*Lespedeza striata*).

Design

The complete silvopasture study involves five treatments that are replicated five times in a randomized complete block design. Each replicate is located on a north to northeast facing slope. The five treatments include: (1) a control (no thin), (2) thin with no forage grass, (3) thin with forage grass, (4) thin, with forage grass and cattle grazing, and (5) thin with no forage grass and cattle grazing. Each treatment unit is 1.25 acres except for treatment (4) which is 2.5 acres in size. At the inception of this study treatment 5 had not yet been created. Across all 37.5 forested acres this created 25 acres that were thinned, with thinning planed on an additional 6.25 acres, leaving the remaining 6.25 forested acres as unthinned control treatments.

Main treatment affects for this epicormic branch study included thinned treatments (treatments 2 through 4) and an unthinned control treatment (treatment 5). The randomized complete block design represents five sample replicates of two treatments, thinned and unthinned.

METHODS

In each replicate we collected data from 16 one-twentieth acre plots: seven in each thinned cattle treatment, three in each of the two additional thinned areas, and three in the control. There were a total of 80 measured plots taken across all treatment replicates. Of these 80 measured plots, 65 are from thinned treatment areas and 15 from unthinned treatments.

There were a total of 902 trees in our measured plots prior to their thinning. Of these trees, those we wanted to keep were identified and marked. A whole-tree commercial thin of research plots was conducted during the winter of 2002-2003. Based on leaving only the marked trees, this thinning essentially represented a heavy low thinning; also know as “thin from below”. After thinning, dominant and codominant white oak and black oak were left uniformly over the area to provide an estimated 50 percent canopy coverage.

The residual trees within each one-twentieth acre plot were measured for dbh and epicormic bole sprouts (March 2003). This was assumed to be equivalent to their condition prior to thinning. Bole sprouts were tallied by location on each tree: the first log (Log1), up to 8 feet in height, or the second log (Log2), from 8.1 feet up to 16 feet in height. This was done by placing a height pole on the uphill side of the tree and measuring to the first and second log heights. The development of epicormic branches, or bole sprouts, on individual trees in each plot was measured over 2 years, from the spring of 2003 through the summer of 2005.

Given the reduced numbers of measured sample trees for post oak, northern red oak, and black walnut (table 1), comparisons in the number of epicormic branches gained over the 2 year time span were only calculated for white oak and black oak. There were a total of 67 black oak and 230 white oak measured and compared.

Statistical analysis was conducted using GLM (general linear model), computed by SAS version 9.1 (2002). Average gains in branches were compared for data collected in 2003 and 2005. This data represents pre- vs. post-thinning treatments for both black oak and white oak. Treatment differences were tested at an alpha level of 0.05.

RESULTS

Black Oak

Log 1 (0 to 8 feet)—Of the 67 black oaks measured, 37 were from thinned treatments and 30 from the controls (no thin). Thirty-five trees from thinned treatments and 28 trees from control treatments had no epicormic branches present in 2003. By 2005 those same trees had not gained any epicormic branches (0 percent gain). Four of the initial 67 trees measured had epicormic branches present in 2003 (2 from thinned treatments and 2 from the control). Three measured trees had fewer branches counted in 2005 than in 2003, and thus lost branches. Only one remained constant and did not lose or gain branches.

Log 2 (8.1 to 16 feet)—Thirty-six black oaks had no epicormic branches in 2003. Thirty-one contained at least one epicormic branch. By 2005, of those trees starting without branches, 8.7 percent from thinned treatments had gained branches. Only 1 out of the original 13 from control areas had gained branches (7.7 percent). Of the trees within log 2 that started with branches, a total of 5 gained and 12 lost branches, with a majority showing no gain or loss in branch count.

ANOVA—Results comparing the average number of epicormic branches, pre- vs. post-treatment, and by first and second log positions showed a loss of branches in both the control and thinned treatments (table 2). Analysis of the pre- vs. post-treatment epicormic branch differences for logs one and two did not identify significant differences (P-values 0.23 and 0.97, respectively).

White Oak

Log 1 (0 to 8 feet)—Of the 230 white oaks measured, 155 were from thinned treatments and 75 from control (no thin) areas. One hundred-twenty-two trees from thinned treatments and 53 trees from control treatments had no epicormic branches present in 2003. By 2005, 93 percent of 122 trees from the thinned plots were still free of branches. From the control areas 45 of 53, or 85 percent, of the original trees having no branches in 2003, showed no development of new branches. Of the initial 33 trees measured from thinned treatments that had epicormic branches, 79 percent of them either had no gain, or lost branches. From the control areas only 68 percent of trees having branches in 2003 had no change, or lost branches.

Log 2 (8.1 to 16 feet)—A majority of the initial 230 white oak trees measured began with epicormic branches in log 2 (150 with vs. 80 without). However, a greater percentage of those starting without branches were found to again be branch free in 2005. Eighty-eight percent of trees from thinned

Table 2—Average gain in epicormic branches and test of difference between thin and unthinned (control) treatments, by species

Species	Log	Control Pre-treatment	Control Post-treatment	Control Difference	Thinned Pre-treatment	Thinned Post-treatment	Thinned Difference	$F_{1,4}$ value	P value
		- - - number of epicormic branches - - -							
Black oak	1st	0.07	0.03	-0.04	0.5	0	-0.5	2.03	0.23
	2nd	1	0.8	-0.2	1.24	1.11	-0.13	0	0.97
White oak	1st	0.88	0.93	0.05	0.46	0.55	0.09	0.09	0.78
	2nd	2.65	2.27	-0.38	2.57	2.45	-0.12	1.17	0.34

treatments that had no branches in 2003 did not have branches in 2005. Only 72 percent of branch free trees in control areas remained thus by 2005. By contrast, only 78 percent of trees from thinned treatments that began the study with branches either lost, or had no gain, in branch count, by 2005. Eighty-three percent of trees in control areas that began with branches either remained the same, or lost branches.

ANOVA—Statistical comparison of the pre- vs. post-treatment epicormic branch differences for logs one and two were not significant (P-values 0.78 and 0.34, respectively).

DISCUSSION

When implementing a silvopasture practice in a fully stocked hardwood stand, reducing stocking through thinning will be necessary to provide enough light for adequate forage production. Trees that remain can have increased diameter growth (Hilt and Dale 1989) because growing space has now been increased by thinning. On the other hand, if epicormic branches result from thinning levels, then log grade and value may be reduced (Miller 1996). So, if trees can be favored that are not subject to factors detracting from their grade and value, then thinning processes enhance residual tree values as a result of improved growth rates. This study shows that thinning stands for a silvopasture practice does not appear to increase epicormic branch development.

Many studies have been done on epicormic branch development as a result of thinnings, and most, would tend to suggest that white oak is prone to develop epicormic branches in response to heavy thinnings (defined as those reducing stands to 40 percent stocking (Hilt and Dale 1989, Smith 1966, Trimble and Seegrist 1973, Ward 1966). In our silvopasture forest stands, thinnings resulted in a residual basal area of 47 square feet per acre, and residual tree diameters of 10 inches. Stand stocking is approximately 40 percent which is below C-line on Gingrich's diagram (Gingrich 1967). However, Lamson and others (1990) reported that within hardwood forests codominant, vigorous crop trees, with clean boles (i.e. no epicormic sprouts initiated), were not likely to develop epicormic sprouts after thinning to 40 to 50 percent stocking. To date, our research supports that finding. Boles of measured white oaks were fully exposed to sunlight and yet the thin treatment did not show an influence on the percent of trees gaining numbers of epicormic branches as compared to trees in the control treatment.

Further, it has been shown by others that epicormic sprouting is more likely in suppressed and intermediate trees, than in dominant and co-dominant forest trees. Trees are much less likely to develop epicormics when they are vigorous co-dominants and have shown no evidence of epicormic branches (Lamson and others 1990, Miller 1996, Ward 1966). Smith and others (1989) reported that 80-year-old codominant Appalachian hardwoods released on four sides did not produce a significant number of epicormic branches. In this study, although data was not collected on crown position at the time of thin, efforts were made to select trees likely to respond to a thin. The selection process was conducted in the manner of a crop tree thin, and thus strongly favored trees in the dominant and codominant crown positions. We observed that a high percentage of those trees selected to remain had no epicormic branches at the time of thinning and did not develop epicormic sprouts over the 2-year time frame of this study.

CONCLUSION

The impact of forest activities on long-term profit opportunities from forest stands' plays a role in the management decisions. When establishing silvopasture practices on farms, decisions on thinning forests to low stocking levels must balance potential gains in forage production with potential value loss due to timber degradation as a result of developing epicormic branches. We thinned to approximately 40 percent stocking by reducing basal area by about 60 percent (from 112 to 45 square feet per acre). This level of thinning has created approximately 50 percent canopy coverage, and in theory this will provide adequate light for forage production. This will be evaluated over time. Additionally, results from this study would indicate that degradation of residual timber by epicormic sprout production in thinned forests may be avoided by selecting/favoring trees that show no tendency to produce branches. However, an important consideration must always be to favor vigorous trees of dominant/codominant crown classes when thinning upland hardwood forests to produce silvopasture practices.

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FOREST PRODUCTS

Moderator:

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ASSESSING VENEER LOG QUALITY ATTRIBUTES

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Abstract—Hardwood veneer logs comprise less than 1 percent of the hardwood forest resource in the eastern United States. In some instances veneer log prices are 10 times greater than grade 1 sawlogs. Hardwood veneer log prices are driven by both exogenous (i.e., economics and consumer preferences) and endogenous factors (i.e., log attributes). In this paper we focus on log attributes: ring count or ring density, ring texture, color, and defects. To better understand and to discern the salient attributes that differentiate veneer logs from sawlogs, and high-end from low-end veneer logs, we surveyed face hardwood veneer manufacturers. We examined veneer log quality attributes for the following species: black cherry, northern red oak, white oak, and sugar maple. The impetus of this research was to discern log attributes via buyer cues and then analyze and develop veneer log quality metrics. Forest management heuristics and buyer guidelines for assessing the potential of high quality veneer trees grown under different hardwood management regimes can be based on the attribute metrics derived from this study.

INTRODUCTION

Hardwood Veneer and Markets

Hardwood veneer logs comprise less than 1 percent of the hardwood forest resource in the eastern United States (Hoover and Gann 1999). In some instances veneer log prices are 10 times greater than grade 1 sawlogs. Hardwood veneer log prices are driven by both exogenous (i.e., economics and consumer preferences) and endogenous factors (i.e., log attributes). In this paper we focus on log attributes: ring count or ring density, ring texture (i.e., a log/disc that contains consistent growth, fast-to-slow growth, and/or slow-to-fast growth), color, and defects. These attributes, singularly or in combination, affect a buyer's perception of log quality and ultimately log value. Several studies have identified veneer log attributes and defects. Which attributes and/or defects are most important have not been quantitatively identified. This research has implications for both business and forest management. For example, veneer manufacturers and their customers have discrete wood quality parameters that are understood among differing entities, but are poorly defined among those same entities. Generalized quality standards for veneer logs may be more or less important depending on the veneer customer and/or market segment, species, and manufacturing system.

Knowledge gained from field visits (with veneer log procurement and production personnel) revealed that subtle appearance factors were salient determinants of veneer value in domestic and foreign markets (e.g., architectural, door, and panel). Consequently, these subtle factors are very important to log procurement personnel when selecting and purchasing logs for processing for high-end markets. The primary color (or hue) of the wood is important for all species, but especially for maple, walnut, ash, and white oak. Minor color variations and blemishes are considered defects in high-end veneer markets because large veneer sections with a consistent appearance are desired. Therefore, color variations caused by insects or fungus are a major concern. These variations include gum pockets and rings in cherry, sugar flecks in maple, and glass worm in ash. Mineral streaks in oak and maple also are important since they, too, cause color variations that are defects in high-grade veneer. Next to color consistency, grain pattern (or ring texture) consistency is equally important, if not more important. The texture of the growth-ring pattern must be uniform (i.e., consistent rate of growth) and the grain must be relatively straight.

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As a result of the especial prices paid for veneer-quality logs, an amplified percentage of a woodlot's timber value may be derived from only a few trees in the woodlot. This price differential can provide significant economic incentive for landowners, foresters, and loggers to manage forest resources to optimize the recovery of veneer logs. Both forest management heuristics and buyer guidelines for assessing the potential of high quality veneer trees grown under different hardwood management regimes can be based on the attribute metrics derived from this study.

To better understand the salient attributes that differentiate veneer logs from sawlogs and high-end from low-end veneer logs, we surveyed face hardwood veneer manufacturers about veneer log attribute. The relative importance of veneer log quality attributes were examined for each of the following species: black cherry (*Prunus serotina* Ehrh.), northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and sugar maple (*Acer saccharum* Marsh.). We utilized Brunswik's (1952, 1955) Lens Model and Social Judgment Theory (SJT) to assess responses to veneer attributes and defects. The impetus of this research was to use buyer's cues to describe veneer log attributes and then analyze and develop veneer log quality metrics.

Social Judgment Theory

Assessing any object in its physical environment can be challenging. In a psychobiological context, the importance or value of an object's attributes is determined by the (subjective) interpretation of these attributes. SJT is a systems-oriented viewpoint for analyzing human (i.e., veneer log buyers) judgment in discrete ecological (i.e., environment) situations. For an in-depth discussion of SJT, see Alderman and others (2004).

One of the premises of SJT is that individuals do not have direct access to information regarding objects in the environment. Instead, one's perception of these objects influences judgment(s); perception is a circuitous process (i.e., non-linear), mediated by the set of proximal cues one receives. It is assumed that judgments result from the integration of "cues" or sources of perceptual information arising in one's "ecology" (i.e., environment: see fig. 1). One of the primary benefits of SJT is the opportunity to compare judgment processes to environmental processes, and also judgments between subjects. Processes and judgments have a common interface that includes the proximal cues (i.e., log attributes, defects, etc.) in perception and the *task system* and the *cognitive* (judgmental) system.

SJT allows for the decomposition of the judgment process after the judgments have been rendered (*a posteriori*) and is accomplished by multiple regression analysis to recover both cue weights and prediction

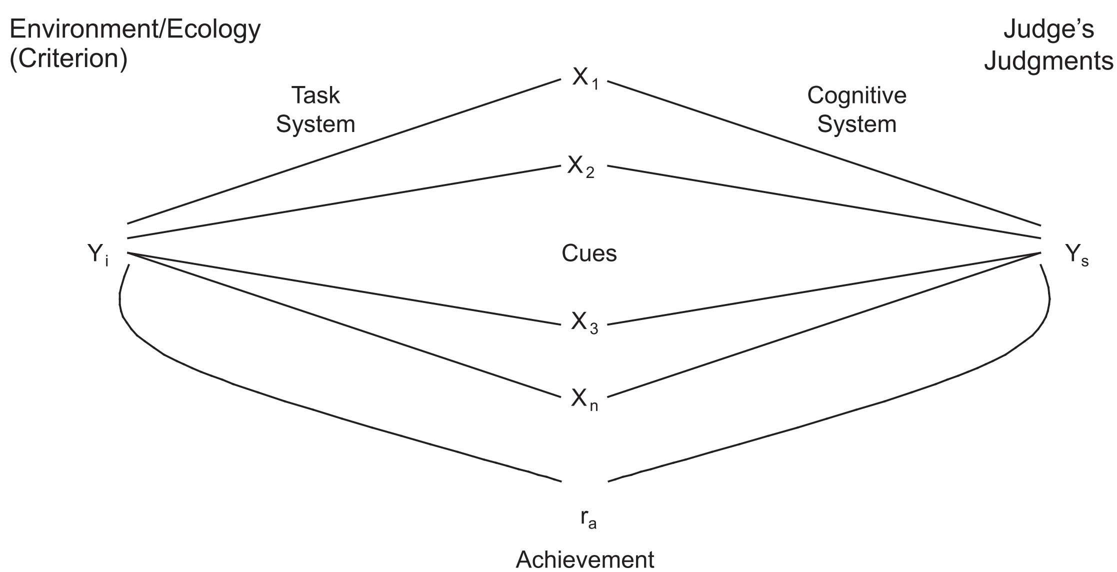

Figure 1—Brunswik's Lens Model.

equations. The Lens Model allows for comparisons between judgments, subjects, and ecological systems. SJT is appropriate for researching veneer log procurement. Log buyers make decisions under uncertainty that require the evaluation of visual cues (e.g., species, diameter, log form and shape, length, quality attributes and defects – both external and internal). For example, log buyers must decide whether to purchase logs based on the aforementioned cues, as well as color, grain pattern, and blemishes. Other, but not all, uncertainties include: consistent color and grain pattern throughout the log; extensive or confined blemishes; and market uncertainties. There are no heuristics for predicting buyer judgments or success. Buyers must make many judgments daily, but little is known about how buyer judgments are made or the accuracy of their judgments.

Decisions concerning the end-user market also are important and judgments are typically made during the evaluation process and before complete log evaluation. Adopting a SJT perspective, buyers generally do not have access to information about cue weighting and the degree of uncertainty in their judgments. From our perspective, minimal attention has been paid to the utility of these evaluation cues in differentiating one attribute or defect from another. To our knowledge, heuristics for predicting buyer judgments or success are not available, or varies from location to location.

SJT's statistical and conceptual approach provides an informative method for assessing and analyzing several factors of the veneer log procurement process. As veneer procurement and production becomes more competitive, SJT allows for valuable insights. These insights include categorization of attributes and defects, ring density metrics for procurement and forest management, and useful information on the weights buyers place on other elements of the procurement process.

OBJECTIVES

The project goal was the identification of veneer log attributes and buyer decision processes that have the greatest effect on the quality, procurement, processing, and value of high-grade hardwood logs. The objectives of this study are to:

1. Identify critical factors in the selection of logs for veneer,

2. Identify relationships between those attributes/defects that may assist veneer buyers in assessing the quality of logs,

3. Produce metrics that can be used to evaluate the veneer potential of trees grown under different forest management regimes.

METHODOLOGY

Testing—Population and Sample Frame

We sampled representatives from 25 face hardwood veneer manufacturers, both members and non-members of the Hardwood Plywood and Veneer Association. The subjects included veneer graders and buyers. We attempted a census (i.e., a 100 percent sample of company log graders).

Questionnaire

The same questionnaire was used for all color photographs (24 inch x 24 inch) of the veneer discs. A script described the logs the subjects were to assess, and subjects used a semantic-differential scale (1 to 7) anchored by good (1) and bad (7) for rating the discs. Four photos of discs of each species were selected to be judged by the subjects. The discs ranged from perfect or near perfect to discs containing representative attributes and defects for the species being queried. To ascertain if confound(s) existed by utilizing photographs, two discs of each species also were rated by the subjects. The questions queried subjects on density and texture, log form and diameter, heart size and heart centeredness, and defect. For example, to evaluate black cherry, questions were developed to address both density and consistency of growth rings (i.e., texture); color and color consistency; roundness of log, diameter, and centered heart; percent of heartwood to sapwood; and gum spots, bird peck, heart rot, and shake. In addition, two open-ended questions were included to address attributes and/or defects that were not anticipated by researchers. Finally, subjects were asked how much they would pay for each log.

Cue Development and Pretest

Multiple photographs of cherry veneer discs (stimulus) were developed for use during the interviews with the veneer log buyers. The photographs ranged from extremely high quality logs to those that contain character marks, density, and texture (i.e., low-quality). In addition to the photos, actual veneer discs were presented to discern if differences (i.e., confounds) in response occurred between the two forms of stimuli. The pretest sample frame included veneer log brokers/buyers and hardwood sawmill procurement foresters with six firms in West Virginia and Virginia.

Pretest results for black cherry, via PCA, yielded a four-factor solution. Ring density, ring texture (i.e., consistency), and centered-heart loaded on factor 1 (31 percent of the variance). Bird peck and gum loaded on factor 2 (17 percent of the variance); heart rot and ring shake loaded on factor 3 (13 percent of the variance); and the sapwood/heartwood ratio loaded on factor 4 (10 percent of the variance). Regression analysis yielded three-cue weights: physical defects (i.e., bird peck, heart rot, ring shake, and gum), ring texture, and centered-heart. The cue weights and equation resulted in very strong evidence of significance ($\alpha = 0.0001$), $r = 0.76$, and the adjusted $r^2 = 0.54$).

Data Analysis

We employed multidimensional scaling (MDS), principal components analysis (PCA), and statistical contrasts of veneer log attributes using SPSS® 12.0 for all analysis. MDS is an alternative to factor analysis and detects meaningful underlying dimensions, which allow for the explanation of observed similarities/dissimilarities. In this study we researched and collected positive and negative attributes (i.e., similarities/dissimilarities) based on subject's preferences. MDS attempts to arrange "objects" in a space with an exacting number of dimensions in order to reproduce the observed distances. As a result, we can "explain" the distances in terms of underlying dimensions; in figures 2-5, we explain the distances in terms of two dimensions. MDS allowed for a perceptual map to be produced for each species and analysis of consistent growth rings versus textured growth rings was executed. PCA was employed to discern similarities and/or dissimilarities in subject's assessments of the growth rate dimension. MDS

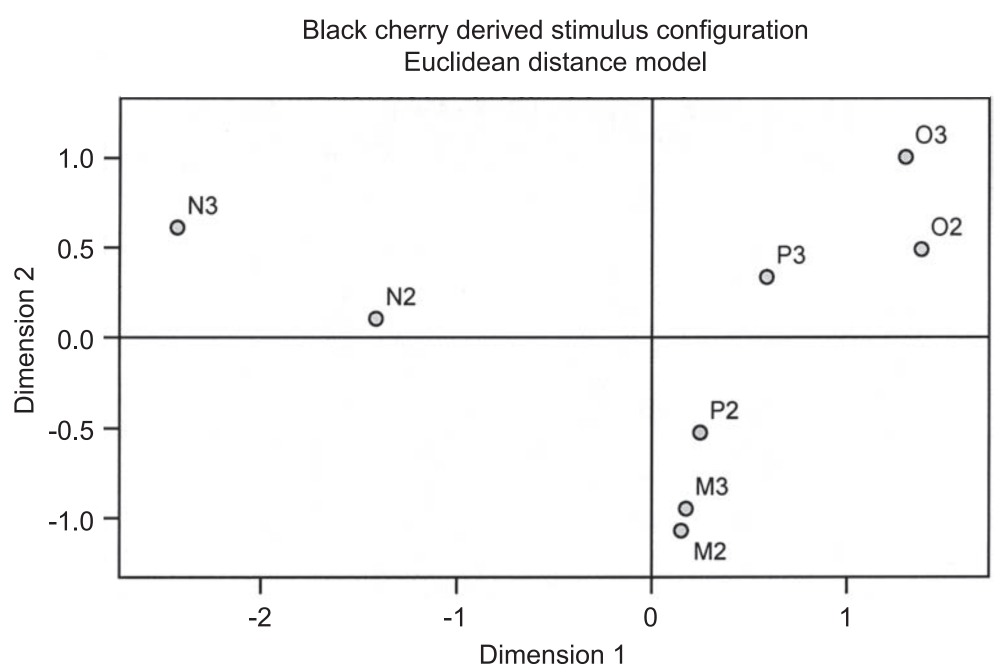

Figure 2—Multidimensional scaling perceptual map, black cherry.

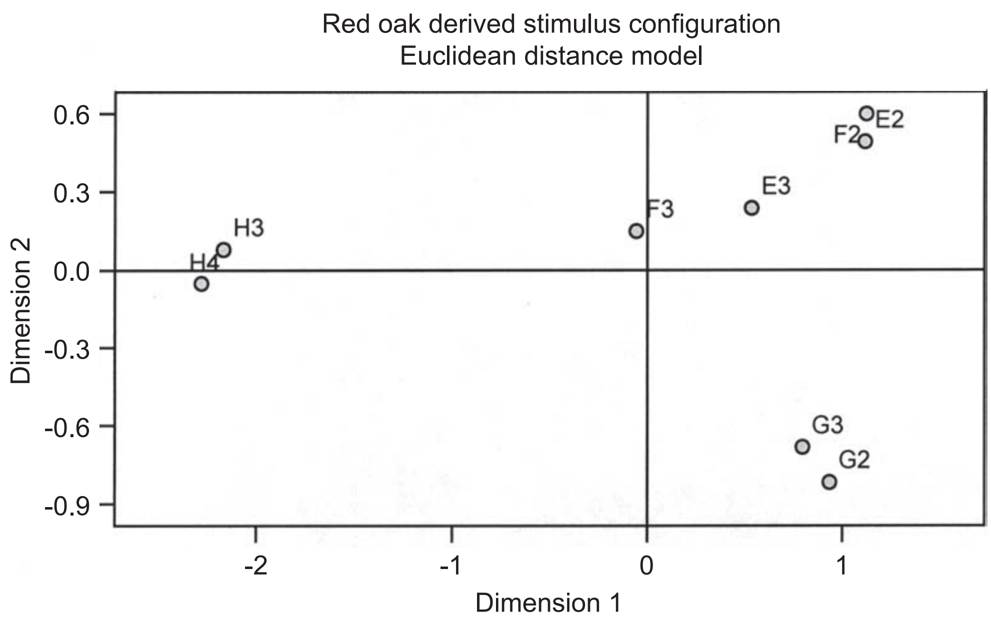

Figure 3—Multidimensional scaling perceptual map, northern red oak.

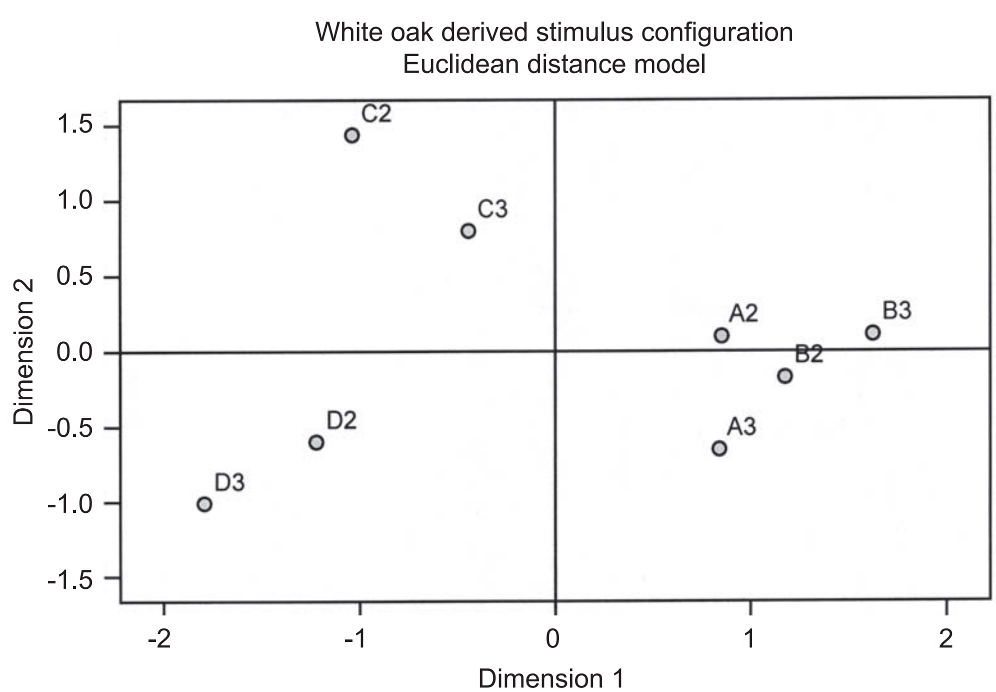

Figure 4—Multidimensional scaling perceptual map, white oak.

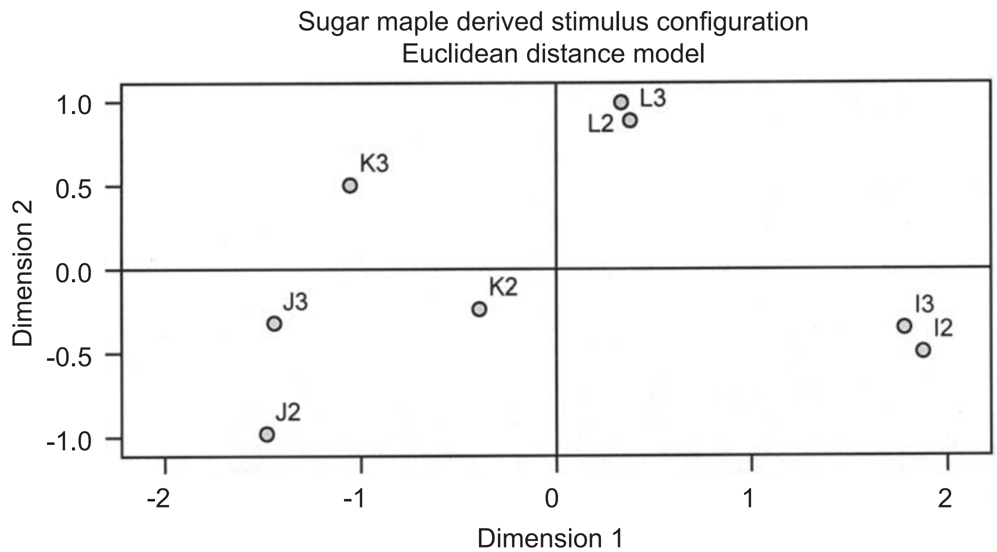

Figure 5—Multidimensional scaling perceptual map, sugar maple.

allowed for a perceptual map to be produced and analysis of consistent growth rings versus textured growth rings was executed. PCA was employed to discern similarities and/or dissimilarities in subject's attribute assessments.

RESULTS AND DISCUSSION

Table 1 contains survey data for each species. Both PCA and MDS (figs. 2-5) were employed to discern subject preferences for positive attributes and/or defects. The analysis of consistent growth rings versus textured growth rings has salient implications for veneer production and hardwood management, particularly in regard to stands with the goal of producing veneer quality stems. In regards to the quality attributes previously mentioned, discrete defects for the species investigated are provided (for a more thorough description of these defects, see Wiedenbeck and others 2004).

Black Cherry

From our field visits, gum spots, bird peck, T-shaped scars, pin knots (typically in clusters), and ingrown bark are exogenous (from a buyer's perspective) defects in cherry that concern procurement personnel. Results indicate that color consistency, color, bird peck, and texture were problematic, with ratings from of 4.50 to 4.16 (table 1). Specific criticisms were noted: color was not consistent, overall color was not the right hue, bird peck is not an acceptable defect, and growth rings were not consistent.

PCA results indicated that (in order) color, consistent color, and ring density accounted for nearly 31 percent of the variance (factor 1). For factor 2, centered heart, log roundness, and heart rot accounted for 26 percent of the variance. Bird peck loaded on factor 3 and accounted for 12 percent of the variance.

We contrasted a consistent growth ring disc versus a disc that was textured (i.e., non-consistent growth rings). Three forms of independent-samples t-tests were conducted: parametric (PTT) and nonparametric, Mann-Whitney U (MW), and Kolmogorov-Smirnov Z (KS). All are asymptotic two-tailed tests. Results indicated very strong evidence that buyers preferred black cherry logs with consistent growth versus textured growth (PTT, $p = 0.005$; MW, $p = 0.006$; and KS, $p = 0.015$).

Figure 2 presents the MDS perceptual map for black cherry. The map provided evidence that the consistency dimension (i.e., distance) was dissimilar or distal from the textured disc. Note that O3 was the "consistent' disc and was contrasted against N3 (textured). These dimensions represent the subject's ratings of similarities and/or dissimilarities between the disc's dimensions and results in a

Table 1—Mean ratings[a] of quality attributes/defects by species

Attribute/defect	Black cherry	Red oak	White oak	Sugar maple
Ring density	4.07	4.52	3.45	3.14
Ring consistency (texture)	4.16	5.02	3.48	2.95
Color	4.40	5.50	5.17	3.09
Color consistency	4.50	5.55	4.81	2.82
Centered heart	2.66	3.40	2.51	2.30
Roundness	3.02	3.92	3.45	2.80
Ratio of heartwood to sapwood	3.05	3.03	3.31	2.25
Gum spots	3.95	4.71	3.25	3.56
Bird peck	4.20	4.51	4.11	4.26
Diameter	3.21	3.47	3.45	2.89
Heart rot	2.70	3.75	3.42	2.31
Ring shake	2.87	2.81	2.49	2.40

[a]1 to 7 interval scale, anchors: good – bad.

preference dimension. In black cherry, there is a preference for consistent growth compared to textured or inconsistent growth.

Northern Red Oak

Our field visits revealed northern red oak is considered an easy species in which to assess quality. Defects include ingrown bark, adventitious buds, and insects. Color consistency, color, and texture were found to be problematic, with a range of 5.55 to 5.02 (table 1).

Results from PCA indicated that ring density and texture, centered heart, and log roundness accounted for 28 percent of the variance (factor 1). For factor 2, consistent color and color accounted for nearly 17 percent of the variance. Gum spots loaded on factor 3 and accounted for 15 percent of the variance. Finally, ratio of heartwood to sapwood and bird peck loaded on factor 4(14 percent of the variance).

Consistent growth was contrasted against textured growth, with results indicating very strong evidence (PTT, p = 0.000; MW, p = 0. 000; and KS, p = 0.004) that buyers preferred northern red oak logs with consistent growth. Figure 3 presents buyer judgments E3 (consistent) versus H3 (textured) and indicated a preference for consistent growth rings.

White Oak

White oak is deemed as a difficult species for which to judge quality compared to red oak. Endogenous defects of particular concern are pin knots, bird peck, and mineral stain. Color, color consistency, and bird peck were rated as problematic, with a range of 5.17 to 4.11 (table 1).

Gum spots, bird peck, heart rot, and ring shake accounted for nearly 37 percent of the variance in factor 1. Texture, ring density, and log roundness accounted for about 24 percent of the variance in factor 2. Log diameter, ratio of heartwood to sapwood, and color loaded on factor 3 and accounted for 18 percent of the variance.

The consistent versus textured growth contrast yielded significant evidence (PTT, p = 0.036; MW, p = 0.034; and KS, p = 0.033) that buyers preferred white oak logs with consistent growth rings. MDS analysis (fig. 4) yielded a similar result, as disc B3 was preferred to D3.

Sugar Maple

A majority of log buyers interviewed stated hard maple is the most difficult species to predict veneer log quality. Of prime concern is color, followed by sugar streak (i.e., pith fleck), ingrown bark, bird peck, and T-scars are all defects that reduce quality. Bird peck was problematic, with a rating of 4.26 (table 1).

Results from PCA (factor 1) indicated that ring density, texture, color consistency, and color accounted for nearly 29 percent of the variance. For factor 2, heart rot, ring shake, and gum spots accounted for approximately 25 percent of the variance. Log roundness, bird peck, diameter, and centered heart loaded on factor 3 and accounted for more than 17 percent of the variance. Finally, ratio of heartwood to sapwood loaded on factor 4 (11 percent of the variance).

A disc with consistent growth was contrasted against textured growth and results indicated strong evidence (PTT, $p = 0.001$; MW, $p = 0.003$; and KS, $p = 0.006$) that buyers preferred sugar maple logs with consistent growth. Figure 5 presents buyer judgments L3 (consistent) versus J3 (textured), indicating a preference for consistent growth rings.

IMPLICATIONS FOR FOREST MANAGEMENT

There are several complex and interrelated factors that have an effect on hardwood forest management: goals (economic and biological), aesthetics, regeneration, and improving current growth, to list a few. Maintaining and enhancing tree growth is an important component of sustainable forestry. Typically, the goal is to simultaneously increase biological and economic growth – increasing the size of bole subsequently results in increased value. This can be achieved through crop tree release, timber stand improvement, shelterwood cuts, group selection cuts, or by thinning, etc. However, results from this research indicate that increasing both stem and stand growth may have deleterious effects on stem quality and is particularly detrimental if the goal is to manage for veneer-quality trees and stands. Ultimately the potential timber receipts from individual trees or timber stands will be decreased by opening up a stand to maximize growth.

Increasing a stem's growth rate at the expense of stem quality is problematic on two fronts. First, buyers preferred logs with consistent growth rings. This is a criterion imposed by secondary manufacturers and the end-consumer, as "textured" growth ring patterns are not aesthetically pleasing to the human eye. Second, during the drying process, when veneer sheets separate it usually is at the conjunction of fast and slow growth rings. In addition, opening up a stand more than likely encourages epicormic branching, which reduces stem quality, whether the goal is sawlog or veneer log production.

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CURRENT TRENDS IN THE U.S. WOOD FLOORING INDUSTRY

Brian H. Bond, Matt Bumgardner, and Omar Espinoza[1]

Abstract—Since the flooring industry is the largest user of low-grade hardwood lumber (excluding pallets), its health can have a significant impact of the value of the hardwood resource. While flooring production remains high, this industry segment is not exempt from the unprecedented changes that other manufacturers in the United States are currently experiencing. Domestic flooring producers face increasing raw material costs and competitive pressure. A clear understanding of market trends, competitive products and production volumes would aid domestic producers in developing strategic plans to combat foreign competition and assist forest planners in making decisions about low grade timber. The research presented focuses on recent trends in the wood flooring industry and is based on data collected from the U.S. Department of Commerce and results of a survey characterizing flooring manufacturers in the United States. Results indicate that while production of hardwood flooring has significantly increased in the last decade, imports are rising at a much faster rate. Many smaller manufacturers of unfinished solid strip flooring have entered the marketplace while larger producers have shifted to a higher value pre-finished product. It was estimated that the wood flooring industry uses 1.6 to 1.7 billion board feet of hardwood lumber per year. Changes in dominant species produced were sporadic among survey respondents; however, red oak (*Quercus rubra* L.) remains the dominant across the entire industry. The commercial grouping of red oak includes: southern red oak (*Q. falcata* Michx.), northern red oak, (*Q. rubra* L.), and black oak (*Q. velutina* Lam.). The study results indicate that while the market share of wood flooring should continue to increase, much of the increase will come from foreign imports. Results also suggest that profit margins will continue to decrease due to increased raw material costs, production capacity and foreign competition.

INTRODUCTION

The market for low-grade lumber is a great concern to the hardwood industry, landowners and land managers. Low-grade lumber is considered to be No. 2 Common, 3A Common and 3B Common grades by the National Hardwood Lumber Grading Rules (National Hardwood Lumber Association 1998). These grades require that only 25 to 50 percent of a board contain clear and defect free material. Lumber producers determined in 1996 that the highest research priority was to identify and develop new and better markets for low-value, low-grade lumber and products (National Hardwood Lumber Association 1996). Sawmill managers have indicated that there has been an increase in low-grade lumber production since 1996 (Cumbo and others 2001). The success of finding reasonable prices for low-grade material has been identified as a requirement for hardwood sawmills to remain in business (National Hardwood Lumber Association 1996). It has been estimated that the flooring industry accounts for 77.6 percent of low-grade lumber consumption (Smith and others 2004); therefore, the health of the wood flooring industry is of great importance to lumber producers and land managers.

This paper describes a brief overview of the wood flooring industry in the United States and some product trends determined from a review of U.S. Department of Commerce data, articles from related manufacturing publications and the results of a survey of flooring manufacturers.

Market Trends

Wood flooring manufacturers have seen an increase in market share, domestic production and imports over the last 20 years. Much of the available data on this trend is for hardwoods. However, since hardwood

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flooring is estimated to make up 85 percent of the total market, its trends should represent the total market fairly well. Hardwood flooring has increased its market share by five percent in the last 20 years while most other floor coverings have remained fairly constant with little gain or loss. While carpet and rug coverings still maintain the largest market share, they have been strongly influenced by the flooring industry, loosing eight percent of the market (fig. 1) (U.S. Department of Commerce 1986–2003). During this time period, hardwood flooring production also significantly increased. Shipments of hardwood flooring increased in value to over $1,589,948,000 in the last 21 years (fig. 2) (U.S. Department of Commerce 1976–2003). The increase in market share and value of shipments indicates an overall increase in demand and use of hardwood flooring in the United States. Production capacity has increased drastically, fueled by a 67 percent increase in new plants (fig. 3) and a 250 percent increase in capital expenditures at existing facilities (fig. 4) (U.S. Department of Commerce 1986–2003).

Wood flooring is typically classified as being solid or engineered. Solid wood flooring is produced from a single piece of wood that has been molded or shaped into the final product. Engineered flooring can be several slices of thin wood glued into a thicker piece or a composite wood product with a wood or paper veneer on the surface. Since there can be so many different types of engineered wood flooring, it is

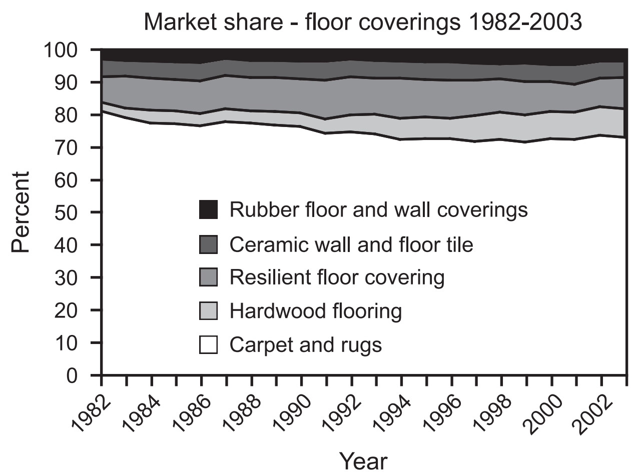

Figure 1—Market share of various floor covering types for 1982–2003 (U.S. Department of Commerce 1992–2003).

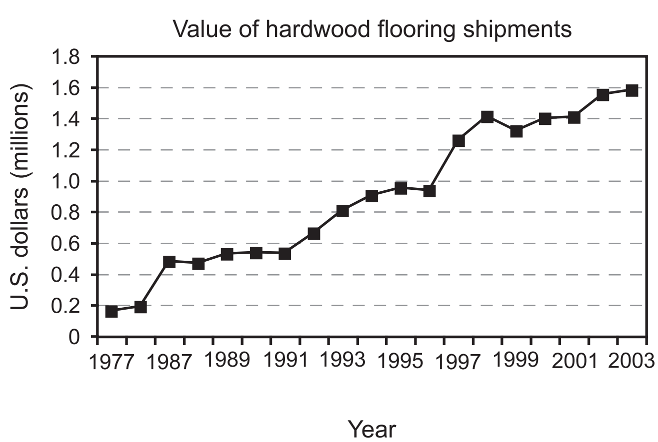

Figure 2—Value of hardwood flooring shipments in millions of dollars (U.S. Department of Commerce 1976–2003).

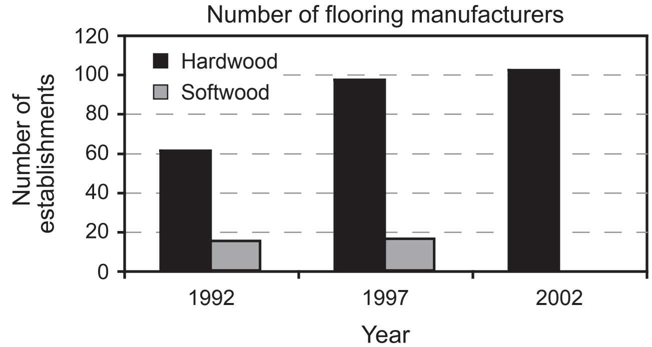

Figure 3—Increase in U.S. hardwood and softwood flooring manufacturing facilities over a 10-year period (U.S. Department of Commerce 1992–2003).

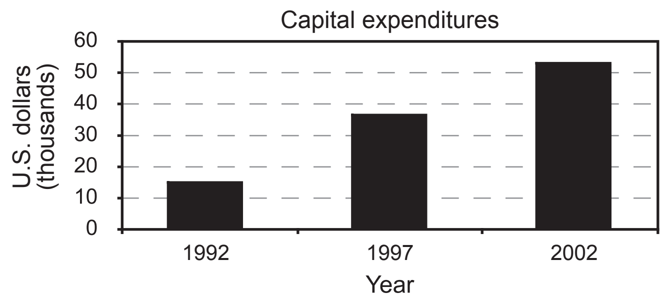

Figure 4—Increase in capital expenditures for U.S. flooring manufacturers over a 10-year period (U.S. Department of Commerce 1992–2003).

difficult to measure the exact market share of this flooring type. Forintek (2004) estimated that engineered wood flooring increased its market by 48 percent between 1985 and 2002 (fig. 5). This estimate includes all types of engineered wood flooring. When estimating engineered flooring that represents a product with a solid wood top layer, the market share appears significantly smaller. The market share for engineered products with a solid wood top varies between 11 percent for contractors and 26 percent for distributors (Hardwood Floors 2005). Little is known about how much of each type of engineered flooring is produced or how much market share each type has.

While solid wood flooring has traditionally been sold as an unfinished product, there is a trend towards moving to a pre-finished product, with 35 percent of solid strip flooring being pre-finished in 2004 (Hardwood Floors 2002–2005).

While the installation of wood flooring continues to predominantly be done as a remodeling project in existing homes, there is a definite trend in the increased amount of wood flooring being used in new home construction (fig. 6) (Hardwood Floors 2002–2005). This finding is a direct result of the 35 percent increase in the number of new homes in the last 10 years.

While flooring prices have increased 66 percent over the last 20 years, raw material costs have increased 161 percent (Hardwood Market Report 2005). Since No. 2 Common lumber makes up the majority of raw material used by the flooring industry (Smith and others 2004), the increase in raw material costs has led to decreased profit margins. Also affecting the decrease in potential profit is the 77 percent increase in value of flooring imports to the United States over the last seven years (fig. 7) (U.S. Department of Commerce 1997–2004). These two factors represent the current largest threat to U.S. flooring producers.

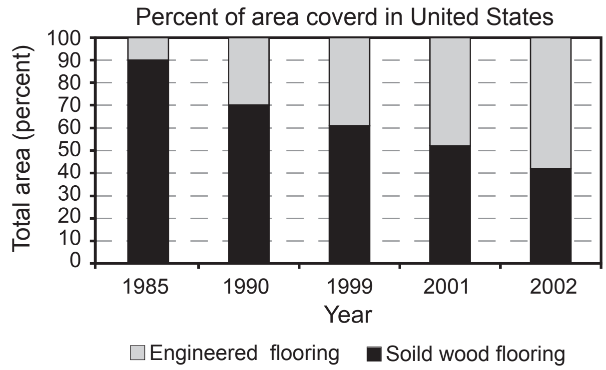

Figure 5—Estimated market share of all types of engineered wood flooring compared to solid wood flooring (Forintek 2004).

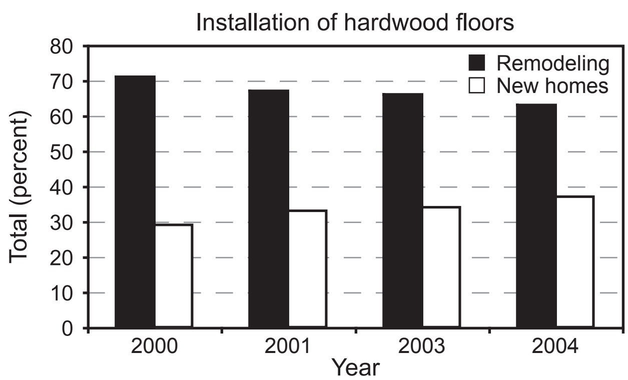

Figure 6—Difference in new flooring installations between new home constructions and remodeling (Wood Floors 2002–2005).

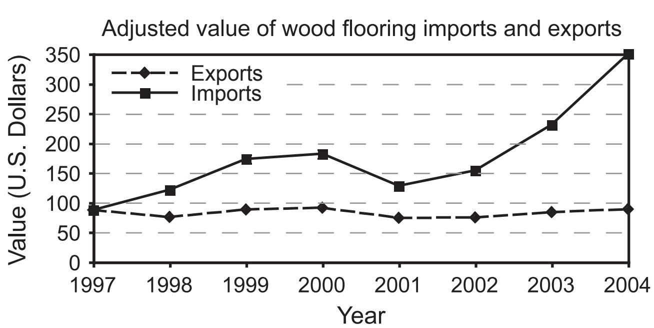

Figure 7—Adjusted value of wood flooring imports and exports (adjusted to 2004 dollars) (U.S. Department of Commerce 1997–2004).

FLOORING SURVEY

To better determine the production volume of wood by flooring type, to estimate wood use in the U.S. used in the manufacture of flooring by type, application, and species, and to discern product use trends in hardwood flooring markets by type, application, and species, a survey of the flooring industry was undertaken.

Sample Frame

The mailing list of flooring manufacturers was developed from an existing database developed by the Forest Products Marketing and Management Center in the Department of Wood Science and Forest Products at Virginia Tech. The list was developed using American Business Disc 2001, SIC 2426 (hardwood dimension and flooring), and association member lists from the National Wood Flooring Association, Maple Flooring Manufacturers Association, and Wood Component Manufacturers Association. Telephone, internet and responses to previous surveys were used to validate the list. The mailing list contains a total of 112 contacts.

Data Collection

Three mailings were conducted. The first survey mailing was conducted in August 2004 and a second mailing was conducted two weeks later. Due to a low response rate a third mailing was conducted in November 2004. Phone calls were made in December to non-respondents.

The total number of usable responses was 22 with an initial response rate of 20 percent. It was determined through internet searches and phone calls that 14 of the original companies included in the survey were non-flooring producers, giving an adjusted response rate of 23 percent. Upon checking for non-respondents it was determined that two of the largest flooring producers did not participate in the survey. The non-response bias is significant since both are considered to have the largest market share of wood flooring produced in the United States, have multiple facilities, and produce finished, unfinished, and engineered wood flooring. One of the non-respondents claims to supply 40 percent of the wood flooring market in the United States (Armstrong 2004). While the survey did fail to capture an accurate representation of engineered flooring manufacturers, it did manage to accurately represent the solid wood manufacturing industry. Validation of this assumption is made later in this paper.

Respondent Demographics

The majority of respondents had a single facility (84.6 percent) verses multiple facilities (13.6 percent). There was no correlation between number of facilities and volume output. The number of employees ranged greatly (fig. 8), with the majority of respondents having more than 30 employees.

The age of manufacturing companies ranged from 4-102 years, with a large increase in firms over the last 10 years (fig. 9). This was expected as the capital expenditures and value of shipments have continually increased over the last ten years.

The main product type produced by respondents is shown in figure 10. To test for survey bias, attempts were made using the internet to identify the type of flooring products produced by those companies that did not respond to the questionnaire. The product type manufactured was determined for 80 percent of non-respondents. A comparison clearly indicates that the survey accurately represents the producers of solid wood flooring but likely under represents the engineered flooring companies and those companies that produce both flooring types.

Manufactures of solid wood flooring can be further separated by the type of flooring produced, with 48 percent producing plank flooring, 38 percent producing strip flooring and 14 percent producing both types. Strip flooring generally refers to flooring consisting of boards that are 2-1/4 inch wide or less. They can be of any thickness and any construction. It is the long, linear visual that is defined by the terminology strip flooring. Plank flooring is defined as boards with a width of three inches or more and accounted for over half of solid wood flooring production.

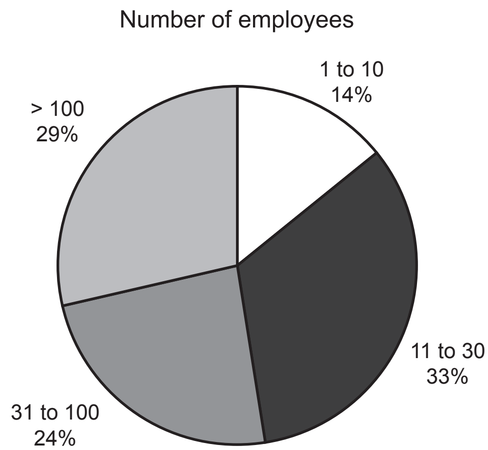

Figure 8—Number of employees at hardwood flooring manufacturers surveyed.

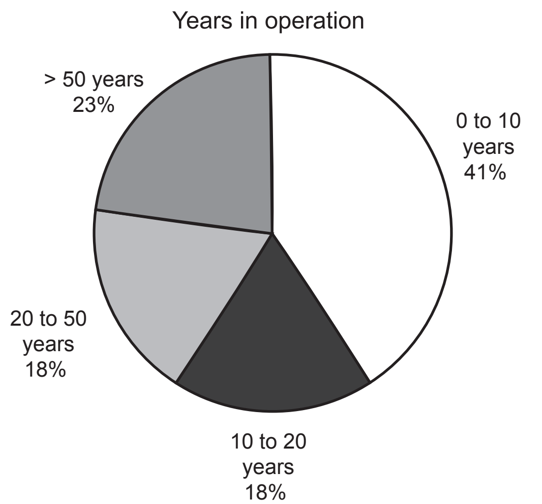

Figure 9—Number of years each flooring manufacturer has been in business.

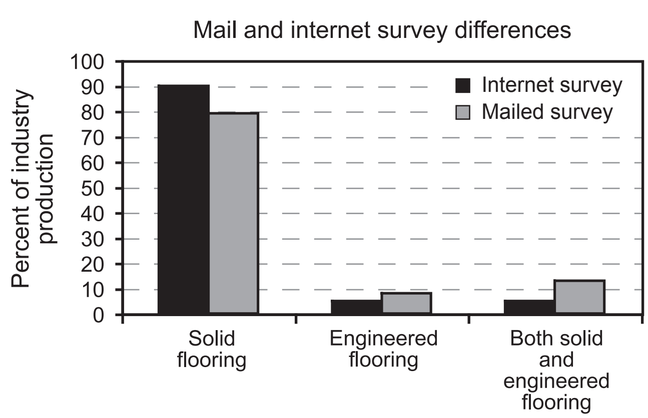

Figure 10—Main product type manufactured of survey respondents compared to Internet survey.

Those producers that produced engineered flooring were also broken into categories based on the construction technique used. Fifty percent used laminated veneer over solid core and 50 percent used a laminated ply construction.

Currently, 35 percent of the solid flooring market is sold as a pre-finished product (Hardwood Floors 2005). The percentage of pre-finished flooring production is expected to increase as larger flooring producers move from an unfinished product to a pre-finished product. The largest producer of solid wood flooring, Armstrong, recently announced that it will substantially reduce its participation in the unfinished flooring market (Armstrong 2004). It is believed that this is a direct response to the increase in the number of domestic manufacturers producing un-finished product.

Lumber Consumption

Two different methods were used to estimate the consumption of lumber for the flooring industry. The first method was based on the assumption that companies use comparable technology; therefore, have similar lumber input or product output per employee. Specifically, an average lumber consumption per employee is calculated with the data of the survey and is multiplied by the total number of employees in the industry, which can be obtained from U.S. manufacturing census information. It was estimated that 1,626,078,830 board feet are consumed by the flooring industry. A different estimate makes the assumption that the average a square foot of flooring (either solid or engineered) requires the same volume of raw material in board feet. The average lumber consumption per square foot of flooring was calculated using the survey data and multiplying it by the estimated total production of hardwood flooring for 2003. This last value was also estimated extrapolating data for year 1997 (Floor Covering Weekly 1998), by using a growth rate corresponding to that of total value of shipments for years 1997 to 2002 (U.S. Department of Commerce 1997–2004). It was estimated that 1,686,195,788 board feet are consumed for 2002.

Species Use

While one of the objectives of the survey was to determine output and consumption by species and flooring type, due to the responses, only species use by solid flooring producers can accurately be determined. The percentage of respondents using a particular species is listed in figure 11. It should be noted that 45 percent of respondents stated that red oak made up the majority (95 percent) of their production, indicating that for solid wood flooring, red oak remains dominant. It should be noted that the commercial name of red oak includes a group of species and is not further separated. Some common species within the commercial classification of red oak are southern red oak, northern red oak, and black oak. The data presented no clear trend in species changes over the last five years. The responses were highly variable among respondents; therefore, no conclusions could be drawn.

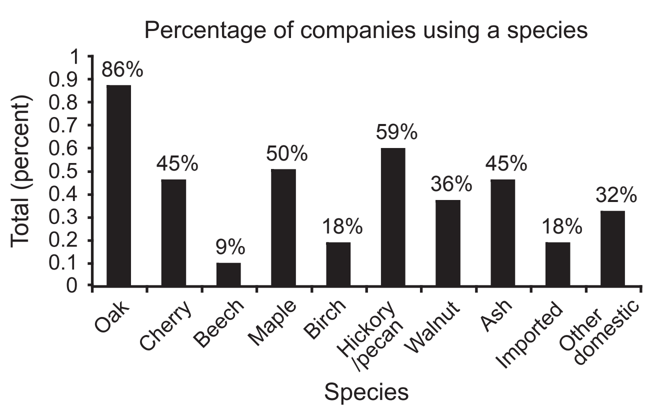

Figure 11—Percentage of flooring manufacturers using a particular species.

One quarter of the respondents used imported species in the last five years. Of those reporting the use of imported species, six percent increased consumption, six percent decreased consumption and eleven percent remained unchanged. The increased use of raw materials ranged between 5-25 percent. There were no clear trends as to a particular species that dominated the imported market. Species listed by producers included: jatoba (*Hymenaea courbaril*), mahogany (*Swietenia* spp.), and camaru (*Dipteryx odorata*).

The majority of respondents (84 percent) indicated that the demand for certified wood flooring has remained unchanged over the last five years. Interestingly, those that indicated there had been a change in demand for certified products (14 percent) thought that the increase was significant, ranging between 25 and 100 percent. Most producers remained unsure about the future of the demand for certified products (50 percent) while 22 percent expected that it would increase and 28 percent expected a decrease.

CONCLUSIONS

Both literature and survey results indicate that while production of hardwood flooring has significantly increased in the last decade, imports are rising at an exponential rate. Many smaller manufacturers of unfinished solid strip flooring have entered the marketplace while larger producers have shifted to higher a value pre-finished product. It was estimated that the hardwood portion of the wood flooring industry uses 1.6 to 1.7 billion board feet of lumber per year. This lumber consumption is mostly of 2A Common and 3A Common, meaning low grade material. Changes in dominant species produced were sporadic among survey respondents; however, red oak remains dominant across the entire industry. While the market share of wood flooring is expected to continue to increase, much of this increase will come from foreign imports. It is likely that profit margins will begin to decrease due to increased raw material costs, production capacity and foreign competition.

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THE OCCURRENCE OF LOG ELLIPTICALITY IN HARDWOODS AND ITS IMPACT ON LUMBER VALUE AND VOLUME RECOVERY

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Abstract—Raw material cost and quality continue to be issues of critical concern for hardwood lumber producers. Sawmill operators must be able to maximize efficiency by controlling the relationship between log quality and lumber recovery. There is no evidence in the literature of any prior research to quantify and classify the cross-sectional shape of hardwood log ends, nor on the quality and quantity of sawn products recovered from non-round logs as compared to round logs. The focus of this study is the characterization of the form of log-ends for several important hardwood species and the estimation of the impact of log form on lumber volume and value recovery. Such information could be used to develop information on how to best saw hardwood logs with non-round shape to achieve the highest lumber grade and value. A survey of several hundred logs indicated that more than 45 percent of sawlogs are non-round having small-end eccentricity in excess of 0.4. The prevalence and severity of log ellipticality in sawlogs and potential difference in lumber yield indicated the need for more in-depth study. To determine if differences in lumber volume and value recovery exist between logs with low and high ellipticality, sawmill recovery studies were conducted at four southern Appalachian sawmills. Logs with high ellipticality were found to produce less volume of lumber with more processing time required than for rounder logs. No differences in the location of lumber grade recovery were found between round and highly elliptical logs. More processing time and steps were required to saw a highly elliptical log, thus higher costs are incurred in processing these logs. There was no increase in lumber value for logs with high ellipticality.

INTRODUCTION

The cost, availability, and quality of raw material resources continue to be issues of critical concern for sawmill producers. It is imperative that the sawmill operator accurately manage the margin between log costs and lumber prices. To maximize efficiency, the sawmill must control the relationship between log quality and lumber recovery (quantity and quality). There is no evidence in the literature of any prior research to quantify and classify the cross-sectional shape of hardwood log ends. Nor has any research on the quality and quantity of sawn products recovered from non-round logs as compared to round logs been conducted. The focus of this study is the characterization of the form of log-ends for several important hardwood species and the estimation of the impact of log form on recovery. No information exists on how to best saw hardwood logs to achieve the highest lumber grade and value.

OBJECTIVES

This study has three principal objectives:

1. Assess the occurrence and degree of ellipticality of red oak (*Quercus rubra* L.), hard maple (*Acer saccharum* Marsh.), and yellow-poplar (*Liriodendron tulipifera* L.) in two discrete locations of the eastern hardwood region.

2. Assess the impact of different degrees of ellipticality on lumber grade and volume recovery for current sawing practices employed by partner mills.

3. Determine processing differences between logs with different degrees of ellipticality for current sawing practices employed by partner mills.

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PROCEDURES

Assess the Occurrence and Degree of Ellipticality

Two sets of elliptical log measurements were taken, one in east-central Ohio and one in southern West Virginia. The Ohio sawlog data were collected at three log yards in the vicinity of Wooster, Ohio; therefore, it is likely that the logs originated within a 100-mile radius. The West Virginia sawlog data were collected at two log yards in the vicinity of Princeton, WV. The two log yards are approximately 20 miles apart from one another. Therefore, it is likely that the logs passing through these two log yards all originated within a 125-mile radius of Princeton, WV. One of these West Virginia yards belongs to a large sawmill and has a lot of log turnover while the other yard is a smaller distribution yard used by a single logger.

The Ohio data were collected from physical measurements taken on the ends of the logs while the West Virginia data were collected using digital array camera pictures (fig. 1). Calibration targets of known diameters (that are similar to the diameters of the logs) were used to calibrate the camera and determine a distance conversion factor for analyzing the pictures using AutoCad software (AutoDesk 2001). The majority of pictures were taken three feet from the log ends. On rare occasions when the end of a log was too big to fit in the frame, the picture was taken four feet from the log end and a different conversion factor was applied for obtaining the log-end measurements.

Since different measurement systems were used in Ohio and West Virginia, a set of 57 logs, 27 red oak and 30 hard maple, were measured by both systems. Paired sample t-tests of the large and small-end eccentricities for each species were performed to ascertain if the results obtained using the two systems were comparable such that interregional comparisons could be conducted.

During the earliest stages of the study every available log of the target species was measured during each visit. However, on a visit to one of the sawlog yards it was noticed that logs which appeared to be cut from the same tree were often laid out next to or very near to each other in the log piles. This potential for auto-correlation is more likely to occur at the smaller log yard that is used by the single logger than at the larger sawlog yard. Therefore, at the smaller yard a systematic random sampling of every 5th log was conducted. Also, by sampling every 5th log rather than every log, our sampling was conducted over a longer time period (sampling occurred over a 12 month period) so that our log sample was more representative of a broader cross-section of the logs harvested by this logger.

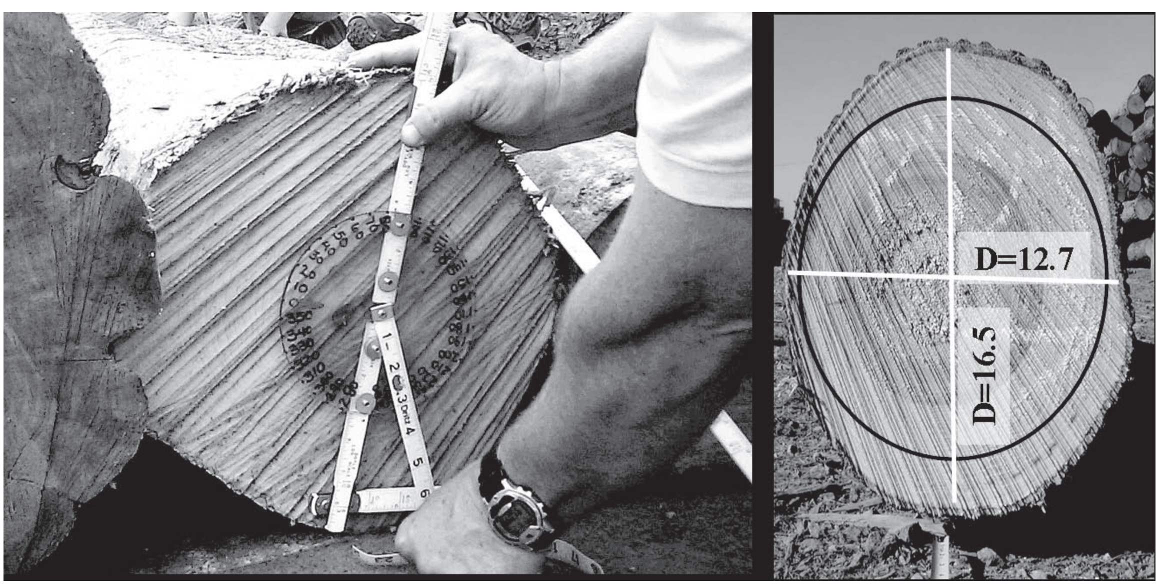


Figure 1—Physical and digital image-based measurement systems used in data collection.

At the larger sawlog yard all logs that we could easily and safely access during visits were sampled. In order to minimize the risk of auto-correlation, logs of the same species sitting proximal to each were evaluated to ascertain if they were from the same tree. Whenever there was any suspicion that two or more logs might have been from the same tree, only the first log encountered was measured. For this part of the analysis both the large-end and small-end eccentricities were evaluated in the log-form analyses.

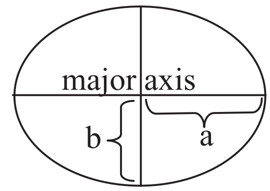
Eccentricity (e) is calculated as: $e = c \div a$

where

$c = \sqrt{a^2 - b^2}$

a = length of major axis $\div$ 2

b = length of minor axis $\div$ 2



Log Form Data Analysis Procedures

In analyzing log form, a two-factor ANOVA test was performed on both large- and small-end eccentricity (α=0.05). The two factors in the analysis were species and log position (butt or upper log). Since we are focused on whether logs with non-round cross-sectional log form have different recoveries in the sawmill and it is known that the volume and value of lumber recovered from different species varies, we must look at the species variable if we are to derive a useful answer to the log form – recovery question. Given that sawmills almost always saw only one species at a time, the application of a best-sawing solution for non-round logs can be species-specific given knowledge of the importance of elliptical log form in particular species.

The butt and upper log evaluation was made because we know that butt logs typically have different defect distribution patterns and are generally of a higher quality than upper logs in the tree. Therefore, they typically yield higher amounts of lumber product of greater value. As they are easy to distinguish in the log yard, it could be operationally feasible to use an elliptical-log-form oriented sawing strategy on butt logs and continue to process upper logs "as usual."

Determination of Log Eccentricity Levels

After cross-sectional form data were collected, a preliminary analysis was conducted using the eccentricity data measured for 490 northern red oak logs to determine what eccentricity groupings might be used in sawmill studies. During the analysis, it became obvious that the accuracy of the large-end eccentricity measurements on butt logs was suspect. Uneven log end cuts and butt swell/flare are among the complications that make it difficult to accurately measure the large end of the butt log. Therefore, it was determined to key on the small end of all logs in separating logs into groups for subsequent study.

Lumber Recovery Pre-Study

Next, a small-scale sawmill prestudy was conducted to determine if ellipicality has an impact on lumber production. During the log sample selection stage of the prestudy, it became evident that visually distinguishing moderately elliptical logs from highly and minimally elliptical logs was not practical. A log grader could, however, be expected to separate highly elliptical logs ($e \geq 0.4$) from minimally elliptical logs ($e < 0.3$). The prestudy was conducted using a sample of 45 straight (no crook or sweep), Forest Service Grade 2 (Rast and others 1973), northern red oak logs. The specification that the logs be straight was imposed because we wanted to ensure that crook and sweep would not influence log positioning on the headsaw in the mill. Also, this specification would help ensure that any tension wood effects associated with crook and sweep would not interact with or mask any tension wood effects associated with ellipticality.

After the prestudy was completed in which it was determined that there was a real possibility that eccentricity does have an effect on sawmill volume recovery, eccentricity data were collected on more than 100 additional logs in both the Ohio and West Virginia log yards. A sample size of at least 75 logs per cell (species x butt or upper) was projected to be necessary for detecting differences in small-end eccentricity between factors in the two-factor ANOVA given an alpha level of .05. This sample size is based on the "*Least Significant Number"* (LSN) given in the SAS (SAS 1999-2001) output that was derived when an initial statistical assessment was conducted on eccentricity data obtained from measurements on 200 logs. LSN is based on a retrospective power analysis.

Lumber Value, Volume and Processing Study

To quantify the impact of log ellipticality on lumber value and volume recovery, sawmill lumber recovery studies were conducted at four southern Appalachian region sawmills. At each mill 20 logs with low ellipticality and 20 logs with high elipticality were measured and processed. All logs were required to meet Forest Service Log Grade 1 specifications (table 1) (Rast and others 1973), in addition to being 10-12 feet in length, 12-18 inches in diameter, and straight. Length and diameter constraints were used to reduce the number of logs required in each grouping. The rationale for using Grade 1 sawlogs is similar to the rationale for using only straight logs, we were concerned that the sawing pattern used to breakdown lower grade logs containing more defects would be more strongly influenced by defect location and less strongly influenced by the cross-sectional form of the log. Also, the presence of more defects introduces greater levels of recovery variability that would add several layers of complexity to the analysis.

Log ellipticality was measured by hand at the small end of each log. The major and minor diameter and length measurements were recorded. All logs were scaled using the International ¼-inch log rule. This rule has proven to provide the best estimation of lumber recovery, regardless of log size and taper, when compared to other log rules. After each log had been measured, the small end was painted with a distinguishing color so that placement of sawlines on the headsaw could be charted relative to the major and minor axes (fig. 2). The color coding also enabled us to associate each board tallied at the grading station with the quadrant from which it was cut so that correlations between lumber grade and position could be investigated. The processing time for each log at the headrig and resaw was recorded. Processing time was considered to be the time that lumber was being produced by a sawing machine. Processing times of cants was not measured. Processing at the headrig was videotaped to determine how the log was oriented for the opening face and how the log was subsequently turned. Two of the sawmills utilized band headrigs and gang saws. One of the mills utilized a circle headrig with a band resaw and gang saw the final mill utilized a band headrig, band resaw and gang saw. For those mills with a separate headrig and resaw, logs were squared at the headrig and processed at the resaw until a low grade cant was sent to

Table 1—Forest Service log grade rules (Rast and others 1973)

Grade factor		Log grade 1		
Position in the tree		Butts only	Butts & uppers	
Minimum diameter (inches)		13–15	16–19	20+
Minimum length (feet)		10+	10+	10+
Clear cuttings on each of the 3 best faces	Minimum length (feet)	7	5	3
	Maximum number	2	2	2
	Minimum yield face length	5/6	5/6	5/6
Maximum sweep and crook allowance; percent of gross volume		15		
Maximum cull and sweep allowance; percent of gross volume		40		

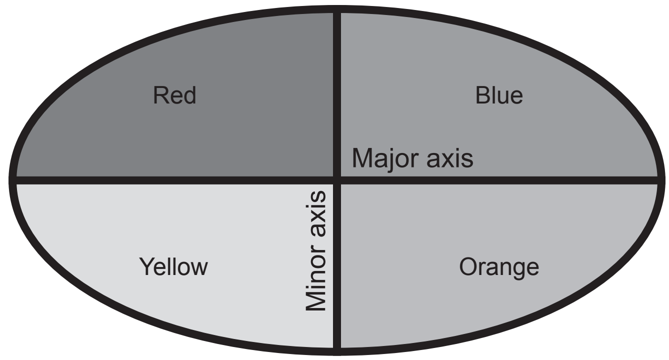


Figure 2—Log-end color codes used for tracking processing during sawmill studies.

the gang. At mills with only a headrig, lumber was produced at the headrig until a low grade cant could be processed at the gang. Lumber volume and grade were recorded as was information regarding the quadrants from which the lumber was sawn.

The analysis of the sawmill data used the SAS general linear models procedure for analysis of variance using α=0.05 (SAS 2004). Several analyses were performed to investigate different response variables: International ¼-inch overrun, the value of the lumber recovered, the percentage of No. 1 Common and Better lumber recovered, the number of sawlines used to breakdown the log, the number of times the log was turned during the process of being sawn on the headsaw, and the total processing time (saw blade in wood time). In all cases, the classification variable was small-end eccentricity class (0.3≥low eccentricity, 0.4≤high eccentricity). To this point all analyses have been conducted based on green lumber volume and value recovery rates.

RESULTS AND DISCUSSION

Comparison of Digital and Physical Measurement Systems

Dual measurements conducted on 57 logs (30 sugar maple and 27 red oak) to ascertain the comparability of the physical system for measuring log-end eccentricity (used in Ohio) and the digital camera-based system (used in West Virginia) yielded variable results. For both the large and small ends of the red oak logs, the paired sample t-tests indicated the differences between the eccentricities obtained using the two systems were not statistically significant (α=0.05). For the sugar maple test, however, the large-end eccentricity comparison indicated the differences between measurement systems were insignificant but the small-end results were significantly different (p=.014). Since we decided to focus on the eccentricity of the small-end diameter in characterizing log ellipticality, this result tells us we cannot combine the Ohio and West Virginia logs into a single analysis nor can we use region as a factor in our analysis of variance evaluation of small-end eccentricity.

Comparisons of Log Form for Different Species and Log Positions

In Ohio, a total of 837 logs of three species — red oak (162 logs), hard maple (424 logs), and black oak (251 logs) were studied. The two-factor (species and butt/upper) General Linear Model (GLM) that was used (α=0.05) for the small-end eccentricity data was significant (p=0.046) with both factors contributing to the significance of the model (p=0.037 for species and 0.034 for log position). The interaction between species and log position was not significant. Curiously, neither the Tukey HSD nor the Student-Newman-Keuls multiple comparison tests found any of the three species' small-end eccentricities to be distinct from the other two. Red oak and sugar maple both had mean small-end eccentricities of 0.35, black oak's was somewhat lower (0.32). The mean eccentricity of the small-ends of butt logs was higher (0.35) than for the small-ends of upper logs (0.34).

The large-end eccentricities of these same logs were similarly tested. In this case neither principal factor nor the interaction between the factors was found to be significant. The log position factor (butt or upper) explained the most variation and had a p-value of 0.072.

The mean small-end eccentricity of the total sample of 669 logs measured at the large West Virginia log yard (logs from many different sources) was 0.382 and the mean large-end eccentricity was 0.407. The small- and large-end eccentricity variances were 0.018 and 0.019, respectively – not a statistically significant difference in variances. Histograms of eccentricity distributions for the logs in West Virginia and Ohio show differences; the Ohio sample contains a lower percentage of logs with small- and large-end eccentricities in excess of 0.4 than does the West Virginia log sample (fig. 3). This variance may be a real regional difference in log form, but because the results of our paired sample t-test comparison of the two measuring systems was significant, we cannot conduct a statistical comparison to ascertain if this is the case.

The three species included in the analyses for West Virginia were sugar maple (86 logs), red oak (298 logs), and yellow-poplar (219 logs). The same two-factor (species and butt/upper) GLM was used (α=0.05) to analyze the small- and large-end eccentricity data as was used on the Ohio log data. Both models proved to be significant (p=0.0212 for the small-end test and 0.0002 for the large-end). Both the Tukey HSD and Student-Neumann-Keuls multiple comparison tests on the factor "species" indicated that the mean eccentricity for sugar maple was not statistically different from the mean for red oak. Likewise, the mean for yellow-poplar was not different from the mean for red oak. However, the means for hard maple (highest mean) and yellow-poplar (lowest mean of the three species) were statistically different. This same result was realized for both the small-end and large-end analyses. The large-end GLM results indicated that log position (butt/upper) also was a significant factor, but the same was not true for the eccentricity results for the small ends of the logs. The interaction between species and log position was not significant in either case.

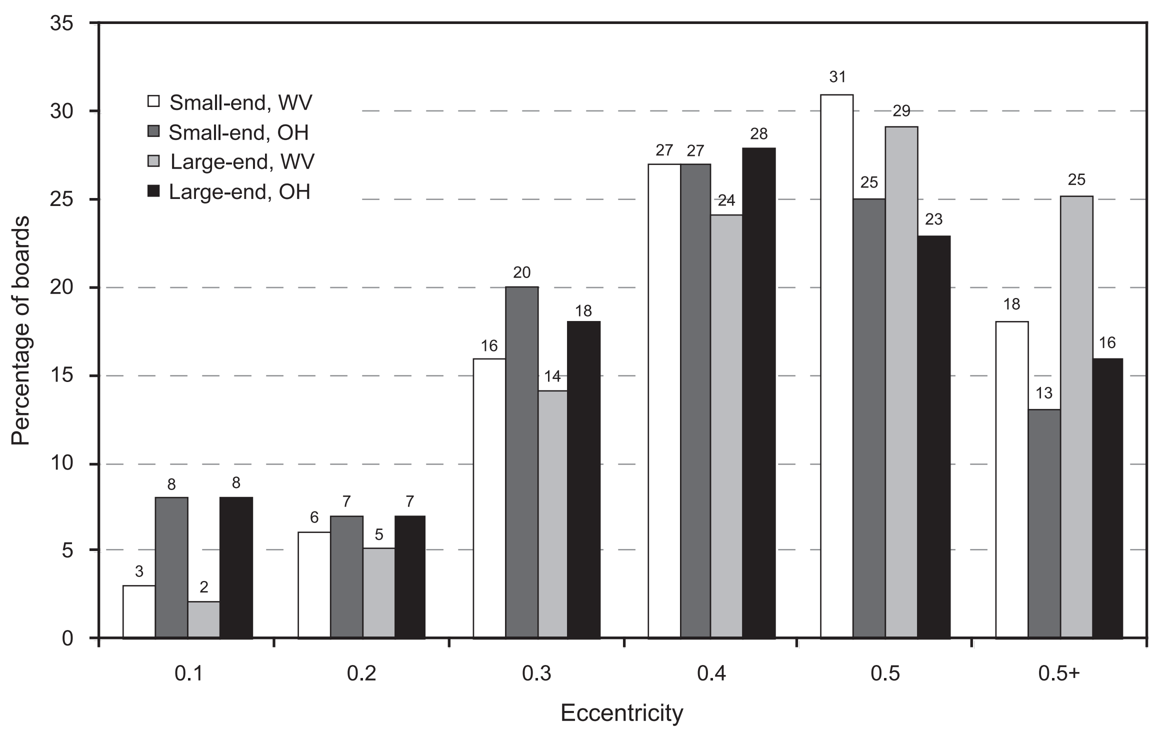


Figure 3—Histogram of eccentricity results for log sampling conducted in Ohio and at the large West Virginia saw-log yard; all logs with eccentricity values between the next lower value up to and including the given value are counted in a grouping.

The histogram and cumulative percentage distribution of the small-end eccentricities for 490 red oak logs showed that a high percentage of the logs had eccentricities between .275 and .450 (fig. 4). Projecting that no more than three levels of log ellipticality could be readily distinguished (visually) by sawmill personnel in the log yard, we defined these three levels as low, medium, and high ellipticality and set the boundaries of these categories such that approximately 1/3 of the logs in this red oak sample fell into each. Low ellipticality logs were thus defined as logs with small-end eccentricities of less than 0.3, medium ellipticality logs had measured eccentricities from 0.3 to less than 0.4, and high ellipticality logs had eccentricities equal to or greater than 0.4.

Sawmill Pre-Study

The 45-log pre-study sample consisted of 30 highly elliptical logs and 15 minimally elliptical logs. A single factor ANOVA (general linear model) was conducted for the response variable lumber recovery factor (LRF; board feet of lumber produced divided by cubic feet of logs input) using small-end eccentricity as the factor variable (with two levels, low and high). The analysis returned a p-value of 0.001 indicating that the two levels of eccentricity could not be assumed to have the same effect on LRF (using $\alpha=0.05$). This result gave us reason to proceed in (1) collecting more eccentricity measurements on a larger and more diverse sample of logs and (2) conducting a more extensive sawmill recovery analysis.

Volume and Value Recovery from Elliptical Logs

Analysis of variance was used to determine that there was a significantly higher overrun for three of the four mills for logs with low ellipticality compared to logs with high ellipticality. Logs with low ellipticality produced an average of 8 percent more overrun than logs with high ellipticality. Close analysis of the log input data revealed that while log lengths between the sample groups were uniform, log diameters were greater in the low ellipticality group at three of the mills. The difference in log diameters should lead to greater overrun or lumber production from this group. For the one mill where there was no significant difference in overrun, log diameters and lengths were equal between ellipticality groups. While logs were selected at random in each log yard, log lengths and diameters were limited so that a smaller sample size could be used. To offset the difference in log diameters within the groupings, different comparisons had to be used. Rather than directly comparing the average log value at each mill, the value per board foot was used. Also, to determine differences in lumber volume produced, analysis of the difference in estimated lumber footage compared to actual lumber footage was used.

Two of the mills produced significantly more lumber footage from logs with low ellipticality. However, the difference in footage at the other two mills was not significant for the two degrees of ellipticality. Analysis

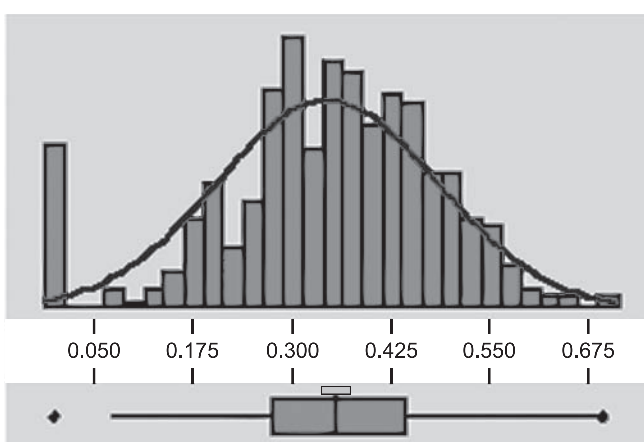


Figure 4—Histogram of small-end log eccentricity measured for 490 red oak saw logs.

of machine types used and other processing variables did not explain the differences in lumber volume recovered between the four mills.

There was no significant difference in the mean lumber value produced from low and high elliptical logs at three of the four mills. One mill was able to produce an average of $0.10 more lumber value from logs with low ellipticality. Analysis of the percentage of 1 Common and Better lumber produced, revealed that the mill with the greatest average lumber value per log for low elliptical logs produced significantly more 1 Common and Better lumber (28 percent) from logs with low ellipticality.

The mill that did not have a total average lumber value difference between high and low ellipticality logs did produce 5 percent more 1 Common and Better lumber by processing the logs differently than the three other mills. This was the only mill that did not produce a pallet cant as a product. This mill sawed through the entire log. Lumber with heart center material was run through the edger to split boards into high- and low-grade material. Even though this sawmill produced slightly higher grade yield than the other mills, it did not produce a higher average lumber value, therefore, this mill's processing approach is not necessarily preferable.

Sawmill Processing Variables

The number of turns used to position and reposition the log during sawing on the headsaw was higher for logs in the highly elliptical sample than for those that were near-round (4 versus 3 turns per log). Similarly, the total number of sawlines recorded on the headsaw and resaw was higher for the more highly elliptical logs (23 per log compared to 19). The total sawing time (time that the saw blade was in the wood) for both the headsaw and resaw was significantly longer (221 seconds) for logs with high ellipticality versus logs with low ellipticality (193 seconds). These last three results establish that elliptical logs take longer to process in the sawmill and thus cost more to process resulting in lower profitability per log. The mill that failed to produce a significant difference in overrun between the two ellipticality classes was the mill that had the smallest difference (5 seconds) in total sawing times between low and high elliptical logs. Three of the mills utilized an average 35 more seconds in processing logs with high ellipticality. This indicates that while the increased time in processing logs does not yield significantly more value between ellipticality classes, it can lead to better overrun or lumber recovery.

These results indicate that logs with high ellipticality typically produce less volume of lumber with more required processing time than rounder logs. There is typically no value difference in the lumber produced from round or elliptical logs. Since there is no difference in the location of lumber grade recovery between major and minor axis between round and highly elliptical logs, there is no reason to pursue the development of new guidelines of how to saw elliptical logs. While there is no difference between lumber values for green lumber produced from either highly or non- elliptical logs, there may be a significant difference in value after drying. The effect of ellipticality on the quality of the lumber produced after drying would likely be to increase warp during the drying process. This aspect remains to be studied.

SUMMARY AND CONCLUSIONS

Highly elliptical logs, defined as those with small-end cross-sectional eccentricities of 0.4 or greater, were found to be extremely prevalent in log yards sampled in Ohio and West Virginia. Forty-nine percent of the logs sampled in West Virginia were markedly non-round in cross-section. In Ohio, the percentage was somewhat lower with 38 percent of the logs categorized as being highly elliptical. This difference in the percentages between regions may have to do with environmental factors such as slope, aspect, basal area, and climate conditions, among other things. However, it also may be impacted by differences in species between the samples; statistical differences in eccentricities between species were identified. Also, butt logs tend to have greater eccentricity than do logs removed from higher positions in the tree and a higher percentage of the logs in the West Virginia sample were butt logs as compared to the Ohio sample. Finally, differences in the measurement approaches that were taken to obtain the log form data cannot be ruled out as a possible contributor to apparent differences in the occurrence of highly elliptical logs between the two measurement locations.

Logs with high ellipticality typically produce less volume of lumber with more required processing time than rounder logs. At three of the four mills no lumber value difference was detected between the two ellipticality groupings. Since there are no differences in the location of lumber grade recovery relative to the major and minor axes between round and highly elliptical logs, there is no reason to pursue the development of new guidelines for sawing elliptical logs. While there is no difference between lumber values for green lumber produced from logs with high and low ellipticality, there may be a significant impact on value after drying. Future work in this area will include determining value recovery differences after the lumber is dried. The sawmill studies demonstrated that more processing steps are required to saw a log that is highly elliptical thus higher costs are incurred in processing these logs with no increase in lumber value.

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AN ASSESSMENT OF HARDWOOD LUMBER MARKETS IN CHINA

Scott A. Bowe, Matthew S. Bumgardner, and Xiping Wang[1]

Abstract—In recent years, domestic production of household furniture has declined due to a shift to offshore production facilities such as those found in the People's Republic of China. As manufacturing has relocated, these offshore producers have sourced much of their hardwood lumber from numerous countries in addition to the United States. To be successful in the global marketplace, domestic hardwood lumber producers must understand how these foreign markets operate. During a 2005 wood products trade mission to China, 45 companies were interviewed concerning their hardwood lumber purchasing practices. Data were collected on company demographics and location, lumber purchasing channels, lumber origin, species, and size and grade specifications. The results showed that United States lumber suppliers face numerous global competitors in the Chinese hardwood lumber market. Several different market channels are used to move lumber into China, and considerable confusion over United States lumber grades was identified.

INTRODUCTION

In recent years, United States domestic production of secondary wood products has declined due to the shift to offshore production facilities such as those found in the People's Republic of China (heretofore referred to as 'China') (Schuler and Buehlmann 2003). As production has moved offshore, these producers have sourced hardwood lumber from countries across the globe. Domestic lumber producers need to participate in these markets to remain competitive in the global marketplace. Exports account for approximately 10 percent of all hardwood lumber produced in the United States (Hardwood Market Report 2005), and China is an important destination. According to data from the United States Bureau of the Census (2005), China (including Hong Kong) accounted for approximately 19 percent by volume and 15 percent by value of United States hardwood lumber exports in 2004. Of this volume, the major species breakdown was as follows: red alder (*Alnus rubra* Bong.) 22 percent, yellow-poplar (*Liriodendron tulipifera* L.) 19 percent, oaks (*Quercus* spp.) 17 percent, and maples (*Acer* spp.) 9 percent.

To increase chances for success, domestic hardwood lumber producers need a better understanding of how these foreign markets operate. For example, United States' suppliers learned early on that the Chinese buy lumber on price, not on grade (Barford 2004). In other words, United States suppliers have to determine the proper mix of grades to include in a shipment to meet the specified price. The United States is generally a high-cost source in a global context, which potentially puts its producers at a comparative disadvantage (Butterworth and Lei 2005). It also puts pressure on profit margins. For example, the average nominal price of United States hardwood lumber exported to Asia has declined in recent years as China has become the major market in the region; in contrast average nominal price to Europe has increased (Bumgardner and Hansen 2001).

This project has taken initial steps to profile hardwood lumber market channels in China. It provided much needed information for Wisconsin's companies and companies in other northeastern and midwestern states that seek to be competitive in the global marketplace.

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PROBLEM STATEMENT AND OBJECTIVES

There is limited market channel and product information available on hardwood lumber markets in China. Understanding this information will give United States' hardwood lumber exporters an advantage in the Chinese market. The primary objectives of this study included the following:

1. Identify the primary market channels through which hardwood lumber flows into the Chinese manufacturing sector.

2. Identify hardwood lumber specifications imported by Chinese wood manufacturing firms.

METHODS

Data were collected utilizing a written questionnaire and short interviews using intercept procedures and on-site interviews. The questionnaire development and data collection procedures are described below.

Questionnaire Development

The questionnaire was developed with the assistance of persons familiar with the hardwood lumber export industry including personnel from the University of Wisconsin, the USDA Forest Service, the Wisconsin Department of Natural Resources, and the Council of Great Lakes Governors in Shanghai, China. The questions developed were designed to collect information on hardwood lumber market import channels within the Chinese wood manufacturing industry. Questions on hardwood lumber volume, species, country of origin, type of sales agent, and grade were included. The questionnaire fit on one page, front and back, and was designed purposively short to capture key market information and to facilitate efficiency of data collection and respondent cooperation.

A native Chinese speaking wood scientist at the USDA Forest Service Forest Products Laboratory translated the questionnaire, which was designed and written in English, into Mandarin Chinese. The translated questionnaire was pre-tested in China with Chinese businessmen familiar with the hardwood lumber industry. Minor changes to the translation were amended to improve the translation after the pre-test.

Data Collection

Data were collected during short personal interviews with hardwood lumber-using firms. The primary data collection points during the trade mission occurred during three industry trade shows including the China Famous Furniture Trade Show in Dongguan, the International Construction & Decorative Material Exhibition in Dalian, and the China 2005 WoodMac–FurniTeck-WoodBuild International Exhibition in Shanghai. During the Exhibition in Shanghai, our trade delegation maintained exhibition space representing the Lake States Lumber Association. Several companies that participated in our survey showed interest in our exhibition display. In addition, four interviews were completed during company tours in the cities of Dongguan and Dalian (fig. 1). These tours were organized prior to our arrival in China with the assistance of the Dongguan Furniture Association and the Dalian Furniture Association. Data collection occurred during March of 2005.

Native Chinese speaking personnel from the staff of the Council of Great Lakes Governors and the USDA Forest Service Forest Products Laboratory conducted the interviews and recorded the information on the survey form. The interviews typically lasted fewer than 5 minutes. The company president or production managers were targeted for the interviews. During the trade shows, these individuals were identified by their trade show name badges and through business card exchanges.

Sample Description

Forty-five companies participated in the survey. Two questionnaires were incomplete and were not included in the analysis resulting in 43 usable questionnaires.

Figure 1—General map of China; respondent locations are shaded.

As described earlier, the types of companies sampled used hardwood lumber in some component of their business. Furniture manufacturers represented 30 percent (n=13) of the respondents followed by lumber brokers at 26 percent (n=11), flooring at 12 percent (n=5), and wood markets at 12 percent (n=5). Wood markets in China can be described as a shopping mall for wood. Individual companies lease garage space within the wood market and sell wood raw materials such as lumber and veneer to area wood manufacturers. Twenty-one percent (n=9) of the respondents indicated other business types. These businesses included veneer, cabinet, window, and door manufacturers. In addition, three of the furniture manufacturers indicated that they also brokered hardwood lumber as a part of their business.

Geographic Distribution of Responding Firms

China consists of 23 provinces (including Taiwan), 5 autonomous regions, 4 municipalities, and 2 special administrative regions (fig. 1). Study participants had facilities located in 8 provinces (including one in Taiwan), one municipality, and one special administrative region (table 1). The Shanghai, Guangdong, Liaoning regions showed the highest response rates. This is likely due to the primary data collection point at the trade shows in those regions and the large concentration of wood manufactures in the Guangdong province.

Responding Firms' Representative

Respondents representing the participating firms included the sales managers, company presidents, lumber buyers, and production managers with 37 percent (n=16), 30 percent (n=13), 12 percent (n=5), and 9 percent (n=4) respectively. Other company representatives, 12 percent (n=5), included positions such as general managers, inspectors, and engineering personnel. Several of the respondents held multiple positions within their company. These types of respondents would be knowledgeable of their company's overall hardwood lumber purchases and use.

RESULTS AND DISCUSSION

Hardwood Lumber Consumption and Sources

Annual hardwood lumber consumption in 2004 for all responding firms totaled 1.47 million m^3 (665 million board feet). Median hardwood lumber use by respondent was 5,380 m^3 (2.43 million board feet), and the mean was 38,700 m^3 (17.4 million board feet). Table 2 shows lumber use by company type. Within the two regions with the greatest response rates, the average lumber use by Shanghai firms was 10 times greater than the average lumber use by Guangdong firms.

Respondents were asked what proportion of their hardwood lumber came from the United States. The median imported volume was 33.0 percent, while the mean imported volume was 38.7 percent. Other sources suggest that China imports approximately 10 percent of its hardwood lumber from the United

Table 1—Location of responding firms

Province	Number of facilities[a]
Guangdong	13
Hebei	2
Jiangsu	2
Jilin	2
Liaoning	4
Shandong	2
Zhejiang	3
Special Administrative Region:	
Hong Kong	3
Municipality:	
Shanghai	17
Taiwan	1

n = 43.
[a] Some firms have multiple locations.

Table 2—2004 hardwood lumber purchases by company type

Company type	2004 hardwood lumber volume	
	Mean	Median
	m³	
Furniture manufacturers (n = 10)	124,700 (56,120,000)[a]	4,000 (1,800,000)
Lumber brokers (n = 11)	7,364 (3,314,000)	5,760 (2,592,000)
Wood markets (n = 4)	5,375 (2,419,000)	5,750 (2,588,000)
Other (n = 13)	9,429 (4,243,000)	6,480 (2,916,000)

[a] Equivalent board foot (bdft) values listed in parenthesis.

States (Barford 2004). United States hardwood lumber imports ranged from 0 to 100 percent with 32 percent (n=12) of the responding firms purchasing no lumber from the United States and 18 percent (n=7) purchasing 90 percent or more of their hardwood lumber from the United States.

When asked to rank the top three countries supplying their hardwood lumber, the United States was ranked number one by 18 of the responding companies and fell into the top three rankings 24 times (table 3). A scoring system was used where a 1st ranking = 3 points, 2nd ranking = 2 points, and 3rd ranking = 1 point. Under this system, the United States scored nearly 3 times higher than the next country, Russia. Russia, Africa, and Germany also ranked within the top three at least six times and showed correspondingly high scores (table 3). Note that some respondents reported specific countries, while others reported general regions.

Hardwood Lumber Import Channels

The hardwood lumber import channels for the Chinese manufacturers are described in table 4. The top three channels were Mainland Chinese Brokers, Chinese Wood Markets, and Direct from United States Manufacturers, which capture 60 percent of the responses when combined.

Thirty-six of the respondents listed what percentages of their hardwood lumber purchased moved through the various import channels. As shown in table 4, 39 percent (n=14) of the respondents purchase

Table 3—Top hardwood lumber sources by country or region

Country/region	First choice[a]	Second choice	Third choice	Score[b]
United States	18	1	5	61
Russia	6	2	—	22
Brazil	3	2	—	13
Germany	1	4	1	12
Indonesia	2	2	1	11
Africa	1	2	3	10
Canada	1	3	1	10
Southeast Asia	2	1	1	9
Europe	1	2	—	7
New Zealand	1	1	2	7
Malaysia	—	3	1	7
Thailand	1	1	1	6
Burma	1	—	1	4
China	1	—	—	3
Romania	1	—	—	3
South America	—	1	1	3
Austria	—	1	—	2
Chile	—	1	—	2
France	—	1	—	2
Gabon	—	—	2	2
Ukraine	—	1	—	2
Korea	—	—	1	1

[a] For 1st, 2d, and 3rd choice, n = 40, n = 29, and n = 21, respectively.
[b] Based on 1st = 3 points, 2d = 2 points, and 3rd = 1 point.

Table 4—Hardwood lumber import channels for Chinese manufacturers

Channel	Frequency	Frequency of exclusive purchases
Mainland Chinese broker	16	2
Chinese wood market	15	2
Direct from United States manufacturer	15	3
United States broker	8	2
Taiwanese broker	8	1
Japanese broker	1	—
Other	14	3

n = 43.

exclusively through one channel, the remaining 61 percent (n=22) purchase their hardwood lumber through two or more channels.

Primary ports of entry were numerous. The respondents identified more than 15 port cities. Shanghai and Hong Kong were cited most frequently representing 42 percent of the responses combined (fig. 1).

Hardwood Lumber Grades Imported from the United States

The hardwood lumber grades imported from the United States are described in table 5. The top two grades were Firsts and Seconds (FAS) and #1 Common, representing the highest frequency by the respondents. This is contrary to other reports, which cite the Chinese preference for lower grade (and price) hardwood lumber (Barford 2004). Regarding special grades, several respondents identified dimension parts as a "grade" that they were interested in buying. For example, dimension of 20 mm x 108 mm x 910 mm (0.79 inches x 4.25 inches x 35.8 inches) would be used as a flooring blank and be machined into a solid hardwood flooring product.

Prior to this study, the authors suspected that there was some grade rule confusion among the Chinese buyers. The hardwood lumber grading rules developed and implemented by the National Hardwood Lumber Association (NHLA), though voluntary, are complex (National Hardwood Lumber Association 2003). Several questions were included within the survey to ascertain the level of understanding of the NHLA grade rules.

Concerning the NHLA grade FAS, data about the respondents' understanding of minimum width, minimum length, and allowable defects were collected (table 6). According to the NHLA rules, the minimum width is 15.2 cm (6.0 inches) and the minimum length is 2.4 m (8.0 feet). Only one respondent closely identified the minimum width stating 15 cm (5.9 inches) with the median response being much smaller at 10 cm (3.9 inches) (table 6). Only one respondent correctly identified the minimum length of 2.4 m (8.0 feet). The remaining respondents were closer on the length with several listing values close to 2.4 m (8.0 feet). The median for the minimum length responses was 2.0 m (6.6 feet).

Regarding allowable defects within the FAS grade, a simple categorical scale including 'none', 'very few', 'some', and 'many' was included. The first three categories, 'none', 'very few', and 'some' were selected one, nine, and eight times respectively. The relatively high occurrence of the 'some' category may indicate that the respondents believed that more defects were allowable in the FAS grade than were actually allowable. None of the 18 respondents providing data for this question selected the 'many' category.

Table 5—Hardwood lumber grades imported from the United States

United States hardwood lumber grade	Frequency	Frequency of exclusive purchases
FAS	14	3
Select	5	2
#1 Common	14	1
#2 Common	9	—
#3 Common	1	—
Special grades	1	—

n = 21.

Table 6—Respondents' knowledge of NHLA FAS grade rules

		Respondent	
Dimension	NHLA FAS rule	Median	Range
Minimum width	15.2 cm (6.0 inches)	10 cm (3.9 inches)	2.5 cm to 35.5 cm (1.0 inches to 14.0 inches)
Minimum length	2.4 m (8.0 feet)	2.0 m (6.6 feet)	0.3 m to 4.0 m (1.0 feet to 13.1 feet)

n = 18.

Given this apparent lack of understanding of NHLA grading rules, we were interested in learning if the respondents believed that they had received subgrade lumber from the United States. Eighteen of 24 respondents answering this question indicated that they had received shipments of subgrade lumber. When asked what percent of the shipment was downgraded, 10 percent was the median response and ranged from 3 percent to 20 percent. Due to the inherent variability in hardwood lumber and judgment of the lumber grader, NHLA grading rules allow for five percent variation in the value of the shipment before the unit is considered mis-graded.

On several occasions, anecdotal evidence from wood market tours during the trade mission corroborated the possible confusion regarding United States lumber grades. In one example, we found clear defect-free hardwood boards, which were too narrow and too short to qualify for the FAS grade; however, the sales agent insisted that the lumber was FAS.

Major Hardwood Lumber Species

Respondents were asked to indicate the top three species of hardwood lumber imported and the country of origin for each of these species. The results are described in table 7. Oak was the most frequently cited species, including red and white oak from the United States as well as ìChineseî oak from eastern and northern Asia. Maple also was cited frequently, as was a collection of tropical and softwood species. Walnut (*Juglans* spp.) also was an important species. A number of lesser cited species included birch (*Betula* spp.), ash (*Fraxinus* spp.), beech (*Fagus* spp.), alder, yellow-poplar, and cherry (*Prunus* spp.). It should be noted, however, that United States Bureau of the Census (2005) figures cite alder and yellow-

Table 7—Summary of the major species of hardwood lumber used by respondents and country of origin for each of the species[a]

Species	Number of times listed	Country/region of origin[b]
Oak	30	United States (23); Russia (4); Germany (3); China (2); Europe (1)
Maple	16	United States (10); China (2); Germany (2); Europe (1); Russia (1); Korea (1); Indonesia (1)
Tropical species[c]	15	Brazil (6); SE Asia (3); Africa (2); Indonesia (2); Thailand (2); China (1); Burma (1)
Softwoods[d]	11	Russia (3); New Zealand (2); Canada (2); United States (2); Austria (1); Chile (1)
Walnut	10	United States (8); Europe (1)
Birch	4	China (3); Russia (1); Germany (1); Korea (1)
Ash	4	United States (3); China (1)
Beech	4	Germany (2); Romania (1); China (1)
Alder	3	United States (3)
Yellow-poplar	3	United States (3)
Cherry	3	United States (2); Canada (1)
Basswood	1	Russia (1)

n = 42.
[a] Respondents were asked to indicate the top three species of lumber used; results presented are aggregated.
[b] For a given species, this may not sum to "Number of times listed" because on occasion respondents left country of origin blank, and some listed multiple countries of origin for some species.
[c] Includes the following species: "teak" (n = 3), rubberwood (*Hevea brasiliensis* Muell. Arg.) (n = 2), lapacho (*Tabebuia* spp.) (n = 2), and n = 1 each for okoume (*Aucoumea* spp.), jatoba (*Hymenaea courbaril* L.), kempas (*Koompassia malaccensis* Maing.), ailanthus (*Ailanthus altissima* Mill.), sandalwood (*Santalum album* Linn.), "African species", "tropical species", and "hardwood species."
[d] Includes the following species: "pine" (*Pinus* spp.)(n = 6), Douglas-fir/hemlock (*Pseudotsuga menziesii* Mirb./*Tsuga Canadensis* L.) (n = 2), and n = 1 each for radiata pine (*Pinus radiata* D. Don), southern pine (*Pinus* spp.), and tamarack (*Larix laricina* Du Roi).

poplar as the two most abundant exports from the United States to China. A lone mention of basswood (*Tilia* spp.) was made by a producer of Venetian blinds who sourced from Russia.

When considering the United States position for the species cited, it seems particularly strong for oak and walnut; it also is strong for ash, alder, yellow-poplar, and cherry though these species were mentioned less frequently. This is not surprising given that some of these species, particularly yellow-poplar, do not occur commercially on a large scale outside of North America. Interestingly, it seems there is a fair amount of international competition associated with maple, even though most commercial maple production occurs in North America. This could indicate that more complex channels than "direct from the United States" are being employed and the ultimate source of maple lumber is being masked. It also could indicate that "trade names" sometimes confuse efforts to botanically identify species. Figure 2 shows the countries exporting lumber to China as identified in the study.

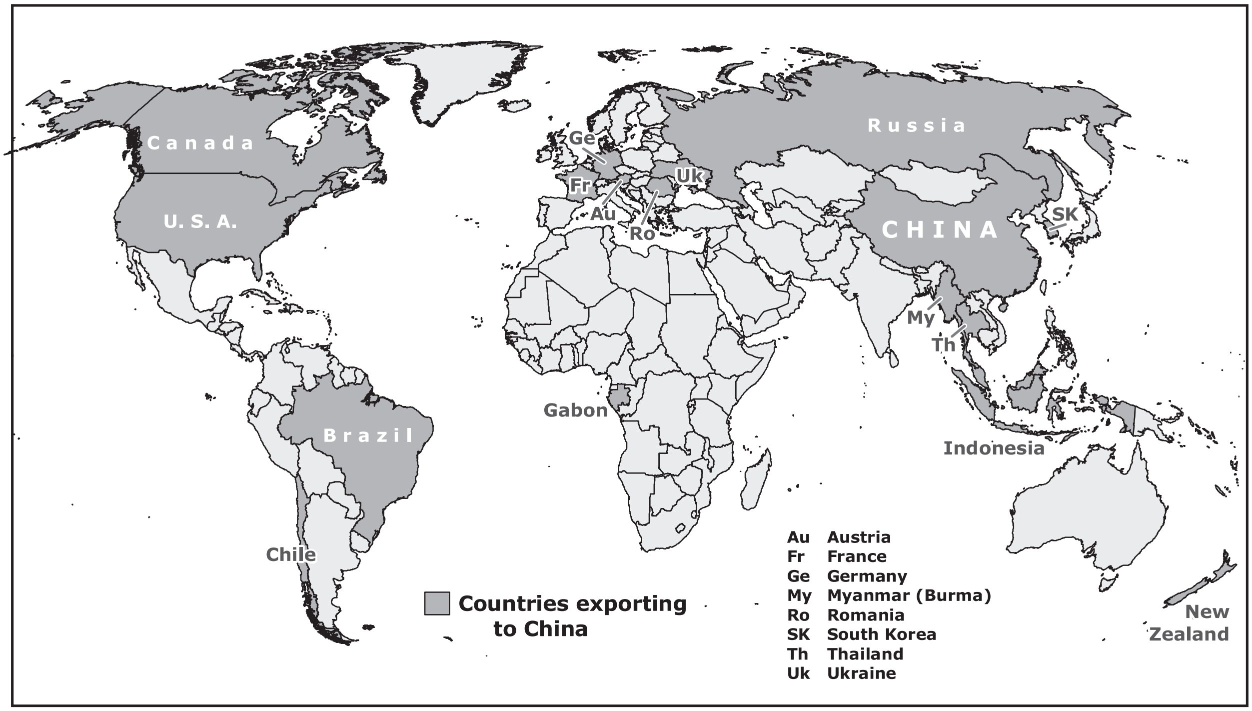

Figure 2—General map of the world; countries exporting to China are shaded.

The United States does not seem to be competitive in terms of birch exports, as sources in eastern and northern Asia were most common. Additionally, most beech exports came from Europe. Collectively, tropical species seem to represent a formidable threat to United States species, with Brazil and Southeast Asia leading as sources in this category (note that, in addition to "Southeast Asia", specific Asian countries such as Indonesia and Thailand are mentioned as well). Also notable was the collective presence of softwoods, with North America sharing the spotlight with Russia and the largely plantation-based sources of New Zealand and Chile.

CONCLUSIONS

Even though the data used in this paper is preliminary given the small sample size, several tentative conclusions can be made. First, the United States faces numerous global competitors in the Chinese hardwood lumber market. Countries such as Russia and Brazil, as well as several from Southeast Asia, were not only cited as sources for hardwood lumber in general terms, but also were found to be suppliers of some of the more common species exported to China. These imports included a number of tropical species, which can be used as substitutes for temperate species, as well as direct competitors to United States temperate species such as birch, oak, and beech. However, it has been noted that China is expected to increase imports of temperate-zone hardwoods due to concerns over price and future availability of tropical hardwoods; the United States is the leading source of temperate hardwoods to China (Butterworth and Lei 2005).

Second, there are many different channels being used to move hardwood lumber into China. Direct from United States manufacturers was found to be a major channel type, but there were many other channels of similar importance. The use of brokers and development of contacts within the Chinese wood market are also important and suggest that exporting to China can involve substantial investment in marketing research and development of selling arrangements.

Third, there seems to be considerable confusion over standard United States hardwood lumber grades among Chinese buyers. These buyers appear to be operating more under a pricing model, not a standard grade model. It could be that Chinese buyers and United States sellers are trading under a system with different understanding of the terminology, and with United States sellers doing what is necessary to remain profitable at pricing levels demanded by Chinese customers.

LIMITATIONS

This study is best described as a preliminary investigation. It is based on data from a small sample of companies, which was collected using trade show intercept procedures and on-site interviews. To draw broad conclusions, a larger sample of a more random nature would be useful. It seems there may be a bias in the sample toward firms importing from the United States. In addition, the import data does not account for hardwood lumber that may be re-exported by the responding brokers. Lastly, a language barrier complicated the survey procedures in some situations, even with the careful translation procedures and use of Chinese-speaking interviewers.

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EXPANDING FOREST MANAGEMENT TO INCLUDE MANAGEMENT OF NONTIMBER FOREST RESOURCES

James L. Chamberlain[1]

Abstract—The central hardwood forests of the United States are the source of many nontimber forest products (NTFPs), most of which originate from the understory flora. The collection, trade, and use of these products have been integral to rural economies since Europeans settled this country. Over the last decade, market demand for NTFPs and interest in managing forests for them have grown tremendously. Increased collection has led to concern about the ecological sustainability of the forest resources from which these products are harvested. The health and functioning of forest ecosystems and associated rural communities depend on sustainable management of NTFP resources. And yet, the science of managing the forests for these products is not well developed. Sustainability and the full range of benefits most likely will not be realized unless scientific management of forest resources includes scientific management of NTFPs. Understanding the extent that NTFPs occur in forests and the breadth of the markets for these products is crucial to improving scientific management. To maintain and enhance the long-term socio-economic benefits that rural collectors and processors realize from NTFPs depends on shifting the forest management paradigm to include nontimber forest resources.

INTRODUCTION

Forest management has evolved over time to reflect changes in society. “People now wish to use their forests for all sorts of purposes and forest management reflects this change” (Davis and Johnson 1987). In their seminal text these authors point out that “forest management is now directed at helping people achieve whatever goals they have for their forests.” It entails meeting the objectives of landowners and society through manipulations of forest resources. Managing forests for nontimber goals is considered a major objective of private forest landowners who are interested in joint production of timber and other forest amenities (Amacher and others 2004). Legislation now mandates that national forests be managed for multiple uses.

In the early 1990s, the paradigm that guides forest management began a slow and unsure shift to include the floral and fungal botanical species that are gathered for personal and commercial uses. Market forces, such as bumper crops of forest mushrooms, increased availability of low-paid migrant workers, and shifts in public policy have fostered an atmosphere that encourages consideration of forest resources harvested for products other than timber in management planning and implementation. As a result, interest in and concern for nontimber forest products (NTFPs) that are harvested for commercial purposes increased tremendously.

In North America, international trade in forest botanicals other than timber dates to the early 1700s, when sassafras, ginseng, and other forest plants were regularly exported along with timber and other natural resources. Since those early days, the harvesting of nontimber forest resources has supported a dynamic and valuable socio-economic market. In the late 1890s, timber and water resources were recognized as essential resources that required active management and became the foundation for the multiple-use forest management paradigm. Over the last 100 years, that paradigm has expanded to include a multitude of resources, issues, and factors.

NTFPs have yet to be fully incorporated into the multiple-use forest management paradigm. They are slowly being recognized as natural resources that require active management for sustainability. Chamberlain (2000) identified three major areas of consideration that must be addressed to integrate

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NTFPs into the multiple-use forest management paradigm. The ecological, social, and economic issues that affect how nontimber forest resources are managed require expansion of knowledge and new ways of examining forest management. More research, development, and support of practices and policies are needed.

FOREST MANAGEMENT PARADIGM

The paradigm that guides management of public forests has evolved to include a multitude of diverse resources and issues. The Organic Administration Act of 1897 (U.S. Code 30 Stat. 35) initiated management of the national forests and became the foundation for the paradigm that guides how forests are managed. The Act directed that forests be established to improve and protect the resources to secure water and to furnish a continuous supply of timber (U.S. Code 30 Stat. 35).

More than 60 years after the Organic Act, the Multiple-Use Sustained Yield Act (MUSYA 1960) expanded the national forest management paradigm. It authorized and directed the Secretary of Agriculture to manage the national forests to ensure the multiple-use and sustained yield of the renewable surface resources of the forests. MUSYA defined the purposes for which national forests would be managed as "outdoor recreation, range, timber, watershed, and wildlife and fish" (MUSYA 1960). The Act reinforced the traditional understanding that national forest priorities regarding wildlife would reflect State priorities, placing heavy emphasis on game management (Fedkiw n.d.). In the early 1960s and again in 1975, the paradigm expanded to include wilderness (Wilderness Act of 1964, Eastern Wilderness Act of 1975). Minerals were integrated into the management paradigm in the 1920s and again in 1970 (Mineral Leasing Act of 1920, Mining and Minerals Policy Act of 1970). By the end of the 1970s the paradigm by which forests were managed had expanded to include a variety of uses, resources, and services.

Protection of endangered species, participatory planning, and seeking public opinion were included in the forest management paradigm in the early 1970s. The Endangered Species Act (1973) focused management on threatened and endangered species and the habitats in which they are found (U.S. Environmental Protection Agency 2005). The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 institutionalized land and resource management planning in the Forest Service (RPA 1974). The RPA legislation directs that forest management plans address recreation and wilderness, range, timber, watershed, and fish and wildlife. The National Forest Management Act (1976) amended the RPA to prevent abuses from timber harvesting (Shands and Healy 1977) and ensure equal consideration for all renewable forest resources.

The paradigm used to manage national forest lands has evolved over the years to become complex and comprehensive. More than 80 laws affect how national forests are managed (Floyd 1999). The multiple-use model is a global icon, and the basis for other more progressive paradigms (e.g., ecosystem management and sustainable forest management). The laws that regulate public forests may not be fully reflected in private forest management, yet the models that guide management of public and private forests are similar. In general, neither approach fully includes management of nontimber forest resources.

NONTIMBER FOREST PRODUCTS

A variety of terms (e.g., non-traditional, secondary, minor, non-wood, and special or specialty) have been used to describe products that come from the forests that are not timber-based. National legislation uses the phrase "forest botanical products" to describe these products (H.R. 2466 1999). The USDA Forest Service defines them as special forest products (USDA Forest Service 2001). A more common and widespread term is "nontimber forest products." Whatever the term used to describe these products, they are all based on plants or fungi or other flora materials. Wildlife or other fauna are not generally included in the definition.

NTFPs are plants, parts of plants, fungi, and other biological material harvested from within and on the edges of natural, manipulated, or disturbed forests. They include fungi, moss, lichen, herbs, vines, shrubs, and trees. Plant parts harvested include roots, tubers, leaves, bark, twigs and branches, fruit, sap and resin, as well as wood (Chamberlain and others 1998). These are commonly classified into four major categories: culinary products, specialty wood-based products, floral and decorative products, and medicinal products and dietary supplements. A newly emerging category of NTFPs used in the landscape industry includes items such as pine straw and live native plants collected from the wild. Chamberlain and Predny (2005) present a comprehensive list of products gathered from the forests of Southern United States. They identify more than 100 NTFPs, the majority of which are harvested for medicinal purposes. Plants used for floral and decorative uses are also well represented.

Forest plants collected for culinary uses include mushrooms, fruits, ferns, greens, roots, and tubers. In the central hardwood region, food festivals are organized around the emergence of wild onions (Allium tricoccum), known regionally as ramps. Maple syrup festivals, such as those in the Mt. Rogers area of Virginia, are common in communities at higher elevations and further north. Fiddleheads (the young, tightly coiled fronds of the fern Matteuccia struthiopteris), dandelion (Taraxacum spp.) greens, and poke salat (Phytolacca decandra) are eaten in the spring as well. Nuts and berries—including black walnuts (Juglans nigra), muscadine grapes (Vitis rotundifolia), blueberries (Vaccinium spp.), raspberries and blackberries (Rubus spp.), and persimmons (Diospyros virginiana)—are gathered, consumed, and sold throughout the Southeastern United States.

Specialty wood-based NTFPs are produced from trees or parts of trees, excluding products made from cut timber. Some important wood-based NTFPs made from trees in the central hardwood region include sassafras (Sassafras albidum) stems for walking sticks, willow (Salix spp.) branches for furniture, and white oak (Quercus spp.) splits for baskets. Products made from vines, such as smokevine (Aristolochia macrophylla) and grapevine (Vitis spp.), are included in this category. The number of species that could be used in production of crafts is limited only by the imagination of crafters and market acceptance.

Many forest plants are harvested and used in the floral industry as complements to flower arrangements. The leaves of galax (Galax urceolata), an evergreen herbaceous perennial, are exported to Europe for background foliage. Sprigs and long lengths of grapevine and smokevine also may be used as complements or backdrops in floral arrangements. Several species of moss and lichen are harvested from Appalachian forests for the European floral industry.

Forest plants also are harvested and used for their therapeutic value and are marketed either as medicines or as herbal remedies. According to Farnsworth and Morris (1976), 25 percent of all prescriptions dispensed in the United States contain active ingredients extracted from higher order plants. The number of plant species harvested from southern forests with medicinal value exceeds 125 (Krochmal and others 1969, World Wildlife Fund 1999). Of these, approximately 50 are commonly harvested and purchased by herb dealers. More than 80 percent of the forest-harvested ginseng comes from Virginia, Kentucky, Tennessee, and North Carolina. The central hardwood region is the principal source of many medicinal plants, including black cohosh (Actaea racemosa), American ginseng (Panax quinquefolius), and bloodroot (Sanguinaria canadensis).

NTFP Enterprises

The NTFP industry is made up of a diverse collection of enterprises. In general, enterprises involved in NTFPs may collect, buy, sell, process, or work with these products to produce goods and services. In this diverse industry, an enterprise may be an individual who collects and sells raw materials with little or no processing, such as ramp harvester; a family farm or small business that produces wreaths or other value-added products; or a formal corporation that employs many people. These NTFP enterprises include a vast array of firms, from individual entrepreneurs to multi-employee organizations, from the point where the NTFPs is collected to the point of final consumption. The fundamental thread that binds these organizations is the use of nontimber forest resource.

The USDA Forest Service, Southern Research Station work unit based in Blacksburg, VA (with support from the USDA Forest Service, Forest Inventory and Analysis (FIA) unit in Knoxville, TN) is working to define the NTFP industry in the southern region of the United States. An enterprise distribution map based on the perceptions of county extension agents reveals the concentration of NTFP enterprises (fig. 1). The distribution of these enterprises appears to be concentrated along the Appalachian Mountain chain and in the central hardwood forest region (Chamberlain and Predny 2003).

Markets and Market Dynamics

Though no formal estimates have been made of the total value of the NTFP markets in this region, available data illustrate the economic importance of some individual products. For example, in 1995 the United States exported moss and lichen, much of which was from southern forests, valued at more than $14 million (Goldberg 1996). In 1997, one company in southwest Virginia specializing in pine roping had sales in excess of $1.5 million (Hauslohner 1997). Several volunteer fire departments in western North Carolina generate from 30 to 90 percent of their budgets from annual ramp festivals. Based on 2001 prices, this author estimates that the average wholesale value of forest-harvested ginseng in a four-State region of Appalachia exceeds $18.5 million. Certainly, the aggregate value of NTFPs to the southern economy far exceeds these examples.

In the early 1990s, a series of major factors helped spark an increased interest in NTFPs. Bumper crops of edible mushrooms appeared on many national forests in Oregon and Washington (Freed 1994) as a result of major forest fires. Market studies of NTFPs revealed potential economic development opportunities (Mater Engineering 1992, 1993, 1994).

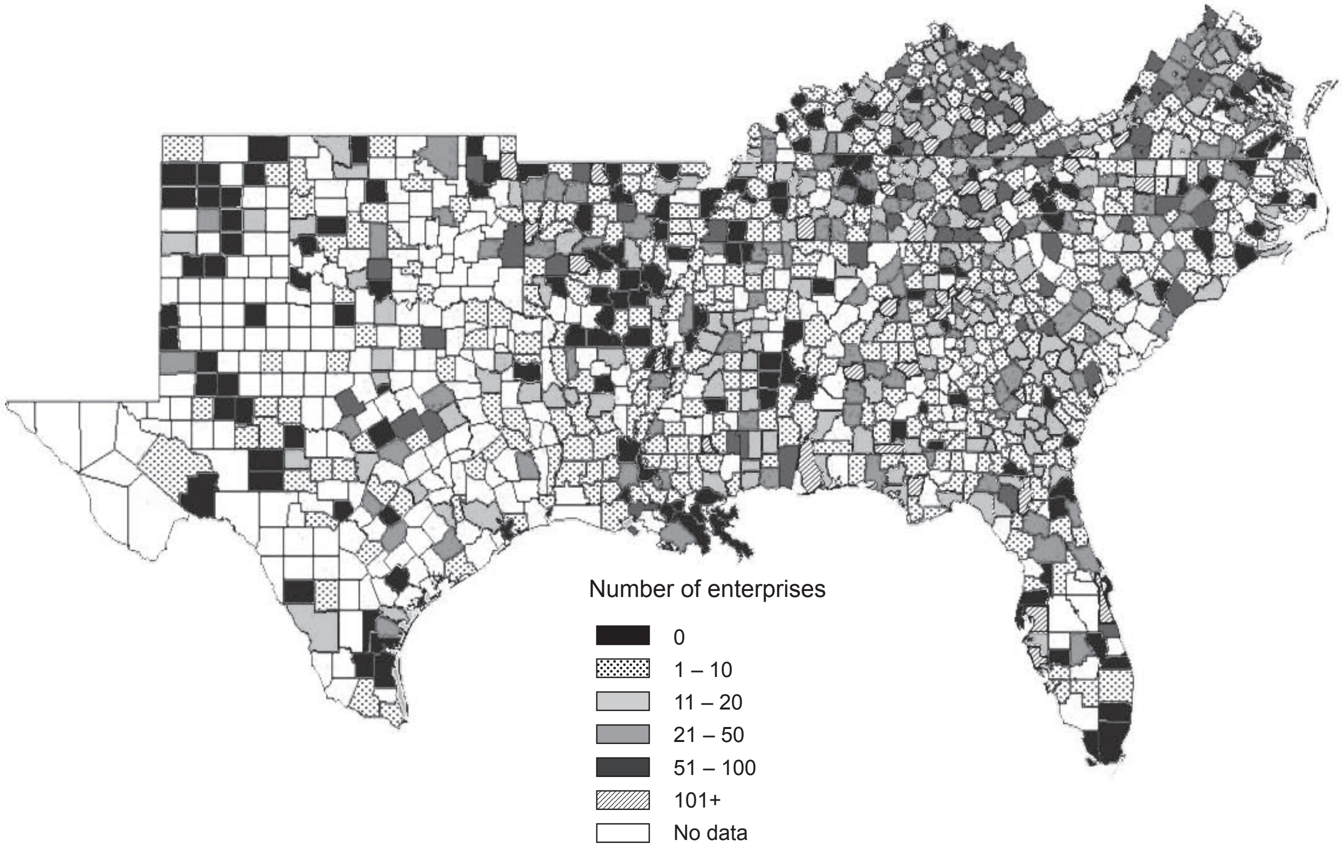

Figure 1—Perceived distribution of NTFP enterprises in the Southern United States.

The findings of medical research also helped to increase market demand for nontimber medicinal forest products (Eisenberg and others 1993, Le Bars and others 1997, Stix 1998). The 1996 estimated value of the global markets for herbal medicines was approximately $14 billion (Genetic Engineering News 1997). Europe and Asia represented more than 80 percent of the global trade at that time. In 1998, the total retail market for medicinal herbs in the United States was estimated at $3.97 billion, more than double the estimate for North America in 1996 (Brevoort 1998, Genetic Engineering News 1997).

In the late 1990s, the mass-market segment for herbal medicinal products, approximately 17 percent of the U.S. market, grew at an annualized rate of over 100 percent (Brevoort 1998). Exports of forest-harvested ginseng grew more than 300 percent from 1993 through 1996 (USDA 1999). Although exports of forest-harvested ginseng decreased in 1997 and 1998, demand for other species increased (USDA 1999). For example, the estimated growth in the mass market for St. John's wort (Hypericum perforatum) and black cohosh, for the 52-week period ending July 12, 1998, was approximately 2,800 percent and 500 percent, respectively (Brevoort 1998).

Over the last 2 decades market factors have continued to change. Overall demand for NTFPs in all market segments has increased. The USDA Forest Service issued a national strategy regarding special forest products (USDA 2001). Legislation has been enacted to develop and strengthen management efforts within the national forest system (H.R. 2466 1999). The U.S. Food and Drug Administration issued several findings that affected the market for herbal remedies (e.g., Hormone Replacement Therapy). Recent medical research has raised health and safety concerns. The 2005 findings by the U.S. Fish and Wildlife Service regarding the export of wild-harvested ginseng will have direct and lasting impacts on the medicinal plant industry (U.S. Fish and Wildlife Service 2005).

INTEGRATING NTFPS INTO FOREST MANAGEMENT PARADIGM

NTFPs will be integrated into forest management when decision makers are fully convinced of the social, economic and ecological effects of not managing for them.

Ecological issues—There is increasing awareness that for all parts of the forest ecosystem to be sustainable, the resources from which NTFPs originate must be recognized as renewable resources and integrated into forest management. Scientific management and sustainable collection methods must be practiced. Unfortunately, the ecological knowledge needed to achieve these is generally lacking. The consequences of not fully understanding the impact of unmanaged harvesting of NTFPs could be the decline of plant populations. Planning for the impact of harvesting will be challenging without a solid understanding of the life cycles of the forest botanicals.

For most NTFP species, ecological data is needed to determine sustainable harvest rates, develop growth and yield models, and craft inventory and monitoring protocols. Most basic information concerning product supply is lacking, and this affects the possibilities for sound inventory and monitoring (Reams and others 2004). Baseline information about the plants' ecological distribution, abundance, condition, and rates of change are fundamental knowledge needed for management. In general there is a lack of knowledge about the biology and ecology of the flora from which these products originate. The diversity of the plants and plant parts complicate management efforts. Reproduction rates and methods need to be determined for most NTFP species.

Economic issues—The people of the central hardwood region have enjoyed tremendous economic benefits from the harvesting of NTFP species. Families have depended on income from the sale of medicinal, floral, and edible plants from the forests of Appalachia since their ancestors moved to this region. Today, local residents still rely on income from the sale of NTFPs. Income from NTFPs becomes more important to local harvesters as economic downturns occur.

Local, regional, national, and international businesses depend on sustainable supplies of NTFPs. The scale of the economy that depends on these natural resources is global, as a significant portion of the annual harvest is exported to European and Asian markets. Although the value of the NTFP industry has not been fully estimated, that which has been discovered indicates a large, vibrant, complex economy. The NTFP economy may be in jeopardy without more active management of the forest resources. Lack of management of the NTFP resources could lead to loss of plant populations, reduced access for the harvester, decline in revenues at all market levels, and loss of market share.

More quantitative analysis is needed to demonstrate the economic value of the NTFP industry. The value additions at each level of the market need to be determined and tracked to provide valuable trends analysis. Studies of possible opportunities for local value-added initiatives are needed to find ways to conserve economic benefits. Full strategic market assessments are needed for each segment (i.e, edibles, floral, medicinal, crafts, and live-plants) of the industry, to help in setting conservation priorities.

Social issues—Some Appalachian harvesters of European descent can trace their relationship with American ginseng, and other NTFPs, to contact between their ancestors and native Cherokee tribes. Other harvesters do not have historical ties to NTFPs, but started collecting out of necessity or interest in nature. Traditional ecological knowledge of long-time Appalachian harvesters could help to educate newer harvesters and forest managers on ethical practices.

Neglecting the social issues in management of NTFP resources could lead to increased tension, distrust, and increased difficulty in enforcing policies. Integration of social issues into forest management will require describing, defining, and estimating demographics that define the people involved at all market levels. Understanding their attitudes, perceptions, and beliefs regarding management of natural resources for NTFPs will help to identify obstacles that could limit conservation efforts.

An expansion of the forest management paradigm to include NTFPs will impact people who may be on the margins of the economy, depending heavily on collection of these plant materials and typically not included in policy dialogue. Changes in forest policies and practices regarding NTFPs can significantly impact these peoples' lives, as they have few income opportunities. Active, transparent, sincere, and engaging dialogue is needed to ensure the full participation of the NTFP community in shifting the multiple-use forest management paradigm to include nontimber forest resources.

CONCLUSIONS

The multiple-use forest management paradigm appears to be shifting, albeit slowly, to include forest botanical species harvested for nontimber values. Market forces are causing an expansion of forest management to incorporate products that have been gathered for hundreds of years. The lack of knowledge concerning economic, ecological, and social factors inhibits efforts to have these products better integrated into management planning and implementation. Efforts are underway to improve the situation, but much more work is needed before these resources are truly part of the overall paradigm.

Academic and government research and management agencies (e.g., the National Forests of North Carolina, North Carolina State University, and the USDA Forest Service, Southern Research Station) are working closely to fully understand the ecological ramifications of not managing the NTFP resources. The USDA Forest Service Southern Research Station and FIA have initiated an assessment to define the NTFP industry in the southern region. As no sample frames exist to contact market players, the study is building the foundation for more comprehensive assessments. Results indicate the concentration of NTFP enterprises throughout the region and are helping to focus research and development.

To fully incorporate nontimber forest resources and associated products into the multiple-use management paradigm will require greater evidence of their value and of the implications and ramifications of not managing for their conservation.

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PRODUCT RECOVERY FROM TREE GRADE 1 NORTHERN RED OAK ON MENOMINEE TRIBAL LANDS

John P. Dwyer and Daniel C. Dey[1]

Abstract—Since 1854 the Menominee Tribal people have practiced some level of forest management on their lands. In April of 2000, Menominee Tribal Enterprises (MTE) forestry staff along with federal, state, and university researchers began a comprehensive study of value in northern red oak (*Quercus rubra* L.). One of the objectives of this study was to relate tree characteristics to lumber yield and grade, and total tree value of mature and old growth northern red oak. During winter 2001, 69 northern red oak (tree grade 1) study trees were identified and harvested from three habitat types on Menominee Tribal lands. Sample trees averaged 111 years old (82 to 181 years) and 22 inches in d.b.h. (14 to 33 inches). Results of the mill yield study showed that almost 70 percent of the value of the tree grade 1 northern red oak trees was in the first two logs. Approximately 40 percent of the tree grade 1 logs were veneer quality. Almost one-third of the veneer logs came from 20- to 24-inches diameter trees. Over one-half (53 percent) of the total veneer value came from butt logs. The total value of all products derived from the northern red oak grade 1 trees increased with age and diameter.

INTRODUCTION

Approximately 65 percent of the 220,000 acres of Menominee Tribal forestland is managed using uneven-aged silvicultural methods in northern hardwood forest types dominated by sugar maple (*Acer saccharum* Marsh.). Within this area, northern red oak is a dominant and featured species on AFVib, AFVib(Ha) and ATM habitat types (Kotar and others 1988). Quality oak can be grown on these dry-mesic to mesic sites of medium fertility using even-aged silvicultural methods.

Hardwood forests on the Menominee Reservation are uniquely different from similar forest types throughout the Great Lakes Region (40 miles west of Green Bay, Wisconsin). Trees are grown to larger diameters and achieve older ages than many other managed forests. For example, northern red oak on Menominee can grow to over 30 inches in diameter and attain ages of 180 years or more.

Menominee forest managers were interested in how tree value changes with time in forests where individual trees are often left to grow for long periods of time which approach the biological upper limit for northern red oak. Their questions focused on whether there is an optimal age or diameter where total tree value is highest. Additionally, they wanted to know if there was a balance between tree value increases due to tree growth and grade improvement, and value loss due to wood decay, discoloration, and other grade defects.

The purpose of this study was to determine how the economic value of individual northern red oaks varies by tree characteristics. We evaluated the relationship between tree diameter, height, age, and other measures of the tree's vigor on product recovery and total tree value.

METHODS

During April 2000 we visited several sites on Menominee lands to develop criteria for the selection of northern red oak trees. Due to sawmill availability for processing logs we limited our study to evaluating total value in tree grade 1 northern red oaks (Hanks 1976). Each tree was also in tree vigor class 1 (as defined by Menominee foresters, vigor class 1 represents trees with no visible signs of biotic or abiotic damage (table 1)). Menominee foresters located 69 trees from 4 different compartments that represented three different habitat types (table 2). For each sample tree the following parameters were recorded: tree

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Table 1—Classification criteria for tree vigor class 1 trees according to Menominee Tribal Enterprises—criteria used to select the study trees

Vigor class	1
Qualifications	Good growing stock
Risk of mortality	"+" no risk "+" roots firm "+" lower/upper bole sound "+" all large, high crotches strong "+" no windfall or main stem breakage anticipated
Crown class	"+" dominant or codominant
Crown size	"+" full crown concentrically
Crown density and leaf condition	"+" good silhouette "+" healthy leaf "+" occasional dead branch in outer crown "+" permits natural pruning
Bole length and form	"+" useable length commensurate with site "+" d.b.h./length ratio good "+" no useable length stoppers on bole Note: if useable length falls short of average then reduce tree vigor by one class
Rot and decay within useable length	"+" cull loss seldom > 3 percent to 7 percent, never > 14 percent "+" slight crook or sweep will cut out "+" heart rot is negligible

Table 2—Summary of northern red oak tree characteristics. Habitat type is according to Kotar and Burger (1989)

Habitat type	Study trees	Average d.b.h.	D.b.h. range		Average stand BA	Average age	Age range	
			Minimum	Maximum			Minimum	Maximum
	no.	*inches*	*- - - - - inches - - - - -*		*ft²/acre*	*years*	*- - - - - - years - - - - - -*	
AFVib	31	19.7	13.7	26.5	91	93	82	101
AQVib(Ha)	25	20.3	15.8	25.5	108	101	84	126
ATM	13	29.0	24.3	33.5	58	175	163	181

AFVib = Acer-Fagus/Viburnum habitat type; AQVib(Ha) = Acer-Quercus/Viburnum (Hamamelis phase) habitat type; ATM = Acer-Tsuga/Maianthemum habitat type.

number, site number, habitat type, d.b.h. (0.1-inch), crown class, tree vigor, bark vigor, lean, defect position on tree, defect description, length, width, and diameter of defect (nearest 1.0-inch). Around each study tree a variable-radius 10-factor basal area prism plot was established. Within each prism plot the species, d.b.h. (0.1-inch), tree grade, and crown class were recorded for all species 5.0 inches d.b.h. and larger. Each northern red oak tree had a 2.0-inch thick "cross-section" removed from each stump once the trees were felled. These samples were sent to the United States Forest Service, Northeast Research Station, Princeton, WV lab where they were aged by counting tree rings. These cross-section disks were subsequently used by other researchers to compare methods of measuring disk and heartwood area (Wiemann 2002).

In February 2001, Menominee logging crews chainsaw-felled the study trees and used specially designed log bucking guidelines to maximize log grade recovery. These veneer log bucking guidelines were developed by two consulting hardwood marketing specialists retained to work on this project. Bucking specifications focused on length of clear faces and scaling diameter as important factors in determining log length or the first buck point. Each log was identified with a number painted on both ends that identified the tree from which the log came and its position in the tree. The length of each log was measured to the nearest (0.1-foot.). Veneer, sawlogs, hardwood bolts, and pulpwood products were taken to the Menominee Tribal Enterprises mill at Neopit, WI. The mill has a dual band headrig with a circular gang re-saw configuration. Each of the logs was scaled and graded in the mill yard by a certified log scaler. The following data were recorded for each log: log number, the small end diameter of the log (nearest 1.0-inch), the gross scale (Scribner Dec. C), the reason for any grade/volume deduction, net scale (Scribner Dec. C), and log grade.

The 69 study trees yielded 212 factory grade sawlogs which were processed through the sawmill in approximately 14 hours. All boards were cut to 4-quarter (1.0-inch.) thickness. Each board sawn from a log was marked with the log number before it reached the edger, where it was edged for optimum lumber value. When all grade boards had been removed from the log, the heart of the remaining log was "boxed" into a cant, where it was graded and any remaining grade lumber was re-sawn. Once all grade lumber had been recovered from each cant we recorded the log number, cant thickness (nearest 1.0-inch), and net volume in board feet in each cant. A NHLA certified lumber grader graded each board using the Northern Hardwood and Pine Association grading rules. For each board we recorded: log number, sawing order, board thickness and net volume by grade. The grades used were: FAS, IF, SEL, #1COM, #2ACOM, #3ACOM, and BG (below grade). Veneer logs (123) were sold as 1 lot using a competitive sealed-bid process.

RESULTS

The 69 northern red oak study trees ranged in diameter from 13.7 to 33.5 inches d.b.h. and averaged 21.6 ± 4.7 inches d.b.h. (table 2), and tree age averaged 111 ± 32 years. The youngest oak sampled was 82 years old and the oldest was 181 years.

Each study tree was manufactured into veneer logs, dimension lumber, cants and hardwood and pulpwood bolts. The value of the veneer logs was determined through a competitive bid process (table 3). Marion Plywood Corporation submitted the highest bid which totaled $23,776. The total net volume of the 123 veneer logs was 18,330 board feet (Scribner Decimal C scale). The sawn lumber was valued using reported lumber prices from the *Hardwood Market Review* for the week that sawing was completed. A grand total of 14,529 board feet millscale were sawn from the 212 factory grade sawlogs. Of this total footage 21 percent of the volume was recovered in the two highest value lumber grades, FAS and 1F. A total of 220 cants were produced from the 212 factory grade logs with a total volume of 7,683 board feet and value of $2,107.

Table 3—Summary of total product value by habitat type. Habitat type is according to Kotar and Burger (1989)

Habitat type	Study trees	Veneer		Lumber		Cant		Total product	
		Volume	Value	Volume	Value	Volume	Value	Volume	Value
	number	*bf Dec C*	*$*	*bf*	*$*	*bf*	*$*	*bf*	*$*
AFVib	31	5,630	7,551	5,272	3,724	3,024	828	13,926	12,103
AQVib(Ha)	25	4,949	6,875	4,747	3,655	2,698	741	12,394	11,271
ATM	13	7,660	9,350	4,510	3,501	1,961	538	14,131	13,389
Total	69	18,239	23,776	14,529	10,880	7,683	2,107	40,451	36,763

AFVib = Acer-Fagus/Viburnum habitat type; AQVib(Ha) = Acer-Quercus/Viburnum (Hamamelis phase) habitat type; ATM = Acer-Tsuga/Maianthemum habitat type.

The distribution of logs (N=335) by diameter class (fig. 1) shows that the number of veneer logs increased with diameter up to the 20.0-inch (d.b.h.) class and then begins to decrease. The diameter class with the highest proportion of veneer logs was the 28.0-inch class (43.8 percent). Veneer logs and grade 1 sawlogs accounted for approximately 43 percent of all logs. Logs that graded veneer also met grade 1 sawlog specifications. Most of the veneer (87 percent) came from trees with diameters (d.b.h.) between 16 and 28 inches. Trees in the 20.0-inch d.b.h. class (20.0 to 23.9 inches) produced the greatest number of logs (N=106) and the most veneer (28 percent of all veneer logs).

Number of quality logs (i.e., veneer and grade 1 sawlog) dropped beyond the first log position (fig. 2). Substantial reductions in number of logs occurred beginning in the third log position, and quality logs were practically absent in the fourth and higher log positions. Most tree grade 1 northern red oaks had 4 logs (mean=4.6 ± 1.1 logs per tree) and half of them had a fifth log. Veneer grade logs dominated the first and second log positions.

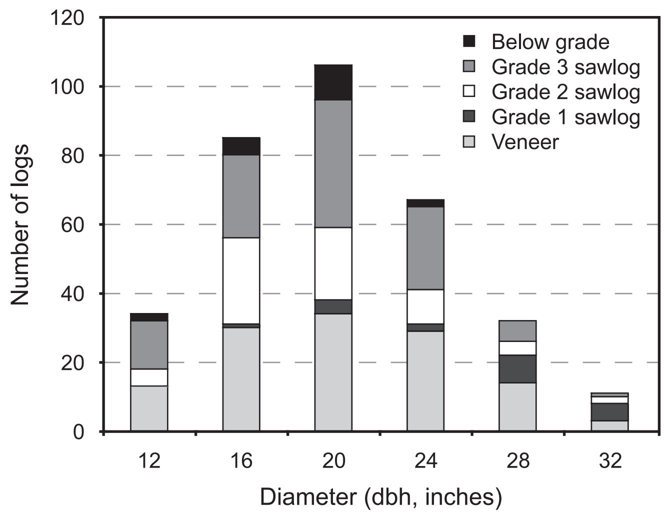

Figure 1—Distribution of logs by grade and tree diameter (d.b.h.) for tree grade 1 northern red oak logs (N = 335).

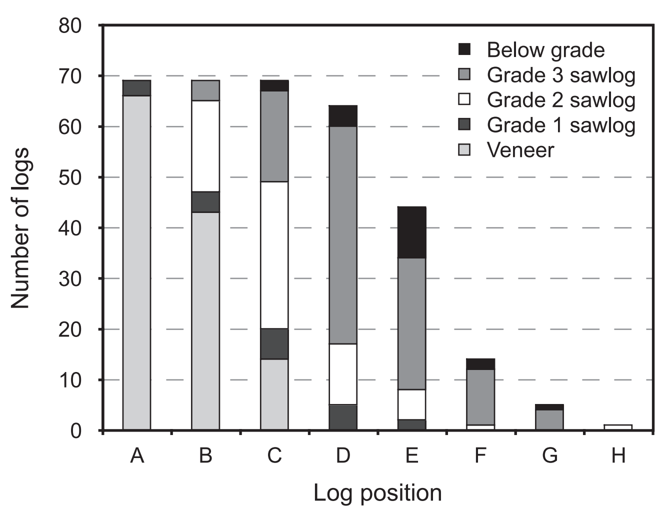

Figure 2—Distribution of logs by grade and log position (A = first or butt log, B = second log, etc.) for tree grade 1 northern red oak.

The distribution of total tree value (veneer + sawlog + cant revenues) by log position for tree grade 1 northern red oak shows the butt log (Log A) contributed 40 percent of the total tree value on average (fig. 3). The first two logs in northern red oak comprised 69 percent of the tree's value on average. Logs averaged 11.1 ± 2.1 feet in length. Log length was fairly constant for logs from the first three log positions, but then gradually decreased to an average length of 9.1 feet in the seventh log position. The average small end diameter was 18.1 inches for the butt log. Slightly over half (53 percent) of the total veneer value was from butt logs, 36 percent came from second logs.

A plot of red oak ages indicated three cohorts, or age classes in our sample of tree grade 1 northern red oak, i.e., one class at 175 years, one near 120 years and the third at 90 years (fig. 4). Age was significantly related to tree d.b.h. (r^2=0.594; p<0.0001). The greatest variation in age for a given d.b.h. was in the range of d.b.h. from 19 to 26 inches, where ages varied by 40 to 100 years depending on d.b.h..

Total tree value included the actual revenue from the competitive sale of the veneer logs and all of the other revenues, which were determined using regional market price averages at the time of product manufacture for the milled lumber. Total value per tree (fig. 5) was significantly (r^2=0.815; p<0.0001) related to tree d.b.h. and age.

DISCUSSION

The results of our northern red oak investigation indicate that tree diameters of 20.0 to 24.0 inches cam be produced in 90-100 years on Tribal Lands. These diameter classes yield the greatest volume of high value products (veneer, grade #1 sawlogs). While northern red oak on the sites investigated do grow longer and get larger in size, the percentage of high value products within individual trees decreases over time.

The implication for future forest management is significant because high volume and quality northern red oak can be grown over a much shorter timeframe than is currently being done. One of the practical recommendations from this study would be to shorten target rotation lengths to less than 100 years. As a result of shortening the length of time to manage for a smaller diameter northern red oak tree, significant financial gains can be realized.

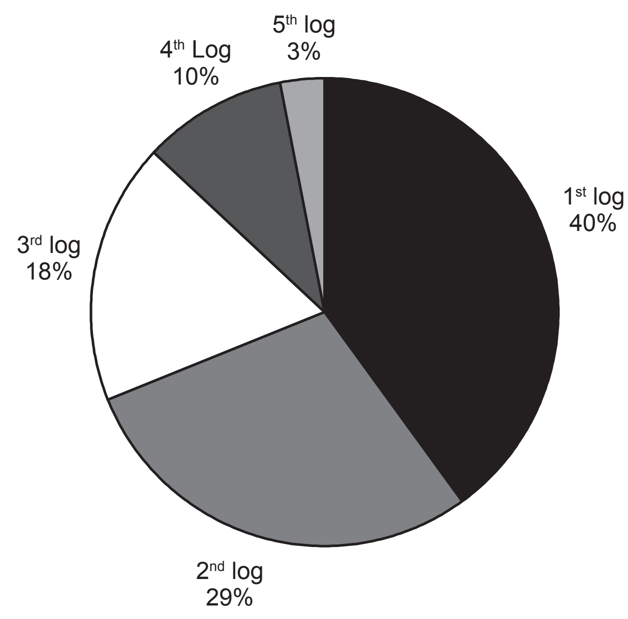

Figure 3—Distribution of tree value for the first five log positions in tree grade 1 northern red oak. Value is the sum of veneer and sawn lumber revenues.

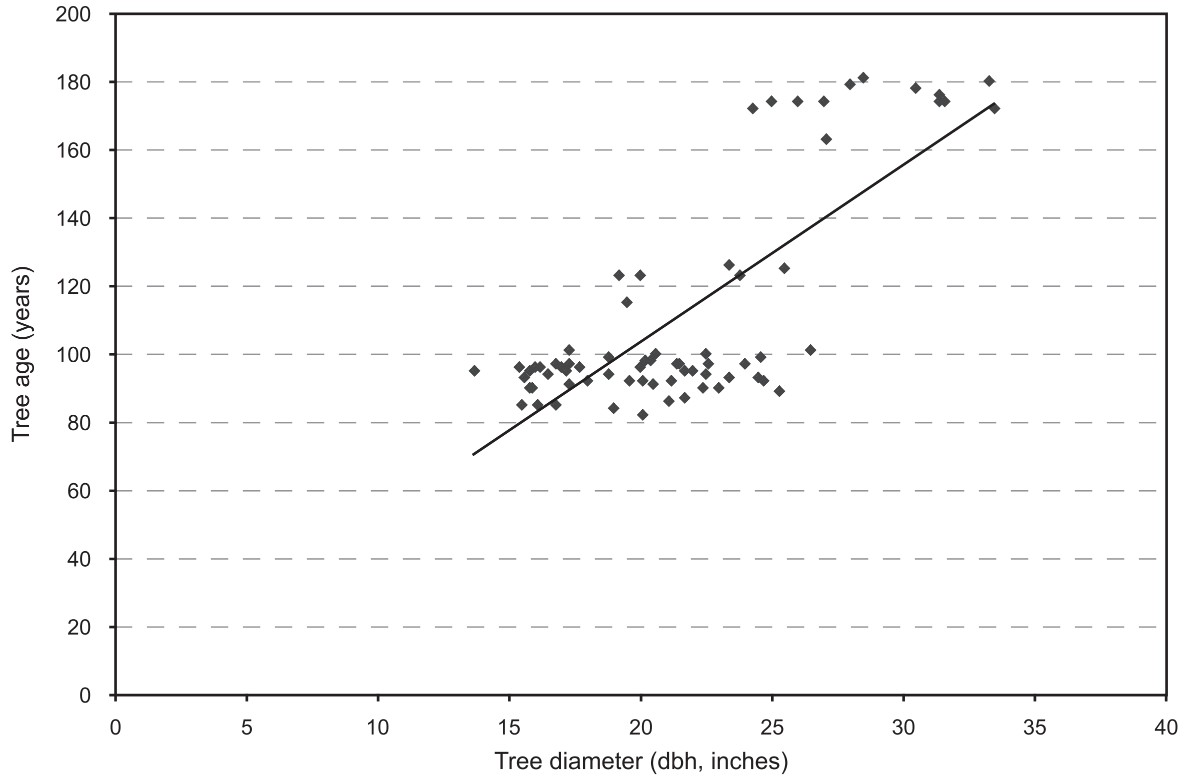

Figure 4—Observed and predicted regression line of tree age by tree diameter (d.b.h.) for tree grade 1 northern red oak.

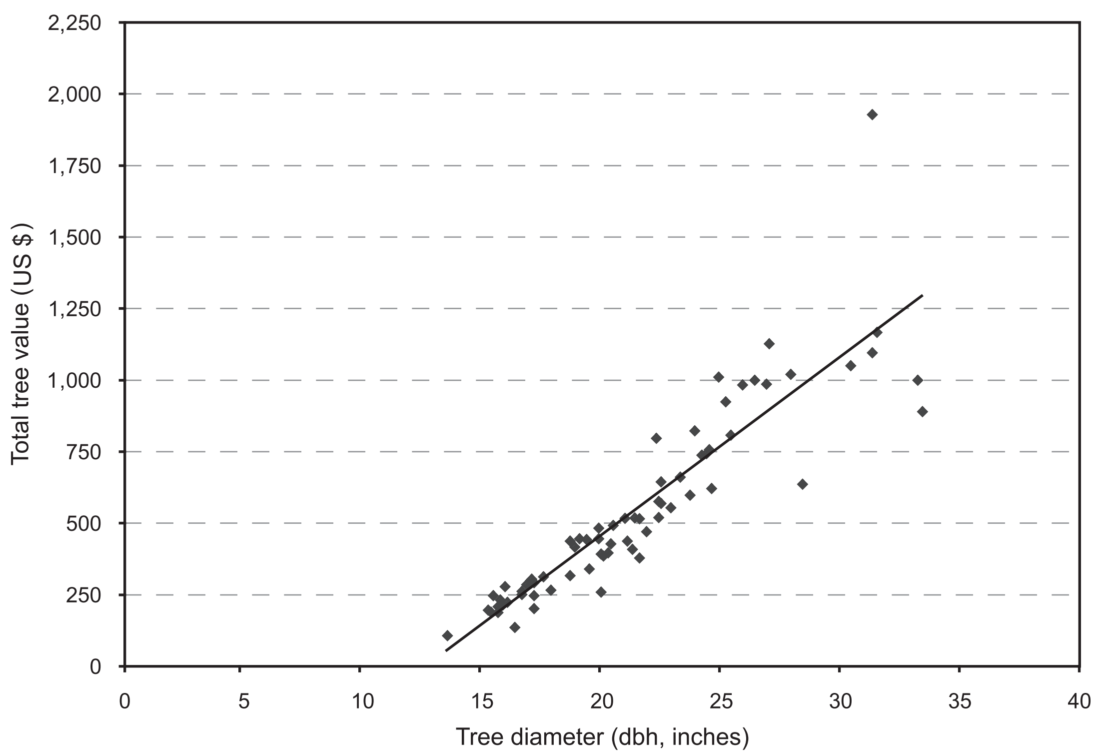

Figure 5—Observed and predicted regression line of total tree value for tree grade 1 northern red oak in relation to tree diameter (d.b.h.). Value is the sum of revenue from veneer, lumber, cants and for each log.

With the large premiums that are paid for veneer logs, it would seem to make economic sense to market these logs through a competitive sealed-bid process rather than saw them in the mill to produce 4-quarter (1.0-inch thickness) sawn lumber.

While this study did not evaluate yields from other than 4-quarter sawn lumber there is a premium in the marketplace for 8-, 12-, and 16-quarter sawn lumber. This is a manufacturing decision that should be evaluated to improve sawmill profitability.

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CAN SMALLER DIAMETER HARDWOOD LOGS BE PROFITABLY SAWN INTO LUMBER?

Matthew S. Scholl, Janice K. Wiedenbeck, and Paul R. Blankenhorn[1]

Abstract—With high stumpage prices, sawmills are processing an increasing number of smaller diameter hardwood logs into lumber. Most mills have little knowledge of the lumber yield, lumber grade, or cost of processing these logs into lumber. This project investigated the processing of small-diameter black cherry (*Prunus serotina* Ehrh.) logs. Every board was examined for drying-related defects and grade both before and after kiln drying. Boards were dried using first the conventional kiln drying schedule prescribed for 4/4 black cherry lumber and then one of two modified kiln schedules. Overall, the percentage of the lumber recovered from small-diameter cherry logs that was Number (No.) 2A Common or Better was less than 26 percent. After kiln drying with the conventional kiln schedule, No. 2A Common and Better recovery dropped to 23 percent. The major reasons for drop in grade after kiln drying were width reductions (caused by shrinkage) and surface checking. The first modified kiln schedule that was tested used a lower final dry bulb setting. The second of the two modified kiln schedules used both lower initial and final DB settings. The second modified black cherry kiln schedule also included the addition of an intermediate step to smooth temperature ramping in the initial stages of drying. Both black cherry modified kiln schedules were modified from the conventional kiln schedule keeping in mind the prescribed equilibrium moisture content conditions. Final grade recovery results were more favorable when the modified kiln schedules were used. The first and second black cherry kiln-schedule modifications produced 27 and 32 percent No. 2A Common and Better lumber grade yield, respectively. By tracking lumber defects and grade change before and after drying, using both conventional and modified dry kiln schedules, we can recommend a modified kiln drying schedule for lumber sawn from small-diameter black cherry logs. Assuming best-case scenario volume and grade yield results post-drying and 1st-quartile manufacturing cost performance, the potential profit that may be realized when sawing small-diameter cherry logs is estimated to be $178 per MBF of lumber produced.

INTRODUCTION

The utilization of low-grade material has been an ongoing challenge to the forest products industry. The low-grade designation often is associated with small-diameter logs. In the past, low-grade material has been used for pallet and pulp production (Luppold and Bumgardner 2003). Today, low-grade material also is being utilized in engineered wood products. Across the major hardwood region of the United States, hardwood stems less than 11 inches diameter at breast height (dbh) account for 32 to 42 percent of the growing stock volume and 93 to 95 percent of the total number of live stems (Bumgardner and others 2001).

Recently, trends in forestry and public attitudes surrounding land-use have brought about changes in how the forests of Pennsylvania are utilized. Increasing stumpage prices and the decrease in average sawlog diameter/size have forced sawmills to process smaller diameter logs. Sawmill managers in Pennsylvania report that the average sawlog size has been diminishing since the mid-1990s.

Increased handling requirements, greater amounts of low quality lumber, and drying induced defects are problematic when processing most types of low-grade logs, including logs that are low-grade by virtue of small diameter. Only minimal information exists addressing the feasibility of sawing and drying small-diameter hardwood logs into factory-grade lumber for appearance markets.

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Log diameter strongly influences both volume recovery and grade recovery. For example the expected lumber volume and value from a Forest Service Grade 3, 10-inch DBH red oak tree (*Quercus rubra* L.) versus a 13-inch tree, versus a 20-inch tree is 31 board feet (BF)/$18, 67 BF/$39, and 339 BF/$208, respectively (Wiedenbeck and others 2004). Grade and volume studies on small-diameter logs have been conducted in the past but only on a small scale. Emanuel (1983) examined red oak, hard maple, and yellow-poplar (*Liriodendron tulipifera* L.) logs removed from a thinning. Twenty small-diameter red oak logs yielded 30 percent No. 1 Common and Better lumber, 20 small diameter hard maple logs yielded 19 percent No. 1 Common and Better lumber, and 20 small-diameter yellow poplar logs yielded 15 percent No. 1 Common and Better lumber (Emanuel 1983).

Hanks (1976) developed the system for using Forest Service tree grades to predict lumber grade and volume yields. One portion of his experiment that is pertinent to this research project is his research done on Grade 3 trees. Grade 3 trees must have a minimum diameter of 8-in. at the top of a cutting section (Hanks 1976). Seventy-one Grade 3 black cherry trees yielded an average 55 BF of No. 1 Common and Better lumber out of an average total lumber yield of 143 BF of lumber (39 percent) (Hanks 1976). Prediction equations of volume and grade yield for black cherry trees having dbh's of 14 inches or less and yielding an average of 1-½ 8-foot logs per tree, tell us that the No. 1 Common and Better grade yield expected from these smaller diameter trees is only 32 percent—7 percent lower than for all sizes of Grade 3 logs. The expected No. 2 Common and Better yield for these smaller Grade 3 trees is 65 percent. The average volume of lumber recovered from these trees is 78 BF per tree (adapted from Hanks 1976).

OBJECTIVES

The goal of this research project was to better understand the processing of small-diameter logs from bucking through kiln drying. Three species were examined: black cherry, sugar maple (*Acer saccharum* Marsh.), and red oak. This section of the project focused on black cherry, a species of great importance to Pennsylvania's economy. The associated research objectives are:

- Find the optimum kiln drying schedule for small-diameter black cherry logs to minimize drying defects.
- Determine why and where in the log lumber drying defects were developed and search for correlations.
- Estimate, based on lumber grade and volume recoveries, the economic feasibility of sawing small-diameter hardwood logs into grade lumber.

PROCEDURES

This project focuses on the drying of 4/4-thickness lumber sawn from small-diameter logs. Small-diameter (less than 11-inches) black cherry logs were sawn utilizing two sawing patterns: live sawing and grade sawing. The patterns were used to the same extent for each group of logs studied (a future study will analyze the effect of sawing pattern on recovery). The lumber produced from the small-diameter logs were dried using either a conventional kiln schedule or one of two experimental kiln schedules. The experimental kiln schedules were modified from the conventional kiln schedule for each species. Each experimental kiln schedule was then compared to the conventional kiln schedule to reveal which drying schedule produced the lowest amount of drying degrade and highest potential value return when drying smaller diameter logs.

Log Handling

Logs were obtained from three sawmills in Pennsylvania (fig. 1). Immediately after the logs were unloaded they were end sealed with wax to prevent end checking and excess moisture loss.

The delivered logs varied in length from 8 to 23 feet; all were bucked to a length of 8 feet 4 inches. In addition, a thin cookie was cut from each log to determine age. Following bucking, logs were numbered with a red crayon. When stems yielded two 8-foot 4-inch logs, they were labeled with an "A" or "B" to designate the log's position from within the tree.

Figure 1—Cherry logs after delivery.

Sawing Procedures
Log breakdown was accomplished using a portable bandmill. After each log was loaded on the mill's infeed deck, the small-end diameter was measured and recorded along with the log number. Scale deductions, log grade, and notes on log form and quality characteristics were recorded. All four faces of the log were assessed.

Two sawing patterns were used throughout this experiment grade sawing and live sawing. In grade sawing, the log was rotated each time a higher grade board was likely to be obtained by sawing the opposite or an adjacent face. In live sawing, the best quality face was broken down until growth stresses in the tree intensified at which point the opening face (opposite the best face) was turned into the sawing plane and the remainder of the log was sawn in to boards. As each log was sawn the resulting boards were numbered and their location in the log was drawn on a data collection sheet.

The radial position from which each board was sawn was noted in terms of quality zones: (1) core (log center with radius equal to one-fifth the log's diameter), (2) inner (with a radius that is located midway between the core zone's radius and the radius of the log), and (3) outer (encompassing the outermost section of the log-end) (Rast and others 1973). Quality zones were spray painted on the log ends (fig. 2). Edging was conducted using a bull edger (selective edger). The edger had one fixed saw with a second maneuverable saw blade. Boards with wane that limited the grade of the board were edged.

Pre-Drying Inspection and Grading
After edging, a pre-drying inspection of the boards was performed. The boards were visually scanned for seven types of defects (end checks, surface checks, shake, bow, twist, crook, and cup). Each defect was physically noted on the board by marking a symbol on the board's end using colored crayons. Quality zone designations were captured such that boards were assigned to only one quality zone–the one that was dominant based on the paint marks that showed on the end of the board.

Before drying, each board was graded using National Hardwood Lumber Association rules (1998). The initial pre-drying grade and surface measure were marked on the board using a green crayon representing the green grade and green surface measure. The cuttings that were used to calculate the green grade were outlined.

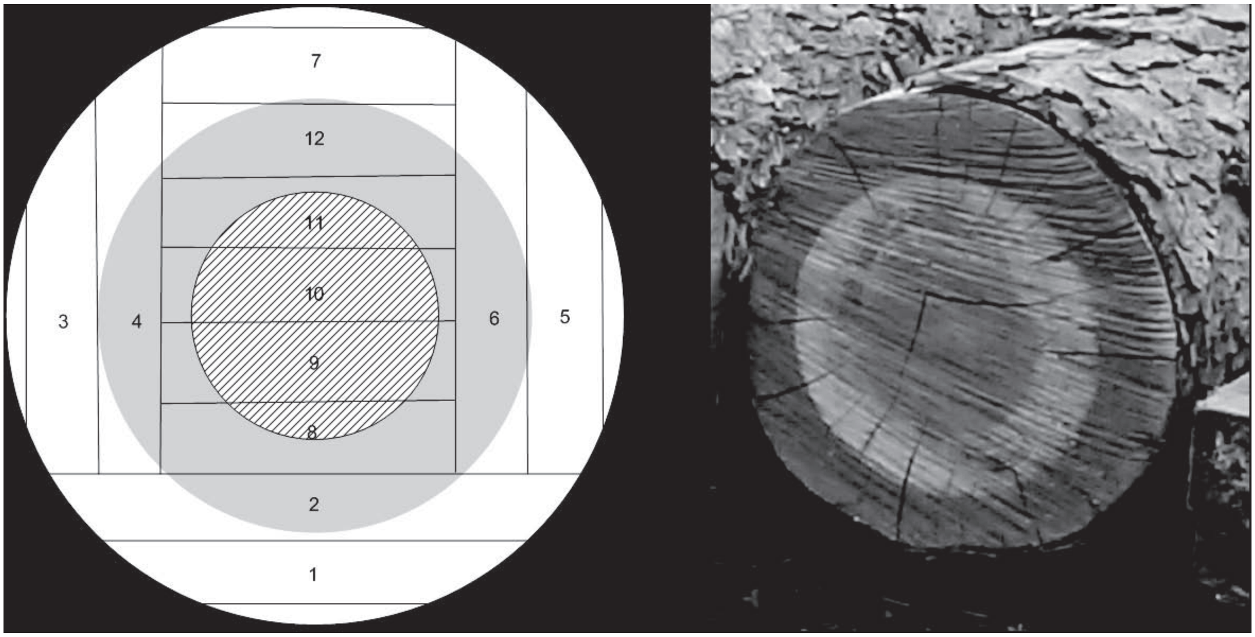

Figure 2—The left figure shows board positioning and log quality zones (outer quality zone—white, inner quality zone—gray, and core center—slashes); the right figure shows the quality zone markings applied to log ends (outer quality zone, inner quality zone, core center) (Rast and others 1973).

Kiln Schedules and Procedures

A conventional kiln schedule along with two experimental kiln schedules were used for drying the lumber sawn from the small-diameter logs. The first experimental schedule lowers the final dry bulb (DB) setting, while the second schedule decreases the initial and final DB setting. For example the standard kiln schedule for black cherry (Simpson 1991) begins with a DB setting of 130 °F and a wet bulb (WB) depression of 7 °F (EMC 14.0 percent). The first modified kiln schedule (MOD1) decreases the final DB temperature by 20 °F. It is hypothesized that the lower final DB temperature will slow the rate of warp in the lumber during the final stages of drying that is caused by premature release of drying stresses. The second modified kiln schedule (MOD2) alters the conventional kiln schedule in three ways: (1) lower initial DB temperature, (2) lower final DB temperature, and (3) addition of an intermediate step change. The additional step change was required to gradually ramp the DB temperature from 110 to 140 °F in the third step.

Each board was hand stacked into packs that were 8 feet x 4 feet x 4.5 feet in size. The layers of boards were then separated by oak stickers (¾ inches x ¾ inches x 48 inches) to create openings for airflow beneath and above the boards. The packs were positioned on two bolsters. The kiln used in this study utilized steam heat and had a drying capacity of 1,500 BF.

Four to six kiln samples were used to track moisture loss within each kiln charge. Samples were chosen from the center of loads to avoid non-representative moisture contents. Also, samples were selected that contained a representative distribution of heartwood and sapwood. The kiln samples were end sealed to prevent moisture loss in the longitudinal direction then built into the stickered charge.

Post-Drying Inspection and Grading

After drying was complete, the data marked with crayon on the ends of the boards related to pre-drying defects and quality zones was tallied. The post-drying inspection replicated the procedures used for the initial inspection but also included: (1) measurement of slope of grain and warp (using taper gauge), (2) examination of the cuttings used previously to calculate green grade, and (3) verification as to whether pith was present or absent in the board. The same surface measurement used to calculate the green grade was used in determining the dry lumber grade. This established a basis that allowed the inspector to determine the effects kiln drying had on the board.

Lumber Value Recovery

Black cherry lumber prices were based on the green and dry lumber pricing information in the September 7th 2005 Hardwood Market Report (2005). Dry lumber prices of $2990, $1760, $1000, $550, and $280 per MBF were used for Selects and Better, No. 1 Common, No. 2A Common, No. 3A Common, and Pallet lumber grades, respectively. In pricing the lumber, the Firsts and Seconds, F1F, and Selects lumber grades were combined into one grade group, Selects and Better. Similarly, the No. 3B Common and Below Grade lumber volumes were combined into a single grade, the Pallet grade, for pricing. The total value per thousand BF of dry lumber produced from the logs was calculated for each charge.

Statistical Methods

The principal statistical procedure used was binary logistic regression for categorical data. Both the predictor variable (kiln schedule), and the response variable (presence/absence of drying defect) are categorical variables. Logistic regression allows for a discrete outcome from a set of variables, which may be continuous, discrete or mixed. In binary logistic regression there are only two outcomes. The outcomes for this experiment were "1" and "0." A "1"indicated that the board had a defect and a "0" was assigned to those boards that lacked a particular defect. The most pertinent piece of information provided by binary logistic regression in this research was the odds ratio. The odds ratio is the increase (or decrease if value is less than 1) in odds that a defect will occur in a treatment when compared to the control. This allows us to compare the occurrence of drying degrade for the modified (treatment) kiln schedules with the amounts for the conventional kiln schedule (control).

RESULTS AND DISCUSSION

In the grade recovery study we examined the numbers, locations, and effects of drying related defects sawn from small-diameter hardwood logs. Black cherry logs were sawn into lumber, evaluated, dried, and reevaluated. Three dry kiln schedules were used for each species: (1) the conventional kiln schedule (CONV), (2) modified schedule #1 (MOD1), and (3) modified schedule #2 (MOD2). Modified kiln schedules are shown along with the conventional schedules in figure 3.

Grade Study

The black cherry grade study evaluated the lumber recovery differences among five kiln charges of lumber. The first three charges were dried using the conventional kiln schedule (T8-B4) from the Dry Kiln Operator's Manual (Simpson 1991). The remaining two kiln charges were dried using modified kiln schedules. Based on pre-kiln drying volume the entire black cherry grade study consisted of 202, 8-foot logs from which were sawn 4,601 BF of lumber (1,281 boards). The average age of the logs sawn in the black cherry grade study was 61 years. The distribution of log diameters ranged from 6 to 13 inches; 9-inch diameter logs (small end, inside bark) made up 37 percent, 10-inch logs comprised 30 percent, and 8-inch logs constituted 16 percent of the log sample. Five percent of the logs were less than 8 inches in diameter, 10 percent were 11 inches, and only 3 logs measured 12 or 13 inches on the small end.

Both the median and mean small-end (scaling) diameters for the cherry logs were equal to 9 inches. The log grade distribution of the sample was: 6 Factory Grade #2, 166 Factory Grade #3 (82 percent), and 30 Cull (logs that were unable to make a factory grade) logs. The three kiln charges dried using the CONV kiln schedule, Cherry #1, #2, and #3, were comprised of 769 bf (221 boards sawn from 34 logs), 976 BF (288 boards from 44 logs), and 1,056 BF (276 boards from 43 logs) of lumber, respectively. The fourth cherry charge (Cherry #4), dried using MOD1 (fig. 3), was comprised of 927 BF (254 boards) sawn from 40 logs. The fifth black cherry kiln charge (Cherry #5), dried using the second modified schedule, MOD2, consisted of 873 BF of lumber (242 boards) sawn from 41 logs.

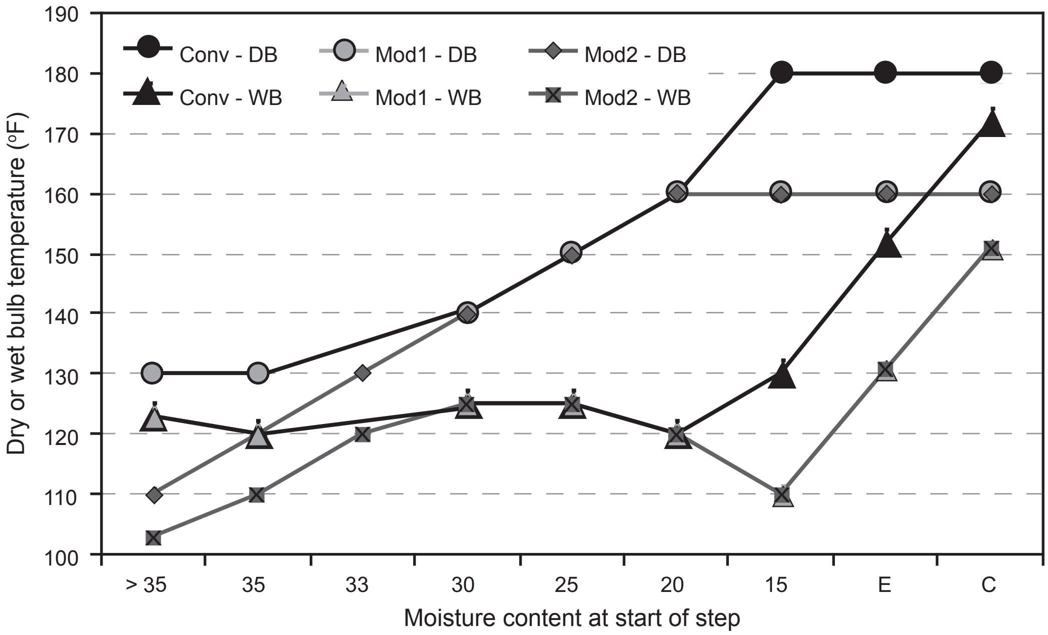

Figure 3—Black cherry kiln schedules used to dry lumber sawn from small-diameter trees to show the wet bulb (WB) and dry bulb (DB) temperature changes for the conventional schedule (Simpson 1991).

The lumber volume recovery results for the five kiln charges indicate that the differences between logs and sawing efficiencies used in producing the lumber for the different kiln drying treatments were minimal. Average Doyle overrun levels [(BF lumber ÷ BF logs)-1x100 percent] for the five groups of lumber were: 81, 77, 96, 85, and 70 percent for Cherry #1 through #5, respectively. The lumber groups used in testing the CONV schedule—Cherry #1, #2, and #3—produced the third, fourth, and first highest volume recoveries, respectively, while the MOD1 and MOD2 groups had the second highest and lowest recoveries. The average footage of lumber produced per log was 23 BF for Cherry #1, #2, #3, and #4 but only 21 BF for Cherry #5. This recovery level is less than 50 percent the level predicted by Hanks (1976) for logs bucked from smaller diameter cherry trees. Hanks' numbers were based on regression equations which were based on a substantially smaller set of small-diameter cherry logs than was used in this study.

Defect comparison by kiln schedule—Defect evaluation focused on seven drying related defects: end checks, surface checks, shake, twist, bow, cup, and crook. For the three charges run using the conventional kiln schedule combined results are given (table 1).

Using the CONV kiln schedule, all drying-related defects increased except for bow, the incidence of which decreased by nearly 25 percent. As the boards were sawn from the log or cant, drying stresses on the jacket boards (outside boards) caused these boards to bow away from the pith. The reduction in bow seen after kiln drying may be due to stress relief during the conditioning phase of kiln drying. There was only a minimal increase in the amount of end checks post-drying; this can be attributed to the application of end sealer to logs as soon as they arrived to the logyard. A substantial increase in surface checking may be the result of the high number of boards containing pith material since checks are often associated with the wood proximal to the pith.

The defect results for MOD1 test boards showed a similar reduction in bow after kiln drying as noted for boards dried under the CONV schedule. Compared to the CONV boards, end checking was reduced using MOD1. Also, the number of boards with crook was lower after drying than before. The decline in the number of boards observed to have crook may be related to the reduction in the final DB temperature. The amount of twist also decreased substantially in comparison to the CONV charges: CONV charges

Table 1—Percentage of black cherry boards possessing defect before kiln drying and the change in percentage seen upon reinspection after drying for three kiln schedules; entries in bold text are particularly notable

Dry kiln treatment	Defect data	End checks	Surface checks	Shake	Twist	Bow	Cup	Crook
		- - - - - - - - - - -	- - - - - -	- - - -	*percent*	- - - - - -	- - - -	- - - - - -
CONV	Pre-drying	67.0	25.2	4.0	11.3	46.1	0.5	37.4
	Kiln-induced	4.2	18.5	4.8	71.8	-24.7	8.0	6.4
MOD1	Pre-drying	69.3	25.2	2.0	32.3	55.1	0.4	38.6
	Kiln-induced	**-3.1**	19.3	2.0	**48.4**	-37.4	9.5	**-2.4**
MOD2	Pre-drying	61.2	26.5	5.8	33.9	64.1	0.4	43.8
	Kiln-induced	**-2.5**	**12.0**	2.5	**53.7**	**-50.4**	11.2	6.6

CONV = conventional kiln schedule; MOD1 = modified kiln schedule # 1; MOD2 = modified kiln schedule # 2.

produced a 72 percent increase in boards with twist while the MOD1 charge produced only a 48 percent increase–an improvement of 24 percent.

Defect inspections on MOD2 boards revealed that all drying-related defect types increased except for end checking and bow. Again, the percentage of boards with end checks and bow dropped after kiln drying using the MOD2 schedule. The reduction in the incidence of bow was greatest for MOD2 (-50.4 percent) compared to MOD1 (-37.4 percent) and CONV (-24.7 percent). Using the MOD2 schedule, the percentage of boards affected by kiln-induced surface checking was smaller (12 percent) than for the CONV kiln schedule (18 percent) and the MOD1 schedule (19 percent). The reduction in surface checking under the MOD2 schedule may be due to the lower initial DB temperatures. The reduction in crook noted for boards dried using MOD1 was not observed in the MOD2 results.

In summary, the occurrence of three of the five types of warp was reduced using MOD2 compared to CONV and all four types of warp (all except cup) were reduced using MOD1. The MOD2 schedule resulted in the smallest increase in kiln-induced surface checks while the MOD1 schedule resulted in the greatest improvement in end checking and crook among the three kiln schedules.

Odds ratios for black cherry grade study—The odds ratio is the increase or decrease (if less than one) in the odds of a particular outcome happening in a treatment group (black cherry modified kiln schedule) when compared to a control group (CONV schedule). For example an odds ratio of 1.45 means that it is 1.45 times more likely for a drying related defect to occur in a specific modified kiln schedule when compared to the control schedule. Conversely, if an odds ratio is equal to 0.45 there is a reduction of 55 percent in the likelihood of occurrence of a defect dried with a modified kiln schedule. The odds ratios for the grade study, with CONV serving as the yardstick for comparison (control), are given in table 2. The odds ratios provide a statistically-based, more easily interpreted way of looking at the defect differences.

Pre- versus post-drying lumber grade—National Hardwood Lumber Association grading rules (1998) were applied to each board before and after drying. The green grade of the board was compared to its dry grade. If a drop in grade was observed, the reason for the drop was recorded. Table 3 presents the pre- and post-drying lumber grade distribution for the CONV, MOD1, and MOD2 treatments in the cherry grade study.

The percentages of boards that graded as No. 1 Common and Better after kiln drying were 6, 9, and 9 percent for the CONV, MOD1, and MOD2 groups, respectively. This is much lower than the estimated

Table 2—Black cherry grade study odds ratios for the relative likelihood of occurrence of drying-related defects for two modified kiln schedules as compared to the conventional schedule

Drying defect	MOD1	MOD2
End checks	0.45	0.47
Surface checks	0.94	0.60
Shake	0.41	0.52
Twist	0.39	0.47
Bow	0.27	0.28
Cup	1.15	1.33
Crook	0.74	1.34

MOD1 = modified kiln schedule # 1; MOD2 = modified kiln schedule # 2.

Table 3—Pre- and post-drying grade distribution for lumber dried in three kiln charges that followed the conventional kiln schedule for black cherry lumber (T8-B4; CONV) and two modified kiln charges (MOD1 and MOD2, fig. 3)

	CONV		MOD1		MOD2	
Lumber grade	Pre-drying	Post-drying	Pre-drying	Post-drying	Pre-drying	Post-drying
	percent					
Selects and better	2.0	1.1	5.1	4.7	4.1	4.1
No. 1 common	7.1	4.8	5.9	4.7	7.4	5.0
No. 2A common	25.1	17.3	24.8	17.7	31.4	23.1
No. 2A common and better	34.2	23.2	35.8	27.1	42.9	32.2
No. 3A common	34.8	28.9	43.7	39.4	35.9	35.1
No. 3B common	21.7	34.8	20.5	33.5	20.7	31.8
Below grade	9.3	13.1	0	0	0.4	0.8
No. 1 common and better grade reduction	3.2		1.6		2.4	
No. 2 common and better grade reduction	11.0		8.7		10.7	
No. 3A common and below grade increase	11.0		8.7		10.7	

CONV = conventional kiln schedule; MOD1 = modified kiln schedule # 1; MOD2 = modified kiln schedule # 2.

32 percent No. 1 Common and Better grade yield predicted by Hanks (1976). While Emanuel (1983) did not study small diameter black cherry logs, the No. 1 Common and Better grade yields that he found for red oak, hard maple, and yellow-poplar also were higher (30 percent, 19 percent, and 15 percent). Hanks' study estimated the No. 2 Common and Better yield for small-diameter (≤14 inches) black cherry to be 65 percent while the best No. 2 Common and Better result achieved in this study was only 32 percent (MOD2, table 3).

For all three kiln schedule treatments there was a reduction in the percentage of boards that graded No. 1 Common and Better and an increase in the percentage of boards that graded No. 3A Common and Below after kiln drying. The reduction in higher grade boards was greatest for the CONV treatment as was the increase in the percentage of lower grade boards. The MOD1 schedule treatment produced slightly better results than the MOD2 treatment, which produced slightly better results than the CONV treatment. Using the CONV schedule, 30 percent of the boards suffered a drop in grade. Using the MOD1 and MOD2 schedules the percentages of boards that dropped in grade after drying were somewhat lower – 20 and 22 percent, respectively.

The reason for the loss in grade after drying was most frequently due to width-wise shrinkage (table 4). This was true for all three drying treatments. In some cases the width-wise shrinkage produced a board that was too narrow to make the grade (minimum width for Common grade boards is 3 inches). More often the width-wise shrinkage led to the reduction in width of cuttings such that the clear areas between defects or between a defect and the edge became too narrow to meet minimum width requirements. The typical amount of shrinkage in width that occurred in going from the green to kiln-dried state was 0.25 inch.

Surface checks occurring in the region of the pith were the second major cause for boards dropping in grade. NHLA grading rules (1998) allow for pith to be included in No. 2A Common and lower grade boards (with limitations). When boards with pith are kiln-dried, a large percentage develops checks and cup along the pith. Clear areas used to meet grade requirements when the boards were graded in the

Table 4—Reason for drop in lumber grade for black cherry lumber dried using three kiln schedules

Reason for drop in grade	Boards that dropped in grade		
	CONV	MOD1	MOD2
	- - - - - - - *percent* - - - - - - -		
Surface checking	10	18	11
Surface checking with pith present	24	23	22
End checking	3	6	2
Shrinkage (width)	54	53	61
Shrinkage (crook)	3	0	0
Shrinkage (standard surface thickness is not met)	3	0	0
Shake	3	0	4
Portion of all cherry boards that lost grade when dried	30	20	22

CONV = conventional kiln schedule; MOD1 = modified kiln schedule # 1;
MOD2 = modified kiln schedule # 2.

green condition often were of insufficient quality after drying to be included and therefore the number of available clear-face cutting units dropped as did the grade.

By tracking the location in the log from which each board was sawn we were able to determine which areas of the log yielded the highest grades of lumber. In addition, we were able to examine which areas of the log produced lumber that maintained grade after drying and which were more susceptible to drops in grade. Log quality zones (Rast and others 1973) were used to capture this information (fig. 2). Table 5 shows the percentage of all lumber recovered from each quality-zone for each kiln treatment. It also shows the grade change trends for the three quality zones. For the CONV group, only data collected from Cherry #1 and #3 were used for this analysis. Cherry #2 was omitted because of excessive surface checking in boards from the outer-quality zone due to prolonged exposure to the elements before sawing.

Before drying, 43, 56, and 79 percent of the CONV lumber recovered from the outer, inner, and core zones, respectively, was low grade (No. 3AC and Below; table 5). This same low-grade distribution trend was evident for the green MOD1 and MOD2 lumber. After drying, the percentage of low-grade lumber increased by variable amounts within the different quality zones and kiln schedule treatments. The greatest increase in the percentage of low-grade lumber for those boards sawn from the outer quality zone occurred under the CONV treatment. For the core center, the largest percentage increase in low-grade lumber also was recorded for the CONV kiln schedule. In contrast, the MOD1 schedule produced the smallest increase in the percentage of low-grade lumber for the outer and inner quality zones. The best grade results for boards sawn from the core centers of the logs were obtained under the MOD2 schedule. However, at the same time the MOD2 schedule produced the greatest increase in low-grade lumber for lumber sawn from the inner quality zone.

Economic Feasibility

The value per thousand BF (MBF) for the black cherry lumber sawn and dried in the five kiln charges (3 treatment groups) was $550, $698, $755, $784, and $787 for Cherry #1 through Cherry #5, respectively. The mean value for the three CONV groups (Cherry #1-#3) was $668 per MBF. The differences between the CONV mean value and the values realized for the MOD1 (Cherry #4) and MOD2 (Cherry #5) schedules appear to be meaningful (without replicas on MOD1 and MOD2 significance cannot be

Table 5—Percentage of black cherry lumber that was extracted from each of the three log quality zones for the three dry kiln schedule treatments and grade change by quality zone, after drying; entries in bold text are particularly notable

	CONV group			MOD1 group			MOD2 group		
	Quality zone			Quality zone			Quality zone		
	Outer	Inner	Core	Outer	Inner	Core	Outer	Inner	Core
	percent								
Origin of lumber	42.0	39.6	18.3	29.9	37.1	33.1	20.7	42.6	36.8
Lumber from zone grading 3AC and below before drying	43.1	56.3	79.2	55.2	56.3	81.0	38.2	52.3	73.1
Lumber from zone grading 3AC and below after drying	59.0	66.2	95.6	61.9	65.8	90.3	49.8	66.9	78.5
Increase in low-grade lumber	**15.9**	9.9	**16.4**	6.7	9.5	9.3	11.6	**14.6**	5.4

CONV = conventional kiln schedule; MOD1 = modified kiln schedule # 1; MOD2 = modified kiln schedule # 2.

established). The high degree of variability between the values for the three CONV tests leaves some doubt as to whether the MOD1 and MOD2 schedules produce greater revenues.

Our estimate of the margin between revenues and manufacturing costs (sawmill and dry kiln) is based on the best-case scenario in which operating costs could be as low as $150 per MBF for sawing and $100 per MBF for drying. In a typical hardwood sawmill operation, an additional $100 per MBF must be deducted from revenue to cover the indirect costs associated with sawmill overhead expenses such as depreciation, selling, administrative expenses, and the like. Thus, before any adjustments are made to account for additional handling costs and additional time in the dry kiln associated with the modified kiln schedules, the dry lumber revenue minus lumber manufacturing costs leaves a margin of only $437 per MBF of lumber (best-case scenario; MOD2) to cover the cost of the raw material (stumpage) and procurement (bucking/hauling) expenses with the remainder being profit. For the case of logs that are purchased upon delivery at the mill (gatewood), this margin represents the available amount for purchasing the delivered logs (plus profit).

Since we are assuming high overrun (75 percent) given the case of small-diameter logs, about 571 BF of logs are required to generate 1,000 BF of lumber and the associated $437 margin. This means that $437 is available (best-case scenario) for purchasing 571 BF of logs (volume required to manufacture 1,000 BF lumber) delivered to the sawmill (stumpage price + procurement costs) if the sawmill is to breakeven in sawing these logs.

The average price paid by sawmills in western Pennsylvania for low-grade (Grade 3) cherry logs delivered to the sawmill was $236 per MBF (Doyle) during the 1st Quarter of 2004 (Pennsylvania Woodlands 2004). Thus, to purchase only 571 BF of low-grade cherry logs would cost about $135. This leaves a potential profit of $302 per MBF of lumber ($437 - $135) given the absolute best case scenario.

Log procurement, lumber manufacturing, and drying costs (due to longer kiln schedules) all will be higher than the best-case scenario when manufacturing lumber from small-diameter logs. Based on our experiences, inflating "best-case" costs by 35 percent is a conservative adjustment to use. Applying this inflation factor to the sum total of estimated sawmill operating, drying, and overhead costs increases those costs from $350 to $473 per MBF lumber shrinking the potential profit per MBF of lumber sawn to $178.

This $178 per MBF margin is less than the difference between the best-case value recovery result (MOD2) and the worst-case result (CONV-Cherry #1)—$237 per MBF lumber. This indicates how important the drying schedule is when drying lumber sawn from small-diameter logs.

CONCLUSIONS

Small-diameter black cherry logs less than or equal to 14 inches in diameter produce only 50 percent the volume expected from regression-based estimates made by Hanks (1976). The high-grade lumber recovery (No. 1 Common and Better) rate is about 65 percent lower than predicted by Hanks. The dry kiln schedule modification in which the initial dry-bulb temperature was dropped by 20 degrees coompared to the conventional black cherry schedule had the smallest negative impact on lumber grade. When best-case scenario revenues and costs are entered into an economic feasibility assessment, it appears that a small profit might be achieved when processing small-diameter cherry logs into lumber. Profitability is dependent on the quality of the lumber drying results that are realized.

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USING EXTERNAL HIGH-RESOLUTION LOG SCANNING TO DETERMINE INTERNAL DEFECT CHARACTERISTICS

Ed Thomas, Liya Thomas, Clifford Shaffer, and Lamine Mili[1]

Abstract—The location, type, and severity of external defects on hardwood logs and stems are the primary indicators of overall log quality and value. External defects provide clues about internal log characteristics. More than 1,000 yellow-poplar defect samples have been collected to establish an external/internal defect databank. There are strong correlations among external indicators and internal features have been discovered. The ability to determine the location and characteristics of internal log defects in real-time should improve the lumber production dramatically with respect to quality and quantity. A high-resolution laser log scanner was used to scan 162 red oak and yellow-poplar logs. The processed laser images show most bark texture features and surface characteristics of the original log or stem. Defects with height differentiation from the background log surface are distinguished using the contour levels of a residual image. Simple shape definition rules combined with the height map allows detection of the most severe defects.

INTRODUCTION

Traditionally, before a hardwood log is processed it undergoes a subjective (visual) assessment, typically by a mill operator. The difference between high and low quality logs is determined by defect type, frequency, size, and location. It is difficult to accurately and rapidly detect and measure defects, either mechanically or manually (Tian and Murphy 1997). For every surface indicator there is usually an associated internal defect. External defect indicators are bumps, splits, holes, and circular distortions in the bark pattern. Bumps usually indicate overgrown knots, branches, or wounds. Some bumps have a cavity or hole in the middle, indicating that the overgrown material has decay or is rotten. Circular distortions, or rings around a central flattened area, indicate a branch that was overgrown many years earlier. Surface defects progress from a pruned or broken branch to an overgrown knot characterized by a significant bump and then to a rotten knot or a distortion defect. For some classes of defects, it is possible to accurately predict internal features based on external characteristics.

Studies have demonstrated that the use of external or internal defect data improves cutting strategies that optimize log recovery or yield, i.e., preserving the largest possible area of clear wood on a board face (Steele and others 1994). The value of the lumber that can be recovered depends on the presence and location of defects. This is especially true for hardwood logs. In the production of hardwood lumber, boards are sawn to fixed thicknesses and random widths. The presence and placement of defects on the boards affect board quality and value, so much attention is focused on log surface defects during processing.

Several scanning and optimization systems are available that aid in the sawing of logs into lumber. Two types of defect detection are used on hardwood logs: internal and external. Various internal defect inspection methods have been proposed in the literature based on X-ray/CT (Computer Tomography), X-ray tomosynthesis, MRI (magnetic resonance imaging), microwave scanning, ultrasound, and enhanced pattern recognition of regular X-ray images (Guddanti and Chang 1998, Schmoldt 1996, Wagner and others 1989, Zhu and others 1991). CT and MRI systems provide excellent internal images of logs, but image acquisition is slow and expensive and variable moisture content and log size can present problems

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to the CT scanning device (Bhandakar and others 1999). Currently, there is no known commercial installation of these methods.

Laser-line scanners are commonly used in sawmills to gather information on external log characteristics, e.g., diameter, taper, curvature, and length (Samson 1993). Optimization systems use the laser-profile information to better position the log on the carriage and improve the sawyer's decision-making ability. These systems typically were developed for softwood, e.g., pine, spruce, fir log processing. They are becoming increasingly commonplace in hardwood mills as well.

Our research takes the three-dimensional log surface image and processes it to determine the location of the most severe external defects: overgrown knots, rotten knots, holes/gouges, and removed branches. These types of defects usually are associated with a significant surface rise or depression depending on the defect type. The image is processed using a robust statistical approach to generate a height map of the log. Defects are characterized and located by a height change from the surrounding log area. Many internal aspects of the defect can be predicted. This system is currently under development and is expected to permit an inexpensive, automated approach to determining interior defect information.

THE INTERNAL/EXTERNAL DEFECT RELATIONSHIP

The Logger Databank is an unpublished USDA Forest Service database containing more than 20,000 logs of various hardwood species collected over a 40 year period by the Forest Products Laboratory and Northeastern Research Station. The databank contains size and location information for all side and end defect indicators. We used the databank to construct a random sample of approximately 33 percent of the total yellow-poplar (*Tulipifera liriodendron*) defect population. For log grades 1, 2, and 3, 80 percent of all defects are in nine defect types. According to the log grading rules the following log surface abnormalities are serious grading defects that lower quality and strength: bulges, bumps, burl, conk, holes, knots (sound, unsound, and overgrown), insect damage, bark distortions, pin, shot, spot, and flagworm holes (Ostrander 1965). Overlaying this information with defect population data, we determined the defect types that should be sampled from the forest.

Two sites in West Virginia were selected for defect sample collection: West Virginia University Forest (WVUF) near Morgantown (elevation: 2,300 feet) and Camp Creek State Forest (CCSF) near Princeton (elevation: 2,600 feet). The two sites are separated by 220 miles. The number of defects obtained from each site by defect type is shown in table 1. In most cases, approximately equal numbers of each type of defect were obtained from each site. The exceptions are the light distortion (LD) and unsound knot (UK) defects. We did not collect LD defects from the WVUF. UK defects occured in much fewer numbers at CCSF than at WVUF. Thirty-three yellow-poplar trees were selected randomly from each site. From each tree the number of defects of each type was counted and recorded. Random numbers were used to select which defects to choose from each tree. The goal was to select three or four defects of each type available from each tree. The placement of defects on the tree often meant choosing one to the exclusion of others.

For each defect sample, the diameter of the log inside the bark, bark thickness, and ring count are recorded. An alignment groove is milled into the top of the sample to indicate orientation and to provide a measurement point for calculating the penetration angle of the defect. Next, each sample was sliced into 1-inch-thick slabs. On the surface and for each slab the defect width, length, and distance from defect center to the bottom center of the alignment groove are measured as is the height of the defect on the surface also is measured. A series of defect slabs is shown in figure 1.

Methods

Using SYSTAT (Wilkinson 1988) a series of linear regression analyses were performed on the exterior/interior data series. The independent variables included: defect surface width, surface length, surface height, diameter, height above ground, and growth rate. Although height above ground and growth rate usually would not be known when examining a given log, we included these variables to determine the

Table 1—Types and numbers of defects collected by site and overall

Defect	Location CCSF	Location WVU Forest	Total
Adventitious knot (AK)	76	76	152
Adventitious knot cluster (AKC)	59	68	127
Bump (BUMP)	3	1	4
Heavy distortion (HD)	74	58	132
Light distortion (LD)	**96**	**6**	**102**
Medium distortion (MD)	87	80	167
Overgrown knot (OK)	89	79	168
Overgrown knot cluster (OKC)	**20**	**1**	**21**
Sound knot (SK)	47	46	93
Sound knot cluster (SKC)	2	0	2
Unsound knot (UK)	**7**	**33**	**40**
Wound (WND)	14	13	27
Total	574	461	1,035

CCSF = Camp Creek State Forest; WVU Forest = West Virginia University Forest.

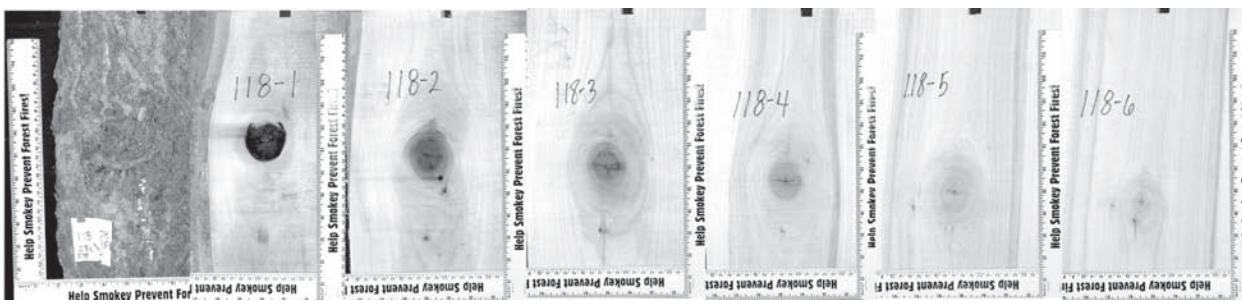

Figure 1—Photo series showing processed defect sample.

effect if any on predicting internal characteristics. The dependent variables are clear-area-above-defect (thickness of usable wood above an encapsulated defect), penetration angle, total depth, halfway in width, and length.

Each defect type was analyzed separately. A stepwise function ($p > 0.15$) was used to identify significant variables; the linear regression package was used to identify outliers. The outliers were examined to determine whether the data could be corrected (data entry error) before exclusion. In all cases, the number of outliers removed from each defect class was less than 7 percent of each defect-class population.

Results

Surface features for most defects generally are correlated with internal features. The results from the stepwise multiple linear regression analyses are presented in table 2. R^2 values were best with the most severe defect types. For sound, unsound, and overgrown knots, the models were effective in predicting total penetration depth of the defect and the cross-section dimensions at the midway penetration point. Another perhaps more important factor is the low mean absolute error (MAE). Even with slightly low R^2 values, the error is sufficiently low to allow a somewhat accurate prediction of internal features. For

Table 2—Correlation results for yellow-poplar samples by defect type

Defect	Dependent variable	Independent variables	Adjusted squared multiple R	Mean absolute error
Sound knot	Halfway-in length	Surface length, DIB	0.823	0.395 inch
	Halfway-in width	Surface length, DIB	0.811	0.242 inch
	Rake angle	Surface length, rise, DIB	0.640	10.90 degrees
	Total depth	Surface length, DIB	0.510	0.544 inch
Unsound knot	Halfway-in length	Surface length, DIB	0.672	0.527 inch
	Halfway-in width	Surface length	0.647	0.312 inch
	Rake angle	Surface length, DIB	0.341	8.118 degrees
	Total depth	Surface length, DIB	0.712	0.601 inch
Overgrown knot	Halfway-in length	Surface length, DIB	0.392	0.469 inch
	Halfway-in width	Surface length, DIB	0.482	0.240 inch
	Rake angle	Surface rise, length, DIB	0.386	8.156 degrees
	Total depth	DIB, surface width	0.810	0.366 inch
Heavy distortion	Halfway-in length	Surface width, DIB	0.438	0.319 inch
	Halfway-in width	Surface width, DIB	0.427	0.221 inch
	Rake angle	—	N.S.	—
	Total depth	DIB	0.799	0.417 inch
	Clear area above	—	N.S.	—
Medium distortion	Halfway-in length	DIB, surface width	0.336	0.257 inch
	Halfway-in width	Surface width, DIB	0.329	0.163 inch
	Rake angle	—	N.S.	—
	Total depth	Surface width, length, DIB	0.822	0.362 inch
	Clear area above	Surface rise, DIB	0.206	0.764 inch
Light distortion	Halfway-in length	—	N.S.	—
	Halfway-in width	Surface length	0.220	0.176 inch
	Rake angle	—	N.S.	—
	Total depth	DIB, surface width, length	0.775	0.334 inch
	Clear area above	—	N.S.	—

DIB = diameter inside bark; N.S. = not significant; — = not applicable.

example, the MAE for overgrown knots is 0.240 inch. Thus, the regression model predicts a size that is on average within ± 0.240 inch of the actual size. For less severe defects, heavy, medium, and light distortions, total depth continues to be highly correlated with surface features and has a low MAE. However, the halfway-in-width and length are not as strongly correlated with surface features as with the more severe defects. A low MAE likely will allow prediction of internal features sufficient for grade recovery optimization. This assumption will be tested in future research.

Adventitious knots and adventitious knot clusters also were examined, but most internal features were not strongly correlated with exterior features. The results of these analyses have been omitted from table 2. One may observe from this that the less severe the defect, the less correlation the internal features have with the external indicators. This may be due to longer encapsulation time (i.e., time since defect began to be overgrown by good wood) that has obscured external indicators.

Rake or penetration angle is not as well correlated to surface features as other internal features for all defect types. In the rake model, growth rate appeared as a significant variable. It was omitted from these results as it is not immediately discerned from a surface examination of the log. For the distortion defects, no surface variables were significantly correlated to rake. Rake angle is approximately normally distributed with a mean of 21.87 and a standard deviation of 11.03, so it may be possible to use these values for the placement of the internal defect. This possibility needs to be tested to discern how sensitive grade recovery is to the variable placement of the defect with respect to penetration angle.

LASER LOG SCANNING TO DETECT EXTERNAL DEFECTS

We used a portable demonstration laser log scanner to collect log surface data http://www.usnr.com/perceptron/products.htm. The scanner had four laser-line generator/camera units stationed at 90-degree intervals around the log's circumference. Triangulation was used to determine locations of log surface points covered by the laser line. A combination of 162 northern red oak (*Quercus rubra*) and yellow-poplar (*Tulipifera liriodendron*) logs was scanned. These are two of the most common and important commercial species in the Eastern United States. The sample of logs scanned was obtained both from the forest and from local sawmills. In general, logs from the forest are in better condition than those from sawmills due to less handling. Also, forest logs have less damage with fewer and smaller areas of missing bark than mill logs.

The log scanner recorded a laser line measurement approximately every 0.78 inch along the logs length. A transducer records the lineal position of the scanner accurate to 0.01 inch. The data set shown in figure 2 consists of 1,290 three-dimensional Cartesian coordinates in a single plane or "cross section." The average distance between points in each cross section is 0.04 inch. When a sequence of cross sections is assembled, a three-dimensional map of the log surface is obtained. Using OpenGL (a 3D programming data display environment), realistic views of the scanned log surfaces (fig. 3) are rendered that are useful for visually examining log surfaces and defect characteristics.

Data Processing

To convert the 3-D log surface data to 2-D images for processing, a reference surface must be imposed on the log data. Since logs are natural objects that are approximately circular or elliptical in cross section, we

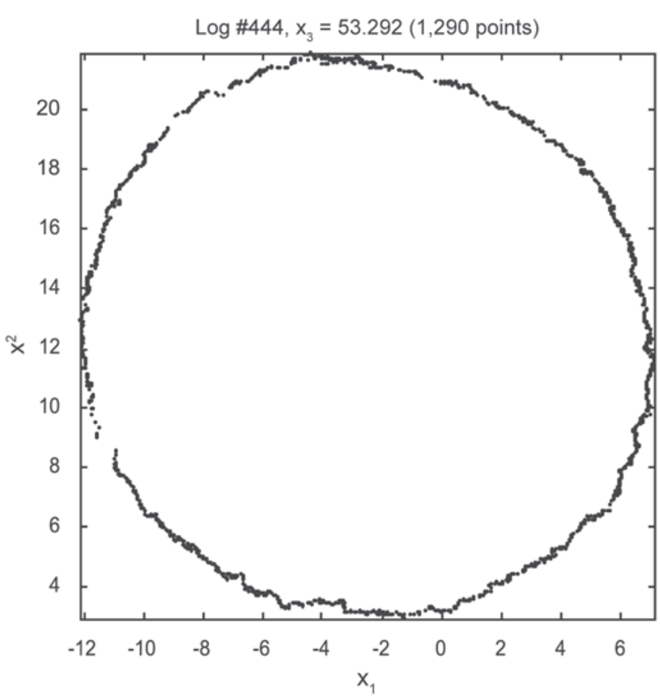

Figure 2—A data cross section representing the circumference of a log on a 2–D plane.

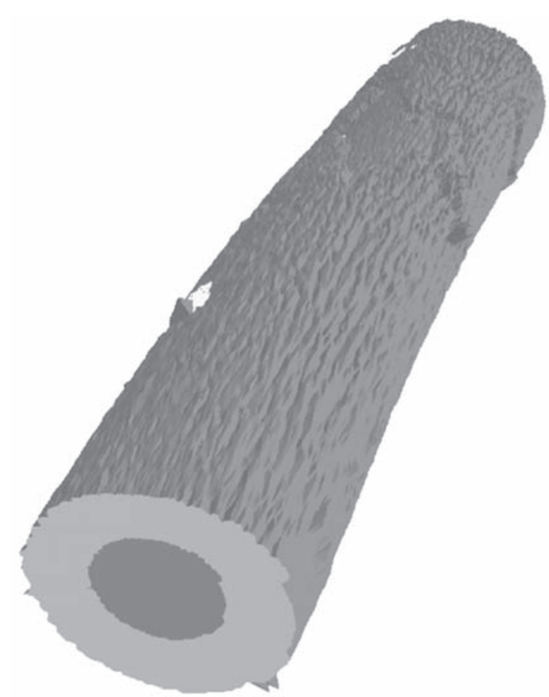

Figure 3—OpenGL rendered image of the laser scanned log data.

fit circles or ellipses to the log data, which together form a reference surface. Defects that correspond to rises or depressions on the log surface can be detected using contour levels estimated from the orthogonal distances between the reference surface and any point of the cross section.

Fitting quadratic curves (i.e., circles, ellipses) to 2-D data points is a nonlinear regression problem (Gander and others 1994). Classic least-squares fitting methods failed because the laser log cross-section data contain missing data and/or large deviant data points. In robust statistics, outliers are defined as data points that strongly deviate from the pattern formed by the majority of the measurements. The laser data sets include outliers generated by dangling loose bark, duplicate and/or missing data caused by scanner calibration errors, unwanted data from the supporting structure under the log, and missing data due to the blockage of the log by the supporting structure. To overcome the non-robustness of the least-square fitting, we resorted to the theories and methods of robust statistics (Hampel and others 1986). The nonlinear form of the circle equation prompted us to develop a new robust estimation method that is an outgrowth of the one proposed by Mili and others (1996).

Our nonlinear regression circle-fitting estimator is a generalized M-Estimator, termed GM-estimator (Thomas and others 2004). It not only filters the errors in the measurements but also the errors in the circle model that are applied to a given cross-sectional data set. For a log sample with 120 cross sections, an equal number of circles are fitted, forming a reference surface for the residual extraction. Unlike the method described in Mili and others (1996), our estimator minimizes an objective function that uses a weight function that levels off for large scaled radial distance between the associated data point and the fitted circle; it does this at every step of the iterative algorithm that solves the estimator. We tested the robustness of our estimator on real log data samples and found that the resulting fitted circles vary little among neighboring cross sections, yielding a smooth fit over the entire data of a log.

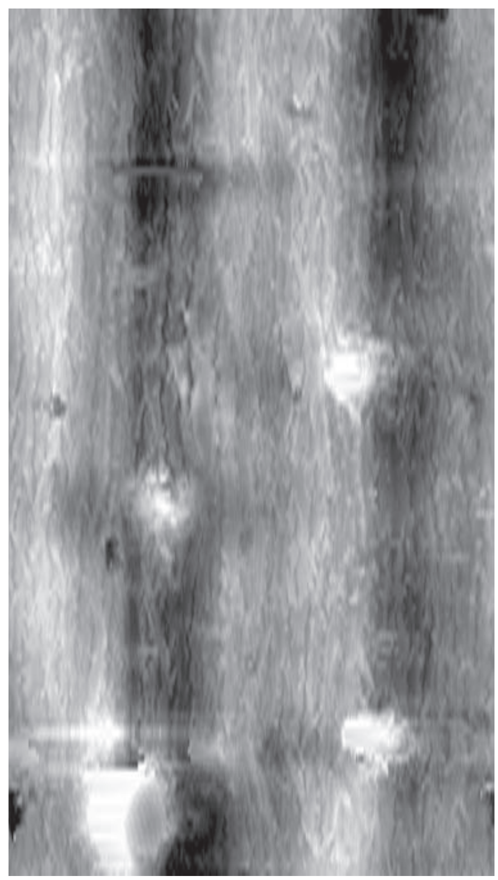

Figure 4—Radial residuals generated by the log-unrolling process presented as a gray-level image. Light pixels represent protrusions from the log surface; dark pixels represent depressions. This log is approximately 9 feet long with a diameter of 2 feet.

Defect Detection

The next step is to convert the three-dimensional, laser-scanned Cartesian coordinates into a two-dimensional, 256 gray-level image (fig. 4). In this process, the log surface is unrolled onto a 2-D coordinate space. In essence, this process creates a “skin” of the log surface representing the pattern of the log’s bark along with the bumps and bulges associated with most defects. Using the adjusted, fitted circle to each cross section, we calculate the radial distances between circle and log surface points, typically ranging from -0.5 to 0.5 inch. The radial distances are scaled to range from 0 to 255 and mapped to gray-levels to create a 2-D image. Originally the log data are not in a grid format. As a result they are processed and interpolated linearly to fill any gaps between data points.

To detect defects, we developed an expert system to accommodate the many possible defect sizes, heights, shapes, types, etc. The main method incorporated in the algorithm is identifying defect areas via a series of elimination of non-defective areas among many potential candidates. This is achieved by using measured and processed log data (converted for the defect detection algorithm), expert knowledge, and expertise in a stepwise fashion. The data resolution (0.8 inch per cross section) and the nature of external defect shapes restrict search scope in the algorithm.

Two major steps are involved in the defect detection algorithm. The first step consists of finding the most obvious defects and their external characteristics, including protrusion on surface, certain width-length ratio, area size. Shape and characteristics were obtained from the samples collected for modeling the external/internal defect relationship. Because most severe defects have a localized height change, a height analysis of the residual image provides information on the presence of severe defects. A substantial, localized, and abrupt surface rise or depression greater than 1.0 inch is almost always a defect. Since the pixel values in the gray-level image represent radial distances between the fitted circle and the log surface, the analysis is straightforward. Using the gray-level image (fig. 4) we generate a contour plot as depicted in figure 5. In the contour plot image, it is possible to discern areas containing likely defects based on height information alone. We developed an algorithm to generate the rectangles that enclose areas within a contour curve at the highest level. The areas are selected depending on their sizes, five of the six surface defects were found using this method. Figure 5 also presents a manually recorded map of the defects on the same log. The defect types represented in the map include SKs (sound knots), OKs (overgrown knots), and a gouge. A type of hole defect, a gouge is an area of missing wood usually created during felling or poor handling.

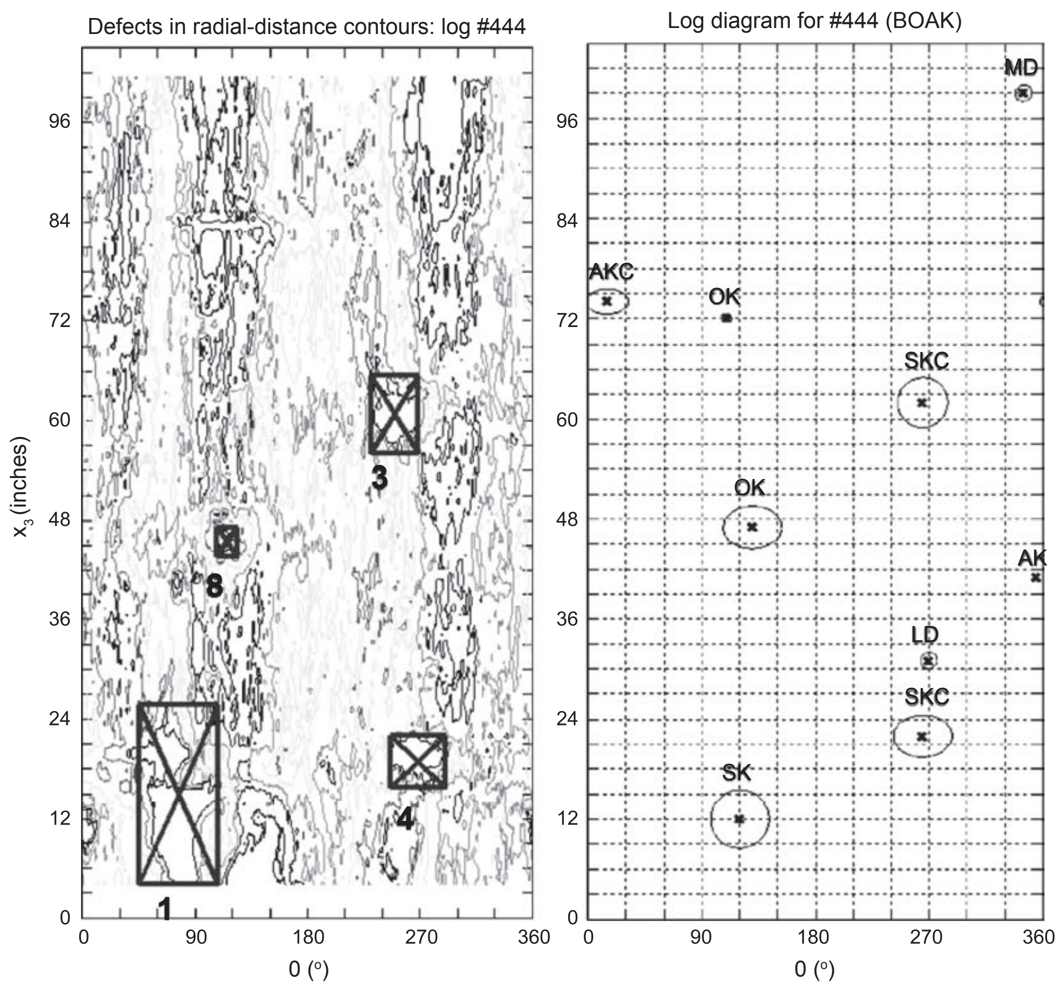

Figure 5—Left: computer generated contour plot of a log surface with the four most obvious defect areas marked with crossed rectangles labeled in the descending order of area size. Right: defect diagram illustrating the “ground truth.” Note that only five small and/or flat defects were not detected.

Certain defects, particularly sawn knots, often are partially detected in the contour because they are relatively low-lying and flat. Thus, only a corner is enclosed in the highest contour. The second step of our algorithm uses a statistical expert system to examine the area surrounding such a small region for relatively straight-line segments. If the coverage of straight-line segments is sufficient, the defect area is adjusted to cover the entire defect surface rather than just a corner.

Results

In the first step of our algorithm, the most severe and obvious defects are identified. They have a relatively significant height change on the surface (≥ 0.5 inch) and/or a relatively significant size (≥ 3 inches in diameter). We refer to such defects as "expected to be detected," while the others are termed "unexpected to be detected" (table 3). We use this grouping because the log-data resolution, 0.8 inch per cross section, is not high enough to clearly detect defects whose diameters are smaller than 3 inches. In addition, the current version of our system uses the contour image generated from the radial distances that provide a map of defect height change against the surrounding bark. For certain classes of defects, our detection algorithm has a probability of detection of 81 percent (48 of 59) for the most serious defect classes. Further, it has a 36 percent detection rate for all defects and 19 percent false detection rate (14 of 73 identified defects).

DISCUSSION

Due to the presence of extreme outliers and missing data in the laser log data, robust estimation techniques are well suited to this application. The developed programs can process an entire log-data sample by transforming the original log data set, which may contain a large number of missing and/or severe deviant data, into a sharper and cleaner image. The quality of the resulting gray-level image lays a solid foundation for the remaining defect-detection process. Contour levels derived from the residuals allowed us to detect and further narrow the potential defect areas.

The laser-log scanning system is effective in locating severe defect types. The external scanning system determines the diameter of the log at the defect and the width, length, and rise (if any) of the surface indicator. These variables are required input to the external/internal defect modeling system. We are working to combine the two systems to provide a simulated external whole log scanner that infers knowledge of internal defect structures based on external indicators. Additional enhancements to the system will require a laser scanner with an increased longitudinal resolution (0.1 inch between cross sections). Such scanners are currently available and would allow texture-based approaches to finding defects without a significant surface rise. Also we may be able to correlate aspects of the surface texture with internal features, thereby improving the model's predictive power for less severe defects.

Table 3—Statistics of the simulation of our defect detection system

	Defects to be detected						
	Expected		Unexpected		Grand total		
Defect type	Total	Detected	Total	Detected	Total	Detected	False
	- - - - - - - -	- - - - - - - -	- - - - - -	*number*	- - - - - -	- - - - - - - -	- - - - - - - -
Knobs	32	28	34	6	66	34	
Sawn knots	19	19	19	2	38	21	
Others	8	1	50	3	58	4	
All types	59	48	103	11	162	59	14

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HARDWOOD LOG MERCHANDISING AND BUCKING PRACTICES IN WEST VIRGINIA

J. Wang, S. Grushecky, Y. Li, and J. McNeel[1]

Abstract—The current state of hardwood log merchandising and bucking practices in West Virginia was examined by on-site interviews with 50 timber harvesting companies. Results indicated that sawlogs, pulpwood, OSB, peelers, veneer, and scragg were the major products hauled off the landing. The average daily production of the logging companies averaged 4.5 loads per day with more than 60 percent of the companies producing 1 to 3 loads per day. The target small end diameter of 10 to 12 inches was normally required for considering careful bucking by the mills in West Virginia and the preferred log length was 10 feet. Some incentives ranging from $10 to $50 per thousand board feet (MBF) in Doyle scale would be needed for some companies to buck logs for grade. Half of the logging companies were willing to take advantage of training for better bucking decisions, while 46 percent of the independent loggers expressed their willingness to accept assistance for sawlog bucking decisions and strategies.

INTRODUCTION

The merchandising of hardwood logs and maximizing their values and volumes is a vital component of the hardwood forest products industry. Maximizing the tree stem into an optimal array of logs requires simultaneous considerations of species, tree stem quality, tree stem dimensions, log lengths, current market prices, and other factors. Maximizing value and volume and minimizing costs have always been a high priority for the forest products industry. However, there are several obstacles that make this goal much more difficult to attain. Value loss from poor bucking was recognized in the United States as early as 1915, but was not sufficiently addressed until the 1950s (Wang and others 2004). Past studies have shown that manual bucking procedures have generally reduced the value of a tree by 20 percent compared to what is considered good practice (Faaland and Briggs 1984). A study of 166 northern hardwood trees in Michigan indicated that the gross delivered values of optimal solutions were 39 to 55 percent higher than those chosen by the buckers (Pickens and others 1992). These previous studies provide sufficient evidence that better merchandising and optimal bucking practices could increase revenues for forest products companies.

Because of the difficulty of correcting poor bucking decisions in the later stages of the manufacturing process, bucking control and optimization have been an essential research topic in forest engineering since the 1960s (Kivinen 2004). As technology becomes commonplace and more accessible to the forest products industry, there has been general shift in timber harvesting from manual to mechanized operation, and as harvesting systems increase in mechanization, there is a general increase in productivity and efficiency. The implementation of computers and computer-aided machines allow foresters to digitally store information of many trees within a stand and aid timber operators in optimal log bucking during harvesting (Murphy and others 2004).

The hardwood industry is often an important contributor to the state's economy in West Virginia where the forests of the Appalachian Mountains provide an abundant and diverse supply of hardwood trees. West Virginia consists of over 500 primary and secondary processors and employs approximately 29,000 workers in the forest products industry, and its timberland covers over 11.8 million acres, making it the third most forested state in the nation (Milauskas and others 2005). Due to the irregular form of most hardwood trees, the diversity of hardwood species existing on an individual site, and variations in the use and value of different species and grades of hardwood logs, tree boles are normally bucked and separated

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by product before proceeding to future processing instead of being shipped in tree-length form to mills as that happens to softwood (Wager and others 2004). Bucking usually operates below maximum efficiency in the state. Suboptimal bucking is a problem that has been persistent in the industry for decades. The lumber that was wasted from poor bucking decisions translates to real monetary loss.

OBJECTIVES AND METHODS

The general objective of this study was to investigate the current state of hardwood log merchandising and bucking practices in West Virginia. Specifically, this study examined the type and size of logging companies in West Virginia, the log products hauled off the landing, the number and type of harvesting equipment used, the bucking locations as well as the daily production rate of the logging companies in West Virginia.

On-site interviews with 50 timber harvesting companies were conducted throughout the state. It was assumed that these logging companies are representatives of the logging companies in West Virginia. These interviews were targeted at revealing the operating characteristics of each harvesting crew, their equipment spread, and geographic locations of their operations. In addition, questions were raised dealing with log product types, production statistics, bucking and merchandising procedures, and mill requirements for contract-based operations as well as incentives for bucking optimization and training willingness of log buckers in West Virginia.

RESULTS

Logging Operations

The logging companies interviewed were spread throughout six forest districts of West Virginia with 70 percent from north and central West Virginia (fig. 1). A majority of the logging companies were contract-based, which accounted for 70 percent of the total number of companies interviewed. The remaining were independent loggers (20 percent) and company crews (10 percent).

There was an average of five workers (including owner and machine operators) per logging company ranging from 2 to 10 people. The survey also revealed that about 50 percent of the company owners/operators were also primary log buckers. Skidder operator accounted for 28 percent of the total number of workers, followed by manual chainsaw feller (22 percent), loader/sawbuck operator (19 percent), and bulldozer operator (16 percent) (fig. 2).

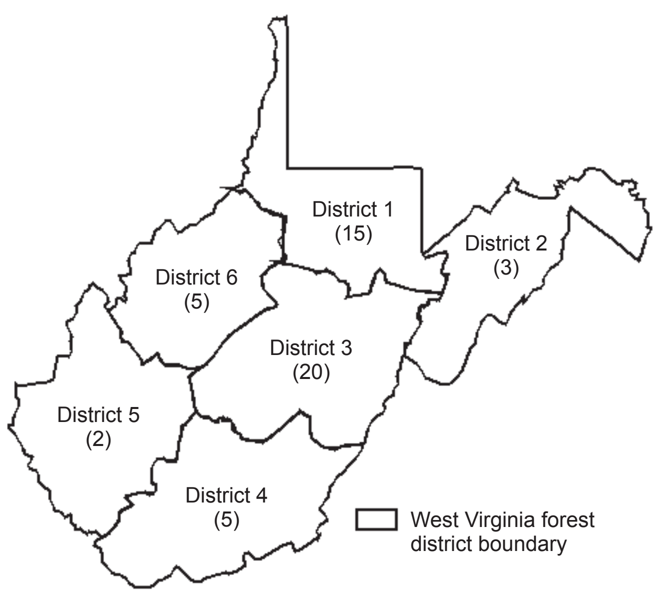

Figure 1—Distribution of the logging companies sampled in West Virginia by forest districts.

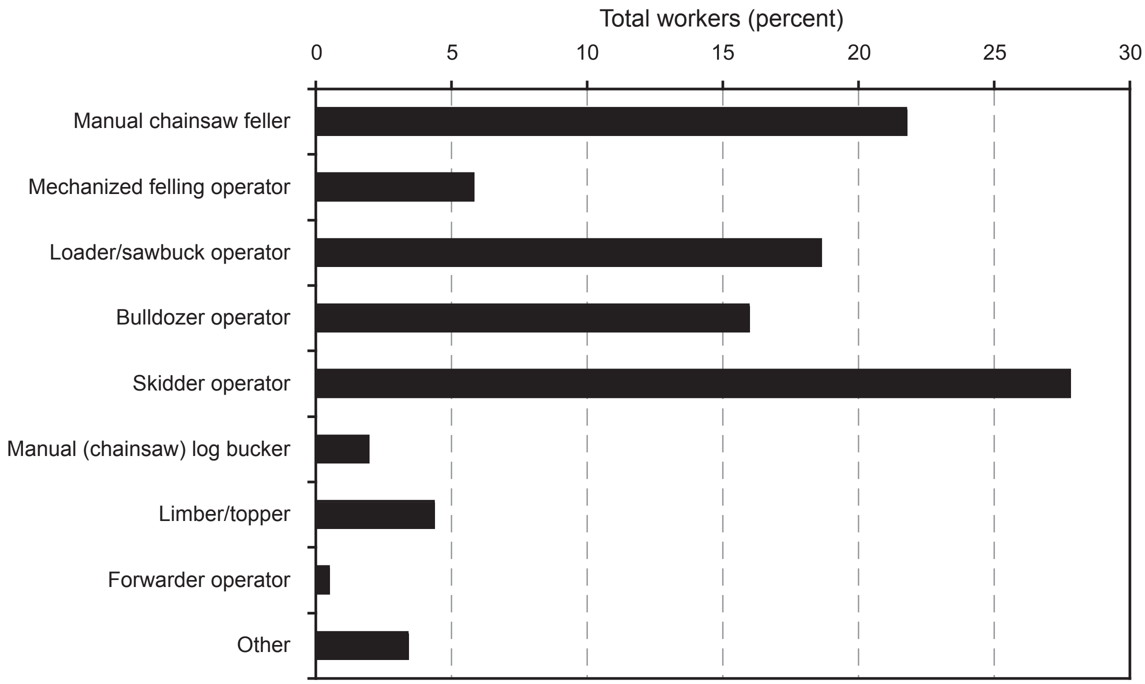

Figure 2—Percentage of worker by operating type.

To facilitate the analysis, the logging companies were grouped into three classes based on their average daily productions: small (1 to 3 loads), medium (3.1 to 6 loads), and large (> 6.0 loads). The target daily production rate ranged from 1.3 to 10 loads with an average of 4.5 loads per day for the logging companies interviewed. The actual average daily production was averaged 3.5 loads ranging from 1.3 to 9.0 loads per day. About one-fifth of the logging companies could reach their target daily production rate while the majority fell below their target production. More than 90 percent of the logging companies in West Virginia were small to medium size with the daily production of less than 6 loads. Fifty-nine percent of the logging companies interviewed were contract-based, and 80 percent of those were in the small and medium categories (table 1). However, all the independent loggers and company crews were in either small or medium group and all the large companies were contract-based. The actual daily production was 5, 4, and 12 percent lower than the target production for small, medium, and large categories, respectively (fig. 3).

The major log products hauled off landings were sawlogs (22 percent), hard pulpwood (17 percent), OSB (15 percent), peelers (14 percent), veneer (13 percent), and scragg wood (10 percent) (table 2). Post/rails hauled off landings were less than 10 percent, while only one company reported the firewood as one of its products.

Manual felling was still dominant in West Virginia logging industry with 78 percent of the logging companies utilizing more than one chainsaw for felling, while mechanical felling with feller-buncher accounted for 28 percent (table 3). Most of the companies used either chainsaw or feller-buncher for felling while 6 percent of them used both. STIHL AND HUSQVARNA were the two most commonly used chainsaw models, which accounted for more than 70 percent of the chainsaws utilized in West Virginia. More than 90 percent of the feller-bunchers used in this region were Timbco T425 or T445 and 8 percent of them were Bell-Serpent feller-bunchers. About 78 percent of the logging companies employed cable skidders for extraction and 38 percent of them utilize grapple skidders. John Deere series cable skidders (JD440, JD540, and JD640) were the most commonly used skidders (71 percent), followed by

Table 1—Type of logging companies in West Virginia by production capacity

Size class	Production capacity	Logging company		Company type		
				Contract	Independent	Company crew
	(loads/day)	*number*	*percent*	*percent*		
Small	< 3.0	28	55	59	31	10
Medium	3.0 – 6.0	18	37	80	7	13
Large	> 6.0	4	8	100	0	0

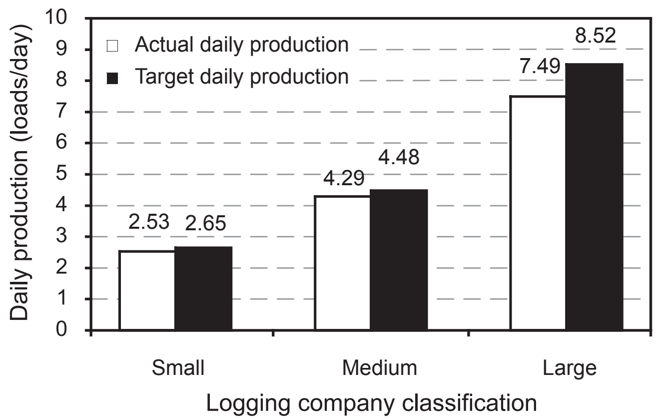

Figure 3—Daily production rate of the logging companies in West Virginia.

Table 2—Types of log products hauled off landings

Product type	Percentage	Cumulative percentage
Saw logs	22	22
Hard pulpwood (pulp and paper)	17	39
Soft pulpwood (OSB)	15	54
Peelers	14	68
Veneer	13	81
Scragg wood	10	91
Post/rails	8	99
Firewood	1	100

OSB = oriented strand board.

Table 3—Harvesting and trucking equipment employed by West Virginia's logging companies[a]

Type of equipment	Logging companies using selected equipment Small	Medium	Large	Sum
	- - - - - - - - *percent*	- - - - - - - -		
Felling				
Chainsaw	48	28	2	78
Feller buncher	14	8	6	28
Skidding				
Cable skidder	46	30	2	78
Grapple skidder	12	18	8	38
Forwarder	0	2	0	2
Bulldozer	14	10	2	26
Bucking				
Chainsaw	8	2	0	10
Sawbuck	48	34	8	90
Loading				
Knuckleboom loader	52	38	10	100
Roadbuilding				
Dozer	55	34	9	98
Excavator	0	2	0	2
Trucking				
Triaxial	22	12	2	36
Triaxial with loader	20	6	2	28
Triaxial with pup	8	14	2	24
Tractor trailer	24	18	8	40

[a] If the total percentage is > 100 for a category, it simply means that some of the companies use more than one machine in that category.

Timberjack series (TJ240, TJ360, and TJ380) (18 percent). Sixteen percent of the logging companies used both cable and grapple skidders for extraction.

Knuckleboom loader was utilized by all the logging companies and 98 percent of the logging companies used dozers for roadbuilding (table 1). About 80 percent of the logging companies in West Virginia have their own trucks while 27 percent of them used contracted trucks, and 7 percent of them used their own trucks as well as contracted trucks. Tractor trailer was the most commonly used truck type, which accounted for 40 percent of the trucks utilized in West Virginia, followed by tri-axial truck (36 percent), tri-axial with pup (24 percent), and tri-axial with loader (28 percent). Twenty-eight percent of the logging companies used at least two types of the trucks.

Bucking Practices

All the bucking operations were done at the landing using either chainsaws or sawbucks (table 4). Bucking with a sawbuck is a typical practice in West Virginia, which accounted for 82 and 86 percent of the bucking operations for small and medium companies, respectively. Accordingly, manual bucking with chainsaws at landing accounted for 18 and 14 percent for these two types of companies. Sawbuck bucking was used by all the large companies.

Seventy percent of the logging companies bucked logs based on the value (grade) and thirty percent of log bucking was based on volume (production). Among them, about two-thirds of the small logging companies bucked logs based on the value (grade) and the portion was increased to three-fourths for the medium size companies (table 4). Bucking based on value was dominant for small and medium size logging companies. Half of the large companies bucked logs based on value and the other half based on volume. For the bucking decisions, the typical practice is that the loader operator makes all bucking with sawbuck from loader cab without ground inspections. Sometimes, the loader turns around a long log for checking defects and makes decisions visually without getting off loader for higher value stems. Only 15 percent of the logging companies measured and marked logs before bucking. There was no in-woods bucking practice with chainsaws reported based on the bucking operations investigated.

For sawlogs, the target small end diameter for considering careful bucking was 10 to 12 inches for most of the species to meet the requirements of the mills. However, 8 to 9 inches of small end diameter was acceptable for black cherry and red oak. As to target lengths of the sawlogs, 10 feet logs were preferred and 8 to 16 feet logs were acceptable. During grading, sweep, crook, forks, and rot were the commonly recognized defects.

Fifty percent of the logging companies who is currently bucking for volume indicated that some incentives ranging from 10 to $50 per MBF would be needed for them to buck for grade. About half of the logging companies in West Virginia expressed the willingness to take advantage of training that would enable their companies to make better bucking decisions (table 4).

Fifty four percent of the independent loggers thought it is not necessary for them to get additional assistance in bucking sawlogs, such as training and information transfer, while 46 percent of them expressed they would welcome the assistance in sawlog bucking decisions and strategies.

CONCLUSIONS AND DISCUSSION

Sawlogs, hard pulpwood, OSB, peelers, veneer, and scragg were the major products hauled off the landing. Manual harvesting of chainsaw for felling and cable skidder for extraction was the dominant system in the region, followed by feller-buncher and grapple skidder system. The average daily production of the logging companies in West Virginia averaged 4.5 loads per day with more than 50 percent of the companies produced 3 to 6 loads per day. Only 20 percent of the logging companies could physically reach their target daily production rate.

Seventy percent of the logging companies bucked logs based on the value (grade) and thirty percent of log bucking was based on volume (production). Target small end diameter of 10 to 12 inches was normally required for considering careful bucking by the mills in West Virginia and the preferred log length was 10 feet. Among the companies currently bucking based on volume, 50, 33, and 47 percent of them were willing to take advantage of training that would enable their company to make better bucking decisions

Table 4—Bucking tools, basis, and incentives for logging companies in West Virginia

Size class	Bucking tools		Bucking basis		Bucking incentives for grade			Training willingness	
	Chainsaw	Sawbuck	Value	Volume	< 20 $/MBF	20 - 30 $/MBF	> 30 $/MBF	Yes	No
	percent								
Small	18	82	72	28	32	0	68	47	53
Medium	14	86	60	40	0	65	35	33	67
Large	0	100	50	50	0	0	100	50	50

MBF = thousand board feet.

for large, medium, and small companies, respectively. Forty-six percent of the independent loggers expressed their willingness to accept assistance in sawlog bucking decision-making.

In West Virginia, the bucking operators with sawbucks sometimes turned logs and looked them over for grading defects from the cab prior to bucking and then made the bucking decisions. The bucking operators generally believed that they could make the right decisions without leaving the cab. Sometimes, the operators bucked logs after the logs were marked on the ground in order to maximize the log value. In some cases, loader operators measured and marked log then made the cuts with chainsaws.

Results regarding incentives for bucking optimization and training willingness of log buckers in West Virginia would be helpful to logging managers and researchers to design an appropriate log merchandising program to improve value recovery of hardwood logs in the state.

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ACOUSTIC ASSESSMENT OF STRESS LEVEL AND POTENTIAL WOOD QUALITY OF LOGS AFFECTED BY OAK DECLINE

Xiping Wang, Henry E. Stelzer, Jan Wiedenbeck, and Robert J. Ross[1]

Abstract—Large numbers of black oak (*Quercus velutina* Lam.) and scarlet oak (*Q. coccinea* Muenchh.) trees are declining and dying in the Missouri Ozark forest as a result of oak decline. Infested trees produce low-grade logs that become extremely problematic to merchandize as the level of insect attack increases in the forest stand. The objective of this study was to investigate the use of a resonance acoustic technique to assess the stress or infestation level of logs affected by oak decline and evaluate potential grade yield of boards obtained from those logs. Following the acoustical testing of 400 black and scarlet oak butt logs obtained from four different stands, the majority of the logs were sawn into 4/4 boards and visually graded based on the local mill standards. A sub-sample of the logs were sawn into 8/4 boards, inspected for defects, and then computer–graded according to the National Hardwood Lumber Association Rules. The results of this study showed a positive relationship between acoustic velocity and grade yield of borer infested logs, suggesting that the resonance acoustic tool can be effectively used to segregate borer infested logs for efficient operation. The poor grade out projected by the computer program is evidence of the poor quality of the oak-decline affected trees in the region. However, the grades imposed by the local mill graders indicate that some of the material could be used for flooring, and virtually all of the material could be used to make pallet and industrial blocking grade products.

INTRODUCTION

Oak decline in the Missouri Ozarks has severely impacted over 200,000 acres of forest land. Black oaks (*Quercus velutina* Lam.) and scarlet oaks (*Q. coccinea* Muenchh.),collectively referred to as red oak in the region, that are commonly found along ridge-tops and south- and west-facing aspects have been the hardest hit. The number of red oak borer attacks, an indicator of the level of stress of trees, has increased to unprecedented levels of 300 to 500 attacks per tree, compared to a typical rate of less than 10 for healthy trees (Lawrence and others 2002). While oak decline occurs naturally throughout the region, it is expected to further increase as the oak forest matures.

Oak decline caused damage, as characterized by borer tunnels and decay inside the tree stem, poses a major problem in the utilization of this oak timber resource. Borer-infested trees produce low grade wood that may not be marketable. If the extent of damage is too severe the most cost efficient decision often is to leave the tree in the woods rather than harvest and process it. But, this decision is usually made after considerable logging costs have been incurred. Technologies are needed in both the forest and sawmill to quantify wood borer damage in affected trees or logs suspected of having excessive infestation. With information on the extent of damage, better decisions can be made in both managing the forest stand and utilizing individual trees and logs.

The objective of this study was to investigate the use of a resonance acoustic technique to assess the amount of damage in logs affected by oak decline and evaluate grade yield of the boards obtained from those logs.

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MATERIALS AND METHODS

Tree Samples

The sample for this study was part of a larger study design centered around Salem, MO that was developed for obtaining random, stratified samples representative of timber in the region that would be used to assess the potential utilization of small-diameter (6 to 12 inches dbh) trees. In each of ten stands, 100 trees were selected that represented the species and diameter (> 6 inches d.b.h.) distribution for that stand. The sample trees were then harvested and the tree-length stems were delivered to the mill yard. Each stem was labeled and numbered. The stem number remained with the tree and each log cut from the tree during the entire test.

Due to oak decline being more problematic in the red oak sub-group and the higher incidence of insect attack on the more xeric sites, only red oak species from the four south- and west-facing stands were used in the current study.

Log Measurement

By stand, the stems were delivered to a portable, three-dimensional laser scanner that was used to acquire three-dimensional geometric profile images of the stems. The images were used in simulation runs of the larger mill utilization study to calculate the most valuable solutions for bucking the stem into sawlogs as well as cutting the sawlogs into lumber.

Once the stems were scanned, they were moved to a manual bucking station in which a chainsaw operator cut the stems into 8- to 10-foot long logs. After bucking, the logs from each stem were delivered together to a manual measuring area where tags were placed on each individual log. During this part of the test, bark measurements were taken, log lengths were recorded, and acoustical test data for predicting lumber quality were obtained on the butt logs.

A resonance based acoustic method was used to measure longitudinal wave velocity in the butt logs. Resonance data were obtained from each log using a resonance acoustic tool (Director HM200) and a build-in Fast Fourier Transformation (FFT) program analyzed the acoustic signals following an impact (Harris and others 2002). The log acoustic velocity is determined based on the equation:

$$C_L = 2 f_0 L \tag{1}$$

where

C_L = acoustic velocity of logs (m per second)
f_0 = the fundamental natural frequency of an acoustic wave signal (Hz)
L = the log length (end-to-end) (m)

After log testing, we selected a sub sample of red oak butt logs (40), 10 from each stand, for characterizing the borer damage, examining the effects of oak decline on grade yield, and determining the mechanical properties.

Mill Process

After the individual logs were measured and tagged, they were stockpiled until they could be processed. All logs were sawn into 4/4 (1 inch thick) boards, targeting at wood flooring products, except the logs selected for defect inspection and future mechanical testing, which were sawn into 8/4 (2 inches thick) boards. The boards from each log were kept together in a stack through edging and grading so that each board could be associated with the appropriate log number.

Because some of the aluminum tags were lost in transportation, sawn through at sawmill, or for a variety of other reasons, not legible when the boards were graded, lumber grade data for some of the logs was not obtainable. Lumber grade data was collected on 333 of the 400 or 83 percent of the butt logs included in the study. The analysis assumes that omission of a log from the test due to loss or destruction of the tag was a random event.

All of the lumber was graded by employees of the local mill based on grade criteria used in their production operations. The local mill grades (Canoak, Inc., Salem, MO) were as follows:

- Select: 2 clear faces with few knots and defects
- #1: 2 clear faces with some knots and defects allowed
- #2: 1 clear face with some knots and defects allowed
- #3: No clear faces with several defects. This grade is sometimes noted as grade “0” since it has zero clear faces
- Pallet: low grade, rough material suitable for pallets or industrial blocking material

Generally, the local mill sells all select grades as molding or cabinet stock and uses grades #1, #2, and #3 in the flooring operation. Pallet grade material is sold for pallet and industrial uses.

Mapping and Characterization of Defects

From the 40 log sub-samples, a total of one hundred and forty 2-inch-thick boards were recovered. These boards were shipped to the USDA Forest Products Laboratory (FPL) in Madison, WS and kiln dried to a target moisture content of 12 percent. The boards were then visually inspected at the Northeast Research Station in Princeton, WV where the defects on each board were digitally mapped using an x-y coordinate system and a digitizing unit adapted for lumber (Anderson and others 1993). This digitized board description allows defect-type summaries to be generated for groups of boards. The defect characteristics for these boards were compared with the defect characteristics of the northern red oak boards in the 1998 red oak lumber data bank (Gatchell and others 1998) to determine if any differences that might be attributable to the oak decline condition were evident.

Computer Re-grading

After mapping and digitizing the defects, these boards were computer-graded using the Ultimate Grading and Remanufacturing System (UGRS) program (Moody and others 1998), which is an automated routine for determining grade under the National Hardwood Lumber Association Rules (1998) that are established for purposes of estimating the utility and value of lumber for use in appearance-type products (e.g., lumber, kitchen cabinets, flooring). The boards were re-graded four times to determine the effect of various sizes of wood borer holes and related defects on the grade of the lumber. In the first re-grade, all pin worm holes (≤ 1/16 inches in diameter) were eliminated to examine the effect of the smallest borer holes on lumber grade. In the second re-grade, both pin worm holes and shot worm holes (≤ 1/4 inches in diameter) were eliminated. In the third re-grade, pin, shot, and grub worm holes (> 1/4 inches in diameter) were eliminated. Finally, the boards were re-graded with all worm holes eliminated as well as incipient decay, mineral streak, and sap stain – defects that may have arisen after and as a result of the borer infestation.

Yield Simulation

The potential value of the wood material removed from the Missouri logs was also evaluated in terms of its suitability for production of higher value appearance-grade products, in this case furniture parts. The cut-up of the 140 digitized boards into furniture parts was simulated using the ROugh MILL Simulator (ROMI-3) (Weiss and Thomas 2005). The number and sizes of the parts used in conducting the simulation study were based on the distribution of 8/4-thick rough-part width and length requirements for solid furniture reported by several manufacturers (Araman 1982). The specific quantities and sizes of parts needed to fulfill a production order are referred to in the industry as a cutting bill. The cutting bill created for this simulation study not only used the distribution information from Araman (1982), but also the Buehlmann cutting bill part group scheme (Buehlmann and others 2003). The assumption was made, based on previous part yield studies conducted for low-grade lumber (Wiedenbeck and others 2004, Shepley and others 2004), that the surface-measure based yield of parts that might be reasonably expected from the Missouri sample was 24 percent.

Since the majority of rough mills cutting lumber into parts use rip-first systems, ROMI-3 (Weiss and Thomas 2005) was setup to conduct a rip-first simulation. The “selective ripsaw” type was used because it produces high yields without requiring that the user be familiar with the detailed information required to optimally specify the operating parameters for the other types of ripsaws available in the ROMI-3 program. In order to estimate not only the potential recovery of parts of required sizes that might be obtained from the Missouri sample, but also to estimate the additional area of wood surface that might yield useable parts for use in edge-glued panels, the ROMI-3 simulation was set up so that random-width sections could be recovered after all available specified sizes were extracted from each piece of lumber. Two quality classes of furniture parts were cut in the study. First, parts that were clear on both faces (i.e., front and back) were required. In the second instance, parts were allowed to included pin, shot, and grub worm holes as well as mineral streak, sap stain, and incipient decay. The second instance was simulated in order to get a ballpark idea of how much impact the quality factors that are most directly associated with red oak decline have on yield. By allowing these defects we are effectively approximating the yield potential of the Missouri lumber for clear face parts if the defects did not exist.

RESULTS AND DISCUSSION

Log Acoustic Velocity

Acoustic velocity is a nondestructive measure that has been proved to be related to the basic wood and fiber properties such as stiffness, density, and microfibril angle etc. (Wang and others 2001, 2004; Carter and others 2005). It has also been recognized as a predicting parameter for wood deterioration caused by any wood decay mechanism (Ross and others 2005). For red oak trees that have suffered from oak decline, physical damages such as warm holes, grub holes, decay are the typical symptoms associated with the borer infestation. It is possible that these physical and chemical changes, in both macro- and micro-structure level, could affect the acoustic wave behavior in the trees and logs. It is therefore important to examine the acoustic characteristics of the red oak logs harvested from infested stands and determine if this nondestructive measure is effective in assessing the stress level and potential quality of the wood.

Table 1 summarizes the d.b.h. and acoustic velocity data of the butt logs sampled in this study. It should be pointed out that the acoustic velocity was measured not long after harvesting and therefore referred to green condition.

Figure 1 shows the distribution of log acoustic velocity data for the four stands investigated. The distribution patterns are similar and appear to be normally distributed. This is to be expected since the four sites represent the same xeric, south- or west-facing aspects. Analysis of variance did, however, reveal

Table 1—D.b.h. of the tree samples and acoustic velocity of the butt logs cut from the trees

Stand number	D.b.h. of tree samples				Acoustic velocity of butt logs			
	Mean	Std. dev.	Min.	Max.	Mean	Std. dev.	Min.	Max.
	- - - - - - - - - *inches* - - - - - - - - -				- - - - - - - - *km/second* - - - - - - - -			
1	8.20	0.964	6	10	3.07	0.264	2.54	3.63
2	8.09	1.615	5	12	2.99	0.317	2.15	3.76
3	8.45	1.690	6	12	2.89	0.237	2.07	3.26
4	8.30	1.784	5	12	3.01	0.340	2.04	3.84

D.b.h. = diameter at breast height; Std. dev. = standard deviation.

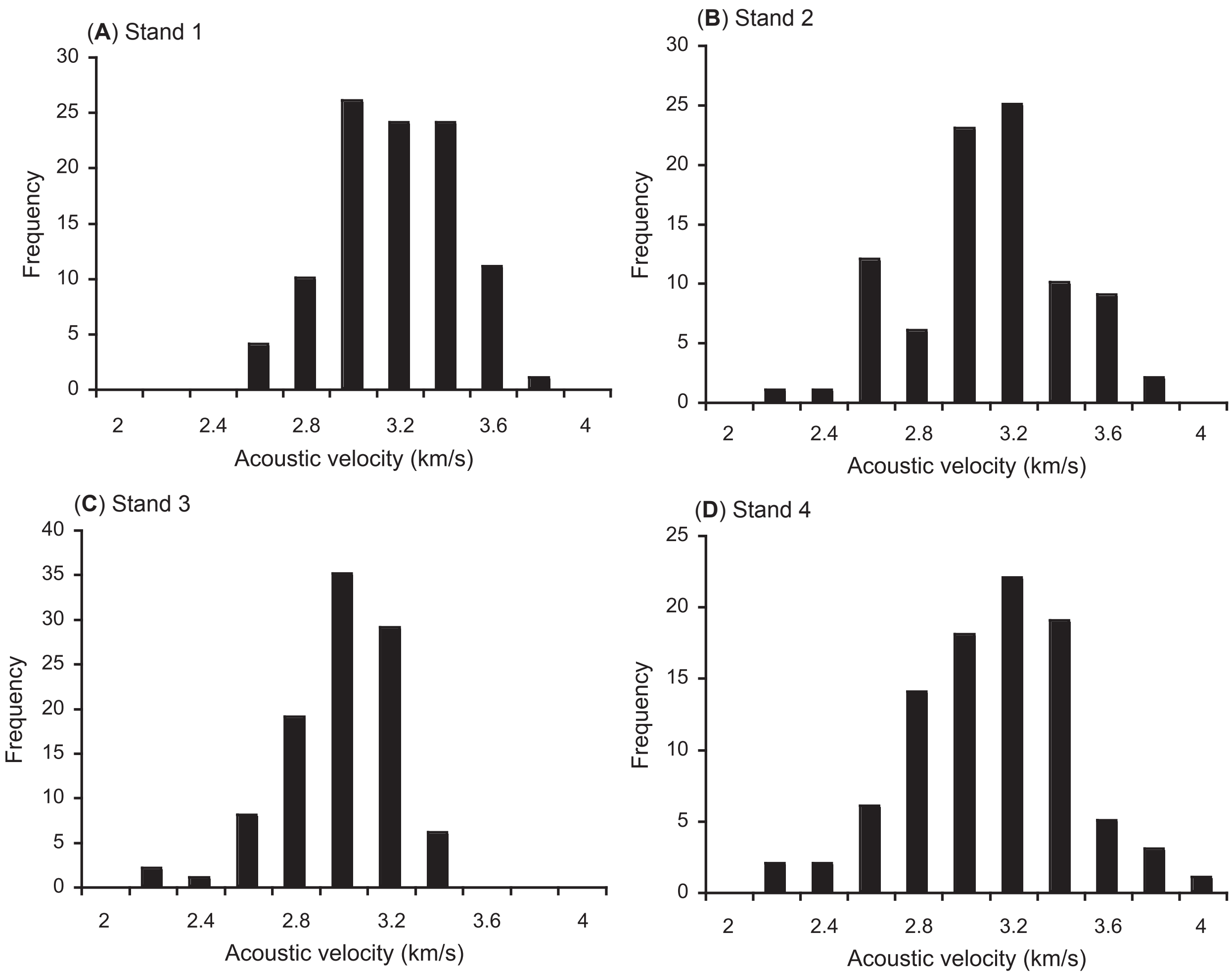

Figure 1—Distribution of log acoustic velocity within each stand.

a significantly lower mean acoustic velocity in Stand 3, suggesting that this stand could have been more severely affected by oak decline than the other stands.

Figure 1 also shows significant variation in acoustic velocity within each stand, implying a wide range of wood properties and quality levels for each stand. If a direct relationship exists between acoustic velocity and stress level of the logs, then acoustic data could be used to segregate good, healthy stems/logs from severely infested stems/logs.

Log Acoustic Velocity in Relation to Board Grade

One way to quantify the effectiveness of acoustic measure as a quality criterion is to determine the relationships between acoustic velocity of the logs and the grade levels of the boards cut from the logs. For this purpose, we pooled the log data of all four stands and divided the logs into six groups based on acoustic velocity of the logs. The six groups of logs have the following acoustic velocity ranges:

- G1: < 2.6 km per second
- G2: 2.6 – 2.8 km per second
- G3: 2.8 – 3.0 km per second
- G4: 3.0 – 3.2 km per second
- G5: 3.2 – 3.4 km per second
- G6: > 3.4 km per second

The group acoustic velocity of the logs was then correlated to the board grade levels as determined based on the grading rules of the local mill - Select, #1, #2, #3, and Pallet. The grade distribution of the red oak boards is illustrated in figure 2. The grades imposed by the local mill graders indicate that some of the material could be used for flooring and virtually all of the material could be used to make pallet and industrial blocking grade products.

Figure 3 shows how the board grade yield changes as the log acoustic velocity changes. Clearly, the board yield of the first four grades (Select, #1, #2, and #3) has a positive relationship with the log acoustic velocity - as the log velocity increased, the yield of these four grades increased. On the other hand, the board yield of the lowest grade deceased significantly as the log velocity increased. These two opposite velocity-grade trends reflected distinct differences between good quality boards with less or no borer infestation and poor quality boards with severe borer attacks. According to the grading rules, the select, #1, and #2 boards have one or two clear faces with no or little defects, suggesting that they were not affected by the borer infestation, or had only minor infestation. The pallet stocks, on the other hand, are the ones that have poor quality with severe defects. These low grade boards, in our case, were mostly cut

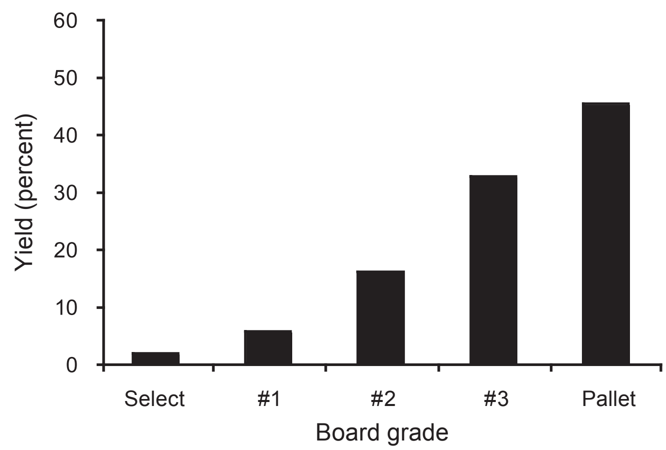

Figure 2—Board grade yield as determined by the local mill grading criteria.

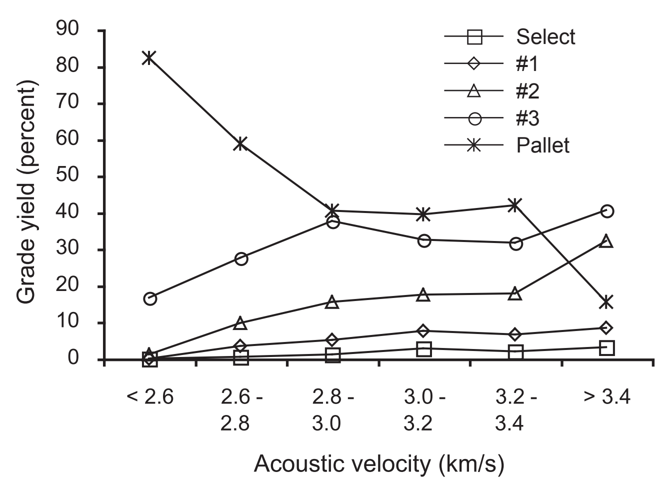

Figure 3—Relationship between log acoustic velocity and board grade yield.

from the red oak butt logs that had suffered medium and severe borer attacks. The yield results showed that about 45 percent of the total boards were actually in pallet stock (fig. 2). This reflects the quality problem associated with the oak decline in the region. The velocity-grade trends shown in figure 3 suggest that log acoustic velocity could be effectively used to segregate severely infested stems/logs from good and healthy stems/logs.

Defect Prevalence, Distribution, and Impact on Board Grade

The inspection and defect mapping of the 140 boards cut from the 40 log sub-sample reveal these boards contain a wide range of severe defects, many of them unsound defects. The most prevalent defects based on the percentage of boards affected, were unsound knot (91 percent of boards affected), bark pocket (89 percent), wane (82 percent), grub hole (71 percent), and split (52 percent) (table 2). Forty-eight of the 140 boards contained pith, an indication that a significant percent of these boards were removed from the inner, lower quality parts of the log. On the other hand, the fact that bark pocket and wane, defects encountered in boards removed from the outer sections of the log, were the second and third most prevalent defects, indicates that a high proportion of these boards contained outer wood. In fact, most of these boards contained both wood from the core of the log and wood from the periphery of the log since these logs were butt logs from small diameter trees.

The right-most column in table 2 shows the defect distribution for the 239 No. 3A Common grade boards in the 1998 red oak data bank (Gatchell and others 1998). The differences between the distributions for the Missouri and data bank boards are revealing. There are several types of defects that are found on at least 20 percent more of the boards sawn from the Missouri oak compared to the No. 3A Common lumber in the 1998 data bank (table 3). Defect types that are listed in bold font in table 3 are especially common in the Missouri lumber: grub hole, mineral streak, wane, incipient decay, decay, and shot worm hole. All of these defect types, except for wane, are ones that are likely associated with the borer infestation that occurs in the majority of trees suffering from oak decline.

Table 2—Types, numbers, areas, and percentages of defects in the Missouri oak subsample and defect percentages for the no. 3A common lumber data bank

	Missouri red oak board defect summary				
Type of defect	Total defects on all boards	Average defect size	Boards affected	Boards affected	3AC boards in 1998 data bank affected
	number	*square inches*	*number*	*- - - - - - - percent*	*- - - - - - -*
Unsound knot	1,185	0.71	128	91	83
Bark pocket	1,006	1.64	125	89	78
Wane	1,612	6.87	115	82	47
Grub hole	455	9.78	99	71	28
Split	443	1.84	73	52	47
Decay	159	36.84	55	39	13
Mineral streak	199	13.98	55	39	0
Pin worm hole	369	0.96	53	38	6
Sound knot	96	0.24	51	36	23
Pith	188	9.83	48	34	36
Shot worm hole	83	0.49	43	31	8
Incipient decay	106	15.43	38	27	0
Pith related defects	352	7.16	37	26	34
Shake	142	27.61	34	24	12

Source: Gatchell and others (1998).

Table 3—The difference between the boards from the Missouri oak sub-sample and the no. 3A common lumber in the 1998 red oak data bank in the percentage of boards having various types of defects

Defect type	Difference in defect distribution percentages[a]
Unsound knot	8
Bark pocket	11
Wane	35
Grub hole	43
Split	5
Decay	26
Mineral streak	39
Pin worm hole	32
Sound knot	13
Pith	-2
Shot worm hole	23
Incipient decay	27
Pith related defects	-8
Shake	12

[a] Positive numbers indicate that more of the lumber sawn from the Missouri oak sub-sample contains the listed defect than does the lumber in the No. 3A common red oak data bank.
Source: Gatchell and others (1998).

The quality and potential value of lumber sawn from hardwood stands affected by oak decline is most easily understood by examining the lumber grade distribution of the sub-sample. Grading the boards with UGRS (Moody and others 1998), the automated hardwood grading program, revealed that only 6 of the 140 boards were No. 3A Common and the rest were either No. 3B Common or Below Grade (table 4). When first pin worm holes; then pin and shot worm holes; then pin, shot, and grub worm holes were ignored (as if they did not exist) the grades of the boards remained practically unchanged. Only in the third iteration (pin, shot, and grub holes) was there even the slightest grade change – one additional board graded out as a No. 3A Common. Finally, the Missouri boards were re-graded one more time with pin, shot, and grub worm holes as well as sap stain, incipient decay, and mineral streak ignored. In this final iteration, 9 of the 140 boards were graded No. 3A Common and 1 board was graded No. 2A Common (table 4). This computer-based grade assignment is lower than the grade assignment made by a National Hardwood Lumber Association trained grader who judged 10 of the 140 boards to be No. 3A Common and 1 board to be No. 2A Common (a total of 8 percent) with all defects considered. So, the quality of the lumber cut from the trees removed from oak-decline affected timber stands is extremely low with only 4 to 8 percent being No. 3A Common or better in grade.

The fact that very few of these boards increased in grade/value when defects associated with insect infestation were ignored, would seem to point to the quality problems associated with sawing small-diameter hardwoods. Wane, split, shake, pith, and pith-related defects such as checking are expected to be more common in lumber from small-diameter trees; this data seems to support this expectation.

Part Yield Simulation

Since the total surface measure of the 140 pieces of lumber in our sample was 441 (i.e., 882 board feet), the cutting bill was created in an effort to have the surface areas of the different parts sum to 105 board feet (441 x 0.24). When all of these considerations were combined, the cutting bill that resulted contained 14 different part sizes and called for a total of 310 parts (table 5).

Table 4—Comparison of lumber grades and furniture part yields for lumber sawn from 40 log subsample of Missouri logs and no. 3A common red oak lumber

Grade/part	Missouri lumber		Red oak data bank lumber	
	All defects considered	Ignoring six defect types	All defects considered	Ignoring six defect types
	percent			
No. 3A common and better board proportion	4	6	100	100
Furniture part yield	20	26	38	40

Source: Gatchell and others (1998).

Table 5—Number of parts required by the cutting bill used in the yield simulation study[a]

Part size width	Part size length				
	10	17.5	27.5	47.5	72.5
inches					
1.5	10	127	29	28	1
2.5	—	48	13	11	—
3.5	—	15	5	4	—
4.25	—	12	4	3	—

— = data not measured.
[a] Based on the Buehlmann and others (2003), structure and the part size requirements recorded by Araman (1982).

The results of the current yield were directly compared with yield results from a duplicate simulation study conducted on previously digitized No. 3A Common northern red oak lumber (Gatchell and others 1998). There are some differences between these lumber sets: (1) the sub-sample of Missouri oak was 8/4 (2-inch) thickness while the 1998 red oak data bank sample was 4/4 (1-inch) thickness material, (2) all of the Missouri oak lumber was 8-feet long while the sample used for comparison ranged from 6 to 10 feet in length, and (3) the Missouri oak lumber ranged from 3 to 6 inches in width while the comparison data ranged in width from 3 to 7 inches. The differences in the defect data sets were minimized by randomly selecting boards with relatively similar lengths and widths from those available in the 1998 data bank (Gatchell and others 1998); boards wider than 7 inches and longer than 10 feet were excluded from the comparison study.

As for the thickness difference between the two samples, there is a dearth of information on the impact of lumber thickness on yield. Based on a basic understanding of defect propagation through the log, it is logical that the location of through-defects in thicker lumber will be more variable from the face to the back side while through-defects in thinner lumber will be more closely aligned from face to back. When the cutting bill calls for parts that are clear on both faces, the defect offset in the thicker lumber may occasionally lead to reduction in yield. However, the defect location offset from face to face is not likely to be more than fractions of an inch. Given that it is rare that a required fixed part length (or width) fits exactly inside a clear area without there being excess clear wood on the ends or edges of the part, it would only be a rare case when the defect offset would cause a part recovery opportunity to be lost. In the yield estimation work by Englerth and Schumann (1969) the statement was made "no yield reduction [from those obtained in cutting 4/4 lumber] was necessary for determining yields from 5/4 lumber."

With the ROMI-3 lumber cut-up simulation program (Weiss and Thomas 2005) setup to maximize yield from clear areas, the yield measured when the 140 boards in our sample were cut into furniture parts was only 20 percent (table 4). When the defects most closely associated with oak decline (pin, spot, and grub worm holes, sap stain, mineral streak, and incipient decay) were allowed in the cuttings (simulating the situation in which these defects are nonexistent), the furniture part yield obtained from the Missouri lumber went up to 26 percent – still a low yield (table 4). By comparison, the yield from a random sample of No. 3A Common boards (Gatchell and others 1998) was 38 percent with all defects included. When the holes, incipient decay, and mineral/stain defects were ignored, the furniture part yield for this comparison group of lumber went up to 40 percent. Part yield improved by 6 percent for the Missouri lumber but only by 2 percent for the data bank boards when specific defect types were ignored in the analysis – an expected result given the defect occurrence patterns discussed previously.

CONCLUSIONS

The acoustic velocity measured on logs had a significant variation within each stand, which shows the advantages of using acoustic velocity to segregate logs. The acoustic velocity of the red oak logs has a positive relationship with the grade yield as determined based on the local mill standard. This indicates that log acoustic velocity could be effectively used to segregate borer infested logs for efficient mill operation.

Of the most prevalent defects found on the red oak boards, grub hole, mineral streak, incipient decay, decay, and shot worm hole are ones that are likely associated with the borer infestation. The computer re-grading of the boards indicated that very few of the boards increased in grade/value when defects associated with insect infestation were ignored. This seems to point to the quality problems associated with sawing small-diameter hardwoods.

The poor grade out projected by the NHLA lumber grader is evidence of the poor quality of the small diameter timber in the region compared to areas where NHLA grades are more commonly used. In most areas of the country, this material would be sold as pulpwood and would have very little value as saw timber. However, the grades imposed by the local mill graders indicate that some of the material could be used for flooring and virtually all of the material could be used to make pallet and industrial blocking grade products.

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NATURAL REGENERATION

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TWENTY-TWO YEAR CHANGES IN REGENERATION POTENTIAL IN AN OLD-GROWTH *QUERCUS* FOREST ON THE MID-CUMBERLAND PLATEAU, TENNESSEE

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Abstract—A study was initiated in 1983 and then reexamined in 2005 to determine regeneration potential and species composition changes in an old-growth forest on the mid-Cumberland Plateau. Response to a 1980s mortality event was evident in the increased density of the largest size class, with *Acer saccharum* (Marsh.) showing the greatest increase (>100 percent). Large (2.5-5.4 inches d.b.h.) *Carya* and *Quercus* regeneration and all *Cornus florida* (L.) regeneration are no longer present, except for *Q. prinus* (L.) (4 percent). Regeneration models predicted similar regeneration outcomes in response to stand-replacing disturbance events: *Acer saccharum* (53 percent), *Fraxinus americana* (L.) (7-13 percent), and *Liriodendron tulipifera* (L.) (7-9 percent). We hypothesize that the potential of this forest to maintain overstory oak species will diminish if current disturbance trends continue.

INTRODUCTION

Many mature forests in eastern North America are losing their *Quercus* component due to changes in the historic disturbance regime (Abrams 1992, Abrams and Downs 1990, Lorimer 1980). The removal of Native Americans and land use changes associated with European settlement have resulted in less frequent disturbances of higher intensity (Ruffner and Abrams 2002). Silvicultural techniques have been developed to improve *Quercus* regeneration potential on high-quality upland sites (Brose and Van Lear 1998, Loftis 1990); however, forest manipulations may not be feasible in older stands where the seed source may be limited or management options may be restricted. In addition to *Quercus*, *Cornus* appears to be decreasing in many undisturbed forest stands due to an introduced anthracnose (*Discula destructive*) disease (Hiers and Evans 1997). The implications of species composition changes in the absence of management are relatively unknown, but are likely important to ecosystem processes and values (e.g., wildlife habitat, aesthetics, soil chemistry) and will be economically important at a local level.

Studies of old-growth forests on the Cumberland Plateau have concentrated primarily on characterizing community types (Haney and Lydic 1999, Hinkle 1978, Schmalzer and others 1978). Natural forest development in undisturbed forests, particularly those dominated by *Quercus* spp., is not well understood. Of special interest to forest and wildlife ecologists and managers in the region are conditions that benefit oak recruitment into the canopy. As a result, models have been developed that predict species response to stand-replacing disturbances based on current densities, size classes, and sprouting probabilities (Loftis 1989, Loftis 1990, Loftis 1993, Schweitzer and others 2004).

We examined successional development of the understory over the last 22 years in an old-growth forest on the mid-Cumberland Plateau. A previous study in 1983 examined and predicted species composition changes in this forest after a mortality episode that resulted in 20 percent of *Quercus* and *Carya* trees dying in a period of 2 to 3 years (McGee 1984, McGee 1986). The mortality resulted in an approximately 18-percent reduction in basal area in the dominant and codominant trees [>17 inches diameter breast height (d.b.h.)]. In 1983, the *Quercus* and *Carya* trees were underrepresented in the understory and were

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predicted to be replaced by shade-tolerant competitors, primarily *Acer saccharum* (Marsh.). We test these earlier predictions through modeling and current stand inventories and examine if the 1980s mortality event affected oak regeneration potential. We also examine if regeneration potential following simulated disturbance events has changed over the last two decades. Data collected will help refine regeneration models for the Cumberland Plateau region.

SITES

The study area lies on the mid-Cumberland Plateau in Franklin County, Tennessee, near the community of Sewanee, on The University of the South's Forest Domain. This portion of the plateau has been described as a weakly dissected plateau surface with strongly dissected sides (Smalley 1982). The stand is located within Dick Cove and has been designated as a Natural Area by The University of the South's Office of Domain Management. The vegetation of Dick Cove is similar to the mixed-mesophytic forests in the Cliff Section of the Cumberland Plateau escarpment as described by Braun (1950). Dick Cove has been designated as landtype association 16, which corresponds to the north aspect of the Plateau escarpment and upper sandstone benches (Smalley 1982). We examined vegetation within an 80-acre portion of the stand that lies below the escarpment and extends in elevation from 1,780 to 1,600 feet. The University's forest records show no logging or other human-caused disturbances in Dick Cove since 1858 until a road was built through a portion of the cove in 1965.

McGee (1986) documented *Carya* and *Quercus* trees with ages in excess of 400 years in the stand. Current forest inventories (Clark, S. 2005. Unpublished data. On file with: USDA Forest Service, Southern Research Station, Alabama A&M University, P.O. Box 1387, Normal, AL 35762.) show that approximately 25 tree species are present in Dick Cove. Primary overstory species are *Acer saccharum* (40 percent), *Quercus* spp. (16 percent), *Carya* spp. (11 percent), *Lirirodendron tulipifera* (L.) (8 percent), and *Tilia americana* (L.) (6 percent).

PROCEDURES

In September 1983, woody plant species were tallied on nested circular plots placed systematically throughout the forest using a 208 foot by 208 foot grid pattern (n=100) (McGee 1984, 1986). Seedlings were enumerated by species in two size classes (0-0.9 feet and 1.0-4.4 feet) in 0.001-acre plots. Saplings were enumerated by species and size class based on height (≥4.5 feet but <2.5 inches d.b.h. and 2.5-5.4 inches d.b.h.) in 0.01-acre plots.

In June 2005, we relocated 18 of the 1983 vegetation plots using written descriptions of plot locations and by finding the original wooden stakes used to mark plot centers. We established a 0.01-acre circular regeneration plot at the center of each original vegetation plot and tallied woody plants by species and size class based on height (0-0.9 feet, 1.0-1.9 feet, 2-2.9 feet, 3-3.9 feet, >4 feet but ≤1.5 inches d.b.h., and >1.5 inches d.b.h.). We measured d.b.h. for trees in the largest size class. If there were more than 25 stems within a species and size class, we did not tally any additional stems, but tallied the stem count as 25 within the individual plot.

In analyses of the 1983 data, we only used data from the 18 plots we were able to relocate in 2005. For the analyses to compare data among years, we grouped the 2005 data into the same size classes as the 1983 data. The only discrepancy was that the maximum height tallied was 4.5 feet in 1983 and 4.0 feet in 2005. We assume that this discrepancy is minimal and would not affect comparison among datasets. Additionally, we did not include trees larger than 5.5 inches d.b.h. for the 2005 dataset. The seedling data from 1983, taken on a 0.001-acre plot, were blown up by a factor of 10 to allow comparisons with the 2005 seedling data, which were taken on a 0.01-acre plot. For both datasets, relative stem density for each species was calculated as a percentage of the total density. Frequency was calculated as the percentage of plots in which the species occurred.

Prediction of species response following a simulated disturbance was conducted using the REGEN for EXCEL computer program based on population models for *Quercus* species (Loftis 1990, 1993; Schweitzer and others 2004). The model uses 0.01-acre plot data to predict composition of a new stand 10 years after a disturbance of high intensity (e.g., a clearcut or other major disturbance that removes all or most of the overstory). The model uses height as a basis to predict seedling performance after disturbance, with larger seedlings ranked as more successful competitors than smaller seedlings. Additionally, each species that can produce sprouts receives a ranking for each size class (Schweitzer and others 2004) and an associated sprouting probability for stump sprouts (defined as sprouts from trees >1.5 inches d.b.h.). In some cases, data have been collected to develop logistic estimates of sprouting probabilities as a function of stem d.b.h.. In some cases, no significant relationship between sprouting probability and stem d.b.h. existed, and the simple proportion of stems sprouting is used as the probability of sprouting. The species ranking and probability data are partially based on field data collected from tests in the southern Appalachians (Loftis 1990, Loftis 1993). If no data were available for a species, the ranking was based on field experience and knowledge of the species regeneration mechanisms and growth rates; sprouting probabilities were set to 0.5. Because *Lirirodendron tulipifera* was present in the overstory, we used an option in the model to add additional *L. tulipifera* seedlings to the stand at time of disturbance to account for new seedlings that would germinate from dormant seed in the ground. The model chooses six "winners" per plot, based on their competitive ranking, to predict the dominant and codominant trees at crown closure on each individual plot. Algorithms are used in the case of ties between individuals with the same ranking. Combined plot data are summarized to produce stand-level results, which provide predicted species composition and density of dominant and codominant trees at crown closure (estimated to be 10 years after disturbance). The model used 100 simulations to provide the mean and range of probable regeneration outcomes for the stand.

The model uses the following height classes: 0-1.9 feet, 2-3.9 feet, ≥4 feet height but <1.5 inches d.b.h., and ≥1.5 inches d.b.h.. The 2005 data could be divided into these size classes for use in the model, but the 1983 tally did not afford this ability. We therefore assigned all trees 0-0.9 feet in height from the 1983 dataset to the smallest height category for the model (0-1.9 feet). We similarly assigned the remaining categories: 1-4.4 feet to the 2-3.9 feet model category, ≥4.5 feet height but <2.5 inches d.b.h. to the ≥4 feet height but <1.5 inches d.b.h. model category, and 2.5-5.4 inches d.b.h. to the ≥1.5 inches d.b.h. model category. We then assigned a d.b.h. of 4.0 inches (midpoint between 2.5 and 5.4 inches) to all trees in the largest size class.

RESULTS

Twenty-five species were tallied in 1983 and 24 in 2005. Total regeneration density decreased by 44 percent from 1983 to 2005 with the majority of this loss in trees 1-4.4 feet in height (table 1). The only size class to show an increase in density was the largest size class, which increased by 67 percent.

The decrease in stem density from 1983 to 2005 was greatest for *Cornus florida* (L.), which once occurred in 72 percent of the plots and had accounted for 8 percent of the total stem density (table 2). This species

Table 1—Total number of stems per acre (standard deviation) by size class in Dick Cove, Sewanee, TN (n = 18) in 1983 and 2005

Size class	1983	2005
Total	9,266.7 (4,894.5)	5,150.0 (2,181.0)
0–0.9 feet height	4,750.0 (2,896.5)	3,944.4 (1,767.8)
1–4.4 feet height	3,666.7 (2,689.9)	433.3 (524.7)
> 4.5 feet, < 2.5 inches d.b.h.	783.3 (296.5)	694.4 (469.6)
2.5–5.4 inches d.b.h.	66.7 (76.7)	111.1 (102.3)

Table 2—Species relative density and frequency by size class in Dick Cove, Sewanee, TN (n = 18) in 1983 and 2005

	Total				0–0.9 feet height				1–4.4 feet height				> 4.5 feet height, < 2.5 inches d.b.h.				2.5–5.4 inches d.b.h.			
	Density		Frequency		Density		Frequency		Density		Frequency		Density		Frequency		Density		Frequency	
Species	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005	1983	2005
Acer rubrum (L.)	2.4	0.3	16.7	11.1	3.4	0.3	16.7	5.6	1.8	0	5.6	0	0	0	0	0	0	0	0	0
Acer saccharum (Marsh.)	32.3	47.2	94.4	100.0	36.5	48.3	72.2	94.4	26.3	11.9	50.0	22.2	33.8	69.1	94.4	94.4	27.8	59.6	16.7	50.0
Aesculus glabra (Willd.)	0.5	2.3	11.1	55.6	0	1.4	0	38.9	0	15.2	0	22.2	1.9	1.9	11.1	5.6	0	7.7	0	5.6
Asimina triloba (L.) Dunal	0	0.5	0	11.1	0	0.5	0	11.1	0	0	0	0	0	0.3	0	5.6	0	0	0	0
Carya spp.	4.5	3.2	38.9	66.7	10.4	4.1	27.8	66.7	0.7	0	5.6	0	1.8	0	11.1	0	22.2	0	11.1	0
Cercis canadensis (L.)	3.4	0.2	38.9	11.1	1.3	0	5.6	0	6.3	0	5.6	0	5.1	2.8	33.3	5.6	0	7.7	0	5.6
Cladrastis kentukea (Dum.-Cours.) Rudd	1.2	2.0	11.1	5.6	1.3	0.8	5.6	5.6	1.8	5.4	5.6	5.6	0.4	3.3	5.6	5.6	0	3.8	0	5.6
Cornus florida (L.)	7.6	0	72.2	0	4.1	0	11.1	0	9.3	0	16.7	0	21.0	0	72.2	0	38.9	0	22.2	0
Euonymus atropurpureus (Jacq.)	0	0.7	0	11.1	0	1.1	0	11.1	0	0		0	0	2.2		5.6	0	3.8	0	5.6
Fraxinus americana (L.)	11.0	10.0	44.4	72.2	9.7	11.2	27.8	66.7	15.1	11.5	38.9	22.2	4.8	1.9	27.8	16.7	0	0	0	0
Hydrangea spp.	8.1	0	22.2	0	4.5	0	11.1	0	9.4	0	11.1	0	2.4	0	11.1	0	0	0	0	0
Lindera benzoin (L.) Blume	5.6	6.7	38.9	55.6	3.9	4.0	11.1	44.4	5.9	27.8	11.1	33.3	6.8	5.3	33.3	11.1	0	0	0	0
Liriodendron tulipifera (L.)	2.0	5.4	16.7	22.2	4.0	5.6	11.1	22.2	0	2.7	0	5.6	0.4	0	5.6	0	0	3.8	0	5.6
Magnolia acuminata (L.)	1.5	0	16.7	0	1.4	0	11.1	0	1.5	0	5.6	0	1.7	0	11.1	0	0	0	0	0
Nyssa sylvatica (Marsh.)	0.5	6.8	5.6	44.4	0.7	7.1	5.6	33.3	0	12.3	0	22.2	0	3.3	0	5.6	0	0	0	0
Oxydendrum arboreum (L.) DC.	0.1	0	5.6	0	0	0	0	0	0	0	0	0	1.0	0	5.6	0	0	0	0	0
Prunus serotina Ehrh.	1.6	0.5	16.7	16.7	0	0.6	0	16.7	7.8	0	11.1	0	0.6	0	5.6	0	0	0	0	0
Quercus alba (L.)	0.1	0.5	11.1	16.7	0	0.6	0	16.7	0	0	0	0	2.4	0	11.1	0	0	0	0	0
Quercus muehlenbergii Engelm.	0.6	0.1	22.2	5.6	0	0.1	0	5.6	0.7	0	5.6	0	1.2	0	11.1	0	11.1	0	5.6	0
Quercus prinus (L.)	0.1	0.6	5.6	11.1	0	0.4	0	11.1	0	0.9	0	5.6	0.8	1.1	5.6	5.6	0	3.8	0	5.6
Quercus rubra (L.)	0.9	3.4	5.6	55.6	1.8	4.2	5.6	55.6	0	0	0	0	0	0	0	0	0	0	0	0
Quercus velutina Lam.	0.8	0	5.6	0	1.1	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Rhododendron spp.	0.1	0	5.6	0	0	0	0	0	0	0	0	0	1.0	0	5.6	0	0	0	0	0
Robinia pseudoacacia (L.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sassafras albidum (Nutt.) Nees	1.6	2.9	11.1	11.1	0	3.5	0	11.1	4.5	1.8	5.6	5.6	0.9	1.1	5.6	5.6	0	0	0	0
Staphylea trifolia (L.)	0	1.7	0	5.6	0	0.3	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0
Tilia americana (L.)	3.6	1.1	33.3	16.7	1.6	0.1	5.6	5.6	5.9	1.2	22.2	5.6	3.0	3.1	16.7	16.7	0	5.8	0	5.6
Ulmus alata Michx.	0	0.1	0	5.6	0	0	0	0	0	0	0	0	0	0.9	0	5.6	0	0	0	0
Ulmus rubra Muhl.	8.0	2.0	50.0	33.3	10.9	2.1	27.8	22.2	3.2	0.4	11.1	5.6	9.1	3.6	44.4	16.7	0	3.8	0	5.6
Vaccinium spp.	0	0.5	0	5.6	0	0.5	0	5.6	0	1.8	0	5.6	0	0	0	0	0	0	0	0
Viburnum spp.	2.1	1.2	11.1	11.1	3.5	1.1	11.1	11.1	0	7.1	0	5.6	0	0	0	0	0	0	0	0

was particularly important as a small sapling (2.5-5.4 inches d.b.h. size class) in 1983, averaging 26 stems per acre. *Acer saccharum* had the largest total increase in relative density and was the only species to occur in all plots in 2005. In 1983, *Quercus* spp. and *Carya* spp. were present in all size classes, but by 2005 we did not tally any oaks > 0.9 feet in height. One exception was *Quercus prinus* (L.), which had a slight increase in abundance in all size classes. *Quercus rubra* (L.) was the most frequent and abundant oak species in 2005, averaging 161 stems per acre, but was never larger than 0.9 feet tall.

The REGEN model predicted similar species composition and density outcomes for both time periods following a simulated disturbance that removed the majority of the overstory (table 3). The model predicted that the stand would be dominated by sugar maple [>50 percent trees per acre (TPA)] after disturbances in 1983 and 2005. Oak regeneration potential was similar and comprised < 3 percent of the dominant and codominant trees following a disturbance. The density of hickory increased slightly from 2 to 5 TPA, but was not well represented in either model prediction. The potential for *Prunus serotina* (Ehrh.) regeneration decreased from 32.4 TPA in 1983 to 11.1 TPA in 2005. *Fraxinus americana*, *Liriodendron tulipifera,* and *Aesculus octandra* (Marsh.) were the next most common competitors after *Acer saccharum* in model predictions for both years.

DISCUSSION

Regeneration potential of *Carya* or *Quercus* was low in 1983 and 2005, and did not increase during the mortality episode of the 1980s. Management recommendations to enhancement oak regeneration on high-quality sites prescribe reductions in the midstory rather than in the main canopy (Loftis 1983, Loftis 1993). We speculate that the increased light from the 1980s mortality benefited the *Acer saccarum* and *Tilia americana* understory trees that were already established. *Quercus* and *Carya* species could not compete after the mortality episode without a simultaneous reduction of these competing species in the midstory. *Acer saccharum* is a strong competitor under a variety of light conditions, particularly shade (Clark and Schlarbaum 2003, Logan 1965), and this species limited *Quercus* regeneration in this stand, similar to results of another study on the mid-Cumberland Plateau (Schweitzer and others 2004). In addition, high levels of deer browsing are probably having a negative effect on *Quercus* regeneration.

A stand-replacing disturbance would not have increased the contribution of *Quercus* and *Carya* species due to the low density of large advanced regeneration (>4.5 feet height) that existed in 1983 and in 2005. We would expect to have fewer *Prunus serotina* stems and more *Liriodendron tulipifera* stems than predicted by the REGEN model; the former is not a strong competitor in Cumberland Plateau forests (Schweitzer and others 2004), while the latter is a strong competitor, particularly in productive environments like cove forests (Loftis 1993, Kolb and others 1990). Schweitzer and others (2004) also found a higher than expected density of *Prunus serotina* and a lower than expected density of *Liriodendron tulipifera* on high-quality sites in the Cumberland Plateau using the REGEN model. The competitive ability of these species may be different in the Cumberland Plateau than in the Blue Ridge Mountains, where developmental model data were collected, and species rankings and sprouting probabilities need to be refined.

This forest, once dominated by *Quercus* and *Carya*, will likely lose diversity in the midstory and overstory and succeed to an *Acer saccharum* dominated forest if the currently observed trends continue. The complete loss of *Cornus florida* was not surprising given its relatively low abundance and loss on nearby sites on the Plateau top and escarpment (Kuers and Kuthe 1998, Schweitzer and others 2004). Dogwood anthracnose was likely playing a role in this loss, but lack of fire or sunlight is probably also a limiting factor (Holzmueller and others 2006).

The forest has a decreased potential to recruit soft-mast *Cornus florida* and hard mast *Quercus* and *Carya* species at the present disturbance levels. These species are particularly important to wildlife (McShea and Healy 2002) and their loss may have important community-level consequences (Hiers and Evans 1997).

Table 3—Predicted density (trees per acre) of dominant and codominant competitors following simulated stand-replacing disturbance using the REGEN for EXCEL model for Dick Cove, Sewanee, TN

Species	1983	2005
Acer rubrum (L.)	15.0	4.3
Acer saccharum (Marsh.)	170.0	166.1
Aesculus glabra (Willd.)	2.7	4.1
Asimina triloba (L.) Dunal	0	0
Carya spp.	1.9	5.0
Cercis canadensis (L.)	1.1	< 0.1
Cladrastis kentukea (Dum.-Cours.) Rudd	0	0.2
Cornus florida (L.)	0.2	0
Euonymus atropurpureus (Jacq.)	0	0
Fraxinus americana (L.)	21.8	38.8
Hydrangea spp.	0	0
Lindera benzoin (L.) Blume	< 0.1	< 0.1
Liriodendron tulipifera (L.)	24.7	28.8
Magnolia acuminata (L.)	11.8	3.9
Nyssa sylvatica (Marsh.)	0.1	6.8
Oxydendrum arboreum (L.) DC.	0.1	0
Prunus serotina Ehrh.	32.4	11.1
Quercus alba (L.)	0	0
Quercus muehlenbergii Engelm.	3.1	< 0.1
Quercus prinus (L.)	0.1	0
Quercus rubra (L.)	0	9.0
Quercus velutina Lam.	0	0
Rhododendron spp.	0	0
Robinia pseudoacacia (L.)	0	0
Sassafras albidum (Nutt.) Nees	< 0.1	1.8
Staphylea trifolia (L.)	0	< 0.1
Tilia americana (L.)	26.5	28.2
Ulmus alata Michx.	0	< 0.1
Ulmus rubra Muhl.	0	< 0.1
Vaccinium spp.	0	0
Viburnum spp.	0	0
Total	318.3	308.5

Lack of disturbance has been cited as an important factor in the loss of the *Quercus* component in many forest ecosystems (Abrams and Downs 1990, Lorimer 1984, Orwig and others 2001). Our results support the theory that *Quercus* will not become more competitive on high-quality upland sites with single minor disturbances (Gilbert and others 2003, Glitzentstein and others 1990, Johnson and others 2002). Fire has maintained oak forest communities, particularly on xeric sites over time (Abrams 1992, Clark and Hallgren 2003, Cutter and Guyette 1994, Ruffer and Abrams 1998). The historical role of fire in mesic ecosystems is less certain, but *Quercus* generally succeeds to more shade tolerant competitors in the absence of disturbance (Abrams and others 1997, Ruffner and Abrams 2002). Fire and harvesting benefit oak regeneration on highly productive sites (Brose and Van Lear 1998), but management may not be an option in old-growth areas because of conflict with public opinion (Proctor 1998).

The origin of existing *Quercus* and *Carya* overstory trees in Dick Cove is unknown, but is likely a result of repeated or sustained disturbances such as those caused by fire or drought or both. A future study will examine stand history using dendrochronology and reconstruct *Quercus* and *Carya* establishment over time in relation to drought and fire events.

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NATURAL OAK REGENERATION FOLLOWING CLEARCUTTING ON THE HOOSIER NATIONAL FOREST

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Abstract—Forest managers have noticed a decreasing oak (*Quercus* spp.) component in many stands once dominated by oak. This decrease is typically attributed to anthropogenic influences, most important of which are past management practices and fire suppression. Even-aged silviculture is typically deemed the most suitable method for oak regeneration in the CHFR, although many studies have observed that even in clearcut stands, oaks continue to be replaced by less desirable hardwood species, especially on higher quality sites. We examined oak regeneration following clearcutting across a variety of landscapes within the Hoosier National Forest (HNF) 21 to 35 years after harvest. These same clearcut stands were previously measured in 1986-1987 when it was 3 to 16 years since they were clearcut. This allowed us to examine oak dynamics and oaks' ability to compete for dominant canopy positions over time. Black cherry (*Prunus serotina*) and yellow-poplar currently dominate the canopy of many of the measured stands with an average relative density (RD) of 16 and 17 percent, respectively. Oaks, maples and white ash are the next most abundant species. Oak importance values (IV) increased across all slope aspects and slope positions over this time period with the exception of the upper slope position on the most mesic sites. Oaks can successfully compete for resources during the stem exclusion stage.

INTRODUCTION

Oak forests (see table 1 for a list of species observed in this study) became an important component of the Central Hardwood Forest Region (CHFR) approximately 7,000 years ago (Davis 1981) following glacial recession. Through pre-settlement times, oak forests dominated the landscape of the CHFR (Abrams & McCay 1996, Dyer 2001), and played an important role in the lives of Native Americans and European settlers. Oak forests provided abundant wildlife, high quality timber, and other non-timber resources.

It is generally recognized that if functional and successional processes of ecosystems are sustained, values associated with those systems will also be sustained (Kimmins 1997). Today, the threat to oak ecosystems is a source of concern for forest managers, and the topic has garnered much interest in recent years. Economically, oaks are a valuable and desired species. They are commonly used in furniture, flooring and other building materials, thus providing value to secondary and tertiary producers. Oak forests supply abundant sources of mast for wildlife. The oak tree is such an important part of American heritage that it was recently voted America's national tree for its broad range, beauty, and value.

Successful natural oak regeneration in mesic forests once dominated by oaks has been considered a problem in the CHFR for more than half a century (Johnson and others 2002). The lack of success of natural oak regeneration has often been attributed to anthropogenic influences; those most commonly cited are past management practices (Smith 1992) and fire suppression (Lorimer 1992). Development of oak ecosystems is a result of changes in stand structure that occur over time arising from interactions of growth, mortality, and recruitment of trees within stands, and further supplemented by regional disturbance regimes.

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Table 1—Species group, common name, and Latin names for species found in the dominant canopy class of the 1987 and 2004 datasets

Species group	Common name	Latin name	Observations 1987	Observations 2004
			- - - number - - -	
White oak	White oak	*Quercus alba* L.	236	784
	Chinkapin oak	*Q. muehlenbergii* Engelm.	20	87
Red and black oak	Black oak	*Q. velutina* Lam.	258	424
	Northern red oak	*Q. rubra* L.	55	758
Other oak	Chestnut oak	*Q. prinus* L.	96	431
	Post oak	*Q. stellata* Wangenh.	0	2
	Scarlet oak	*Q. coccinea* Muenchh.	15	185
	Shingle oak	*Q. imbricaria* Michx.	4	10
	Swamp white oak	*Q. bicolor* Willd.	0	6
Black cherry	Black cherry	*Prunus serotina* Ehrh.	490	2,131
Yellow-poplar	Yellow-poplar	*Liriodendron tulipifera* L.	828	2,277
Red maple	Red maple	*Acer rubrum* L.	222	758
Sugar maple	Sugar maple	*A. saccharum* Marsh.	498	1,302
White ash	White ash	*Fraxinus americana* L.	397	1,038
Miscellaneous	Tree-of-heaven	*Ailanthus altissima* (P. Mill.) Swingle	0	29
	Blue beech/hornbeam	*Carpinus caroliniana* Walt.	142	6
	Blackhaw	*Viburnum prunifolium* L.	0	1
	Catalpa	*Catalpa speciosa* (Warder) Warder ex Engelm.	0	1
	Flowering dogwood	*Cornus florida* L.	175	3
	Devil's walking stick	*Aralia spinosa* L.	0	1
	Eastern redcedar	*Juniperus virginiana* L.	5	22
	Honeylocust	*Gleditsia triacanthos* L.	1	1
	Ironwood/hophornbeam	*Ostrya virginiana* (P. Mill.) K. Koch	341	146
	Ohio buckeye	*Aesculus glabra* Willd.	0	12
	Royal paulownia	*Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.	0	2
	Persimmon	*Diospyros virginiana* L.	17	90
	Red bud	*Cercis canadensis* L.	349	131
	Rock elm	*Ulmus thomasii* Sarg.	0	43
	Winged elm	*U. alata* Michx.	46	0
	Sumac	*Rhus* species	0	77
	Downy serviceberry	*Amelanchier arborea* (Michx. f.) Fern.	0	4
	Sourwood	*Oxydendrum arboreum* (L.) DC.	0	15
	Red mulberry	*Morus rubra* L.	0	7
	Willow species	*Salix* species	4	0
	River birch	*Betula nigra* L.	1	0
Sassafrass	Sassafras	*Sassafras albidum* (Nutt.) Nees	550	744
Elm	American elm	*Ulmus americana* L.	27	67
	Red elm	*U. rubra* Muhl.	316	590
Other hardwood	American beech	*Fagus grandifolia* Ehrh.	20	52
	Basswood	*Tilia americana* L.	8	5
	Blackgum	*Nyssa sylvatica* Marsh.	94	63
	Black locust	*Robinia pseudoacacia* L.	49	108
	Cottonwood	*Populus deltoides* Bartr. ex Marsh.	2	13
	Hackberry	*Celtis occidentalis* L.	3	8
	Sweetgum	*Liquidambar styraciflua* L.	1	75
	Sycamore	*Platanus occidentalis* L.	46	134
	Butternut	*Juglans cinerea* L.	5	8
Hickory	Bitternut hickory	*Carya cordiformis* (Wangenh.) K. Koch	11	45
	Mockernut hickory	*C. alba* (L.) Nutt. ex Ell.	11	12
	Pignut hickory	*C. glabra* (P. Mill.) Sweet	21	127
	Shagbark hickory	*C. ovata* (P. Mill.) K. Koch	21	46
Aspen	Aspen species	*Populus* species	41	183
Black walnut	Black walnut	*Juglans nigra* L.	18	64
			5,444	13,128

Lack of natural oak regeneration has lead to numerous studies aimed at identifying silvicultural systems that best encourage perpetuation of oak ecosystems. Even-aged silviculture is typically deemed the most reliable method to promote natural regeneration of oak stands in the CHFR (Roach & Gingrich 1968). Oak species found in the CHFR have the ability to stump sprout after stem disturbance, and that may make them more competitive in a clearcut environment (Johnson and others 2002). George and Fischer (1989) found that about 55 percent of the post-harvest dominant oak regeneration was from stump sprouting. Method of regeneration will not be addressed in this study, although its importance in oak regenerative success is recognized.

Numerous studies have demonstrated limited success of even-aged management in perpetuating oak ecosystems (Beck and Hooper 1986, Jenkins and Parker 1998). Many studies have monitored stand composition after harvest only to find a considerable decline in oak species composition. Higher quality sites commonly become dominated by faster growing, less valuable species such as maples, yellow-poplar, and white ash, while oaks seem able to compete only on poorer sites (Heiligman and others 1985, Hilt 1985, Fischer 1987, Wright and others 1998, Shostak and others 2002). Translated to a landscape level over time, this trend bodes important changes in species composition in the CHFR. A problem in understanding the dynamics of stand development is that many studies were constrained in landscape variation and time frame (Standiford and Fischer 1980, Heiligman and others 1985, Arthur and others 1997, Wright and others 1998, Ward and Stephens 1999, Shostak and others 2002), and few studies examine the long term species interactions (Oliver 1978, Clatterbuck and Hodges 1988).

Site diversity within the region requires an understanding of influence of site on oak regeneration, as has been demonstrated in many previous studies (Cantlon 1953, Adams and Anderson 1980, McCarthy and others 1984, Rubino and McCarthy 2003, Collins and Carson 2004). The problem with many such studies is that they examine relatively short time frames in the early stages of stand regeneration, and typically examine a limited number of sites. Although limited success of oak regeneration following clearcutting is well documented, there is little data available to examine long term trends in dynamics of oak development during the stem exclusion stage.

This study examines influence of site variables on natural oak regeneration dynamics and the competitive success of oaks over time. It is a follow up to an earlier study conducted within the same sample stands (Fischer 1987); thus, we can directly compare the two data sets. This study examined 32 clearcut sites 21 to 35 years after clearcut harvesting on the Tell City Ranger District in the Hoosier National Forest (HNF). It is a subset of data that includes an estimated 1,443 plots over 584 ha (70 sample stands) throughout the HNF. The temporal and spatial scale of this study provides us with a unique opportunity to examine influence of clearcutting on natural oak regeneration across many different sites over an extended time period.

METHODS

Study Sites

This study was conducted within the HNF, an upland hardwood forest in the unglaciated central portion of southern Indiana. The HNF is located within the Highland Rim and Shawnee Hills Ecological Sections of the Interior Low Plateau (Homoya and others 1985). The 80000 ha forest is divided between the Brownstown Ranger District in the north, and the Tell City Ranger District in the south. The focus of this study is the Tell City Ranger District which is further subdivided into the Patoka Lake and Tell City management units.

The majority of the Tell City and Patoka Lake management units fall within the Crawford Uplands Ecological Subsection of the Shawnee Hills Section, although the two units have large areas within the Escarpment Subsection (Homoya and others 1985). The Patoka Lake area also has a minor portion of its area in the Mitchell Karst Plain Subsection, although no units were sampled in this area.

The Crawford Uplands Subsection is characterized by rugged hills of acid silt loams of the Wellston-Zanesville-Berks association formed from sandstone and loess, which are marked by sandstone outcrops and rock shelters. Broad ridge tops and flats may also be found throughout the area. Oak-hickory is the dominant forest type on the upland slopes. White oak, black oak, scarlet oak, chestnut oak, and hickory species (table 1) are typical of the upland slopes, while more mesic species such as American beech, sugar maple, white ash, yellow-poplar, and black walnut are more common in the coves.

In the Escarpment Subsection, sandstone outcrops and rock shelters are not present as in the Crawford Uplands Subsection, although much of the upland sections are otherwise similar in soils and topography. However, the lower areas may contain limestone-derived soils and karst topography. In the upland areas, post oak and black oak will tend to replace chestnut oak on drier sites, while some of the cove species present on the Crawford Uplands Subsection are absent in the Escarpment Subsection.

Sample sites were chosen based on previous selections made during a 1986-1987 study conducted by Fischer (1987). Fischer selected mature upland hardwood sites on the HNF that were clearcut harvested between 1969 and 1982 and a minimum of five years old at the time of first measurement. United States Forest Service (USFS) records containing location, unit size, and sawtimber volumes were compiled for all stands.

Field Methods

Study sites were outlined using SOLO Field GPS software® (TDS, Corvallis, OR) to more accurately determine size and location of each stand. Permanent sampling plots were established on a 63.5 x 63.5 m grid using SOLO Field GPS software (<3 m accuracy), which yields an approximate sampling intensity of 2.5 plots/ha. Each plot consisted of a 0.04 ha tree tally and a 0.004 ha reproduction plot.

Within each 0.04 ha plot, all trees with a diameter at breast height (dbh) greater than 2.54 cm were tallied by species and measured using calipers. The dbh, crown class (dominant, intermediate, suppressed), and origin (sprout, seed) was recorded for each tree. Within each 0.004 ha plot, all trees less than 2.54 cm dbh were tallied and species recorded.

Aspect at each plot was recorded by compass to the nearest 5° of azimuth. Slope percentage to the nearest 5 percent was recorded using a clinometer, and slope position was classified as a ridge, shoulder, mid-slope, toe-slope or bottom. One tree deemed to be representative of average canopy height was selected and measured to the nearest 1.5 m using a clinometer. The plot was also assigned a category based on the amount of surface rock present (< 1 percent, 1 – 10 percent, > 10 percent). A digital photograph was taken to provide a perspective of the four cardinal points as viewed from plot center.

Data Analysis

For the purposes of this study, we considered only dominant-codominant trees from the 1987 and 2004 data sets. Dominant-codominant trees are the best indicators of what species are established on a site, and given that the stem exclusion stage is well underway, this may provide us with a clearer picture of future stand composition. This approach is similar to that used by Hilt (1985). Pre-harvest species composition was derived from USFS records outlining final sawlog volumes harvested from each stand. It was assumed that there was an average of 0.354 m^3/tree harvested (mean tree: 40.6 cm with two 4.9 m logs), and that each tree was a member of the overstory.

Species were assigned to 6 species groups: mixed hardwood, black cherry-ash-walnut, yellow-poplar, white oaks, red and black oaks, and other oaks (table 1), as used by the HNF. We then divided species into finer groups for a more thorough examination. Considering that the number of dominant trees per acre are predominantly a function of stand age and site quality, we used relative density (RD) (number of stems of a given species/total number of stems tallied) to quantify species composition. In addition, relative frequency (RF) (number of plots where a species occurred/total number of plots) was tabulated for each species group. We also computed importance value (IV = (RD+RF)/2) of each species group. Of particular interest was the change in each of these values by species group over the 17-year time period. Differences in the RD, RF, and IV of the two data sets were denoted as ΔRD, ΔRF, and ΔIV.

Species groups were stratified by a combination of aspect code and slope position code. Aspect code was determined using Beers and others (1966) aspect transformation procedure, which was reduced to 4 aspect codes. Aspect codes 1 and 2 range from southeast to northwest, typically drier sites, while aspect codes 3 and 4 denotes an aspect ranging from northwest to southeast (fig. 1). Slope position was grouped according to lower, middle, and upper slope, an approach adopted by Hilt (1985).

RESULTS AND DISCUSSION

It is evident in table 2 that composition of sampled stands looks much different today than the pre-harvest period. On average, oaks were the dominant species of the overstory with a RD of 67 percent. In contrast, average RD of yellow-poplar and cherry-ash-walnut groups each averaged only 8 percent. The oak groups all show striking declines in RD following harvest, while the mixed hardwood, yellow-poplar and cherry-ash-walnut groups average 90 percent of the regenerating stands and dominate the canopy of the stands in 1987. The 2004 data show that, although the oaks have increased in RD as these stands mature through the stem exclusion stage, yellow-poplar and cherry-ash-walnut groups continue to increase in RD. The result is that these stands now have a very different composition than they did in 1987; however, it should be noted that the oaks do have an average greater number of trees per hectare in a dominant canopy position relative to the pre-harvest numbers, thus some sort of management intervention could be used to elevate the status of oaks in the canopy of these stands.

A more detailed examination of the data with more refined species groups shows that black cherry composes a large component of the cherry-ash-walnut group, RD of 16 percent in 2004 (table 3), and yellow-poplar has the highest RD of dominant species, 17 percent. Sugar maple, red and black oak group, and white ash follow in RD with 10, 9 and 8, respectively.

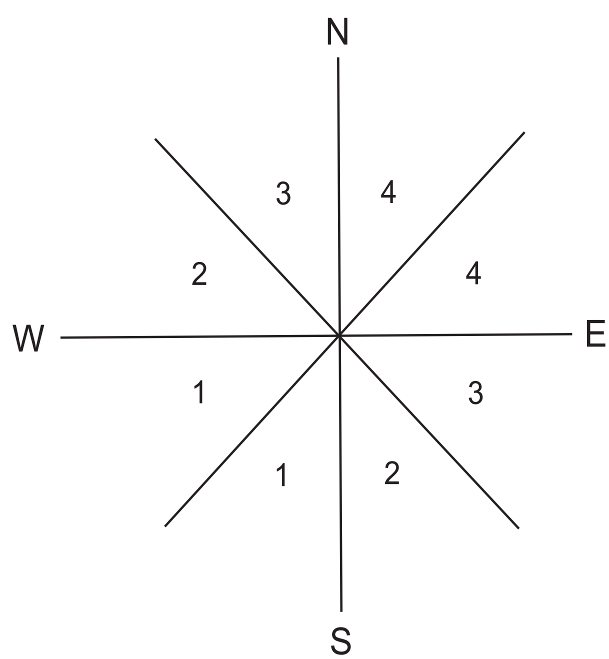

Figure 1—Aspect transformation code (adapted from Beers and others 1966).

Table 2—Relative density, and trees per hectare of species groups on 32 sampled stands on the Tell City Ranger District of the Hoosier National Forest including preharvest estimates and datasets from 1987 and 2004

	Preharvest[a]		1987[b]		2004	
Species group	TPH	RD	TPH	RD	TPH	RD
White oak	32	26	109	3	37	7
Red and black oak	37	31	133	5	52	9
Other oak	12	10	49	2	27	5
Cherry-ash-walnut	5	4	388	16	138	25
Yellow-poplar	5	4	356	16	99	17
Mixed hardwood	30	25	1445	58	210	38

RD = relative density; TPH = trees per hectare.
[a] Estimated from timber volume removed and assumes 0.354 m^3 per tree.
[b] Adapted from Fischer (1987).

Table 3—Average relative density, relative frequency, and importance value of species groups on 32 sampled stands on the Tell City Ranger District of the Hoosier National Forest and the difference (∆) between the period from 1987 and 2004

	1987			2004			Change		
Species group	RD	RF	IV	RD	RF	IV	∆ RD	∆ RF	∆ IV
White oak	3	13	8	7	48	27	4	35	19
Red and black oak	5	21	13	9	59	34	4	38	21
Other oak	2	6	4	5	22	14	3	16	9
Black cherry	9	38	23	16	80	48	7	42	25
Yellow-poplar	16	43	30	17	68	43	1	25	13
Red maple	4	13	9	6	35	20	1	22	12
Sugar maple	9	31	20	10	56	33	1	25	13
White ash	7	25	16	8	52	30	1	27	14
Miscellaneous	20	60	40	4	34	19	-15	-26	-21
Sassafrass	11	31	21	6	38	22	-5	7	1
Elm spp.	7	25	16	5	35	20	-2	11	4
Other hardwood	4	17	10	4	32	18	-1	15	7
Hickory spp.	1	6	4	2	20	11	1	15	8
Aspen	1	2	2	1	7	4	1	5	3
Black walnut	0	1	1	0	8	4	0	6	3

RD = average relative density; RF = relative frequency; IV = importance value.

Numerous studies have shown similar patterns of dominance by shade intolerant or noncommercial species in stand regeneration after clearcut harvesting (Standiford and Fischer 1980; Beck and Hooper 1986; Hilt 1985). In the same natural region of this study, Jenkins and Parker (1998) found that yellow-poplar and black cherry importance in the overstory also greatly increased after clearcut harvesting relative to reference stands. In 90 oak-dominated stands between the ages of 20 and 33 in Pennsylvania, Gould and others (2002) found that even-aged silvicultural prescriptions resulted in significant declines of relative basal area of all oak species, accompanied by large increases in red maple and sweet birch (*Betula lenta* L.).

If not already in a dominant crown position as crown closure begins, oaks can attain a dominant position in the canopy through either faster growth than its competitors, or persistence (Johnson and others 2002). Black cherry, followed by the red and black oak group, and the white oak group showed the greatest average increase in all three categories: RD, RF, and IV (refer to table 3). When the three oak groups are examined collectively, it is evident that a larger percentage of oaks have assumed a dominant position in the canopy relative to the data in 1987 (fig. 2). It would appear that many oaks were able to persist and grow in the competitive stem exclusion stage.

The miscellaneous group in table 3 is composed of non-commercial species, and they have shown a marked decrease in RD, RF and IV in the time between measurements. This is related to the silvics of the species in question, largely redbud, hornbeam, hophornbeam, and dogwood. These species are of small to medium stature, and they are often found in the understory and mid canopies of mature stands.

The black cherry, red and black oak, and white oak groups showed the largest increases in IV from 1987 to 2004, thus taking advantage of the increased growing space resulting from the loss of the miscellaneous species from the canopy. The increase in IV was largely a result of their large increases in RF. This implies that these species have increased their spatial distribution throughout these stands, likely through persistence and growth in the highly competitive stem exclusion period.

Gould and others (2002) observed significant differences in larger quadratic mean diameter of oak species compared to red maple and sweet birch in stands 20 to 33 years of age. In a 28 year old clearcut in southeastern Ohio, Heiligmann and others (1985) observed that potential oak crop trees exhibited

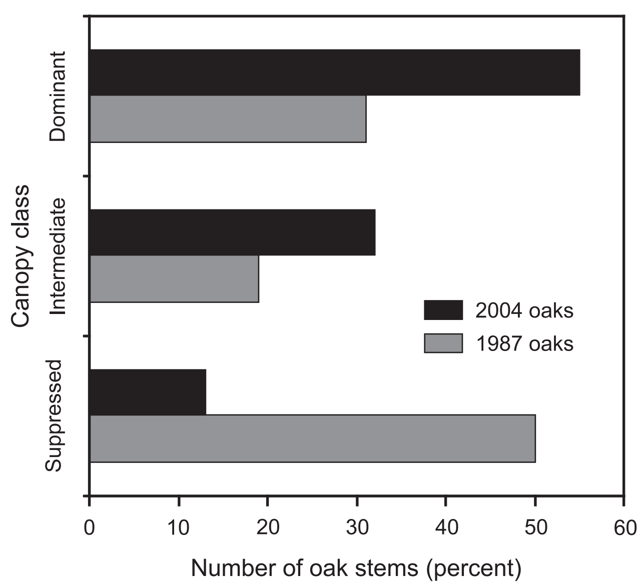

Figure 2—Percent number of oak stems by canopy class for 1987 and 2004 oak regeneration data.

very competitive average dbh growth rates in clearcuts when compared to yellow-poplar and red maple, falling behind only the mixed hardwood group. Williams and Heiligmann (2003) found that the average diameter of oak-hickory crop tree group in 38 year old clearcuts in Ohio were not significantly different than the mixed hardwood group, but both groups average dbh were greater than that of red maples. They also observed oaks ability to persist by correlating the number of overstory oak-hickory 38 years after clearcutting relative to 18 years after harvest.

Oaks' growth potential and ability to persist may differ according to site location as indicated by George and Fischer (1989). They determined that the interaction of slope position, transformed aspect, and age were significant in determining the RD of dominant trees for all species with the exception of black walnut. Figure 3 shows the changes in RD, RF, and IV of the main species of interest.

The white oak group is the only group to exhibit a positive increase in RD, RF and IV across all categories when influence of slope and aspect are combined. The red and black oak group improved in IV, with a range of 4 to 33, across all categories with the exception of aspect code 4 on the upper slope positions. The other oak group showed a similar pattern, with a range of IV increase of 2 to 14, although it showed a range of IV values of -11 to 2 in the upper slope positions overall.

There is extensive literature discussing oaks' lack of ability to compete on more mesic sites, and that they have greater competitive success on xeric sites. This appears to hold true in the stem initiation stage and early stages of the stem exclusion stage, as evidenced in the 1987 data set (Fischer 1987). Jenkins and Parker (1998) observed that white oak, red oak, and black oak had higher overstory density and IV on dry-mesic slopes compared to mesic slopes, and black oak and white oak both had higher overstory density and IV than yellow-poplar on older dry-mesic clearcuts. Black oak is the only species that did not show a significant difference in IV relative to dry-mesic reference stands in stands 16 to 27 years old. Hilt (1985) found that the interaction of age and site were significant in determining RD of dominant and codominant oak trees. Oaks dominated clearcuts greater than 15 years of age on poorer sites, while yellow-poplar, maple, black cherry, white ash and aspen eventually controlled the higher quality sites.

It may be argued that a drought in 1987 benefited the oaks which have greater drought tolerance than many of their primary mesic species competitors. Although many yellow-poplar were found to be dead or injured on these upper slope positions, yellow-poplar increased in RD, RF, and IV on all aspects of upper slope positions, while the oaks showed mixed results on the upper slopes. Even on the driest sites, upper slopes of aspect 1, where the oaks all increased in IV, yellow-poplar also increased, while the miscellaneous species group exhibited its greatest decline in RD, RF, and IV on these sites. Somewhat surprisingly, the other oak group declined in RD across all aspects on the upper slopes. Overall, the white oak and red and black oak groups showed a more consistent increase in RD, RF and IV across all aspect code and slope position combinations with the exception of the very driest sites found on aspect code 1 of upper slopes.

This evidence may seem contrary to the current literature, but, in fact, it supplements the literature. Most studies examined a relatively short time frame after clearcutting but this study allowed us to examine average change in species composition throughout the period of stem exclusion. While concern regarding decline of oaks in the CHFR appears to be valid, oaks have greatly decreased in RD compared to pre-harvests levels, our data suggests that oaks can compete on more mesic sites during this period. The average number of oak trees per hectare found on these sites is greater than that found in the original stands, which indicates that some form of intervention could help preserve the oak component of many of these regenerating stands.

These findings are important because they exhibit oaks ability to withstand intense competition for resources on these productive sites at a critical period of stand development. The fact that all three oak groups increased in RF and IV across all but one category of combined aspect code and slope position,

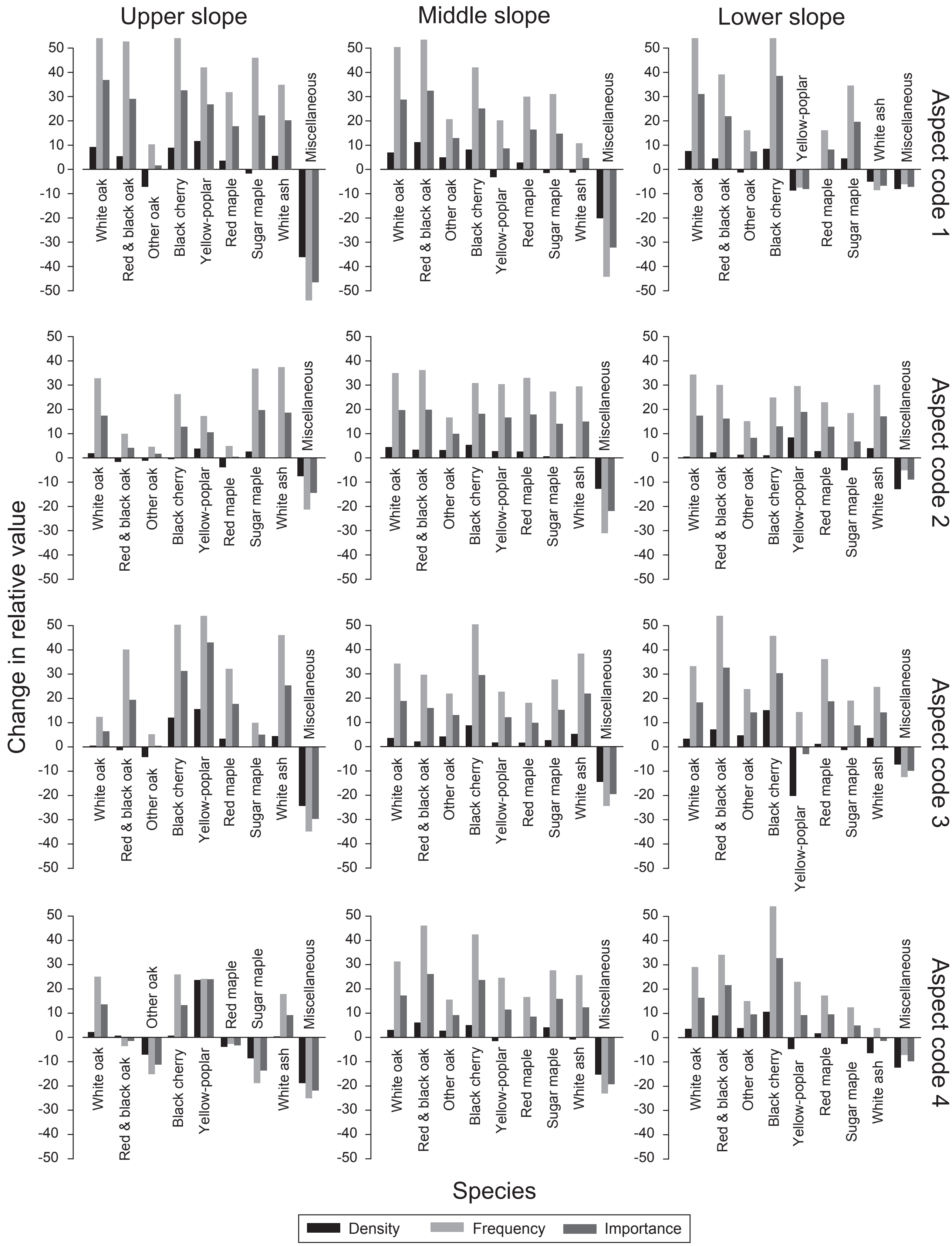

Figure 3—Change in relative values between 1987 and 2004 by slope position, transformed aspect code, and species group.

confirms the competitive ability of oaks in the period of development examined in this study. This information may help provide forest managers with more flexibility in applying silvicultural options to increase amount of oak in regenerating forests in the future. It may also help focus the timing and spatial applications of silvicultural treatments when oak regeneration is the management goal.

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OAK REGENERATION RESPONSE TO MODERATE AND HEAVY TRAFFIC UNDER MECHANICAL HARVESTING IN AN OAK-HICKORY FOREST ON THE CUMBERLAND PLATEAU

Callie Jo Schweitzer[1]

Abstract—Forest harvest operations can cause ground disturbances that negatively impact regeneration. On the Cumberland Plateau, managers must often rely on very small (less than a foot in height) oak advanced reproduction that is susceptible to disturbance by harvesting equipment. Furthermore, sites on the plateau top are often harvested when conditions are too wet to permit operations elsewhere, and the potential for small seedlings to be pulled from the ground may be heightened because of greater soil moisture. This study was designed to assess the effect of heavy and moderate equipment traffic on small oak advance reproduction under a clearcutting prescription. A feller-buncher and grapple skidding were used to harvest sites under "free access," resulting in heavy traffic on the sites, or under "strip access," with moderate site traffic. Five hundred oak seedlings were permanently tagged preharvest; species, height, and basal diameter were recorded and have been remeasured 3 years postharvest. Fifty-three percent of the tagged seedlings survived, and the survival rate for seedlings exposed to moderate traffic did not differ from that for seedlings exposed to heavy traffic. No evidence of seedlings being pulled out of the ground was observed. After three growing seasons, there is no significant difference in site disturbance between the two treatments. Initial assessment of the impact to the regeneration suggests that little damage was incurred under heavy equipment traffic.

INTRODUCTION

Forest harvest operations usually result in ground disturbances that may negatively impact regeneration. Because many stands located on the Cumberland Plateau have been degraded by generations of selective logging, clearcutting is often the only viable management option. Clearcutting on the plateau is most economical when implemented by mechanical harvesting, using a feller-buncher and grapple skidding. There are concerns that because of the topography and species composition, heavy traffic by such equipment may negatively impact desirable regeneration and small seedlings of the oak species in particular.

Advance reproduction of oak is the key to obtaining oak as a component of the future overstory in upland hardwood systems. Many studies have shown that the size of this advance reproduction before the final harvest is positively related to the growth of the reproduction after the overstory removal. However, on Cumberland Plateau sites, managers must often rely on very small advanced reproduction as the larger size classes are nonexistent. Therefore, the physical effect of harvesting practices on these small seedlings is very important.

Current forest conditions on the Cumberland Plateau vary greatly. Both site characteristics and past disturbance history have contributed to stands that are considered to be of low to medium quality. The most viable management option is often to clearcut to minimize costs and to aid in regeneration of a better quality stand.

Regeneration of hardwood stands in these systems has been documented in key studies by Loftis (1983, 1985, 1990), McGee (1967, 1975), McGee and Hooper (1970), Sander (1971, 1972), Sander and Clark (1971), and Sander and others (1976). These studies have shown that growth of oak reproduction following a harvest is a function of the size of advance reproduction and the pre-existing vegetative structure. Stump sprouts and advance reproduction must both be considered when evaluating the

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regeneration potential. However, managers often do not have the time and resources it takes to promote small advance reproduction into larger size classes. As a result, they rely on the small reproduction (< 1 foot in height) whose fate becomes of paramount importance to successful regeneration.

Assessments of ground disturbances that result from silvicultural operations in the Cumberland Plateau region have focused on physical site characteristics. Soil and litter displacement studies have described the surface soil conditions associated with forest operations conducted with the appropriate equipment (Aust and others 1993, Dyrness 1965, Greacen and Sands 1980, Green and Stuart 1985, Incerti and others 1987, Miller and Sirois 1986, Reisinger and others 1988). Few studies in the Cumberland Plateau region have focused on the impacts of harvesting traffic on small oak reproduction (Shostak and others 2002).

This study was designed to assess the effect of moderate and heavy traffic by equipment on small oak advance reproduction following clearcutting. Because of the nature of sites on the Plateau top, clearcutting operations with a feller-buncher and grapple skidding usually allow the feller-buncher free access to all trees on the site and result in heavy traffic throughout the site. An alternative to this free access technique is to designate strips of access and allow the feller-buncher to pick only trees that can be reached from these strips. Trees are then bunched and placed on the strip for skidding. Current management objectives include increasing the oak component while maintaining a complex and diverse species mix that will compliment wildlife habitat requirements and objectives. We planned to assess the disturbance by examining preharvest and postharvest conditions, tagging individual oak seedlings, and quantifying the physical soil characteristics before and after harvesting.

METHODS

Study Area

The study site is located in Jackson County, Alabama. The study was concentrated on a 20-acre area on the strongly dissected southern portion of the mid-Cumberland Plateau (Smalley 1982). The soils are moderately deep to deep, loamy, and clayey. The slope does not exceed 10 percent. The soil is well drained and low in fertility. Site index is 60 (base age 50) for the upland oaks (*Quercus alba* L., *Q. coccinea* Muench., *Q. montana* L., and *Q. velutina* Lamarck) and 85 (base age 50) for yellow-poplar (*Liriodendron tulipifera* L.). The yellow-poplar typically occurs on concave surfaces on the plateau (Smalley Land Type 1, broad, undulating sandstone uplands (Smalley 1982)). Oak reproduction is usually prolific on these sites, although seedling height is often < 2 feet. Clearcutting is commonly used for regenerating these sites because competition is sparse and oak advance reproduction numbers are high.

Study Design

Two disturbance treatments were tested. Treatments are adjacent 1-acre units with 10 replications per treatment. Treatment units were strips 66 feet wide by 660 feet long. Treatments were assigned systematically, alternating free access by the equipment (heavy traffic) with strip-only access (moderate traffic). In the heavy traffic treatment, the operator of the feller-buncher was allowed to choose the shortest route when approaching the trees. When possible, the trees were skidded after bunching. However, many were skidded from the fell point. In the moderate traffic treatment, the operator of the feller-buncher was allowed to select, cut, and bunch trees only from an access trail. This trail was then used for skidding. The entire 20-acre area was clearcut harvested in the fall of 2001 and winter of 2002.

Data Collection and Analysis

We systematically established 5 measurement plots per treatment unit prior to treatment application. We permanently marked the plot centers with rebar and captured their GPS coordinates. Regeneration was sampled on 0.01-acre circular plots. Seedlings were tallied by species in 1-foot height classes, up to 4.0 feet tall, and then by diameter. Using the same plot center, we established a 0.025-acre plot and recorded species and diameter at breast height (d.b.h.) for all trees with a d.b.h. > 1.6 inches.

We selected five oak seedlings that were representative of the plot species and permanently tagged them with a brass tag. Data collected about these tagged oaks included species, distance and azimuth from plot center, height, and basal diameter. We remeasured all regeneration plots in 2004.

We assessed and recorded soil and litter displacement (disturbance) on the regeneration plots immediately after harvesting in March 2002 and in the fall of 2003 and fall of 2004. We recorded the soil disturbance class (defined in Kluender and Stokes 1992) as untrafficked, trafficked with litter in place, trafficked with litter removed, trafficked with mineral soil exposed, or trafficked with mineral soil displaced to top of litter. Additionally, we recorded the number and depth of soil depressions.

Analysis of variance according to a randomized block design was used to quantify the significance of treatment differences; t-tests and Duncan's new multiple range test in SAS version 8.1 were used to separate means at an alpha level of 0.05 (SAS Institute 1990).

RESULTS AND DISCUSSION

Preharvest Tree Composition

Units averaged 130.3 square feet of basal area per acre (BA/A) and had 554 stems per acre (SPA). The dominant species in the stands were the oaks (black oak, chestnut oak, scarlet oak, and white oak). They represented 79 percent of the total BA/A. Other common mid- and overstory species included sourwood (*Oxydendrum arboreum* DC.), red maple (*Acer rubrum* L.), and hickories (*Carya glabra* Sweet, *C. ovata* K., *C. glabra* var. *odorata* (Marsh. Little), *Carya ovalis* [Wangenh.] Sarg.), representing 7, 6, and 4 percent of the total BA/A, respectively.

Regeneration plots averaged 9,698 stems per acre (SPA). There was a total of 28 different species. Sixty-seven percent of the reproduction was < 1 foot in height and 28 percent were small oak stems. The majority of these small size-class stems was in the other species category (*Diospyros virginiana* L., *Magnolia acuminata* L., *Ulmus* spp., *Cercis canadensis* L., *Ostrya* spp., *Ilex* spp., *Vaccinium* spp., and others). Five percent of the reproduction, 468 SPA, was > 1.5 inches in d.b.h. Species distribution in this size class was 31 percent white oaks, 21 percent sourwood, 14 percent blackgum, and 13 percent red maple.

Soil Disturbance

In March 2002, immediately after harvest, there was significantly more logging disturbance (rutting and bare soil exposure) in the heavy traffic units than in the moderate traffic units. However, in 2003 and 2004 the treatment-to-treatment difference in disturbance was no longer significant. Within each treatment, the measured disturbance decreased significantly with time. There was significantly less disturbance in 2003 than 2001, and significantly less in 2004 than 2003.

In 2002, 58 percent of the moderate traffic plots was characterized as trafficked with litter in place or litter disturbed, but without any mineral soil exposed, and 12 percent of the plots had traffic with mineral soil exposed. Sixty percent had at least one 6-inch deep depression. Forty-four percent of the heavy traffic plots had litter in place or slightly disturbed and 20 percent had exposed mineral soil. Fifty-four percent had at least one 6-inch deep depression. In 2003, 34 percent of the moderate traffic plots had traffic with litter in place or with litter disturbed, and 10 percent had mineral soil exposed. In 2003, 20 percent of the heavy traffic plots had litter disturbance, and 32 percent had mineral soil exposed. Twenty-two percent of both moderate and heavy traffic plots had depressions in 2003. By 2004, 2 percent of moderate traffic plots and 4 percent of heavy traffic plots had traffic with litter in place, and the remaining plots were all characterized as untrafficked. There were no depressions recorded in 2004.

Postharvest Oak Seedling Response

SPA of black oak, chestnut oak, scarlet oak, and white oak were reduced significantly in both treatments following harvest (table 1). Following harvest, total SPA of all species combined was significantly

Table 1—Average number of oak regeneration stems per acre from 2001 (preharvest) to 2004 for the two treatments

Species	Moderate traffic 2001	Heavy traffic 2001	Moderate traffic 2004	Heavy traffic 2004
	- - - - - - - -	- - - - - - - *stems per acre*	- - - - - - - -	- - - - - - - -
Black oak	757 (8)	540 (6)	288 (3)	459 (4)
Chestnut oak	743 (7)	968 (10)	378 (4)	450 (4)
Scarlet oak	855 (9)	686 (7)	490 (5)	478 (4)
White oak	338 (3)	437 (5)	384 (3)	241 (2)
All species	10,030	9,366	10,850	11,096
All oak species	2,693 (27)	2,631 (28)	1,540 (14)	1,628 (15)

Number in parenthesis is percent of all species tallied.
All differences between 2001 and 2004 by species and treatment were significantly different at $\alpha \leq 0.05$.

greater for the heavy traffic units than for the moderate traffic units. In the heavy traffic units there were significantly more black oak stems and fewer white oak stems than in the moderate traffic units.

Most of the oak advance regeneration was < 2 feet in height (table 2). The proportion of small oaks decreased significantly in both treatments following harvesting.

Survival of permanently tagged seedlings did not differ significantly from treatment to treatment (table 3). Fifty-three percent of all tagged oaks were alive following moderate traffic, and 38 percent were alive following heavy traffic. There was no clear evidence of seedlings being ripped from the ground. Nearly all of the dead seedlings had no visible signs of trauma, and some evidence (stem, roots, or both) of all but 10 seedlings was found.

The tagged seedlings averaged 0.7 feet in height and 0.1 inch in basal diameter. Three growing seasons after logging disturbance the seedling growth did not differ significantly between the two traffic treatments. An exception was chestnut oak, which grew 0.7 feet in the moderate traffic units and only 0.3 feet in the heavy traffic units.

CONCLUSION

Oak reproduction densities (1,540-1,628 SPA) and stocking levels (14 percent) after three growing seasons suggest that harvesting traffic had minimal impact on regenerative potential on these disturbed sites. Although the plateau tops are often harvested when conditions are too wet for machinery on the slopes, only minimal degradation to the site appears to occur. The disturbance seems to have been mitigated within just 3 growing seasons. None of the seedlings appeared to have been dragged or pulled from the ground. Current oak reproduction is small but has grown since the treatments were applied.

The harvesting methods used in this study did not result in severe soil disturbance or immediate impacts on the seedlings. The high competitiveness of oaks on these lower quality sites, the small amount of competition from other species, and the relatively high numbers of advance reproduction of oaks all contribute to a desirable species composition in these stands. Foresters and logging contractors have some control over the severity and extent of soil disturbance and should continue to take harvesting season into account, limiting operations during high soil moisture conditions and employing specific harvest planning techniques.

Table 2—Oak 2001 preharvest and 2004 postharvest regeneration average stems per acre for stems < 2 feet in height/total stems (percent of total), for moderate and heavy traffic harvesting treatments

Species	Moderate traffic 2001	Heavy traffic 2001	Moderate traffic 2004	Heavy traffic 2004
Black oak	668	486	247	354
	757 (88)	540 (90)	288 (86)	459 (77)
Chestnut oak	615	798	248	250
	743 (83)	968 (82)	378 (66)	450 (56)
Scarlet oak	763	650	414	354
	855 (89)	686 (95)	490 (84)	478 (74)
White oak	241	354	284	150
	338 (71)	437 (81)	384 (74)	241 (62)

Table 3—Oak seedling survival and growth comparisons, by species, between moderate and heavy harvesting traffic treatments

Species	Traffic treatment	Pretreatment number	Number alive 2004	Number dead 2004	Alive 2004	Height growth	Diameter growth
					percent	*feet*	*inches*
Black oak	Moderate	63	29	34	46	0.6	0.17
	Heavy	62	21	41	34	0.4	0.13
Chestnut oak	Moderate	51	28	23	55	0.7[a]	0.14
	Heavy	72	27	45	38	0.3	0.10
Scarlet oak	Moderate	107	63	44	59	0.3	0.11
	Heavy	99	41	58	41	0.2	0.12
White oak	Moderate	29	13	16	45	0.4	0.11
	Heavy	17	7	10	41	0.5	0.10
All oaks	Moderate	250	133	117	53	0.5	0.13
	Heavy	250	96	154	38	0.3	0.11

[a] Indicates significant difference between traffic treatments at $\alpha \leq 0.05$.

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FIFTEEN YEARS OF STUMP SPROUT DEVELOPMENT FOR FIVE OAK SPECIES IN SOUTHERN INDIANA

Dale R. Weigel and Daniel C. Dey[1]

Abstract—Following even-aged harvesting, oak stump sprouts can contribute significantly to the presence of oak in the future forest. It is important to understand how oak sprout clumps develop, grow, and self-thin. A study to evaluate oak stump sprout dynamics was initiated on the Hoosier National Forest in southern Indiana in 1987. Before clearcut harvesting and 1, 5, 10, and 15 years after harvest, 2,187 oak trees (*Quercus* spp.) were measured. Species studied included white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and northern red oak (*Q. rubra* L.). Of all the trees measured, 4 and 5 percent produced dominant or codominant stems 10 and 15 years after harvest, respectively. For stumps that sprouted, 12 percent produced dominant stems and 19 percent produced codominant stems 10 or 15 years after harvest. Chestnut oak sprouts were the tallest (5.3 m) at year 5 while white oak sprouts were the shortest (4.1 m). After 15 years, chestnut oak stump sprouts remained the tallest (> 12 m) while white oak and northern red oak were the shortest (< 10 m). Height of the dominant sprout in each clump averaged 11 m, 10.3 m, 8.8 m, and 6.2 m for trees that were in the dominant, codominant, intermediate, and suppressed crown classes, respectively. The average number of sprouts per clump dropped from 4.9 at year 5 to 3 at year 10 to 2.4 at year 15. Five years after harvest scarlet oak and northern red oak each averaged over 6 sprouts per stump while white oak averaged the fewest with just over 4 sprouts per stump. At year 10, sprouts per clump ranged from 2.7 for white oak to 3.7 for northern red oak. By 15 years after harvest the average sprouts per clump for the five species decreased to between 2.2 and 2.7.

INTRODUCTION

Oak species dominate the overstory of many forest stands in the Central Hardwood Region. They are important for wildlife, biodiversity, and timber production. Following harvest, oak stump sprouts provide a vital component to oak presence in subsequent developing stands (Sander and others 1984). It is important to understand how these sprout clumps develop, grow, self-thin, and contribute to the sustainability of oak species in the region.

Both Lamson (1983) and Wendel (1975) reported on height growth of stump sprouts for several oak species in Northeast clearcut stands. Wendel (1975) reported on height growth of oak stump sprouts the first 10 years after clearcutting while Lamson (1983) measured sprout height up to 17 years. They reported that all oaks were slower growing than other competing species such as yellow-poplar (*Liriodendron tulipifera* L.) and black cherry (*Prunus serotina* Ehrh.). Wendel (1975) found that season of cutting and site index were not related to sprout height or number of sprouts per stump. This differs from Buckley and Evans (2004) who reported white oak (*Q. alba* L.) and Shumard oak (*Q. shumardii* Buckl.) sprouting was greatest on stems cut in late summer, fall, or winter. Wendel observed that the number of stump sprouts decreased from over 20 per stump 1 year after harvest to less than 5 sprouts per stump at year 10. He also noted that the dominant stem in a clump of sprouts was not always the same stem over time.

In more recent research in oak stump sprouting dynamics, Weigel and others (2006) and Weigel and Peng (2002) observed that parent tree age, diameter-breast-height (dbh), species, and site index were important predictors of stump sprouting success at years 1, 5, 10, and 15 after clearcutting for five oak species in southern Indiana. They found sprouting probabilities decreased with increasing parent tree age and dbh, and the importance of site index varied by species and time since overstory removal.

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In our study of oak stump sprouting in southern Indiana, we evaluated sprout height growth and changes in sprout density for oak trees that produced sprouts after clearcutting. Specifically, our objectives were to determine if height growth of the dominant stump sprout and stump sprout density were different among the oak species, and if it varied by crown class at 5, 10, or 15 years after clearcutting.

METHODS

Study Sites

The study was conducted on the Hoosier National Forest in the Shawnee Hills and Highland Rim Sections (Keys and others 1995) of south central Indiana. Nine stands scheduled to be clearcut were selected for measurement. There were three stands in each of three age classes: 71-90, 91-110, and 110+. Harvesting was done between October 1987 and May 1989. In any given stand, we did not determine the season (growing or dormant) individual stems were harvested.

Measurements

Before harvesting, 0.04-ha plots were established along transects in the nine stands. We inventoried and tagged 1,371 white oak, 180 chestnut oak (*Q. prinus* L.), 399 black oak (*Q. velutina* Lam.), 130 scarlet oak (*Q. coccinea* Muenchh.), and 108 northern red oak (*Q. rubra* L.) that were greater than 4.0 cm dbh. Measurements included dbh on all trees and heights and ages of selected trees used for site index determination. Post-harvest measurements were completed 1, 5, 10, and 15 years after clearcutting. First-year measurements included aging the parent tree by counting rings on the stump surface and noting if any sprouts were present. Fifth- and tenth-year measurements included recording the number of sprouts and the height of tallest sprout. Tenth-year measurements also included recording the crown class (Smith and others 1997) of tallest sprout. At year 15 we remeasured surviving oak stump sprouts and recorded the number of sprouts and the height, crown class, and dbh of the tallest sprout.

Data Analysis

We used SAS GLM procedure (SAS Institute 2004) to determine differences in stump sprout density and height growth among oak species and crown classes. Student-Newman-Keuls multiple range test was used to detect within year differences in crown class and species.

RESULTS

Height Growth

At year 5, chestnut oak was taller ($p < 0.05$) than the other four species (fig. 1). Black oak and scarlet oak sprouts were similar in height and taller ($p < 0.05$) than white oak and northern red oak sprouts which were similar. This trend among species was the same at years 10 and 15. At year 10, chestnut and scarlet oaks were tallest ($p < 0.05$), followed by black oak ($p < 0.05$), and then white and northern red oak which were again similar in height. By year 15, chestnut oak was the tallest ($p < 0.05$), followed by scarlet oak ($p < 0.05$), then black oak ($p < 0.05$), and finally white and northern red oak.

As would be expected, stump sprouts in the dominant crown class were the tallest at both year 10 and 15 ($p < 0.05$), followed by sprouts in the codominant, then intermediate, and lastly, overtopped crown classes (fig. 2). By year 15, stump sprouts in the dominant crown class averaged over 11 m tall and were nearly twice as tall as the stump sprouts in the overtopped crown class, which were just over 6 m tall. Stump sprouts in both the intermediate and overtopped crown classes are no longer competitive.

Chestnut oak stump sprouts in the dominant crown class were taller ($p < 0.05$) than similarly classed sprouts of the other four oak species at both year 10 (fig. 3) and year 15 (fig. 4). Black oak and scarlet oak stump sprouts in the dominant crown class were similar in height both years and were taller ($p < 0.05$) than dominant white oak and northern red oak stump sprouts at years 10 and 15. These results are similar to those reported by Wendel (1975) for white oak, chestnut oak, and northern red oak 10 years after clearcutting. The heights for northern red oak were slightly shorter than those reported by Lamson (1983) for 12-year-old northern red oak stump sprouts.

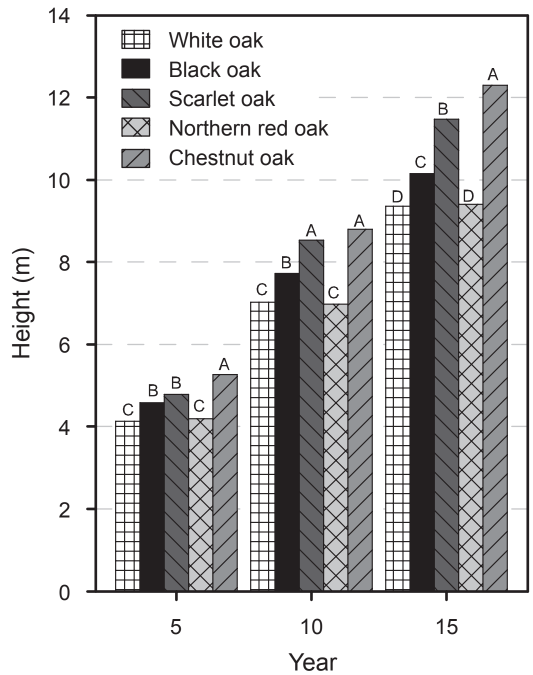

Figure 1—Height of stump sprouts by year and species. Within years, columns with the same letter are not significantly different (α = 0.05).

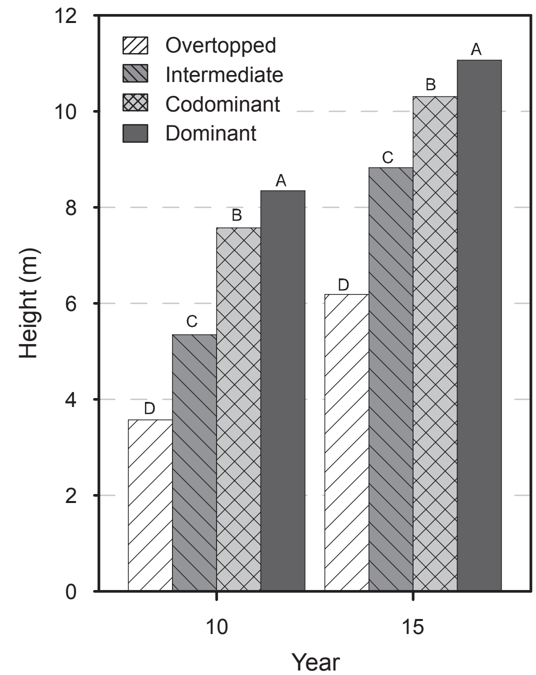

Figure 2—Height of stump sprouts by year and crown class. Within years, columns with the same letter are not significantly different (α = 0.05).

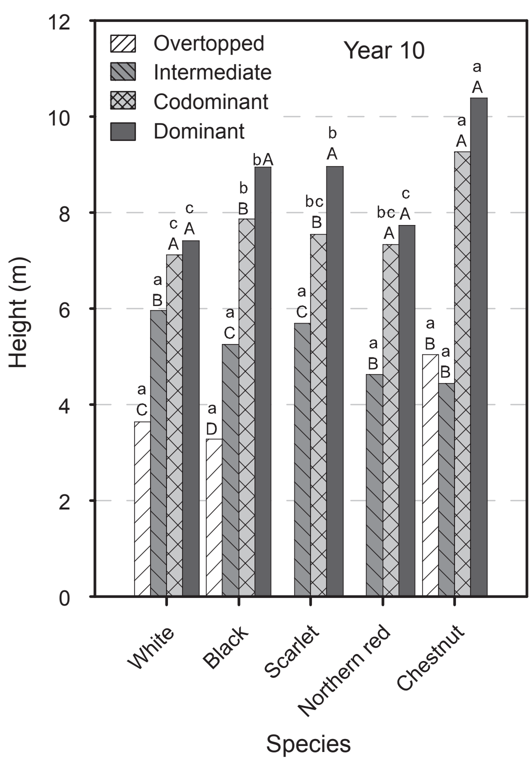

Figure 3—Height of stump sprouts at year 10 by species and crown class. Within the same crown class, columns with the same lower case letter are not significantly different. Within species, columns with the same upper case letter are not significantly different (α = 0.05).

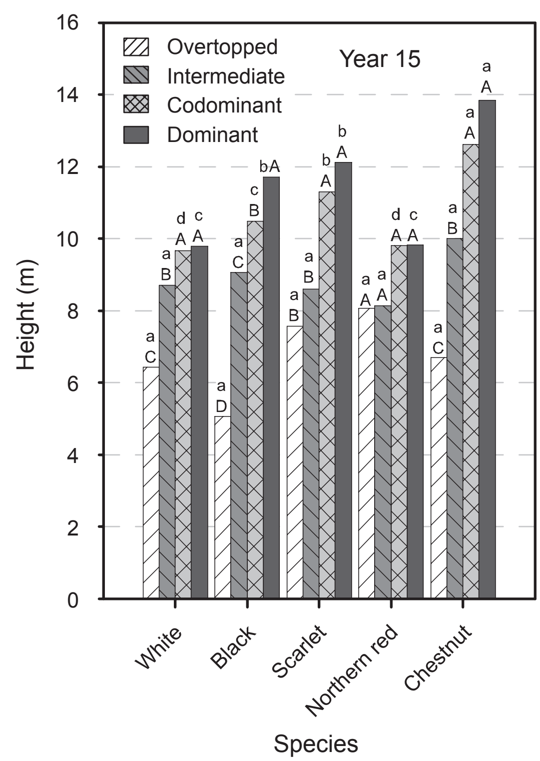

Figure 4—Height of stump sprouts at year 15 by species and crown class. Within the same crown class, columns with the same lower case letter are not significantly different. Within species, columns with the same upper case letter are not significantly different (α = 0.05).

Similar trends were observed for oak stump sprouts in the codominant crown class. Codominant chestnut oak stump sprouts were taller ($p < 0.05$) than the codominant stump sprouts of the other four oak species at age 10 and 15 (figs. 3 and 4). Codominant scarlet oak, black oak, and northern red oak stump sprouts were all similar in height at year 10. Only black oak sprouts were taller ($p < 0.05$) than codominant white oak stump sprouts at year 10. By year 15, scarlet oak was the second tallest within the codominant crown class, and was followed by black oak. White oak and northern red oak codominant stump sprouts were the shortest at year 15 ($p < 0.05$).

Oak stump sprouts in the overtopped and intermediate crown classes showed no differences in height either at year 10 (fig. 3) or year 15 (fig. 4). This is a strong indication that they are not competing well against the other dominant and codominant tree species on the sites and will not be a component of the future stand.

Within individual species, the sprouts in the dominant and codominant crown classes were similar in height at 10 and 15 years, except for scarlet oak at year 10 and for black oak both years (figs. 3 and 4). Except for northern red oak at year 15, the dominant and codominant stems were taller ($p < 0.05$) than the intermediate and overtopped stems.

Sprout Density

The five oak species all averaged more than four live stump sprouts per stump at year 5 (fig. 5). Northern red oak and scarlet oak stumps averaged over six sprouts while white oak stumps averaged the fewest sprouts, just over four, ($p < 0.05$). These densities of sprouts are slightly lower than those reported by Wendel (1975) for year 5. By year 10, the number of sprouts per stump dropped to less than four for all species except white oak, which had fewer ($p < 0.05$) than three sprouts per stump. These results correspond to those reported by Wendel (1975) at year 10 for white oak and chestnut oak, but are slightly less for northern red oak. Fifteen years after overstory removal there was no difference in the number of sprouts per stump by species. They all had less than three sprouts per stump (fig. 5).

Stumps with a sprout in the dominant crown class had higher density of sprouts per stump, > 3.5, ($p < 0.05$) than stumps with sprouts in other crown classes (fig. 6) at year 10. Stump sprouts in the overtopped crown class had the fewest ($p < 0.05$) sprouts, averaging 1.5 sprouts per stump. At year 15, stumps with dominant sprouts had higher densities, averaging 2.9 sprouts per stump, ($p < 0.05$) than the stumps in other crown classes. Stumps in the overtopped crown class again had the least dense sprout clumps ($p < 0.05$) averaging 1.7 sprouts per clump.

At year 10, there was no difference in density of sprouts per stump by species for stumps in the dominant crown class (fig. 7). Stump sprout density ranged from an average of 3.1 sprouts for white oak to 4.4 sprouts for northern red oak and chestnut oak stumps. White oak stumps (average 2.5 sprouts per stump), and scarlet oak (average 2.4 sprouts per stump) had fewer ($p < 0.05$) codominant sprouts than northern red oak, which averaged 4.0 sprouts per stump (fig. 7)

By year 15, there was no difference in sprout density between species for any of the crown classes (fig. 8). Sprout density per stump in the dominant crown class ranged from an average of 2.7 for white oak to 3.3 for chestnut oak. In the overtopped crown class, stumps tended to have the fewest sprouts, ranging from an average of 1.0 for northern red oak to 2.2 for black oak.

Within individual species, the only species showing a difference ($p < 0.05$) in the number of sprouts by crown class were white oak and northern red oak. At year 10 in the overtopped crown class, white oak had less dense stump sprout clumps. At the same time, northern red oak stumps had fewer stump sprouts per stump in the intermediate crown class, and no stumps in the overtopped crown class (fig. 7). By year 15, the overtopped stump sprouts of northern red oak were less dense than stumps in the dominant crown class (fig. 8). Dominant white oak stump sprouts were denser than the other stumps in the other three

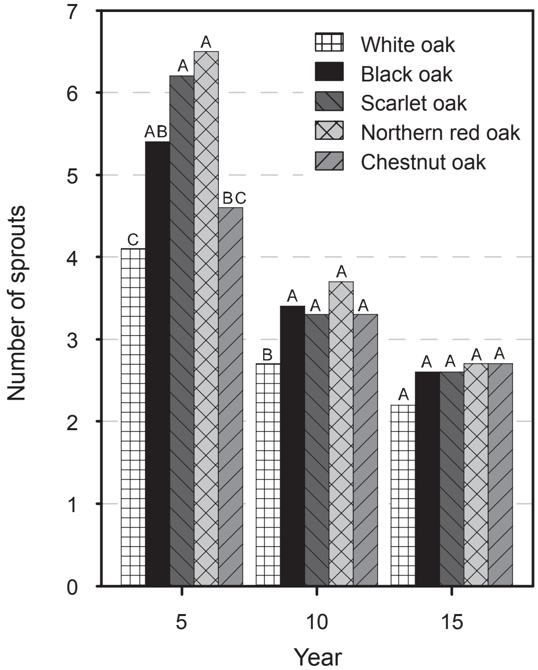

Figure 5—Number of stump sprouts by year and species. Within years, columns with the same letter are not significantly different (α = 0.05).

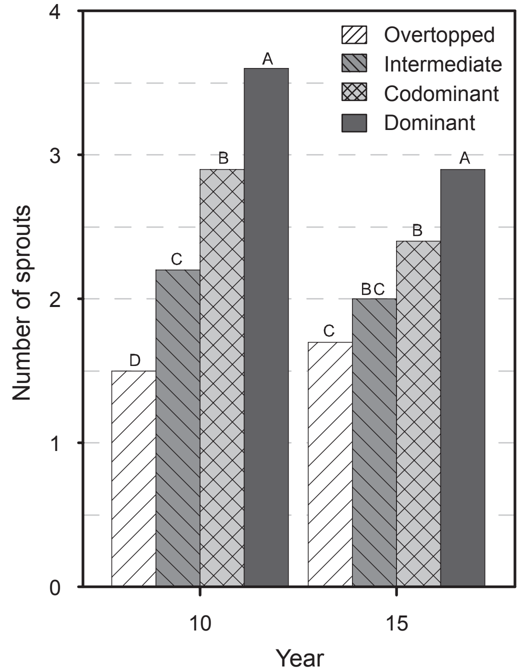

Figure 6—Number of sprouts by year and crown class. Within years, columns with the same letter are not significantly different (α = 0.05).

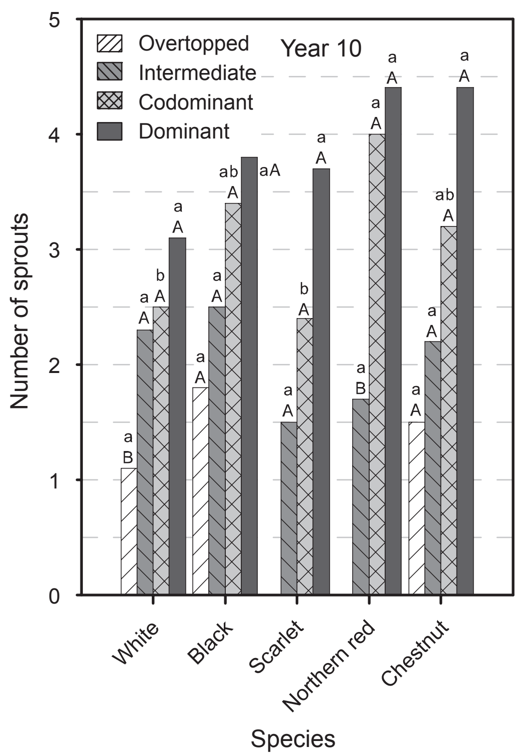

Figure 7—Number of stump sprouts at year 10 by species and crown class. Within crown class, columns with the same lower case letter are not significantly different. Within species, columns with the same upper case letter are not significantly different. For all analyses α = 0.05.

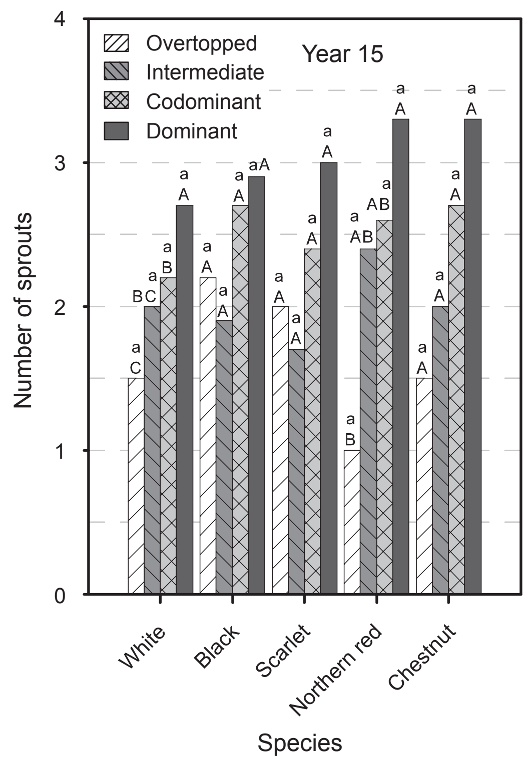

Figure 8—Number of stump sprouts at year 15 by species and crown class. Within crown class, columns with the same lower case letter are not significantly different. Within species, columns with the same upper case letter are not significantly different. For all analyses α = 0.05.

crown classes. White oak stumps in the codominant and intermediate crown classes had similar sprout densities, as were stump sprout densities in the overtopped and intermediate crown classes.

DISCUSSION AND CONCLUSION

Height growth was influenced by species. Chestnut oak stump sprouts were always the tallest while white and northern red oak sprouts were the shortest. This relation did not change with age. As would be expected, dominant sprouts were the tallest while overtopped sprouts were the shortest. Northern red, scarlet, and black oaks had the most sprouts at year 5 while white oak had the fewest. By year 15 this difference had disappeared.

As Loftis (2004) has reiterated "the First Law of Oak Silviculture had not been repealed", i.e., it is necessary to have competitive oak regeneration present when the overstory is removed. Sander and others (1984) developed a process to evaluate oak regeneration potential. One component of oak regeneration is sprouting from stumps. The results presented here plus those of Weigel and Peng (2002) and Weigel and others (2006) can be used to more quantitatively evaluate the contribution of stump sprouts to sustaining oak species in future forests.

Stump sprouts of white oak and northern red oak may need release from surrounding competition to remain competitive and in the dominant and codominant crown classes compared to chestnut oak, black oak, and scarlet oak. Care must be taken to not release the sprouts too extensively. This can have the adverse impact of slowing oak growth while releasing faster growing competitors (Allen and Marquis 1970, Nixon and others 1983, Schuler and Miller 1999, Ward 1995). White oak and northern red oak were on average 4 m shorter than chestnut oak and 2 m shorter than black oak and scarlet oak by year 15. Reduced height in white oak and northern red oak stump sprouts places them at a severe competitive disadvantage, suggesting that they could soon be permanently suppressed by surrounding competitors unless they are released by thinning early in the regeneration period.

Stump sprouts of the five oak species studied all underwent self thinning during the 15 years following complete overstory removal. It is reasonable to assume that the rate of self thinning has or will soon stabilize at approximately 1 to 2 sprouts per stump. The rate of natural self thinning suggests that it may not be necessary to mechanically thin the sprout clumps. However, it is not known if mechanically thinning the sprout clumps would have increased survival, height growth, or improved crown class position over what has occurred naturally.

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ARTIFICIAL REGENERATION

Moderator:

Stacy Clark
Southern Research Station

A COMPARISON OF THE 36-YEAR PERFORMANCE OF ARTIFICIAL AND NATURAL OAK REGENERATION IN THE RIDGE AND VALLEY PROVINCE OF EASTERN TENNESSEE

Samuel W. Jackson[1]

Abstract—Due to the apparent lack of natural oak regeneration success, this study was designed to determine if planting oak seedlings could improve the success of oak regeneration on a low to medium quality site in eastern Tennessee. The site was subjected to a severe wildfire followed by a salvage harvest and a subsequent site preparation treatment resulting in a complete clear cut of the burned area. Treatment blocks contained 1-0 bare root seedlings of white oak (*Quercus alba*) and northern red oak (*Q. rubr*a) that were planted on a 4 foot by 8 foot spacing and an adjacent portion of the stand was allowed to regenerate without the planted seedlings. At year 18, a release treatment was implemented, leaving half of each treatment block released and half unreleased. In unreleased treatments, mean tree height of oaks in the naturally regenerated blocks was 39 percent greater than planted northern red oaks and 221 percent greater than planted white oaks. In the release cells, mean tree height of oaks in the naturally regenerated blocks was 228 percent and 94 percent greater than planted northern red oaks and white oaks, respectively. Mean diameter breast height (dbh) of unreleased oaks was greater in the naturally regenerated treatment (44-280 percent) than planted oaks. In the release treatment, mean diameter of naturally regenerated oaks was 84-220 percent higher than that of planted oaks.

INTRODUCTION

One of the primary issues that silviculturists have faced over the last 50 years is the decline in oak regeneration (Van Lear 1990). As a mid-successional species, oaks (*Quercus* spp.) are being replaced by later successional species (Abrams 2000). Lorimer (1989) provides an in-depth look at the oak regeneration problem and possible solutions. As oak forests are harvested, most sites will regenerate with a smaller portion of oak than the original stand. O'Hara (1986) showed that on quality sites, yellow-poplar (*Liriodendron tulipifera*) dominated a site where an oak forest had been harvested at 80 years of age. Oak is generally more competitive on poorer quality sites, though red maple (*Acer rubrum*) may present some competition. To date, most research has focused on developing an understanding of this oak regeneration issue and identifying some possible ways to address it with silvicultural tools. One method is the use of artificial regeneration, the planting of oak seedlings, before or after harvesting to supplement the natural regeneration on a site.

However, many studies have shown that artificial regeneration is not successful. Both Johnson (1976) and McGee and Loftis (1986) reported very low success rates when planting northern red oak seedlings after clearcutting. Other research, though, has shown the potential for selecting for the number of first-order lateral roots of seedlings to improve seedling success (Clark and others 2000, Schlarbaum and others 1997). These roots are related to overall genetic growth qualities and may improve seedling survival. Johnson (1984) found that seedlings with larger diameters were much more likely to survive and grow than those of smaller diameters. Artificial regeneration research also has been undertaken following partial cuts. Johnson (1984) also evaluated under-planted seedlings after a shelterwood harvest. These seedlings exhibited a higher growth rate during the initial years after the overstory was removed than did the seedlings in a clearcut. Olson and others (2004) found, however, that there is often a high rate of mortality of under-planted seedlings due to mechanical damage when the overstory is removed as well as the shading produced by the remaining canopy. Buckley and others (1998) found that the strongest growth potential increases occurred in clearcuts or light (25 percent) overstory retention. However, when taking

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into consideration other factors, such as browsing and frost damage, the study found red oak seedlings were much more successful under partial canopies.

Protection of planted seedlings may also increase artificial regeneration success. Potter (1988) showed the growth benefits of seedling tubes when comparing tree with tubes to those without. The tubes protect the seedling from browsing by deer and also from wind. However, tubes are expensive and many managers are reluctant to conduct this fairly high intensity practice. Competition control, by herbicide or mechanical means, is also a way to promote the growth of artificial regeneration. Buckley and others (1998) indicated the importance of competition control, especially in harvest situations where little to no overstory was left.

The study described in this paper reviews a research project first established in 1968. White (*Q. alba*) and northern red (*Q. rubra*) oaks were planted after a wildfire and subsequent salvage operations. This study reviews data and the progress of the seedlings over the last 36 years. Many ideas and theories on oak regeneration have changed since this study was initiated. However, it is still representative of the issues relating to artificial oak regeneration and provides more information about natural and artificial oak regeneration. The study is an ongoing project on which several individuals have collected and analyzed data. Data collection was random at best over the last 20 years. This analysis collected current data and compares it with previous data.

OBJECTIVES

The primary objective of this study was to evaluate planted oak seedling survival and growth and compare the results with natural oak regeneration that had been developing on-site for the same period of time. Oak seedling success was determined by measuring and describing survival, diameter growth, and height growth.

STUDY AREA

The study site is located just north of Oliver Springs, Tennessee, near the community of Stephen Switch. The area is located in the Ridge and Valley province of eastern Tennessee on property owned by the University of Tennessee Forestry Research and Education Center (Lat. N 36° 3.696', Long. W 84° 26.056'). A stand of mixed oaks and other hardwoods dominated this variable but fairly xeric site of low soil productivity. Shortleaf (*Pinus echinata*), eastern white (*P. strobus*), and Virginia pine (*P. virginiana*) were once a significant part of the forest overstory. Approximately 1 acre of land was utilized for the study in a small drain. Aspect ranged from south to west and east.

This study was initiated after a wildfire burned the site on April 7, 1966. The fire was intense and destroyed much of the overstory. The timber was salvaged and remaining residual trees were injected with 2,4,5 –T amine herbicide in the spring of 1967. In March, 1968, the study was designed and seedlings were planted. Seedlings were 1-0 stock obtained from a Tennessee Valley Authority nursery and of an Alabama-66 seed source.

TREATMENTS

The stand was divided into 3 study blocks (fig. 1). Each study block as divided into four 56 foot by 56 foot treatment cells. In study block one, white oak seedlings were planted on 4 X 8 foot spacing (98 seedlings per treatment cell). In block two, northern red oak seedlings were planted on a similar spacing. In total, 392 seedlings were planted in each study block. In study block 3, no seedlings were planted, instead natural oaks were numbered with aluminum identification tags. Oak species found in the natural regeneration block were white oak, southern red oak (*Q. falcata*), scarlet oak (*Q. coccinea*), and black oak (*Q. velutina*), with little to no northern red oak present. During the second and third growing seasons after planting, half of the treatment cells in study blocks 1 and 2 were cleaned and weeded using hand tools, herbicides or combinations of both. Seedlings were protected from herbicides by plastic cone guards. The survival rate at the end of the first growing season was 98 percent in each of the two blocks.

Block 1 - White oak seedlings N = 392

Rep. 1 - release treatment n = 98	Rep. 1 - unreleased treatment n = 98	Rep. 2 - unreleased treatment n = 98	Rep. 2 - release treatment n = 98

Block 2 - Northern red oak seedlings N = 392

Rep. 2 - unreleased treatment n = 98	Rep. 2 - released treatment n = 98	Rep. 1 - released treatment n = 98	Rep. 1 - unreleased treatment n = 98

Block 3 - Natural oak regeneration N = 169

Rep. 2 - release treatment n = 40	Rep. 2 - unreleased treatment n = 33	Rep. 1 - released treatment n = 47	Rep. 1 - unreleased treatment n = 49

Figure 1—Experimental plot design at Stephen Switch, TN.

In late 1985 and early 1986, the seedlings, both planted and natural, were released. This was accomplished by cutting and applying herbicide to the stumps all non-oak species.

METHODS AND ANALYSIS

Diameter breast height (dbh), total height, and survival were determined for each seedling in study block 1 in 1987 and 1991, two and five growing seasons post-release. Study block 2 was measured in 1985, one growing season prior to the release treatment. Study block 3 was measured in 1986 and 1991, one growing season after release and again five seasons later. In November 2004, survival and dbh was recorded for each tree and total height was measured on a 30 percent sub-sample in all study blocks. The heights of the remaining trees were estimated with a regression analysis of dbh to total height. Regression formulas were calculated for each cell within each block (table 1).

Mean dbh, height, and survival rates were calculated for all years measured by using SAS 9.1 and the Proc Means statement. Additional analyses to detect differences between treatments were conducted in SAS using the General Linear Model procedure. Missing data in previously collected data was replaced by using a regression equation developed from the existing data (table 1). The Tukey's mean separation technique was used to test for treatment and block differences. While no measurements were taken at the time of release it is reasonable to assume that the average size of seedlings was similar in the unreleased and released treatment cells prior to treatment and differences between treatments were the direct result of the release treatment.

RESULTS

White Oak

Two years after the release treatment white oak bare root seedlings showed significantly greater dbh and height growth ($P<.0063$ and .0362, respectively) compared to unreleased seedlings. Released seedlings averaged 0.79 inches in dbh compared to 0.60 inches for unreleased seedlings and 9.9 feet in total height compared to 8.1 feet (tables 2 and 3, respectively). Similar results were found in 1991 at stand age 23,

Table 1—Regression equations for missing data replacement at Stephen Switch, TN, by block and year

Block	Year	Element	Equation	r^2
1 White oak	1987	Height	HT = 12.22 + 4.77(DBH)	0.388
		Diameter	DBH = -0.03 + 0.08(HT)	0.388
	1991	Height	HT = 7.27 + 4.86(DBH)	0.442
		Diameter	DBH = 0.35 + 0.09(HT)	0.442
	2004	Height	HT = 6.18 + 7.99(DBH)	0.8
2 N. red oak	1985	Height	HT = 21.04 + 12.66(DBH)	0.3
		Diameter	DBH = -0.25 + 0.02(HT)	0.3
	2004	Height	HT = 0.2135 + 10.12(DBH)	0.959
3 Natural oaks	1986	Height	HT = 14.89 + 5.91(DBH)	0.724
		Diameter	DBH = -0.89 + 0.12(HT)	0.724
	1991	Height	HT = 31.13 + 2.96(DBH)	0.462
		Diameter	DBH = -1.70 + 0.12(HT)	0.462
	2004	Height	HT = 33.35 + 4.53(DBH)	0.331

Table 2—Mean DBH in inches by year and treatment at Stephen Switch, TN

		Year				
Block	Treatment	1985	1986	1987	1991	2004
		- - - - - - - -	- - - - - - - -	*inches*	- - - - - - - -	- - - - - - - -
1	Unreleased			0.6B	0.92A	1.75A
1	Release			0.79A	1.39B	2.88B
2	Unreleased	2.9A				4.63B
2	Release	1.74A				1.66A
3	Unreleased		3.6A		4.87A	6.65B
3	Release		3.23A		5.11A	5.31A

Means, within years, with the same letters are not different at the $\alpha = 0.05$ level of significance.

Table 3—Mean tree height in feet by year and treatment at Stephen Switch, TN

Block	Treatment	Year 1985	1986	1987	1991	2004
		- - - - - -	- - - - - -	feet	- - - - - -	- - - - - -
1	Unreleased			8.1A	7.55A	20.15A
1	Release			9.91B	10.36B	29.21B
2	Unreleased	3.0A				46.64B
2	Release	2.64A				17.25A
3	Unreleased		36.15A		45.79A	64.65B
3	Release		33.87A		45.93A	56.56A

Means, within years, with the same letters are not different at the $\alpha = 0.05$ level of significance.

or six growing seasons following release (P<.0001 and .0019, respectively). The release treatment had a mean dbh of 1.4 inches, while the unreleased planting had a mean dbh of 0.9 inches. The mean height of the release white oaks was 10.4 feet and the unreleased mean height was 7.6 feet. The 2004 white oak measurements (18-years after release, stand age 36) indicated the release treatment had significantly greater mean tree heights (P<.0072) and mean dbh (P<.0055) than the unreleased planting. Released mean tree height was 29 feet while the unreleased planting mean tree height was 20 feet (table 3). Mean dbh for the release treatment was 2.9 inches and the unreleased planting was 1.8 inches (table 2). White oak seedling survival was lower in the unreleased planting when compared to the released treatment, a difference that became more pronounced over time (fig. 2). White oak survival rates in the unreleased treatment, based on the number of seedlings planted, gradually declined to 15 percent in 2004. In the release treatment, survival was 53 percent in 2004.

Northern Red Oak

In 2004, at stand age 36, the release treatment had a significantly lower (P<0.0001) mean tree height (17 feet) than did the unreleased planting (46.6 feet) (table 3). The unreleased planting also had a significantly greater dbh (4.6 inches) than the release treatment (1.7 inches) (P<.0001) (table 2). Northern red oak survival in the unreleased planting declined to 15 percent in 2004 while the released planting had a 27 percent survival rate.

Natural Regeneration

In Block 3, naturally regenerated oaks, data collected in 1986 (stand age 18) showed no significant differences in mean tree height among treatments (P<.0782) or in mean dbh (P<.0510). The 1991 (stand age 23) no significant treatment differences in mean tree height or dbh (P<.6793 and .5983, respectively) were found (tables 2 and 3). In 2004, at a stand age of 36-years, the naturally regenerated oaks in the unreleased trees had a significantly greater mean dbh, 6.7 inches, than the release treatment, 5.3 inches (P<.0026, table 2). Figure 3 provides a comparison of 2004 dbh measurements across all blocks and treatments. Mean tree height significantly differed between treatments (P<.0013). Mean tree height for the unreleased trees was 64.7 feet while the release treatment averaged 56.6 feet (table 3). Figure 4 provides a comparison of 2004 height measurements across all blocks and treatments. Natural oak regeneration survival was difficult to assess due to the lack of data prior to 1986 (fig. 2). If survival is set at 100 percent in 1986 (stand age 18-years), then the data shows the natural oaks with a survival rate of 92 percent in 1991 (stand age 23-years) and 66 percent in 2004 (stand age 38-years).

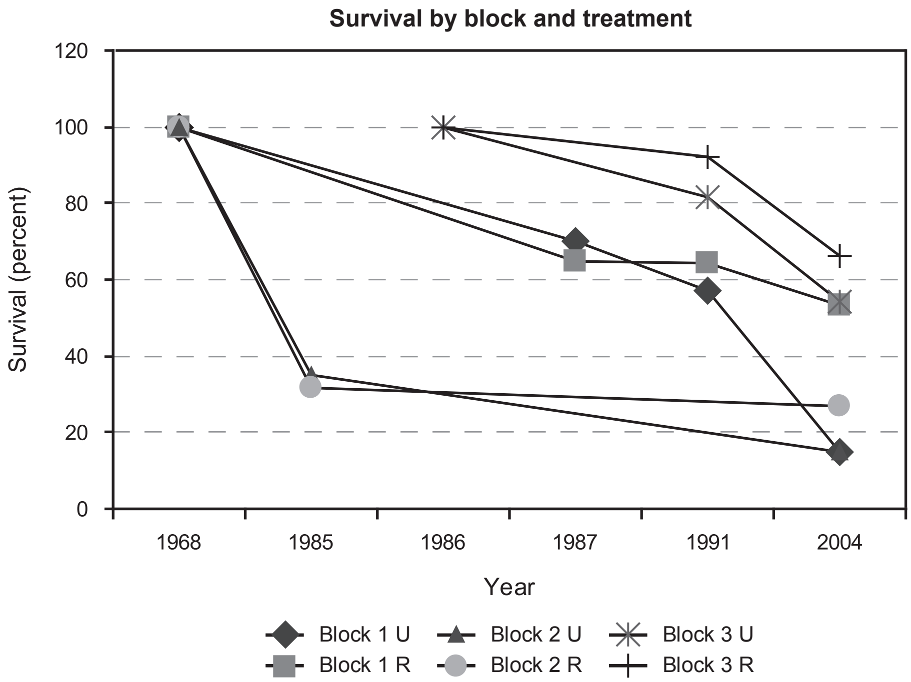

Figure 2—Comparison of unreleased treatment data measurements by treatment at Stephen Switch, TN. In the legend, U is unreleased and R is the release treatment.

DISCUSSION

Results indicated that white oak responded well to the release treatment increasing in both total height and dbh. However, the planted northern red oak and the natural oak regeneration exhibited significant negative dbh and height growth responses to release over the entire study period. It should be noted that the release treatment did improve survival of northern red oak.

The natural oak regeneration exhibited greater dbh and height growth than both species of planted seedlings (figs. 3 and 4). The primary reason for this difference is thought to be attributable to the source of the new stems. The natural oak stems more than likely originated as stump sprouts from advanced regeneration that was top-killed by the fire or from the stumps of harvested trees. These sprouts had sufficient root stock to support resprouting and had more resources to use for initial growth than did seedling competition that established after the fire. A second reason natural regeneration may have been more successful is that it was likely more adapted to the site than the planted seedlings. Species-site relationships are important in determining the success rate of artificial regeneration in hardwoods (Brenneman 1980, McElwee 1970). Genetic variation within species can be attributed to geographic differences in seed source among others (Webb 1970). The seed stock for the planted seedlings in this study, although from genetically improved seed stock, likely came from a different site type. With the lack of success in the northern red oak planting, it is important to note that little to no northern red oak was present on the natural regeneration block, while several other species of red oaks and white oak were present. This lack of northern red oak indicates poor site suitability for the species. In both the released treatment and the unreleased plantings, natural oaks simply outgrew the planted seedlings in any situation.

Other potential factors that could have affected planted seedling growth include competition control over a longer period of time than two years, better seedling selection, and/or decrease amount of time between planting and release. These seedlings were released almost 20 years after planting. If this release was moved to an earlier point in the timeline, perhaps year 10-12, a manager may be able to increase survival and increase the growth rate earlier to produce larger, healthier trees in a shorter period of time. This

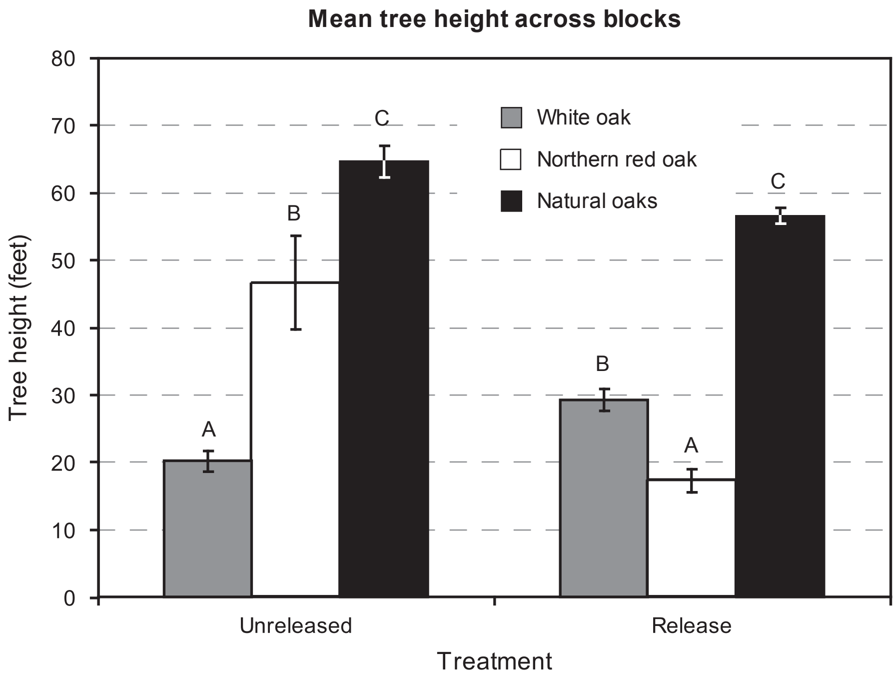

Figure 3—Comparison of 2004 height data measurements by treatment and block at Stephen Switch, TN. Bars with the same letters are not different at the $\alpha = 0.05$ level of significance.

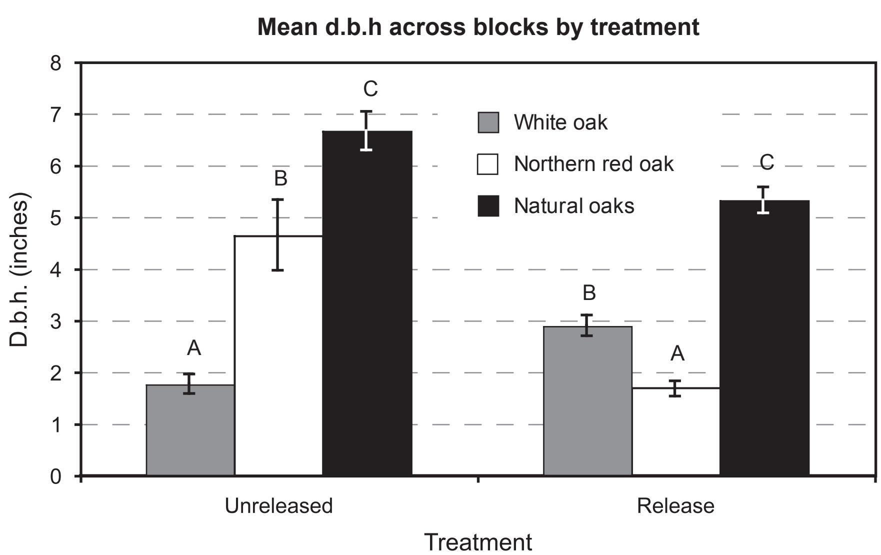

Figure 4—Comparison of 2004 d.b.h. data measurements by treatment and block at Stephen Switch, TN. Bars with the same letters are not different at the $\alpha = 0.05$ level of significance.

release would need to be combined with a long-term program of competition control around the newly established seedlings. However, the increasing intensity of management comes at an increased cost. The purchase of the seedlings, continued competition control, and release treatment costs add up quickly and may offset any potential benefits.

A viable alternative, and one the results of this study supports, would be to capitalize on advanced oak regeneration (Larsen and Johnson 1998, Sander 1972). The manager would have less control over species mix and stocking, but the species found on that site would be better adapted for that area. Competition control and release treatments could still be implemented to increase the growth of the trees. However, as shown in this study, natural oak regeneration still outperformed the planted oaks even in an unreleased situation where no competition control was implemented. Using natural regeneration will also reduce the cost of the management because no seedlings are required to be purchased and potentially less intensive competition control may be done. Several techniques have been studied and found to be successful at regenerating oaks from natural regeneration on specific sites including the shelterwood-burn technique and others (Brose and Van Lear 1998, Buckley and others 1998, Loftis 1990).

CONCLUSION

Planting oak seedlings to facilitate oak regeneration may not be the best method for ensuring a new oak forest on poor quality sites. Due to the high cost and low productivity when compared to natural regeneration, using artificial regeneration on sites like the one described in this study will not produce the desired results without more intensive and expensive management. New research by Kormanik, Schlarbaum, and others into selecting genetically or growth-superior seedlings may give land managers a better tool in selecting seedlings more suited to the specific site where planting is to occur. However, on a lower quality site like to one used in this study, the natural oaks provide the best regeneration success.

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EVALUATING THE FLOOD TOLERANCE OF BOTTOMLAND HARDWOOD ARTIFICIAL REPRODUCTION

John M. Kabrick, Daniel C. Dey, and Jonathan R. Motsinger[1]

Abstract—We experimentally compared the survival and growth after flooding of six bottomland species: eastern cottonwood (cuttings) (*Populus deltoides* Bartr. Ex Marsh.), pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), bur oak (*Q. macrocarpa* Michx.), black walnut (*Juglans nigra* L.), and pecan [*Carya illinoensis* (Wangenh.) K. Koch]. Flood treatments (5-week flowing, 5-week stagnant, 3-week flowing, and control) were initiated in May, 2004, and plants were evaluated in September. Cottonwood maintained high survival and growth but had a significant basal diameter growth reduction with increased flood duration. Swamp white oak and pin oak each had greater survival than cottonwood, exceeding 95 percent regardless of treatment. Swamp white oak maintained high growth, regardless of treatment. Although not significant, pin oak and pecan had high survival but reduced growth and bur oak and black walnut had both reduced survival and growth with increased flood duration.

INTRODUCTION

Throughout the Central Hardwood Region, there is increasing interest in establishing bottomland hardwood seedlings. Collectively, thousands of acres in floodplains are being planted on both private and public land driven by bottomland restoration efforts (Shaw and others 2003, Kabrick and others 2005), the Wetland Reserve Program (Stanturf and others 2001), and efforts to establish riparian buffers in intensively-managed agricultural fields (Dey and others 2004, Schultz and others 2000).

Ensuring successful hardwood tree establishment requires carefully matching the ecological requirements and tolerances of the species to the environmental conditions of the planting site (Allen and others 2001). In bottomlands, it is particularly important that the planted seedlings are tolerant of the flood regime of the site.

Several factors influence the flood tolerance of bottomland seedlings. In addition to differences among species, other factors include the plant size and age, the timing and duration of flooding, and the flood water quality (Kozlowski and Pallardy 1997). In general reproduction is more vulnerable to flooding than are older trees. Floods during the growing season are more damaging than those during dormant periods because they restrict oxygen to roots when both root and shoot growth are most active. Additionally, stagnant flood water contains less oxygen than flowing water and thus is more damaging to plants (Kozlowski and Pallardy 1997).

Although much is known about the factors that influence flood tolerance, flood tolerance ratings remain largely qualitative. Flood tolerance often is expressed with vaguely-defined terms such as “moderately tolerant” or “somewhat tolerant” (Kabrick and Dey 2001). Even when explicitly defined, flood tolerance often has been determined observationally, based on case histories rather than experimentally from controlled studies where confounding influences were reduced or eliminated.

The wide-spread tree planting in bottomlands throughout the Central Hardwood Region has prompted us to more carefully examine the flood tolerance of bottomland hardwood reproduction. Our objectives were to compare survival, recovery, and growth after flooding of commercially-available hardwood planting stock and to compare our results to published tolerance ratings for the species we examined. Our findings are important for guiding species selection for hardwood plantings on both private and public land.

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METHODS

We tested six commonly-planted bottomland species in a state-of-the-art outdoor flood tolerance laboratory located at the Horticulture and Agroforestry Research Center in New Franklin, MO. This facility comprises twelve 20-foot wide x 600-foot long channels constructed on the floodplain of Sulfur Creek, a perennial stream that flows into the Missouri River. Water pumped from an adjacent retention pond can be regulated to control flood depth, duration, timing, and flow rate in each channel. Detailed information about the soil conditions at the flood tolerance laboratory is described by Van Sambeek and others (2007).

Species tested in this experiment included eastern cottonwood (*Populus deltoides* Bartr. Ex Marsh.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), bur oak (*Q. macrocarpa* Michx.), black walnut (*Juglans nigra* L.), and pecan [*Carya illinoensis* (Wangenh.) K. Koch]. We established cuttings for cottonwood and planted 1-0 bareroot stock for the other species (table 1). All stock was purchased from the George O. White State Forest Nursery located near Licking, MO. These species and stock types were selected because foresters and wildlife managers often plant them and collectively their published flood tolerances range from intolerant to very tolerant. For each species, there is some inconsistency in the reported flood tolerance (table 2).

Table 1—Postplanting basal diameter and shoot length prior to flooding of the bare-root seedlings used in the study[a]

	Treatment			
Species[b]	Control	Three-week flood, flowing	Five-week flood, flowing	Five-week flood, stagnant
	inches			
Basal diameter				
Black walnut	0.22	0.22	0.21	0.21
Pecan	0.16	0.17	0.17	0.17
Bur oak	0.19	0.22	0.21	0.19
Pin oak	0.20	0.18	0.19	0.18
Swamp white oak	0.22	0.24	0.23	0.24
Cottonwood	—	—	—	—
	feet			
Shoot length				
Black walnut	1.7	1.8	1.8	1.9
Pecan	0.7	0.7	0.7	0.7
Bur oak	1.0	1.1	1.2	1.2
Pin oak	1.2	1.1	1.2	1.1
Swamp white oak	1.0	0.9	0.9	0.9
Cottonwood	—	—	—	—

[a] Basal diameter is the average of two measurements made in orthogonal directions. No pretreatment measurements were made on the cottonwood cuttings. For each species, there were no significant pretreatment differences in basal diameter or shoot length.
[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.).

Table 2—Published flood tolerances for the tree species evaluated in this study illustrating the range in flood tolerance among and within each species[a]

Species[b]	Flood tolerance[a] Teskey and Hinckley 1977[c]	Whitlow and Harris 1979[d]	Allen and others 2001, Haynes and others 1988[e]
Black walnut	Intolerant	Intolerant	Weakly tolerant
Pecan	Intermediately tolerant	Tolerant to very tolerant	Weakly tolerant
Bur oak	Tolerant	Somewhat tolerant	Intolerant
Pin oak	Intermediately tolerant	Tolerant	Moderately tolerant
Swamp white oak	Tolerant	Somewhat tolerant	Moderately tolerant
Eastern cottonwood	Very tolerant	Tolerant	Weakly tolerant to moderately tolerant

[a] Note that tolerance definitions differ slightly among authors.
[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (Populus deltoides Bartr. ex Marsh.).
[c] Very tolerant: withstands flooding for two or more growing seasons; tolerant: withstands flooding for most of one growing season; intermediately tolerant: survives flooding for 1 to 3 months during the growing season; intolerant: cannot withstand flooding during the growing season.
[d] Very tolerant: survives prolonged flooding for more than 1 year; tolerant: survives flooding for one growing season; somewhat tolerant: survives flooding or saturated soil for 30 consecutive days during the growing season; intolerant: unable to survive more than a few days of flooding during the growing season.
[e] Tolerant: survives saturated or flooded soil for long periods during the growing season; moderately tolerant: survives saturated or flooded soil for several months during the growing season; weakly tolerant: survives saturated or flooded soil for a few days or weeks during the growing season; intolerant: unable to survive short periods of saturated or flooded soil during the growing season.

We used a split plot design with three blocks, each comprising four adjacent channels. Within blocks, a single treatment (main effect) was randomly assigned to each channel: 5-week flowing, 5-week stagnant, 3-week flowing, or control. Twenty-five, 1-0 bareroot seedlings or cuttings (cottonwood) of each species were planted per channel (subplot effect) (75 seedlings per species per treatment and 1800 seedlings total).

Flood treatments were initiated on May 15, 2004, approximately one month after seedling planting. In the flooded channels, the water depth was maintained at 8 to 10 inches. The timing and depth of the flood treatments were selected to simulate late spring floods that commonly occur throughout the Central Hardwood Region. Also, floods during the growing season generally cause greater seedling mortality than do dormant season floods.

During the growing season at times when the channels were not flooded, weedy competition was controlled by mowing and applying a 2 percent glyphosate solution around the experimental trees.

At the end of the growing season, seedlings were evaluated for survival and shoot growth or dieback. We also rated the foliage condition of all living seedlings noting whether the foliage appeared green and healthy or chlorotic, browsed by deer or rabbits, or partially or fully defoliated by insects.

We used analysis of variance to determine treatment effects (error = treatment x block interaction) and differences among species (error = residual error for the experiment) on measured variables. For significant effects ($\alpha = 0.05$), we conducted multiple comparison tests using a procedure of Milliken and Johnson (1984).

RESULTS AND DISCUSSION

Overall, flooding significantly decreased the survival (P = 0.03) and diameter growth (P < 0.01) of the plants (table 3; figs. 1 and 2). Generally, the greatest differences were between the five-week flood treatment and the controls. For the five-week flood treatment, we found few differences in survival or diameter growth between seedlings in stagnant and flowing water. We anticipated that seedlings would suffer more dieback or greater mortality in the stagnant treatment because of the greater potential to develop anoxic soil conditions. However, we did not measure soil oxygen levels and we cannot be sure that it was lower in the stagnant treatment than in the flowing treatment. The flood treatments did not significantly decrease seedling shoot growth (P = 0.08) or significantly decrease the proportion of seedlings with healthy, green foliage (P = 0.10).

The effects of the flood treatment and survival and diameter growth differed significantly among species (P < 0.01). Black walnut suffered the greatest mortality and diameter growth reduction in flooded channels (table 3; figs. 1 and 2). This was expected because black walnut is considered very sensitive to

Table 3—Postflood treatment survival and proportion of seedlings having healthy foliage at the end of the first growing season[a]

	Treatment				
Species[b]	Control	Three-week flood, flowing	Five-week flood, flowing	Five-week flood, stagnant	All
	percent				
Survival					
Black walnut	61 A a	16 B a	9 B a	4 B a	23 a
Pecan	95 A b	99 A b	87 A bc	63 B b	86 b
Bur oak	96 A b	75 B b	76 B bc	67 B b	79 b
Pin oak	97 A b	95 A b	95 A bc	99 A c	97 b
Swamp white oak	99 A b	100 A b	99 A bc	97 A c	99 b
Cottonwood	89 A b	83 A b	73 A c	65 A b	78 b
All	89 A	78 AB	73 AB	66 B	
Healthy foliage condition[c]					
Black walnut	28 a	13 a	3 a	0 a	11 a
Pecan	81 bc	87 b	73 b	51 b	73 b
Bur oak	59 c	48 c	45 c	53 b	51 c
Pin oak	84 bc	81 b	60 c	79 b	76 b
Swamp white oak	95 c	96 b	96 b	96 c	96 b
Cottonwood	89 c	83 b	73 b	65 b	78 b
All	73	68	58	57	

[a] Flood treatments were initiated on May 15, 2004, 1 month after planting. For survival, there were significant differences among treatments (*p* = 0.03) and species within treatments (*p* < 0.01). For the proportion of seedlings having healthy foliage, there were no treatment effects (*p* = 0.09), but there were significant species differences (*p* < 0.01). Differences within rows are indicated with uppercase letters; differences within columns are indicated with lowercase letters.
[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.).
[c] Healthy foliage condition is the proportion of seedlings having green foliage and lacking obvious symptoms of chlorosis or browning leaves.

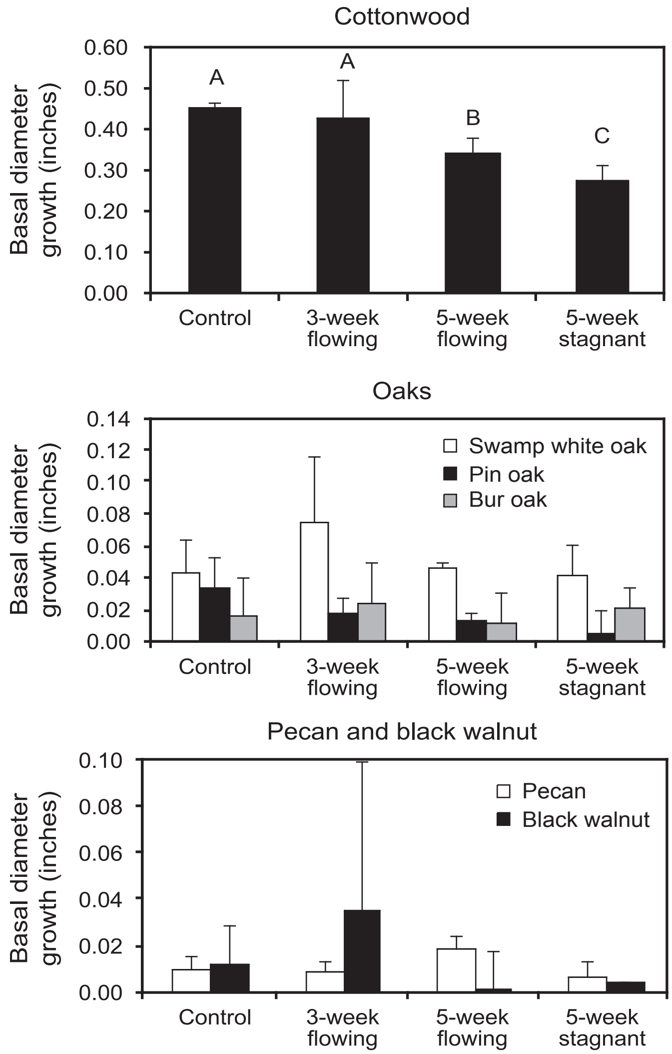

Figure 1—Basal diameter growth of the six species by flood treatment determined at the end of the growing season. Species were arranged by significant differences ($P < 0.01$) in growth increment: cottonwood (*Populus deltoides* Bartr. ex Marsh.) > oaks [bur oak (*Quercus macrocarpa* Michx.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.)] > pecan [*Carya illinoensis* (Wangenh.) K. Koch] and black walnut (*Juglans nigra* L.). Flood treatments were initiated May 15, 2004, 1 month after planting. Cuttings were planted for cottonwood and 1-0 bare-root stock was planted for the other species. All stock was from the George O. White State Forest Nursery located near Licking, MO. Error bars are + one standard deviation. Significant treatment effects ($P = 0.01$) are indicated with different uppercase letters.

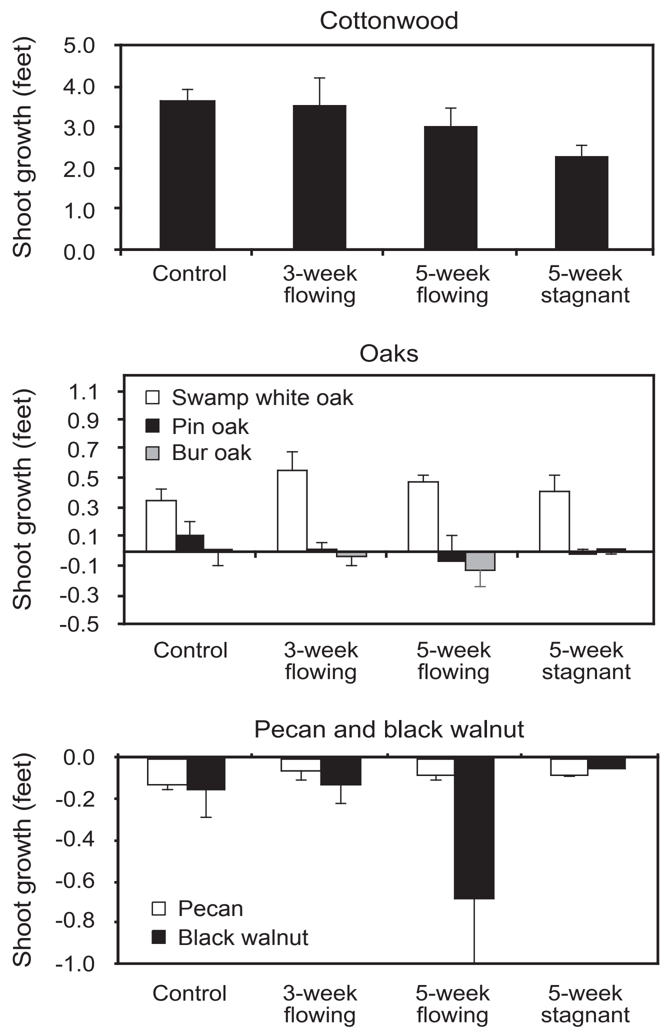

Figure 2—Shoot growth of the six species by flood treatment determined at the end of the growing season. Species were arranged by significant differences ($P < 0.01$) in growth increment: cottonwood (*Populus deltoides* Bartr. ex Marsh.) > oaks [bur oak (*Quercus macrocarpa* Michx.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.)] > pecan [*Carya illinoensis* (Wangenh.) K. Koch] and black walnut (*Juglans nigra* L.). Flood treatments were initiated May 15, 2004, 1 month after planting. Cuttings were planted for cottonwood and 1-0 bare-root stock was planted for the other species. All stock was from the George O. White State Forest Nursery located near Licking, MO. Error bars are + (or −) one standard deviation. There were no significant differences in shoot growth among treatments ($P = 0.08$).

site conditions and intolerant of flooding (Williams 1990) and was included in our study to serve as a sensitive indicator of flood-induced stress. We also found that black walnut in controls had relatively low survival and a chlorotic appearance. This most likely occurred because the soils of the control channels remained nearly saturated when adjacent channels were flooded because of seepage (Van Sambeek and others 2007).

Eastern cottonwood, which is commonly classed as moderately tolerant to very flood tolerant (Teskey and Hinckley 1977, Allen and others 2001), maintained high survival and had the greatest diameter and shoot growth even though cuttings were completely inundated in the flooded channels early in the growing season (table 3; figs. 1 and 2). However, cottonwood showed a significant reduction in diameter growth with increased flood duration. Despite growth reductions in flooded channels, cottonwood maintained healthy and green foliage in all treatments.

Surprisingly, both swamp white oak and pin oak had equal or greater survival than cottonwood in all treatments, exceeding 95 percent (table 3). Moreover, swamp white oak maintained a high growth rate, second only to cottonwood (figs. 1 and 2). Swamp white oak also maintained healthy and dark green foliage regardless of treatment (table 3). Despite high survival, pin oak had substantial but nominal diameter and shoot growth reductions with increased flooding (figs. 1 and 2). Of the three oak species, bur oak appeared to be the most sensitive to flooding and had nominal reductions in survival and growth in all flood treatments (figs. 1 and 2). A large proportion of bur oak seedlings also appeared to be chlorotic at the end of the growing season, particularly in the 3-week and 5-week flowing treatments. This apparent chlorosis was the primary reason that bur oak seedlings had a lower proportion of healthy seedlings than all others except black walnut.

Pecan had very high survival, but also substantial shoot length reductions due to stem dieback in all treatments (table 3; figs. 1 and 2). This may not have been caused by flooding because the seedlings in the control treatment suffered as much dieback. Others have reported that pecan has a slow juvenile growth rate compared to other bottomland species (Stanturf and others 1998) so that the dieback that we observed may be characteristic for planted seedlings of this species. Despite stem dieback, the foliage of the pecan seedlings generally appeared dark green and healthy in all but the five-week stagnant flood treatment.

Our findings show both consistencies and discrepancies with published flood tolerance ratings for the species that we evaluated (for example, see table 2). There generally is good agreement in the literature that black walnut is intolerant and eastern cottonwood is tolerant to very tolerant of flooding, as our findings confirm. However, the published flood tolerances of the bottomland oaks that we examined ranged from intolerant to tolerant and no single species consistently was rated as more tolerant than the others. Our findings strongly suggest that swamp white oak is more tolerant to flooding than are the other oaks we examined and appeared to tolerate flood treatments better than did eastern cottonwood. This may be partially attributable to the stock used. As noted earlier, cuttings were used for eastern cottonwood and they were completely inundated by the flood treatments. Bareroot stock was used for the other species and most of them were not completely submerged in the flooded channels. Undoubtedly, complete inundation is more stressful than is partial inundation.

Some of the inconsistencies between our findings and those in the literature may be related to how flood tolerance is measured. For example, if seedling survival is the only consideration, then all species except black walnut performed well. However, when shoot growth (or dieback) and overall health relative to controls was considered, some species appeared more tolerant than others. These findings demonstrate that the characteristics used to define flood tolerance must be explicitly described. In addition to survival, measures of flood tolerance should include consideration of seedling growth and vigor relative to these attributes in non-flooded conditions.

We also acknowledge that our findings may have been different if the floods completely inundated the trees or if they were of longer duration. Deeper floods would more severely restrict oxygen diffusion into soil or roots causing increased root damage and associated disease and eventually leading to defoliation or mortality (Kozlowski and Pallardy 1997). The prolonged anoxic conditions caused by floods of longer duration are more likely to inhibit leaf growth, leading to leaf chlorosis, senescence, and abscission (Kozlowski and Pallardy 1997). In addition, our results are of response after one flood event during the establishment year. Flood tolerance may rate differently for larger trees or after a series of flood events.

Flood tolerance may also vary by genotype and ecotype, and stock from individual families or provenances may be more flood tolerant than stock of others. Our objective was to evaluate the stock most commonly available to managers in the Central Hardwood Region. However, future studies will include stock of known genetic origin and ecotype (e.g., upland vs. bottomland) to determine their role in governing flood tolerance.

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TWENTY-FOUR YEARS OF GROWTH OF NATURALLY REGENERATED HARDWOODS, PLANTED YELLOW-POPLAR, AND PLANTED PINE IN PLOTS WITH AND WITHOUT COMPETITION CONTROL ON AN UPLAND HARDWOOD SITE ON THE CUMBERLAND PLATEAU NEAR SEWANEE, TN

Karen Kuers[1]

Abstract—Twenty-four years of growth of naturally regenerated hardwoods and planted yellow-poplar, loblolly pine, and eastern white pine was compared in plots established with and without early competition control. After the removal of all stems down to 4 inches dbh by shearing, the residual stems over 4.5 feet tall were injected in the plots assigned to the competition control treatment. A portion of each white pine plot was re-treated in year six. After 24 years, average total volume in pine plots was twice that of hardwood plots (3503 vs 1716 cubic feet per acre). Injection increased loblolly pine basal area (BA) 66 percent (83.7 to 149.9 square feet per acre) but white pine BA only 16 percent (54.5 to 63.2 square feet per acre). The second treatment increased white pine BA by 64 percent and height by 10.6 feet. Injection did not affect BA of hardwood plots. Yellow-poplar performed poorly, and at best comprised 39 percent of plot volume. Oaks dominated all hardwood plots, averaging 68 percent of the BA in naturally regenerated plots.

INTRODUCTION

Decades of high-grading, grazing, and wildfires in the 20th century produced thousands of acres of low quality hardwood stands on the Cumberland Plateau in Tennessee. By the 1970's, research scientists at the U.S. Forest Service Silviculture Laboratory at Sewanee, TN recognized the challenge these degraded stands presented to landowners, and believed that many sites had the potential to produce forest products of higher quality. As a result, these scientists focused on identifying management opportunities for low quality hardwood stands (McGee 1982). Stand improvement required removal of the existing low quality stems, and the then relatively new practice of in-woods, whole-tree chipping was chosen in 1976 for the site discussed here, both as a means of utilizing the wood on the site and clearing it for regeneration. The 1976 work was initiated to analyze how canopy removal by shearing and chipping affected subsequent vegetative growth. In addition, to determine the degree of site clearing needed for successful stand establishment, half of the study area received an herbicide treatment to remove small stems not utilized during the chipping operation. Four different regeneration options were included in the study: planting loblolly pine *(Pinus taeda* L.), eastern white pine (*P. strobus* L.), or yellow-poplar (*Liriodendron tulipifera* L.); or naturally regenerating hardwoods. The purpose of this report is to 1) compare 24 years of growth of the four stand types, and 2) evaluate the effectiveness of pre-planting herbicide treatment of residuals on subsequent growth of the planted and naturally regenerated species.

METHODS

The Study Area

The 37-acre study area is located on the Cumberland Plateau near Sewanee, TN (35°12'30"N and 85°55'W.) Ranging in elevation from 1900 to 1948 feet, the site is typical of Landtype 1 for the mid-Cumberland Plateau (Undulating Sandstone Uplands) (Smalley 1982a). The soils are classified as fine-loamy, siliceous, mesic Typic Hapludults. Annual precipitation is evenly distributed throughout the year, averaging 63 inches per year.

Prior to harvest the overstory was dominated by white oak (*Quercus alba* L.) and scarlet oak (*Q. coccinea* Muenchh) and the stand consisted primarily of culls and low quality stems. Site index (SI) was estimated to range from 55 to 75 feet at age 50 (*Quercus* spp.), but the site lacked good overstory oaks upon which to base the estimate (McGee 1980).

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Harvest and Initial Plot Layout

The site was harvested in the fall of 1976. All stems 4 inches dbh or greater were sheared and skidded to a central location on-site where they were fed into a chipper (McGee 1980). The harvest removed 1200 tons of chips and 30 tie or sawlogs from the entire 37 acres. After harvest, 24 1-acre plots were established and six plots were randomly selected for each of the following regeneration options: planting 1.0 loblolly pine (LP), planting 2.0 eastern white pine (EWP), planting 1.0 yellow poplar (YP), and naturally regenerating hardwoods (NAT). Seedlings were obtained from the Tennessee Division of Forestry nursery at Pinson, TN, and because of their large size, yellow-poplar seedlings were top- and root-pruned prior to planting. All seedlings were planted at a spacing of 8 x 10 feet in March 1977. In half of the plots of each regeneration type, stems over 4.5 feet tall were injected (INJ) with herbicide (Picloram plus 2,4-D) prior to planting, and the remaining plots were left untreated (CNTL). The INJ treatment reduced the number of residuals over 4.5 feet tall from 400 to about 32 stems per acre (McGee 1986). At age five it was noted that the eastern white pines were becoming overtopped by the competition. The following year (age 6), half of each of the EWP plots was cleaned by manually or chemically removing trees to release the overtopped pines. The early growth and development of the trees have been discussed by McGee (1980, 1986, 1989) and Dethero (1992).

Study Design

At the end of the 24th growing season, a central 0.25 acre square measurement plot was delineated in each of the 1-acre plots. Each 0.25-acre measurement plot was subdivided into nine 32.8 x 32.8 foot modules. Dbh, height, and crown class for all stems 4.5 feet tall and greater (living and dead) were recorded by module for each of the measurement plots. The height of every sixth dominant or codominant stem was measured and heights of the remaining trees were estimated to the nearest 5 foot interval. In addition, understory plant species (woody and non-woody stems < 4.5 feet tall) were tallied by module to compare the effects of regeneration type and competition control on total plant diversity and species richness. Diversity and species richness data were reported in a separate publication (Kuers 2002).

Density, BA, canopy height, SI, and total volume were calculated for each plot. SI values for the loblolly pine (base age 25) were calculated from the average height of the 25 tallest pines in each measurement plot (100 stems per acre) using equations developed by Smalley and Bower (1971) for abandoned fields in the highlands of Tennessee, Alabama, and Georgia. SI (base age 50) for eastern white pine was calculated from the 12 tallest trees in the plot halves that received the manual cleaning at age six using equations for white pine planted in North Carolina, Tennessee, and Georgia (Vimmerstedt 1962). SI for the hardwoods was based only upon trees in the INJ plots to reduce the possibility of including older trees in the SI determination. Yellow-poplar SI was determined using the average of two equations: one developed for the southern Appalachian mountains (Beck 1962) and the other for West Virginia (Schlaegel and others 1969). Three Oak SI equations were used: 1) upland oaks (Olson 1959); 2) black oak (*Q. velutina* Lam.; Carmean and others 1989); and 3) a combined equation for black, scarlet, and white oak (McQuilkin 1978).

Loblolly pine total and merchantable cubic foot volumes were estimated using equations developed for cutover, site prepared plantations (Amateis and Burkhart 1987), and eastern white pine total volumes were estimated using equations developed for plantations in the southern Appalachians (Smalley and Beck 1971). Total volumes for non-pine species were calculated from diameter and total height using regression equations developed for southern uplands and the southern Appalachian mountains. Species-specific equations were used for yellow-poplar, oaks, and other species for which such equations were available, and overall hard-hardwood or soft-hardwood equations were used for all other species (Clark and Schroeder 1985, Clark and others 1986).

Effects of INJ on dbh, height, BA, and volume were tested using General Linear ANOVA models (SPSS 2003). Tukey's HSD test was used to compare means when significant differences were detected. The paired-T test was used to evaluate the effects of the manual cleaning in EWP at year 6, as well as plot difference in the height, dbh, BA, stem density, volume of red oaks (black and scarlet) and white oak (mostly white and chestnut).

RESULTS

Overall Growth Comparison

Plots planted with pine (both white and loblolly) had taller average heights (29.5 vs 22.4 feet), greater average dbh (3.4 vs 2.3 inches), fewer total stems (1439 vs 2086 stems per acre), and larger BA (145.6 vs 93.5 square foot per acre) and total volume (3464 vs 1727 cubic foot per acre) than plots planted to yellow-poplar or naturally regenerated to hardwoods (table 1). Among the pines, LP plots had higher average BA (161 square foot per acre) than EWP plots (130.7 square foot per acre), as well as higher average volumes (3960 vs 2974 cubic foot per acre). Injection increased LP total BA by 31.8 square foot per acre and total volume by 1015 cubic foot per acre, but did not impact either BA or volume of the EWP. There were no significant differences among the non-pine plots, although CNTL plots tended to exhibit slightly greater BA and volume than the INJ plots, with YP plots tending to have slightly higher average BA and volume than NAT plots, regardless of INJ (table 1).

Loblolly Pine

Loblolly pine survival, BA, and volume were increased by the INJ treatment, while average height was unaffected (table 2). Pine survival was 1.5 times higher (346 vs 225 stems per acre; p= 0.09), BA was 1.8 times greater (149.9 vs 83.6 square foot per acre; p = 0.06), and total pine volume was 1.9 times larger (4010 vs 2114 cubic foot per acre; p = 0.05) in the INJ plots. While loblolly averaged only 58 percent of the basal area in CNTL plots, INJ increased this percentage to 85 percent (fig. 1). Merchantable volumes (4-inch top, outside bark) were 1939 and 3753 cubic foot per acre in the CNTL and INJ plots, respectively.

Table 1—The 24-year average height, codominant canopy height, d.b.h., stem density, basal area, and volume of all stems (all species) in sites planted with eastern white pine, loblolly pine, or yellow-poplar, or naturally regenerated with hardwoods on the Cumberland Plateau

Plot	Average height	Canopy height[a]	D.b.h.	Number of stems	BA	Volume
	- - - - - - - *ft*	- - - - - - -	*in.*	*ac*$^{-1}$	*ft*^{2} *ac*$^{-1}$	*ft*^{3} *ac*$^{-1}$
EWP[b]						
Cntl	31.7 a	56.5 ab	3.5 ab	1,376 ab	130.1 bc	2,947 b
Inj	30.2 ab	56.5 ab	3.5 a	1,358 a	130.8 bc	3,001 b
LP						
Cntl	26.5 abc	61.9 a	3.1 abc	1,619 abc	144.8 ab	3,448 b
Inj	29.4 bc	62.8 a	3.7 a	1,402 ab	176.6 a	4,462 a
YP						
Cntl	22.5 bc	51.2 bc	2.3 cd	2,186 bc	106.9 cd	1,910 c
Inj	23.0 bc	48.9 c	2.2 cd	2,278 c	91.8 d	1,739 c
NAT						
Cntl	23.6 bc	51.0 bc	2.5 bcd	1,572 abc	91.0 d	1,776 c
Inj	20.3 c	46.8 c	2.1 d	2,305 c	84.2 d	1,486 c

Numbers within a column followed by the same letter are not significantly different *p* > 0.05.
BA = basal area; EPW = eastern white pine; Cntl = control; Inj = injected; LP = loblolly pine; YP = yellow-poplar; NAT = naturally regenerated.
[a] Canopy height represents the average height of the 25 tallest trees per 0.25-acre plot (100 stems per acre).
[b] EWP represent only the plot portion that did not receive a manual cleaning at age 6.

Table 2—The 24-year average height, codominant height, d.b.h., stem density, basal area, and volume of only the planted eastern white pine (EWP), loblolly pine, and yellow-poplar stems in planted plots, and naturally regenerated oaks in naturally regenerated hardwood plots on the Cumberland Plateau (standard mean error)

Plot	Average height	Codominant height	D.b.h.	Number of stems	BA	Plot BA	Volume
	- - - - - - - - - ft	- - - - - - - - -	*in.*	ac^{-1}	$ft^2\ ac^{-1}$	*percent*	$ft^3\ ac^{-1}$
				Eastern white pine[a b]			
Cntl	28.6 (6.9)	56.4 (1.9)	4.2 (1.0)	391 (30)	58.0 (19.0)	45	1,397 (499)
Inj	37.8 (4.3)	57.5 (1.1)	5.7 (0.7)	342 (28)	67.2 (10.7)	51	1,647 (322)
				Loblolly pine[c]			
Cntl	50.5 (3.0)	58.7 (1.8)	7.8 (0.5)	225 (45)	83.6 (24.2)	58	2,114 (669)
Inj	55.2 (1.3)	62.6 (1.1)	8.7 (0.3)	346 (34)	149.9 (7.8)	85	4,010 (134)
				Yellow-poplar[b]			
Cntl	24.7 (2.6)	43.1 (3.0)	2.3 (0.2)	315 (55)	14.1 (3.9)	13	303 (116)
Inj	29.0 (1.9)	47.2 (2.5)	2.7 (0.3)	335 (34)	20.1 (4.2)	22	479 (125)
				Oaks (red and white)[c]			
Cntl	33.3 (1.7)	50.6 (0.9)	2.5 (0.1)	619 (26)	66.7 (2.7)	73	1,369 (51)
Inj	28.3 (2.7)	46.4 (2.8)	2.1 (0.1)	731 (110)	52.8 (8.0)	63	1,027 (219)

BA = basal area, Cntl = control; Inj = injected.
[a] Represents only the portion of EWP plots that did not receive a manual cleaning at age 6 (approximately 0.12-acre subplot).
[b] Codominant height represents the average height of the 12 tallest trees per 0.12-acre subplot (50 stems $acre^{-1}$).
[c] Codominant height represents the average height of the 25 tallest trees per 0.25-acre plot (100 stems $acre^{-1}$).

Eastern White Pine

Eastern white pine BA averaged 62.2 square foot per acre for all plot halves that did not receive the cleaning treatment at age six (table 2). While BA values were higher in the INJ plots (67.2 vs 58.0 square foot per acre), the difference was not statistically significant ($p = 0.363$) because of a high degree of variability in the CNTL plots. The pattern was similar for total white pine volume.

While the INJ treatment had only a minor influence on the white pine growth, the manual competition control at age six had a large positive impact on pine growth. It increased BA by 64 percent (62.2 to 101.9 square foot per acre), volume by 68 percent (1515 to 2533 cubic foot per acre), height by 10.6 feet (33.1 to 43.8 feet), and dbh by 2.3 inches (5.0 to 7.2 inches; table 3). The cleaning increased pine BA from 48 to 77 percent of the total plot BA (fig. 1).

Yellow-Poplar

Growth and survival of the yellow-poplar varied greatly among the plots, and after 24 years, survival averaged only 55 percent, ranging from 35 to 67 percent. While planting did increase yellow-poplar stem density and BA in YP plots relative to NAT plots (325 vs 32 stems per acre; 17 vs 1.3 square foot per acre), yellow-poplar BA remained low, and averaged only 18 percent of the total BA on the YP plots (table 2). In fact, oaks dominated the YP plots with 4 times more BA than the yellow-poplar (53 vs 17 square foot per acre), and yellow-poplar volumes averaged only 391 cubic foot per acre.

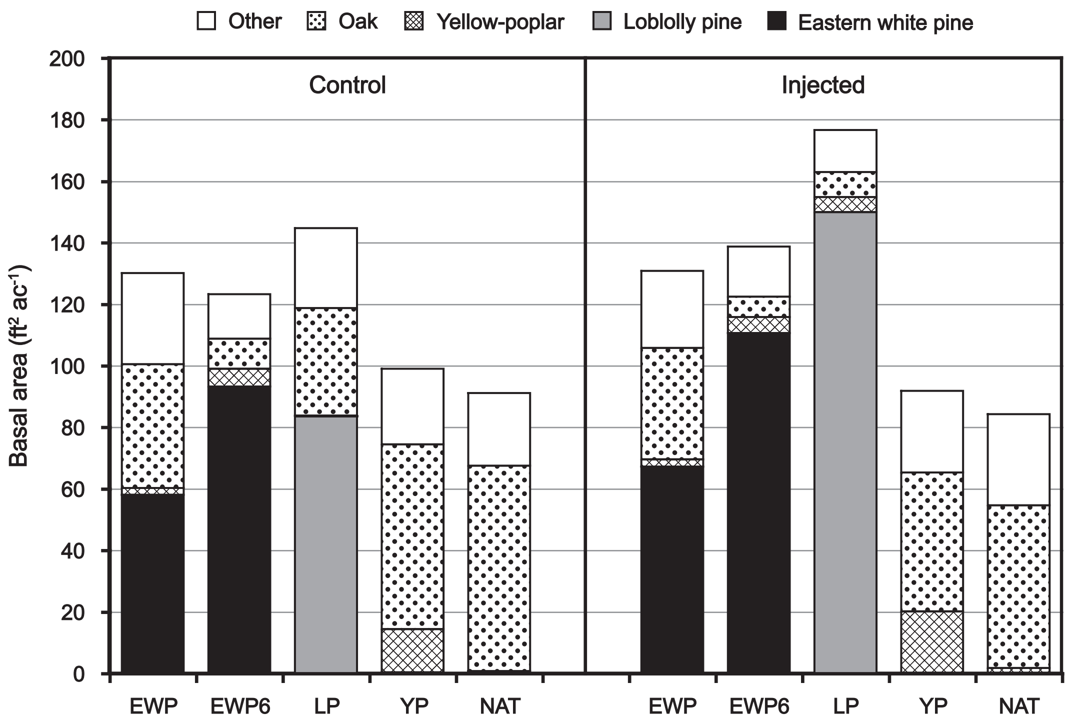

Figure 1—Basal area (age 24) by species in planted eastern white pine, loblolly pine, or yellow-poplar, or naturally regenerated hardwood plots established after the removal of all stems 4 inches d.b.h. and larger from an upland hardwood site on the Cumberland Plateau. Control: No treatment after harvest. Injected: All residual stems 4.5 feet and taller injected after harvest. EWP6: Received an additional release treatment at age 6.

Table 3—Effects of manual cleaning at age 6 on the 24-year average height, diameter, basal area, and volume of the planted eastern white pine in the EWP plots (± SEM)

Eastern white pine plot	Without age 6 cleaning[a]	With age 6 cleaning[a]	Average increase
Average height (ft)	33.1 ± 4.2	43.8 ± 1.6	10.6 ($p = 0.029$)
Average d.b.h. (in.)	5.0 ± 0.6	7.2 ± 0.3	2.3 ($p = 0.011$)
Pine BA (ft^2 ac^{-1})	62.2 ± 10.3	101.9 ± 8.5	39.7 ($p = 0.009$)
Pine volume (ft^3 ac^{-1})	1,515 ± 276	2,533 ± 241	1,018 ($p = 0.019$)

EWP = eastern white pine; BA = basal area.
[a] Values represent averages for plots with and without the first year injected treatment because year 1 injection did not significantly impact the results.

INJ did not significantly impact survival, dbh, or BA of the yellow-poplar, although values for all of these variables were higher with INJ (table 2). While less yellow-poplar than oak stems were part of the codominant canopy in the YP INJ plots (114 vs 194 stems per acre), the average height of all codominant yellow-poplar stems (42.2 feet) in these plots was only 1 foot less than that of codominant oak stems (43.3 feet). In the plot with the best yellow-poplar growth, where codominant oak and yellow-poplar were nearly equal in number, the yellow-poplar averaged 3 feet taller (44.9 vs 42 feet).

Natural Regeneration and Oaks

Oaks dominated all of the NAT plots, comprising 89 percent of the codominant stems within the measurement plots. While the average was somewhat higher in the CNTL plots (92 vs 86 percent), the difference was not statistically significant (p = 0.50). Oaks comprised 63 and 73 percent of the BA in the INJ and CNTL plots, respectively, while oak mean dbh was 2.5 inches (INJ) and 2.1 inches (CNTL). Average height of all oak stems in NAT plots was 30.8 feet and did not differ significantly with INJ (table 2). The slight increase in height of the codominant oaks in the CNTL plots (4.2 feet) likely represented residual stems left after the harvest.

Red oaks (mostly scarlet and black) comprised 73 percent of the oak BA in INJ plots and 46 percent in CNTL plots. They grew faster than white oaks (white and chestnut), averaging 10.5 feet greater height and 1.5 inch larger dbh (table 4). This was true across both YP and NAT plots, and for both CNTL and INJ treatments. There were approximately 2.6 times as many codominant red oaks as codominant white oaks in the INJ plots but only 1.2 times as many in the CNTL plots.

Site Index and Hardwood Stocking

Estimated SI (base age 50) calculated from the codominant heights of stems in the INJ plots (table 2) was 84 feet for eastern white pine and 75 feet for upland oak (combined red and white). SI for the oak varied among plots and ranged from a low of 69 to a high of 82. While the average SI for yellow-poplar (base age 50) was 71 feet, it ranged from a low of 65 to a high of 77 feet. SI for loblolly pine (base age 25) was estimated to be 63 feet.

Hardwood stocking in the NAT plots was calculated using total BA and tree tallies of all stems 2 inches dbh and larger (Roach and Gingrich 1968). Overall stocking approached 100 percent in both CNTL and INJ plots, with oak stocking somewhat higher in the CNTL plots (83 vs 72 percent).

DISCUSSION

Given the low management intensity, loblolly pine grew surprising well, and outgrew both eastern white pine and the hardwoods in this study. Assuming a conversion of 80 cubic foot per cord, the INJ plots produced 2.1 cords per acre per year, and the CNTL averaged 1 cord per acre per year. The successful

Table 4—Comparison of average height, diameter, stem density, basal area, and volume of red oaks and white oaks across all hardwood plots (standard mean error)

Plot	Average height	D.b.h.	Stems	BA	Volume
	ft	*in.*	*ac*$^{-1}$	*ft*^{2} *ac*$^{-1}$	*ft*^{3} *ac*$^{-1}$
RO	36.7 (0.9) a	4.3 (0.1) a	273 (25) a	33.4 (3.7) a	722 (85) a
WO	25.9 (1.1) b	2.8 (0.1) b	354 (40) a	22.4 (3.5) a	412 (70) b

RO = mostly scarlet and black oak; WO = mostly chestnut and white oak.
Numbers within a column followed by different letters are significantly different (p = 0.05).

establishment of even the CNTL plots must be partially attributed to the harvest method, which removed all stems larger than 4 inches dbh and provided some degree of site preparation. It must also be noted that there was a great deal of variability among the CNTL plots, and production ranged from 0.4 to 1.4 cords per acre per year. Wood volume at age 24 in the CNTL plots (1939 cubic foot per acre) was slightly less than that of a younger, 15-year-old plantation in west Tennessee (2383 cubic foot per acre) while volume in the INJ plots (3753 cubic foot per acre) was 1.6 greater (Miller and others 2003). The younger stand had a similar SI, and had not received any treatment beyond site preparation chopping and burning prior to planting, and the treatment of some large residuals

The LP INJ plots were clearly dominated by loblolly pine, which averaged 85 percent of total plot BA. While two of the three CNTL plots had 73 percent of their BA in pine, the third plot had only 26 percent pine. The results indicate that it is possible to obtain a pine-dominated stand from a cutover hardwood site on the Plateau with no treatment beyond a harvest that removes all stems 4 inches dbh and larger. However, the landowner must be willing to chance the probability of a large hardwood component to the stand, and the possibility that the site could remain hardwood dominated.

The overall growth of the eastern white pine in this study, while greater than that of the hardwoods, was less than that of loblolly pine, even with the white pine release at age six (fig. 1). This is different from the pattern observed by Schubert and others (2004) who measured 1.2 times greater volume in eastern white pine than in loblolly pine after 22 years of growth on the Eastern Highland Rim in middle Tennessee. Total pine cubic foot volumes in the plot halves that received the second release were only 57 percent of the 4474 cubic foot per acre of merchantable volume projected by Vimmerstedt (1962) for 25 year old eastern white pine plantations in the southern Appalachians (SI 83). Smalley and Hollingsworth (1997) also found lower than expected volumes for a 25 year-old direct-seeded eastern white pine plantation with a similar SI (84) and landtype (Landtype 1) on the mid-Cumberland Plateau. They attributed the reduced production to the lower fertility of the Plateau soils compared to soils of the Southern Appalachians.

It is apparent from this study that eastern white pine, with its initial slow growth, will require a higher degree of competition control to attain site dominance on the Plateau. This is similar to the findings of Clinton and others (1997) in southern Appalachian hardwood systems. McGee (1986) suggested that a more cost effective method of establishing eastern white pine on moderate sites was an intensive harvest without any immediate treatment of residuals, followed by a later competition treatment as needed.

Not surprisingly, results from this study indicate that planting either loblolly or eastern white pine can substantially boost wood production relative to that of natural hardwood regeneration, and Hepp (1989) concluded that the superior growth rate of the pine relative to hardwood was sufficient to compensate for high pine establishment costs. However, as noted by McGee (1989) minimal site preparation on cutover hardwood sites will likely produce a pine-hardwood mixture, and the amount of pine in the stand will depend upon initial site quality. Hepp (1989) suggested that the mediocre quality of this Plateau site resulted in lower hardwood competition, which allowed for successful pine establishment with less site preparation than would be effective in much of the south.

Growth of planted yellow-poplar was generally disappointing. Although planting did increase yellow-poplar basal area relative to NAT plots, even in the YP INJ plots it still averaged only 18 percent of the total BA, with oaks maintaining 4 times greater BA. It is likely that several factors contributed to the poor performance of the yellow-poplar, including marginal site quality and inadequate competition control, two factors known to be critical to successful yellow-poplar establishment (Russel 1977). While yellow-poplar can grow as fast or faster than associated oaks on upland sites where the yellow-poplar is able to maintain a dominant canopy position (Gingrich 1971), the study area’s yellow-poplar SI range of 71 to 77 is lower than the 81 to 96 that researchers have suggested is necessary for satisfactory growth of yellow-poplar (Olson and Della-Bianca 1959, Russel 1977, Nelson and Beaufait 1957, Doolittle 1958).

Competition control greatly improved yellow-poplar growth on an average quality Cumberland Plateau site where yellow-poplar height and dbh after the harvest of all hardwoods over 2 inches dbh doubled that of sites where only stems greater than 6 inches dbh were removed (McGee 1978). The potential added growth boost of subsequent density control is apparent from a separate study, also on the Plateau, in which successive weeding and thinning produced 20-year old yellow-poplar with an average dbh of 5.1 inches (1.9 times the current study), and BA of 76.5 square foot per acre (3.8 times the current study)(Smalley 1982b). The single initial competition treatment in this study was inadequate to allow the yellow-poplar to develop and maintain a dominant canopy position. It would have been instructive to test whether release at age six would have significantly increased yellow-poplar growth.

The overwhelming dominance of oak in the NAT and YP plots indicates that oak can be maintained after harvest of upland Plateau sites without extensive competition control. While this is undoubtedly fostered by the somewhat mediocre site quality of the Plateau top in this region, the intensive nature of even the CNTL harvest certainly contributed to the successful oak establishment by knocking back a number of non-commercial, more shade tolerant residual stems that are generally left after a commercial harvest.

The average oak SI measured for the study area was 75 feet, the SI boundary between good sites (more typical of coves or north and east facing slopes), and medium sites (typical of mid-slopes, lower south-slopes, and broad ridges with deep, well drained soils) (Roach and Gingrich 1968). The good sites are more prone to oak regeneration failures and conversion to species such as yellow-poplar, while oaks generally form a major component of the stand on medium sites (Roach and Gingrich 1968). With an average oak SI near 75, small differences in surface topography and available moisture can cause shifts in dominant species composition allowing species such as yellow-poplar to outgrow oak in an otherwise oak-dominated system. Thus it is not surprising that the average heights of codominant oak and yellow-poplar were quite similar in the INJ YP treatment, that the yellow-poplar growth was quite variable, and that while yellow-poplar growth was generally poor, the codominant yellow-poplar were able to grow taller than the oak on one plot.

In conclusion, while loblolly pine can be successfully established on the Cumberland Plateau with no treatments other than a true silvicultural harvest, eastern white pine requires a greater degree of competition control, which may be better accomplished as a release treatment sometime after harvest. In both cases, while wood volume can be greatly increased over that of naturally regenerated hardwoods, without further intervention, pine stands are likely to have a substantial hardwood component. In fact, this has been proposed as one method of developing pine-hardwood mixtures (McGee 1989). While planting yellow-poplar after a silvicultural harvest and injecting residuals may add a component of yellow-poplar to a stand, the return on investment will likely be low or negative on average Plateau sites since wood volumes will not likely exceed those of naturally regenerated hardwood stands. The mediocre quality of these Plateau sites means that oak regeneration is not generally problematic, although small variations in surface topography can shift composition towards yellow-poplar. The main challenge on upland Plateau sites is not the quantity of oak produced, but the quality of the stems.

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DEPLOYMENT OF HIGH-QUALITY OAK SEEDLINGS FROM LOCAL SEED SOURCES ALONG ELEVATIONAL GRADIENTS IN WEST TENNESSEE BOTTOMLANDS

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Abstract—Conversion of bottomland agricultural sites to forests using artificial regeneration is becoming increasingly common due to decreased profitability of agricultural production and persistent flooding of marginal farmland. In west Tennessee, the Tennessee Wildlife Resources Agency has been acquiring former bottomland agricultural sites for conversion to wildlife habitat. A planting program using high quality oak (*Quercus* L.) seedlings from local seed sources was initiated in 2000 to provide a source of hard mast. Acorns of nine species were collected from local sources and grown at the Georgia Forestry Commission's Flint River Nursery. Seedlings were planted on 18 sites ranging from 3 to 530 acres in size, and comprising a total of 1446 acres. Species were initially matched to site by visual inspection, which evolved into species/site matching by elevation. Survival and invasion of other woody species were evaluated through sample plots at each location. The logistics of establishing a project on this scale, associated economics, and post-planting management are discussed.

INTRODUCTION

Bottomland hardwood restoration is the subject of considerable interest in the southern United States, specifically in the Lower Mississippi Alluvial Valley (LMAV). Despite this interest, restoration success is considered to be elusive (Stanturf and others 2001). The LMAV has undergone the most widespread loss of bottomland hardwood forests in the United States (Stanturf and others 2000). Extensive areas of forested wetlands in Tennessee were drained and cleared for agricultural production. In addition, regional and local hydrologic cycles have been changed due to river dredging and flood control practices by farming operations. Deforestation and drainage have resulted in a loss of critical wildlife and fish habitat, increased sediment loads, and reduced floodwater retention (Stanturf and others 2000).

The Tennessee Wildlife Resources Agency has been acquiring large acreages of former bottomland agricultural sites for conversion to wildlife habitat. A planting program was initiated in 2002 to restore bottomland hardwood forests that will provide a source of mast to aid in restoration of wildlife communities. The former agricultural sites that are restored often have altered hydrology and are very low in elevation and wet. Various adaptations of correctly matching species to site have been explored to overcome the land alterations.

Recurring problems in operational plantings have been ascribed, in part, to the failure of planters to recognize adverse site conditions and failure to use appropriate methods for overcoming site limitations (Stanturf and others 2004). One of the important factors to successful artificial regeneration is the correct selection of species and seed source for proper establishment and productivity of a site (cf. Zobel and Talbert 1984). If a seedling is not planted where it is most likely to survive and thrive, overall productivity will be reduced (Wakely 1963). Other problems associated with using a seed source not adapted to locality include: poor growth, vigor, and even stand failure (cf. Post and others 2003). Unfortunately, nursery managers usually grow hardwood seedlings from unspecified seed sources due to the rarity of hardwood seed orchards or hardwood seed production areas.

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Planting failures can be partially attributed to the failure of commercial forest tree nurseries in providing nursery stock that can compete successfully in the field (Clark and others 2000). Because of variability in planting stock quality, many hardwood plantings do not grow vigorously or have good survival, especially several years after planting. A number of studies have shown that nursery-grown seedlings with larger stems and/or root collar diameters have better survival and growth than smaller stock (Olson and Hooper 1972, Zaczek and others 1997). Ruehle and Kormanik (1986) and Johnson (1989) have demonstrated that first-order lateral root number, stem height, and root collar diameter are important factors for the successful establishment of planted oak seedlings.

Matching the appropriate species to the proper elevation can be critical to seedling survival when planting sites are located in a floodplain. Elevational changes of only a few inches can have a marked effect on a site and drive species occurrence and development (Hodges and Switzer 1979). Immersion of seedlings after budbreak by overbank or backwater flooding can cause mortality of even the so-called flood tolerant species (Stanturf and others 2004). As elevation is related to flood depth, and often duration, it is critical to consider flood tolerance of each species used in restoration plantings.

The Tennessee Wildlife Resources Agency (TWRA) has adopted the policy of using local seed sources for the production of high-quality oak (*Quercus* L.) seedlings to use for restoration of bottomland forests in west Tennessee. This paper will present and discuss the approach that TWRA has used to implement this policy and overcome some of the above challenges to successful establishment of seedlings.

PROCEDURES

Acorn Collection and Processing

Acorns were collected each autumn, starting in 2000, from the following oak species: willow (*Q. phellos* L.), water (*Q. nigra* L.), cherrybark (*Q. pagoda* Raf.), pin (*Q. palustris* Muenchh.), Nuttall (*Q. texana* Buckley), overcup (*Q. lyrata* Walt.), swamp chestnut (*Q. michauxii* Nutt.), bur (*Q. macrocarpa* Michx.), and Shumard (*Q. shumardii* Buckl.). The acorns were generally collected from naturally occurring trees, but scarcity in some years dictated collection from locally planted trees, particularly in pin oak. Acorns were bulked by species after collection and weighed to estimate the number of acorns.

The acorns were floated in water, with the floating acorns discarded and sinking acorns retained for planting (cf. Olson 1974). Sinking acorns were allowed to surface dry, then were placed into polyethylene bags and kept at 36° F until shipping.

Nursery Culture and Processing

Each year the acorns were transported to the Georgia Forestry Commission's Flint River Nursery near Montezuma, GA. The Flint River Nursery was chosen for seedling production due to the consistent production of high quality hardwood seedlings. Seedlings were grown according to the fertilization and irrigation protocols developed by Kormanik and others (1994, 1995), which allow seedlings to attain maximum potential size in a single growing season. Acorns were sown at a rate to achieve a final density of approximately 24 seedlings per running foot of nursery bed.

Seedlings were lifted in late January or February. Prior to processing, a random sample of 90 seedlings was taken from each species by the second author. Seedlings were visually evaluated (sequentially) for root collar diameter, height, and root system development. Five to six seedlings were then selected from the sample to represent the minimum acceptable size for planting according to the judgment of the second author. The size of the selected seedlings was primarily influenced by the overall quality, but also influenced by the knowledge that a large number of seedlings were needed for planting. Selected seedlings were given to the packing crew's foreman, who instructed workers to cull any seedlings that were smaller than selected seedlings. Culled seedlings were collected and packaged separately from the higher quality seedlings. Counts were kept for both high quality and cull seedlings by species and divided by the number of acorns to calculate germination rates.

Seedlings were placed in a bag, squirted with slurry, and bundled, with each bag marked as to species and number of seedlings within. The seedlings were stored under refrigeration until shipping to west Tennessee by tractor-trailers. Upon arrival, the seedlings were placed in a cooler until planting.

Site Preparation

Seedlings were established on 18 bottomland sites in west Tennessee that were purchased by TWRA and formerly used for row crop production (table 1). The sites ranged from 3 to 530 acres in size, and a total of 1446 acres were planted. Site preparation prior to planting varied according to available resources and site condition (table 2). Some sites received no preparation, while others were disked, burned, mowed, sprayed with herbicides or had berms constructed to slightly elevate the seedlings above the field.

Matching Species to Site

Placement of different species within a site was made by visual observations of site characteristics, e.g., low areas, in combination with species tolerance to flooding. Matching species to site by visual observations occurred until the 2005-planting season, when surveyed elevations were used to determine planting schemes. Contour maps were developed for the Moss Island (South) and Three Rivers WMA sites. The contours were surveyed and marked at one-foot intervals using a real time kinematics (RTK) capable global positioning system (GPS). True elevations were surveyed for Three Rivers WMA from a known benchmark, while true elevations for Moss Island (South) are not known, but the contour maps could detect elevational changes within the sites.

Table 1—Planting information and survival for data collected during the summer of 2005

Site	Species[a]	Acres	Year planted	Planting method	Survival
					percent
White oak WMA (Sulphur Wells)	1,2,3,4,6	30	2002	Hoe-dad	74
White oak WMA (Claiborne site)	1,2,3,4,6	30	2002	Hoe-dad	100
Maness Swamp Refuge	1,2,3,4,6,7	50	2002	Hoe-dad	100
Horns Bluff Refuge	1,2,3,4,6	60	2002	Hoe-dad	34
Turnpike	1,2,3,4,5,7,8	10	2003	Hoe-dad	57
Black swamp	1,2,3,4,5,7	21	2003	Hoe-dad	83
John Tully WMA	Not available	22	2003	Auger	61
Tumbleweed	1,2,3,4,5,7,8	150	2003	Hoe-dad	70
Moss Island WMA (north)	1,2,3,4,5,6,7	150	2003	Shovel; hoe-dad	48
Bean Switch Refuge[b]	1,2,4,5,6,7	3	2004	Auger	79
White oak WMA (Crooked Creek Lane)	1,2,4,5,6,7	15	2004	Dibble	59
Chambers Creek	1,2,4,5,6,7	30	2004	Dibble; hoe-dad	90
White Lake Refuge	1,2,4,5,6,7,8,9	30	2004	Shovel	36
Tigrett WMA	1,2,4,5,6,7,8,9	100	2004	Hoe-dad	66
Fullen Tract	1,2,4,5,6,7,9	100	2004	Shovel; hoe-dad	67
Bogota Tract	1,2,3,4,7	6	2005	Machine	Not taken
Moss Island WMA (south)	1,2,3,4,5,6,7,8	109	2005	Modified dibble	62
Three Rivers WMA	1,2,3,4,5,6,7,8	530	2005	Modified dibble	83

WMA = wildlife management area.

[a] Oak species are: willow = 1; water = 2; cherrybark = 3; pin = 4; nuttall = 5; overcup = 6; swamp chestnut = 7; bur = 8; shumard = 9.

[b] Seedlings at this site were culls.

Table 2—Site management, planting scheme, seedling density, and cost per seedling at each site

Site	Site preparation	Planting scheme[a]	Seedlings per acre	Postplanting maintenance	Cost per seedling[b]
White oak WMA (Sulphur Wells)	None	Visual	194	One mowing	0.488
White oak WMA (Claiborne site)	None	Visual	194	One mowing	0.488
Maness Swamp Refuge	None	Visual	194	None	0.488
Horns Bluff Refuge	None	Visual	194	One mowing	0.488
Turnpike	Bushhog; glyphosate	Visual	242	Herbicide for vine control	0.4795
Black swamp	Berms constructed	Visual	363	Glyphosate; mowing	0.4290
John Tully WMA	None	None	302	None	N/A[c]
Tumbleweed	Disking; berms constructed	Visual	194	Partial mowing in rows without *populus*	0.5169
Moss Island WMA (north)	Berms constructed	Visual	242	Mowing	0.4795
Bean Switch Refuge	Burned	None	302	Mowing	N/A[c]
White oak WMA (Crooked Creek Lane)	None	Visual	302	None	0.4938
Chambers Creek	Burned	Visual	302	None	0.4938
White Lake Refuge	None	Visual	302	None	0.4938
Tigrett WMA	Partial disking	Visual	302	None	0.4938
Fullen Tract	None	Visual	302	None	0.4938
Bogota Tract	None	Visual	363	Herbicide to control vines	N/A[c]
Moss Island WMA (south)	Berms constructed	Site elevation	302	Disking between rows	0.5178
Three Rivers WMA	Bedding	Site elevation	363	Disking between rows	0.4994

WMA = wildlife management area.
[a] Method used to match species to variations within a site, e.g., low areas.
[b] Seedling costs calculated in dollars as described in text.
[c] Costs were not calculated, as TWRA employees established the plantings.

Different elevation areas were marked and flagged by color to distinguish elevation and guide assignment of specific species to these areas. At Moss Island WMA (South), species assignment was as follows: Elevation 52 (10 acres) - cherrybark, swamp chestnut, and bur oaks; Elevation 51 (30 acres) -willow, water, and pin oaks; Elevation 50 (50 acres) – water, Nuttall, and overcup oaks. The Three Rivers WMA was divided by fields and elevations within fields. Species allocation was as above. Field 1 - Elevation - 280 nuttall, pin, and overcup oaks, Elevation 281 – willow, water, and pin oaks, and Elevation 282 – cherrybark, swamp chestnut, and 303 bur oaks; Field 2 – Elevation 280 – pin, nuttall, and overcup oaks, Elevation 281 – willow, water, and pin oaks, Elevation 282 – cherrybark, swamp chestnut, and bur oaks; Field 3 – Elevation 280 – pin, nuttall, and overcup oaks, Elevation 281 – willow, water, and pin oaks, Elevation 282 – cherrybark, swamp chestnut, and bur oaks, Field 4 - Elevation 280 – Nuttall, overcup, and pin oaks, in addition to leftover water and willow oaks.

Planting

The seedlings were planted using a variety of planting tools and a Whitfield SP 3202 planting machine, beginning in 2002 (table 1). In the early years, hoe dad planting was used, but concern over fitting the large root systems into the relatively small and shallow hole made by hoe dads eventually caused a shift to planting shovels and modified dibble bars (blades were 15 inches long and 6 inches wide at midpoint) in later years. The planting machine was tried on two sites (Bogota and a second Moss Island site) in 2005. Planting densities could differ by site depending on what species was needed and how many seedlings of each species were available.

For sites that were planted by elevation in 2005, the trailers that transported the seedlings to the site were color-coded to corresponding elevation flags. TWRA employees were assigned to migrant workers to monitor planting activities and supply seedlings to them. One area manager and two technicians generally supervised a 4-man crew of migrant workers. Technicians and managers were also responsible for mixing up seedlings prior to allowing migrant workers to put the appropriate mix of seedlings in their planting bags. Migrant workers were instructed to mix species, as indicated by size, as they planted. The ends of each berm were flagged with a respective color flag. Each four-man team was assigned a color.

Post-Planting Maintenance

Post-planting maintenance varied by site (table 2) and ranged from none to applications of Oust, Glyphosate and mowing. Maintenance was conducted as needed and as resources were available.

Sampling

During the 2005 summer, sample plots were established at each site to estimate survival for the entire tract planted. For sites with 60 acres or less, one 1/100-acre plot per acre was sampled for survival of planted species and presence of species that had naturally seeded into the site (data not presented). Sites that were over 60 acres had one 1/100-acre plot per two acres sampled for survival and naturally seeded species.

Economics

The cost per seedling at each site was calculated using the cost of seedlings (nursery price), an average 20 percent cull rate (data not shown), planting density, and the cost of the planting crew by acre. Acorn collection and processing costs were not included in the calculations, nor were the costs of TWRA personnel that oversaw the planting operations, facilities to store the seedlings, and transportation costs incurred by TWRA to deliver seedlings to planting sites.

RESULTS

Success of seed collection was affected by the flowering cycle of each species and environmental conditions. In some years, all nine species were collected and grown, while as few as six species were grown in other years. Seed quality was fairly consistent among species over time, with average germination rates around 60 percent. In general, Flint River Nursery seedlings were comparably larger than seedlings from other nurseries (Maxedon personal observation), although there is year-to-year variation in overall size.

Bundled high quality seedlings took more bags, cooler space and truck space than smaller seedlings. Culling seedlings in the packing shed by the migrant crew, according to minimum standards set by the second author, was successful. Surprisingly, cull rates for each species averaged approximately 20 percent and were fairly consistent year to year.

Transportation of large numbers of seedlings, ca. 200,000+, from South Georgia to west Tennessee initially strained Flint River Nursery's allocation of tractor-trailers and storage facilities and TWRA's ability to secure adequate cooler space proximal to planting sites. By 2004, these logistic problems had virtually disappeared with the exception of cooler facilities in Tennessee.

All sites were successfully established, although flooding caused stunting of trees in some sites, e.g., White Oak WMA (Sulphur Wells), and partial mortality at Moss Island WMA (North). Survival ranged from 34 to 100 percent, averaging 68.8 percent. Survival did not generally decrease with time, as some of the first plantings still have 100 percent survival. It is unknown if there was a planting tool effect on survival and growth. Inspection of table 1 suggests that the type of planting tool had no effect. Similarly, the impact of post-planting management and matching species to site was difficult to access across sites. Anecdotal observations of survival and growth suggest that post-planting management does have a positive impact, particularly in controlling vines.

Seedling costs varied from $0.4290 to $0.5178 per seedling established in the field. In general, nursery costs increased with time, planting densities varied by site, and planting crew costs were variable.

DISCUSSION

Overall, establishment of large plantings of high quality oak seedlings from local seed sources on west Tennessee bottomland sites has been a success from both survival and operational standpoints. Survival rate is generally acceptable and growth on some sites has been exceptional (data not presented). Use of local seed sources alleviates any concerns about localized adaptability in the short or long term. Operationally, the entire process, from seed collection to planting, was completed without any major problems. In the initial years, coordination with the Georgia State Nursery for transport of the seedlings to Tennessee and obtaining the appropriate amount of cooler space in Tennessee took more time. Those minor problems are now resolved.

Planting seedlings by hand requires close supervision of migrant crews to ensure proper planting. The most common planting mistake made by the migrant crews was not getting the roots deep enough. Due to the large root systems the planting crews sometimes could not get the whole root in the ground exposing the root collar and some of the lateral roots. These trees were replanted when noted by TWRA personnel.

Planting tools used by the planting crew varied by year of planting, as different companies were used. Although the root systems were relatively large, it was possible to plant the trees using hoe-dads. Survival of trees planted by hoe-dads is comparable to trees planted with other implements. The long-term impact of hoedad planting is, however, unknown, and may only be expressed after a number of years as in J-rooting of pine.

Establishment of species according to elevation was successful. TWRA personnel and migrant crews responded well to a procedure that was very different than encountered in most planting operations. Matching the proper species to the proper elevation was successful due to the marking of each bed by colored flagging.

Seedling survival data taken on the Three Rivers WMA and Moss Island (South) followed two growing season floods. Initial survival data suggests that matching species to site by elevation may increase survival in bottomland floodplains. Differences in elevation are clearly related to hydrologic factors when dealing with floodplains and bottomland hardwood plantings. Water drainage, soil moisture, and species selection are associated with elevational differences. Bottomland hardwood species differ in flood tolerance and should be matched to correct elevations depending on flood frequency and depth from past flood records.

Costs per 1000 seedlings were comparable to other nurseries that produce high-quality seedlings. The stock planted on these sites, however, were further high-graded for quality with approximately 20 percent of the seedlings culled. Correspondingly, the actual cost per seedlings was increased. Additionally, there was a cost for collecting the seed incurred by TWRA that was not reflected in the calculated costs in table 2. Survival and growth over time will decide whether the additional expenses are justified.

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NITRATE REDUCTASE ACTIVITY IN 1+0 *JUGLANS NIGRA* SEEDLINGS WITH N FERTILIZATION

M.A. Nicodemus, K.F. Salifu, and D.F. Jacobs[1]

Abstract—Nitrate reductase activity (NRA), a measure of the capacity for plants to reduce nitrate (NO_3^-) into forms that can be used for metabolic activity, was assessed in black walnut (*Juglans nigra* L.) seedlings fertilized with either $NaNO_3$ or NH_4NO_3-based N fertilization at 400 or 800 mg N per plant. N content in leaves was also assessed. We found that there were no significant differences in NRA in roots but we found higher levels of NRA in the leaves of NH_4NO_3-fertilized plants and higher levels in the leaves of the 800 mg N treatment compared with the control. N concentration was increased in the highest treatment level with both N sources, but was higher in $NaNO_3$-treated seedlings. We suggest that the greater NRA in NH_4NO_3-fertilized plants could be a result of the N already having been assimilated in $NaNO_3$-treated seedlings. This result agrees well with the finding of higher N concentration in $NaNO_3$-treated seedlings.

INTRODUCTION

The location of nitrate (NO_3^-) reduction has a critical influence on the energy use of the plant. If NO_3^- is reduced in the roots, there is an increase in root respiration as more energy would be required to assimilate NO_3^- and subsequently (NH_4^+) (Zogg and others 1996). Conversely, if NO_3^- is assimilated in the leaves, there would be little energy needed in the roots to transport it, since NO_3^- transport into the xylem is a passive process (Sivasankar and Oaks 1996). It would involve less energy overall since reduction in the leaves is powered mostly from excess photosynthetic energy (Schrader 1984). In the case of a plant that transports NO_3^- to the leaves, NH_4^+ fertilization would require greater respiratory energy since NH_4^+ is not transported in the xylem and must be converted into organic N in the roots (fig. 1) (Atkins 1988).

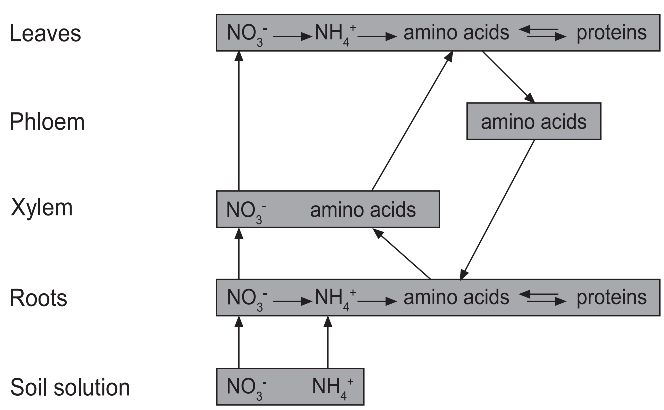

Figure 1—Pathway of nitrate uptake, reduction, and protein synthesis in higher plants. N is absorbed from the soil as NO_3^- or NH_4^+. NO_3^- is either reduced into NH_4^+ or transported to the leaves via the xylem, where it is reduced. NH_4^+ is mostly not transported, so it must be assimilated into amino acids. The amino acids may be transported in the xylem to the leaves or in the phloem to the roots or incorporated into proteins. The location of N assimilation has important implications for the energy demands of the plant (adapted from Haynes 1986).

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Woody species are thought to reduce NO_3^- mainly in the roots (Faure and others 2001, Smirnoff and Stewart 1985). This is true for most coniferous species (Sarjala 1991, Sarjala and others 1987, Seith and others 1994, Yandow and Klein 1986). Conversely, in studies of hardwoods, there is quite a bit of variation, with slightly more than half of the studies surveyed showing greater NO_3^- reduced in the leaves than in the root (table 1). Many of these differences are species-specific, but within species, differences are associated with age of trees, environmental conditions, and treatments.

No studies found in an extensive search of the literature have shown location of nitrate reductase activity (NRA) in *Juglans* species. Small amounts of NO_3^- transported in the xylem exudates of *Juglans* species suggest significant quantities of NO_3^- was reduced in the root (Frak and others 2002, Prima-Putra and Botton 1998) since NO_3^- levels in the xylem exudate have been shown to be directly proportional to the ratio of leaf:root NRA (Polisetty and Hageman 1988). This suggests that, in these studies, NO_3^- was reduced in the root before being transported. The objective of this study was to determine the location of NRA in black walnut (*Juglans nigra* L.) seedlings. This was accomplished by using different levels of fertilizer based on NO_3^- or half NO_3^- and half NH_4^+ to determine the effect of fertilizer type on NRA in walnut. As a valuable species of the Central Hardwoods Forest Region of the United States, it is important to determine how black walnut responds to N amendments. We therefore hypothesized that NO_3^- would be reduced mainly in the roots. We further hypothesized that NRA will increased with NO_3^- addition as suggested by other studies that have shown increases in NRA with NO_3^- addition (Blacquiere and Troelstra 1986, Downs and others 1993, Gojon and others 1991, Krywult and Bytnerowicz 1997).

PROCEDURES

18 half-sib (Purdue #1) 1+0 walnut seedlings were grown at the Indiana Department of Natural Resources Division of Forestry Vallonia Nursery (38° 85´ N, 86° 10´ W) and lifted and stored in a cooler at the Purdue Horticulture Farm. These were planted in 10.65-l Treepot™ containers (Stuewe and Sons, Inc.,

Table 1—Nitrate reductase activity in the leaves and roots of hardwood species taken from the literature

Species	Age	Leaf NRA	Root NRA	Reference
	years	*- - µmol NO_2 g FW^{-1} h^{-1} - -*		
Alnus glutinosa	1	2.8	3.0	Vogel and Dawson 1991
A. glutinosa	3 – 5	1.64	0.10	Gebauer and Schulze 1997
Malus spp.	1	24	40	Toselli and others 1999
M. domestica	1	0.020	0.318	Lee and Titus 1992
Quercus robur	2	0.011	0.028	Thomas and Hilker 2000
Q. robur	5 – 8	0.67	0.10	Gebauer and Schulze 1997
Quercus spp.	1	0.5307	0.0453	Krywult and Bytnerowicz 1997
Fraxinus excelsior	10 – 15	1.40	0.11	Stadler and Gebauer 1992
F. excelsior	10 – 15	1.32	0.13	Gebauer and Schulze 1997
Prunus persica	< 1	0.0672	0.0024	Reilly and Edwards 1986
Acer saccharum	< 1	0.005	0.019	Rothstein and others 1996
A. pseudoplatanus	3 – 5	0.45	0.04	Gebauer and Schulze 1997
A. rubrum	2	0.98	0.18	Downs and others 1993
Populus tremuloides	< 1	0.1	0.5	Min and others 1998
Populus spp.	< 1	5.16	0.14	Black and others 2002
Fagus sylvatica	14 – 23	0.33	0.10	Gebauer and Schulze 1997

NRA = nitrate reductase activity.

Corvallis, OR) with Scotts Metromix® 560 (Scotts Company, Marysville, OH, USA) potting media. These were kept well-watered and fertigated (200 mg N l^{-1}) every two weeks. After 2 months, plants were fertilized with 0, 400, or 800 mg N as $NaNO_3$ or NH_4NO_3. The experimental design was a 3×2 factorial completely randomized design testing N rate and N source at 3 and 2 levels, respectively.

Two months after fertilization, NRA was assessed using methodology in Truax and others (1994) modified as follows. Roots and leaves were rinsed and then dried of surface water before sampling to minimize contamination and ensure that weights were not skewed by water on the samples. Roots were sampled that were <1 mm diameter and alive (white or light brown in color and broken into <1 cm sections by hand or using a knife. Leaf disks were cut using a hole punch and taken from the youngest fully expanded leaf. A 0.2 g fresh tissue sample was placed in a test tube containing 2 mL incubating solution (100 mM phosphate buffer [pH 7.5], 40 mM KNO_3, and 1.2 percent 1-propanol) and sealed and placed in the dark for 1 hour at room temperature. The enzymatic reaction was stopped by removing the plant tissue. A 1 mL aliquot was taken from the tube with a pipette, mixed with 1 mL NED (0.02 percent) and 1 mL sulfanilic acid, and the initial absorbance at 540 nm was read on a Perkin-Elmer LC-95 UV/Visible spectrophotometer (Perkin-Elmer Inc., Norwalk, CT, USA). After 30 minutes, the samples were again measured for absorbance at 540 nm (Truax and others 1994).

Plants were separated into components and dried for dry mass determination. The leaves were ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) to pass a 20 mesh sieve. To determine content of the tissues, 50 µg of ground sample was placed into a ceramic boat which was inserted into a LECO CNS-2000 (LECO Corporation, St. Joseph, MI, USA). This machine determines C and N concentrations in gas following combustion of the samples in a 1350°C oven under high pressure. The N concentration of the leaves is a good indicator of the nutrition status of black walnut (Phares and Finn 1971).

Analysis of variance was conducted on growth NRA and N status of treated plants and where significant treatment means were ranked according to Tukey's highly significant difference test at $\alpha = 0.10$ using SAS software (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Nitrate Reductase Activity

The observed notable trends in root NRA by fresh weight were not significantly different by N source ($p = 0.7034$) or by treatment level ($p = 0.1709$) (figs. 2A and 2C). It could be that NRA reached a limit in the roots and excess NO_3^- was transported to the leaves before being reduced. Leaf NRA by fresh weight was significantly higher ($p = 0.0148$) in the NH_4NO_3 treatment than in the $NaNO_3$ treatment (fig. 2B). Level of fertilizer also showed significant treatment effects ($p = 0.0247$) with the 800 mg level being significantly higher than the 0 mg level (fig. 2C). The interaction between N source and level was also significant ($p = 0.0511$), with the highest level of NH_4NO_3 being higher than the other levels.

Higher NRA with NH_4NO_3 than $NaNO_3$ fertilization is not what we expected in this study. We expected the $NaNO_3$ treatment to have higher NRA since NRA is often inducible *de novo* with NO_3^- addition (Ting 1982, Hoff and others 1992). We anticipated that the higher levels of NO_3^--N would lead to higher NRA induction. Most studies in hardwoods show reduced NRA with NH_4^+ addition than with NO_3^- as the N source (Downs and others 1993, Frith 1972, Reilly and Edwards 1986, Thomas and Hilker 2000) but studies in corn (*Zea mays*) and rose (*Rosa hybrida*) have shown increased NRA with both NO_3^- and NH_4^+ than with NO_3^- alone (Lorenzo and others 2000, Oaks and others 1979). This observation is consistent with the results of this study and suggests that N source effects on NRA are species specific. It could be that enough NO_3^- was reduced in the roots in the $NaNO_3$-fed seedlings so that less NO_3^- was delivered to the leaves or less energy was available for NRA in the leaves. The data suggest that this could be the case although the difference between N sources in the roots is not significant (figs. 2A and 2B).

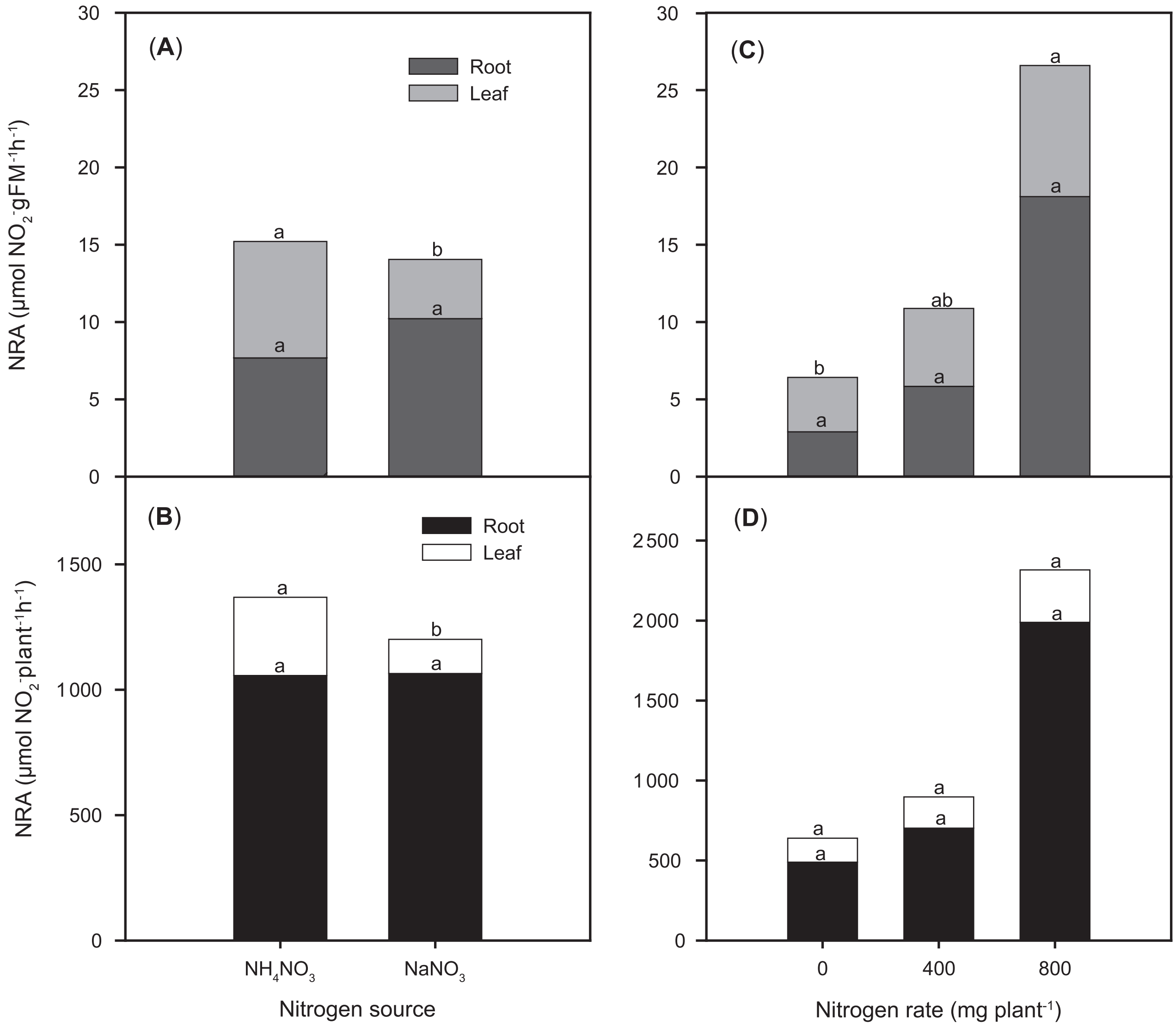

Figure 2—Nitrate reductase activity (NRA) by gram fresh weight in the leaves and roots of *Juglans nigra* seedlings by (A) N source and (B) N application rate and NRA by (C) N source and (D) N application rate (means that were significantly different are signified by different lower case letters).

The increase in NRA in the leaves with increases in the level of fertilization was expected. It would make sense that as the roots are saturated for NRA, the excess NO_3^- would be transported to the leaves to be reduced. This would concur with the observed data (fig. 2B).

The NRA in the leaves was higher for the total plant in the NH_4NO_3 treatment than in the $NaNO_3$ treatment ($p = 0.0629$) with no other source or level effects in leaves or roots (fig. 2). The level effect in the leaves by total plant were no longer significant ($p = 0.2563$). It could be that the plants devoted more energy to producing mass, so that even though the rates by fresh weight were likely important, they were no longer significant due to mass differences.

Plant growth and N allocation

There were no significant differences in dry mass of seedlings by N source or level (figs. 3A and 3D). There was a higher concentration of N in seedlings treated with $NaNO_3$ ($p = 0.0413$) and at the highest level of N addition ($p = 0.0484$) (figs. 3B and 3E). The higher concentration at the highest level is intuitive since there was more N available to those seedlings.

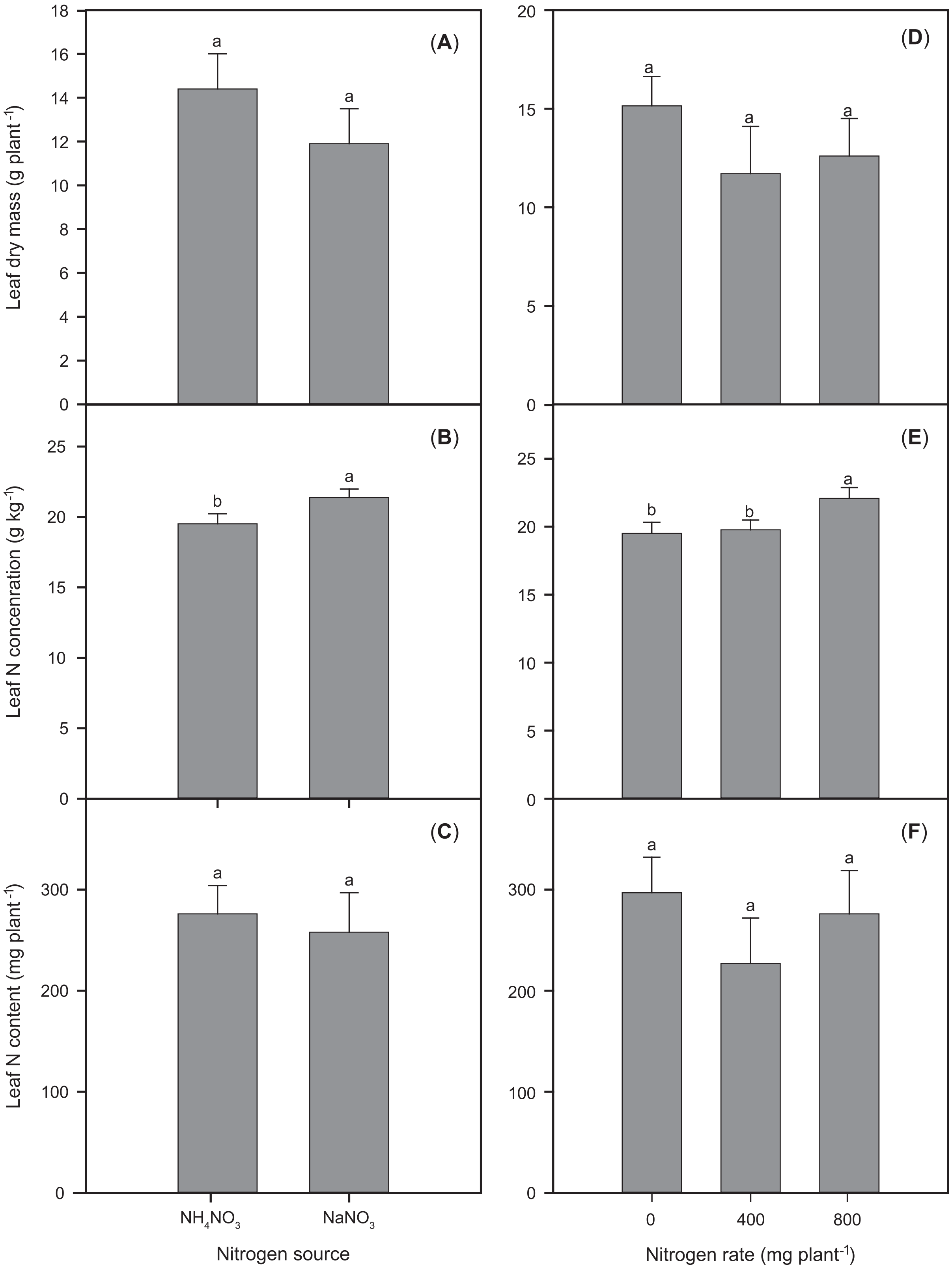

Figure 3—(A) Leaf dry mass, (B) leaf N concentration, and (C) leaf N content by N source; (D) leaf dry mass, (E) leaf N concentration, and (F) leaf N content by N rate (means that were significantly different are signified by different lower case letters).

It seems odd that seedlings fed with $NaNO_3$ had a higher leaf N concentration (fig. 3B) but lower NRA than the NH_4NO_3 seedlings (figs. 2A and 2B) but this could actually help explain why the $NaNO_3$ seedlings did have lower NRA. It could be that the $NaNO_3$ seedlings had already assimilated so much N that energy was diverted from NRA to other processes in the plant.

Future studies will be designed to measure the respiration and photosynthesis of seedlings under different N treatments to determine if the energy requirements of the plant may be related to NRA. A third source without nitrate will also be added to further elucidate source effects on NRA. More samples will be added to find out if apparent, but insignificant trends in the data are legitimate.

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FIFTEEN-YEAR PERFORMANCE OF FIVE OAK SPECIES IN PLANTATION CULTURE

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Abstract—An oak species comparison study was established in 1987 on a bottomland site in western Kentucky. This study examined survival and growth differences among five oak species: water oak (*Quercus nigra* L.), cherrybark oak (*Q. falcata* var. *pagodaefolia* Ell.), willow oak (*Q. phellos* L.), Nuttall oak (*Q. nuttallii* Palmer), and pin oak (*Q. palustris* Muenchh.). The test design was a randomized complete block consisting of six blocks and 49-tree block plots planted at 9 x 9 feet. Measurements included height at ages one, three, and five and dbh and height at ages 10 and 15. While the test was maintained by disking during the first and second years, it was not at the intensity given other hardwood species such as cottonwood and sycamore. At age 15, overall test survival averaged 87.4 percent, with water oak being the lowest at 80.3 percent and Nuttall oak the highest at 93.0 percent. Tree-to-tree competition at age 15 is very intense resulting in a number of suppressed trees. Diameter at age 15 averaged 5.8 inches, with willow oak and water oak showing no significant difference at 6.1 and 6.2 inches, respectively. Nuttall oak exhibited the smallest diameter at 5.2 inches. The test average for age-15 height among the five species was 46.8 feet, with pin oak being the tallest at 48.7 feet and Nuttall oak the shortest at 42.9 feet. Growth between ages 10 and 15 showed that cherrybark oak is growing the fastest for both diameter and height while Nuttall oak is performing the worst. The site is a poorly drained clay loam soil seemingly better suited to pin oak and willow oak rather than cherrybark.

INTRODUCTION

Plantation culture in the United States has focused primarily on conifers where pulpwood and chip and saw markets provide mid-rotation revenue allowing a longer rotation for sawtimber. Loblolly pine (*Pinus taeda* L.) in the Southeast, Douglas fir [*Pseudotsuga menziesii* (Mirb) Franco] in the Northwest and even red pine (*P. resinosa* Ait.) in the Lake States are examples of softwood species and successful plantation culture. Hardwood species such as eastern cottonwood (*Populus deltoides* Bartr.) and sweetgum (*Liquidambar styraciflua* L.) have done well in plantation culture, but the primary end product of these species has historically been primarily pulpwood (Stanturf and Portwood 1999, Scott and others 2002).

With pulpwood as the end product, growth must be extremely rapid to insure an adequate rate of return. Other than rich alluvial soils of the Mississippi River, the return on investment is certainly not adequate due to high establishment costs (Robison and others 1998, Stanturf and Portwood 1999). Plantations of high valued hardwood species such as oak (*Quercus* sp.) and black walnut (*Juglans nigra* L.) have met with only limited success in plantation culture.

One of the primary problems associated with plantation hardwoods is the inability of a hardwood species to grow well over a wide array of sites. In comparison, loblolly pine performs well over numerous site types throughout the southeastern United States and provides a greater rate of return because of its sawtimber potential. Unfortunately, hardwoods tend to be extremely site specific, making it difficult to plant large acreages to a single species (Meadows and Hodges 2004, Siry 2002). In addition, establishment costs are extremely high because of the need to use mechanical means of controlling herbaceous and vine competition. The unavailability of low cost site preparation chemicals as well as over-the-top chemicals to control herbaceous and vine competition has nearly eliminated hardwood plantation culture. However, continued research into species-site selection and optimal seed sources is

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needed along with testing of various agricultural chemicals to solve these limiting problems (Gardiner and others 2004, Schweitzer and Stanturf 1999).

During the early 1980's, Westvaco's Central Region covered approximately 250,000 acres in north Mississippi, west Tennessee, western Kentucky, southern Illinois, and southeast Missouri. The program was divided into loblolly pine plantations, natural hardwood regeneration, and hardwood plantations. The hardwood plantation program focused on fast growing species such as eastern cottonwood, American sycamore (*Platanus occidentalis* L.), sweetgum, and European black alder [*Alnus glutinosa* (L.) Gaertn.]. To determine the species best suited to specific sites, the Baker-Broadfoot (1979) system of species selection based on soil characteristics was employed. However, the method had one specific twist: no matter what the system recommended for a specific site, the recommendations were to regenerate the site to the fastest growing species ahead of the recommended species. The prevailing thought was that the recommended species was suitable for long term production, but the site could support the faster growing species for the time needed to produce pulpwood. This theory proved to be faulty as a number plantations met with failure from poor survival, diseases, and overall poor growth prior to meeting the specified height and diameter. For the most part, these failed plantations were not on alluvial soils but rather on secondary drainages (bottomland sites) and upland sites.

During this time, oak plantations were never considered because of the slower growth expected from various oak species. In addition, the uncertainty of seed availability and poor quality seedlings, combined with the lack of knowledge of not only the correct seed sources for various geographic areas but the correct species for specific sites made oak establishment a risky proposition. Successful reforestation requires an understanding of site variation to match species to these site characteristics (Stanturf and others 1998, Meadows and Hodges 2004, McCoy and others 2002). Fortunately, during the late 1970's and early 1980's species-site studies were established by Westvaco on a number of sites in the western Kentucky area with many located on bottomland soils. Survival and growth of pin oak (*Q. palustris*) indicated that on specific sites it was the best recommendation over such species as cottonwood, sycamore, sweetgum, and green ash (*Fraxinus pennslyvanica* Marsh.).

The objectives of this particular study were to determine if oak plantations could be established on poorly drained, moderately fertile sites not suitable for short rotation woody crops such as cottonwood and sycamore and to identify the optimal oak species for deployment. The study was also an initial step by Westvaco to determine how oak plantations could be managed to provide both pulpwood and sawtimber.

PROCEDURES

Open-pollinated seed from seven mother trees were collected during the fall of 1985 from each of five species of red oaks, which included cherrybark, Nuttall, pin, water, and willow oak species. The test species origins were cherrybark from west Tennessee (Ames Plantation), Nuttall from north-central Mississippi, pin oak from western Kentucky, water oak from the Mississippi Delta near Stoneville, MS, and willow oak from western Kentucky.

Following collection, seed were floated in water to facilitate removal of damaged or insect infested seed. Sound seed were drained and stored in sealed plastic bags at approximately 35°F until sowing. Monthly, the bags were opened and seed were washed and re-floated as an additional means of discarding bad seed. Prior to sowing, each seed lot was re-floated and germinated on blotter paper in flats. Every third day, the germinated seed were sown at a rate of five seedlings per square foot at the J. P. Rhody Kentucky State Nursery, near Gilbertsville, Kentucky. All of the seed were sown between April 14 and April 23, 1986. Nursery practices included fertilization with ammonia nitrate, foliar sprayings of chelated iron, and lateral root pruning. Application of chelated iron followed each flush of growth. Lateral root pruning was done to enhance a more compact root system. This technique was done three times during the growing season. The seedlings were lifted on February 8, 1987 graded, arranged into test plots by replication, and stored at 35°F until planting.

The test site is located on the Pittman Tract in Ballard Co., Kentucky. Soil type is described as a Falaya-Collins silt loam, with high available moisture, moderate permeability, moderate natural fertility, medium organic matter content, and strongly acidic. Periodic flooding of the test site for various lengths of time can occur during the winter and spring as the result of high water conditions on the lower Mississippi River. Stand history indicated that the area was a native bottomland hardwood stand containing red oak, green ash, silver maple (*Acer saccharinum* L.), sugarberry (*Celtis laevigata* Wild.), and sweetgum. In 1979, the natural stand was cleared and an eastern cottonwood plantation was established. The stand never received any lime or fertilization and after six years the stand did not exhibit sufficient stocking levels or growth and was sheared, piled and burned. Site preparation included disking, row marking, and slitting at a spacing of 9 x 9 feet.

The field design is a randomized complete block consisting of six blocks and five oak species arranged in 49-tree block plots. Unfortunately there were only enough Nuttall oak seedlings for two complete blocks. Research personnel planted the test on March 27, 1987. Herbaceous and vine competition was controlled during the first and second year by disking. First-year maintenance was excellent. Measurements included height at ages 1, 3, 5, 10, and 15 while dbh was taken at ages 5, 10, and 15. Statistical analyses were generated using SAS/STAT software, version 9.1 of the SAS System for Windows.[2]

RESULTS

Survival

As with any species, it is imperative that age-one survival be greater than 90 percent (Sweeney and Czapka 2004). Age-one test survival was quite high at 97.1 percent, indicating quality seedlings, a favorable environment, and adequate herbaceous control (table 1). Water oak exhibited the lowest survival at 94.2 percent. This was somewhat expected because of the southerly seed origin. Water oak was the only species retaining green leaves during lifting.

Although, second and third-year competition was not controlled at the level of intensity that would have kept trees in a weed free environment, mortality was at a minimum. Water oak was the most affected dropping from 94.2 percent at age one to 86.7 percent at age three (table 1). Survival for all species

Table 1—Survival at ages 1, 3, 5, 10, and 15 years for the five oak species included in the 1987 oak species comparison study located in Ballard County, KY

	Survival				
Oak species	Age 1	Age 3	Age 5	Age 10	Age 15
	- - - - - - - - - - - - - - - *percent* - - - - - - - - - - - - - - -				
Cherrybark	95.6c	95.6b	95.6b	94.6b	90.1b
Nuttall[a]	100.0a	99.0a	98.0a	98.0a	93.9a
Pin	97.6b	96.6b	96.6b	96.6b	93.2a
Water	94.2c	86.7c	86.7c	86.2c	82.0c
Willow	98.3b	95.2b	95.2b	95.2b	93.5a

[a] Nuttall oak is only represented in two of the six blocks.
Percentages followed by the same letter are not significantly different at the 0.05 level.

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remained nearly the same from age three through age 10. However between ages 10 and 15, survival dropped for all species, indicating that tree-to-tree competition intensified with the slower growing trees falling into the suppressed class and leading to mortality. With the canopy completely closed by age 10 there was no herbaceous growth or shade tolerant woody species. The mean test survival at age 15 is 90.5 percent, thus there are still 438 trees per acre. The high number of trees per acre suggests that thinning will be necessary to avoid a slow process of suppression and mortality.

Growth

Significant species and block by species interactions were noted for height and diameter at all ages (tables 2 and 3). While species differences were noted, selection of the optimal species varied somewhat from age to age. As expected, growth during the first year was rather slow, with the age-one mean test height being less than two feet. Only willow oak was significantly taller than the other four species at age one (table 2). It has been shown that grass may be the greatest competitor of planted seedlings (Ford 1999). Although the site was kept fairly weed free during the first year, subsequent growing seasons did not receive similar care. In fact, the majority of the trees were hidden by herbaceous material during the second year. By age three a majority of the trees were taller than the herbaceous competition with the entire test averaging better than 7.6 feet in height. Although significant species differences existed for age-three height, only three feet separates the tallest species, willow oak, and the shortest species, cherrybark oak. This three-foot separation between the tallest and shortest species was maintained at age five. Cherrybark oak averaged only 10.4 feet while pin oak and willow oak averaged 13.6 feet and 13.4 feet, respectively (table 2). By age 10 this separation increased to five feet but was only 3.4 feet by age 15.

Annual height growth rate for the various species indicated height growth for all species increased from age one to age 10 but decreased between ages 10 and 15 (table 3). Although cherrybark oak was among the shortest at age 15, its growth rate between ages 10 and 15 was the greatest, and it was the only species that maintained similar growth through age 15. The decrease in growth rate between ages 10 and 15 may be the result of tree-to-tree competition. Generally, height growth rate of all species between ages three and five nearly doubled. Height growth rate for all species doubled again between ages five and 10, but total height at age 15 was only 1.5x that of height at age 10. Growth rates between ages five and ten among the five species were similar, indicating that these species are well adapted to this site. In addition, the growth rates shown between ages five and 10 are very similar to what you might expect from fast growing species such as sycamore (Rousseau 1989).

Table 2—Least square means for height at ages 1, 3, 5, and 10 and d.b.h. at ages 10 and 15 for all oak species of the 1987 oak species comparison study located in Ballard County, KY

	Height					D.b.h.	
Oak species	Age 1	Age 3	Age 5	Age 10	Age 15	Age 10	Age 15
	- - - - - - - - - - - - - - - - - *feet* - - - - - - - - - - - - - - - - -					- - - - *inches* - - - -	
Cherrybark	1.7	5.7	10.4	28.5	45.9	3.9	5.6
Nuttall[a]	2.0	7.6	12.9	30.9	44.9	4.1	5.4
Pin	1.9	8.1	13.6	33.2	48.3	4.4	5.7
Water	1.8	7.9	12.6	32.6	48.3	4.5	6.1
Willow	2.3	8.8	13.4	32.9	46.9	4.6	6.1

D.b.h. = diameter at breast height.
[a] Nuttall oak is only represented in two of the six blocks.

Table 3—Total growth and average height and diameter growth among the various age groups for all oak species of the 1987 oak species comparison study located in Ballard County, KY

	Height			D.b.h.	
Oak species	1 – 3	1 – 5	5 – 10	10 – 15	10 – 15
	- - - - - - - - - - *feet* - - - - - - - - - - -			- - - - - *inches* - - - - -	
Cherrybark	4.0/2.0[b]	8.7/2.3	18.1/4.5	17.4/4.4	1.7/0.4
Nuttall[a]	5.6/2.8	10.9/2.7	18.0/4.5	14.0/3.5	1.3/0.3
Pin	6.2/3.1	11.7/2.9	19.6/4.9	15.1/3.8	1.3/0.3
Water	6.1/3.1	10.8/2.7	20.0/5.0	15.7/3.9	1.6/0.4
Willow	6.5/3.3	11.1/2.8	19.5/4.9	14.0/3.5	1.5/0.4

D.b.h. = diameter at breast height.
[a] Nuttall oak is only represented in two of the six blocks.
[b] Total height precedes the slash and mean height growth follows the slash.

Age-10 dbh measurements for all species indicated that growth was nearly four-tenths of an inch per year (table 3). Between ages 10 and 15 diameter growth seem to slow somewhat as the result of tree-to-tree competition. Cherrybark oak grew slightly more than the other four species.

DISCUSSION

The test site was chosen based on soil characteristics, the knowledge of native stand species, growth of operational plantations and the results of a species-site study planted by Westvaco in 1981 on the same tract. Bottomland sites slightly higher in elevation, such as that of the test site, are predominately occupied by various oak and hickory species. In fact, a small willow oak seed production area is located just south of the oak species comparison test site. Western Kentucky is geographically located where the ranges of a number of northern and southern red oaks merge. The ranges of Nuttall oak and water oak are located further south than western Kentucky. The far northern edge of willow oaks natural range is the western Kentucky area, but its occurrence is only infrequent.

Total height of the age 15 Nuttall oak plots averaged nearly 45 feet which is excellent when compared to 27 feet of age 15 Nuttall oak on heavier soils in the Mississippi Delta (Krinard and Kennedy 1987). An oak spacing study located in southeastern Arkansas showed that at age 10 cherrybark oak, Nuttall oak, and water oak averaged 20 feet, 18 feet, and 25 feet, respectively (Kennedy and others). In comparison, cherrybark, Nuttall, and water oak of the Oak Species Test in western Kentucky averaged 28, 31, and 33 feet, respectively at age 10. A decrease in growth between ages 10 and 15 has also been reported for Nuttall oak in the Western Gulf Region by Gwaze and others (2003) and in cherrybark oak by Clatterbuck (2002).

A species-site study established on the same tract in 1981 showed that cottonwood, sycamore, green ash and sweetgum were taller than the pin oak plots, but the oak plots seemed to be poised for better growth while the other species were declining. The average height of the pin oak plots at ages five and 10 were 11.8 and 29.3 feet, respectively (table 4). The wider 12 x 12 foot spacing of the species-site study did not result in much larger age-10 diameter (4.6 inches) than the narrower 9 x 9 foot spacing (4.4 inches) of the oak species comparison study. This same trend was also observed in oak spacing study located in Arkansas (Kennedy and others 1988).

Comparison of the growth rates of cherrybark oak, pin oak, and eastern cottonwood on similar sites are an excellent indicator of site adaptability and the importance of proper species selection. Age-one height of the pin oak in the Oak Species Comparison Study and the 1981 Species-Site Study located on the same

Table 4—Total height growth at measurement ages and average annual height growth between measurement ages for cherrybark oak, pin oak, and cottonwood in the tests on western Kentucky sites

	Cherrybark oak				Pin oak				Cottonwood	
	Progeny test[a]		Oak species test[b]		Species/site study[c]		Oak species test		Species/site study[c]	
Year	Total height	Annual growth	Total height	Annual growth	Total height	Annual growth	Total height	Annual growth	Total height	Annual growth
	feet									
1	1.5	—	1.7	—	1.9	—	1.9	—	5.3	—
3	4.9	1.7	5.7	2.0	5.9	2.0	8.1	3.1	22.0	8.4
5	11.2	3.2	10.4	2.3	11.6	2.9	13.6	2.8	36.6	7.3
10	34.6	5.9	28.5	4.5	29.3	4.4	33.2	4.9	55.8	4.8
15	51.1	4.1	45.9	4.3	—	—	48.3	3.8	—	—

— = not applicable.
[a] 1987 cherrybark oak progeny test located on a loess bluff site in Carlisle County, KY.
[b] 1987 oak species comparison study located on a bottomland site in Ballard County, KY.
[c] 1981 species site study located on a bottomland site in Ballard County, KY.

tract were identical but by age-three height in the oak species comparison study was over two foot taller than the species-site study. This height difference was probably the result of better competition control at ages one and two in the Oak Species Comparison Study. It is also noteworthy that this height difference was maintained through age 10.

Species site selection is often difficult in hardwoods and at times species found in the natural stand may not accurately predict what the optimal species may be for a plantation scenario. This difference may have resulted in regeneration of species under unusual environmental factors or due to extreme micro-site variability. The inclusion of mean height and mean annual growth of cottonwood provides a prime example of poor species selection. Early growth of cottonwood was fairly decent and height at age five was greater than the oak species at age 10. However, height growth between ages five and ten had slowed to 4.8 feet and was now being equaled by the various oak species. The slow growth of the cottonwood from ages five to 10 indicates that the species is off site and instead of being able to harvest in a year or two as on alluvial sites, this cut may never come as diseases such as cottonwood leaf rust (*Melampsora medusae* Thuem. f.sp. *deltoides* Shain) and poplar canker (*Cytospora chrysoperma* Fr.) and insects such as the cottonwood leaf beetle (*Chrysomela scripta* F.) will cause a extreme loss of yield.

In 1987, a cherrybark oak progeny test was established on an excellent loess site in Carlisle Co., Kentucky at nine by nine foot spacing. Comparing cherrybark oak progeny test and the cherrybark oak in the Oak Species Comparison Test showed that while age-one height was similar between the two sites by age 15 the overall height of the cherrybark on the loess site was six foot taller than the cherrybark on the bottomland site (table 4). Both sites maximized height growth between ages five and 10 then slowed somewhat between ages 10 and 15 (Adams and others 2005). While cherrybark oak was the shortest in the Oak Species Comparison Study at age 15, it did show the fastest annual growth between ages 10 and 15. Based on the growth rates and the higher quality of cherrybark oak, it would be the preferred species. However, if the site was a little lower we would then select either willow oak or water from a southern seed source as well as pin oak from western Kentucky.

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DEER BROWSING PATTERNS IN A RECENTLY AFFORESTED BOTTOMLAND

Kenneth J. Ruzicka, John W. Groninger, and James J. Zaczek[1]

Abstract—The intensity and distribution of deer browsing on planted and volunteer seedlings were examined at Grassy Slough, a recently afforested, 526 ha formerly row-cropped bottomland site in southern Illinois. Three to five years prior to measurement, the site was planted at a 3.66 m by 3.66 m spacing with primarily bottomland oak species. The management objective was the restoration of pre-agricultural vegetation composition. Planted oaks constituted seven percent of trees observed on site. Deer herbivory influenced early tree growth and disproportionately impacted seedlings of *Quercus palustris* Muenchh. and *Celtis occidentalis* L. The relationship between browse and distance from forest cover is less clear as more trees were browsed close to cover while a greater percentage of trees were browed away from the edges. These results suggest that deer herbivory may play an important role in determining the eventual overstory composition at Grassy Slough.

INTRODUCTION

Hardwood forests historically covered many of the floodplains in southern Illinois. However, many of these forests were cleared in the 1960s for agriculture, primarily soybean production. In the early 1990's, interest in the afforestation of these bottomland sites has steadily increased. Justifications for returning these lands to forest cover include improving water quality, wildlife habitat production, and biodiversity enhancement (Groninger 2005). Afforestation projects on these sites typically include planting heavy seeded oak species and anticipating volunteer recruitment of light seeded species through natural dispersal from surrounding areas with the goal of achieving a mixed species forest (King and Keeland 1999, Stanturf and others 2001). Attainment of this goal is often hampered by stochastic factors, mismatches of species to site conditions, and herbivory (Kruse and Groninger 2003).

Heavy browsing of young trees by white-tailed deer (*Odocoileus virginianus*) is sometimes an important factor limiting afforestation success in this region (Zaczek and others 1997, Russell and others 2001). White-tailed deer is an edge species that prefers to feed in disturbed or early successional communities (Russell and others 2001). Populations of white tailed deer have increased dramatically since the early 1900s and are currently at population densities higher than historical levels. Deer have been broadly implicated in limiting tree regeneration (Tilghman 1989, Marquis 1974) and reducing forest diversity (Rooney and Waller 2003, Russell and others 2001). Moreover, deer browsing affects individual seedlings by altering stem morphology and reducing stem height, thereby decreasing survivability (Russell and others 2001). When the terminal leader of a sapling is no longer vulnerable to predation by white-tailed deer, at approximately 1.37 m in height (Zaczek and others 1997), these stems have an increased likelihood to be long-term components of the stand. In some areas, white-tailed deer now have sufficiently strong impacts on the ecosystems they inhabit to be considered a keystone species (Rooney and Waller 2003).

Understanding the interaction between site characteristics, deer browsing and tree growth has consequences for the planning and implementation of bottomland afforestation. This study assesses the relationships between distance from the nearest forest edge, deer herbivory, and tree species composition within a large bottomland afforestation project.

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METHODS

Owned and managed by The Nature Conservancy, Grassy Slough is a 526 ha old-field restoration project located in the Lower Cache River Watershed near Belknap, Illinois. Karnak (Fine, montmorillinitic, nonacid, mesic, Aquic Haplaquepts) and Weinbach (Fine-silty, mixed, mesic, Aeric Fragiaqualfs) soil series predominate. Both soils are classified as poorly drained and are associated with bottomland forest cover (USDA 1959). Prior to restoration, the site was in agricultural production, primarily soybean row cropping, until the growing season immediately before planting. During fall 1999, the site was planted with tree seedlings grown for one year at the Nature Conservancy nursery at Grassy Slough. The planting was done on a 3.66 m by 3.66 m spacing. Most seedlings planted initially were pin oak (*Q. palustris* Muenchh.) but also included swamp white oak (*Q. bicolor* Willd.) and bald cypress (*Taxodium distichum* [L.] Rich. var. *distichum*). Subsequent plantings in 2000 and 2001 included willow oak (*Q. phellos* L.), shumard oak (*Q. shumardii* Buckl.) and bur oak (*Q. macrocarpa* Michx.).

Vegetation sampling occurred during summer 2004. Sampling transects were positioned 200m apart across the entire site. The sampling was designed to uniformly sample the site which approximated a rectangle 1.4 km long and 4.6 km wide. A total of 537, 5.51 m^2 circular plots were placed 50 m apart along these transects. In each plot, all stems of tree species greater than 50 cm tall were tallied. Height was measured and incidence of deer browse was recorded for each tallied stem. Only trees with cut terminal leaders were considered to be browsed by deer. Browse on leaves was not recorded. A plot was considered to be stocked if at least one stem was above the browse line at 1.37 m (Kruse and Groninger 2003).

Plots were grouped for analysis by distance from a forest edge at intervals of 100 m. Most of the site was adjacent to a forested area but the eastern edge bordered an agricultural field. The occurrence of deer browse damage was represented by dividing the number of browsed stems by the total number of stems within each plot. Simple linear regression was used to assess the relationship between deer browse and distance from the nearest forest edge (i.e., potential cover).

RESULTS

A total of 1878 trees of 26 species encompassing 15 genera were observed within sample plots (table 1). The major constituents, green ash (*Fraxinus pennsylvanica* Marsh.), box-elder (*Acer negundo* L.) and sweetgum (*Liquidambar styraciflua* L.), and sycamore (*Platanus occidentalis* L.) accounted for over 90 percent of all stems above the browse line. Planted oaks represented 5 percent of all stems, and 3 percent of the stems >1.37 m. Only 23 percent of plots attained stocked status with stems >1.37 m. Thirteen percent of these stocked plots (three percent of all plots) contained at least one oak stem, while 9 percent were stocked with only oak.

Decreased stem height was positively correlated with incidence of deer browsing ($F = 11.8$, $DF = 1,22$, $P = .002$) (table 1). Incidence of browsing varied dramatically among tree species, most dramatically between sycamore and hackberry (*Celtis occidentalis* L.). Both species represented approximately 8.5 percent of all stems taller than 0.5 m. However, with 2.5 percent of its stems browsed, sycamore constituted 15 percent of stems above the browse line whereas hackberry had 95 percent of its stems browsed and represented less than one percent of stems above the browse line.

Stem density decreased with increased distance from a forest edge ($F = 10.4$, $DF = 1,8$, $p = .01$). The percentage of stems browsed increased with distance from a forest edge ($F = 8.4$, $DF = 1,8$ $p = .02$) (fig. 1). Percentage browse may not be as important as the total number of stems browsed which did not differ significantly as a function of distance from forest cover. Analysis was similar for stems above the browse line ($F = 5.4$, $DF = 1.8$, $p = .05$). The density of oaks increased slightly with increasing distance from the forest edge but was not significant at the $\alpha = .05$ level ($F = 5.4$, $DF = 1,8$, $p = .07$) (fig. 2).

Table 1—Tree species composition of Grassy Slough near Belknap, IL [a]

Species	Total seedling composition ≥ 0.5 m	Stems ≥ 1.37 m	Browsed	Average height: Unbrowsed seedlings	Average height: Browsed seedlings
	percent	percent	percent	cm	cm
Fraxinus pennsylvanica	39.0	27.4	21.6	99.8	89.7
Acer negundo	16.3	23.6	31.3	133.5	87.8
Liquidambar styraciflua	13.3	24.6	0.4	137.3	75
Platanus occidentalis	8.4	15.1	2.5	138.8	100
Celtis occidentalis [b]	8.5	0.5	95.0	100	69.7
Quercus palustris	4.8	3.3	93.4	158.8	86.3
Ulmus americana	2.0	0.2	71.1	93.2	62
A. rubrum	1.7	0	9.7	72.3	108.3
Populus deltoides	1.0	0.9	5.6	141.2	50
A. saccharinum	0.9	0.5	18.8	85.4	66.7
Taxodium distichum v. distichum	0.9	2.4	6.3	140	125
Ulmus rubra	0.5	0	88.9	100	57.1
Total	97.4	98.6	38.8	116.7	81.5

[a] Species comprising < 1 percent of all stems in decreasing value of importance include: *Quercus macrocarpa, Q. michauxii, Salix nigra, Q. bicolor, Q. rubra, Q. velutina, Nyssa sylvatica, Acer saccharum, Catalpa speciosa, Crataegus* spp., *Juniperus virginiana, Q. stellata,* and *Q. falcata*.
[b] Some may be *Celtis laevigata.*

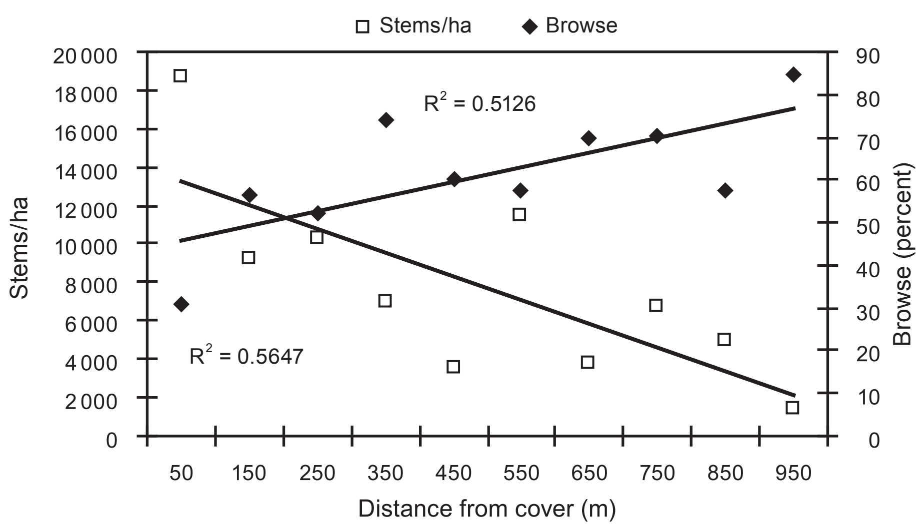

Figure 1—The relationship between percentage browse, stem density and distance from nearest cover.

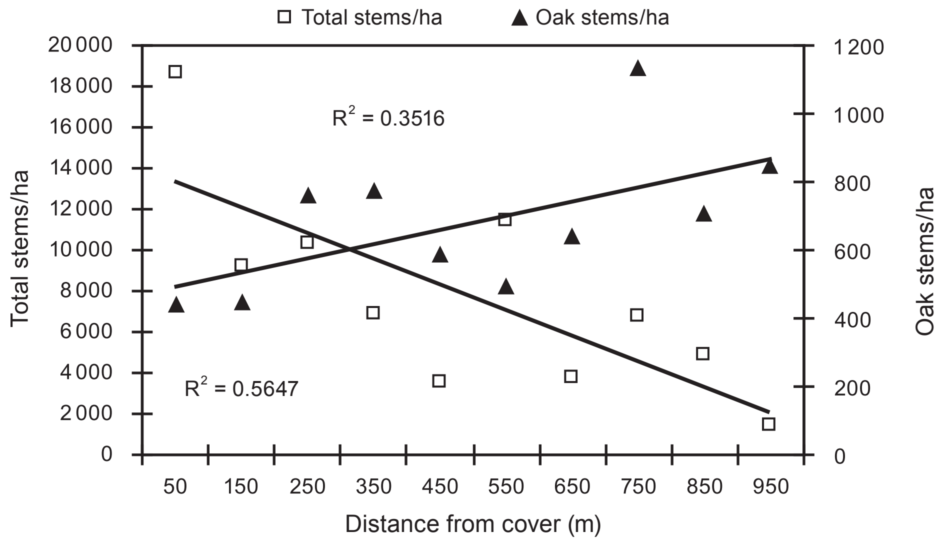

Figure 2—The relationship between total stem density oak density, and distance from nearest cover.

DISCUSSION

The tree species composition of Grassy Slough was comparable to other reforested bottomland sites in the area (Kruse and Groninger 2003). Light-seeded volunteer species from surrounding forested areas contributed heavily to stocking and thus the incidence of stocked plots was negatively correlated with distance from forest cover. Many of the plots contained more stems of light seeded species than would be expected from typical wind borne dispersion (Meiners and others, 2002). One explanation for the abundance of light seeded invasion is that the site is flooded frequently, thereby providing water-borne dispersal of tree seeds.

For most tree species, the average stem height was smaller for browsed versus non-browsed individuals. This observation is well supported by other research (McCormick and others 1993, Rooney and Waller 2003). Deer browsed a higher percentage of oaks, elms (*Ulmus* spp.) and hackberry than other species. Deer preference for browsing oak and hackberry over sweetgum is supported by previous research (Castleberry and others 1999, Strole and Anderson 1992, Morellet and Guibert 1999). Sweetgum and sycamore were browsed lightly allowing these species to have a greater percentage of stems above the browse line than would be predicted by their total abundance alone. Considering the typically small stature of oak stems relative to that of other species, it is probable that oak stocking will increase substantially over the next several years (Twedt and Wilson 2002).

The pattern of deer browse across the site has several possible explanations: Deer may be seeking to browse preferred species. The decrease in stem density with increasing distance would make it easier to locate hackberry and elm even though the total density of these species would have decreased. To browse on oak stems, deer may seek areas with a greater proportion of oak. Not only did the number of oaks increase as a function of distance from the forest edge, but the density of other species decreased. A reduction in competing vegetation may facilitate more intense browsing in areas where total tree density is low and deer are able to locate and obtain preferred browse (Van Der Wal and others 2000). This seems likely with deer browsing ubiquitous across this site.

A study incorporating differences in seedling micro site characteristics, including soils and competitive status, would be necessary to fully understand the mechanism underlying the observed increase in oak density with increasing distance from forest cover.

CONCLUSION

Most of the areas where a closed canopy forest is most likely to develop on this site, barring extreme flooding or other unforeseen disasters, will be near to existing forest cover and will contain proportionally few oak. It appears that the desired restoration to a pre-settlement bottomland oak forest will not be fully realized under the intense deer browsing occurring on the site (Hutchison, map on file with the Nature Conservancy, Peoria, IL).

Oaks commonly exhibit an initially slow rate of growth, yet may still attain dominance later in stand development. However, the likelihood of eventual oak dominance is diminished by white-tailed deer browse on the planted seedlings. The exact patterns of deer browse across this site are not clear, but it is evident that this plays an important role throughout. The eventual effectiveness of this afforestation effort may depend on the implementation of a management program to address the intense influence of deer herbivory on the growth of the tree component.

ACKNOWLEDGMENTS

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EXPONENTIAL NUTRIENT LOADING AND RETRANSLOCATION RESPONSE OF *QUERCUS RUBRA* SEEDLINGS

K. Francis Salifu, Douglass F. Jacobs, and Z. Birge[1]

Abstract—Exponential nutrient loading was examined in container and bareroot northern red oak (*Quercus rubra* L.) seedling culture using a broad range of N supply from deficiency to toxicity to characterize and quantify optimum fertilizer prescriptions for this species. Subsequently, the proportional contribution of ^{15}N uptake versus retranslocation was determined in new growth of transplanted exponential and conventional plants that received the same fertilizer rate during nursery culture. Exponential nutrient loading increased dry mass and N content by 65 and 78 percent in containers, and by 200 and 350 percent in bareroot culture. The sufficiency rate was determined at 25 mg N per plant in containers and at 0.84 g N per plant in bareroot culture. Maximum N uptake occurred at 100 mg N per plant per season in containers and at 1.68 g N per plant per season in bareroot culture. Exponential fertilization promoted retranslocation, growth and ^{15}N uptake in transplanted seedlings. Exponential nutrient loading provides a rationale for quantifying optimum fertilizer prescriptions to produce high quality seedlings for field planting.

INTRODUCTION

There is an increasing demand to produce high quality nursery stock of temperate deciduous forest tree species that are nutritionally well conditioned to promote successful reforestation and afforestation plantings. A new approach to nutritionally pre-condition nursery stock for outplanting, referred to as exponential nutrient loading (Timmer 1997), has been shown to increase the nutritional quality of conifer seedlings. Transplanted nutrient loaded seedlings remobilized higher internal nutrient reserves to promote new growth, which enhanced early plantation establishment success. Increased nutrient storage in northern red oak (*Quercus rubra* L.) seedlings after nutrient loading should not be dissipated because of resorption. This important nutrient conservation mechanism exhibited by deciduous trees may recover 50 to 90 percent of the nutrients from senescing leaves into shoot and root tissues for later utilization (Aerts 1996, Cheng and Fuchigami 2002, Duchesne and others 2001). Increased nutrient storage through loading may provide the critical nutrient and carbohydrate reserves needed to meet increased sink demand during episodic growth events, which could maintain the multiple flushing required for rapid growth under field conditions (Crow 1988, Dickson 1989, Tagliavini and others 1998).

Although exponential nutrient loading in the nursery can lead to production of high quality seedlings for field planting, the quantities of fertilizer required to optimize growth and nutrition for each species and cultural system are unknown. A proposed model of nutrient loading (fig. 1) can help rationalize and quantify optimum fertilizer prescriptions for forest tree seedlings. The model suggests that plant growth and nutrient status conforms to a curvilinear pattern with increased fertilization, but partitioned here into phases to distinguish nutrient deficiency, sufficiency, luxury uptake and toxicity. Incorporation of plant nutrient status in this newly configured model will help improve diagnostic capacity when compared with the traditional model based on dry mass alone (Grossnickle 2000, van den Driessche 1974). Figure 1 has been validated for container production of black spruce [*Picea mariana* (Mill.) BSP] planting stock (Salifu and Timmer 2003b), but has yet to be examined in hardwood culture. Additionally, although internal N redistribution has been shown to promote growth and nutrient acquisition of transplanted seedlings (Millard and Proe 1993, Miller 1984, Salifu and Timmer 2003a), the proportional contributions of current N uptake compared with retranslocation in meeting new growth demand of hardwood species are unknown. Exponential nutrient loading was examined in hardwood culture to quantify

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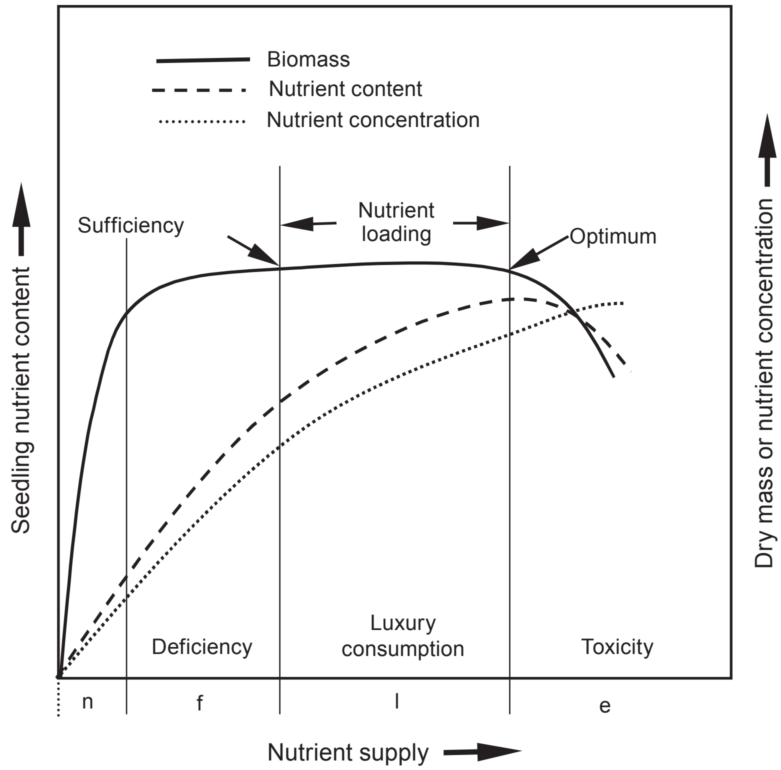

Figure 1—Plant growth and nutrient status conforms to a curvilinear pattern with increased fertilization, but partitioned here into phases to distinguish nutrient deficiency, sufficiency, luxury uptake, and toxicity. Fertilizer (f) supplements native fertility (n) to avert nutrient deficiency to maximize growth at sufficiency. Extra high fertilization or nutrient loading (l) induces luxury uptake in excess of growth demand, which are stored as reserves for later utilization. Excess fertilization (e) may induce toxicity signified by diminished plant growth and N content at increasing tissue N concentration (adapted from Salifu and Timmer 2003b).

thresholds of sufficiency, optimum N uptake, and toxicity for container and bareroot red oak seedlings. Additionally, current N uptake was labeled with the stable isotope ^{15}N which allowed discrimination and quantification of the proportional contribution of retranslocation as indicated by N derived from plant (NDFP) versus current uptake from the soil represented by N derived from fertilizer (NDFF) in new growth of transplanted seedlings. We hypothesized that (1) exponential nutrient loading in the nursery will induce luxury N uptake in red oak seedlings, and (2) nursery plants that received the same fertilizer rate but followed exponential addition schedules will outperform same rate conventional cohorts when transplanted on a simulated soil fertility gradient. The study focused on N because this element most commonly limits plant production (Chapin 1980).

MATERIALS AND METHODS

Greenhouse Trials

Northern red oak container plants were germinated using acorns from an equivalent seed source and seedlings grown for 18-weeks in 2.8-l Treepots™ (Stuewe and Sons, Corvallis, OR, USA) filled with Scotts Metro-Mix® 560 growing medium (The Scotts Company, Marysville, OH, USA). Seasonal dose rates ranged from 0 to 150 mg N per plant, applied conventionally (25 mg N per plant) or exponentially (from 25 to 150 mg N per plant). The conventional treatment reflects the average rate generally used for production of container red oak seedlings (Beckjord and others 1980, Struve 1995). Fertility treatments (fig. 2) were assigned in a randomized complete block design with three replications (18 plants per

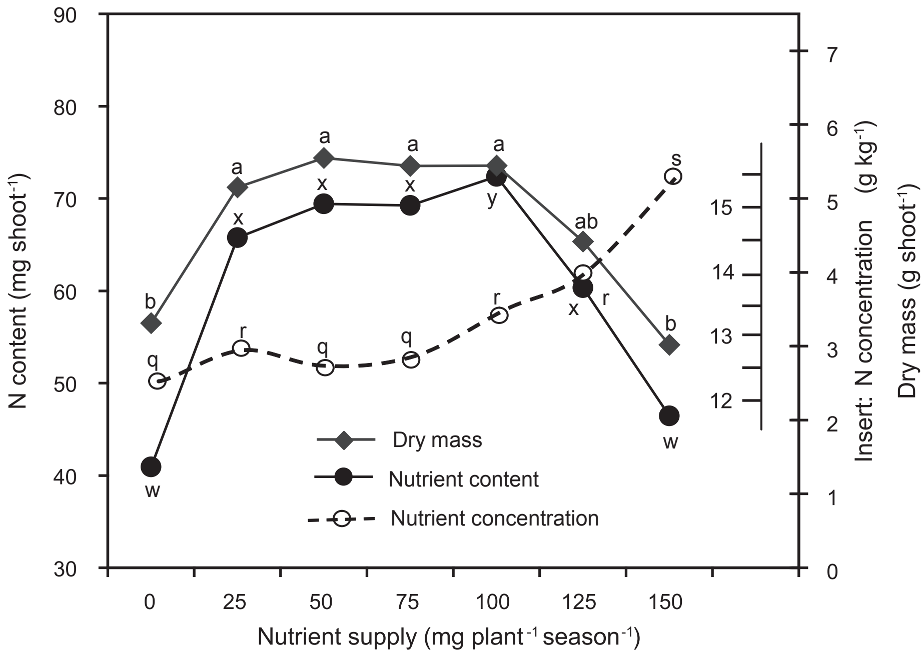

Figure 2—Responses of red oak container seedling shoot dry mass, N content, and concentration in relation to increasing nutrient supply for one growing season (18 weeks) in the greenhouse. The vertical scale insert represents N concentration (g/kg). Points marked with the same letter (biomass a to b, content w to y, and concentration q to s) are not statistically different according to Tukey's highly significant difference test at $\alpha = 0.10$.

replication) on a greenhouse bench (mean day/night temperature of 24/20 °C) under ambient light conditions in the Department of Horticulture and Landscape Architecture Plant Growth Facility at Purdue University, West Lafayette IN, USA (40°25 ' N, 86°55 ' W). A commercial water-soluble fertilizer [Miracle Gro® Excel® 15N-5P_2O_5-15K_2O plus other macro- and micro-elements (The Scotts Company, Marysville, OH, USA)] was applied in solution. Pots were irrigated to container capacity determined at planting (White and Mastalerz 1966). Supplemental irrigation was supplied twice weekly by periodic weighing of pots to determine amount of water to be added (from 100 to 150 ml per pot) to bring pots back to container capacity.

Bareroot northern red oak seedlings were grown under operational conditions (Jacobs 2003) for 18-weeks at the Vallonia State Nursery (38°85 ' N, 86°10 ' W) south of Indianapolis, IN, USA. Seeds were mechanically sown in the fall of 2003 to obtain about 54 seedlings m^{-2} after germination. Fertilizer rates ranged from 0 to 3.35 g N per plant per season (fig. 3). Fertility treatments were laid-out as a RCBD with 4 replications. The standard practice at this nursery is to supply a total of 0.84 g N per seedling per season at seven equal amounts (bi-weekly), which was chosen as the conventional treatment in this study. Ammonium nitrate (34-0-0) in crystal form was broadcast manually on treatment plots. For all trials, weekly applications for exponential treatments followed exponential functions (Timmer 1997, Timmer and Aidelbaum 1996) designed to synchronize fertilizer supply with exponential growth and nutrient uptake of seedlings (Ingestad and Agren 1995, Ingestad and Lund 1986). Seedlings were harvested at the end of nursery culture and processed according to standard protocols detailed in Salifu and Timmer (2003b).

Greenhouse Transplanting Trial

This study was conducted in the same greenhouse as discussed above to evaluate the importance of prior nursery treatments in promoting retranslocation, N uptake and growth of transplanted seedlings. One–year old container red oak seedlings that received the same rate of fertilizer during nursery culture but supplied

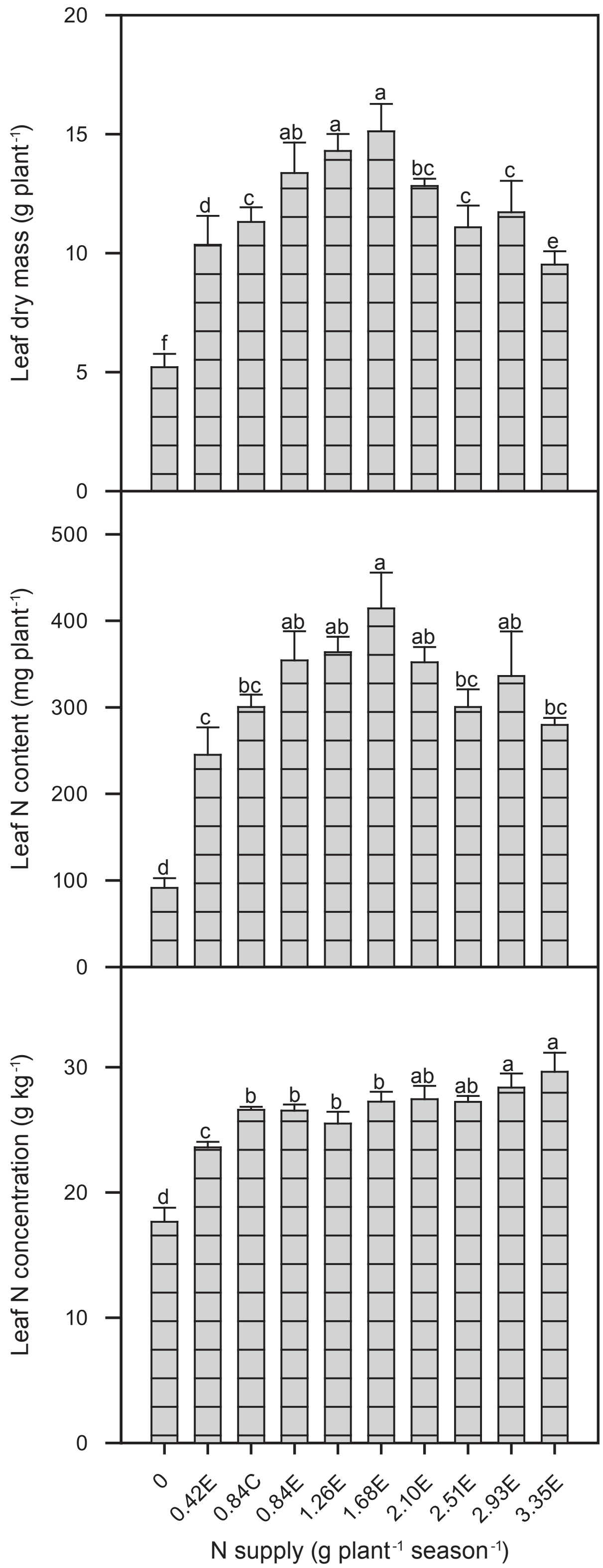

Figure 3—Responses of bare-root red oak seedling leaf dry mass, N content, and concentration in relation to increasing nutrient supply for one growing season (18 weeks). Bars marked with the same letter are not statistically different according to Tukey's highly significant difference test at $\alpha = 0.05$.

either conventional (25C) or exponential (25E) were chosen for the transplanting trial. Seedlings were barerooted and transplanted in sand culture using 6.2-l Treepots™ (Stuewe and Sons, Corvallis, OR, USA). Barerooting was done to ensure that carry-over effects from last year fertilizer does not contaminate current uptake, which was labeled with the stable isotope ^{15}N. The isotopic approach allowed direct quantification of retranslocation (unlabeled N), which could be discriminated from current ^{15}N uptake in new growth. Nitrogen was supplied with the irrigation as $(^{15}NH_4)_2SO_4$ enriched to 5 atoms percent ^{15}N (34-0-0, ISOTEC Inc. USA). Transplanted seedlings received either 0 (control) or 100 kg N/ha simulating poor and rich soils based on the weight of soil in pots in relation to silvicultural prescriptions under field conditions (Brady and Weil 2002, Salifu and Timmer 2003a). Chelated micronutrients were applied with the irrigation at the rate of 0.08 g/L and phosphorus (P) supplemented by $KH_2 P_2O_5$ (0-52-34, Plant Products Co Ltd., Brampton Ont.) at the rate of 30 kg P/ha to avert deficiency of other nutrients. Seedlings flushed one week after planting at which time fertilization commenced. Three split applications were conducted at 1, 2 and 4-wk after planting to improve uptake efficiency. The experiment was conducted as a 2 x 2 factorial design that examined nursery fertilization and N supply each at 2 levels and was replicated three times. Plants were harvested 2 months after transplanting and processed for total N and ^{15}N analyses following protocols detailed in Rundel and others (1989). Total N and ^{15}N were determined using a Stable Isotope Mass Spectrometer coupled to a Micro-Dumas Elemental analyzer at the stable Isotope Laboratory located at the University of Georgia, Athens GA, USA. Nitrogen retranslocation was directly quantified in new growth where unlabelled N represents N derived from plant (NDFP) and labeled N represents N derived from fertilizer (NDFF) or current uptake (Millard and Proe 1993, Salifu and Timmer 2003a).

RESULTS AND DISCUSSION

Greenhouse Response

Figure 2 shows that growth and N content of container seedlings increased with N supply up to the sufficiency rate (25 mg N per plant per sesaon), remained relatively stable during luxury uptake, but declined at higher N addition suggesting induced toxicity (Imo and Timmer 1992, Salifu and Timmer 2003b). Similar trends were found for bareroot culture (fig. 3). The close correspondence of experimental data (figs. 2 and 3) with trends in the conceptual model (fig. 1) demonstrates suitability of the model for rationalizing and quantifying fertilizer prescriptions for forest tree seedlings. Exponential nutrient loading increased container seedling shoot dry mass from 10 to 65 percent, N content from 14 to 78 percent and N concentration from 2 to 26 percent (fig. 2). Total N content for 25C plants was 57 mg and about 72 mg for the suggested optimum rate (100E). Thus, relative to 25C, luxury uptake increased N content by 27 percent in 100E. Nutrient toxicity reduced growth and N content by 45 and 36 percent, respectively, but increased N concentration by 17 percent when 100E is compared with 150E (fig. 2).

For bareroot culture, fertilization increased leaf dry mass from 83 to 200 percent, N content from 204 to 350 percent and N concentration from 33 to 67 percent (fig. 3). Growth and N content were maximized at the optimum index (1.68E). Toxicity occurred at 3.35E, which reduced leaf dry mass and N content by 37 and 33 percent, respectively, but increased N concentration by 8 percent relative to the optimum index. Luxury uptake increased N content by 38 percent in bareroot culture. Induced luxury N uptake following nutrient loading in bareroot and container culture observed here are in agreement with results of other studies (Imo and Timmer 1992, McAlister and Timmer 1998, Salifu and Timmer 2003b).

Field Response

Pre-plant shoot N content of plants that received the same fertilizer rate in the nursery but fertilized conventionally (25C) was 52 mg N per plant compared with 67 mg N per plant when fertilized exponentially (25E). Thus, exponentially cultured seedlings contained 29 percent more N at outplanting. Relative to conventional plants, exponential fertilization increased seedlings dry mass by 67 percent (fig. 4A), demonstrating benefits of exponential over conventional fertilization in promoting seedling growth. Internal N redistribution is represented by N derived from plant (NDFP) while current uptake is indicated by N derived from fertilizer (NDFF) as shown in figure 4B. Exponentially cultured seedlings exhibited

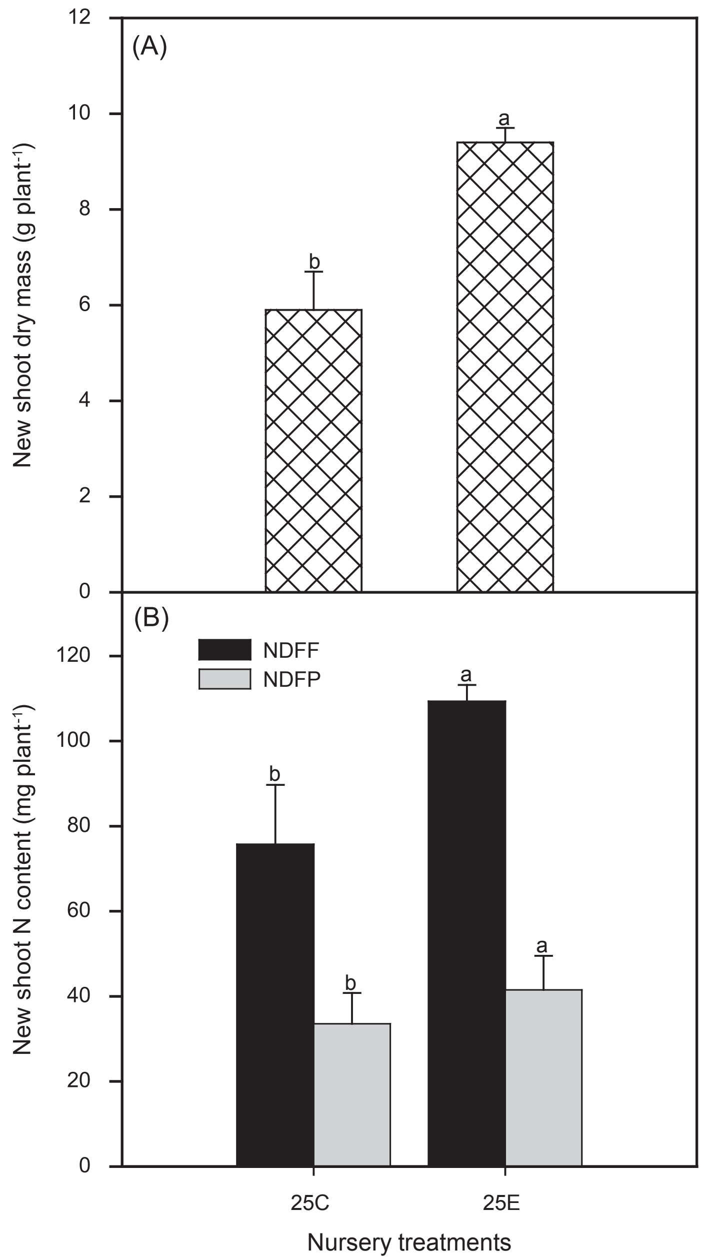

Figure 4—Seedling new shoot growth (A) and current N uptake represented by N derived from fertilizer (NDFF) versus retranslocation represented by N derived from plant (NDFP) (B) for container red oak seedlings raised conventionally (25C) or exponentially (25E) during one growing season in the nursery (18 weeks) and outplanted in sand culture for 60 days under controlled greenhouse environments. Similar bars marked with the same letter are not statistically different according to Tukey's highly significant difference test at $\alpha = 0.10$.

higher (P = 0.0815) retranslocation (21 percent) than observed in conventional cohorts. Similarly, N uptake increased 43 percent in exponential seedlings and differed (P = 0.0127) from estimates observed in conventional plants (fig. 4B). Greater pre-plant N reserves and increased growth or sink strength (fig. 4A) partly explains higher NDFP and NDFF in exponential seedlings (Salifu and Timmer 2003a). Improved retranslocation and nutrient acquisition from the soil following exponential fertilization is consistent with results found elsewhere (McAlister and Timmer 1998, Salifu and Timmer 2003a). Total N in new growth of exponential plants was 151 mg and about 109 mg in conventional seedlings. Thus, internal redistribution met 31 and 27 percent of the N demand in new growth of conventional and exponential plants, respectively. These estimates are lower than about 40 to 100 percent found in other species (Miller 1984, Salifu and Timmer 2003a). Similarly, current uptake accounted for 69 percent of the N in new growth of conventional seedlings and 73 percent in exponential plants (fig. 4B), which are higher that about 15 to 45 percent found in other studies (Amponsah and others 2004, Salifu and Timmer 2003a). Exponential fertilization demonstrates potential to promote field performance of transplanted seedlings and can be applied to other species or cultural systems.

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ECOLOGY AND FOREST DYNAMICS

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GENOTYPIC VARIATION IN FLOOD TOLERANCE OF BLACK WALNUT AND THREE SOUTHERN BOTTOMLAND OAKS

Mark V. Coggeshall, J.W. Van Sambeek, and Scott E. Schlarbaum[1]

Abstract—Open-pollinated bare-root seedlings from six families of cherrybark oak (*Quercus pagoda* Raf.), seven families of water oak (*Q. nigra* L.), six families of willow oak (*Q. phellos* L.), and eight families of black walnut (*Juglans nigra* L.) were planted in spring 2003 in nine channels of the University of Missouri Center for Agroforestry Flood Tolerance Laboratory. At onset of budburst, seedlings were left non-flooded or flooded for 5 weeks with 15 cm deep flowing water or stagnant water. A species by flood treatment interaction existed for seedling survival, new shoot growth, and basal sprouting. Based on seedling response, black walnut exhibited the least flood tolerance followed by cherrybark oak, water oak, and willow oak. No significant differences were found for any oak species by partial inundation between flowing or stagnant water flooding. Significant family differences in survival, growth, and basal spouting were found within all three oak species. A strong opportunity exists to make significant genetic gains in field survival and growth on flood-prone sites through selection of flood tolerant seedling families for all three oak species.

INTRODUCTION

In the Central Hardwood region, there is considerable interest in restoring native ecosystems on former bottomland forests that are now used for agriculture (Kruse and Groninger 2003). The suitability of a particular tree species in a bottomland hardwood forest depends on soil moisture, stream deposition patterns, flooding season and duration, and disturbance history (Hodges 1997). Planted oak acorns and seedlings are a major component of these restoration efforts. However, with the exception of overcup oak (*Q. lyrata* Walt.), the published flood tolerance of oak species is rated no higher than “moderately tolerant” (Hook 1984), and even this classification is open to some debate (Kabrick and Dey 2001).

Results of past restoration efforts have been mixed. Stanturf and others (2001) observed major (90 percent) regeneration failures in tree plantings established under the 1992 Wetland Reserve Program in Mississippi. While some of the regeneration failures may be attributable to planting species that are not adapted to the hydrological conditions that are common in floodplain soils, these poor planting results maybe due to the use of maladapted planting stock (Connor and others 1998). Battaglia and others (2004) suggested that many oak species have the capacity to grow on both upland and lowland sites. In Missouri, nine of the twenty native oak species can be found growing on bottomland sites (Kurz 2003, Steyermark 1974). Bottomland forest restoration programs in both the Missouri and Mississippi River floodplains have yet to focus on the role of non-adapted seed sources in contributing to planting failures.

A few studies exist that have looked at intraspecific patterns of genetic variation within woody species in response to flooding. Hook (1984) suggested that the ability of a bottomland tree species to survive flooded conditions is dependent on a number of factors including age, microclimate, soil type and internal drainage, topography, and its inherent genetic makeup. Keeley (1979) found significant levels of genetic variation in flood adaptations among three seedling populations of blackgum (*Nyssa sylvatica* Marsh.). Topa and McLeod (1986a, 1986b) likewise noted significant growth differences in response to flooding for two distinct loblolly pine (*Pinus taeda* L.) seed sources. Recently, Bauerle and others (2003) reported intraspecific variation in red maple (*Acer rubrum* L.) as mesic-origin seedlings suffered greater growth

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losses due to flooding than seedlings from more flood prone (hydric) provenances. Nielsen and Jorgensen (2003) also found significant variation in growth rates among provenances of European beech (*Fagus sylvatica* L.) that had been exposed to three different levels of soil moisture.

The goals of our project were (1) to determine if significant levels of genetic variation for flood tolerance exists within hardwood species, especially those that are capable of growing from frequently flooded bottomlands to dry uplands, (2) to ascertain if nursery environment affected flood tolerance for large, high quality bare-root seedlings, and (3) to evaluate field performance of high-quality nursery seedlings grown under protocols described by Kormanik and others (1994) and Schlarbaum and others (1997). This study represents the first attempt to quantify intraspecific genetic responses to flooding for any North American oak species.

MATERIALS AND METHODS

In the fall of 2001, seed from open-pollinated mother trees from western Tennessee and northern Mississippi were collected from the following species: cherrybark oak (*Q. pagoda* Raf.) (n=6), water oak (*Q. nigra* L.) (n=7), willow oak (*Q. phellos* L.) (n=6), and black walnut (*Juglans nigra* L.) (n=8). The University of Tennessee Tree Improvement Program grew the seedlings in replicated nursery plots at the Georgia Forestry Commission's Flint River Nursery. In the fall, seedlings were lifted, individually numbered, and evaluated for number of first-order lateral roots (FOLR), root collar diameter (RCD), and stem length before shipping to Missouri. In the spring of 2003, 1706 seedlings were planted in the Flood Tolerance Laboratory (FTL) at the University of Missouri Horticulture and Agroforestry Research Center (HARC) in New Franklin, MO.

The 1-0 bare-root seedlings were planted in early April 2003 using a split-plot design replicated three times with three flooding treatment as main plots and species as subplots. The nine channels with predominantly Nodaway silt loam soils were planted with a tree-spacing of 0.75 x 1.00 m as described by Van Sambeek and others (2007). Each species was represented by a total of 6 to 8 families within each flood channel and each family was represented by a total of 2 to 14 individual trees randomly distributed within each species plot.

The flooding treatments commenced at the onset of seedling budbreak in mid May. The flooding treatments were 15 cm deep flowing water for five weeks, 15 cm deep stagnant water for five weeks, and a non-flooded control. As described by Van Sambeek and others (2007), soils in the non-flooded channels developed a high water table and remained saturated for five weeks in response to seepage from adjacent flooded channels and frequent spring rains. In addition, the entire facility was under water for three days midway during the treatment period due to a heavy rain event. Based on twice weekly sampling for gravimetric soil water content, soils remained at or above field capacity in all channels for an additional two weeks as a result of two post-flooding rain events.

Approximately 10 months after flooding, we evaluated all seedlings for survival, stem basal diameter (mm) and live height (cm), total number of new shoots with > 0.5 cm growth including basal sprouts, total new shoot length (cm), and total number of basal sprouts originating within 20 cm of the root collar (cm). Family means by species and channel were determined for percent survival, total number of new shoots, total length of new shoots, and percent of surviving seedlings producing basal sprouts. Because of unbalanced seedling numbers, a general linear model (PROC GLM) was used to determine sums of squares and examined for differences (alpha = 0.05) among treatments, species, families within species, and their interactions (SAS, Cary, NC). Least significant difference values were calculated to determine differences among specific treatments and families.

RESULTS AND DISCUSSION

Overall survival across all flood treatments ranged from 12.5 percent for black walnut, 61.4 percent for water oak, 66.4 percent for cherrybark oak, and 82.5 percent for willow oak. The low survival of black walnut seedlings (33 percent) within the non-flooded channels is likely a response to prolonged exposure to saturated soils and a high water table and not low quality planting stock. Other studies have shown that mishandling of black walnut planting stock leads to extensive stem dieback and basal sprouting but not high mortality (Rietveld and Van Sambeek 1989, von Althen and Webb 1982). Because survival within the treatments with flowing or stagnant water was less than 1 percent, black walnut was not included in any further analyses.

To evaluate genetic variation for flood tolerance, we chose to examine survival, total number and length of new shoots, and sprouting. Due to variable seedling planting depth and shoot dieback on most seedlings, we could not use the original stem diameter and length measurements to determine net height and diameter growth. In addition, Rink and Van Sambeek (1987) had previously shown that total length of new shoots produced during the first growing season in the field for planted walnut was a better indicator of future tree height than was net height and diameter growth. Analysis of variance on all measured variables for the three oak species using family means frequently showed a significant interaction for species by flooding treatment and highly significant responses among species and families within species (table 1). The lack of an interaction between flood treatment and family indicates that each family within a species had a similar response to flooding treatment while maintaining genetic differences in overall growth and survival.

The interaction between species and flood treatment was significant for two of the three oak species. Willow oak seedlings had greater than 80 percent survival across all flood treatments, while seedlings of cherrybark and water oak had lower survival rates when exposed to partial inundations in both flowing and standing water than did seedlings in the water-saturated control treatments (table 2). The flood duration was probably too brief for the more flood-tolerant willow oaks to reveal treatment differences in this study although we did find differences in survival among the six willow oak families across all three flood treatments (table 3). Differences in survival among families for cherrybark and water oak tended to be larger than for willow oak.

Table 1—Analysis of variance results for three oak species exposed to three flooding treatments in spring 2003 (expressed as percent contribution to total sums of squares)

Source	df	Seedling survival	New shoots	Length of new shoots	Basal sprouting
		(percent)	*(number)*	*(cm)*	*(percent)*
Block	2	5.04	3.95	0.05	0.18
Treatment	2	8.24	3.39	0.13	1.90
Error A	4	4.11	6.14	2.77	1.16
Species	2	12.45 [a]	12.77 [a]	46.03 [a]	47.06 [a]
S X T	4	3.72 [a]	5.13 [b]	0.59	3.83 [a]
Family (species)	16	26.96 [a]	16.45 [a]	14.01 [a]	11.45 [a]
T X F(S)	32	10.61	10.59	7.01	13.00 [a]
Error B	103	39.24	27.64	26.98	21.53

[a] = statistical differences at $p = 0.01$.
[b] = statistical differences at $p = 0.05$.

Table 2—Effects of three flooding treatments on percent survival, total number of new shoots, total length of new shoot growth, and percent with basal sprouts for cherrybark, water, and willow oak species

Treatment[a]	CBO	WAO	WLO
	Percent survival fall 2003		
	- - - - - - - - - - *percent* - - - - - - - - - -		
DRY	79.9	77.5	83.1
FLOW	52.9	52.1	83.2
STAG	66.2	54.1	81.4
Mean	66.4	61.4	82.5
$LSD_{0.05}$ = 11.0 percent			
	Total number of new shoots		
	- - - - - - - - - - *number* - - - - - - - - - -		
DRY	3.8	2.9	3.8
FLOW	2.5	2.5	3.9
STAG	2.4	3.2	3.8
Mean	2.9	2.9	3.8
$LSD_{0.05}$ = 0.7 percent			
	Total length new shoots/seedling		
	- - - - - - - - - - - - *cm* - - - - - - - - - - - -		
DRY	25.0	52.6	67.1
FLOW	16.5	49.3	72.2
STAG	18.6	54.5	69.1
Mean	20.0	52.2	69.5
$LSD_{0.05}$ = 12.9 percent			
	Percent seedling w/basal sprouts		
	- - - - - - - - - - *percent* - - - - - - - - - -		
DRY	15.4	92.5	66.5
FLOW	32.1	76.9	73.8
STAG	25.8	66.1	57.5
Mean	24.4	65.8	79.0
$LSD_{0.05}$ = 13.4 percent			

CBO = cherrybark oak; WAO = water oak; WLO = willow oak.

[a] Flooding treatments were a water-saturated, nonflooded control (DRY), 15 cm deep flowing water for 5 weeks (FLOW), and 15 cm deep stagnant water for 5 weeks (STAG).

Table 3—Percent seedling survival, total number of new shoots, total length of new shoots, percent basal sprouting, and flood tolerance index values for six to seven families of cherrybark oak, water oak, and willow oak

Species[a]	Family	Seedling survival	New shoots	Length of new shoots	Basal sprouting	Flood tolerance index
		percent	*number*	*cm*	- - - - - - *percent* - - - - - -	
CBO	CBO6	54.8	3.4	31.1	28.0	0.65
	PHC4	78.6	3.4	20.6	7.8	0.61
	MS57	71.8	2.9	19.4	30.4	0.45
	MS56	56.4	2.4	19.9	25.5	0.34
	PHC1	84.8	2.4	11.0	22.2	0.28
	CBO1	50.0	2.7	18.0	33.8	0.27
WAO	MS2	73.7	3.6	61.0	71.3	0.90
	PH2	80.0	2.8	62.3	89.3	0.78
	PHWA4	70.6	3.0	53.3	51.5	0.63
	MS54	59.0	3.0	54.4	81.7	0.53
	MS51	63.9	2.6	45.8	73.9	0.43
	WTR26	54.2	2.3	37.6	92.9	0.26
	PHWA1	26.6	2.7	46.1	99.9	0.18
WLO	PH17	87.3	6.9	82.8	54.4	0.93
	PH18	93.1	4.1	79.5	63.7	0.56
	PHWL1	86.7	4.0	79.2	57.4	0.51
	MS25	79.9	3.4	83.8	80.2	0.42
	PH8	75.1	3.3	46.0	67.1	0.21
	PH13	71.0	2.8	48.1	72.5	0.16
$LSD_{0.05}$		15.6	1.0	18.3	18.9	NA

CBO = cherrybark oak; WAO = water oak; WLO = willow oak; NA = non-applicable.
[a] Flood tolerance index is the product of ratio of family mean divided by mean for the best family within each species for survival, number, and length of new shoots.

The total number of new shoots per seedling reflected both a significant species by treatment and family response (table 1). While seedlings of water oak and willow oak showed no differences in the number of elongating shoots in response to flooding, both flowing and stagnant flooding reduced the number of elongating shoots on cherrybark oak seedlings (table 2). There were no significant differences in the total number of new shoots among families of cherrybark oak, in contrast to water oak and willow oak (table 3). For water and willow oak, better surviving families tended to have the highest number of new shoots. This trend was particularly noticeable among willow oak families where the best surviving families, PH17, PH18 and PHWL1, had the greatest number of actively elongating shoots during the first growing season.

There was a significant species effect but not a significant species by treatment effect on total length of new shoots (table 1). Willow oak appeared to be the most flood tolerant species and showed the greatest cumulative new shoot growth across all flood treatments followed by water oak and cherrybark oak (table 2). Differences were found in cumulative shoot growth among families within all three oak species (table 3). As expected, the families with the highest number of elongating shoots had the greatest cumulative shoot growth.

The expected pattern of extensive dieback followed by basal sprouting observed with black walnut was not observed among the three oak species. For the least flood tolerant species, cherrybark oak, increased flooding stress in response to flowing or stagnant flooded increased the percent basal sprouting (table 2). In contrast, over 90 percent of the water oak seedlings in the non-flooded control channels produced basal sprouts compared to approximately 70 percent of the seedlings in the channels flooded with flowing or stagnant water. There was also a significant family within species effect for percent sprouting. For cherrybark oak, one of the best surviving families, PHC4, had the lowest basal sprouting percentage (table 3). In contrast, family CB001 had the poorest survival and highest basal sprouting percentage. Similarly, water oak family PHWA1 had only 26.8 percent survival and 100 percent sprouting compared to family PH2 that had 80.0 percent survival and an 89 percent sprouting rate. For willow oak, however, the best surviving families, PH17, PH18, and PHWL1, had fewer seedlings producing basal sprouts than did the families with the poorest survival.

Significant family within species variation occurred for FOLR number (first order lateral roots > than 1 mm in diameter), root collar diameter, and stem height (table 4). To determine whether family differences associated with size of planting stock out of the nursery impacted flood tolerance, we created an index to rank families within species as to their flood tolerance. Index values were determined by multiplying the ratios of observed divided by maximum values for survival and total number and length of new shoots, i.e. flood tolerance index for water oak MS2 equals 0.89 or (73.7/80.8) x (3.6/3.6) x (61.0/62.3), which allowed us to rank families from most to least tolerant. Using Spearman's rank correlations, we found strong concordance between flood tolerance and outplanting root collar diameter and FOLR number for willow oak. In contrast, no concordance was found between initial seedling size and the family flood tolerance index rankings for black walnut, cherrybark oak, or water oak. Kormanik and others (2005) have indicated that under stress newly planted upland oak seedlings can rapidly shed lateral roots including the first order lateral roots. The lack of significant correlation between seedling FOLR and flood response may in part be due to root loss and differences among families within the less flood tolerant species to recover from stress.

In summary, all four hardwood species tested responded differently to the flooding treatments used in this study. The low survival for black walnut confirms previously published results that indicate black walnut is a flood-intolerant species as reported by Kabrick and Dey (2001). There was a definite trend towards the greatest shoot growth, highest numbers of shoots, and lowest percent sprouting among the best surviving willow oak families (e.g., PH17, PH18, and PHWL1). These relationships were less apparent among the water oak families, in which the best surviving families tended to also have the greatest shoot growth (e.g., MS2, PH2, and PHWA4), but not necessarily the fewest number of new shoots or lowest percent sprouting. Similarly, the best surviving cherrybark oak families did not always have the greatest shoot length and lowest sprouting percentage. The highly significant differences among families within oak species for all variables would lead us to conclude that there is a strong opportunity to make significant genetic gains in field survival through selection of more flood tolerant seedling families.

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Table 4—Initial seedling size measurements (standard deviation) for first-order lateral roots, root collar diameter, and stem height on six to eight families of black walnut, cherrybark oak, water oak, and willow oak from the University of Tennessee Tree Improvement Program planted in 2003 in the Flood Tolerance Laboratory

Species	Family[a]	Number	FOLR	RCD	Stem height
			number	*mm*	*cm*
BLW	BW14	72	—	15.2 (2.6)	90.2 (24.0)
	BW17	65	—	13.6 (2.2)	83.2 (19.1)
	BW21	29	—	14.2 (1.9)	63.7 (14.7)
	BW02	36	—	13.0 (2.4)	73.4 (17.7)
	BW21	29	—	14.2 (1.9)	63.7 (14.7)
	BW35	37	—	12.6 (2.1)	69.0 (15.0)
	BW36	72	—	13.3 (2.7)	81.3 (13.8)
	BW45	34	—	14.3 (5.0)	78.6 (22.9)
	BW49	34	—	13.3 (2.8)	85.6 (20.8)
CBO	CBO6	93	7.6 (5.3)	9.4 (1.3)	112.9 (13.7)
	PHC4	52	7.8 (4.2)	10.4 (1.8)	106.9 (16.9)
	MS57	90	5.6 (3.6)	9.0 (1.1)	108.1 (13.0)
	MS56	88	6.8 (4.3)	9.4 (1.2)	120.6 (12.6)
	PHC1	91	8.7 (6.3)	9.3 (1.4)	106.9 (15.0)
	CBO1	40	7.4 (3.4)	9.9 (1.8)	108.3 (26.5)
WAO	MS2	62	5.6 (3.9)	10.0 (1.9)	107.9 (12.3)
	PH2	63	4.3 (2.8)	9.9 (1.4)	99.4 (14.4)
	PHWA4	80	5.8 (3.1)	9.6 (1.5)	101.9 (13.2)
	MS54	53	5.2 (4.1)	9.3 (1.6)	112.3 (14.6)
	MS51	60	5.9 (2.7)	10.2 (1.3)	103.5 (16.3)
	PHWA1	92	2.5 (2.0)	8.8 (1.6)	98.2 (16.4)
	WTR26	24	4.0 (2.0)	8.8 (0.9)	100.2 (8.7)
WLO	PH17	37	6.6 (2.9)	11.0 (1.8)	92.7 (11.6)
	PH18	76	4.8 (2.5)	10.2 (1.4)	101.1 (13.2)
	PHWL1	84	5.2 (2.8)	9.9 (1.3)	97.4 (12.9)
	MS25	89	5.0 (3.0)	9.9 (1.6)	105.6 (12.8)
	PH8	52	3.1 (2.4)	9.5 (1.3)	103.2 (15.2)
	PH13	93	2.9 (1.9)	9.4 (1.3)	106.4 (12.7)

— = data not measured.
FOLR = first-order lateral roots; RCD = root-cellar diameter; BLW = black walnut; CBO = cherrybark oak; WAO = water oak; WLO = willow oak.
[a] Families within species are ranked from most to least flood tolerant according to flood tolerance index values shown in table 3.

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EFFECTS OF SHADE ON THE GROWTH OF NATURAL AND ARTIFICIALLY ESTABLISHED WHITE OAK (*QUERCUS ALBA* L.) REGENERATION

Dylan Dillaway and Jeff Stringer[1]

Abstract—-Treatments, such as mid-story removal, have been designed to enhance the vigor of advance oak regeneration through the increase of diffuse light levels reaching the forest floor. In order for these treatments to be successful, proper light levels are crucial in order to maximize oak seedling growth while simultaneously suppressing the growth of shade intolerant species. This study was designed to assess light levels needed to maximize the growth potential of white oak advance regeneration and artificially established white oak seedlings. Shade frames using shadecloth were used to impose shading treatments. Thirty natural advance regeneration and thirty 1-0 bare root seedlings were monitored in each plot (720 total). Results for white oak advance regeneration indicate that the 21 percent and the full sunlight resulted in significantly greater height growth than the other treatments. However, ground line diameter growth did not differ among the 21, 45, and 100 percent treatments.

INTRODUCTION

Regenerating oak (*Quercus* spp.) on intermediate to high quality sites (upland oak site index >65 ft, base age 50) has proven difficult to achieve (Deen and others 1992; Janzen and Hodges 1985; Lockhart and others 1992; Lockhart and others 1999; Loftis 1983; Loftis 1990a, 1990b, 1992; Lorimer and others 1994; Miller and others 2004). Forest conditions have changed from pre-settlement times allowing mid-stories of shade tolerant species, such as maple (*Acer* sp.) and American beech (*Fagus grandifolia*), to develop (Abrams 2003, Clark 1992, Lorimer and others 1994) in many of our oak dominated forests resulting in significant competition for oak regeneration.

The oak shelterwood system is designed to enhance the size and vigor of small low-vigor advance regeneration growing under intact canopies (Stringer 2005a, 2005b). The system is composed of a mid-story removal designed to increase diffuse light to intact advance regeneration followed by full or substantial canopy removal after the advance regeneration has reached adequate size. This system has been explored in northern red oak dominated ecosystems (Loftis 1990b, Lorimer and others 1994) and in bottomland cherrybark oak stands (Lockhart and others 1992, 1999). However, research involving white oak (*Q. alba*) response to the oak shelterwood system has not been undertaken.

White oak is one of the most shade tolerant oak species in the eastern United States (Abrams 2003). Significant research on physiological attributes of fast growing commercially important oak species such as northern red oak and cherrybark oak has been completed to determine optimal regeneration strategies for these species. However, optimal light levels and stand conditions needed to encourage natural white oak regeneration are yet to be determined.

Artificial shading studies using shade cloth have been used to determine ideal light levels for maximizing growth of northern red oak, black oak, and cherrybark oak (Gottschalk 1994, Gardiner and Hodges 1999). Gottschalk (1994) performed shading studies in a garden plot where seedlings of northern red oak, black oak, black cherry (*Prunus serotina* Ehrh.) and red maple (*A. rubrum* L.) were grown under eight levels of shade. Results indicated that light levels of greater than 20 percent produced more vigorous oak seedlings than did light levels less than 20 percent. Gardiner and Hodges (1999) also performed an artificial shading study on cherrybark oak in a garden plot at four levels of shade. They reported that maximum biomass

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was accumulated and the highest seedling vigor was obtained at 53 percent of full sunlight. Both studies were conducted in garden plot settings and used seedlings grown from seed. While these studies focused on the response of artificially reared seedlings, oaks are typically regenerated naturally through the release of advance regeneration. Unfortunately less is known about the light response of natural advance regeneration.

The focus of this study was to determine the response of *in situ* white oak advance regeneration and artificially established seedlings growing under differing levels of shade. This study provides an assessment of the light regimes needed to increase the vigor of intact natural oak advance regeneration and can be used to provide guidelines for the use of the oak shelterwood system in white oak dominated stands.

MATERIALS AND METHODS

The study site was located in central Kentucky (Madison County) on the western edge of the Cumberland Plateau. The site is at the base of a south-facing slope, typical of "intermediate" quality sites (upland oak site index >65-75 feet). White oak dominated the pre-harvest canopy, while the mid-story was dominated by red maple, beech (*Fagus grandifolia)* and minor components of other associated species. Numerous cohorts of white oak advance regeneration were present on the site.

A four acre commercial clearcut was completed in November 2003 and all residual stems >1 inch dbh were felled in January and February of 2004. Undesirable species were treated with Garlon 4® or 100 percent Roundup Pro®. In February of 2004 a total of twelve 14'x14'x4' plots were established in the harvested area and were located based on the presence of advance regeneration. The plots were cleared of all logging debris and thirty white oak advance regeneration seedlings were flagged, labeled, and measured in each plot (360 seedlings total). Additionally, thirty white oak 1-0 bare root seedlings were planted on each plot in February and March 2004 (360 total). All undesirable species larger than the size of the seedling in the study plots were cut with a chainsaw and stumps were sprayed with 100 percent Roundup Pro® to prevent re-sprouting.

Four light treatments were randomly assigned to the twelve plots resulting in 3 replicates of each treatment. Three of the treatments were shaded (9 plots) and one treatment was not shaded (3 plots). Shade treatments were selected to span the range of photosynthetically active radiation (PAR) created by management practices to encourage oak regeneration. The light levels under shade cloth were developed to simulate a mid-story removal, a traditional shelterwood, and a clearcut.

Shade frames (14'x 14' x 4') were erected before the start of the growing season in 2004. Shade cloth (Ecologic Technologies®) at 10, 30, and 60 percent transmittance was used to establish the shading treatments. Shade cloth was draped over the 14' x 14' x 4' shade frames to within 1 foot of the ground. Shade cloth was left in place throughout the growing season and was taken down in November of 2004 after leaf fall. Shade cloth resembling an intact canopy (<2 percent sunlight) was not available and a control plot under an intact canopy directly adjacent to the clearcut was established for pairwise comparisons among treatments (light levels). Fifty white oak advance regeneration and seventy bare root seedlings were monitored under the intact canopy.

Initial measurements of all seedlings in the 12 plots were taken before the beginning of the growing season including total height, length of all internodes (growth flushes), and ground line diameter (gld). Survival, total height, gld, and length of current season flushes were determined at the end of the first growing season after treatment. Total height was taken from ground line (mineral soil) to the base of the terminal bud. All growth flushes, or internodes, were measured between bud scale scars. Ground line diameter (gld) was measured at the surface of the mineral soil and determined from two perpendicular measurements using a digital caliper.

PAR was measured at one foot above the ground in each of the 12 plots using a Li-cor® light wand. Measurements were taken on cloudless days between 12:00 and 2:00 pm. Thirty readings were taken at random locations at each of the twelve plots.

Survival data was analyzed using Proc genmod and Proc logistic (SAS Institute 2000). Odds ratios were used to detect significant differences between treatments. Growth data was analyzed using Analysis of Variance (ANOVA) and multiple comparisons were performed using Least Significant Difference (LSD) pairwise tests at the $p \leq 0.05$ level.

RESULTS

Photosynthetically Active Radiation

The mean PAR for each treatment was 178, 390, 825, and 1862 µmol/m2/s corresponding to 10, 21, 45, and 100 percent full sunlight respectively. Mean PAR under the intact canopy was 46 µmol/m2/s corresponding to 2 percent full sun.

Advance Regeneration Growth and Survival

Height growth of advance regeneration exhibited a significant treatment response. The 21 percent treatment resulted in significantly greater height growth (p=0.0004) than other treatments with the exception of the full sun treatment where the difference was not significant (fig. 1). The seedlings in the intact canopy treatment performed significantly worse (p=0.0128) than other treatments with the exception of the 45 percent treatment.

There was no significant difference in gld growth among the 10 percent, 21 percent, and 100 percent treatments (fig. 2). However, the 45 percent treatment produced significantly greater gld than the 10 percent and the intact canopy treatment (p=0.0001). Seedlings of all treatments exhibited significantly greater gld growth than the seedlings in the intact canopy treatment (p=0.0002) (fig. 2).

Ten percent of all advance regeneration monitored experienced top death. However, 45 percent of these were able to resprout. Four percent of all advance regeneration experienced some top dieback and 3 percent of all advance regeneration was browsed.

1-0 Bare Root Seedling Growth and Survival

First year survival of bare root stock by treatment ranged from 70 to 90 percent. Seedlings in the 10 percent treatment had the highest percent survival (~90 percent) while the 45 percent treatment had the lowest survival (~70 percent) (fig. 3).

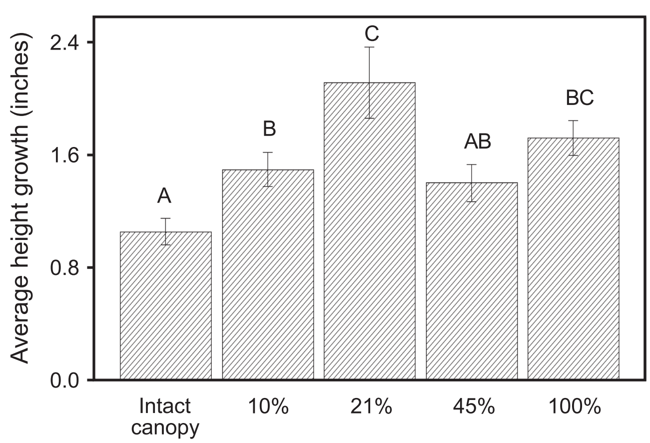

Figure 1—Height growth of advance white oak regeneration by treatment (percent full sunlight). Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

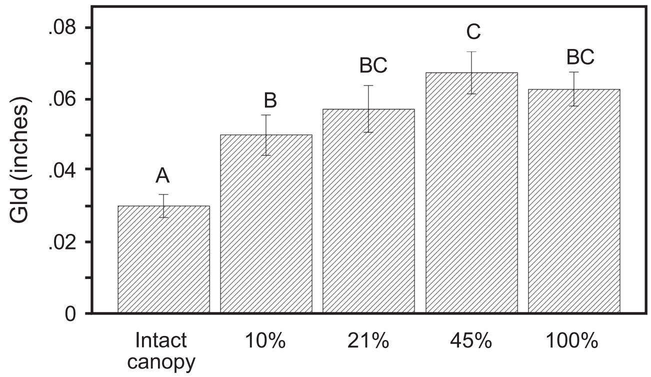

Figure 2—Ground line diameter (gld) growth of white oak advance regeneration by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

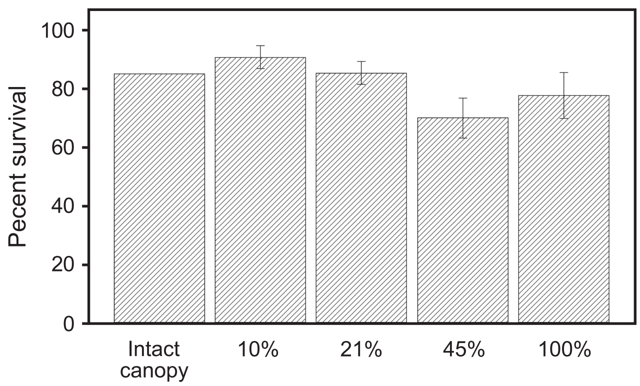

Figure 3—Survival of bare-root 1-0 white oak seedlings by treatment.

There was a general negative relationship between height growth and light with the intact canopy treatment resulting in significantly greater height growth than all other treatments ($p<0.0001$). In the artificially shaded treatments, the 21 percent light treatment resulted in significantly greater height growth than the 10 percent, 45 percent and the 100 percent treatments ($p=0.0022$) (fig. 4).

There was no significant difference among treatments with respect to ground line diameter ($p=0.0713$) with the exception of the 10 percent treatment which grew significantly less than the control and 100 percent treatments ($p=0.0448$) (fig. 5).

DISCUSSION

While artificial shading, provided by shade cloth, does not simulate the entire suite of environmental variables associated with naturally shaded conditions it is a reasonable means of investigating light requirements. It is suggested from other shading studies that light is not the only abiotic factor affecting growth and development. Soil moisture, humidity, temperature, and overall microclimate are all extremely important variables to consider in the development of tree seedlings. While no other abiotic factors were measured other than PAR in our study, it was apparent from observation that soil moisture in the more heavily shaded treatments was higher and remained longer after a precipitation event. The effect of silvicultural treatments on available soil moisture is a reasonable area of study and should be assessed further.

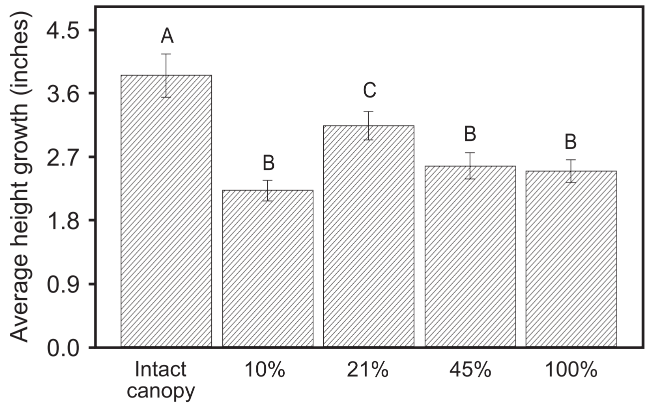

Figure 4—Height growth of bare-root 1-0 white oak seedlings by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

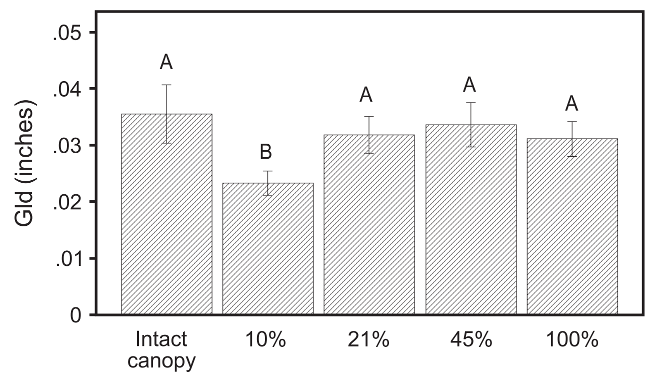

Figure 5—Ground line diameter growth of bare-root 1-0 white oak seedlings by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

White oak being one of the more shade tolerant oaks will most likely be able to maintain height growth at lower light levels compared to less tolerant oaks such as northern red oak and cherrybark oak. These initial insights suggest that while northern red oak and cherrybark oak may grow best at around 50 percent of full sunlight, white oak advance regeneration seems to prefer slightly lower irradiance levels around 20 percent. This difference in light requirements indicates that species specific treatments should be applied and tested to successfully increase the vigor of advance oak regeneration.

Bare root seedlings performed best initially under an intact canopy. Although we did not measure the diameter of the new growth, from observation the initial growth put on by these seedlings in an intact canopy was extremely etiolated. As time progresses we do expect that this initial trend will be reversed. Subsequent growing seasons will reveal the light preferences of bare root seedlings once they are fully established and have no confounding effects of transplant.

CONCLUSIONS

Results of this study indicate that 20 percent full sunlight is a reasonable target for mid-story removal treatments to increase the height growth of white oak advance regeneration. Results also show the potential for long-term vigor increases as indicated by increases in gld at this light level as compared to the intact canopy treatment. This response in height and gld of the white oak advance regeneration in this study occurred at lower light levels than have been found for other oaks adapted to mesic sites. The results indicate that the oak shelterwood system initially developed for northern red oak and cherrybark oak has potential for implementation in white oak stands but needs further study.

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OVERSTORY AND REGENERATION STRUCTURE AND RELATIONSHIPS IN MIXED STANDS ON THE SOUTHERN CUMBERLAND PLATEAU

Luben D. Dimov and Callie Jo Schweitzer[1]

Abstract—This study examined the regeneration of oak (*Quercus* spp.), hickory (C*arya* spp.), and several other common hardwood species in mixed stands on the Cumberland Plateau. The stands are dominated by pine that recently experienced substantial natural mortality. Nearly a quarter of the basal area is in hardwoods. We used nonmetric multidimensional scaling, an ordination technique, to evaluate the relationships among the overstory attributes and regeneration presence and abundance. The gradient in hardwood regeneration abundance, especially oak, was highly negatively related to the amount of basal area in pine. The proportion of basal area in pine was more negatively correlated with hardwood regeneration than was the basal area of all species combined. Overstory composition, not just density, appears important for growth and survival of natural hardwood regeneration. Overstory composition and density in the immediate vicinity appears more important for regeneration abundance than the same overstory variables in larger plots.

INTRODUCTION

Large areas of plantations and natural stands dominated by pine (*Pinus* spp.) in the southeastern United States suffered extensive damage from southern pine beetle (*Dendroctonus frontalis* Zimmerman) over the recent decades (Michaels 1984, Price and others 1998, Thatcher 1960). Price and others (1998) estimated that the value of the trees in the southern United States killed by southern pine beetle between 1970 and 1996 was US$1.5 billion. One of the most important factors influencing such infestations is climate (Gagne and others 1980, Ungerer and others 1999). Global climate change is expected to intensify the southern pine beetle infestation risk 2.5-5 times (Gan 2004). Much of the pine forests of the South, including areas designated as wilderness areas (by the Wilderness Act of 1964) could therefore be at risk. Many wilderness areas in National Forests, National Wildlife Refuges, and National Parks, which are designed to experience little or no intervention by forest managers in order to achieve and retain their "primeval character and influence" (United States Forest Service 2004) may be particularly at risk, because of the "hands-off" management approach in them. This could increase the scale of disease and pest outbreaks with little knowledge of the path that forest succession would take. In particular, southern pine beetle infestations impact on forest succession and on the regeneration of valuable hardwood species, particularly oaks and hickories, has been relatively unexplored. Although much work on regeneration of valuable hardwood species has been done in hardwood dominated ecosystems (Schweitzer 2004, Schweitzer and others 2004) and some information on the successional pathways for Virginia pine (*Pinus virginiana* Mill.) in the absence of major disturbances is available (Fenton and Bond 1964), information and recommendations for successful oak, hickory, and other hardwood regeneration is scarce for pine dominated stands that have experienced high level of sudden mortality associated with pine beetle infestations.

The Bankhead National Forest (BNF) in Alabama, located on the Southern Cumberland Plateau and within three Alabama counties - Winston, Lawrence, and Franklin - is one of the forests that experienced such southern pine beetle damage. The natural tree cover was thought to have contained a mixture of hardwoods and some pines. In the 1970s, it was planted with loblolly pine (*Pinus taeda* L.), but hardwood species established around the same time and now account for nearly a quarter of the basal area on

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the examined plots. Changes in forest management goals lead to diminished efforts at single species plantation management. These management changes, the presence of hardwood seed source in the overstory, and pine mortality caused by southern pine beetle, contributed to the establishment of advance regeneration from various hardwood tree species.

We collected data concerning the overstory attributes and the species, size, and number of seedlings. Our objective was to find the relationships between the overstory attributes and the species and abundance of hardwood regeneration of various size classes without making assumptions regarding the normality of the data and nature of the relationship (e.g., whether it is linear). We used a method (nonmetric multidimensional scaling), which is considered more appropriate for analysis of ecological community data than are many of the other common statistical methods (e.g., linear and nonlinear regression analysis and principal component analysis) (McCune and others 2002). Such information is hoped to improve the predictability of the outcome from the inevitable pine mortality that continues to occur in this and other pine forests of the South.

MATERIALS AND METHODS

Sites and Procedures

The study was carried out within the boundaries of the Bankhead National Forest. BNF is one of the four Alabama national forests and covers 180,500 acres in the northern part of the state. Its management purposes include timber production, recreation, wildlife and fish habitat enhancement, and improvement of water quality and soil protection, among others. The forest covers watersheds of several municipalities and possesses a diversity of plant and wildlife species. Additionally, it has cultural and historical significance to members of the local communities and special historical and cultural significance to Native American tribes. It has a history of repeated highgrading, unsustainable farming practices, and resulting soil erosion. Much of these activities occurred during and after the 1930s economic depression. Smalley (1979) describes the area as the strongly dissected plateau subregion of the Southern Cumberland Plateau. The soils in the broad undulating uplands of this subregion are moderately deep, well drained, and permeable (fine-loamy, siliceous, semiactive, thermic Typic Hapludults). Site indices are 75 feet for loblolly pine and 66 feet for red oaks and white oaks (base age 50 years, Smalley 1982).

The dominant pine species in the stands are loblolly pine and Virginia pine. In the late 1990s, the forest experienced pine tree mortality that affected over 10 percent of the trees. We established 45 study plots at or near the ridge tops to examine woody species regeneration in these stands. The specific plot locations were chosen by systematically selecting five locations on the map and later finding these locations on the site through the use of the Geographic Positioning System (GPS). Each study plot contained three nested concentric circular measurement plots. The regeneration was tallied by species and size class (0-1 feet, 1-2 feet, 2-3 feet, 3-4 feet, and taller than 4 feet, but less than 1.5 inch diameter at breast height (d.b.h. – 4.5 feet above ground)) on 0.01 acre plots (regeneration plot). Species and diameter of both midstory trees (d.b.h. 1.5 to 5.6 inches) and the overstory trees (d.b.h. > 5.6 inches) were recorded on a 0.025 acre plots. The overstory trees were measured on the largest plot (0.2 acre).

Statistical Analysis

We used nonmetric multidimensional scaling (NMS) in the statistical analysis to investigate the relationships between seedling attributes (species, size, and abundance) and overstory attributes (species, basal area, and overstory mortality). This type of analysis is a multivariate statistical ordination method (Kruskal and Wish 1978). Ordination is the arranging of measurements along one or more axes. Ordination in multidimensional space (when multiple axes are used) provides a summary of complex relationships between variables and extracts a few dominant patterns from multiple possible ones (McCune and others 2002). NMS performs iterative simulations that aid in the placement of the plots on a small number of axis. The use of ordination is considered particularly appropriate when there are correlations and multicollinearity among the studied variables. Nonmetric methods possess great flexibility, because they do not depend on any assumptions regarding the type of relationship between the calculated distance and the similarity measure (Hair and others 1998). Other multivariate statistical methods (e.g., principal component analysis and canonical correspondence analysis) take into account only the portion of a configuration that fits the limited perspective specified by the underlying model (McCune and others 2002). McCune and others (2002) also stress that NMS does not assume linear relationships among the variables and is especially appropriate for non-normal data or data that may be on arbitrary or discontinuous scales.

There were 13 seedling variables represented the most abundant species and reflected the number of seedlings per acre (abbreviations of the variable names are shown in brackets):

1. Number of seedlings < 1 foot tall of the species: oak (*Quercus* spp., all oak species combined, QUSP<1), hickory (*Carya* spp., all hickory species combined, CASP<1), red maple (*Acer rubrum* L., ACRU<1), and blackgum (*Nyssa sylvatica* Marsh. NYSY<1)

2. Number of seedlings > 1 foot tall and d.b.h. < 1.5 inches of species: oak (all oak species combined, QUSP>1), hickory (all hickory species combined, CASP>1), red maple (ACRU>1), and blackgum (NYSY>1)

3. Number of seedlings (d.b.h. < 1.5 inches, any height) of species: oak (all oak species combined, QUSP), black oak (*Quercus velutina* Lam., QUVE), white oak (*Q. alba* L., QUAL), hickory (all hickory species combined, CASP), and yellow-poplar (*Liriodendron tulipifera* L., LITU)

There were 14 overstory variables (abbreviations of the variable names are shown in brackets):

1. Basal area of the snags on the 0.025 acre plot (SN_0.025) and on the 0.2 acre plot (SN_0.2), respectively

2. Basal area of the pines (PINE_0.025), hardwoods (HRDW_0.025), red maple (ACRU_0.025), and all species combined (ALL_0.025), respectively, with d.b.h. > 1.5 inches and on the 0.025 acre plot

3. Basal area of the pine (PINE_0.2), hardwood (HRDW_0.2), and red maple (ACRU_0.2), and all species combined (ALL_0.2) trees, respectively, with d.b.h. > 5.6 inches and located on the 0.2 acre plot

4. Proportion of the basal area in pine (PINE_P), hardwoods (HRDW_P), red maple (ACRU_P), and snags (SN_P) on the 0.2 acre plot

The multivariate statistical analysis was performed with the software Pc-Ord version 4.36 (McCune and Mefford 1999). All regeneration variables were placed in the "main" (the species) matrix, while the overstory variables were placed in the "second" (the environmental) matrix. We used the Sorensen (Bray-Curtis) distance measure (a proportion coefficient measured in city-block space), a random starting number, a maximum of 400 iterations, instability criterion of 0.00001, 6 initial axes, 40 runs with the real data, and 50 runs with the randomized data. These parameters are specified for replication purposes and are defined in general statistical texts dealing with NMS (e.g., McCune and others 2002). We sought a solution such that it can provide significantly more reduction in stress than expected by chance. Stress is the measure of departure from monotonicity in the relationship between the dissimilarity (distance) in the original high-dimensional space and the distance in the reduced lower-dimensional ordination space (McCune and others 2002). We rotated the ordination to align axis 1 with the strongest explanatory variable.

RESULTS AND DISCUSSION

The basal area of the two dominant pine species, loblolly pine and Virginia pine, averaged 77.4 square feet per acre (standard deviation (stdev) 26.7), while hardwood basal area averaged 21.4 square feet per acre (stdev 12.5). The snags had a mean basal area of 2.8 square feet per acre varying substantially (stdev 8).

Of the examined species and species groups, red maple was the most common seedling with an average of almost 1473 stems per acre and 642 stems per acre in the < 1 foot and > 1 foot sizes, respectively (table 1). This is hardly surprising, considering that red maple, one of the most abundant trees in eastern North America (Hutnick and Yawney 1961), is relatively more shade tolerant than the majority of the species it associates with (Walters and Yawney 1990). The oak seedlings were just over a half as many as the red maple seedlings (53 percent) in the < 1 foot size class, but 71 percent in the > 1 foot and d.b.h. < 1.5 inches indicating the oaks' relatively higher survival, faster growth in the current conditions, or both. Although blackgum is considered shade tolerant (McGee 1990), while oaks are considered to be relatively intolerant (Burns and Honkala 1990, Johnson and others 2002), there were fewer blackgum seedlings than there were oaks. Blackgum and hickory seedlings were the third and fourth, respectively, most abundant seedling on the studied plots. Yellow poplar seedlings were found on only 20 of the 45 plots and averaged 96 stems per acre. The oak seedlings in the understory (advance regeneration) represent a desirable stand component and together with the stump and root sprouts are the main source for oak following overstory removal (Loftis 1990, Roach and Gingrich 1968).

The ordination represented 88 percent of the dataset variation. The analysis resulted in a three-dimensional solution (i.e., three axes) with thirty-eight percent loaded on axis 1, 23 percent on axis 2, and 27 percent on axis 3. The stress, an inverse measure of fit to the data, can be visually inspected by a scree plot (fig. 1). The solution provided significantly more reduction in stress than expected by chance, accepting a probability type I error < 0.05.

Table 1—Average number of seedlings per acre and standard deviation for selected species or species groups

Size category and species	Mean	Standard deviation
	- - - - - - *number per acre*	- - - - - -
< 1 foot tall		
Acer rubrum	1,473	965
Quercus spp.	782	771
Nyssa sylvatica	213	216
Carya spp.	147	177
Any height, d.b.h. < 1.5 inches		
A. rubrum	2,115	1,054
Quercus spp.	1,240	1,074
N. sylvatica	571	523
Carya spp.	351	311
Q. alba	176	372
Q. velutina	171	214
Liriodendron tulipifera	96	141
> 1 foot tall and d.b.h. < 1.5 inches		
A. rubrum	642	572
Quercus spp.	458	534
N. sylvatica	358	376
Carya spp.	204	232

Sorted by abundance within size category.

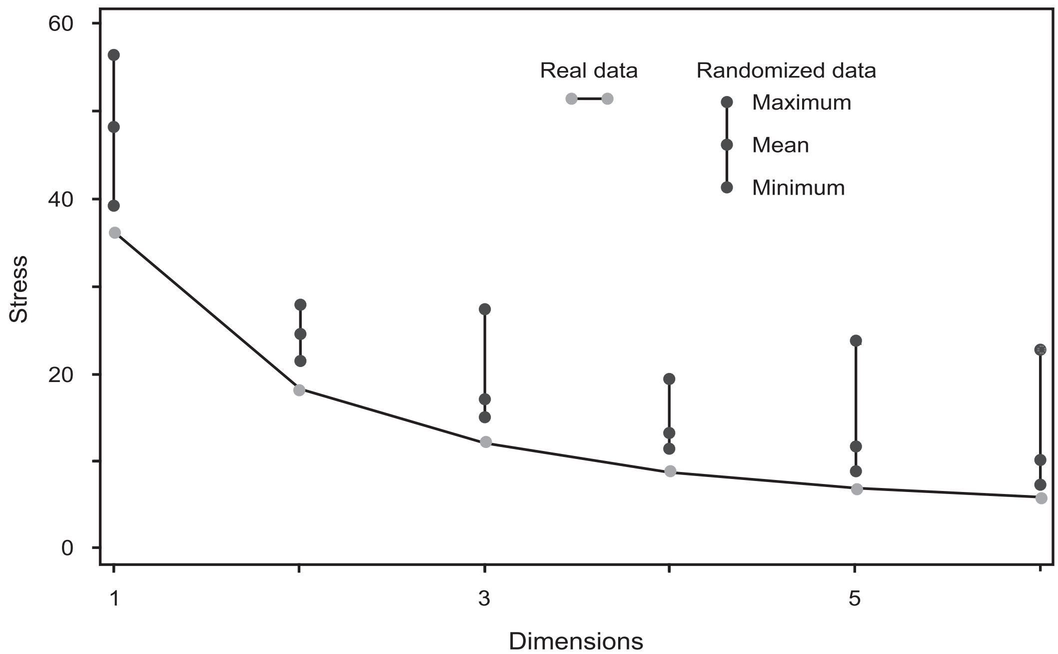

Figure 1—A scree plot with stress as a function of model dimensionality. Stress can be thought of as an inverse measure of fit to the data, while the randomized data is analyzed as a null model.

The first and strongest ordination axis was negatively related to the abundance of oaks, regardless of their species, grouping, or size class (table 2). Of the other variables most also showed a negative relation, although a weaker one, while ACRU>1, ACRU>1, and NYSY>1 had some positive correlation with axis 1.

The second ordination axis was positively related to the abundance of the hickory regeneration, regardless of regeneration size class (table 2). NYSY<1 and LITU were also positively correlated with axis 2, though not as strongly as the hickories. ACRU>1 had a stronger relationship with axis 2 than with axis 1 and it was in the opposite direction. The oaks were all negatively, though much weakly, correlated with axis 2 than they were with axis 1.

The third axis was dominated by a positive relationship with ACRU<1. The oaks and hickories were generally negatively correlated to axis 3.

The gradients in regeneration abundance and composition were related to the forest structure as described by the overstory species and basal area (table 2). The first axis was positively correlated with the overstory pine basal area in the 0.025 acre plots, 0.2 acre plots, and the proportion of basal area in pine. The total tree basal area on the plots of these sizes was also positively related to axis 1. The hardwood basal area, however, showed a negative relationship with this axis.

The second and third axes were less closely related to forest overstory structure than axis 1 was. Most notably, the second axis was most strongly (and negatively) correlated with SN_0.025 and SN_P, while the third axis showed some negative correlation with both ACRU_0.025 and ACRU_0.2.

The gradient in regeneration abundance of hardwood species, especially the oak regeneration, appeared to be highly negatively related to the amount of basal area in pine that was within and immediately surrounding the 0.01 acre plots. Additionally, the high proportion of the basal area in pine appeared to be detrimental to the successful regeneration and growth of oaks and other hardwoods. The proportion of basal area in pine was even more negatively correlated with hardwood regeneration than was the total basal area. This suggests that it is not only the overstory density, but also the overstory composition that

Table 2—Linear correlations (Pierson's r), coefficients of determination (r^2), and rank correlations (Kendall's τ) of the three ordination axes and the individual variables

Seedling variables [a]	Axis 1			Axis 2			Axis 3		
	r	r^2	τ	r	r^2	τ	r	r^2	τ
QUSP	-0.91	0.83	-0.83	-0.16	0.03	-0.28	0.00	0.00	-0.09
QUSP < 1	-0.78	0.61	-0.53	-0.16	0.03	-0.29	0.18	0.03	0.04
QUSP > 1	-0.71	0.50	-0.61	-0.09	0.01	-0.14	-0.26	0.07	-0.26
QUAL	-0.47	0.22	-0.35	-0.03	0.00	-0.03	-0.07	0.01	-0.21
ACRU > 1	0.29	0.08	0.17	-0.45	0.21	-0.30	-0.23	0.05	-0.09
NYSY > 1	-0.11	0.01	-0.01	0.06	0.00	0.15	0.24	0.06	0.21
NYSY < 1	0.11	0.01	0.07	0.17	0.03	0.21	0.05	0.00	-0.02
QUVE	-0.09	0.01	-0.03	0.00	0.00	-0.02	-0.31	0.09	-0.21
CASP > 1	-0.08	0.01	-0.03	0.47	0.22	0.39	-0.11	0.01	-0.15
CASP	-0.06	0.00	0.01	0.71	0.50	0.60	-0.15	0.02	-0.16
ACRU < 1	0.07	0.00	0.04	0.18	0.03	0.15	0.94	0.88	0.79
LITU	-0.01	0.00	-0.06	0.17	0.03	0.23	0.23	0.05	0.20
CASP < 1	-0.01	0.00	0.02	0.62	0.38	0.50	-0.13	0.02	-0.08
Overstory variables [b]									
PINE_0.025	0.52	0.27	0.35	0.04	0.00	0.03	0.06	0.00	0.04
HRDW_0.025	-0.44	0.19	-0.30	0.05	0.00	-0.01	-0.05	0.00	-0.06
HRDW_P	-0.43	0.19	-0.29	-0.06	0.00	-0.02	0.04	0.00	0.08
PINE_P	0.43	0.19	0.29	0.06	0.00	0.02	-0.04	0.00	-0.08
HRDW_0.2	-0.36	0.13	-0.22	0.06	0.00	0.06	0.11	0.01	0.08
ALL_0.025	0.34	0.12	0.21	0.08	0.01	0.05	0.04	0.00	0.00
PINE_0.2	0.34	0.11	0.18	0.14	0.02	0.06	-0.02	0.00	-0.06
ALL_0.2	0.19	0.04	0.06	0.19	0.04	0.07	0.04	0.00	0.03
SN_P	-0.18	0.03	0.10	-0.26	0.07	0.15	-0.04	0.00	0.13
ACRU_P	-0.17	0.03	-0.24	-0.07	0.00	-0.05	-0.10	0.01	-0.07
ACRU_0.2	-0.10	0.01	-0.24	0.04	0.00	-0.04	-0.11	0.01	-0.07
SN_0.2	-0.08	0.01	0.09	-0.11	0.01	0.15	-0.01	0.00	0.13
SN_0.025	-0.07	0.01	0.05	-0.29	0.08	0.01	0.02	0.00	0.12
ACRU_0.025	0.03	0.00	0.04	-0.11	0.01	0.08	-0.13	0.02	0.02

[a] The seedlings used for constructing the ordination included oaks (QUSP), hickories (CASP), white oak (QUAL), black oak (QUVE), red maple (ACRU), blackgum (NYSY), and yellow-poplar (LITU) that were under a foot tall (< 1) or taller than 1 foot and d.b.h. < 1.5 inches (> 1).
[b] The overstory variables represented the basal area of the pines (PINE), hardwoods (HRDW), all species (ALL), or the snags (SN) on the 0.2-acre plots (_0.2) or the 0.025-acre plots (_0.025). Three variables represented the proportion (_P) of the pine, hardwood, and snag basal area on the 0.2-acre plot.

seems to be important for the successful regeneration and survival of natural hardwood regeneration. The higher the proportion of hardwood basal area, at least within the range examined in this study, the better the chance for an abundant oak and other hardwood regeneration. An exception was the relatively shade tolerant and light-seeded red maple, whose regeneration did not appear to be negatively related to the higher pine basal area.

The overstory basal area, whether pine or hardwood, in the 0.025 acre plots was more related to the regeneration abundance than was the basal area in the larger 0.2 acre plots indicating that the overstory composition and density within and immediately outside of the regeneration plots is more important for the regeneration abundance than are the same overstory variables in the larger plots. Therefore, microsite conditions appear to be of more importance for hardwood natural regeneration survival and growth than overall stand averages.

The observed relationships with the weaker second and third axes raise some interesting questions regarding the negative association of the snag basal area on the 0.025 acre plots and the proportion of the basal area in snags with the second axis, which turns out to be related to the abundance of hickory regeneration. The association of the number of ACRU>1 with the second axis, however, does appear easier to explain, as the high amount of snag basal means more open overstory and better red maple seedling survival. Another interesting result is the strong correlation of ACRU<1 with axis 3, which appears to be negatively correlated with the red maple basal area. These relationships are somewhat difficult to interpret, considering that the forest structure does not seem to be as strongly correlated with the second and third ordination axes. Further examination of aspect, microtopographic position, and other abiotic factors will be considered for addition and is expected to provide further insight into the forces that drive the presence and abundance of regeneration from valuable hardwood species.

CONCLUSION

The oak regeneration was highly negatively correlated to the pine basal area in the immediate vicinity. Pine basal area was more important to oak and other hardwood regeneration than even total overstory basal area. Therefore, overstory composition, not just overstory condition, should be considered when applying silvicultural treatments in similar conditions. The higher proportion of hardwood basal area relative to pine basal area appears to increase the chance for an abundant regeneration oak and some other hardwood species. Red maple regeneration does not seem to be negatively related to the higher pine basal area. Overstory composition and tree density close to the regeneration may be more important for abundant and successful hardwood natural regeneration than average stand overstory condition. The high pine mortality, associated with the presence of snags, appears to be beneficial for the survival and development of red maple seedlings, but does not seem to have the same benefit for hickory seedlings.

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CULM PRODUCTION AND MORPHOLOGY OF FRESH AND STORED RHIZOMES FROM FIELD-PLANTED AND WILD GIANT CANE

John L. Hartleb and James J. Zaczek[1]

Abstract—Drastic loss of giant cane (*Arundinaria gigantea* [Walt.] Muhl.) dominated habitat or canebrakes has spurred interest in restoration. However, a lack of available planting stock and practical methods of propagation has limited restoration progress. The purpose of this experiment was to determine factors that influence the propagation and subsequent growth of culms from giant cane rhizomes planted in containers. Six hundred sections of rhizomes from a four-year-old field-planted cane nursery and an established natural stand of unknown age were planted in containers immediately after collection or after cold storage and allowed to develop for up to two months in a greenhouse. Natural stand rhizomes tended to be larger in diameter, the internodes were longer, and there were fewer buds per unit length than nursery collected rhizomes. After one month, culms developed from 77 percent of nursery rhizomes while only 37 percent of the rhizomes from the natural stand formed culms. Percentage of culm formation was not affected with an additional month in the greenhouse nor influenced by one month of refrigerated storage. Mean height of the tallest shoot of culm-producing rhizomes was similar for stock collected from an establishing cane nursery and from a naturally occurring mature stand when grown for one month. Mean height of nursery-collected stock grown for two months was nearly four times greater than the stock grown for one month.

INTRODUCTION

Giant cane (*Arundinaria gigantea* [Walt.] Muhl.) is a native species of bamboo found as a component of riparian and bottomland forest ecosystems or in dense monotypic stands called canebrakes throughout the southeastern United States (Brantley and Platt 2001). Giant cane's range encompasses 22 different states in the southeastern U.S. and is limited in its distributional pattern by winter conditions in the north and xeric conditions in the west (Marsh 1977). Although cane covers an extensive range, historical accounts indicate that 98 percent of canebrake communities no longer exist (Noss and others 1995). Research has suggested that frequent burning, overgrazing by livestock, and overall habitat conversion to agriculture have contributed to canebrake loss (Platt and Brantley 1992, 1997). The depletion of canebrakes has left a variety of wildlife species facing decline and even local extirpation because of a lack of food and habitat. Aside from the benefits to wildlife, cane also acts as a buffer in riparian areas, greatly decreasing the effects of erosion and reducing inputs of nutrients and sedimentation into waterways (Schoonover and others 2003, 2005).

Although there is a need and desire to restore canebrake habitat, difficulties in propagation present barriers to restoration efforts. A serious problem associated with cane establishment is that its flowering and seeding cycles are unpredictable and unreliable, perhaps spanning decades. Once germinated from seed or started from fragments, canebrake establishment relies mostly on spread by vegetative propagation of rhizomes. Unfortunately, there is a lack of a constant or abundant supply of cane propagules and field establishment techniques are lacking for the restoration of cane habitat and riparian buffers (Brantley and Platt 2001).

Recent cane propagation research by Sexton and others (2003) determined that small rhizome pieces with few nodes (2 to 4) produced significantly fewer culms per node than larger pieces with more nodes (>10 +). Culm production was increased with light exposure from surface-planted rhizomes compared to buried rhizome sections. It was also concluded that the number of culms produced varied according to the date

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and site of collection. Our current study was designed to further investigate culm production and growth from rhizomes within a greenhouse-based containerized production system compatible with machine field-planting methods; and generate plant material for use in subsequent planting trials to determine factors important in field establishment of the species. The objectives of our current study include determining if culm production and growth were related to rhizome origin, morphology, refrigerated storage, or duration of exposure to growing conditions in the greenhouse.

METHODOLOGY

Dormant rhizomes were gathered in late winter and early spring (Feb. 18, Mar. 4, and Mar. 25, 2005) from two locations, one mature and one juvenile cane stand. The first site is located in Johnson County, Illinois on former agricultural lands purchased and managed by The Nature Conservancy known previously as the Rose Farm. Here cane was collected from an establishing cane "nursery" planted in spring 2001 within cultivated raised beds. The original source of this planted juvenile cane was from several cane stands in the local Cache River region. The rhizomes gathered from the Rose Farm were hand-dug with shovels on February 18, 2005 and March 4, 2005 in locations within 3 m of each other. Collection of a second group of rhizome stock took place on March 25, 2005 at the Bellrose tract of the Cypress Creek National Wildlife Refuge. The stock came from a naturally occurring mature stand of mixed cane and woody species growing under a utility right-of-way adjacent to a wooded riparian zone that borders Big Creek. Here stock was obtained mechanically from the help of a backhoe. Work hours were also recorded in hopes to compare the time efficiency of cane rhizomes dug by hand versus cane gathered mechanically. Immediately after digging, most of the soil was removed from the rhizomes and they were placed in white plastic bags to avoid desiccation until processing at the greenhouse.

After the rhizomes were collected they were brought back to the Tree Improvement Center greenhouse at Southern Illinois University. Rhizomes were briefly washed to remove excess soil, trimmed to remove damaged sections, tagged, and numbered. Some rhizome stock was potted within several days while other rhizomes were lightly misted and stored under refrigeration in plastic bags at 4 degrees C for approximately one month before planting in containers.

Prior to planting, length (cm) and the number of roots, buds (except treatment designation Rose Farm 2 month described below), and nodes were recorded for each rhizome section collected. Diameter (mm) was measured at the distal end of the rhizome sections using a digital caliper. Since the majority of rhizomes were oval in cross-section, two readings at right angles to the major and minor axes were taken and the geometric mean of these readings was calculated as the diameter (Husch and others 1972). These measurements were used later in an attempt to relate survival and growth of cane culms to rhizome morphology. Six hundred sections of rhizomes were planted in D40 Deepot containers (Stuewe & Sons, Inc., Corvallis, OR) that were 6.4 cm in diameter by 25.0 cm tall filled with Promix BX potting media (Premier Horticulture Inc., Quakertown, PA). Rhizomes were planted based on recommendations by Sexton and others (2003) with at least 2 cm of the distal end protruding from the media. Containers were exposed to intermittent mist for 20 seconds every 16 minutes during daylight hours in a heated greenhouse. Aside from misting, containers were also watered once or twice a week as necessary to keep the soil moist. Measurements of the number of new culm shoots and height (cm) of the tallest culm from each rhizome section were taken on the stock following the growing period on May 6, 2005.

For the purpose of data analysis, three treatment groups were designated by collection location and time grown in the greenhouse. Treatments were as follows: Rose Farm 2 month, Rose Farm 1 month, and Bellrose 1 month. The Rose Farm rhizome stock was collected from the juvenile nursery planting on February 18 and March 4, 2005. Stocks from these two collection dates were combined to simplify comparisons. Rose Farm 2 month treatment group was planted immediately (without refrigerated storage) and placed under greenhouse conditions for over 2 months. Rose Farm 1 month treatment group also originated from the same stock but was stored under refrigeration for one month prior to planting and was subsequently grown for approximately one month in the greenhouse. After refrigeration, some of the stock exhibited some degradation and rotting at cut or damaged surfaces, which was removed with pruning shears prior to planting. The Bellrose 1 month treatment group consisted of rhizome stock collected at Bellrose on March 25, 2005 and was grown for approximately one month in the greenhouse without refrigeration.

Once all measurements were taken the data was entered into a spreadsheet and subsequently analyzed. Analysis of variance was used to answer the following questions: (1) Were there differences in rhizome morphology among treatments? (2) Did rhizomes that successfully produced a culm differ in morphology from those that did not produce culms? (3) Were there differences in culm production among the rhizome treatments? A chi-square test of independence was used to determine if culm production was independent of: (1) duration of rhizome exposure to greenhouse growing period (Rose Farms 1 month grown for one month versus Rose Farms 2 month grown for two months) (2) rhizome stock origin (Rose Farms 1 month with Bellrose 1 month) exposed to a similar growing period. For rhizomes that produced culms, stepwise regression analysis was used to determine if the height of the tallest culm was related to rhizome morphology.

RESULTS AND DISCUSSION

Rhizome morphology differed among stock types (table 1) in diameter ($p<0.0001$), internode length ($p<0.0001$), and nodes per bud ($p<0.0001$). Bellrose 1 month stock had significantly larger mean rhizome diameter and greater mean internode length than Rose Farm's stock. There were small but significant differences in rhizome diameter between the treatments using Rose Farm stock, which may be attributed to the refrigeration storage period and perhaps desiccation and subsequent shrinking of stock. Additionally, some of the rhizome stock stored under refrigeration had degraded at cut or damaged surfaces, which required removal of the damaged tissues. This may have contributed to the reduced size of the stored rhizomes. The internode length of the Bellrose stock was at least a centimeter larger than the internode length of the Rose Farm stock. Bellrose stock also contained only one bud for every 2.6 nodes while the Rose Farms 1 month stock contained one bud for every 1.4 nodes. Therefore, for a given length, rhizomes from Bellrose had fewer nodes and buds.

Culm production from rhizomes between the Rose Farm treatments was similar ($p=0.1141$) and averaged 77 percent. Of the 240 containerized rhizomes in the Bellrose 1 month treatment 37.1 percent produced culms, which was significantly lower ($p<0.0010$ for both comparisons) than either of the Rose Farm treatments (table 2). Culm production from Rose Farm stock was similar to that reported by Sexton and others (2003) at 76 percent using stock that was slightly longer averaging 25.9 cm.

Table 1—A morphological comparison of the diameter, internode length, and the mean number of nodes per bud of rhizomes for each treatment before planting in containers

Treatment[a]	Diameter	Internode length	Nodes per bud
	mm	*cm*	
Bellrose 1 month	11.6 a	3.6 a	2.6 a
Rose Farms 2 months	7.3 b	2.5 b	—
Rose Farms 1 month	6.8 c	2.3 b	1.4 b

Means in a column with the same letter are not significantly different at p = 0.05.

[a] Origin and time grown in greenhouse.

Table 2—Percentage of rhizomes producing at least one culm and the number of rhizomes planted per treatment

Treatment[a]	Rhizomes planted	Percentage of rhizomes producing at least one culm
	number	*percent*
Rose Farms 2 months	120	78.3 a
Rose Farms 1 month	180	76.7 a
Bellrose 1 month	240	37.1 b

Means in a column with the same letter are not significantly different at p = 0.05.
[a] Origin and time grown in greenhouse.

The height of the tallest culm was not different (p=0.0533) between treatments grown for one month, which had originated from different locations (Bellrose 1 month 8.0 cm and Rose Farms 1 month at 6.3 cm). However, for the same stock origin, culm height was greater (p<0.0001) when grown for approximately two months versus one month (Rose Farms 2 month at 23.3 cm in comparison to 6.3 cm for Rose Farm 1 month). Stepwise regression related rhizome diameter and the number of roots per rhizome section to height of the tallest culm (p<0.0001) accounting for 13 percent of the variation.

Culm production of the rhizomes from the Rose Farm 1 month and 2 month treatments was similar suggesting that refrigerated cold storage for one month did not affect the viability of the rhizomes. This was the case even though some tissue degradation was noticed on stored rhizomes. Additionally, a second month in the greenhouse did not increase the percentage of culm producing rhizomes but did increase the height of the tallest rhizome.

Some rhizome morphological characteristics differed when comparing rhizomes of each treatment that produced culms versus those that did not (table 3). Culm producing rhizomes were significantly larger in diameter for two of three comparisons tested and had a greater number of buds in the only two comparisons tested. However, rhizomes that produced culms tended to have a shorter mean length for all treatments. We did not expect culm-producing rhizomes to be shorter based on experience with a previous experiment. This experiment tested rhizomes with 2, 4, and 10+ nodes and found that rhizomes with greater numbers of nodes (suggesting longer length) produced more culms (Sexton and others 2003). However, given the nature of the containers used in the current study, which had a soil depth of approximately 22 cm, it is possible that longer rhizomes would have had more of the rhizome exposed above the soil surface. This may have made these rhizomes more susceptible to desiccation during nighttime hours when the misting system was off.

McClure (1993) suggested that rhizome sections be 45-60 cm long for cutting propagation. Others suggest that rhizome sections should be cut into 38-102 cm lengths with at least ten buds per rhizome section and any attached culm should be cut back to 30 cm when planting directly in the field (Platt and Brantley 1992). In the current study in a containerized system, rhizomes less than one half that size resulted in culms forming on 77 percent of the rhizomes from Rose Farm stock. In fact, sections of rhizomes that produced culms were significantly shorter and had more buds on average than those that failed to produce culms. Use of smaller rhizomes, if culm production is maintained, can allow for more planting stock to be generated in a containerized system from a given amount of collected rhizomes.

Table 3—Comparison of rhizome morphology for those rhizomes that produced a culm versus those that did not

Treatment[a]	Rhizome response	Roots per rhizome	Rhizome length	Rhizome diameter	Nodes per rhizome	Buds per rhizome
		number	*cm*	*mm*	- - - - - *number* - - - - -	
Rose Farms						
1 month	Culm	16.6 a	17.4 b	6.9	8.6	7.8 a
	No culm	11.2 b	19.9 a	6.8	7.8	5.0 b
Rose Farms						
2 months	Culm	16.0	23.2 b	7.6 a	10.5	—
	No culm	13.2	27.2 a	6.8 b	10.7	—
Bellrose						
1 month	Culm	12.1	22.6 b	12.0 a	7.2	4.6 a
	No culm	11.4	24.6 a	11.4 b	7.3	2.0 b

Means in a column within a treatment with the same letter are not significantly different at $p = 0.05$.
[a] Origin and time grown in greenhouse.

The large differences in culm production between stock collected from Rose Farms and Bellrose may be related to several factors. Rose Farm rhizomes had greater number of nodes per unit length and more buds for a given number of nodes than rhizomes from Bellrose. In mature stands the culms typically have fewer buds at the nodes (Marsh 1977). This held true for this experiment because smaller stock with more internodes usually contained more buds. Rose Farm stock had a significantly lower bud to node ratio confirming that Rose Farm sections did contain more buds per unit length. This may have impacted culm production since buds develop into rhizomes or culms (Marsh 1977). It is also necessary for rhizomes to have buds or no new culms will be produced (Bell 2000) suggesting that culms or rhizomes are not formed adventitiously. If this is the case, it is important to collect stock with several buds and be careful that buds are not damaged either during collection or when storing or processing rhizomes when planting.

Based on estimates, three times as many rhizomes were collected per man-hour using a backhoe than by hand digging. This difference is very likely to be underestimated because the soil at the hand-dug nursery site, which had been cultivated in recent years, was relatively uniform, loose, and free from intruding roots of other woody plants. The mature cane stand on the other hand was located along the edge of a wooded riparian zone and the soil had many woody roots from trees and vines, which would have been very difficult to dig by hand. Our past cane-collecting experiences support this point. The backhoe worked very effectively at saving time and effort, but resulted in damage to cane rhizomes, roots, and buds likely impacting their propagation ability. Indeed, the percentage of culm production (37 percent) of backhoe dug stock from the natural stand in this current study was much lower than that of stock dug by hand also from established natural cane stands adjacent to woods (at 76 percent) as reported by Sexton and others (2003). This increased damage from machine digging may have been in part due to the presence of interfering and intertwining roots from other woody plants and trees, which made rhizome extraction difficult. Overall, compared to the hand digging the backhoe was much more efficient and effective at collecting rhizomes but the stock quality was reduced.

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CHANGES IN TREE SPECIES IMPORTANCE FOLLOWING HARVESTING DISTURBANCE IN NORTH MISSISSIPPI BETWEEN 1967 AND 1994

Andrew J. Hartsell and James F. Rosson, Jr.[1]

Abstract—We used continuous forest inventory data from the Forest Inventory and Analysis unit of the U.S. Department of Agriculture, Forest Service to study the impacts of timber harvesting on species composition and species importance in a 26-county region in north Mississippi. The region was 59 percent forested and contained 1 965 223 ha of timberland. There were 524 upland sample plots on a 4.8 by 4.8 km square grid. These were measured in 1967 and remeasured in 1977, 1987, and 1994. Across the period, only 110 plots had < 5 percent of basal area removed. In 1967, on these undisturbed plots, *Pinus echinata* Mill., *Carya* spp., *Quercus falcata* Michx., and *Q. alba* L. were the top four overstory ranking species in terms of basal area, accounting for 13.8, 12.7, 10.6, and 9.9 percent of basal area, respectively. Upon final remeasurement of these same undisturbed plots in 1994, *Q. alba* had become dominant and was followed by *P. echinata*, *Q. falcata*, and *Liquidambar styraciflua* L. In contrast, the total 1994 plot population, which included both disturbed and undisturbed plots, was strongly dominated by *P. taeda* L., which accounted for 22.4 percent of basal area. In stands that had > 75 percent of basal area removed, *P. taeda* accounted for > 50 percent of stand basal area. It appears that harvesting disturbance and management preferences has resulted in an alteration of the normal trajectory of species composition dynamics. *P. taeda* is now the dominant species and the dominant overstory softwood across the uplands of north Mississippi. This appears to be markedly different than what would occur naturally as evidenced by the dominance of *Q. alba* on the undisturbed plots. There were also noteworthy differences in understory species composition; most notably *P. taeda* was dominant on disturbed plots and *Cornus florida* L. was dominant on undisturbed plots.

INTRODUCTION

The southern forest has been subjected to a substantial harvesting disturbance since the 1880s (Williams 1989, Davis 1983). After most of the old-growth was cut, a cycle of harvesting second-growth timber began. This has continued up to the present, with harvesting pressure increasing over the last 30 years in both intensity and area covered (Rosson 1994). The result has been shorter and shorter stand rotations and younger stands across the landscape. Depending on ownership objectives, some stands were placed under management, but many were not.

Continued harvesting disturbance impacts stand development over time (Kohm and Franklin 1997). In the South, many second-growth stands have been harvested and replaced with pine plantations while many stands were left to regenerate naturally (Rosson 1994). Such impacts alter species composition and stand development as forests pass through various stages of recovery and succession. The long term consequences are not known but do raise concerns about the maintenance of species diversity and ecosystem health.

Over the last 30 years, intensive forest management has impacted the forest stands of north Mississippi. Much of this disturbance has been directed toward increases in plantation area, established after initial removal of second-growth hardwoods and hardwood-pine stands (Rosson 2001). Locally, continued disturbance and management practices that remove tree species may require decades or longer for enough propagules to reinhabit such areas and successfully reestablish new populations (Duffy and Meier 1992, Peterkin and Game 1984). Shifts in overall species composition across the landscape in north Mississippi have likely occurred, and this gives rise to concern about the maintenance of species diversity and ecosystem health in the area.

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Decreases in species abundance may be detected early on by monitoring shifts in species composition. We tracked changes in species composition between 1967 and 1994 across 26 counties in north Mississippi to determine if stand composition had changed over time across the landscape. We also determined if shifts in species importance had occurred. Such studies can quantify the impacts of forest management on individual species populations over time. Another important facet of these types of studies is to identify instances where overall stand composition may not change but the relative degree of species importance may shift substantially.

METHODS

To determine shifts in species composition and species importance, we compared data from the 1967 and 1994 surveys of upland forests in a 26-county region in north Mississippi (fig.1). The vegetation of this area has been broadly classed as oak-hickory-pine and oak-hickory (Kuchler 1964). An elongated strip called the blackbelt prairie extends through the central portion of this region. This blackbelt is intermixed with forests composed of *Liquidambar*, *Quercus*, and *Juniperus* species (Kuchler 1964). About two-thirds of the study region falls in Braun's Mississippi Embayment Section of the Western Mesophytic Forest Region. The remainder is in the Gulf Slope Section of her Oak-Pine Forest Region (Braun 1950).

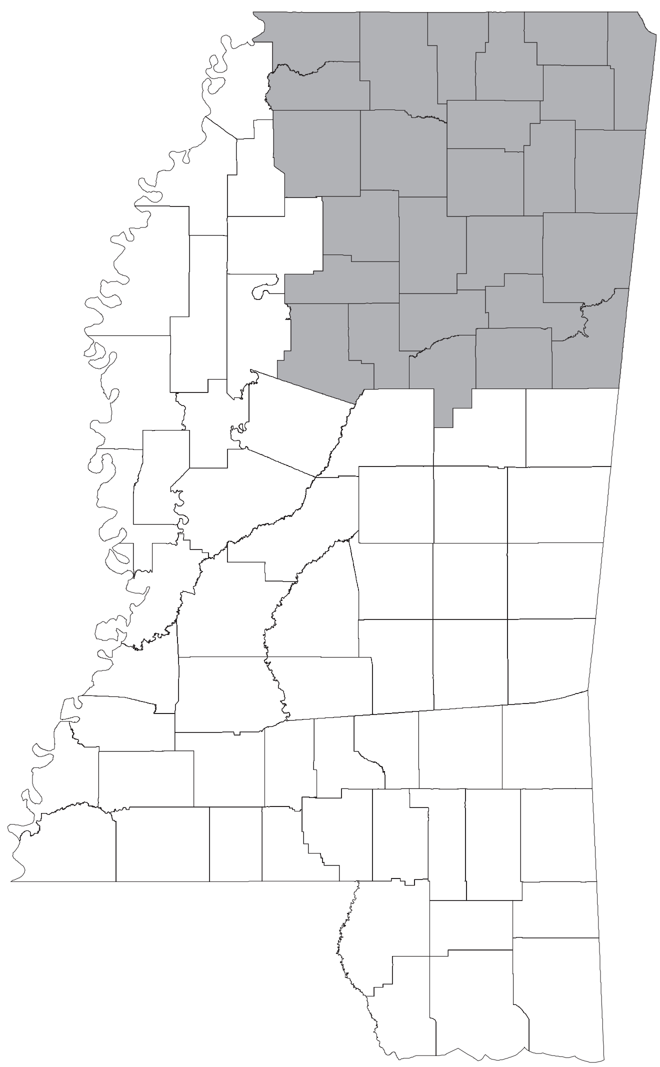

Figure 1—The 26-county study area of north Mississippi.

The data came from forest surveys of Mississippi conducted in 1967, 1977, 1987, and 1994. The sample design consisted of a two-phase method: dot counts on aerial photographs for estimating timberland area and tree measurements on permanently placed sample plots for determining forest stand and tree attributes. The sample design was unchanged throughout all four surveys with sample plots being remeasured each survey. Sample plots were located on a 4.8 km square grid. Each sample plot consisted of a 10-point satellite system covering about 0.4 ha. Trees ≥ 12.7 cm in diameter at breast height (d.b.h.) were tallied on every point, based upon inclusion with an 8.6 m^2 basal area factor prism. Trees < 12.7 cm in d.b.h. were tallied on a 2.2 m radius fixed plot on the first three satellite points. At each satellite point, trees were tallied by species, d.b.h., height, and other tree-character variables for the determination of volume and biomass. Additionally, for each plot, stand level attributes were determined by computer algorithm for stand size and forest type. See Rosson (2001) for more details about the Mississippi surveys.

The 26-county region was 59 percent forested and contained 1 965 223 ha of timberland. In at least one of the surveys during the four survey periods 817 plots were forested. Of these, 606 plots were forested through all four surveys. Eighty-two of these 606 plots were in a bottomland physiographic class and were removed from the plot population. This left 524 upland plots in the study plot population. These study plots were then classed by the amount of cutting disturbance (if any) they received during the four survey periods. The degree of cutting was the amount of stand basal area removed since the previous survey on each sample plot. Across all four measurements, only 110 plots had < 5 percent of stand basal area removed. These plots were labeled the undisturbed plots. Unless otherwise noted, plots that had > 5 percent of their basal area removed by cutting were classified as disturbed. We arbitrarily chose the 5 percent threshold in order to increase the number of undisturbed study plots. Plots that had this low level of cutting (usually consisting of one or two trees per plot) would not impact the overall conclusions inferred from the undisturbed plot population.

The data from the 1967 survey were not directly available but were reconstructed from the 1977 data set. This was possible because measurements from the 1967 survey were maintained in the records of the 1977 data set. For example, information about tree attributes such as previous d.b.h., was available for survivor trees (trees measured in 1967 and measured again in 1977). Some stand information, such as the previous forest type and stand size, was available as well.

To determine shifts in species composition and species importance, we compared data from the 1967 and 1994 surveys. It was only necessary to monitor plot data from the 1977 and 1987 surveys to determine whether plots were disturbed or eliminated from the plot population by conversion from a forest to nonforest state.

The data are presented in two types of format: (1) a set of tables (for 1967 and 1994) for all upland forest plots that remained in forest across four survey periods (tables 1 and 2) and (2) a set of tables (for 1967 and 1994) for the upland forest plots that were undisturbed across the four survey periods (tables 3 and 4). Comparisons can be made between and within 1967 and 1994 for each set of tables. It was determined that the best temporal comparison would be between the total plot population (disturbed and undisturbed combined together) and the undisturbed plot population. This seemed the best logical comparison since the present forest condition in north Mississippi is a complex consisting of both disturbed and undisturbed stands. The comparisons thus reflect the number of disturbed plots and degree of disturbance in the total plot population. Each table lists the 15 most dominant species in the overstory and understory. In all cases, these 15 species capture at least 85 percent of all tree species importance in north Mississippi.

Table 1—Importance, by basal area, of the 15 most dominant trees, by canopy position, for all remeasured plots in north Mississippi, 1967[a]

Common name	Scientific name	Basal area	Basal area[b]
		thousand m²	*percent*
Overstory trees[c]			
Shortleaf pine	*Pinus echinata* Mill.	3349.00	23.82
Post oak	*Quercus stellata* Wangenh.	1419.08	10.09
Loblolly pine	*P. taeda* L.	1408.72	10.02
Southern red oak	*Q. falcata* Michx.	1324.80	9.42
White oak	*Q. alba* L.	1157.52	8.23
Sweetgum	*Liquidambar styraciflua* L.	1066.92	7.59
Hickory	*Carya* sp. Nutt.	1046.16	7.44
Black oak	*Q. velutina* Lam.	444.17	3.16
Blackjack oak	*Q. marilandica* Muenchh.	356.32	2.53
Blackgum	*Nyssa sylvatica* Marsh.	355.03	2.53
Winged elm	*Ulmus alata* Michx.	240.63	1.71
Yellow-poplar	*Liriodendron tulipifera* L.	215.79	1.53
Cherrybark oak	*Q. falcata var. pagodifolia* Ell.	210.55	1.50
Shumard oak	*Q. shumardii* Buckl.	180.34	1.28
Scarlet oak	*Q. coccinea* Muenchh.	166.96	1.19
Total		14059.22	92.05
Understory trees[d]			
Shortleaf pine	*P. echinata* Mill.	1697.20	19.44
Loblolly pine	*P. taeda* L.	1048.39	12.01
Sweetgum	*Liquidambar styraciflua* L.	906.91	10.39
Flowering dogwood	*Cornus florida* L.	643.16	7.37
Southern red oak	*Q. falcata* Michx.	483.48	5.54
Post oak	*Q. stellata* Wangenh.	449.95	5.16
White oak	*Q. alba* L.	428.00	4.90
Hickory	*Carya* sp. Nutt.	421.85	4.83
Red maple	*Acer rubrum* L.	270.14	3.10
Blackjack oak	*Q. marilandica* Muenchh.	229.76	2.63
Black oak	*Q. velutina* Lam.	228.00	2.61
Water oak	*Q. nigra* L.	205.12	2.35
Winged elm	*Ulmus alata* Michx.	198.10	2.27
Common persimmon	*Diospyros virgininana* L.	184.80	2.12
Blackgum	*N. sylvatica* Marsh.	168.64	1.93
Total		8728.22	86.66

[a] All FIA plots in the study area that remained forested for the entire study period (1967–94), n = 606.
[b] Based on all live trees in sample.
[c] Trees ≥ 12.7 cm d.b.h.
[d] Trees ≥ 2.5 but <12.7 cm d.b.h.

Table 2—Importance, by basal area, of the 15 most dominant trees, by canopy position, for all remeasured plots in north Mississippi, 1994[a]

Common name	Scientific name	Basal area	Basal area[b]
		thousand m²	*percent*
Overstory trees[c]			
Loblolly pine	*Pinus taeda* L.	3792.69	22.44
Shortleaf pine	*P. echinata* Mill.	1900.78	11.25
Sweetgum	*Liquidambar styraciflua* L.	1723.77	10.20
Southern red oak	*Quercus falcata* Michx.	1521.05	9.00
White oak	*Q. alba* L.	1402.67	8.30
Post oak	*Q. stellata* Wangenh.	1101.31	6.52
Hickory	*Carya* sp. Nutt.	1031.32	6.10
Cherrybark oak	*Q. falcata var. pagodifolia* Ell.	491.58	2.91
Black oak	*Q. velutina* Lam.	437.37	2.59
Water oak	*Q. nigra* L.	433.22	2.56
Yellow-poplar	*Liriodendron tulipifera* L.	358.99	2.12
Red maple	*Acer rubrum* L.	317.06	1.88
Blackgum	*Nyssa sylvatica* Marsh.	274.29	1.62
Winged elm	*Ulmus alata* Michx.	228.25	1.35
Eastern redcedar	*Juniperus virginiana* L.	197.65	1.17
Total		16900.03	90.01
Understory trees[d]			
Loblolly pine	*P. taeda* L.	895.45	17.97
Sweetgum	*Liquidambar styraciflua* L.	763.65	15.33
Flowering dogwood	*Cornus florida* L.	520.96	10.45
White oak	*Q. alba* L.	275.53	5.53
Red maple	*A. rubrum* L.	266.48	5.35
Hickory	*Carya* sp. Nutt.	248.15	4.98
Winged elm	*U. alata* Michx.	245.41	4.93
Shortleaf pine	*P. echinata* Mill.	209.21	4.20
Eastern redcedar	*J. virginiana* L.	172.54	3.46
Blackgum	*N. sylvatica* Marsh.	147.19	2.95
Southern red oak	*Q. falcata* Michx.	121.71	2.44
Black cherry	*Prunus serotina* Ehrh.	110.43	2.22
Yellow-poplar	*Liriodendron tulipifera* L.	95.22	1.91
Post oak	*Q. stellata* Wangenh.	88.20	1.77
Ironwood	*Ostrya virginiana* (Mill.) K. Koch	87.34	1.75
Total		4982.97	85.24

[a] All FIA plots in the study area that remained forested for the entire study period (1967–94), n = 606.
[b] Based on all live trees in sample.
[c] Trees ≥ 12.7 cm d.b.h.
[d] Trees ≥ 2.5 but < 12.7 cm d.b.h.

Table 3—Importance, by basal area, of the 15 most dominant trees, by canopy position, for all remeasured plots on undisturbed stands in north Mississippi, 1967[a]

Common name	Scientific name	Basal area	Basal area[b]
		thousand m²	*percent*
Overstory trees[c]			
Shortleaf pine	*Pinus echinata* Mill.	256.97	13.79
Hickory	*Carya* sp. Nutt.	237.33	12.74
Southern red oak	*Quercus falcata* Michx.	197.28	10.59
White oak	*Q. alba* L.	184.83	9.92
Post oak	*Q. stellata* Wangenh.	182.95	9.82
Sweetgum	*Liquidambar styraciflua* L.	179.01	9.61
Black oak	*Q. velutina* Lam.	98.19	5.27
Blackgum	*Nyssa sylvatica* Marsh.	70.12	3.76
Loblolly pine	*P. taeda* L.	66.07	3.55
Blackjack oak	*Q. marilandica* Muenchh.	55.62	2.99
Cherrybark oak	*Q. falcata var. pagodifolia* Ell.	36.77	1.97
Yellow-poplar	*Liriodendron tulipifera* L.	30.08	1.61
Red maple	*Acer rubrum* L.	25.02	1.34
Scarlet oak	*Q. coccinea* Muenchh.	24.64	1.32
Shumard oak	*Q. shumardii* Buckl.	23.88	1.28
Total		1862.93	89.58
Understory trees[d]			
Shortleaf pine	*P. echinata* Mill.	217.44	17.51
Sweetgum	*Liquidambar styraciflua* L.	150.78	12.14
White oak	*Q. alba* L.	100.46	8.09
Flowering dogwood	*Cornus florida* L.	98.93	7.97
Hickory	*Carya* sp. Nutt.	88.48	7.12
Southern red oak	*Q. falcata* Michx.	70.20	5.65
Eastern redcedar	*Juniperus virginiana* L.	60.34	4.86
Post oak	*Q. stellata* Wangenh.	58.74	4.73
Loblolly pine	*P. taeda* L.	50.23	4.04
Winged elm	*Ulmus alata* Michx.	44.26	3.56
Water oak	*Q. nigra* L.	43.62	3.51
Sourwood	*Oxydendrum arboreum* (L.) DC.	39.70	3.20
Black oak	*Q. velutina* Lam.	37.58	3.03
Common persimmon	*Diospyros virgininana* L.	30.31	2.44
White ash	*Fraxinus americana* L.	22.85	1.84
Total		1241.90	89.69

[a] All FIA plots in the study area that remained forested for the entire study period (1967–94), n = 606.
[b] Based on all live trees in sample.
[c] Trees ≥ 12.7 cm d.b.h.
[d] Trees ≥ 2.5 but < 12.7 cm d.b.h.

Table 4—Importance, by basal area, of the 15 most dominant trees, by canopy position, for all remeasured plots on undisturbed stands in north Mississippi, 1994[a]

Common name	Scientific name	Basal area	Basal area[b]
		thousand m²	*percent*
Overstory trees[c]			
White oak	*Quercus alba* L.	523.12	13.57
Shortleaf pine	*Pinus echinata* Mill.	448.31	11.63
Southern red oak	*Q. falcata* Michx.	403.93	10.48
Sweetgum	*Liquidambar styraciflua* L.	379.32	9.84
Hickory	*Carya sp.* Nutt.	299.03	7.76
Post oak	*Q. stellata* Wangenh.	287.76	7.47
Loblolly pine	*P. taeda* L.	266.03	6.90
Cherrybark oak	*Q. falcata var. pagodifolia* Ell.	167.96	4.36
Water oak	*Q. nigra* L.	137.06	3.56
Black oak	*Q. velutina* Lam.	124.26	3.22
Yellow-poplar	*Liriodendron tulipifera* L.	111.37	2.89
Willow oak	*Q. phellos* L.	72.38	1.88
Scarlet oak	*Q. coccinea* Muenchh.	70.49	1.83
Blackgum	*Nyssa sylvatica* Marsh.	62.72	1.63
Red maple	*Acer rubrum* L.	59.49	1.54
Total		3 853.58	88.57
Understory trees[d]			
Flowering dogwood	*Cornus florida* L.	156.92	19.99
Sweetgum	*Liquidambar styraciflua* L.	127.18	16.20
Red maple	*A. rubrum* L.	56.58	7.21
Eastern redcedar	*Juniperus virginiana* L.	55.83	7.11
Winged elm	*Ulmus alata* Michx.	48.63	6.20
White oak	*Q. alba* L.	44.59	5.68
Blackgum	*N. sylvatica* Marsh.	35.40	4.51
Sourwood	*Oxydendrum arboreum* (L.) DC.	32.96	4.20
Loblolly pine	*P. taeda* L.	24.51	3.12
Hickory	*Carya sp.* Nutt.	22.85	2.91
Chestnut oak	*Q. prinus* L.	16.31	2.08
Southern red oak	*Q. falcata* Michx.	16.18	2.06
Post oak	*Q. stellata* Wangenh.	15.92	2.03
Sassafras	*Sassafras albidum* (Nutt.) Nees	14.96	1.91
Common persimmon	*Diospyros virgininana* L.	11.19	1.43
Total		784.86	86.64

[a] All FIA plots in the study area that remained forested for the entire study period (1967–94), n = 606.
[b] Based on all live trees in sample.
[c] Trees ≥ 12.7 cm d.b.h.
[d] Trees ≥ 2.5 but < 12.7 cm d.b.h.

RESULTS

For all remeasured plots in 1967, the dominant overstory species was *P. echinata* (table 1). It accounted for 23.8 percent of the basal area across the 26 north Mississippi counties. Ranked next in importance were *Q. stellata* and *P. taeda*, each accounting for 10 percent of the basal area in the study area. These three species, together, made up 44 percent of total overstory basal area.

Pinus echinata was also dominant in the understory (table 1). There, it accounted for 19.4 percent of basal area. Ranked next were *P. taeda* and *L. styraciflua*, accounting for 12 and 10 percent of the understory basal area, respectively.

By 1994, *P. taeda* had become dominant in the overstory (table 2). The relative rankings remained very close, but many of the top 15 species changed in their rank position. *Pinus echinata* moved from number 1 to number 2 position, replaced by *P. taeda,* which moved from number 3 to number 1. *Quercus marilandica*, *Q. shumardii*, and *Q. coccinea* dropped below number 15 while *Q. nigra*, *Acer rubrum* L., and *Juniperus virginiana* L. were new additions to the top 15 species. Change in importance rank did not always indicate a substantial shift in basal area between 1967 and 1994. For example, *P. echinata* moved from number 1 to number 2 in rank, and the basal area change was very large, dropping from 3 349.0 thousand m^2 in 1967 to 1 900.8 thousand m^2 in 1994. In contrast, *Q. falcata* var. *pagodifolia* moved from number 13 to number 8 in rank but the basal area change was from 210.6 thousand m^2 to 491.6 thousand m^2.

The understory of the total plot population also had substantial shifts in species ranks. *Pinus echinata* was number 1 in 1967 but was replaced by *P. taeda* by 1994. Basal area for *P. echinata* decreased from 1 697.2 thousand m^2 to 209.2 thousand m^2 in 1994, dropping it to number 8 in rank. *Quercus marilandica*, *Q. velutina*, *Q. nigra*, and *Nyssa sylvatica* Marsh. dropped below the top 15 while *J. virginiana*, *Prunus serotina* Ehrh., *Liriodendron tulipifera* L., and *Ostrya virginiana* (Mill.) K. Koch moved into the top 15.

In the subset of undisturbed plots, *P. echinata* was dominant in the overstory in 1967. It accounted for 13.8 percent of total basal area (table 3). Ranked next were *Carya* spp. and *Q. falcata*, representing 12.7 and 10.6 percent of basal area, respectively. By the time of the 1994 survey *Q. alba* had surpassed *P. echinata* in dominance (table 4). *Acer rubrum* and *Q. shumardii* dropped out of the top 15 species while *Q. nigra* and *Q. phellos* moved into the top 15.

Pinus echinata was dominant in the understory of the undisturbed plots in 1967. Ranked next was *L. styraciflua*. Together, these two species accounted for almost 30 percent of total basal area in the understory. By 1994, *Cornus florida* L. was ranked number 1 while *L. styracilflua* remained in the number 2 position. *Cornus florida*, alone, accounted for 20 percent of understory basal area. One of the biggest shifts between 1967 and 1994 was *P. echinata* dropping out of the top 15 understory species. Also dropping off the list were *Q. nigra*, *Q. velutina*, and *Fraxinus americana* L. In 1994, new additions were *A. rubrum*, *N. sylvatica*, *Q. prinus*, and *Sassafras albidum*.

DISCUSSION

Between 1967 and 1994, only 110 (21 percent) out of 524 sample plots went through the four survey periods with harvesting < 5 percent of basal area. These 110 plots were used as the baseline (control) group in our study to mimic how north Mississippi stands may develop over time when undisturbed.

When levels of harvesting disturbance are this high, two modes of regeneration influence and impact stand development. The first is implementation of plantations after harvest. The establishment of plantations usually indicates intense cutting activity and site disturbance (clearcutting) since large open areas are necessary to operate planting equipment efficiently. The second is natural regeneration after some form of harvesting activity. This may range from removing only 10 percent of a stand to clearcutting. The implementation of plantations is usually the more intrusive action and has the potential to allow a single species to dominate an entire landscape. In addition to intensive overstory removal, plantation establishment may involve substantial site preparation and competition control; both may strongly influence post-harvest species abundance. However, a clearcut operation, without subsequent plantation establishment, allows the invasion of opportunistic species to become established. Additionally, stump sprouting may result in a forest stand very similar to the one that was cut.

On the disturbed plots, the most substantial change in species composition between 1967 and 1994 was *P. echinata* dropping from the number 1 ranking to number 2. Although the shift was only one position in the overstory ranking, the larger change was in basal area. *Pinus echinata* dropped from 3 349.0 to 1 900.8 thousand m^2 in total landscape basal area, a 43-percent decrease. In contrast, *P. taeda* went from third in importance in 1967 to first in 1994. Basal area of *P. taeda* went from 1 408.7 to 3 792.7 thousand m^2, a 169-percent increase. This left little available niche space for hardwood development.

On the undisturbed plots, *P. echinata* was number 1 in 1967 and moved to number 2 in 1994. Even though it moved downward in rank its basal area increased, going from 257.0 thousand m^2 to 448.3 thousand m^2, a 74-percent increase. *Quercus alba* became the most dominant species with basal area increasing from 184.3 thousand m^2 to 523.1 thousand m^2, a 184-percent increase. If stand succession is progressing normally on these undisturbed plots, oaks should move into dominance over time, in place of pine, in north Mississippi. This would be especially so if the successional phases are given the opportunity to proceed, without interruption, for 75 years or more.

One of the important things these data show is that replacement stands on these disturbed areas concentrate larger relative amounts of basal area in fewer species. In the disturbed stands, almost 25 percent of total basal area was in the number 1 ranked species, *P. echinata* in 1967 and *P. taeda* in 1994. The cause of most of this was old field invasion or management preference (disturbance) for *P. taeda* through the 1970s, 1980s and 1990s.

In forests of north Mississippi, between 1967 and 1994, *P. echinata* has been displaced by *P. taeda* as the landscape dominant mostly because of preference for *P. taeda* in plantation management (Rosson 2001, Rosson 1995). However, many other species have changed position in relative ranking across the landscape because of this disturbance. Some changes have been minor but many have been substantial.

Stand dynamics analysis is difficult because of the complexity involved in separating natural stand succession dynamics from anthropogenic disturbance dynamics. Our study used a control group of undisturbed plots to compare with disturbed plots but the control group may have been of limited value. First, the ownership properties of these plots may have biased their status. Personal ownership values (such as preservation or economics) may have influenced stand development. Second, we did not know the status of the undisturbed plots prior to 1967. Some may have been disturbed recently while there may have been many years since disturbance in other stands. Therefore, some of the undisturbed plots may have been further into successional stages than others.

None of the species in the overstory of the undisturbed plots are considered very tolerant (on the hierarchical scale of very tolerant, tolerant, intermediate, intolerant, and very intolerant) as described by Baker (1950). *Quercus alba*, the dominant hardwood, is considered intermediate in tolerance. The other major components, *P. echinata*, *L. stryaciflua*, *Carya* spp., and *P. taeda* are all considered intolerant. This indicates that succession is still progressing and that overstory stand development is still in early recovery from past disturbances.

In the understory, *C. florida* is the only tree that is considered very tolerant. Other indicators of advancing succession are *A. rubrum*, *N. sylvatica*, and *Diospyros virginiana* L., all considered tolerant.

Our preliminary study has demonstrated the replacement of *P. echinata* by *P. taeda* across north Mississippi along with the suppression of the hardwood component. Future studies will include refinements in defining the control group of plots and testing the sensitivity of species associations. Also, work needs to be done on assessing the overall impact of changes in species dominance and relative species ranking across the landscape. We do not know the degree of disturbance that is harmful to forest ecosystems, especially disturbance that impacts species populations. For example, there are no indicator values in place that define limits to which specific population numbers may fall before irreparable harm is done to a forest ecosystem or to where species populations cannot recover.

Presently, the data demonstrate the resilience of hardwoods to displacement disturbance. As site disturbances decrease, hardwoods maintain or return to dominant positions, as *Q. alba* has done. Additionally, available habitat is shared on a more even basis by several species rather than one or two dominants. The natural type of oak-pine in north Mississippi appears persistent as foresters try to silviculturally maintain the dominance of pine because of current economic benefits. Unknown is how long the hardwood component can be suppressed and still maintain enough resilience to regenerate and occupy their normal positions in stand composition. Future studies will compare disturbed and undisturbed areas directly. This will give a more rigorous indication of the impact of harvesting disturbance on stand development.

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A HIGH RESOLUTION LASER-BASED TECHNIQUE FOR QUANTIFYING THE ELEMENTAL COMPOSITION OF WOOD: APPLICATIONS IN FOREST FIRE ECOLOGICAL RESPONSE

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Abstract—The wood of tree trunks is an ideal archive for the identification of critical events such as forest fires. This research has focused on the development of high resolution laser-induced breakdown spectroscopy (LIBS) to determine rapidly the elemental composition of wood. The chemical composition of annual growth rings can be correlated to external parameters such as changes in climate, forest fires, and disturbances involving human activity. The objectives of using this technology in fire scar determination are: 1) To determine the characteristic spectra of wood exposed to forest fire and 2) To examine the viability of this technique for detecting fire occurrences in stems that did not develop fire scars. The spectral data obtained from tree rings have the potential to be used for biomonitoring environmental and ecological events such as forest fires. Principal component analysis was essential to extract information from the large datasets and to determine natural events in trees. This technique shows a great deal of promise for detecting past fire events in trees, even though visible fire scars may be absent. As a result, this technique may prove valuable for constructing more accurate fire histories for forest ecosystems.

INTRODUCTION

Wood represents a heterogeneous material comprised largely of lignin, cellulose, and hemicellulose. The relative composition of these components varies with plant species, management, and growth environment, but typically is 30:40:25 percent (Tuskan and others 1999). In addition, wood contains inorganic compounds that remain after high-temperature combustion in the presence of abundant oxygen; such residues are known as ash. Ash is traceable to the occurrence of incombustible compounds containing elements such as calcium, potassium, magnesium, manganese, sulfur, phosphorus and silicon. The presence of lead, chromium and other heavy metals in wood has been used for decades in the field of dendrochemistry to document the presence of pollutants in the soil and aerial environment. Thus, major environmental events are recorded and locked in the growth rings of the trees that grow in the vicinity or in the path of atmospheric particulates (Prohaska 1998, Watmough 1999). Annual growth rings of trees have the potential for providing a chronology of bioavailable contaminants present in the environment in which the trees grow (Hartsough and others 2003). This is just like the recording of major environmental events that are locked in the growth rings of the trees that grow in the vicinity or in the path of where the atmospheric particulates are released. Recently, researchers analyzed metal trace concentrations within Kiawe trees's rings that grow on the island of Oahu, Hawaii, to see if their trace element composition reflects the environmental conditions and changes occurring within the tree's lifespan (Parry and others 2003). Fire scar information has been applied to the reconstruction of historical fire regime leading to fire-environment, fire-climate linkages. Fire scar chronologies have been widely used to justify and guide fuel reduction and natural fire reintroduction in forests. In other words, we can use historical ecology to help in the management of the forests in future.

Numerous techniques have been examined for determining the structural composition of wood, and several high-throughput spectroscopic tools have emerged providing information on chemical, physical, and mechanical properties of wood and wood products (Kelley and others 2004, Rials and others 2002, Tuskan and others 1999). The focus of such work is primarily on organic constituents of wood, neglecting the inorganic trace elements. This focus, while understandable, highlights the limited availability

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of analytical techniques for assessing trace elements in wood. Early studies used atomic absorption spectroscopy to analyze the elemental composition of wood digests (Barnes and others 1976, Becnel and others 2004, Guyette and others 1989), but the technique has received limited use due to high detection limits and the inability to perform multi-element analyses. Other techniques have been used to assess the elemental composition of wood, including photon-induced x-ray emission spectroscopy, secondary ion mass spectroscopy, and laser-ablation ICP-MS (Saarela and others 2005, Watmough 1999), but they too suffer from a unique set of practical and technical limitations.

Laser-induced breakdown spectroscopy (LIBS) has been used for the first time to analyze the elemental composition of wood for environmental applications (Martin and others 2005). This LIBS technique was performed on 165 samples and principal component analysis (PCA) and partial least squares (PLS) regression were performed on the LIBS data. The results highlight the potential for this technique to predict the concentration, as well as identify the type of inorganic preservatives present. Principal component analysis was used to observe any clustering and/or separation in the sample sets.

This paper is focused on the simultaneous multi-elemental analysis in wood especially configured for biomonitoring environmental and ecological events such as forest fires.

MATERIALS AND METHODS

A schematic diagram of the experimental LIBS system proposed for its use in determining the elemental composition of wood is shown in figure 1. A Q-switched Nd:YAG laser (A Big Sky™ laser, model Ultra 532) is used as the excitation source. The maximum beam energy at 532 nm wavelength is 50 mJ per pulse. The laser pulse width is 4 ns, and the repetition rate is variable from 1 to 20 Hz. The first step in LIBS is plasma initiation. Plasma can be formed when a laser beam of sufficient energy is focused onto a small volume of material (~ 14 x 10^{-9} cm^3.), creating a power density inside the volume exceeding tens of gigawatts/cm^2.

All elements in the sample matrix are instantly released into their elemental constituents. A computer software data acquisition program written by the Catalina Scientific Corp., KestrelSpec® is used to acquire the spectra, identify the peaks, calculate the full width at half maximum (FWHM) of the peaks of interest, and also to calculate the area under the peak which can be used in the semi-quantification of elements from a similar matrix. This software interfaces with the spectrometer and the ICCD detector to the computer which will monitor spectra from any sample that is tested using the LIBS technique.

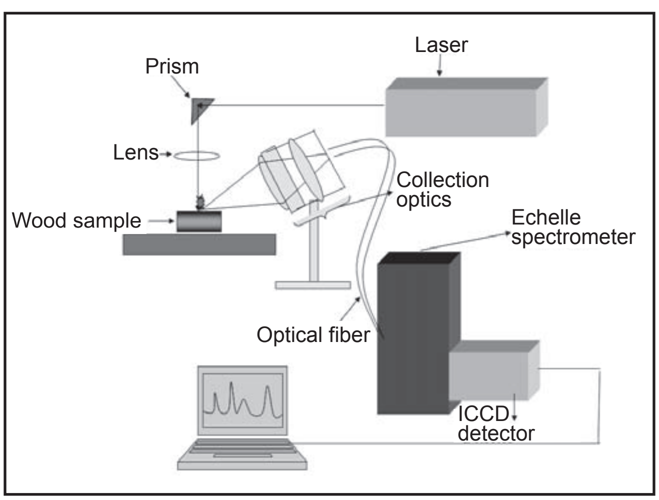

Figure 1—Schematic diagram of the experimental laser-induced breakdown spectroscopy system.

We have successfully added a translational stage to the experimental configuration. This has enabled us to excite the sample and collect the LIBS signal along the length of a wood sample with very fine spatial resolutions (~1 µm) when needed. We have been successful in modifying existing software that controls the spectrometer, detector and laser in also controlling the translational stage movement. Now the modified software has made it possible to wait for the laser to excite at a certain point on the sample, the spectrometer and detector will collect and save the data to the computer and then signal the stage to move to the next step based on a step size (spatial resolution) that has been decided prior to the data collection.

A cross section of a Table Mountain pine (*Pinus pungens* Lamb.) was used for this first study. This tree was chosen for analysis because a scar, resulting from a fire, was observable on the sample. Spectra were collected from the pith to the bark every 2500 µm. In total 20 spectra were collected. The intensity and signal-to-background ratio for these emitted wavelengths were used to determine the presence of the specific element of interest. The emitted wavelengths are fingerprints for the different elements present in the wood matrix that was sampled with high spatial resolution.

The LIBS spectra data sets are large and complex representations of the samples. Each spectrum provides more than 36000 data points. Chemometric methods such as principal component analysis (PCA) are commonly used for this type of analysis (Martens and Naes 1991). PCA is a mathematical procedure for resolving sets of data into orthogonal components whose linear combinations approximate the original data to any desired degree of accuracy. As successive components are calculated, each component accounts for the maximum possible amount of residual variance in the set of data (Mark 2001).

Multivariate analysis of the data was performed using The Unscrambler (vsn. 9.0) software, CAMO, Woodbridge, NJ. The package has the capability to perform any pretreatment of the data (normalization, average…) and multivariate analysis [principal component analysis (PCA), classification, partial least squares (PLS)]…

The wavelength range for the LIBS spectra collection was 200-800 nm. The spectral resolution was 0.02 nm wavelength. The data were averaged to 0.08 nm. The data were normalized prior to analysis.

RESULTS

Figure 2 shows a cross section of the scanned sample. The LIBS spectra were collected from the pith to the bark along the arrow (line scan). The spatial resolution at which the data were acquired was 2500 µm step size. In total, 20 spectra were recorded. The line scan was not collected on the fire scar on purpose. The idea was to compare the elemental composition of the tissue grown post-fire to the pre-fire tissue.

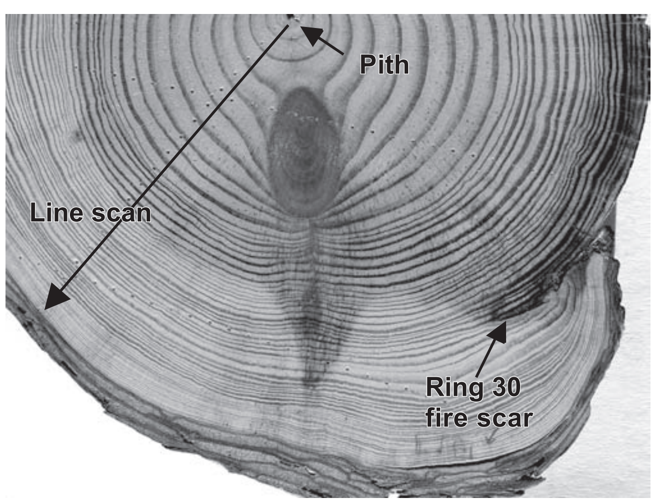

Figure 2—Cross section of the scanned sample.

Collecting spectra on the scar would have shown changes in the elemental composition due the burning process.

Figure 3 shows a spectrum collecting on the third ring (before the fire) and a spectrum collected on the 32nd ring (after the fire) along the line scan. Some differences between the elemental composition of the tissue before and after the fire can be observed. One can easily assign the emission lines of sodium at 588.98 and 589.54 nm. Two emission lines at 422.66 and 396.82 nm are also observed in the two spectra with different intensity. These signals are due to the presence of calcium in the tissue. The spectrum of the tissue after the fire has a very strong emission line at 249.3 nm. This band is assigned to iron. Although chemical differences are obvious by direct visual analysis of the two spectra, comparing the 20 spectra is impossible by the same way. Application of statistical analysis, especially principal component analysis (PCA), is very useful to examine the information available regarding the elemental composition of the tissue along the line scan. PCA was used to highlight chemical differences between the spectra.

Figure 4 is a plot of the score values of PC1 versus distance (from the pith to the bark). This plot is useful to detect a trend or patterns in the dataset. The smaller the vertical variation (i.e. the closer the score values are to each other, the more similar the samples are for the principal component one. One can clearly see that there is a very large negative score value compared to the others for the spectrum collected at 37.5 mm. In fact, this spectrum corresponds to the spectrum collected right after the fire scar on the cross section, on the ring 31. This means there is an important change in the elemental composition at this location.

The score of PC1 shows that chemical differences that result from a fire can be identified. Each score has an associated “loading” which provides information about the chemical differences between the spectra. Figure 5 shows the loading of PC1. The PCA loading is the chemical features that define the differences between spectra seen in the PCA score plot. Several emission lines are responsible of the clustering such as Na at 588.98 nm, S at 551.54 nm, Ca at 430.66 nm and Fe at 249.54 nm. These results show the effect of a fire on the elemental composition of wood tissue. By monitoring the elemental composition pattern of a tree and by looking for abrupt changes, one can reconstruct the disturbance history of a tree and a forest.

CONCLUSIONS

This preliminary data indicate that we can detect the ecological fire event in trees, even in the absence of fire scars. The next part of our research will be to attempt multivariate analysis on the data that we have

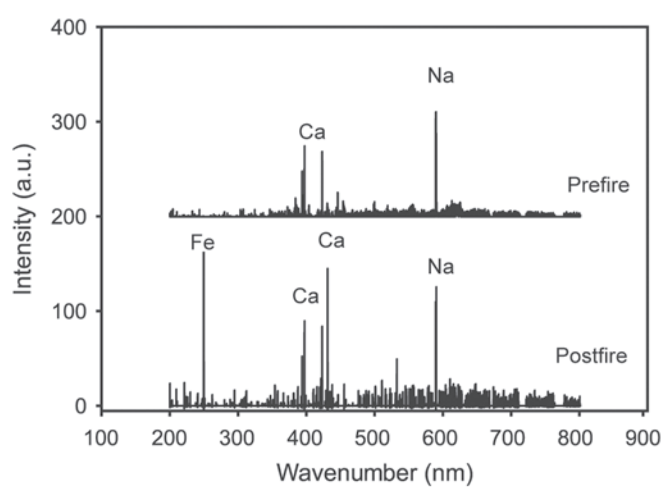

Figure 3—Spectra collected on the third ring (prefire) and on the 32nd ring (postfire) along the line scan.

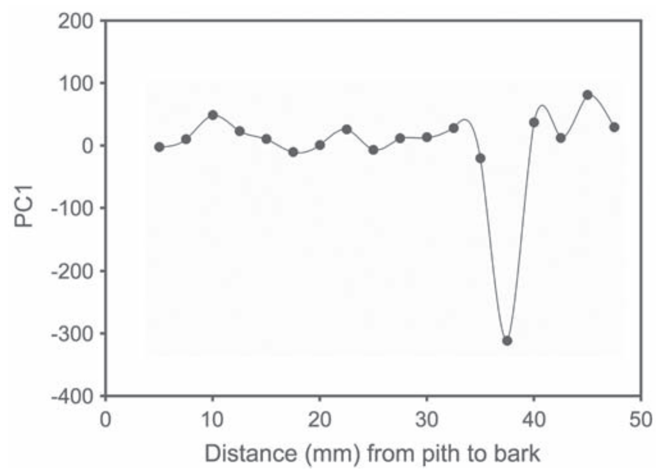

Figure 4—Plot of the score values of PC1 versus distance (from the pith to the bark).

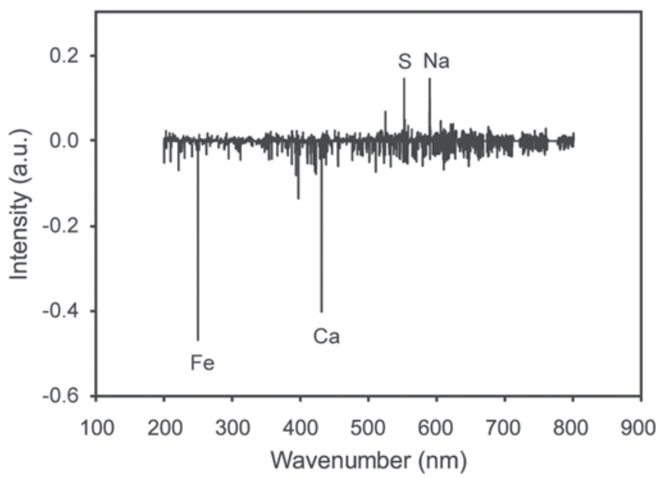

Figure 5—Plot of the loadings of PC1.

obtained and also successful completion of LIBS data acquisition on more fire scarred wood cores to make a statistical viable correlation. In the near future we would like to scan the core from the "bottom to the top": before and after the fire without the effect of the ring number (age of the tree). This makes it possible to date tree rings and to correlate the properties of the annual growth rings with external parameters such as fire events or other environmentally related events.

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PLANT COMPOSITION IN OAK SAVANNA AND WOODLAND RESTORATION AT PRAIRIE FORK CONSERVATION AREA IN MISSOURI

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Abstract—The wooded areas of the Prairie Fork Conservation Area in central Missouri are typical of the oak/hickory forest/prairie transition zone that will require active management to restore pre-settlement, grass dominated savannas and open woodlands to improve habitat for wildlife. We initiated a management program to restore savannas and woodlands by reducing the midstory (understory) canopy and invasive species using prescribed burns, mechanical removal, and herbicide applications. Two years after removal of the midstory and several invasive shrub species, canopy coverage remains over 90 percent; however, reductions in litter and enhanced light penetration into the understory have improved native plant diversity and density. Permanent plots are inventoried annually for reemergence of native species, especially for indicator species of savannas and woodlands. More than 150 native plant species including 27 tree species were identified in fall 2004 and spring 2005. The largest changes in diversity have occurred with the native early-successional woodland forbs, cool-season grasses, and sedges.

INTRODUCTION

Post-European settlement land management practices including crop production and grazing, the elimination of fire, and the introduction of invasive species have eliminated or severely degraded many of the pre-settlement plant communities within the prairie and oak savanna/woodland plant communities (Smith 2001, Nigh and Shroeder 2002, Smith 2004). Based on remnants found throughout Missouri, savannas and woodland communities are high in plant diversity with most of their richness present in the ground cover herbaceous layer. For example, in Bennett Spring State Park there are 342 native plants, of which 20 are sedges, 41 grasses, and 243 are forbs (McCarty 1993, Nelson 2005). Other studies show that savannas can provide habitat to more than 40 bird species, 20 mammals, and a large number of insects (Leahy 2000). In 2000, there were reported approximately 9000 acres of remnant high quality savannas and woodlands in Missouri with the potential for 800,000 additional acres with degraded stands that could be restored with special management (Leahy 2000).

Prairie Fork Conservation Area is located in both the Glaciated Plains and the Ozark Border Divisions and has adequate conditions for prairie, savanna, or woodlands management. Characteristically this landscape consisted of upland prairies and savannas transected by wooded draws along drainages and streams. Packard (1997) define savannas as fire-maintained natural communities dominated by grasses and/or sedges and scattered fire-tolerant tree species with a 20 to 30 percent canopy cover. He defines woodlands as fire-maintained communities with grass-dominated understory and tree canopy coverage of 30 to 80 percent. Subsequently, Nelson (2005) divided woodland natural communities into 18 separate communities and savannas into six separate communities. Nelson defines woodlands as plant communities with patchy to dense ground cover with up to 300 hundred plant species observed throughout the growing season. The tree canopy coverage can be between 30 to 100 percent for woodlands and less than 30 percent for savanna.

There is considerable interest in restoring or reconstructing quality savannas and woodlands dominated by native plant species to increase plant diversity and improve wildlife habitat using prescribed burns (Shirley 1994, Packard and Mutel 1997). In Missouri, species richness of savanna and woodland plant communities remnants have been reduced greatly due to the lack of natural fires and the presence of aggressive native and non-native species (Packard and Ross 1997, McCarty 1998). Restorations may require more than

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re-introduction of fires. For example, repeated prescribed burning for four years did not affect species richness of the understory in lowland or upland woodlands at Dinsmore Woods State Nature Preserve in Kentucky (Luken and Shea 2000). Abrams (2005) suggests that increases in mesic species such as maples and black cherry in the understory produce leaf litter less flammable than oak litter reducing the intensity and benefits of fire on the ground cover. In some cases, we need to determine the effects of frequent fires on rare plants before implementing restoration activities (Owens and Brown 2005).

Donated in 1997 by Pat and Ted Jones, Prairie Fork Conservation Area was established by the Missouri Department of Conservation to facilitate hands-on conservation, education, and research. This area is representative of many farms situated within the transitional Ozark Border Natural Division (Nigh and Shroeder 2002). The uplands were historically covered by prairie grasses and wildflowers, while the moist stream corridors were dominated by trees and shrubs. The transition between these two ecotypes was eastern hardwoods and savanna. This 450 ha area was farmed including grazing of the woodlands for more than a century until the end of the Civil War. Although various conservation measures were initiated to control soil erosion, the woodlands within the draws and riparian zone were left largely unmanaged following the removal of livestock.

Among other objectives (Missouri Department of Conservation 1998) the current management plan calls for improving wildlife habitat through restoration or rebuilding of native prairie and savanna and grass-dominated woodlands adjacent to the creeks and intermittent streams. The goals are to restore the pre-settlement prairie/savanna ecosystem, increase native plant diversity, and provide suitable habitat for wildlife dependent on high quality savanna and woodlands such as the bell's vireo (*Vireo bellii* Audubon), loggerhead shrike (*Lanius ludovicianus* L.) and ruffed grouse (*Bonasa unbellus* L.) (Gough and others 1998). The objective of this paper is to describe the early changes in plant composition within two savanna and two woodland restorations at the Prairie Fork Conservation Area following reintroduction of fire and other treatments to remove invasive non-native and pre-climax woody species.

MATERIALS AND METHODS

Prairie Fork Conservation Area is located in eastern Callaway County, southwest of Williamsburg, MO. In 2004 we surveyed the overgrown woods populating the uplands and bottomlands for remnant native plant populations. We identified two 1-ha mid-slope areas for savanna restoration and two 1-ha areas adjacent to intermittent creeks for woodland restoration. In this paper we will refer to bottomland-woodland plant communities as woodlands and upland-woodland plant communities as savannas. Corners are delimited with fiberglass poles and GPS located. Each area was divided into six 0.167 ha rectangular plots each divided into three 0.056 ha subplots (north, center, and south). The center of a 0.03 ha circular sampling plot randomly located within each subplot also was marked with a fiberglass pole. Using a 10-factor prism to determine basal area, trees with greater than 12-cm diameter-at-breast height were identified as to species and stem diameter in fall 2004 and spring 2005. Canopy coverage in each cardinal direction around each plot center was determined with a concave densitometer or solar pathfinder in spring 2004 and spring 2005.

Within each tree sampling plot, a 0.003 ha permanent sampling plot was established to inventory understory vegetation less than 12 cm dbh as to species in fall 2004 and spring 2005. Plant taxonomy for the monocots is according to Yatskievych (1999) and for the dicots is according to Steyermark (1965) (see appendix for list of all plants identified by taxa and common name). Circular 0.25 m^2 vegetation or ground cover sample plots were marked 2.5 m east and west of the center of each regeneration plot. One of each pair of vegetation plots was inventoried in fall 2004 and spring 2005 as to plant species and stem number using procedures described by Masters (1997). In addition, plot coverage as to percent of surface as bareground, litter, or vegetation was estimated.

In fall 2003, invasive introduced amur and Morrow's bush honeysuckles and autumn and Russian olive with stems greater than 2.5 cm inside and within 10 m of each plot were cut and stumps treated with 1:1 glyphosate:water solution. These species, especially the bush honeysuckles, were most abundant in the woodland closest to the original homestead. In spring 2004, firebreaks were cut along the perimeter and plots burned to reduce the heavy litter layer and cover of shrubs and brambles. In addition, seedlings of these invasive species were spot sprayed with glyphosate prior to emergence of most native vegetation. In summer 2004 to further open the midstory canopy, many pioneer tree species that included most of the red cedar, green ash, white ash, sugar maple, and honeylocust were also girdled and herbicide-treated. Plots were burned again in spring 2005 and emergent bush honeysuckles were spot sprayed with glyphosate.

Data from 0.03 ha tree sampling plots were used to determine average canopy coverage and individual tree data tallied to determine number of stems and basal area by species. Importance value was calculated as sum of relative frequency, relative density, and relative dominance (Cox 1967, Chester and others 1995). Data from 0.003 ha regeneration plots and 0.25 m^2 vegetation plots were summarized by species for occurrence and number of stems. For these plots, importance values were calculated at the sum of the relative frequency and relative density.

RESULTS AND DISCUSSION

Twenty-seven native tree species were identified in fall 2004 and spring 2005 (appendix). Based on average importance value, the more prominent tree species in the woodlands were shagbark and mockernut hickories and swamp white oak followed by green ash, shingle and red oak (table 1). For the savanna plots, hickories were also the most abundant followed by green ash, shingle oak, and swamp white oak. Importance value of early successional tree species including red cedar, green and white ash, elms, sugar maple, and honey locust is lower in 2005 than in 2004 due to mechanical removal and girdling to reduce the midstory layer.

Vegetation, litter and bareground coverage changed two years after removing invasive shrubs and conducting prescribed burns in spring 2004 and spring 2005 (table 2). Pre-treatment tree canopy cover was 94 percent in 2003 and has decreased to 91 percent. Vegetation cover was increased in both woodlands and savannas while bareground decreased. Litter increased in woodlands and was reduced in savanna plots. We assume that litter was not reduced in woodlands because litter was too wet and brambles were still occupying parts of the midstory. Abrams (2005) reports that an increase in understory mesic species such as maples and black cherry produces leaf litter less flammable than leaf litter of oak/hickory dominated forest.

More than 150 native plant species were found in the understory and ground cover (table 3). We identified nine introduced plant species in both woodlands and savannas in fall 2004 and spring 2005 (appendix). Only 75 native species were identified within randomly located sampling areas. Some areas have been freed of leaf litter allowing non-competitive ephemerals such as Virginia bluebells, putty root orchid, adder's tongue, and Dutchman's breeches to grow. Seven taxa, including coralweed, white snakeroot, black snakeroot, wild licorice, nodding fescue, white grass, and clumped sedges were present in all plots and were abundant throughout (table 3). Of the more conservative species indicative of woodland and savanna plant communities, we found beak grass, bell flower, green dragon, hog peanut, mayapple, nodding tick-trefoil, Ohio horsemint, putty root and ragged orchids, wild geranium, four-leaf and purple milkweeds, rattlesnake fern, rosy sedge, and starry campion. The identification of these species has helped us determine what kind of plant communities we had in these areas.

Based on the dominant tree species and composition of the herbaceous layer, the restorations at the Prairie Fork Conservation Area are typical of dry-mesic loess/glacial till woodland (Nelson 2005). However, these plots also have characteristics typical of other woodland plant community such as dry-mesic bottomland woodland.

The document *Key to Restoration Options* (Packard and Mutel 1997) and restoration techniques recommended by the Missouri Department of Natural Resources, Missouri Department of Conservation, and USDA Forest Service are being used as tools to help in management decisions. Some of the techniques recommended include physical removal, tree girdling, prescribed burns, herbicide applications,

Table 1—Importance value[a] for tree species in 2004 and 2005 at Prairie Fork Conservation Area

	Woodlands		Savannas	
Tree taxa	2004	2005	2004	2005
Carya spp.	97	100	76	57
Quercus bicolor	65	83	25	26
Fraxinus pennsylvanica	28	32	50	44
Q. imbricaria	31	32	52	70
Q. rubra	3	9	14	45
Juniperus virginiana	17	2	32	0
Ulmus americana	14	5	13	3
Q. shumardii	7	9	4	12
Q. macrocarpa	0	11	8	11
F. americana	0	3	0	15
Gleditsia triacanthos	6	0	7	3
Q. marilandica	1	3	6	0
Acer saccharum	10	0	0	0
U. rubra	1	2	0	7
Celtis occidentalis	1	0	4	3
Morus rubra	1	4	1	0
Prunus serotina	5	0	1	2
Platanus occidentalis	3	0	2	1
Cercis canadensis	3	1	2	0
Q. stellata	3	1	0	0
Q. alba	3	1	0	0
Juglans nigra	1	3	0	0
Diospyros virginiana	0	0	1	1
Viburnum prunifolium	0	0	1	0
Ostrya virginiana	0	0	1	0
Carpinus caroliniana	0	0	1	0

[a] Importance value 300 is the sum of relative dominance of trees with d.b.h. 12 cm or larger, relative frequency and relative density. Each value is the average of two savanna or two woodland plots.

Table 2—Percent ground cover in 2004 and 2005 on savanna and woodland restoration plots at Prairie Fork Conservation Area

	Woodlands		Savannas	
Ground cover	2004	2005	2004	2005
Vegetation	32	48	21	41
Bareground	47	18	24	21
Litter	21	34	55	38

Table 3—Understory and ground cover vegetation in 2004 and 2005 with importance value[a] > 1 for savanna and woodland restoration plots at Prairie Fork Conservation Area[b]

Tree taxa	Savannas 2004	Savannas 2005	Woodlands 2004	Woodlands 2005	Tree taxa	Savannas 2004	Savannas 2005	Woodlands 2004	Woodlands 2005
Agrimonia parviflora	1	1	2	1	*Juniperus virginiana*	1	1	2	0
Allium spp.	0	2	0	1	*Lactuca* spp.	0	1	0	1
Amphicaerpa bracteata	8	9	1	4	*Leersia virginica*	10	22	8	24
Aplectrum hyemale	0	0	0	1	*Lonicera mackii*	1	1	1	2
Arisaema dracontium	0	0	0	1	*Menispermum canadense*	0	3	0	0
Aristolochia serpentaria	0	0	3	0	*Monarda fistulosa*	0	0	0	1
Aster anomalous	0	1	3	3	*Oxalis* spp.	3	3	2	1
Boehmeria cylindrica	9	5	0	2	*Panicum clandestinum*	0	3	0	1
Botrychium virginianum	0	0	0	1	*Parthenocissus quinquefolia*	6	5	3	5
Carex spp.	23	16	17	17	*Phlox divaricata*	0	1	0	0
Carya spp.	2	1	0	1	*Platanthera lacera*	0	1	0	0
Celastrus scandens	1	0	0	0	*Polygomum scandens*	2	0	0	0
Celtis occidentalis	1	0	1	0	*Polygonum* spp.	3	8	0	1
Cercis canadensis	2	0	0	1	*Polygonum virginianum*	3	2	0	1
Claytonia virginica	0	1	0	0	*Polystichum acrostichoides*	1	2	2	1
Coniza canadensis	1	0	0	0	*Prunus americana*	1	0	0	0
Cornus spp.	0	0	1	0	*Prunus serotina*	1	1	1	1
Cuscuta gronovii	1	0	0	0	*Quercus* spp.	1	1	3	1
Daucus carota	0	1	0	0	*Ranunculus abortivus*	1	1	8	3
Dioscorea villosa	0	1	0	0	*Rhus aromatica*	2	1	3	2
Elymus canadensis	1	0	0	1	*Ribes missouriense*	3	2	2	6
Elymus villosus	3	0	5	1	*Rosa multiflora*	1	1	0	5
Eupatorium altissimum	0	17	8	21	*Rubus* spp.	3	1	2	0
Eupatorium rugosum	24	6	21	16	*Ruellia humilis*	2	0	1	3
Festuca arundinaceae	0	0	2	0	*Sanicula gregaria*	10	16	32	15
Festuca subverticillata	14	10	12	3	*Sassafrass albidum*	0	0	1	4
Fraxinus pennsylvanica	1	2	2	0	*Silphium perfoliatum*	1	0	0	0
Galium aparine	11	12	2	3	*Solidago* spp.	0	0	4	0
Galium circaezans	10	8	26	15	*Strophostyles helvola*	4	0	2	1
Galium triflorum	2	1	1	1	*Symphoricarpos orbiculatus*	5	7	14	9
Geranium maculatum	1	0	3	0	*Toxicodendron radicans*	0	2	0	0
Geum canadense	16	0	0	0	*Ulmus* spp.	3	0	3	2
Gleditsia triacanthos	0	8	0	8	*Verbascum blattaria*	0	0	0	1
Glyceria striata	0	1	0	0	*Viola pubescens*	0	2	0	0
Hackelia virginiana	2	0	0	0	*Viola* spp.	3	14	4	5
Helianthus hirsutus	0	0	0	4	*Vitis* spp.	3	1	1	1

[a] Importance value 200 is the sum of relative frequency and relative density of ground cover. Each value is the average of two savanna or two woodland plots.
[b] Only tree seedlings are included in this table.

and reintroduction of extirpated species. To address the later, local seed has been obtained from shrubs, native grasses, and herbaceous plants at Prairie Fork Conservation Area, local savanna and woodland remnants, and roadsides in Callaway and surrounding counties. Herbaceous native vegetation not found during plant surveys and indicative of savanna or woodlands will be reintroduced from seed or seedlings starting in Spring 2006. Planned introductions include native cool season grasses such as river oats and manna grass, legumes such as slender and round-head lespedezas, and woody species such as paw paw, wafer ash, buttonbush, wild plum, native dogwoods and native roses.

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Appendix—List of native and introduced vegetation[a] observed in savanna and woodland restorations at Prairie Fork Conservation Area

Taxa	Common name	N/I
Acer rubrum L.	Red Maple	N
Acer saccharum Marshall	Sugar Maple	N
Agrimonia parviflora Ait.	Agrimony	N
Allium cernuun Roth	Nodding Wild Onion	N
Ambrosia bidentata Michx.	Small Ragweed	N
Amphicarpa bracteata (L.) Hook.	American Hog Peanut	N
Apios americana Medic.	Groundnut	N
Aplectrum hyemale (Muhl. Ex.Willd) Torr.	Putty Root Orchid	N
Arisaema drancronium (L.) Schott.	False Dragon	N
Aristolochia serpentaria L.	Virginia Snakeroot	N
Asclepias purpurascens L.	Purple Milkweed	N
Asclepias quadrifolia L.	Fourleaf Milkweed	N
Asclepias syriaca L. var. *kansana* (Vail) Palmer and Steyerm.	Common Milkweed	N
Aster anomalous Engelm.	Woodland Aster	N
Aster pilosus Willd.	White Heath Aster	N
Bidens polylepis Blake	Beggars's Sunflower	N
Blephilia ciliata L. Benth. f. *ciliata*	Ohio Horsemint	N
Boehmeria cylindrica (L.) Sw.	False Nettle	N
Botrychium virginianum (L.) Sw.	Rattlesnake Fern	N
Bromus pubescens Muhl. Ex Willd.	Canada Brome	N
Campanula Americana L.	Bell Flower	N
Carex gravida L.H. Bailey	Long-Awned Bracted Sedge	N
Carex hirtifolia Mack	Hairy Sedge	N
Carex normalis Mack	Intermediate Sedge	N
Carex rosea Schkuhr ex Willd.	Rosy Sedge	N
Carex shortiana Dewey	Short's Sedge	N
Carpinus caroliniana Walter	Hornbeam	N
Carya ovata (Miller) K. Koch	Shagbark Hickory	N
Carya tomentosa (Poiret) Nutt.	Mockernut Hickory	N
Cassia marilandica L.	Wild Senna	N
Celastrus scandens L.	Bittersweet	N
Celtis occidentalis L.	Hackberry	N
Cephalantus occidentalis L.	Buttonbush	N
Cercis canadensis L.	Redbud	N
Chamaecrista fasciculata (Michx.) Greene	Partridge Pea	N
Chasmanthium latifolium (Michx.) H.O. Yates	River Oats	N

continued

Appendix—List of native and introduced vegetation[a] observed in savanna and woodland restorations at Prairie Fork Conservation Area (*continued*)

Taxa	Common name	N/I
Claytonia virginica L.	Spring Beauty	N
Coniza canadensis (L.) Cronq.	Horseweed	N
Cornus L.	Dogwood	N
Cuphea viscosissima Jacq.	Waxweed	N
Cuscuta gronovii Willd. ex J.A. Schultes	Common Dodder	N
Cynoglossum virginianum L.	Wild Comfrey	N
Cystopteris protusa (Weath.) Blasdell	Lowland Fragile Fern	N
Danthonia spicata (L.) Beauv. ex Roem. & Schult	Poverty Grass	N
Daucus carota L.	Wild Carrot	I
Desmodium glutinosum (Muhl.) Wood	Round-Leaf Tick Trefoil	N
Desmodium nudiflorum (L.) DC	Nodding Tick Trefoil	N
Desmodium paniculatum (L.) DC.	Paniculated Tick Trefoil	N
Diarrhena americana P. Beauv.	American Beakgrass	N
Dioscorea villosa L.	Wild Yam	N
Diospyros virginiana L.	Persimmon	N
Elaeagnus augustifolia L.	Russian Olive	I
Eleagnus umbellata Thumb.	Autumn Olive	I
Eleagnus aungustifolia L.	Russian Olive	I
Elymus canadensis L.	Canadian Wild Rye	N
Elymus hystrix L.	Bottlebrush	N
Elymus riparius Wiegand	Streambank Wild Rye	N
Elymus villosus Muhl.	Downy Wild Rye	N
Erechtites hieracifolia (L.) Raf.	Fireweed	N
Euonymus atropurpureus Jacq.	Wahoo	N
Eupatorium altissimum L.	Tall Boneset	N
Eupatorium rugosum Houtt.	White Snakeroot	N
Eupatorium serotinum Michx.	Late Boneset	N
Festuca arundinacea Shreb.	Tall Fescue	I
Festuca pratensis Huds.	Meadow Fescue	I
Festuca subverticillata (Pers.) E. B. Alexeev	Nodding Fescue	N
Fraxinus pennsylvanica Marshall	Green Ash	N
Galactea volubilis L.	Milk Pea	N
Galium aparine L.	Cleavers	N
Galium circaezans Michx.	Wild Licorice	N
Galium triflorum Michx.	Fragrant Bedstraw	N
Geranium maculatum L.	Wild Geranium	N

continued

Appendix—List of native and introduced vegetation[a] observed in savanna and woodland restorations at Prairie Fork Conservation Area (*continued*)

Taxa	Common name	N/I
Geum canadense Jacq.	White Avens	N
Gleditsia triacanthos L.	Honey Locust	N
Glyceria striata (Lam.) Hitchc.	Fowl Manna Grass	N
Hackelia virginiana (L.) I. M. Johnston	Beggar's Lice	N
Hammamelis vernalis Sarg.	Ozark Witchhazel	N
Helianthus hirsutus Raf.	Bristly Sunflower	N
Hypericum sphatulatum (Spach) Steud.	Shrubby St. John's-wort	N
Impatients capensis Meerb.	Spotted Touch-Me-Not	N
Impatients pallida Nutt.	Yellow Flower	N
Juglans nigra L.	Black Walnut	N
Juniperus virginiana L.	Red Cedar	N
Lactuca canadensis L.	Wild Lettuce	N
Lactuca L.	Lettuce Species	N
Leersia virginica Willd.	White Grass	N
Lespedeza cuneata (Dumont)G. Don	Sericea Lespedeza	I
Lespedeza procumbens Michx.	Creeping Lespedeza	N
Lespedeza violacea (L.) Pers.	Bush Clover	N
Lobelia cardinalis L.	Cardinal Flower	N
Lonicera maackii (Rupr.) Maxim.	Amur Honeysuckle	I
Lonicera morrowii Gray	Morrow's Honeysuckle	I
Menispermum canadense L.	Moonseed	N
Mertensia virginica (L.) Pers.	Virginia Bluebells	N
Monarda fistulosa L.	Bee Balm	N
Morus rubra L.	Red Mulberry	N
Muhlenbergia sobolifera (Muhl.) Trin.	Rock Muhly	N
Osmorhiza claytonii (Michx.) Clarke	Sweet Cicely	N
Ostrya virginiana (Miller) K.Koch	Musclewood	N
Oxalis L.	Wood Sorrel	N
Panicum acuminatum Sw.	Panic Grass	N
Panicum clandestinum L.	Deer Tongue Grass	N
Panicum commutatum Schult	Panic Grass	N
Parietaria pensylvanica Muhl.	Mercury	N
Parthenocissus quinquefolia (L.) Planch.	Virginia Creeper	N
Penstemon digitalis Nutt. ex Sims	Beardtongue	N
Phacelia purshii Buckl.	Woodland Phacelia	N
Phlox divaricata L.	Wild Sweet William	N

continued

Appendix—List of native and introduced vegetation[a] observed in savanna and woodland restorations at Prairie Fork Conservation Area (*continued*)

Taxa	Common name	N/I
Physalis virginiana P. Mill.	Ground Cherry	N
Pilea pumila (L.) Gray	Clearweed	N
Plantago L.	Plantain	N
Platanthera lacera (Michx.) G. Don	Ragged Orchid	N
Platanus occidentalis L.	Sycamore	N
Poa sylvestris A. Gray	Woodland Bluegrass	N
Podophyllum peltatum L.	Mayapple	N
Polygomum scandens L.	False Buckwheat	N
Polygonum punctatum Ell.	Water Smartweed	N
Polygonum virginianum L.	Virginia Knotweed	N
Polystichum acrostichoides (Michx.) Schott	Christmas Fern	N
Prenathes alba L.	White Lettuce	N
Prunus americana Marshall	Wild Plum	N
Prunus serotina Ehrh.	Black Cherry	N
Quercus alba L.	White Oak	N
Quercus bicolor Willd.	Swamp White Oak	N
Quercus imbricaria Michaux	Shingle Oak	N
Quercus macrocarpa Michaux	Bur Oak	N
Quercus marilandica Muenchh.	Black Jack Oak	N
Quercus rubra L.	Northern Red Oak	N
Quercus shumardii Buckley	Shumard Oak	N
Quercus stellata Wangenh.	Post Oak	N
Ranunculus abortivus L.	Short-Leaf Buttercup	N
Rhus aromatica Ait.	Fragrant Sumac	N
Ribes missouriense Nutt.	Gooseberry	N
Rosa multiflora Thunb. ex Murray	Multiflora Rose	I
Rosa setigera Michx.	Wild Rose	N
Rubus flagellaris Willd.	Dewberry	N
Rubus pensilvanicus Poir	Blackberry	N
Ruellia humilis Nutt.	Wild Petunia	N
Sambucus canadensis L.	Elderberry	N
Sanicula gregaria E. Bickn.	Black Snakeroot	N
Sassafrass albidum (Nutt)Nees	Sassafras	N
Scrophularia marilandica L.	Figwort	N
Silene stellata (L.) Ait. f.	Starry Campion	N
Silphium perfoliatum L.	Cup Plant	N

continued

Appendix—List of native and introduced vegetation[a] observed in savanna and woodland restorations at Prairie Fork Conservation Area (*continued*)

Taxa	Common name	N/I
Sisyrinchium campestre E.P. Bicknell	Blue-Eyed Grass	N
Smilax tamnoides L. var. *hispida* (Muhl.)	Bristly Greenbrier	N
Solanum carolinense L.	Carolina Nightshade	N
Solidago altissima L.	Tall Goldenrod	N
Solidago nemoralis Ait.	Old-Field Goldenrod	N
Strophostyles helvola L. Ell.	Wild Bean	N
Symphoricarpos orbiculatus Moench.	Coralweed	N
Thalictrum L.	Meadow Rue	N
Teucrium canadense L.	Germander	N
Toxicodendron radicans L.	Poison Ivy	N
Tradescantia virginiana L.	Spiderwort	N
Ulmus americana L.	American Elm	N
Ulmus rubra Muhlenb.	Slippery or Red Elm	N
Urtica dioica L. var. *procera* (Muhl.)Wald.	Stinging Nettle	N
Verbascum blattaria L.	Moth Mullein	N
Verbena hastata L.	Purple Verbena	N
Verbena urticifolia L.	White Verbena	N
Vernonia Schreb.	Ironweed	N
Viburnum prunifolium L.	Blackhaw	N
Viola pubescens Ait.	Yellow Violet	N
Viola L.	Unidentified Violets	N
Viola triloba Schwein.	Three-Lobed Violet	N
Vitis L.	Wild Grapes	N
Woodsia obtusa (Spreng.) Torr.	Cliff Fern	N
Xanthium strumarium L.	Cocklebur	I

N=native; I=introduced.
[a]Plant names according to Yaskievych (1999) and Steyermark (1965).

DYNAMICS OF A BOTTOMLAND HARDWOOD-PINE STAND IN GREENE COUNTY, TENNESSEE

Matthew G. Olson and P. Daniel Cassidy[1]

Abstract—Compositional and structural data were used to interpret the past, present, and future status of a bottomland hardwood-pine woodlot in Greene County, Tennessee. The woodlot currently supports a unique assemblage of upland and lowland species. Importance values indicate that oaks (white oak [*Quercus alba* L.], southern red oak [*Quercus falcata* Michx.], and willow oak [*Quercus phellos* L.]) were the most important contributor to total species abundance; while other hardwoods (blackgum [*Nyssa sylvatica* Marsh.], elm [*Ulmus* spp.], ash [*Fraxinus* spp.], red maple [*Acer rubrum* L.], etc.) and pine (shortleaf pine [*Pinus echinata* Mill.] and Virginia pine [*Pinus virginiana* Mill.]) had substantially lower ranking. Size and age structure indicated that this woodlot is in the understory reinitiation stage and approaching the complex stage of development. The successional status suggests that this stand and, perhaps, similar woodlots will likely experience an immediate loss of some species, such as pines, and a long-term decline of other species, such as oaks, with concomitant increases in both shade tolerant species and opportunistic species, such as blackgum and elm.

INTRODUCTION

In this paper, the historical dynamics of a 20-acre bottomland woodlot is reconstructed using a combination of compositional and structural data. The goal of this research is to characterize the past and present status of this unique community as a means to predict future successional and developmental pathways. Understanding the historical dynamics of small woodlots can potentially yield relevant information for management and conservation.

SITE CHARACTERISTICS

The woodlot described in this study is located along seven springs creek near the town of Midway in Greene County, Tennessee. The study site is located in the Great Valley Physiographic Province of eastern Tennessee. The climate in this region is humid continental with a frost-free period of approximately 185 days. Average temperatures in the nearby Tri-Cities area ranges from a January mean daily low of 24.3°F to a July mean daily high of 84.8°F (National Oceanic and Atmospheric Administration 2003). Average annual precipitation is 41.3 inches. Soil underlying this woodlot is mapped as the Prader series, which is in the fine-silty, mixed, nonacid, mesic family of Typic Fluvaquents. This stand is dominated by white and red oak subgenera with an admixture of conifers and other hardwoods.

METHODS

Vegetation sampling was accomplished using 15 sets of nested fixed-area plots located systematically along transect lines during the Fall and Winter of 2002. Trees (dbh $\geq$ 1 inch) and reproduction ($\geq$ 4 inches tall and < 1 inch dbh) were recorded separately using 0.1-acre and 0.01-acre plots, respectively. Species, dbh, and crown class were recorded for trees. The census of tree reproduction consisted of seedling counts by species and is further subdivided into two size classes: small (> 4 inches tall and < 4.5 feet tall) and large (> 4.5 feet tall and < 1 inch dbh).

At each plot center, cores from six canopy trees and cross-sections from six saplings were taken for age determination. Trees representing a wide range of diameters were selected for age determination, while trying to adequately represent tree composition. Increment cores were extracted from trees at breast height using increment borers. Cross-sections from saplings were taken at ground line. All tree cores and

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seedling cross-sections were prepared using standard dendrochronological techniques (Fritts and Swetnam 1989) and aged using dissecting microscopes to innermost ring.

Tree diameter and age data were used to generate diameter-frequency and age-frequency distributions for stand structural analysis by grouping stems into 2-inch diameter and 10-year age classes, respectively. Importance values (IV) were calculated separately for overstory and understory vegetation using data collected for common tree species and species groups. IVs were calculated by summing the relative dominance (basal area), relative frequency, and relative density. Small and large reproduction was analyzed using relative density and relative frequency separately in order to facilitate comparisons between density and dispersion among species.

All aged trees were grouped according to decade of establishment for analysis of recruitment patterns. In order to improve interpretability of the recruitment data, species were separated into three groups, oaks (white oak, willow oak, and southern red oak), pines (shortleaf pine and Virginia pine), and mixed hardwoods (blackgum, elm, ash, and red maple).

This research focuses on interpreting historical and future forest development from graphs and tables depicting structure and composition at the stand-level. Two catch-all categories called miscellaneous hardwoods and miscellaneous conifers are used for uncommon species tallied. The miscellaneous hardwood group includes eastern redbud (*Cercis Canadensis* L.), pawpaw (*Asimina triloba* L.), sweetgum (*Liquidambar styraciflua* L.), sycamore (*Platanus occidentalis* L.), black cherry (*Prunus serotina* Ehrh.), and sassafras (*Sassafras albidum* Nutt.). The miscellaneous conifer group includes both eastern red cedar (*Juniperus virginiana* L.) and pine saplings.

RESULTS

Stand Structure and Composition

Both diameter-class and age-class profiles approximate the negative exponential curve (figs. 1 and 2). The curve of the diameter distribution, however, is more irregular than the age-class profile with a single peak that corresponds with the 10-inch class. There is a strong positive skew in both distributions with fairly long, flat "tails". The continuous appearance of the age distribution is an artifact of grouping trees into age classes, since the oldest tree recorded, a 193-year old blackgum, was added to the > 100 age class.

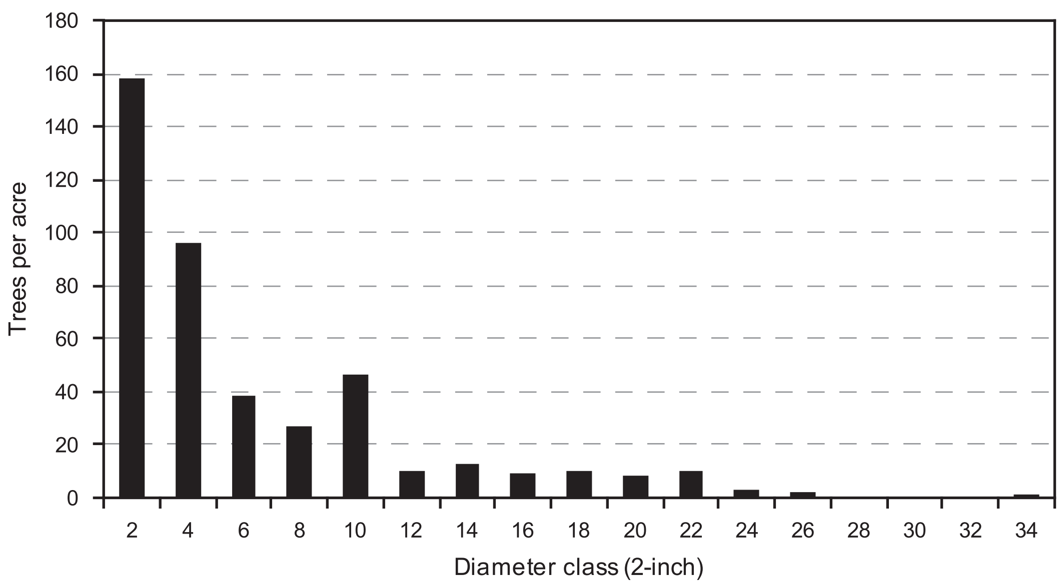

Figure 1—Diameter-class distribution of a small woodlot, Greene County, TN.

The composition of this stand, inferred from table 1, is a fairly complex mixed-species assemblage comprised of upland and lowland species. Oak currently dominates this stand. White oak (52.9 percent), southern red oak (52.4 percent), and willow oak (49.0 percent) have the highest importance values of all species. These species are followed in order of decreasing IV by: blackgum (35.0 percent), miscellaneous hardwoods (29.7 percent), elm (29.3 percent), red maple (25.7 percent), shortleaf pine (17.9 percent), and Virginia pine (8.2 percent).

Making comparisons among species using the three IV components provides insight into the position of each species within the community. The large IVs for all three oak species are not because of similar IV component values. The high IV for white oak comes primarily from a large relative frequency value of 27.7 percent; whereas, both southern red oak and willow oak have similar IV component values with the majority of their IVs coming from a large relative dominance (32.4 percent and 28.0 percent, respectively).

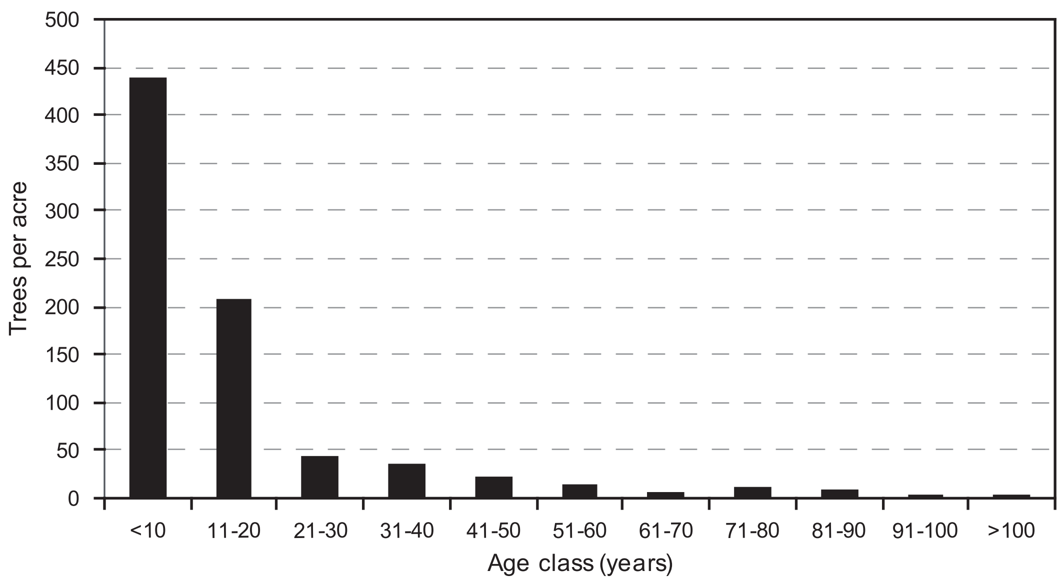

Figure 2—Age-class distribution of a small woodlot, Greene County, TN.

Table 1—Relative dominance, relative density, relative frequency, and importance values of common tree species in a small woodlot, Greene County, TN

Species/group	R-dom	R-den	R-freq	IV
Blackgum	4.2	13.0	17.8	35.0
Elm	4.5	13.0	11.8	29.3
Miscellaneous hardwoods	3.3	15.6	10.8	29.7
Red maple	4.8	10.4	10.5	25.7
Shortleaf pine	9.1	5.2	3.6	17.9
Southern red oak	32.4	13.0	7.0	52.4
Virginia pine	2.8	3.9	1.5	8.2
White oak	10.9	14.3	27.7	52.9
Willow oak	28.0	11.7	9.3	49.0

R-dom = relative dominance; R-den = relative density; R-freq = relative frequency; IV = importance values.

For the other hardwoods, relative dominance contributes little to their importance values. Separation among the remaining hardwoods, miscellaneous hardwoods, elm, and red maple, are primarily due to differences in relative density (15.6 percent, 13.0 percent, and 10.4 percent, respectively). Shortleaf pine and Virginia pine have equable relative density and frequency values. The larger IV for shortleaf pine derives from a higher relative dominance value compared to Virginia pine (9.1 percent compared to 2.8 percent).

Overstory composition by crown class is presented in table 2. In this stand, the few emergent trees are exclusively shortleaf pine. The dominant class is comprised of shortleaf pine (40 percent), southern red oak (40 percent), and willow oak (20 percent). Southern red oak and willow oak are the most abundant taxa in the codominant class comprising 37.0 percent and 35.0 percent of all stems, respectively. In order of abundance, the four most common species in the intermediate class are southern red oak (41.2 percent), willow oak (23.5 percent), shortleaf pine (12.0 percent) and Virginia pine (11.8 percent). The overtopped class is comprised exclusively of hardwoods. White oak is the leading species comprising 30.6 percent of all overtopped stems followed by blackgum (21.4 percent), elm (14.3 percent), red maple (10.2 percent), willow oak (7.1 percent), and southern red oak (2.0 percent).

The estimated abundances of small and large woody vegetation in the understory are 3,393 and 108 per acre, respectively. Red maple has the highest relative density (43.0 percent), relative frequency (20.0 percent), and IV (63.0 percent) of small woody plants in this woodlot, yet is conspicuously absent from the large-size class (table 3). The species exhibiting the greatest consistency of high relative density and frequency values across size classes is the elm group. Although all three oaks are represented in the small-size class, only white oak has made it into the large-size class (27.4 percent). The miscellaneous hardwoods and blackgum are more apparent in the large-size class than in the small-size class.

Recruitment Patterns

There is considerable overlap in recruitment times of oak age trees (fig. 3), which forms a continuous sequence of recruitment starting from 1901-1910 up to the present. Of the age trees established during 1901-1910, only southern red oak and white oak are represented. Early spikes in recruitment of southern red oak and willow oak took place in the decade of 1901-1910 and 1921-1930, respectively, while the recruitment of white oak remained at a low level with little fluctuation. This dampened fluctuation in white oak recruitment lasts until the start of the 1950s. After 1951, there were two peaks of recruitment

Table 2—Percent compositional makeup of emergent, dominant, codominant, intermediate, and overtopped crown classes for common overstory species/species groups in a small woodlot, Greene County, TN

	Canopy position				
Species/group	E	D	CD	I	OT
Blackgum	0	0	2.2	0	21.4
Elm	0	0	0	0	14.3
Red maple	0	0	2.2	5.9	10.2
Shortleaf pine	100.0	40.0	15.2	11.8	0
Southern red oak	0	40.0	37.0	41.2	2.0
Virginia pine	0	0	2.2	11.8	0
White oak	0	0	6.5	5.9	30.6
Willow oak	0	20.0	34.8	23.5	7.1

E = emergent; D = dominant; CD = codominant; I = intermediate; OT = overtopped.

Table 3—Relative density, relative frequency, and importance values of large and small tree reproduction of species/species groups common in the understory of a small woodlot, Greene County, TN

	Size class					
	Small			Large		
Species/group	R-den	R-freq	IV	R-den	R-freq	IV
Ash	5.6	7.7	13.3	0	0	0
Blackgum	3.6	9.2	12.8	28.7	20.0	48.7
Elm	23.0	15.5	38.5	21.3	20.0	41.3
Miscellaneous conifers	2.1	9.2	11.3	13.9	10.0	23.9
Miscellaneous hardwoods	3.0	13.8	16.8	28.7	30.0	58.7
Red maple	43.0	20.0	63.0	0	0	0
Southern red oak	1.1	4.6	5.7	0	0	0
White oak	3.4	9.2	12.6	7.4	20.0	27.4
Willow oak	15.2	10.8	26.0	0	0	0

R-den = relative density; R-freq = relative frequency; IV = importance values.

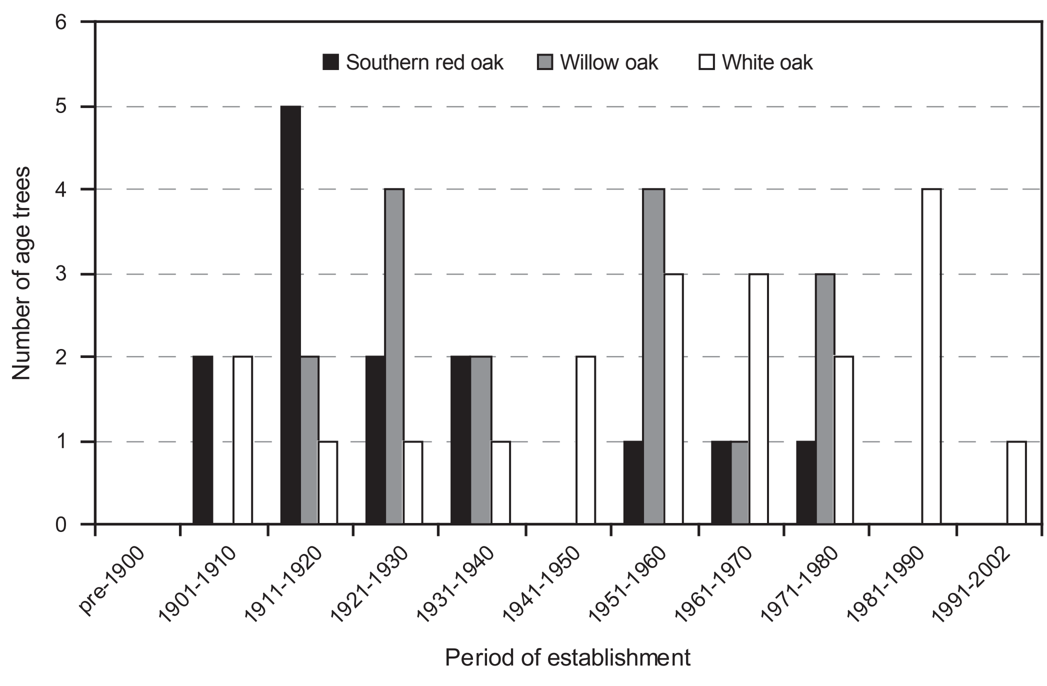

Figure 3—Recruitment pattern of oaks in a small woodlot, Greene County, TN.

in willow oak (1951-1960 and 1971-1980) and elevated recruitment in white oak from 1951-1980 and a peak during 1981-1990; however, little southern red oak establishment took place after 1930s. White oak sustained recruitment in each decade throughout the 1900s; meanwhile, the other oaks showed discontinuous recruitment with periods of zero recruitment of age trees during the decades of 1941-1950, 1981-1990, and 1991-present. Therefore, of all oak age trees, only white oak has recruited since 1980.

The time of earliest recruitment for pine age trees is pre-1900 (fig. 4); represented by a single shortleaf pine. Interestingly, the overall pattern is bimodal with pine recruitment partially segregated in time by species. The period from 1901-1940 was dominated by the recruitment of shortleaf pine with a pronounced peak during 1911-1920. The earliest decade of establishment for Virginia pine was 1921-1930. The last decade of shortleaf pine recruitment was 1931-1940; meanwhile, recruitment shifted to Virginia pine from 1941 to 1980. Pine recruitment ceased after the 1970s in this woodlot.

Aside from a single age tree recruited prior to 1900 (blackgum, 193 years), all age trees in the mixed-hardwood group initiated after 1921 (fig. 5). From 1921 and 1980, the recruitment of mixed hardwoods was equable to the establishment of oak and pine. Blackgum has shown consistent recruitment in each decade during this period, whereas, recruitment of other hardwoods, especially red maple and ash, has been more variable. After 1980, there was a substantial increase in the number of mixed hardwoods recruited. Leading this pulse in recruitment was blackgum and elm with the remaining non-oak hardwoods coming on more recently from 1991 to present. Consequently, the mixed-hardwood group has dominated recruitment since 1980.

DISCUSSION

The recruitment of a shade-intolerant group, like pine, prior to 1900 and the presence of a 193-year old blackgum are evidence that this site was partially forested during the 19th-century. Recruitment of oak started in the first decade of 1900. Oaks are generically classified as mid-tolerant and grow well in open and semi-open environments (Carvell and Tryon 1961). Historically, upland sites were cleared preferentially over the less desirable lowlands for farming (Foster and Aber 2004). Where farmland borders streams, this

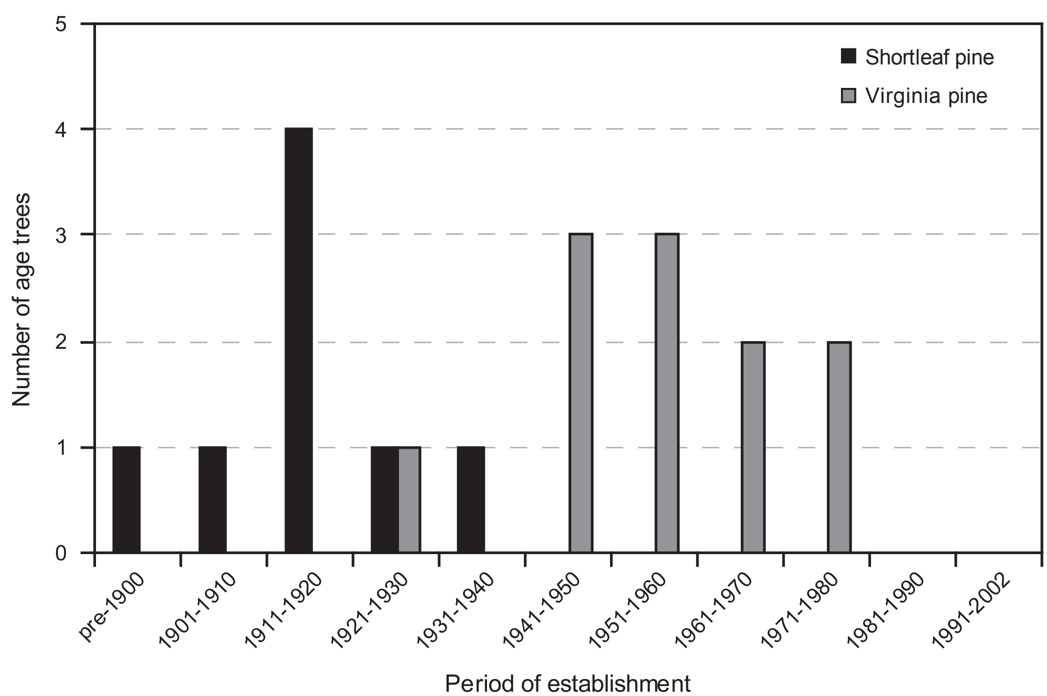

Figure 4—Recruitment pattern of pines in a small woodlot, Greene County, TN.

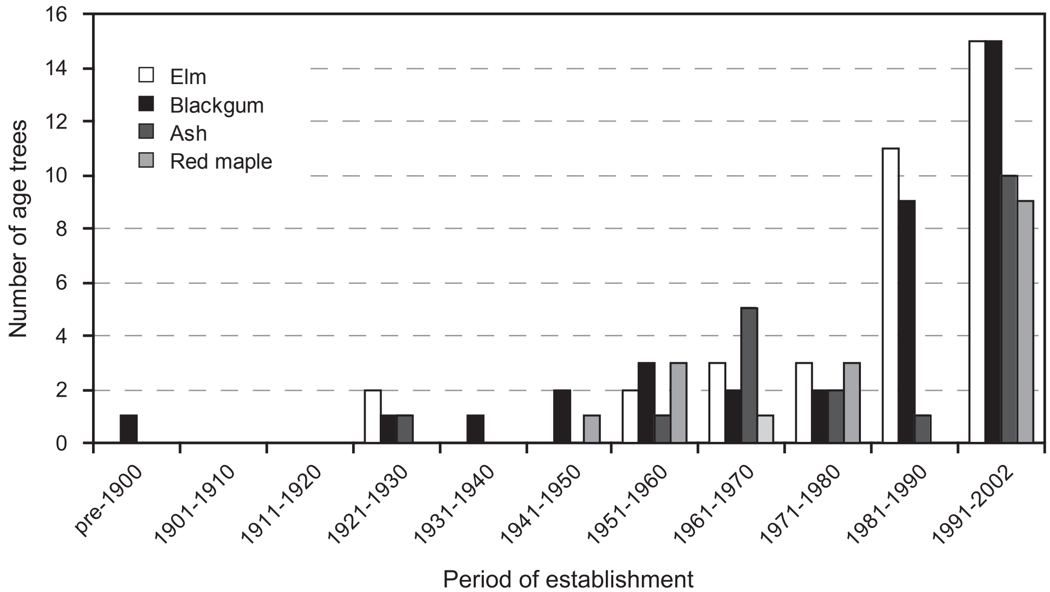

Figure 5—Recruitment pattern of mixed hardwoods (non-oak) in a small woodlot, Greene County, TN.

preference enabled forest vegetation to persist on the edges. Therefore, it is plausible that the subject stand may have remained at least partially forested as a consequence of growing on a poorly-drained site.

Woodlots were used in a number of activities (Foster and Aber 2004). Landowners could selectively fell trees from woodlots for fuelwood and timber. Wooded pasturing was common in the southern Appalachians (Nesbitt 1941). The presence of barbed wire in and around this stand suggests that this area may have been used for raising livestock (Russell 1997). Livestock often select non-oak hardwoods over pine and oak species as forage (Russell 1997), which, in addition to the presence of barbed wire, might explain the near absence of non-oak hardwood recruitment prior the 1920s. Another possibility is that this site may have been burned periodically in order to promote grass growth. The application of fire at this site would further explain the prevalence of pine and oak recruitment in the 19th- and early 20th-centuries, since both groups generally have high survivorship following surface fire (Little and Moore 1949). Additionally, a history of fire could also account for negligible establishment of non-oak hardwoods at this time, since these species are considered fire sensitive. However, without evidence of burning, the role of fire at this site is speculative.

Recruitment after 1921 suggests a change in the factors affecting tree composition. One major trend after 1921 is the shift in pine recruitment from predominately shortleaf to Virginia pine. Virginia pine reaches reproductive maturity earlier and consistently produces more seed and with greater regularity than shortleaf pine (Burns and Honkala 1990), which may give Virginia pine a recruitment advantage over shortleaf pine in terms of seed availability. A shift in recruitment from shortleaf pine to the more opportunistic Virginia pine potentially signals a change in disturbance parameters. Other remarkable trends around 1921 are rises in recruitment of elm, blackgum, and ash and early peaks in southern red oak and willow oak recruitment. One explanation for these trends is the occurrence of intermediate-scale disturbances favoring a wide diversity of tree species, as suggested by the intermediate disturbance hypothesis (Connell 1979).

Presently, the size and age structures roughly approximate a reverse J-shape indicative of a stratified, multi-aged stand. These structural patterns are typical of later stages of stand development (Oliver and Larson 1996). One interpretation is that small- to intermediate-scale disturbances have selectively removed the older and larger trees favoring the establishment of new trees. This is consistent with the structural pattern exhibited by stands at or beyond the understory reinitiation stage (Oliver and Larson 1996). Mixed-species stands exposed to relatively frequent, minor disturbances tend to develop complex structures. This is because a typical developmental pattern in mixed stands comprised of an ecologically diverse group of species is canopy stratification (Oliver and Larson 1996). Thus, perhaps another facet to the development of this woodlot is that cohorts comprised of an array of tree species were admitted in intermediate-size gaps. As gap-phase development proceeded, the canopy of these young patches would stratify along species-specific lines producing a negative exponential structure.

A mix of pine and hardwood establishment from 1900 up through 1980 is evidence for partial disturbances in this woodlot. Orwig and Abrams (1993) associated continuous recruitment of pine and hardwood species in forests of the mid-Atlantic with small- to intermediate-scale disturbances capable of simultaneously releasing hardwood advance reproduction and stimulating pine establishment. A number of sizable white oak stumps dot this stand. The high economic value of white oak makes it a target for selective felling. The selective harvesting of this species from larger size classes would create conditions favorable for regeneration. Another disturbance agent that likely played a role in the development of this woodlot is the southern pine beetle (*Dendroctonus frontalis* Zimmerman). In terms of beetle infestation, the coexistence of pine and hardwood species would tend to predispose this stand to partial canopy destruction, which appears to be the primary mode of disturbance in this woodlot over the last century. Furthermore, windthrow is a form of disturbance that selectively removes larger trees (Webb 2001) and is prevalent in small woodlots (Esseen 1994). The stronger winds associated with edge environments makes trees growing close to edges more susceptible to windthrow (Chen and others 1990). Therefore, the relatively high edge to interior ratio of forest fragments and the higher wind velocity of edge environments interact to enhance windthrow disturbance in woodlots. There are a number of moderate-sized canopy gaps in this stand supporting thick patches of sapling and pole-sized trees, which likely formed after a combination selective cutting, beetle outbreak, and windthrow events.

The main ecological trend suggested by the stand structure, species composition, and recruitment pattern of this woodlot is that canopy dominance by oak and pine is transitional and that non-oak hardwoods are the likely successors. Although white oak, southern red oak, and willow oak represent the top three species in this woodlot, total oak reproduction is sparse in the understory; meanwhile, red maple, blackgum, elm, and ash reproduction is numerous and widespread. This pattern is further reinforced by the recruitment of new trees, which has been dominated by non-oak hardwoods since the 1981-1990 decade. Despite elevated recruitment of non-oak hardwoods, a high density of pole-sized white oak suggests that the oak group will persist into the near future due to the superior longevity and moderate shade tolerance of this species. The failure of oak recruitment is a common problem in many Eastern Temperate Forest ecosystems and has been linked to the expansion of non-oak competitors (Lorimer 1994, Abrams 1992). Furthermore, the pine group, a major component in the upper canopy, has failed to recruit new trees into this woodlot since the 1971-1980 decade. Pine regeneration typically exhibits disturbance dependence and, therefore, is susceptible to failure in the absence of canopy disturbance (Frelich 2002, Abrams 2001). The future development of this stand will likely see increases in non-oak hardwoods accompanied by concurrent decreases in oak and pine if present trends continue.

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NATURAL HISTORY FROM DENDROCHRONOLOGY: MAXIMUM AGES AND CANOPY PERSISTENCE OF RARELY STUDIED HARDWOOD SPECIES

Neil Pederson, Anthony W. D'Amato, and David A. Orwig[1]

Abstract—Tree-ring research has made significant contributions to our understanding of environmental change and forest stand dynamics. Its application to understanding natural history, however, has been limited. Biodiversity of the central hardwood forest offers many opportunities for tree-ring based, natural history research. Recent tree-ring research examining several rarely studied hardwood species has yielded ages well beyond maximum expectations. For example, a sampling of 20 *Magnolia acuminata* trees in one population included two individuals 315 and 348 years, respectively, which are nearly two centuries more than the average life expectancy reported for this species. Also, research in recently discovered old-growth stands in western Massachusetts has illustrated the common occurrence of *Betula lenta* in *Tsuga canadensis* dominated old-growth forests with individuals frequently living beyond 320 years in these systems. These studies illustrate that tree-ring research can expand our knowledge of the natural history of central hardwood species.

INTRODUCTION

The science of dendrochronology (tree-ring analysis) has enhanced our understanding of environmental change, succession, and forest stand dynamics. In the eastern U.S., this type of research has been substantial and rich (i.e., Lorimer 1980, Foster 1988, Canham 1990, Runkle 1990, Stahle and Chaney 1994, Nowacki and Abrams 1997, Orwig and others 2001, Shumway and others 2001, Lafon and Speer 2002). In recent years, however, dendrochronology has been less frequently applied towards the understanding of natural history (cf. Dayton 2003). This type of natural history information may be more important now than ever before (Dayton, 2003; Schmidly 2005) as species and ecosystems are threatened by invasive species, land-use (development/urban sprawl), forest fragmentation and future climate change. The term 'natural history', unfortunately, is a rather nebulous term (Schmidly, 2005). In this paper we will focus on the application of dendrochronology towards determining a species' longevity and its persistence in the forest. We posit the idea, however, that dendrochronology can reveal many aspects of a species' life-history traits, which is an important part of its natural history.

Tree-ring studies in old-growth forests are valuable sources of information regarding the natural history of central hardwood species (cf. Rentch and others 2003a,b), as well as the natural disturbance dynamics, and development patterns for forest types throughout the region. This paper will highlight specific examples of new information concerning the natural history of four species. This information is derived from two recent dendrochronological studies in old-growth forests (Pederson 2005, D'Amato and others in review). The purpose of these studies was to identify the climatic sensitivity and growth history of several species in the eastern U.S. (Pederson 2005) and to estimate the amount of old-growth forest in Massachusetts (D'Amato and others in review). And yet, the ease at which new maximum ages were found highlights the fact that there are significant gaps in the natural history of many species characteristics of the central hardwood forest. Our hope is that this paper will stimulate additional research that will enrich our knowledge for many eastern U.S. species.

The first portion of this paper will focus on the longevity of four rarely studied temperate hardwood species: black birch (*Betula lenta* L.), cucumbertree (*Magnolia acuminata* L.), red maple (*Acer rubrum* L.), and shagbark hickory (*Carya ovata* (Mill.) K. Koch). New data and a review of maximum ages found

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in primary literature sources will be compared to illustrate how the ages found in our research are well beyond common maximum age expectations. There is currently no information available for any of these species in the International Tree-Ring Databank, a storehouse of dendrochronological information on hundreds of species worldwide (ITRDB 2005).

The second portion of this paper will focus on the natural history (recruitment, longevity and persistence) of black birch within eastern hemlock-mixed hardwood dominated old-growth forests in Massachusetts. Black birch is commonly reported in association with eastern hemlock (*Tsuga canadensis* (L.) Carr.) in old-growth forest ecosystems throughout the central hardwood and New England regions (e.g., Hough and Forbes 1943, Foster 1988); however, little is known about the natural history and dynamics of this species in old-growth forests. Data from eleven old-growth eastern hemlock-mixed hardwood forests in western Massachusetts are used to illustrate the surprising persistence of black birch as well as its overlooked importance in the structure and dynamics of old-growth eastern hemlock forests.

METHODS

Increment cores were collected and processed using standard tree-ring analysis techniques (Cook and Kairiukstis 1990). Generally, a minimum of twelve trees in a stand was cored, with one to two cores removed from each tree depending on the goals of the study (Pederson 2005, D'Amato and others in review). Twenty *M. acuminata* and twenty-one *C. ovata* trees representing the perceived range of age classes from a stand in George Washington National Forest in the Blue Ridge Mountains of central Virginia were selected for coring (Pederson 2005). Twenty *A. rubrum* trees in the eastern Catskills, NY equal to or greater than 10 cm dbh within two designated stands were randomly selected for coring (Charles Canham, 65 Sharon Turnpike, P.O. Box AB, Millbrook NY 12545-0129 & Paul Sheppard, 105-C1 West Stadium, Tucson, AZ 85721 USA personal communication). *B. lenta* outside of Massachusetts were sampled over two periods. In 1974, twelve individuals were sampled at the Mohonk Preserve in New Paltz, NY (Dr. Edward Cook, unpublished data). A second collection of 17 individuals was made at the Preserve in a different stand in 2002 (Neil Pederson, unpublished data). Finally, all trees equal to or greater than 10 cm dbh falling within 3-5 400 m^2 plots were sampled in the study examining old-growth *B. lenta* in Massachusetts (D'Amato and others in review).

Cores were glued to wooden core mounts and, in most cases, progressively sanded up to 600-grit sandpaper. *B. lenta, M. acuminata and A. rubrum* samples were often sanded using 2400 or 3200 grit sandpaper to ensure ring boundaries were visually distinct in these species with diffuse porous ring structures. Samples of *B. lenta, M. acuminata and A. rubrum* were not stained or enhanced in any way beyond sanding. Ages presented here are derived from crossdated samples. Finally, ages presented here are minimum ages; no extrapolations have been made for the number of missing rings to the center of the tree or the time it took each tree to reach coring height. Therefore, the ages presented for these trees are certainly less than their absolute age.

RESULTS AND DISCUSSION

Maximum Ages for *A. rubrum, B. lenta, M. acuminata*, and *C. ovata*

Maximum ages and comparisons for each species are summarized in table 1. Maximum age in a sample of 40 *A. rubrum* trees is 300 years. The next four oldest trees from this collection were 212, 132, 129 and 128 years old. Interestingly, this maximum age is 150 years greater than the maximum age listed for this species in Loehle (1988) and 10 years older than the oldest reported in the early Pennsylvania study by Hough and Forbes (1943). The oldest *Betula lenta* tree in a sample of 29 trees is 361 years, while the next four oldest trees were 318, 257, 169 and 166 years old. Similar to the *A. rubrum* finding, the oldest *B. lenta* in the population was far greater than the maximum age listed for this species in the current USDA Silvics manual (Burns and Honkala 1990) and Hough and Forbes (1943) (table 1). Further discussion of the age structure of *B. lenta* will be presented in the next section. The oldest *C. ovata* in a sample of 20 trees is 354 years old with the next four oldest trees in the population being 257, 255, 254 and 251 years old. The oldest individual tree is 54 years greater than the maximum age for this species listed in Loehle

Table 1—Comparison of maximum ages from the *Silvics of North America* (Burns and Honkala 1990), Hough and Forbes (1943), and recently acquired data

Species	Silvics manual[a]	Hough and Forbes	New data	Difference[b]
	- - - - - - - - - - - - - *years*		- - - - - - - - - - - - -	
Acer rubrum	150	290	300[c]	150
Betula lenta	265	265	361[d]	96
Carya ovata	300	n/a	354[e]	54
Magnolia acuminata	150	310	348[e]	198

[a] If no age is given in the Silvics manual, ages are substituted from Loehle (1988) or Hough and Forbes (1943).
[b] Difference between new maximum age data and Silvics manual, or if no age is given, Loehle (1988) or Hough and Forbes (1943).
[c] Catskill Mountains, NY.
[d] New Paltz, NY.
[e] George Washington National Forest, VA.

(1988). Finally, the oldest *M. acuminata* in a sample of 20 trees is 348 years old with the next four oldest trees in the population obtaining ages of 318, 215, 177 and 174 years old. The oldest individual tree is 198 years greater than the maximum age for this species listed in Burns and Honkala (1990) and 38 years greater than in Hough and Forbes (1943).

The frequency at which greater ages are found in our studies compared to the Silvics Manual of North America (Burns and Honkala 1990) or Loehle's (1988) list of known maximum longevity suggests that there is much yet to learn about the basic natural history of central hardwood and eastern US forests. Further, with the exception of *A. rubrum*, the proximity of the next oldest individuals in the recent studies either to the new or previous maximum age suggests that longevity in these species may be even greater than those reported here. This hypothesis is built upon the premise that maximum ages for each species has a normal distribution; a 'common' maximum age. It could be, however, that a species' maximum age could be significantly larger than what is reported if maximum age has an asymmetrical distribution or a long tail (sensu Clark and others 1998). Such a distribution could explain the 800+ year maximum age reported for eastern hemlock (*T. canadensis*) (Burns and Honkala 1990), despite the fact that a collection of more than 1000 *T. canadensis* collected from across its range has not yielded an individual greater than 600 years old (ITRDB 2005).

The similarity of the new maximum ages presented here and those ages reported in the classic study of the high plateau region of Pennsylvania by Hough and Forbes (1943) indicates that these maximum ages may represent a common maximum age. It should be noted, however, that the ages of Hough and Forbes (1943) are ring counts of stumps in the field and could be significantly off due to measurement error. Likewise, a lack of dating control might explain the extreme maximum age reported for *T. canadensis*. Crossdated samples of *A. rubrum* indicate the possibility of up to 12 missing rings per tree in extreme cases (Pederson 2005). Similarly, work on *M. Acuminata* and *B. lenta* indicates that these species can have a significant number (greater than 10) of false and missing rings (N. Pederson, unpublished data). Nonetheless, the near agreement of the Pennsylvania ages and recent studies suggest that the work of Hough and Forbes (1943) provides an excellent early estimate of the maximum ages for many of these species.

Black Birch in Old-Growth Eastern Hemlock Forests

Overall, black birch was a minor component of the old-growth stands investigated in Massachusetts, making up less than 15 percent of the overstory species composition (table 2). Within these stands, black birch was most commonly found in the intermediate and codominant crown classes and attained diameters smaller than the associated hemlock (table 2, mean hemlock diameter = 33.2 cm). Maximum ages of black birch individuals within these stands exceeded those previously reported for this species (Hough and Forbes 1943), including several individuals between 320-332 years old (table 2). In addition, only two of the eleven stands investigated did not contain at least one black birch individual greater than 210 years old (table 2).

Black birch recruitment generally occurred in episodic peaks with other species within these stands (fig. 1). These episodic recruitment patterns indicate that successful birch recruitment occurred predominantly during large disturbance events, such as the hurricane of 1893 (fig. 1). These findings are consistent with other studies that have also demonstrated the importance of moderate disturbance events in facilitating the establishment of black birch (Ward and Stephens 1996). While these recruitment events lead to an increase in the amount of black birch, the age data collected from these sites suggests that several older trees may also have became established from smaller unknown events.

Although other studies have previously reported the presence of *B. lenta* in old-growth forests (Hough and Forbes 1943, Morey 1936, Foster 1988, Orwig and others 2001), this species has traditionally been thought of as an associate of younger forest ecosystems (e.g., Stephens and Waggoner 1970, Trimble 1970). The findings from our research indicate that black birch commonly plays a prominent role in the structure and dynamics of old-growth hemlock stands attaining ages well beyond previous expectations. In the populations examined in this study, most *B. lenta* were less than 150 years old; however, 58 percent of those individuals greater than 180 years old have lived beyond 250 years illustrating the ability of this species to consistently persist within the canopy of these old-growth stands. Interestingly, *B. lenta* is often the species replacing eastern hemlock in stands infested with hemlock woolly adelgid in southern New

Table 2—Summary table for attributes of black birch populations in 11 old-growth mixed eastern hemlock stands in western Massachusetts

Study area	Importance value[a]	Age[b]	Diameter
			cm
Mt. Everett	9.4	65 (77)	18.2
Grinder Brook	5.7	175 (218)	27.3
Bash Bish Falls	2.8	172 (211)	28.3
Cold River A1	11.0	127 (251)	28.9
Cold River A2	9.0	169 (326)	30.3
Cold River B	9.0	146 (238)	32.0
Cold River D	8.6	165 (261)	21.4
Manning Brook	7.2	87 (158)	24.0
Wheeler Brook	10.4	203 (284)	27.5
Black Brook	12.5	182 (328)	30.3
Todd Mountain	6.9	163 (332)	28.4
Average	8.4	150	27.0

[a] Importance value = (relative basal area + relative density)/2.
[b] Average age with maximum found at site in parentheses.

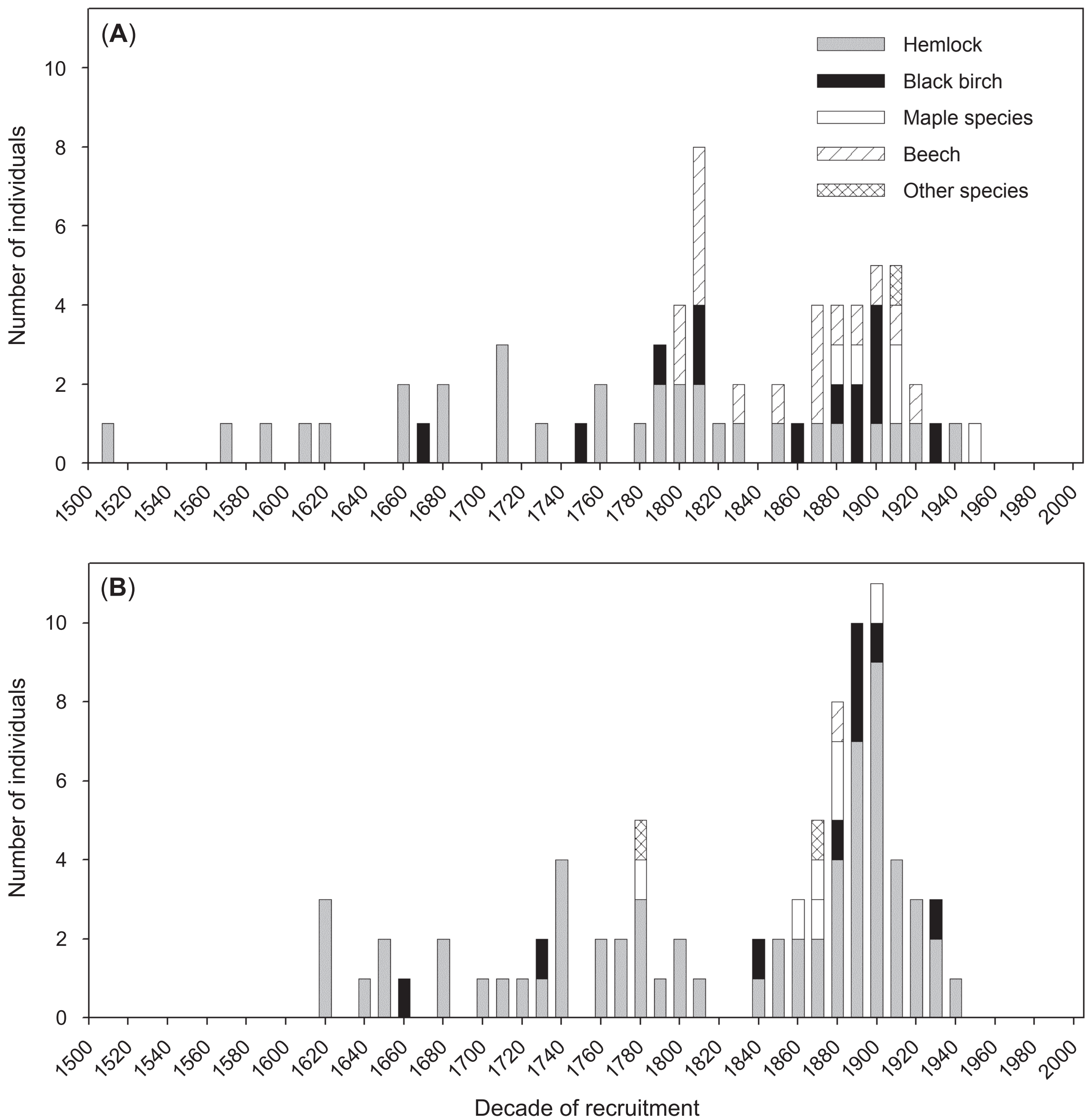

Figure 1—Example age structures from two eastern hemlock-mixed hardwood dominated old-growth forests, (A) Cold River A2 and (B) Todd Mountain, in western Massachusetts. N = 74 (13 *B.lenta*) and 88 (9 *B. lenta*) for (A) and (B), respectively.

England (Orwig and Foster 1998). In light of our findings, it is likely that *B. lenta* may persist in these affected stands longer than previously expected.

CONCLUSIONS

Data presented here suggests that rarely studied trees species can live much longer than previously thought. Our results also show how dendrochronology is an excellent tool to deepen our knowledge of the natural history of central hardwood tree species. Besides maximum age, tree-ring analysis can reveal other facets of natural history such as how long a species can remain suppressed in the understory, how they respond to disturbance events or how long they can sustain high levels of productivity. Not only will this dendrochronology-derived information help expand our knowledge of natural history, it will provide important data for simulation models to produce realistic estimations of tree longevity. Future studies of other central hardwood species will be critical for future efforts aimed at modeling long-term forest dynamics, as well as for predicting the population and system responses to the effects of environmental changes and novel disturbances such as the hemlock woolly adelgid, on future forest structure and composition (Dayton 2003; Schmidly, 2005).

The 'accidental' discovery of new maximum ages for four species typical of central hardwood forests and the surprising persistence of *B. lenta* suggests the lack of natural history knowledge for many eastern U.S. tree species. We hope this presentation emphasizes the need for more research. Such research would be an excellent avenue for inspiring motivated undergraduate and graduate-level students to incorporate the field of natural history into their studies.

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EFFECTS OF LIME, FERTILIZER, AND HERBICIDE ON HERBACEOUS SPECIES DIVERSITY AND ABUNDANCE FOLLOWING RED OAK SHELTERWOOD HARVEST

William E. Sharpe and Chad R. Voorhees[1]

Abstract—Three strongly to extremely acidic, fenced, predominately red oak (*Quercus rubra* L.), shelterwood harvest sites (17-20 ha) were studied in Pennsylvania.Two sites contained 20m x 20m plots with control (C) herbicide (H), lime and fertilizer (LF), and herbicide with lime and fertilizer (HLF) treatments and a third site had only H and HLF treatments. Fences were designed to exclude white-tailed deer (*Odocoileus virginianus*) and herbicide was applied to control hay-scented fern (*Dennstaedtia punctilobula* [Michx.] Moore). Soil was sampled in 2003 for calcium (Ca), aluminum (Al), Magnesium (Mg), Phosphorus (P), Potassium (K) and pH. Four sub-plots of 10.45 m^2 were randomly chosen within the treatments and controls and were monitored bi-weekly for herbaceous species (excluding ferns and grasses) occurrence and abundance. Numbers of stems and species diversity were influenced by soil amendments and site treatment. Hay-scented fern suppression plus lime and fertilizer application increased herbaceous species diversity and biomass following red oak shelterwood harvest on sites fenced to exclude whitetailed deer.

INTRODUCTION

Forest management is continually changing as more is being learned about anthropogenic effects on complex processes. Forest productivity, diversity and stability are key goals of current management practices. The forest soil environment is likely to be a key factor in the accomplishment of these goals. Soil chemistry is an essential determinant of forest plant composition and long-term productivity. Each plant has its own nutrient requirements that may only be met by soils of compatible chemistry.

In general, most forests are managed for the future harvest of overstory trees. Although some concern has been expressed over the degradation and recovery of herbaceous plants following timber harvest (Ford and others 2000, Meier and others 1995), typically, regeneration of species of higher value is sought with attention given to reducing understory competition by undesirable species. Herbaceous plants have also been used to indicate forest site quality (Gilliam and others 1994, Zas and Alonso 2002). Although the topic is argued, diversity may have an effect on productivity and ecological stability; furthermore, the importance of diversity associated with forest health is recognized in the reduction of pest damage and the proliferation of invasive species (Bengtsson and others 2000). Honnay and others (1999) indicated that Ca and pH were significantly and positively correlated with total numbers of plant species in ancient forests. Keersmaeker and others (2004) also found that total cover of fast-colonizing species and plant species diversity were positively correlated with soil pH. Meier and others (1995) suggested that higher pH should result in greater diversity of herbaceous plants.

In Pennsylvania, many decades of acidic deposition have resulted in soil acidification (Bailey and others 2005, Drohan and Sharpe 1997) that is relatively widespread (Lyon and Sharpe 1999). Soil acidification leads to soil infertility as a result of increased leaching of important base cations and increased availability of Al and Mn (Cronan and Grigal 1995, Driscoll and others 2001, Ljungström and Nihlgård 1995, Schottelndreier and others 2001, Tomlinson 2003). Leaching of base cations may be doubled by deposition of strong acids (McLaughlin and Wimmer 1999).

From a long-term perspective, timber harvesting may also increase acidity and leaching by removing base cations (Federer and others 1989, Hornbeck and others 1990, McLaughlin and Wimmer 1999). Likens

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and others (1970) found that Ca in stream water increased 417 percent in two years following clearcutting and regrowth suppression by herbicides. A common practice in Pennsylvania is to use sulfometuron-methyl herbicides, such as Oust®, following timber harvest to reduce hay-scented fern competition for tree seedlings. This herbicide has been reported to lower soil pH, increase plant available aluminum, and decrease soil calcium to aluminum ratios (Schreffler and Sharpe 2003).

One alternative to alleviate soil acidity is the application of high magnesium dolomitic lime. Although the addition of lime and fertilizer to combat soil acidity and relieve nutrient deficiency has long been studied in agriculture and in the forests of Europe, little research has been done in the United States. Little is known of the effects of liming at the species level in forest plants. Lime application has been shown to have wide-ranging effects on different tree species which are in part dependent upon the abundance of other elements such as nitrogen (Westling and Hultberg 1990-91). In a study done by Ljungström and Nihlgård (1995) the addition of dolomitic lime was shown to increase foliar Ca by 20-50 percent and Mg by 1.5 to 2 times. In that study, lime additions also reduced foliar Al and Mn. Ljungström and Nihlgård (1995) concluded that additions of two tons/ha of dolomitic lime would be sufficient to amend low soil Ca/Al ratios. In trees with Mg deficiency, fertilizers containing Mg increased growth and vigor when pH was also stabilized (Frank and Stuanes 2003). Demchik and Sharpe (2001) reported increased numbers of forest floor plants following lime and fertilizer addition and partial cutting of a predominately red oak stand.

The intent of this study was to look at the affects of herbicide, lime and fertilizer (inside deer exclosures) on the species composition and above ground biomass of herbaceous understory following a northern red oak shelterwood harvest at three sites in southwestern Pennsylvania.

Materials and Methods

Three similar shelterwood harvest sites (17-20 ha) (Beam Run, Hickory Flats and Mt. Davis) were chosen in Somerset County, southwestern Pennsylvania on the Forbes State Forest. The soils at the sites were either Hazelton or Hazelton-Dekalb (*Typic dystrochrepts*), extremely to strongly acidic, stony, sandy loams (Schreffler and Sharpe 2003). Mt. Davis and Hickory Flats were harvested in 1998 and Beam Run was harvested in 1999, leaving residual basal areas of 4.9 m^2 - 11.1 m^2/ha. Fourteen-gauge wire mesh deer exclusion fencing was erected to reduce the impact of white-tailed deer (*Odocoileus virginianus*). Fencing was installed at Mt. Davis in 1998, Hickory Flats in 1999 and at Beam Run in 2001. Within the fenced shelterwood cuts, four adjacent 20m x 20m plots were established at Mt. Davis and Beam Run and two at Hickory Flats. Plot treatments were: herbicide (Oust®) only (H), lime and fertilizer only (LF), herbicide, lime and fertilizer (HLF) and a control (C) with no herbicide, lime or fertilizer at Mt. Davis and Beam Run. At Hickory Flats only an H and a HLF plot were established, because the entire area was herbicided prior to the study. Lime used was high magnesium pulverized limestone and fertilizer was 10-20-20 NPK Agri-Gro. Lime and fertilizer were broadcast by means of a tractor fitted with a hopper/spreader or by hand at a rate of 3360 kg/ha while fertilizer was applied at a rate of 1120 kg/ha. Oust® was applied at a rate of 0.11 kg/ha. Lime, fertilizer and herbicide treatments were accomplished in the summer of 1999.

Four sub-plots of 10.45 m^2 were randomly established on each plot and were checked bi-weekly during summer for herbaceous (excluding ferns and grasses) species occurrence and abundance (number) during 2002 and 2003. Species diversity was calculated using the Shannon-Weaver Diversity Index. Different 20m by 2m transects were also examined bi-weekly within each treatment at each site in order to determine species composition of the 20x20m plots. Ferns were not included in our analyses because of the herbicide treatment and grasses were only a significant cover type on the control at Mt. Davis. In 2004, three sub-plots on each treatment were harvested for above ground biomass. All herbaceous and woody vegetation was bagged and oven dried (105°C for two weeks) then weighed (Extech Instruments; hanging scale #160393, Forestry Suppliers) to the nearest ounce.

Identification and scientific names were derived from “The Plants of Pennsylvania” (Rhoads and Block 2000) and “Gray’s Manual of Botany” (Fernald 1987). Most identifications were verified by Rex Melton, Emeritus Professor of Forestry, Pennsylvania State University. Normality was measured using the Anderson-Darling test in Minitab 13 (2000). Mean Shannon-Weaver index and mean number of species were compared using the two-sample T-test in Minitab 13 (2000) and median biomass differences were evaluated with Mann-Whitney tests for nonparametric statistics.

RESULTS

For a summary of soil and soil solution chemistry and woody regeneration results following treatment, the reader is referred to Schreffler and Sharpe (2003). In summary, median 0 horizon pH, and exchangeable Ca and Mg were significantly higher on limed and fertilized plots, while pH was significantly lower on the herbicide plots (table 1).

The deer exclusion fencing was not effective in totally eliminating deer from the study plots. Deer were confirmed to be present inside the fences at the Beam Run and Mount Davis sites during the course of this study. Confirmation was by visual sighting, tracks and evidence of browsing.

There was a total of 50 different herbaceous species present on the transects for all three sites for all treatments when both years were combined (table 2). The HLF plots contained 47 of the total species present while the controls and H treatments had only 14 total species present each. The most abundant species at the three sites were sessile-leaved bellwort (*Uvularia sessilifolia*), common blackberry (*Rubus allegheniensis*), star flower (*Trientalis borealis*) and Canada mayflower (*Maianthemum canadense*), which were present on all treatments and the controls.

For the years 2002 and 2003, the highest number of species found on the sub-plots was for the HLF treatment with 9 and 21 species, respectively. The number of species found on all sub-plots was considerably higher in 2003 than in 2002 possibly owing to greater dissolution of the applied lime.

For the years 2002 and 2003 combined, a total of 24 different species occurred on the HLF sub-plots. The next highest number of species was for the LF sub-plots with 15 total species. The herbicide treatment sub-plots had 12 total species while the control sub-plots had only 9 total species. The mean number of species on the subplots was not significantly different between treatments in 2002 or 2003 with 3.2, 3.8, 3.4 and 4.5 species for the control, LF, H and HLF treatments, respectively. The mean number of herbaceous stems was significantly different between the control and HLF treatments in 2002 ($\alpha \leq 0.1$)

Table 1—Soil parameters between treatments by horizon

Parameter	C	LF	H	HLF
pH O-horizon	4.05a	5.20b	3.9a	5.20b
pH A-horizon	4.00a	4.15a	3.7b	4.10a
		- - - - - - - - *meq/100g*	- - - - - - - -	
Ca O-horizon	6.35a	26.25b	8.0a	20.70c
Ca A-horizon	0.60a	2.10b	0.6a	1.60b
Mg O-horizon	1.00a	11.05b	1.6a	6.30b
Mg A-horizon	0.20a	1.15b	0.3a	0.70b

C = control; LF = lime and fertilizer; H = herbicide only; HLF = herbicide, lime and fertilizer; Ca = calcium; Mg = magnesium.
Different letters within rows indicate significant differences between treatments at $\alpha \leq 0.05$.

Table 2—Species by treatment

Species	Treatment C	LF	H	HLF
Anaphalis margaritacea (L.) Benth. & Hook	0	0	0	1
Anemone quinquefolia (L.)	0	0	1*	1*
Aralia nudicaulis (L.)	0	0	0	1*
Asclepias syriaca (L.)	0	0	0	1
Aster divaricatus (L.)	1	1*	1*	1*
A. lateriflorus (L.) Britton.	0	0	0	1
A. pilosus (Willd.)	0	1	0	1
Baptisia tinctoria (L.) Vent.	0	0	0	1
Chrysanthemum leucanthemum (L.)	0	0	0	1*
Chrysopsis mariana (L.) Elliot.	0	0	0	1
Cirsium arvense (L.) Scop.	0	0	0	1
C. vulgare (Savi) Ten.	0	1	0	1
Corydalis sempervirens (L.) Pers.	0	0	0	1*
Crepis capillaris (L.) Wallr.	0	1	0	1*
Dianthus armeria (L.)	0	0	0	1
Dioscorea villosa (L.)	1*	1*	1*	1*
Epilobium glandulosum (Lehm)	0	0	0	1
Erechtites hieracifolia (L.) Raf. Ex DC.	1	1*	1*	1*
Erigeron annuus (L.) Pers.	0	1*	0	1
Eupatorium perfoliatum (L.)	0	1	0	0
E. rugosum (Houtte.)	1	1*	1*	1*
Galium concinnum (Torr. & A. Gray)	0	0	0	1
Gnaphalium obtusifolium (L.)	0	1	0	1*
G. ulginosum (L.)	0	0	0	1
Hieracium caespitosum (Dumort)	0	0	0	1*
Hypochoeris radicata (L.)	0	0	0	1
Lobelia inflata (L.)	0	0	0	1*
L. spicata (Lam.)	0	1	0	1
Lysimachia quadrifolia (L.)	1	1	0	1
Maianthemum canadense (Desf.)	1*	1*	1*	1*
Panax trifolius (L.)	0	1*	1*	1*
Phytolacca americana (L.)	1*	0	0	1
Plantago lanceolata (L.)	0	0	0	1
Polygonum caespitosum (Blume)	0	1	0	0
P. scandens (L.)	0	0	0	1*
*Rubus allegheniensis (*Porter)	1*	1*	1*	1*
R. hispidus (L.)	1	0	0	0
Rumex acetosella (L.)	0	0	0	1
Senecio vulgaris (L.)	0	0	0	1
Solidago graminifolia (L.) Salisb.	0	1*	0	1*
S. rugosa (Mill.)	0	1*	1*	1*
Stellaria graminea (L.)	0	0	0	1
Taraxacum officinale (Weber)	0	1	0	1*
Trientalis borealis (Raf.)	1*	1*	1*	1*
Trillium undulatum (Willd.)	1*	0	1	1*
Uvularia sessilifolia (L.)	1*	1*	1*	1*
Viola hastata (Michx.)	1*	1*	1*	1*
V. pallens (Banks)	0	1*	0	1*
V. sororia (Willd.)	0	1	0	1

C = control; LF = lime and fertilizer; H = herbicide only; HLF = herbicide, lime and fertilizer; 0 = not present; 1 = within treatment; * = on subplots.

and in 2003 ($\alpha \leq 0.05$). The mean Shannon-Weaver diversity index was highest for the HLF treatment (fig. 1), and the HLF Shannon-Weaver index was significantly different from the control in 2002 and 2003.

Median above ground biomass was highest on the HLF treatments (fig. 2), and the between treatment differences were significant ($\alpha \leq 0.1$) for H and HLF when compared to the control. The LF treatment was not significantly different from the other treatments.

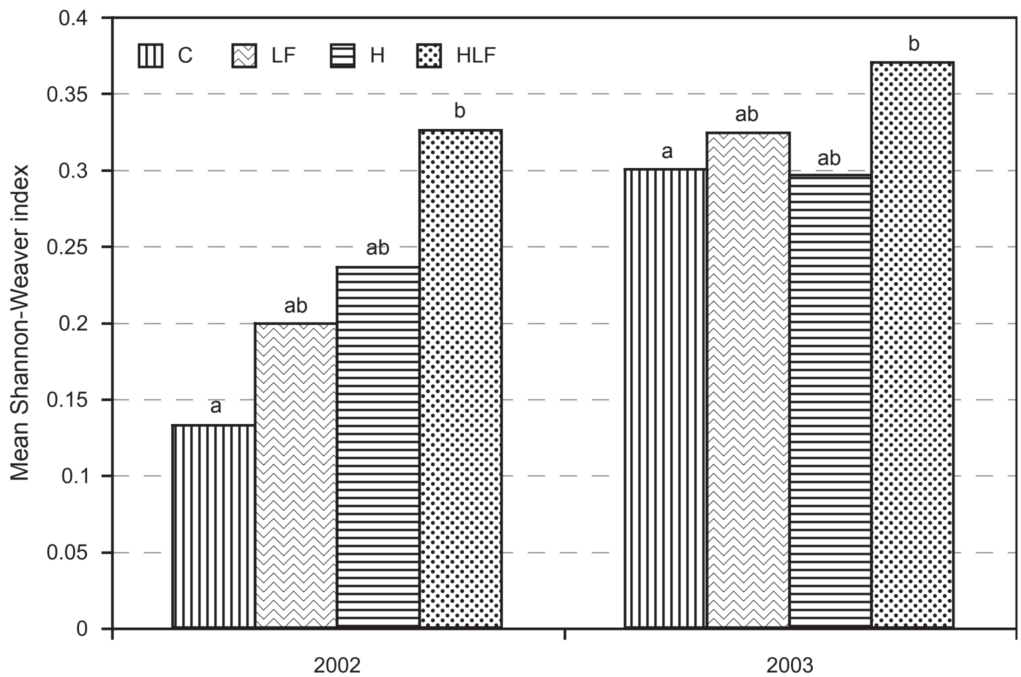

Figure 1—Mean Shannon-Weaver Diversity Index for 2002 and 2003. All sites combined. Letters denote statistical difference between treatments for that year.

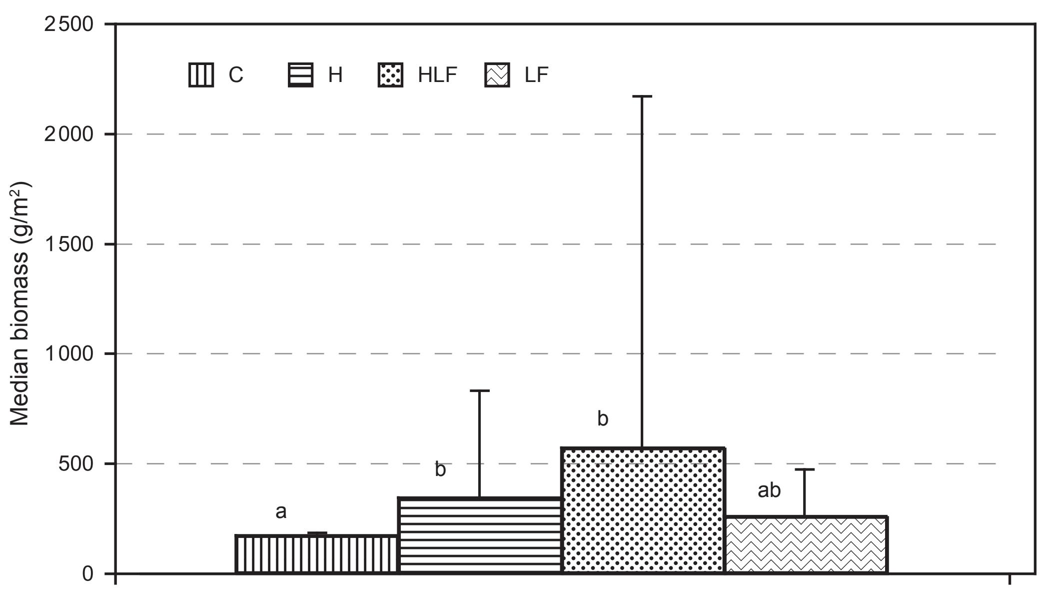

Figure 2—Median biomass (2004) estimates for the different treatments. Different letters above bars indicate significant differences at a <0.1.

DISCUSSION

We hypothesized that treatments of herbicide, lime and fertilizer would result in increased Ca and Mg content and pH of soils on treated plots and increased diversity and abundance of forest floor and understory plants. Soil chemistry was affected by amendments of herbicide, lime and fertilizer. Median Ca and Mg concentrations in soil were highest, as expected, in the treatments that received lime and fertilizer (LF and HLF). Herbicide, in conjunction with lime and fertilizer appeared to increase herbaceous diversity and above ground biomass. Schreffler and Sharpe (2003) also reported improved woody regeneration on the HLF treatment plots. Huebner and others (1995) found a positive relationship among tree seedling diversity and overall understory diversity and maintained that it was likely a response to resource availability.

English plantain (*Plantago lanceolata*), was reported to occur with higher frequency on sites with higher pH and higher soil nutrient levels (Zas and Alonso 2002) and it occurred only on the HLF treatments in this study (table 2). Many other species only occurred on either the LF or HLF treatments (table 2).

Herbicide alone or in conjunction with lime and fertilizer resulted in increases in above ground plant biomass. Use of lime and fertilizer alone also more than doubled above ground plant biomass over that of the control, but the difference was not significant. These results were expected as a consequence of increased nutrient availability and reduced hay-scented fern competition.

CONCLUSION

Liming forest soils that may be low in calcium and magnesium and pH is an option for forest managers to remedy nutrient deficiencies, improve site productivity and increase plant species diversity. This study indicates that soils may be a factor influencing understory species diversity and that on strongly to extremely acidic forest soils liming in combination with herbicide application following shelterwood harvest may greatly improve plant abundance and diversity when white-tailed deer are controlled.

ACKNOWLEDGMENTS

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PLANT COMMUNITIES ASSOCIATED WITH MULTI-AGED CLEARCUTS IN THE MISSOURI OZARKS

Irene M. Unger, Rose-Marie Muzika, and Nevin Aspinwall[1]

Abstract—The effects of clearcutting on herbaceous species of a Missouri Ozark upland deciduous forest were examined using a chronosequence of clearcuts (3, 8, 17 and 56 years since harvest). The herbaceous flora of these clearcuts was compared with adjacent unlogged sites using coverage data collected from sampling transects. Based on similarity coefficients calculated for the plant communities, the three- and eight-year-old clearcuts were highly dissimilar from the adjacent control plots. Similarity of the plant communities increased over time and 56 years after clearcutting the herbaceous communities of the clearcut site were not significantly different from the adjacent unlogged site, suggesting that these herbaceous communities had successfully reestablished. Individual species responded in much the same way as the communities in general. Although nearly half of the species did not display any clear trends in abundance, several early successional species had cover values that were high initially but decreased over time to reflect levels found in the control plots.

INTRODUCTION

The type and severity of a disturbance can alter the biodiversity of an ecosystem by determining which life history strategies are likely to produce viable colonists, as well as how long the recovery will take (Runkle 1985). Succession following a forest disturbance such as clearcutting is dependent on a number of site variables and on the species' life history traits (Boring and others 1981; Godefroid and others 2005; Halpern 1988, 1989). Shade-tolerant species as well as species lacking an established seed bank or long-distance dispersal ability have been shown to be negatively impacted by clearcutting (Godefroid and others 2005). Alternatively, perennials that have been suppressed by the low light levels of the mature forest or species present in the seed bank are released and often dominate initially or at least establish a more visible role in the community. These species are often followed by others that reproduce vegetatively or via wind borne seeds (Halpern 1989).

The succession of forest floor herbaceous species in the Missouri Ozarks has not been extensively characterized. The Missouri Ozarks serves as a transition zone between the eastern deciduous forests and the western grasslands and has a variable, but important, history of logging and human disturbance (Cunningham and Hauser 1992, Nigh 1992, Palmer 1991). Missouri forests, at one time, resembled open woodlands with abundant grasses and forbs; fire was an important disturbance that maintained this appearance (Beilmann and Brenner 1951, Nelson 1997, Nigh 1992). Between 1880 and 1920, nearly all Missouri forests were cut with the dominant result of substantial losses of shortleaf pine (*Pinus echinata*) and a compositional switch to forests dominated by oaks (Cunningham and Hauser 1992).

In order to understand more contemporary changes in Ozark flora with disturbance, we examined whether clearcutting has a long-term effect on the Ozark forest herbaceous community. Of interest was the consequence of the current management regime on the ground flora. More specifically, we wished to know the longevity of effects that conventional timber harvest practices have on the herbaceous vegetation and if the herbaceous community is able to return to its pre-harvest state.

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STUDY AREA

Many stands in the Missouri Ozarks date from the logging era (1880-1920) and a majority of these have not been managed since. Consequently many Ozark forests are even-aged stands dominated by black oak (*Quercus velutina*) and scarlet oak (*Q. coccinea*). We selected clearcut areas of 3, 8, 17, and 56 years-old and paired them with adjacent areas which had not been logged for 90-100 years (control) to determine whether, and to what extent, successional processes were operating. Since this study does not include pre-clearcut data, a major assumption of this approach was that the vegetational composition in each clearcut plot resembled the adjacent control site before harvest. To reduce variability between sites, all sites were south facing with similar slope percentage and were located within a 4 mile radius of each other in the Potosi Ranger District of the Mark Twain National Forest (Crawford County, Missouri). Two of the four clearcut sites were 8 acres; the other two sites were 23-24 acres. The four control sites ranged in acreage from 9-22. The sites were found on either Coulsone (loamy-skeletal, siliceous, semiactive, mesic Typic Paleudults) or Hobson (fine-loamy, siliceous, active, mesic, Oxyaquic Fragiudalfs) soils and overstory dominants included black oak (*Q. velutina*), white oak (*Q. alba*) and post oak (*Q. stellata*).

METHODS

Selection of Quadrat Size and Placement

Within each of the study areas, four quadrats were constructed to serve as sampling units. A quadrat size of 500 m^2 (10 m x 50 m) was selected based on the results of a preliminary survey. The quadrats were established such that the long axes were oriented down slope; aspect and slope were matched both within and between pairs of study areas. Quadrats were placed at least 20-30 m from roads, power line right of ways, and stand boundaries to reduce possible edge effects. Within each quadrat, three transect lines were established: one corresponding to each boundary of the quadrat (long axis) and one located down the center of the quadrat.

Vegetational Sampling

Each quadrat was surveyed prior to taking cover measurements to determine the species composition of the plots. Representatives of species not easily identified were collected from outside the quadrat for later identification. Nomenclature generally follows Yatskievych and Turner (1990).

Cover measurements were calculated for each species along (or within 10 cm of) the transect line by tallying the amount of transect line intercepted by the plant. Since the emphasis was on ground flora, only woody species that occupied the forest floor as seedlings or saplings (height of ≤ 1 m) were included in the analysis. All mosses and lichens were grouped into one category, as were all grasses and sedges. Sampling was carried out twice over the course of a year, once in the spring (May 20-31) and again in the summer (July 17-27). Only summer data are presented here as the summer sampling represents a more complete assessment of the flora. A cursory examination of the sites was conducted the following fall and early spring to determine if any species were overlooked. Very few additional species were found; therefore, additional quantitative surveys were not carried out.

Analysis

Woody and herbaceous species encountered in each quadrat were tallied to calculate plot species richness. In addition, cover measures of each species were used to calculate diversity [Shannon Diversity Index (H′)] and evenness (J′).

$$H' = -\sum p_i \ln p_i \qquad (1)$$

where

p_i = the proportion of the *i*th species in the total sample

$$J' = H' / \ln s \qquad (2)$$

where

S = the number of species present

Paired T-tests ($\alpha = 0.05$) were used to determine if clearcut sites differed from control sites in diversity measures.

The Czekanowski coefficient (Sc) was calculated to determine the similarity among sites. The formula for this measure is:

$$Sc = \frac{2\sum \min(x_i, y_i)}{\sum x_i + \sum y_i} \qquad (3)$$

where

$2\sum \min(x_i, y_i)$ = the sum the lesser scores of species *i* where it occurs in both sites
x_i and y_i = the abundance of species *i* at each site

The Czekanowski coefficient ranges in value from 0, where communities have entirely dissimilar species or vastly different abundances of the same species, to 1, where communities have identical species composition and cover (Kent and Coker 1992). Paired T-tests ($\alpha = 0.05$) were used to compare Czekanowski coefficients between clearcut plots and control plots.

To reveal the level of variation found between undisturbed sites, two kinds of pair-wise comparisons were made using cover measures. First, cover measures for each species were summed for each control plot and compared; then, to reveal variation within individual control plots, quadrat sums of species' cover were compared.

The Czekanowski coefficient was also employed to determine if the experiment and control plots within a site were becoming more similar over time. Analysis of variance (ANOVA) and Tukey tests were conducted to determine the effects of treatment (clearcutting vs control) and site (location) for the most common species (i.e. those with a mean cover value > 5 cm).

RESULTS AND DISCUSSION

Richness, Diversity and Evenness

Species richness in the clearcut sites seems to reflect the effects of crown closure (fig. 1). The 3 year old site and the 56 year old site have approximately equal richness (38 and 40 species respectfully), however species numbers are lower for the clearcuts at 8 years and 17 years (34 and 27 species respectfully). When the herbaceous species are examined independently, a similar pattern is seen; again the 3 year old site and the 56 year old site have approximately equal richness (23 and 26 species respectfully) and species numbers drop at 8 year- and 17 year-old sites (21 and 15 species respectfully). This pattern is not seen on the control sites or when the woody species are examined separately. Both total species and total herbaceous species are less variable on the control sites, with the exception of lower richness at the 8 year-old site. The number of woody species does not differ significantly between the clearcut and control sites. The drop in richness observed for the clearcut sites may reflect a shift in the species composition from ruderals or shade-intolerant species to competitors or more shade tolerant species which would occur during canopy closure.

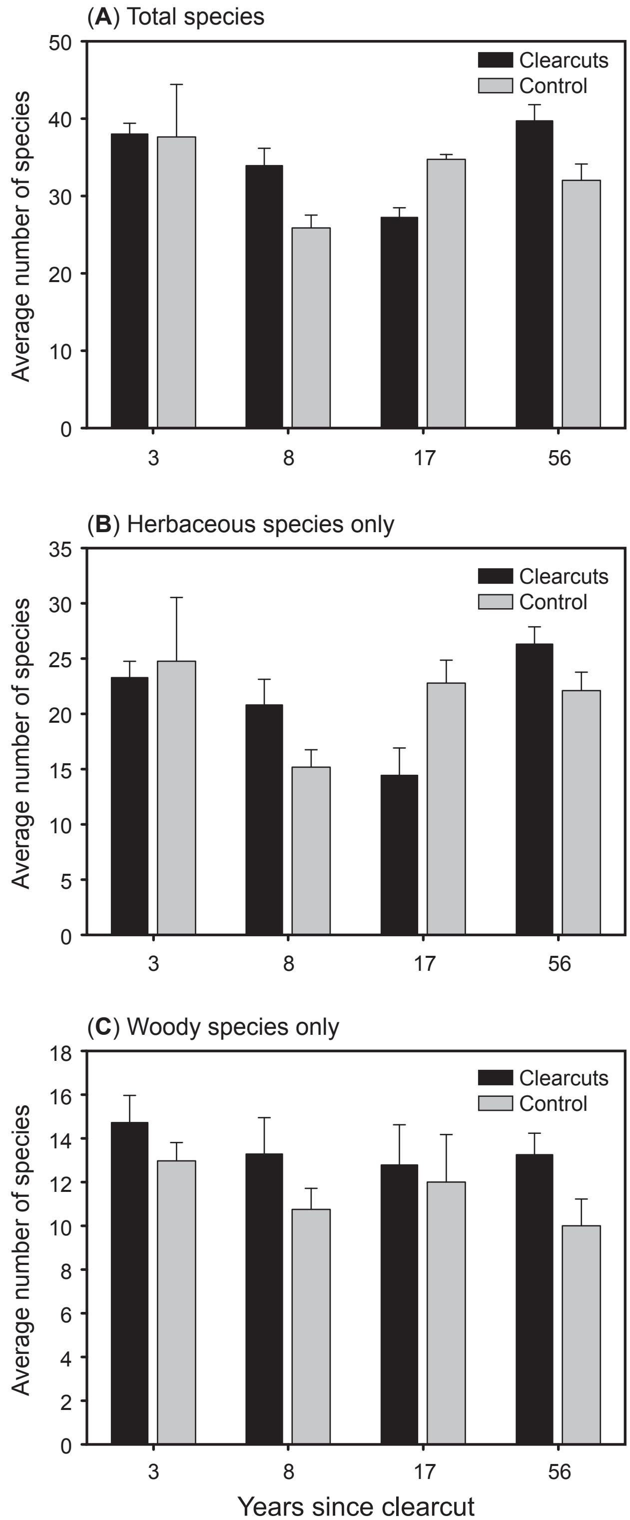

Figure 1—Species richness for clearcut and control sites. (A) average total species per site, (B) average herbaceous species per site, and (C) average woody species per site.

The influence of clearcutting on diversity or evenness is not evident from this data. Clearcut plots had an average diversity (H′) of 2.95 and an average evenness (J′) of 0.76. And the control plots had an average diversity (H′) of 3.08 and an average evenness (J′) of 0.80 (table 1). These values were not significantly different.

Similar observations regarding diversity and evenness have been reported elsewhere (Fredericksen and others 1999, Gilliam 2002, Gilliam and others 1995, Halpern and Spies 1995). Gilliam (2002) found no differences in H′ and J′ between clearcut and mature stands when studying the effects of harvest on herbaceous diversity in an Appalachian hardwood forest. In an earlier study that included some of the same watersheds, Gilliam and others (1995) reported that stand age had little effect on species composition of the watersheds. Fredericksen and others (1999) determined that despite shifts in species composition to more shade-intolerant species with increased harvest density, harvesting did not affect understory plant richness or diversity. While Halpern and Spies (1995) did observe initial changes in diversity following harvest in forests of the Pacific Northwest, these declines in diversity were short lived and richness exceeded pre-harvest values within two years after disturbance. Our findings are similar to Fredericksen and others (1999); species richness and composition varied from site to site but species diversity and evenness did not. It is worth noting however that our earliest observations were 3-years post-disturbance; and therefore the immediate response to clearcutting was not evident. Clearcutting likely initially impacted diversity or evenness in these sites but sufficient time may have passed for the sites to return to pre-disturbance levels.

Cover and Similarity Measures

Harvesting also affected ground-level cover measures (fig. 2). Clearcuts possessed greater cover overall than the control sites (mean = 23,612 cm). Similar to the findings of Ash and Barkham (1976), Reader and Bricker (1992) and Papp (1984), the clearcut sites were initially quite dense, but became less so after 8 and 17 years of regeneration, becoming similar to the control sites after 17 years. However, 56 years post clearcutting, total cover values increased again. The four control plots were similar in their vegetational density and low cover values. The 8 year old site possessed somewhat lower cover than the other control sites; the control sites combined had a mean cover value of approximately 13,000 cm.

Table 1—Diversity and evenness measures

Site	Plot	Shannon diversity (H′)	Evenness (J′)
3	Clearcut	3.0177	0.753
8	Clearcut	3.1515	0.8015
17	Clearcut	2.6115	0.7032
56	Clearcut	3.0072	0.7687
Average		2.946	0.757
3	Control	3.0967	0.78
8	Control	3.1915	0.8594
17	Control	3.0313	0.7789
56	Control	2.9840	0.7885
Average		3.076	0.802

Site numbers = age of clearcut.
Shannon diversity indexes were calculated using natural log; averages were compared using T-test.

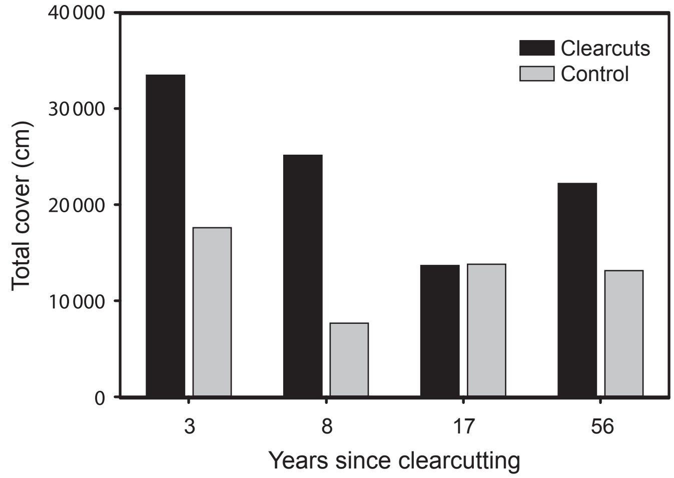

Figure 2—Total cover (cm) for control and experimental plots at the four sites.

The similarity comparisons of the control sites were calculated to determine the level of similarity ultimately expected between control and clearcut sites. With these types of comparisons, it is expected that the values obtained will lie some where between those calculated for any two randomly selected control sites and those calculated for any two randomly selected quadrats within a particular control site. Between control site comparisons produced a mean Czekanowski coefficient of 0.535 for the summer sampling (table 1). Whereas the within control site comparisons produced an overall average Czekanowski coefficient of 0.596 (fig. 3). Therefore, if harvesting has no effect, then the Czekanowski coefficient for a clearcut and its control will fall somewhere between 0.535 and 0.596.

Our results show that in the first 17 years after harvest, the clearcut and control plots were highly dissimilar with coefficients ranging from 0.34 to 0.45 (fig. 3). The coefficients for the 3- and 8-year old sites were significantly different from the average between control site coefficient ($t = 2.9$, $p < 0.03$; $t = 3.6$, $p < 0.01$; respectively). Therefore the plant communities of the clearcut and control plots of these sites were more dissimilar than any two randomly chosen control ("undisturbed") plots. The plant communities of the control and clearcut plots did become more similar over time as measured by increases in the Czekanowski coefficient (fig. 3). Fifty-six years after harvest, the plant communities of the clearcut and control plots had obtained levels of similarity that were not significantly different from those found for the within control plot comparisons ($t = -0.2$, $p > 0.3$) or between control plot comparisons ($t = -1.4$, $p > 0.10$). In other words, these communities were as similar as any two randomly chosen undisturbed communities.

These results imply that the herbaceous community in this particular area will return to pre-disturbance conditions over time. This transition takes between 17 and 56 years to occur. This may be similar to the findings of Elliot and others (1997) who note that ground flora of their southern Appalachian sites were in a transitional state between early and late successional species 17 years after clearcutting. In our study, 56 years after logging, similarity increased to a level that was not significantly different from the within or between control site levels. A number of individual species followed the trend of the sites in general and did not return to precut levels until at least 56 years after logging while other species were able to return to pre-cut levels within 17 years of logging.

ANOVA results revealed that 55 percent of the species tested were affected significantly either positively or negatively by clearcut logging. The species affected included, among others, *Amphicarpaea bracteata*, *Aster patens*, *Aster linariifolius*, *Coreopsis palmata*, *Parthenocissus quinquefolia*, *Rhus aromatic and Rubus pensilvanicus*. In addition, 71 percent of the species tested showed significant site effects and 63 percent of the species showed a significant interaction (treatment x site). Overall, cover values for the

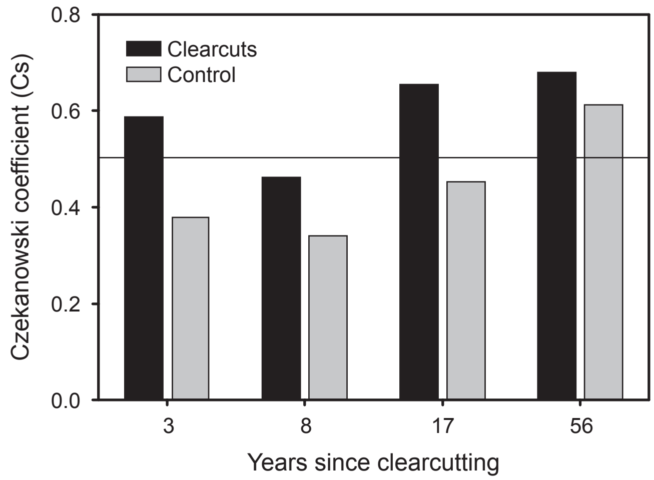

Figure 3—Czekanowski coefficients. The vertical line represents the average between control site similarity (Cs = 0.535); black bars represent the within control site similarity of the four sites calculated by comparing control quadrat cover measures; gray bars represent the similarity between the clearcut and the control plots at sites of particular ages.

plant species of the herbaceous community decreased over time (figs. 2 and 4) as would be expected for a forest community that is in the process of re-developing the overstory and thus increasing canopy closure. Significant interaction is expected since cover values of clearcut sites decreased over time while the control sites remained nearly constant.

Responses of individual species, based on cover values, changed substantially over time. While many species did not display obvious trends in abundance, one group of species had cover values that were high initially but decreased over time to pre-cut levels. This group included: *Euphorbia corollata*, *Lactuca canadensis*, *Lespedeza procumbens*, *Potentilla simplex*, *Rhus copallina*, *Rubus pensilvanicus*, *Solidago nemoralis*, *Tephrosia virginian*, *Toxicodendron radicans* and the grass/sedge species category (fig. 4). These may be considered ruderals or early successional species. This group includes species that demonstrate a pulse in abundance that lasts approximately 17 years; these species are: *Lactuca canasensis*, *Rhus copallina*, *Rubus pensilvanicus* and *Solidago nemoralis* all of which were able to recover to pre-cut levels within 17 years of logging. One species encountered during the summer sampling, *Parthenocissus quinquefolia*, had cover values that were low initially and rose over time, showing a pattern that reflects shade-tolerance (fig. 5).

Many species lacked an obvious trend that would disclose their response to clearcutting. This finding may support Bock and Van Rees' (2002) and Hughes and Fahey's (1991) findings that disturbances which remove the overstory do not necessarily disturb the forest floor or affect understory plants. Alternatively, our results may agree with Duffy and Meir's (1992) conclusion that restoration of plant community composition requires at least several centuries or a period of time longer than the current management cycles of 40 to 150 years.

Management Implications

By using a chronosequence, the data can be used to interpret temporal patterns. The shift in richness observed in the 8 year- and 17 year-old sites for example may represent the effects of canopy closure on richness. Species diversity and evenness were not adversely affected by clearcut logging and richness was able to return to levels comparable to those observed on control sites. The effects on individual species are less clear however, herbaceous communities do not seem to be adversely affected by clearcut

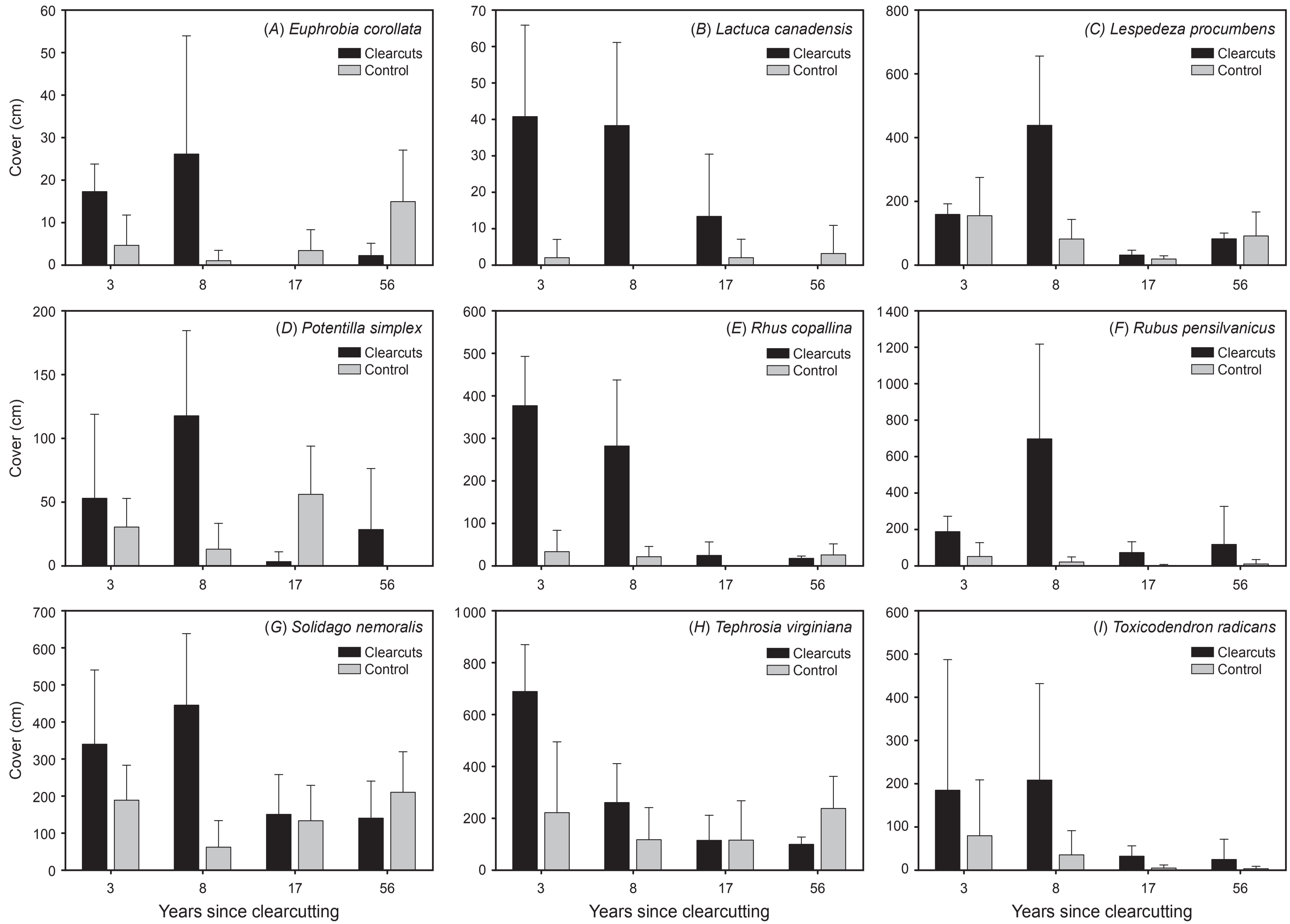

Figure 4—Cover values for specific plant species, i.e., early successional species, in control and clearcut plots over time. (A) *Euphorbia corollata*, (B) *Lactuca Canadensis*, (C) *Lespedeza procumbens*, (D) *Potentilla simplex*, (E) *Rhus copallina*, (F) *Rubus pensilvanicus*, (G) *Solidago nemoralis*, (H) *Tephrosia virginiana*, (I) *Toxicodendron radicans*, and grass/sedge group (not shown) also shows similar trend.

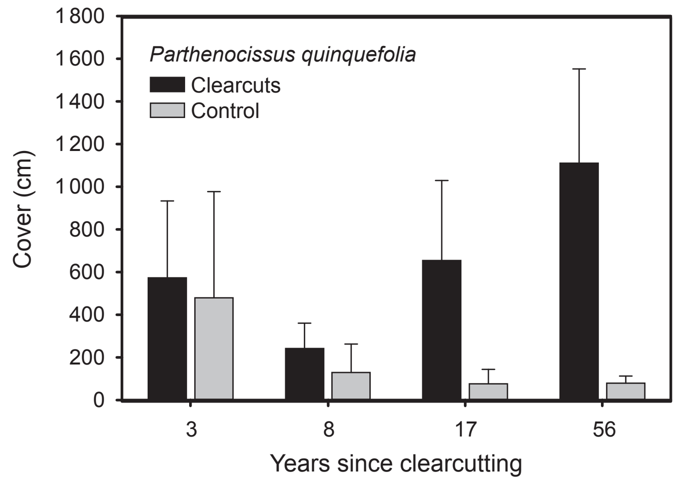

Figure 5—Cover values for *Parthenocissus quinquefolia*, a shade-tolerant species.

logging and are able to reestablish within 50-60 years of the harvest. Analyses are exploratory and should be interpreted with caution. Specifically, it should be noted that this study was conducted on relatively xeric upland sites. The conclusions drawn here should not be generalized to include more mesic forests or bottomland sites. In the Missouri Ozarks, bottomland sites and more productive forests have well developed spring flora communities. The impact of clearcut logging on these communities is unknown.

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LAND-USE HISTORY AND RESULTING FOREST SUCCESSION IN THE ILLINOIS OZARK HILLS

Saskia L. van de Gevel and Charles M. Ruffner[1]

Abstract—A historical ecology project was designed to quantify the influence of different land uses on forest development in the Ozark Hills of southern Illinois. By incorporating land-use history research, dendrochronology, and stand structure analysis, disturbances such as selective cutting, burning, grazing, and agricultural clearing have been investigated to determine their long-term effects. After the settlement of Union County in the 1830s, much of the landscape has been manipulated by humans via logging, grazing, agricultural clearing, and fire exclusion. Selective logging of upland sites removed some pre-settlement trees, yet most of these sites retained their forest structure. Bottomland sites were mostly cleared for subsistence agriculture by the 1860s then abandoned around 1925, allowing for recruitment of mesophytic species. With state management in the 1930s came a fire suppression program, which ultimately fostered the expansion of sugar maple (*Acer saccharum* M.) and American beech (*Fagus grandifolia* Ehrh.) onto rich upland loess soils. This alteration of the disturbance regime is currently causing a transition from the presettlement oak-hickory forest type to a later successional sugar maple-beech forest type.

INTRODUCTION

Land-use history has been used to analyze the change from pre-European to present forest conditions (Foster and others 1996, Ruffner and Abrams 1998). The historical context provided by land-use studies reveals a long-term pattern of change that challenges assumptions about the pristine conditions of presettlement forests (Foster and others 1996). Investigations of land-use history and vegetation change provide a background for understanding the development of the modern vegetation landscape (Christensen 1989).

Across the Central Hardwoods Region, old-growth forests appear to be in transition from oak-hickory dominated species to shade tolerant species. The decline of these forests is attributed to a combination of climatic change and the removal of anthropogenic and natural disturbances (Parker 1989). The Illinois Ozark Hills have been studied with relation to changes between presettlement and current forest communities (Leitner 1981, Weaver and Ashby 1971). In the presettlement community, white oak (*Quercus alba* L.) was the leading dominant while sugar maple was consistently low in importance. Sugar maple has dramatically increased in importance over the past 160 years (Leitner and Jackson 1981). Weaver and Ashby (1971) related this increase to a lack of major disturbance in the last century, increased precipitation, and selective cutting.

Our objectives were to (1) Research the land-use history, documented in land ownership tax records, and local and historical documents, (2) Understand land-use variation across different topographic gradients, and (3) Characterize the current stand composition and structure.

STUDY AREA

Braun (1950) classifies the vegetation of the Illinois Ozark Hills as Western Mesophytic, while Küchler (1964) includes it in the Oak-Hickory region. The study area within Trail of Tears State Forest (TTSF) was chosen because it was adjacent to agricultural land and had a relatively low percent slope (0-50 percent) compared to other parts of TTSF, where slopes are as steep as 80 percent.

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Mild winters and hot summers characterize the climate of southern Illinois. The mean January temperature is 2°C while the mean July temperature is 26°C. The average number of frost-free days is 206, extending between April and October. Approximately 50 percent of the 116.8 cm of annual precipitation falls from April to September. The growing season averages 230 days (Miles 1978).

METHODS

In the summer of 2001, a 117 ha area in the eastern section of TTSF was sampled for present forest structure and disturbance history. Sixty 0.04 ha rectangular (40 m x 10 m) plots were proportionally allocated across the ridgetop (greater than 183 m elevation, n = 14), midslope (165-183 m elevation, n = 27), and riparian (less than 165 m elevation, n = 19) forest sites. Site characteristics recorded at each plot included percent slope and slope position, which was assigned as ridgetop (1), midslope (2), and riparian (3).

Overstory vegetation was sampled within each 0.04 ha rectangular plot. All trees greater than 5.0 cm at diameter breast height (dbh: 1.47 m) were recorded by species. Tree crowns were classified into four categories (dominant, co-dominant, intermediate, and suppressed) based on the amount and direction of intercepted sunlight (Smith 1986). All saplings less than 5.0 cm but greater than 1.0 cm in diameter at ground level (dgl) were tallied every 10 m within a 0.025 ha (L = 5 m) nested rectangular plot. Seedlings less than 1.0 cm dgl were measured within a 0.0025 ha (L = 1.58 m) nested rectangular plot in the sapling plot every 10 m.

In each overstory plot, 4-8 trees were selectively cored for age determination using a sharpened increment borer. After sanding the 315 collected tree cores, cores were initially dated and then visually crossdated using the signature year technique (Yamaguchi 1991). Historical data of TTSF was collected from local land deed and tax records, from Union County historians, and from past Illinois Natural History Surveys.

RESULTS AND DISCUSSION

Land-Use History

The influence of Native American hunting grounds, railroads, sawmill towns, and the Civilian Conservation Corps (CCC) on forest development reflects an interesting history of land-use in the Ozark Hills through pre and post-European periods (table 1). Historic inhabitants, like the Shawnee and Kaskaskia Indians, either passed through TTSF on their way to other areas or used the region on an ephemeral, task specific basis (Hassen and Schroeder 1987). Although this region of southern Illinois appears to have been largely uninhabited by Native Americans after 1450 AD, several groups passed through this region throughout the 17th and 18th centuries. While their influence on the landscape is not quantified, the prevalence of disturbance-oriented vegetation across this region at settlement suggests a high incidence of burning from either natural (low incidence of lightning caused fires in the Midwest) or human ignitions (Parker and Ruffner 2004). The land survey records of 1806-1807 suggest fire was common in the forests of southern Illinois mentioning prairies, barrens, glades, open woodlands, and burnt trees (Fralish 1997). European settlers began coming into the area at a steady pace after the War of 1812. The region was known for excellent hunting grounds, and the proximity of the Ohio and Mississippi Rivers offered additional transportation and commercial advantages to the area.

Approximately 13,000 Cherokee were forced to travel on an overland route in October 1838, and arrived in Union County in the winter of 1838-39. Approximately three miles south of TTSF, the Cherokee were forced to camp as they waited for the ice of the Mississippi River to melt so they could cross over to Missouri and complete their journey (Norton and Anderson 1989). We suggest these Cherokee were collecting firewood for cooking and heating and numerous accounts admit to widespread hunting and foraging to augment the meager rations of the US Army (Parker and Ruffner 2004).

The Illinois Central Railroad was given land by the Land Grant Act of 1850, to sell to European settlers as a source of revenue, and to cut railroad ties so railroad expansion could continue across the Midwest. In the 1881 Atlas of Union County (Griffing 1881), the study area in TTSF was solely owned by the Illinois

Table 1—Major land uses affecting Trail of Tears State Forest and resulting forest development

Date	Land use practice	Forest impact
Before 1800	Native American hunting grounds	Hunting pressure and understory burning
After 1803	European-American settlement	Timber cut to build homes, roads, and towns
1811–1812	New Madrid earthquakes	Downed timber and oak regeneration
1830–1930	Grazing of domestic livestock	Soil compaction and understory damage
1838–1839	Trail of Tears-exiled Cherokee Indians	Cherokee hunted and made make-shift camps
1840–1930	Sawmill towns	Timber cut for barrels and lumber industry
1850–1880	Railroads	Timber cut for railroad ties and routes
1913	Ice storm	Trees damaged
1929	Purchased by the Department of Conservation	Much of TTSF has been selectively logged
1934–1937	Civilian Conservation Corps	Fire trails on ridgetops, pine planted, and tree nursery
1938	State inaugurated fire protection program	Suppression of forest fires that were historically common on the landscape

TTSF = Trail of Tears State Forest.

Central Railroad. Although Union County was established in 1818, European settlers did not start buying land from the railroads in the study area until 1899. This does not suggest that land was not managed before 1899, but does explain why there are no tax records showing timber harvesting occurring before that time.

The earliest settlers had discovered that the terrain and climate of Union County were conducive for the production of fruit trees in the Ozark Hills, and the new railroad provided fast shipment of produce to Chicago markets (Mohlenbrock 1974). For income in the 1890s, people worked in timber production during the winter to cut railroad ties for fifty cents per day (Adams 1994). Most of the old-growth forests on the uplands of Union County were harvested in the 1890s (Adams 1994).

Between 1870 and 1940, southern Illinois was at its height of lumber and wood production. During that period, the region held a national role in timber production (Mohlenbrock 1974). Timber was cut for the manufacture of crates, barrels, and baskets for shipment of locally grown produce to markets, in addition to selective harvesting for building supplies, railroads, and roads (Mohlenbrock 1974). Timber prices were highest during the 1920s, supporting at one time as many as thirty-two sawmills in Union County. These tree-ring and land-use data supports and strengthens Fralish's (1997) previous work comparing presettlement forests and increased oak importance in the present forest overstory. The increase in oak is consistent with higher levels of disturbance associated with postsettlement timber harvesting, fire, and grazing that occurred in the 1920s and 1930s (Fralish 1997). Fire frequency decreased considerably in the last 60 years in xeric oak-hickory communities in southern Illinois, due largely to fire suppression efforts by local, state, and federal agencies (Robertson 1994).

Current Vegetation

Repeated sampling of permanent plots in east-central Illinois and in southern Illinois (Ozier 2001) has established that the importance of oak species have declined and that sugar maple has increased over the past five decades. The increased presence and importance of mesophytic species along the topographic gradient indicates a transition from disturbance-oriented species to more shade tolerant species. Oak seedlings are common in these stands, but larger saplings and subcanopy trees are absent, suggesting that the absence of large-scale disturbances on these sites since the 1930s has contributed to the failure of oak to recruit into the canopy (fig. 1). In general, oaks are being successionally replaced by other species, despite observations that many forests contain a substantial number of oak seedlings (Abrams 1992).

This transition will result in reduced mast, wildlife habitat, and species diversity. The future forest, if current trends continue, will be dominated by sugar maple (Shotola and others 1992). Based on a stand table projection analysis in the Illinois Ozark Hills, Helmig (1997) found that the south slope, ridgetop and north slope site types will support a forest of sugar maple, American beech, and other mesophytes in approximately 50 years. In addition to anthropogenic disturbances over the past 300 years, a natural landscape-level disturbance occurred as well. The New Madrid earthquakes of 1811-1812 caused a large amount of downed timber in southern Illinois (Jones 2003), and a hurricane shortly after the earthquake would have caused additional damage (Shotola and others 1992). Dates for red oak (*Q. rubra* L.) establishment (from 1816 to 1841) suggest that much of the oak regeneration occurred during the period of the New Madrid earthquake and hurricane disturbance. White oak recruitment was also initiated on the ridges after the earthquakes in 1811 and 1812 (fig. 2).

An icestorm in 1913 fostered tree recruitment on bottom sites (fig. 2). Glaze damage to trees occurs when ice adds excessive weight to leaves and branches (Warrillow and Mou 1999). Most icestorm damage involves large branch breakage without the loss of the whole tree, thus creating scattered canopy openings of varying size, rather than the larger contiguous openings characteristic of wind blowdowns (De Steven and others 1991, Runkle 1985). Warrillow and Mou (1999) found that susceptibility of canopy trees to ice damage is determined not only by species characteristics, but also by site conditions, like aspect and landform. The icestorm in 1913 caused recruitment of tulip-poplar (*Liriodendron tulipifera* L.), hickory (*Carya* sp.), white oak, and sweetgum (*Nyssa sylvatica* Marsh.). The trees on the bottoms in 1913 would have been only 25 years old (grazing kept bottoms open until 1890s), so a major icestorm would have killed many of these young trees. The trees that were recruited in 1913 now make up the dominant-intermediate canopy classes on the bottom sites.

In the 1930s, white oak and sugar maple recruitment were initiated after the Civilian Conservation Corps (CCC) cut the ridgelines to build firetrails. Recruitment followed human disturbance patterns, while many species benefitted from these cuttings, sugar maple recruitment was further enhanced by suppression of fires by the CCC. The overall increase of mesophytic species on the ridgetop and midslope sites after 1940, reflects a reduced disturbance frequency (fig. 2). It is important to note that with the state inaugurated fire protection program in the 1930s came a large cohort of sugar maple recruitment across ridge, midslope, and bottom sites. Without canopy disturbances increasing the amount of sunlight, oak reproduction generally fails, allowing more shade tolerant species, in the absence of fire, to become established in the understory and slowly replace dominant oaks in the overstory (Brose and Van Lear 1998).

Currently no cutting is taking place at TTSF, but prescribed fire is being used in an attempt to suppress the invasion of mesophytic species. The artificial suppression of natural disturbances, particularly fire, ultimately eliminated disturbance-dependent species (Fralish 1997). Brose and Van Lear (1998) demonstrated that fire treatments reduce densities of all hardwood species relative to not burning, with spring and summer fires causing the greatest density reduction. They also noted that prescribed fires improved oak advance regeneration with spring burning providing the most benefit.

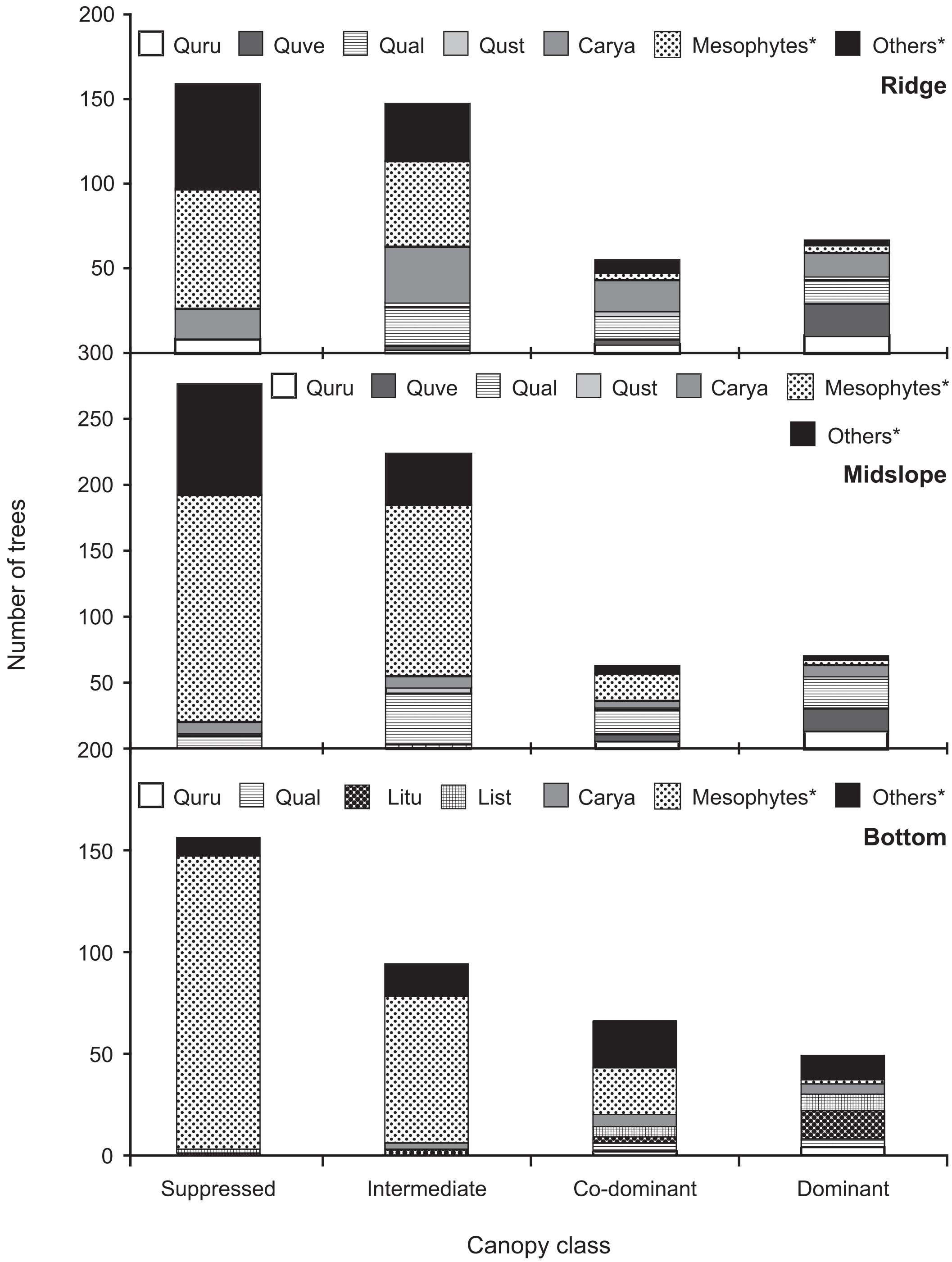

Figure 1—Canopy class distributions across topographic positions. Quru= *Quercus rubra*, Quve= *Quercus velutina*, Qual= *Quercus alba*, Qust= *Quercus stellata*, Carya= *Carya* species, Litu= *Liriodendron tulipifera*, List= *Liquidambar styraciflua*, Mesophytes= *Acer saccharum*, *Fagus grandifolia*, Others= *Sassafras albidum*, *Ostrya virginiana*, *Fraxinus americana*, *Fraxinus pennsylvanica*.

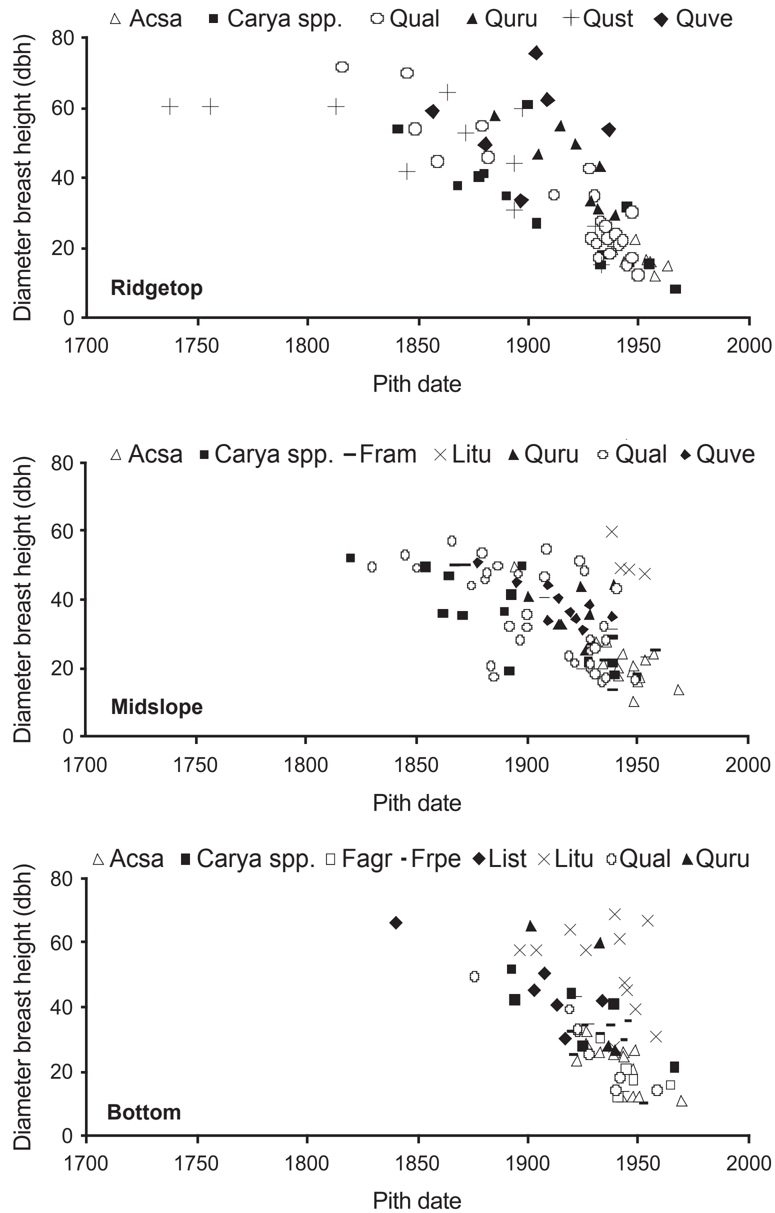

Figure 2—Age-diameter relationship for all cored trees on ridgetop, midslope, and bottom sites. (Species labels in fig. 1.)

CONCLUSION

Land-use practices on TTSF included the use of hunting, fuelwood collecting, and burning by Native Americans to drive game. European settlers then cut forests to develop farms, agricultural clearing, railroads, and sawmill towns from 1850-1930, followed by fire suppression and trail building by the CCC in the 1930s. The New Madrid earthquake in 1811, a localized icestorm in 1913, periodic fire, and drought characterized the natural disturbance regime. Site susceptibility to these disturbances was controlled by the rugged terrain, and slope position. The results of this historical ecology project support previous interpretations, drawn from witness tree data and permanent plot inventories, that disturbance processes have been important in this region over the past 300 years.

Along the ridge and midslope sites, the uneven-aged stands were dominated by oak and hickory, while smaller diameter classes consisted of sugar maple and American beech. The bottom sites were dominated by tulip-poplar, but are also being replaced by sugar maple and American beech, due to the continued absence of disturbance. Further research should be conducted on a combination of shelterwood harvests and prescribed fire, to regenerate oak and hickory species on xeric and mesic sites.

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DEVELOPING A FIELD FACILITY FOR EVALUATING FLOOD TOLERANCE OF HARDWOOD SEEDLINGS AND UNDERSTORY GROUND COVERS

J.W. Van Sambeek, Robert L. McGraw, John M. Kabrick, Mark V. Coggeshall, Irene M. Unger, and Daniel C. Dey[1]

Abstract—Information about the flood tolerance of most plants has been obtained from either observations following natural floods or pot studies with amended soils. To better evaluate and compare flood tolerance among hardwood seedlings and ground covers for use in riparian buffer and bottomland plantings, a large outdoor facility with natural floodplain soils is needed where flood timing, depth, flow, and duration can be controlled and replicated. In 1999, the University of Missouri Center for Agroforestry constructed a field facility at the Horticulture and Agroforestry Research Center on the floodplain adjacent to Sulphur Creek. Using soil excavated to create a retention pond, 6-m wide by 2-m high berms were constructed on the original floodplain soil with minimal disturbance to soils within twelve parallel 6-m wide x 180-m long channels. Water from the retention pond can be pumped independently into each channel to control timing, depth, and duration of either standing or flowing water. First year survival of spring planted seedlings of black walnut (*Juglans nigra* L.) in the control channels has continued to increase each year with annual modifications to lower the high water table caused by seepage and improved post-flood draining of channels. On-going studies include evaluating genotypic variation in response to flooding within hardwood species and seedling flood tolerance among hardwood species and forage crops.

INTRODUCTION

Installation of riparian buffers and afforestation of bottomland sites that are subject to period flooding requires species specific information as to plant tolerances to saturated soils (Allen and others 2001, Schultz and others 2000). Published information on flood tolerance is based largely on observations following natural flooding for many of the hardwood species in the Central Hardwood region (Allen and others 2001, Hook 1984, Hosner 1960, Kabrick and Dey 2001, Loucks 1987). Differences in the testing regimes and time of the year has resulted in conflicting information for some hardwoods, i.e., reported flood tolerance of bur oak (*Quercus macrocarpa* L.) and black walnut (*Juglans nigra* L.) ranges from intolerant to tolerant (Bell and Johnson 1974, Catlin and Olsson 1986, Kabrick and Dey 2001, Loucks 1987).

Stanturf and others (2004) indicated that lack of detailed knowledge of a species flood tolerance is a major cause of regeneration failures when the wrong species are planted in flood prone areas. In the past, species have been placed in broad categories ranging from intolerant to very tolerant based primarily on observations made following natural flooding during the growing season (Bell and Johnson 1974, Hook 1984, Loucks 1987, Melichar and others 1983). For a number of hardwoods including black walnut (*J. nigra* L.), more detailed information has been obtained from replicated pot studies (Catlin and Olsson 1986, Frye and Grosse 1992, Kaelke and Dawson 2003, Pezeshki and others 1999, Smith and Bourne 1989). Extrapolating results from pot studies can be problematic as most studies have been done with highly disturbed soil frequently amended with sand or other bulking agents to improve drainage and reduce bulk density. These soils may be quite different from actual floodplain soils characterized by a relatively shallow rooting zone due to poor aeration, high clay contents, and high bulk densities.

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Information is also needed on flood tolerance of potential ground cover vegetation when establishing riparian buffer strips or implementing agroforestry practices such as alley-cropping on bottomland or floodplain sites subject to period flooding (Garrett and others 2000, Van Sambeek and Garrett 2005). Flood tolerance of herbaceous species, especially native forbs, appears to be less well documented than for woody plants. Partially, this is a consequence of greater susceptibility to inundation and changing flood tolerance during different growth stages of forage crops (Brady 1974).

Our objective for this paper is to describe our experiences in designing, constructing, and modifying a field facility using native bottomland soils to be used to evaluate flood tolerance of hardwood seedlings and ground covers to flooding of controllable timing, flow, depth, and duration. In addition, we will highlight some of the information that can be found in other papers as to observed variability in annual survival of black walnut seedlings in response to different flood treatments (Coggeshall and others 2007, Kabrick and others 2007).

MATERIALS AND METHODS

Initial construction of a field facility for evaluating flood tolerance of forage species began in 1999 at the Horticulture and Agroforestry Research Center in New Franklin, Missouri on a wide first terrace floodplain between Sulphur Creek and a limestone-covered county road (fig. 1). Soil types are a mix of moderately well drained Nodaway silt loam (fine-silty, mixed, nonacid, mesic, Mollic Udifluvents) and poorly drained Carlow silty clay (fine, montmorillonitic, mesic, Vertic Endoaqualls) (Grogger and Landtiser 1978). Soil excavated for a retention pond was used to build parallel 2-m-high berms that resulted in twelve 6 m wide by 180 m long channels. Slope within each channel averages less than a 15 cm drop from inlet to outlet. Two 1,600 L/hour electric pumps move water from the retention pond to adjustable butterfly valves located at the inlet end of each channel. Once all channels were flooded, flow rates within channels with flowing water were adjusted to exchange the water once each day (120 L/minute). Adjustable flood leveling gates at the outlet end control the depth of water between 0 and 0.5 m for flowing water flood treatments.

Figure 1—Aerial photograph taken July 3, 2004, of the flood tolerance facility at the Horticulture and Agroforestry Research Center in New Franklin, MO. Sulphur Creek is in the upper left corner, the county road in the lower right corner, and the pump house sits adjacent to graveled berm behind the retention pond in lower left corner.

Adjustable float valves were installed on the inlet end to control flooding depth for standing water flood treatments. Excess water in all channels flows back into the retention pond through outlet pipes installed 15 cm lower than the surface of each channel.

Several improvements have been made to the flood tolerance facility since initial construction. In spring 2000 we installed flapper check valves to the outlet drain pipes to prevent backwater from flowing into channels during flash flooding along Sulphur Creek. In 2001, we had 30 m^2 depressions excavated approximately 20 cm deep at the outlet end of each channel to collect post-flooding water and allow the use of self priming water pumps (930 L/minute) to rapidly drain each channel when flooding was terminated. In spring 2003, we cut 20-cm-deep circular ditches with a field digger along both sides of each channel to increase post-flooding flow of water from the channel and to intercept water seeping under berms into the control channels. After the entire facility flooded in 2002 and 2003, we raised the height of the berms surrounding the facility an additional 50 cm in summer 2004 so that it exceeds the 500-year flooding depth. In winter 2005, we further improved the capacity to remove flood water by laying a supplemental drain pipe across all channels beneath the outlet depressions. During flooding, open grid caps are replaced with removable stand pipes.

To characterize the variation in soils within the facility, 0 to 20 cm soil cores were taken from each channel following flooding in 2003. Composite samples were dried and analyzed for soil pH, electrical conductivity (1:2 soil ratio with water), and major macro- and micro-nutrients following Mehlich 3 extraction (1:7 ratio) and inductively coupled plasma atomic emission spectrometric determination. Gravimetric water content and soil temperature were monitored during and after flooding in spring 2004. Water content was measured weekly with Watermark Sensors (Irrometer Cc., Inc.) and temperature was recorded hourly with Stowaway temperature dataloggers (Onset Computer Corp, Bourne, MA). In spring 2005, we installed electronic sensors connected to CR23X microloggers (Campbell Scientific, Logan, UT) in each channel to monitor soil temperature and soil water at 5 and 15 cm depths, soil pH and redox potential at 5 cm, oxygen at the water/soil interface, air temperature, and daily rainfall during flooding and post-flooding recovery. In addition, twice a week we monitored soil pH, redox potential, dissolved oxygen, and temperature at 5 cm with portable Oakton 300 series meters and 90 cm long submersible electrodes (Cole-Parmer, Vernon Hills, IL).

Four adjacent channels were grouped into three blocks from the road to the creek. Within each block, one of four flood treatments was randomly assigned to each channel. Flooding treatments each spring (May and June) from 2002 through 2005 were (1) a no flood control, (2) five weeks of 15 cm deep stagnant water, (3) five weeks of 15 cm deep flowing water, and (4) three weeks of 15 cm deep flowing water (2004 and 2005 only). For evaluating shrubs and herbaceous species in 2003 through 2005, individual plants of fifteen grasses and ten legumes were established on a 1-m x 1-m spacing in five pseudo-replications in each channel the summer before spring flooding. When evaluating flood tolerance of recently planted seedlings, nursery stock of five to seven species was purchased from the George O. White Nursery and each species planted in 25-tree plot on a 0.75-m x 1.0-m spacing (Kabrick and others, 2007). When evaluating genotypic variation for flood tolerance among oak seedlings from single-tree collections, 1-0 bareroot seedlings grown at the George O. White Nursery or container-grown seedlings grown at the Horticulture and Agroforestry Research Center were planted on a 0.75-m x 1.0-m spacing with a completely random arrangement within each channel (Coggeshall and others, 2007).

RESULTS AND DISCUSSION

The site for the flood tolerance laboratory was originally chosen in 1999 because the area was large enough to construct twelve nearly level channels with minimal disturbance to the existing floodplain soils. Post-construction evaluation of the field facility indicated experimental designs for conducting flood tolerance studies would require blocking because the soil type gradually changed from a Nodaway silt loam adjacent to the creek to Carlow silty clay adjacent to a county road (table 1). Subsequent soil nutrient analyses revealed nutrient gradients also exist across the channels for pH, calcium, and zinc (table 1), but not for electrical conductivity (84 umhos/cm), phosphorus (82 kg/ha), potassium (530 kg/ha), magnesium

Table 1—Soil properties within top 20 to 25 cm across three replications of four channels each within the flood tolerance facility at the Horticulture and Agroforestry Research Center in New Franklin, MO

Variable	Block I[a]	Block II	Block III
Dominant soil type[b]	Carlow and Nodaway	Nodaway and Carlow	Nodaway
Estimated percent silt content[b]	58	63	68
Estimated percent clay content[b]	34	28	23
Estimated water content (cm) at field capacity[b]	4.5	5.1	5.6
Soil pH			
Post flooding in 2003	7.4	6.9	6.5
When flooded in 2005	6.9	6.8	6.6
Post flooding in 2005	6.6	6.6	6.5
Soil redox potential (mV)			
Post flood 2005 recovery	357	394	422
Soil nutrients in 2003			
Ca (kg ha^{-1})	6100	5200	4900
Zn (kg ha^{-1})	5.6	5.9	6.6

CA = calcium; ZN = zinc.

[a] Block I includes the northern four channels adjacent to the gravel road and block III includes the southern four channels adjacent to Sulphur Creek.

[b] Values as reported by Grogger and Landtiser (1978).

(790 kg/ha), sulfur (26 kg/ha), iron (400 kg/ha), manganese (195 kg/ha), copper (4.5 kg/ha), and boron (1.5 kg/ha). We hypothesize the pH and calcium gradients are in response to limestone dust from the adjacent graveled county road rather than past cropping activity on the floodplain.

Flood tolerance trials with forage crops in 2002 indicated and subsequent soil water monitoring in 2004 confirmed that lateral movement of water under the berms from flooded channels raised the water table within a few centimeters of the soil surface in the non-flooded control channels. Fortuitously, newly planted seedlings of black walnut have been included in flood tolerance each year since 2003. As expected, newly planted seedlings of black walnut exhibit little tolerance to 3 or 5 weeks of flooding by flowing or stagnant water (table 2). Catlin and Olsson (1986) also reported that few walnut seedlings survived partial inundation for three weeks. We also had high mortality of black walnut seedlings in the non-flooded control channels. Because black walnut seedlings, even when subjected to improper lifting at the nursery or handling before planting, typically show high first year survival (Rietveld and Van Sambeek 1989, von Althen and Webb 1982, Williams 1974), we hypothesize that seedling mortality is a consequence of creating a high water table and saturated soils due to lateral movement of water from adjacent flooded channels.

Reductions in the redox potential occurred under all four flood treatments including the non-flooded control channels (fig. 2). With flowing or stagnant flood water, redox potentials declined from between 500 and 550 mV to less than 200 mV during the first week of flooding. This was followed by a slight recovery the second week and subsequent decline to less than 100 mV with continued flooding. Ponnamperuma (1984) describes similar changes in his review on effects of flooding on soils. The redox potential in the control channels rapidly declined during a 6-day period when we received over 150 mm of precipitation producing saturated soils over a high water table. With the cessation of rainfall or flooding, soil redox potentials rapidly recovered to pre-flooding values over a two week period.

Table 2—First-year survival of bare-root black walnut seedlings exposed to four flooding regimes within the field flood tolerance laboratory from 2003 through 2005

Year	Control	3-week flowing	5-week flowing	5-week stagnant
	- - - - - - - - - - - - - - - *percent*	- - - - - - - - - - - - - - -		
2003	34	nd	1	1
2004	64	16	9	4
2005	55	24	12	29

nd = treatment not tested in 2003.

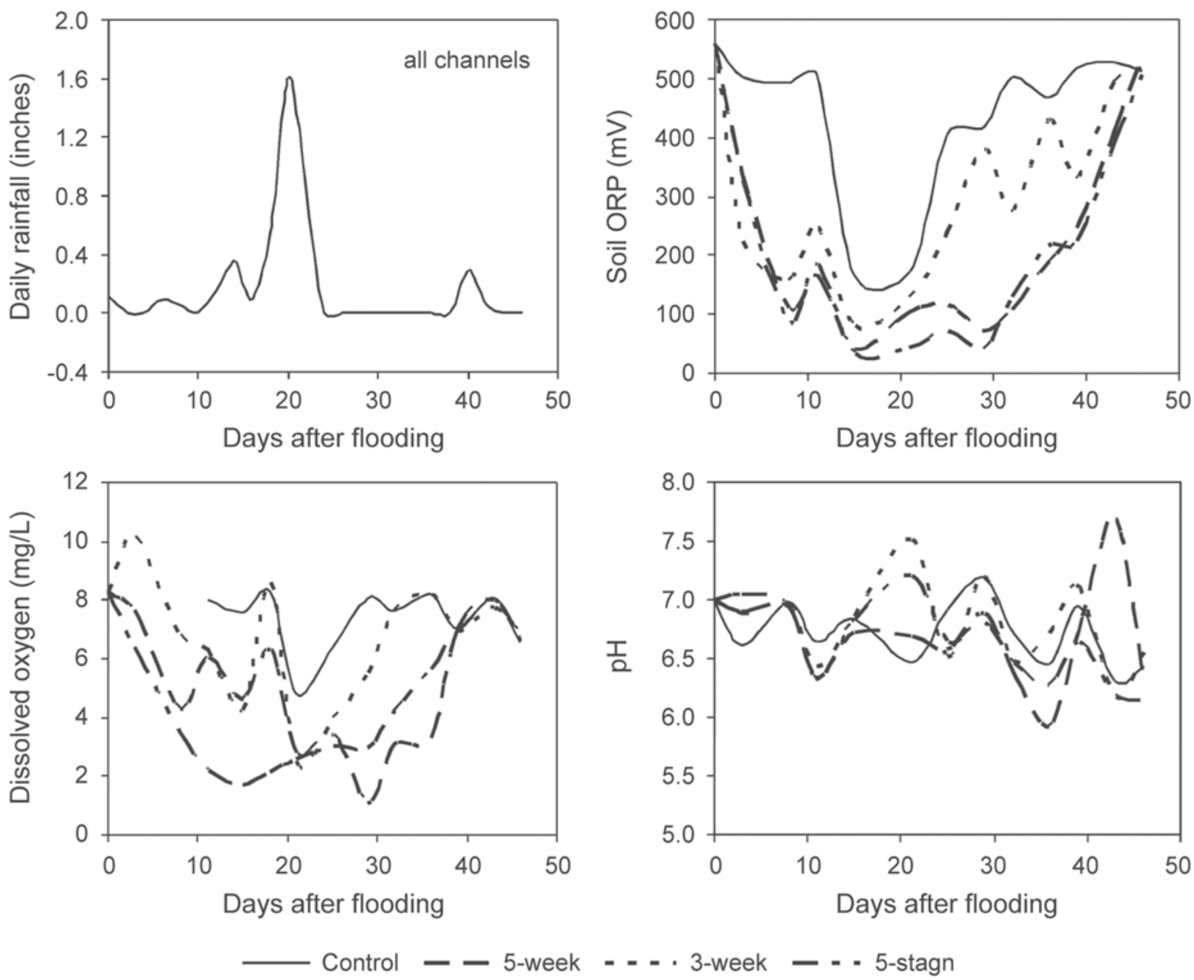

Figure 2—Changes in soil pH, dissolved oxygen, and redox potential (ORP) during and after flooding under four flooding regimes. Flood treatments were initiated on May 23, 2005, (day 0) and terminated on day 21 for 3-week flowing (3-week) and day 35 for 5-week flowing (5-week) and stagnant (5-stagn) treatments.

Dissolved soil oxygen also showed a rapid decline from near equilibrium levels [8.9 mg/L at 20 ˚C (Drew 1990)] to less than 2 mg/L with five weeks of flooding (fig. 2). Spikes in dissolved oxygen were detected in response to oxygen-rich precipitation in the control channels and treatments with flowing water. In contrast to the treatments with flowing water that remained muddy, the soil surface was visible within a week of flooding as suspended soil settled out in treatments with stagnant water. We failed to detect changes in soil water pH or temperature in part because this data was obtained from portable equipment rather than stationary sensors. In addition, because soils were nearly neutral prior to flooding, changes in soil pH are expected to be small (Ponnamperuma 1984).

Although the flood tolerance laboratory is now functional, we are continuing to make modifications to address several concerns. The most significant remains to be the high water table that exists within the control channels when adjacent channels are flooded. Based on observed changes in soil redox potentials and dissolved oxygen, maintaining soil water at or below field capacity can still be problematic especially during periods of extended precipitation. Lastly, having a mix of hardwood seedlings and understory ground covers in each channel has precluded our use of short-term flooding to alleviate moisture stress during summer droughts and has complicated selection of herbicides to control weeds, especially the highly invasive yellow nutsedge (*Cyperus esculentus* L.) and smartweed (*Polygonum* spp.).

In summary, our design for a field facility to evaluate flood tolerance of hardwood seedlings and understory ground covers allows for inexpensively evaluating large numbers of plants on floodplain soils under typical flood conditions. Cost for initial construction and modifications total fewer than 200,000 dollars including 75,000 dollars for micro-meteorological sensors and dataloggers. The current system of pumps, valves, gates, and drainage field allows each channel to be independently controlled for time of flooding, duration, flow, and, to some extend, depth.

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POSTERS

SPATIAL ALLOCATION OF WEST VIRGINIA TIMBER PRODUCT OUTPUT DATA

John P. Brown[1]

Timber Product Output (TPO) studies are part of a national program conducted by the USDA Forest Service Forest Inventory and Analysis program. These studies include periodic assessments of roundwood received by industry according to geographic origin.

A new method to spatially allocate sawmill roundwood receipts data was developed from West Virginia TPO data. This method allows for the allocation of total roundwood production to counties-of-origin surrounding a sawmill in the absence of detailed county level records provided by the mill owner or mill manage. This distribution is based solely on one value — total sawmill roundwood receipts.

Data collected by mill that included detailed county level roundwood receipts information (n=55) was used to create a function, which distributes roundwood receipts to the counties surrounding each mill. This procedure determined the distances within which 25, 50, 75, and 100 percent of the sawmill's roundwood was procured (the 25th, 50th, and 75th quartiles and maximum procurement radius) using county-of-origin data collected in a census of WV sawmills. Distances were calculated as the distance from the mill to the geographic county center. The means of these values for all mills were then calculated. The mean distances for the quartiles and the maximum were found to be 16.8, 24.5, 31.3, and 49.7 km, respectively.

The mean distances were then utilized to apportion total roundwood receipts for each mill. The first step was to locate all county centers within the mean distance for the 25th quartile (16.8 km) for each mill. One-quarter of total production was allocated evenly to all the counties with county centers within this distance. Second, one-quarter of total production was allocated evenly to all the counties with county centers within the mean 50th quartile distance (24.5 km). This procedure was than repeated for the 75th and maximum mean distances.

A sum was then generated for each county from each mill estimate. The absolute percent error abs [(actual county total-estimated county total)/actual county total]*100 was calculated for each county. The median absolute percent error was found to be 58 percent.

With some refinement through stratification, this method may be of use in estimating the county-of-origin of roundwood receipts for sawmills when there is an absence of detailed county level data. By developing a reliable estimation approach, the TPO survey form could be greatly simplified, which might improve response rates and reduce the costs and potential response errors associated with record-intensive data collection.

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A CASE STUDY ASSESSMENT OF SMALL-DIAMETER UTILIZATION IN THE UPPER MIDWEST

Matthew S. Bumgardner and Scott A. Bowe[1]

The presence of profitable markets and uses for small-diameter and other low-grade material can influence treatment decisions in eastern forests. Commercial and precommercial thinnings, timber stand improvement, and other silvicultural activities that can affect forest health and revenues may be feasible in areas where small-diameter markets exist. Several portions of the eastern hardwood forest are dominated by poorly stocked stands of small-stemmed trees, often the result of past cutting practices. Small-diameter timber utilization in the Upper Midwest was investigated in 2003 and 2004 using postharvest plot data. The objective was to gain a better understanding of the effects of ownership type, proximity to pulpwood markets, and predominate forest cover on the use of this material. Case studies in four Wisconsin counties indicated that each of these factors influenced harvest activities and small-diameter utilization.

The counties of Crawford, Door, Eau Claire, and Florence were selected for the study. Harvests in Crawford and Door Counties were primarily hardwood while those in Eau Claire and Florence Counties were a mix of hardwoods and softwoods. Eau Claire and Florence counties are within 40 miles of the nearest pulpmill while Door and Crawford counties are located somewhat farther from pulp markets. A total of 1,664 tree stumps and 851 tops were measured on 96 plots, i.e., harvested stands, within the four counties. The ownership types investigated included nonindustrial private forest (NIPF) ownerships under Wisconsin's Managed Forest Law (MFL) program, non-MFL NIPF ownerships, and county forest ownerships. The MFL program promotes active forest management by offering landowners reduced annual property taxes in exchange for professionally written management plans. It was anticipated that each ownership type would have different management objectives, and thus realize varying opportunities for small-diameter utilization. In each county, 10 percent of the sales for each ownership type were selected randomly for sampling.

Although the study was a preliminary attempt to determine the influence of the factors cited, several conclusions were drawn. Particularly noteworthy was the positive impact of professional management, i.e., the MFL and county forest sales, on pulpwood removal and residual stand characteristics. MFL and county ownerships tended to have more residual volume in sawlog-sized trees and less in pulpwood-sized trees on a proportional basis than non-MFL ownerships. It was observed that the NIPF harvests were more likely to be selective harvests and less likely to be diameter-limit harvests when a forester was involved in the sale. On county harvests, it was observed that policies requiring loggers to cut unmerchantable trees for the sake of future forest health also resulted in proportionally lower residual basal area in pulpwood-sized trees compared to non-MFL private harvests.

It appeared that Door County had better-than-expected pulpwood utilization given the distance to pulp markets, perhaps due to the marketing abilities of the forester(s) involved. Or the relatively high property values in Door County might encourage MFL enrollment and subsequently better management and more complete resource utilization. This suggests that active professional management of private forest land can create opportunities for small-diameter utilization.

Also of interest was the large amount of unused hardwood pulpwood material in southern portions of the State (represented by Crawford County), where nearly three 8-foot pulp sticks per harvested tree were left in the woods. Hardwood sawlogs, particularly oak species, were the most common roundwood removal there, and Crawford County had the highest average stump diameter (16.7 inches) and top diameter (11.2 inches) among the counties studied. The other counties ranged from 9 to 10 inches in average stump diameter and 4 to 5 inches in average top diameter.

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THE ROLE OF THE WVU EXTENSION SERVICE IN FORESTRY EDUCATION AND TECHNICAL ASSISTANCE FOR PRIVATE FORESTLAND OWNERS

Larry G. Campbell, David W. McGill, Chad Pierskalla, and Kevin Saunders[1]

The Cooperative Extension Service is an organization that takes different forms in different states. An organization that has deep roots in many communities, it is one that traditionally has served as a pipeline for new innovations, translating recent findings in agriculture and forestry from Land Grant Universities into working solutions for farmers and other landowners in rural America. As U.S. demographics have shifted from largely rural to urban populations, extension personnel find themselves involved with many nontraditional issues. Concurrently, technical assistance resources available to private landowners from state and federal organizations seem to be on a downward spiral as forestry agencies, working with limited budgets, spend more time on logging compliance and fire protection and less on direct technical assistance. In an effort to better define the contribution of West Virginia Extension personnel to the broader network of forestry outreach programs and organizations, we surveyed Extension Service personnel to illuminate the type and quantity of forestry-related assistance and information they provide in the state.

We used a mailed questionnaire as our survey instrument. Our database was taken from an August 2005 list of 235 West Virginia Extension personnel working at the county level, outside of central extension administration at West Virginia University in Morgantown, WV. Our instrument was initiated in September 2005 with a pre-survey announcement, followed by a cover letter and questionnaire, a reminder letter, and finally a second cover letter and questionnaire mailed to nonrespondents; these subsequent mailings were made approximately at two-week intervals following the initial mailing.

Just over three-quarters (76 percent) of the questionnaires we mailed out were returned. Completed questionnaires totaled 162; about a third (32 percent) of the respondents indicated they never receive forestry-related questions. Of those receiving forestry questions at least "a few times a year", 72 percent answered at least some of incoming questions posed by their respective county's residents. Those that did answer forestry questions answered an average of 24 percent of incoming questions themselves. A large percentage (76 percent) of forestry questions were referred to other individuals or organizations. Most Extension personnel (70 percent) provide no direct forestry services. Sixteen percent, however, provide forest site visits and discuss opportunities with landowners, and 2 percent offer estimates of the value of forest resources; none provide forest management plans. Most respondents (76 percent) had no forestry training. Only one percent had a college-level forestry degree. Others had taken forestry courses (10 percent), attended workshops (8 percent), or had become familiar with forestry topics in other ways (3 percent).

WV Extension Service personnel provide an important linkage between landowners and technical providers. Additional training of extension personnel, however, regarding the most frequently asked forestry questions will help to extend the state's overall forestry information network.

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STEM DIAMETER AND HORIZONTAL CROWN AREA CORRELATIONS FOR HARDWOOD TREE SEEDLINGS PLANTED ON RECLAIMED STRIP-MINED LANDS IN EASTERN KENTUCKY

Lucas R. Cecil and Jeffrey Stringer[1]

Grading criterion on reclaimed strip-mined lands outlined in PL 95-87, the Surface Mining Control and Reclamation Act of 1977, have resulted in spoil compaction exceeding the levels required for proper root development for most hardwood species. At these compaction levels, high rates of seedling mortality and growth reductions occur. New reclamation techniques in eastern Kentucky have been established to significantly reduce spoil bulk density and increase tree vigor and survivability. The success of these new techniques has provided for significant tree survival and exceptional early development. This has resulted in the need to better understand the development of forest cover on these sites and the ability to predict crown closure and potential thinning regimes.

Correlating stem diameter and crown area for open grown trees is one method used to predict canopy closure and possible thinning regimes for further stand development. In 1997, 6 hardwood tree species were planted on 3 experimental spoil treatments resulting in a wide range of spoil bulk densities (115 – 122 pcf). The hardwood species consist of red oak (*Quercus rubra*), white oak (*Q. alba*), yellow-poplar (*Liriodendron tulipifera*), white pine (*Pinus strobus*), royal paulownia (*Paulownia tomentosa*), and white ash (*Fraxinus americana*). In 2005, the trees were measured to develop regressions and correlations with stand parameters to develop prediction models and determine compaction density effects. Allometric equations and linear regression techniques were used to develop species specific growth relationships for ground-line diameter and horizontal crown projections of open grown trees over a wide range of diameter classes.

The resulting equations provide a reliable formula for predicting canopy closure at varying planting densities in the 3 experimental spoil treatments. Regression models can be used to define limits of maximum stocking, which can be related back to the initial planting densities of the reclaimed strip-mine. The resulting equations are for the sites with the lowest spoil bulk densities (115 – 118 pcf).

HCA = Horizontal Crown Area SD = Stem Diameter

White oak	HCA = 1.8167(SD) + 1.4723
Red oak	HCA = 2.1331(SD) + 1.1067
White ash	HCA = 2.0543(SD) + 0.5166
Yellow-poplar	HCA = 2.2903(SD) + 0.604
White pine	HCA = 1.7444(SD) + 0.979
Royal paulownia	HCA = 0.9404(SD) + 5.9661

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INDIVIDUAL-TREE, OUTSIDE-BARK, MERCHANTABLE GREEN WEIGHT EQUATIONS AND SCALING FACTORS FOR SAWTIMBER-SIZED NORTHERN RED OAK, WHITE OAK, AND SWEETGUM IN NORTHWEST ARKANSAS

Paul F. Doruska, Jonathan I. Hartley, Matthew B. Hurd, David W. Patterson, and Don C. Bragg[1]

To date, weight scaling and weight equation research in Arkansas has focused primarily on loblolly pine (*Pinus taeda* L.) and select bottomland hardwood species. However, Arkansas also has over 7 million acres of upland hardwood forests. Since buying and selling timber by weight is now commonplace within the region, similar research is needed for upland hardwood species as well. The Arkansas Forest Resources Center, in cooperation with the Forest Service, has initiated a project to address this research need.

Twenty-one sweetgum (*Liquidambar styraciflua* L.), 19 white oak (*Quercus alba* L.), and 12 northern red oak (*Q. rubra* L.) trees found in the Boston Mountains in northwest Arkansas were measured and weighed in September of 2005. Total tree height and dbh were measured while each tree was standing. After felling, outside bark diameter and bark thickness were measured at the butt, at 1-foot increments from the butt to 8 feet along the bole, and at 3-foot increments thereafter until the merchandized sawlog top was reached. Boles were then merchandized into sawlogs of varying lengths, with each merchandized log being a multiple of the desired 8.67-foot standard log length utilized in the region. Each log was attached to a load cell (Measurement Systems International, Challenger 2, Model 3360, 10,000 pound capacity, 2 pound precision) using chains and tongs and suspended from a loader to determine outside-bark green weight.

The sweetgum averaged 79 years in age, 16.1 inches in dbh, 89 feet in total height, and 1.5 tons in total sawlog weight; the white oak averaged 102 years in age, 19.7 inches in dbh, 85 feet in total height, and 2.2 tons in total sawlog weight; the northern red oak averaged 113 years in age, 24.0 inches in dbh, 85 feet in total height, and 3.7 tons in total sawlog weight. The average sawlog merchantable length weight scaling factor (outside bark green weight divided by inside bark volume) for northern red oak (81.9 pounds per cubic foot), while not significantly different from that of white oak (78.8 pounds per cubic foot) was significantly larger than the weight scaling factor for sweetgum (76.6 pounds per cubic foot). Northern red oak boles had a significantly larger average Girard form class (81.3) when compared to those of sweetgum and white oak (76.8 and 76.4, respectively).

Species specific regression equations were developed to predict outside-bark green weight (in tons) for the sawlog portion of the bole based on dbh and sawlog merchantable length. A combined species regression equation was also developed, with indicator variables used to determine if the parameters differed by species. The combined species model possessed an R^2 of 0.9523 and a mean absolute error of 0.17 tons per bole. The equation was parameterized differently for northern red oak but not for the other two species, as a result of the larger weight scaling factor and larger Girard form class exhibited by the northern red oak trees measured. Use of these equations and the corresponding weight scaling factors should assist those inventorying and/or buying and selling northern red oak, white oak, and sweetgum sawtimber by weight in northwest Arkansas and similar regions.

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IMPACT OF CHANNELIZATION AND DAM CONSTRUCTION ON KASKASKIA RIVER MORPHOLOGY

Xizhen Du and Karl W. J. Williard[1]

The 58 miles lower Kaskaskia River corridor in southwestern Illinois contains the largest contiguous tract of forestland in the state of Illinois that provides critical stopover and breeding habitat for neotropical migratory songbirds along the Mississippi flyway. Since the 1960's, two big human in-stream modifications, Carlyle Lake Dam and Channelization, have substantially interrupted the natural hydraulic and ecologic equilibrium of the river. Carlyle Lake Reservoir was a multipurpose project and was completed in 1967. Kaskaskia River channelization consisted of shortening of approximately one-third of its original length, and it was completed in 1972.

In this study, historical aerial photographs from seven multiple-dates (1938-1998) were utilized to quantify the river channel bank widening rate changes during both pre-modification period and post-modification period in the study reach downstream from Carlyle Lake Dam and upstream from Fayetteville. Bankfull channel width was used as the primary indicator variable to assess pre- and post-period channel change. Fifty channel cross-sections were selected and divided into three sub-reaches. The first sub-reach included the first twenty channel cross-sections immediately downstream of Carlyle Lake Dam. The second sub-reach included the middle ten channel cross-sections. And the last one included the last twenty channel cross-sections right upstream from the channelization terminus, Fayetteville. The bankfull channel widths of cross-sections were measured under magnifying stereoscope and caliper. Aerial photograph interpretation results indicated that significant bank widening($p< 0.001$) has occurred since completion of the two projects. Mean pre-modification widening rates were 0.25 ± 0.10 m yr^{-1} compared to post-modification widening rates of 0.88 ± 0.10 m yr^{-1} across the entire study reach. The interpretation also showed that the mean channel bank widening rates in sub-reach 3 were substantially higher than the other two, implying that channelization had much greater impacts than the dam construction on the lower Kaskaskia River channel morphology change. The significant widening that occurred as the channel adjusted to its increased slope has resulted in a net loss of riparian habitat in this important bottomland forest corridor.

Long-term river gage information from USGS and USACE was also used to investigate the channel bed degradation conditions near river gages through Specific-gage-analysis technique. Specific-gage-analysis is a technique that holds discharge constant to observe trends in a parameter such as stage over time. Two river gages, Kaskaskia River at Carlyle and Kaskaskia River near Venedy Station, were used in the analysis. The downward trends at both studied gage stations suggested that local channel bed degradation occurred at both sites since 1960's.

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SOIL AMENDMENT EFFECTS ON OAK SEEDLINGS AND WOODY COMPETITORS

Jennifer Franklin and Richard Evans[1]

Soil amendments can alter soil fertility and water holding capacity, thereby affecting the relative competitive ability of woody species. The objective of this study is to determine how alterations of the soil carbon:nitrogen ratio affect the growth and survival of planted oak seedlings and the natural establishment of woody competitors on a recently harvested site. Carbon in the form of sawdust, sugar, or a sawdust and sugar mixture (6 percent sugar by weight) was applied at rates of 500 g C m^{-2} and 1500 g C m^{-2} to 5 x 10m plots on a recent clear-cut site in spring of 2004. The site is located on the Tennessee Forestry Research and Education Center in Morgan County, TN. Sugar was spread on the surface using a hand seeder, and sawdust was incorporated by disking. Both disked and non-disked controls were included. On one half of each plot were planted 6 each of one-year-old chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*) and white oak (*Q. alba*) seedlings. The growth and survival of planted oak, and the number of all woody species naturally regenerating on the site are being monitored.

In August of 2005, soil moisture was still significantly greater where high rates of sawdust were incorporated. In the first month after treatment, transpiration rates of all species were reduced in the treatments of sugar alone. Reduced transpiration rates continued in white oak where a high level of carbon had been applied through the first growing season. Significant mortality occurred only in the 1500 g C m^{-2} sugar treatment. There was no significant treatment effect on height or root collar diameter growth of oak seedlings over the first growing season, but herbaceous biomass was reduced by sawdust application. Over two growing seasons honeysuckle cover was reduced in plots with a high application rate of sawdust. The number of stems of red maple and autumn olive declined with the addition of carbon. Stems of other woody species and grass cover did not differ between treatments. Second year growth, soil respiration rates, and leaf nutrient and pigment contents are being analyzed.

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RELATING LAND-USE PRACTICES TO SEDIMENT LOADS IN WEST VIRGINIA'S UPPER ELK RIVER WATERSHED

Jennifer B. Fulton, J. Todd Petty, Steven E. Harouff, Kyle J. Hartman, David W. McGill, and Shawn T. Grushecky[1]

The upper Elk River, located in east-central West Virginia, is considered to be one of the premier cold-water fisheries in the Eastern United States. Timber harvest and development pressures are particularly high in this watershed, and these non-point sources of sediment may threaten the quality of resident trout populations. This project was initiated in order to provide managing agencies with a watershed scale approach for identifying and effectively managing non-point sediment sources. We used satellite imagery and GIS to identify landscape attributes associated with elevated total suspended solid (TSS) concentrations in the watershed. We found that spatial variation in TSS concentration was primarily explained by land use, specifically by development (partial $R^2 = 0.66$), timber harvest (0.13) and census road area (0.08). Temporal variability of TSS concentration was explained by geological and topographical attributes rather than landscape disturbance; these features included the presence of karst geology (0.21), dry flat area (0.28), slope crest area (0.11), and slope bottom area (0.09). Our sampling and GIS modeling approach allowed us to identify critical areas within the watershed where remediation actions may produce significant reductions in sediment delivery to the upper Elk River. This framework will provide watershed managers with the tools necessary to pinpoint areas within the watershed that may be particularly vulnerable to future TSS problems.

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COMPOSITION AND STRUCTURE OF AN OLD-GROWTH WHITE OAK FOREST IN TRANSITION

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Johnson Woods State Nature Preserve is one of Ohio's largest and least-disturbed old-growth forests (62.7 ha). According to the pre-European settlement surveys of Ohio, the area was dominated by white oak (*Quercus alba* L.) and American beech (*Fagus grandifolia* Ehrh.) forests. Dendroecological studies have shown that many of the canopy white oaks are at least 400 years old and have experienced repeated releases from suppression. E. Lucy Braun in her classic text (Braun 1950) described Johnson Woods (then known as Graber Woods) as a white oak forest developing towards a beech-maple forest type. Based on her observations, Braun concluded the development trend of the forest both in the depressions and swells was toward the establishment of a white oak-beech forest with the ultimate establishment of a beech-maple forest.

Since 2001, we have investigated several aspects of the ecology of this forest, including a study of recent canopy gaps that revealed an important portion (17.7 percent) of this old-growth forest was in gaps, most of which were large in area (100-400 m^2). Additionally, over half of the gaps sampled were formed by more than one tree and the average gap maker size was 71.8 ± 21.7 cm, with gap makers ranging in size from 23.7 to 133.7 cm. These results differ from other canopy gap studies in old-growth forests. Specifically, the gap fractions and gap sizes at Johnson Woods are higher than those reported from other forests with similar site characteristics. While there may be many reasons for these differences, we surmise the predominance of poorly drained soils and the advanced age of canopy individuals (canopy white oaks are > 400 years), whose deaths would create a more open canopy, are largely responsible for the larger gap sizes at Johnson Woods than in other old-growth forests of the region where the canopy trees are not nearly as old and large.

In this study, we examined the composition and structure of the current forest and compared these data with similar measurements made by E.L. Braun in the 1930s. While the diameter distribution of Johnson Woods is indicative of a multi-cohort forest, a comparison between Braun's 1930s survey and our current study indicates a shift in species importance. Specifically, white oak canopy tree importance has decreased from 45.7 percent in the 1930s to 2.8 percent in 2004, while sugar maple (*Acer saccharum* L.) and American beech have increased in terms of relative density over the past 70 years. Similarly, although white oak seedlings are common in the ground-flora layer, white oak was entirely absent in the sapling layer. Based on a comparison of these results with the earlier surveys, it appears that Johnson Woods is following Braun's predicted successional trajectory towards a mesophytic or beech-maple forest type.

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INCREASED USE OF LOW-QUALITY WOOD IN THE UPLAND HARDWOOD REGION OF NORTH AMERICA: CAN WE UTILIZE MORE OAK IN ORIENTED STRAND BOARD?

Jody D. Gray, Joseph F. McNeel, and John R. Noffsinger[1]

Abstract—An extremely large quantity of low quality oak is available each year in West Virginia. This paper looks at overcoming some of the obstacles associated with the use of this oak in oriented strand board. Different variables that effect strand production were investigated and an optimal combination determined. It is possible to produce geometrically desirable strands from different low quality oak species.

INTRODUCTION

Research has shown that over 1,125,000 tons of low quality oak logging residues are available each year in West Virginia. One of the largest consumers of low quality logs and tree parts is the engineered wood products industry, particularly oriented strand board (OSB). Current use of oak in resin bonded engineered wood products, such as OSB, is limited by the manufacturers to a very small percentage of the total wood mass. This limitation is primarily due to the poor strand ability of oak. The refractory nature of oak species results in a very thin and narrow strand that may lower mechanical properties. Another draw back of stranding oak species is the resulting higher percentage of fine wood particles produced. These fines must be screened out of the process, hence lowering the yield from the log. The working life of the knives used by the strander is significantly reduced as well, which may be due to the density of the oak species.

METHODS

Oak logs of both red oak (*Quercus rubra*) and white oak (*Q. prinus*) were sent to the Pallmann Corporation in Germany for test stranding. We investigated the effect of varying knife angles, knife projection, knife grinding angle, and carriage speed on the geometric pattern of strands produced. Strands were sent back to the United States and analyzed for geometry. Size was classified into eight different categories using a BM&M shaker. Strands were measured for thickness from the 1 ¼ inch tray, and a weighted average of strands was measured from all trays for length and width, along with fines content.

RESULTS AND DISCUSSION

The descriptive statistics of the study are shown in table 1. The "Length" and "Width" variables are the weighed average results. The "Thickness" is average strand thickness and is not a weighted average. The classification data is shown as < 3/16 inch or fines and 1inch+ or strand material.

Table 1—Descriptive statistics

Variable	n	Mean	Standard deviation	Minimum	Median	Maximum
Length	6	3.8987	0.0262	3.8571	3.8976	3.9385
Width	6	0.7442	0.0918	0.6231	0.7350	0.8958
Thickness	300	0.0291	0.0074	0.0130	0.0290	0.0610
< 3/16 inch	6	10.03	1.81	7.37	10.22	12.01
1 inch +	6	66.94	5.04	59.82	67.68	72.40

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The weighted average length of 3.9 inches and width of 0.74 inch are comparable to the weighted average of the surface furnish at the OSB mill. The mill's weighted average length after drying is 3.10 inches and the width is 0.56 inch. The oak results appear to be better but it may be due to not drying the material in a rotary dryer like the mill does before measuring the weighted average length and width. The rotary dryer tends to break up the furnish as it "tumbles" through the dryer drums. On the other hand, the oak strands were air freighted from Germany, and the handling of the oak strands may have created breakage but how much was undeterminable. The fines content is excellent when compared to the mill's typical fines content. The mill normally has fines after the stranders, before drying, of around 15 percent to 25 percent with an average of about 19 percent, by weight. The oak fines content of 10.03 percent is superb in comparison. The fines results are comparable since both were taken after stranding before screening and drying. If anything the oak strands may have been adversely impacted because they were dry when shipped back from Germany.

VARIATION AMONG YEARS FOR MAST PRODUCTION BY OAKS IN MISSOURI

David P. Gwaze[1]

The ecological significance of oak mast production is manifold, particularly in the heavily forested portions of Missouri. Oak mast is an important source of fall and winter food for deer, squirrels, turkeys, and many other wildlife species. Abundance of wildlife may be expected to increase in good mast years. Conversely, a poor mast year can result in lowered reproductive success and reduced numbers of mast-consuming wildlife. Furthermore, mast production is essential for oak regeneration. Despite the importance of mast production to wildlife and regeneration, there is little information about oak mast production patterns in Missouri. The objectives of the study were: (1) to estimate species-to-species and year-to-year oak mast production and (2) to determine if climatic factors account for the year-to-year variation in oak mast production.

The study was conducted in oak-hickory forests owned by the Missouri Department of Conservation located in south Missouri. The major oak species can be classified into two groups: red and white oaks. Species in the red oak group included black oak (*Quercus velutina* Lam.), scarlet oak (*Q. coccinea* Meunchh.) and northern red oak (*Q. rubra* L.), while those in the white oak group included white oak (*Q. alba* L.) and post oak (*Q. stellata* Wangenh.). Oak mast data consisted of yearly visual evaluation of mast yields of individual trees collected from 1960 to 2004 by the Missouri Department of Conservation Forestry Division staff. Each tree was evaluated for mast production using a relative abundance rating (heavy-3, medium-2, light-1, few to none-0). The ratings were used to calculate a mast production index for each species and each species group. Climatic data were obtained from the Missouri Climate Center, University of Missouri-Columbia, Columbia, MO. The climatic data included rainfall, maximum temperature, minimum temperature, and average temperature.

The Pearson correlation coefficients were used to evaluate: (1) masting cycles by correlating current mast production with lagged values of mast production for 1, 2, 3, 4, and 5 prior, (2) masting synchrony among the red and white oaks, and (3) the influence of weather variables on mast production. All statistical analyses were carried out using SAS.

Over the 45-year period, red oaks had a higher average mast production than white oaks. Year-to-year variation in mast production was considerable in both red and white oaks, as observed in many other oak mast studies. There were no regular masting cycles observed in these oaks, and the interval between good masting years appears to range from 1 to 10 years. Poor mast years occurred frequently, and occasionally they occurred in successive years. Thus, the resource depletion phenomenon was not observed in the study because a good masting year was not necessarily followed by a poor masting year. Generally, red and white oaks appeared not to mast in synchrony with each other, although in some years good or poor mast crops occurred in the same year. The best mast production year for red oaks was 2000, and that for white oak was 1974. The worst mast production years for red oaks were 1983 and 1984, and those for white oaks were 1973 and 2001. The years 1983 and 1984 are likely to have had the most severe impact on mast dependent wildlife species because mast production for both red and white oaks was poor.

In red oaks, current mast production was positively correlated with spring rainfall 2 years prior ($r = 0.46$, $P < 0.01$), but negatively correlated with maximum temperature in winter 2 years prior ($r = -0.50$, $P < 0.01$). In white oaks, current mast production was positively correlated with spring maximum temperature in the same year ($r = 0.45$, $P < 0.01$). The study suggests that masting in red and white oaks are affected by different climatic factors in different years. The pattern of mast production in red and white oaks

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may reflect responses not only to the different climatic factors in different years, but also to the different reproductive cycles. White oaks require only one growing season from the time of pollination to acorn maturity, while red oaks require two growing seasons.

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THE ENCYCLOPEDIA OF SOUTHERN APPALACHIAN FOREST ECOSYSTEMS (ESAFE)

William Hubbard, Daniel Cassidy, and H. Michael Rauscher[1]

The Forest Encyclopedia Network (FEN) is an online scientific content management system (CMS) designed to connect scientific results, conclusions, and impacts with management needs and issues. This particular network is a hypertext-based CMS. FEN is currently comprised of four encyclopedias including the Encyclopedia of Southern Appalachian Forest Ecosystems (ESAFE), the Encyclopedia of Southern Fire Science, the Encyclopedia of Southern Forest Science and the Encyclopedia of Southern Bio-energy Resources. These are available online at http://forestencyclopedia.net. ESAFE was published in November 2004 and contains a wealth of information on the ecology and management of southern Appalachian forest ecosystems. Literature from thousands of sources have been synthesized to provide resource managers, land-owners, researchers, students, and the public at large easy access to scientific knowledge about the forests of the southern Appalachians. All the scientific knowledge in this encyclopedia has been organized as follows:

Landscape: This section contains a biological, geological, climatological, hydrological, and soils description of the southern Appalachian landscape.

Resource Management: This section contains information on the management of the many resources provided by the southern Appalachian region.

Ecology: This section explains the ecological foundations to understand the management of resources.

Forest Health: The insect, disease, nonnative invasive species, and air quality threats to forests of the region are covered in this section.

Social Science: Economics, recreation, native American history, etc., round out the ESAFE encyclopedia.

FEN allows for continuous update to accommodate new research results in a peer-reviewed fashion. The objective of FEN is not to replace the current primary, peer-review journal culture but to add value by extending research to a broader audience.

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EFFECTS OF *MICROSTEGIUM VIMINEUM*, AN INVASIVE C_4 GRASS, ON HARDWOOD REGENERATION

Rochelle R. Jacques and Brian C. McCarthy[1]

Microstegium vimineum (Asian stiltgrass), an invasive C_4 grass, is currently invading the Eastern United States. Its plasticity with respect to various light conditions and ability to rapidly dominate the forest understory makes it a considerable threat to hardwood forest understories. Despite the increasing threats and concerns associated with *M. vimineum*, little is known regarding its direct community-level effects. The objective of this study is to assess the impact of *M. vimineum* on hardwood regeneration in the central hardwood Appalachian forest region.

In the spring of 2005, a randomized complete block design consisting of five open-canopy and five closed-canopy sites (n = 10 total) was established in Calhoun County, WV. Within each block, three treatments were employed: chemical (Sethoxydim), mechanical (hand pulling) and no treatment (control). The growth and survival of planted, two-year old hardwood seedlings (*Quercus rubra*, *Acer saccharum*, *Liriodendron tulipifera* and *Ailanthus altissima*) were assessed within each treatment. Natural herbaceous regeneration and soil nutrients were also measured to determine if site variability affects the competitive ability of *M. vimineum*.

First-year results suggest that *M. vimineum* is very aggressive but that restoration efforts in infected areas may be successful. Continued study will ultimately determine to what extent forest understories can be restored by land owners and forest managers and at what scale.

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EFFECTS OF CONTROLLED BURNING AND SHELTERWOOD THINNING ON OAK MAST PRODUCTION IN TWO SOUTHEASTERN OHIO FORESTS

Jeffrey A. Lombardo and Brian C. McCarthy[1]

The decades long practice of fire suppression in the hardwood forests of the central and Eastern United States has likely contributed to the establishment of a dense understory of mesic, fire intolerant species. These species, namely red maple (*Acer rubrum* L.) and sassafras (*Sassafras albidum* (Nutt.) Nees.), inhibit the natural regeneration of the canopy dominant oaks by suppressing the growth of the oak seedlings and inhibiting their progress toward advanced regeneration. More recently, fire has resurfaced as a management tool for promotion of the oak-dominated hardwood forest. In addition, thinning of the forest is also being incorporated as a fire surrogate to reduce the amount of basal area and stimulate regeneration. An important mode of action by which these silvicultural techniques work is by destroying the fire intolerant competition. Stand level treatment effects on oak seed production are less well studied and understood, despite the obvious relevance to regeneration. In this study we examined oak seed production from two forests in southeastern Ohio under different treatments of thinning and prescribed fire, beginning in the fall of 2001. Each of the two study sites were divided up into four 20 ha treatment areas consisting of: (1) control, (2) thinning, (3) thinning followed by prescribed fire, and (4) prescribed fire. Within each treatment, nine black oak (*Quercus velutina* Lam.) and nine chestnut oak (*Q. prinus* L.) trees were selected and two 0.25 m^2 seed traps were set up 1.5 m above the ground beneath each tree. Traps were set up each season in July and collections were conducted mid-month beginning in August and ending in December. Thinning treatments were completed in late fall 2000 and controlled burns were conducted the following spring 2001 and again in spring 2005. A mast crop of chestnut oak occurred the second season after the initial treatments were installed and a second mast crop occurred in the fall of 2005. Seed production in the intervening years was consistently low; however, we did find the greatest number of seeds in the thin + burn plots. The black oaks in our study sites produced a bumper crop in 2001; subsequently production remained moderate for the remaining 2002-05 seasons with the greatest amount of seeds occurring in the burn plots. We were unable to show any significant treatment effects on acorn production. Additionally, treatments failed to initiate a mast crop for either species of oak. Seed production has been known to vary considerably among species as well as among individual trees of the same species. Thus, genetics and environment appear to be of greater importance to masting than do stand level treatments. From a forest management perspective, identification of the best seed producers prior to any stand level silvicultural application may be the best technique for promoting increased oak seed production and putatively enhanced oak regeneration.

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EVALUATION AND COLLECTION OF SUPERIOR BLACK CHERRY TREES IN THE ALLEGHENY NATIONAL FOREST

James McKenna and Keith Woeste[1]

In 1966, the USDA Forest Service began a tree improvement program based on plus-tree selection of black cherry (*Prunus serotina*) primarily from the Allegheny National Forest (ANF), the most important timber production area for the species. Mature plus-trees were selected in areas where black cherry is a dominant species growing in even-aged stands. The goal of the program was to provide genetically improved planting stock for reforestation. For each plus-tree, three comparison trees of similar age were evaluated. Traits selected for were: merchantable volume, apical dominance, absence of black knot (caused by the fungus *Apiosporina morbosa*), gummosis, and timber form. Detailed records for each select tree have been maintained by the ANF and the USDA Forest Service Region 9 Geneticist, providing the opportunity to re-evaluate and re-collect these trees. These selections represent a genetic resource whose breeding value remains to be fully investigated.

In March of 2005, we re-visited 36 of these trees to collect scion wood for our breeding population at the HTIRC. At the time of collection, we re-measured DBH, recorded incidence of black knot and gummosis, and noted the general health of each tree. Trees were 64 years old on average when they were selected in the 1960's and had an annual average DBH growth rate of 0.77 cm^{-yr}. Today, they average 102 years old with an annual DBH growth rate of 0.50 cm^{-yr}. Eighty-six percent (31/36 trees) remained black knot free in the 38 years since selection.

A 23-year-old planting of open-pollinated seedlings from ramets of these selections and comparison seedlings from non-select parents was measured in the fall of 2005. The planting site was a clear-cut in the ANF (McKean Co., PA). The select seedlings were significantly larger than the comparison seedlings in height, diameter, and volume (19 percent, 24 percent, and 160 percent, respectively), but the incidence of black knot was not significantly different between source types.

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EVALUATION OF TREE SPECIES COMPOSITION AS A TOOL FOR CLASSIFYING MOISTURE REGIMES IN OAK FORESTS OF EASTERN KENTUCKY

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Some workers predict site moisture regime, and by extension site quality, on the basis of tree species composition. By using a species composition method they avoid difficulties involved in using relationships between tree height and tree age to predict site quality in many-aged and multi-species hardwood forests like those common in the Eastern United States. A prototype method of site classification based on arborescent species was compared with conventional ordination analysis for stratifying plots by moisture regime on upland areas in the Daniel Boone National Forest. The species composition method was developed by assigning each arborescent forest species in the Southern Appalachian region to a class associated with its typical occurrence on a perceived moisture gradient (i.e.; xeric = 1, mesic = 4). A site moisture index is determined by calculating the mean gradient value for all species occurring on a sample plot.

We identified to species all arborescent plants with d.b.h. ≥ 2 cm on 93 0.4-ha plots and noted the presence or absence of these plants by species for the individual plots. Thirty-seven arborescent species were present in the study area and moisture index values ranged from 1.83 to 3.17. Ordination by nonmetric multidimensional scaling of species presence or absence values indicated that most variation in the plot x species matrix was associated with three multivariate axes, one of which was highly correlated (r = 0.92) with the moisture index values. Classification of the ordinated plots on that axis into three moisture-regime groups resulted in complete separation of plots assigned to the driest and wettest regimes; plots in the intermediate regime moderately overlapped the other two.

This study suggests that the prototype species composition method produces site classification results that are similar to those produced by an objective ordination analysis. The species composition method of site classification employs routinely available plot inventory data and provides managers of forest resources in eastern Kentucky with a simple, intuitive, and easily applied method for stratifying sites into moisture regime classes.

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CARBON SEQUESTRATION AND ENHANCED WILDLIFE HABITAT RESULTING FROM BOTTOMLAND HARDWOOD AFFORESTATION ACTIVITIES IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY

Richard P. Maiers, Andrew J. Londo, Donald L. Grebner, Jeanne C. Jones, Changyou Sun, Michael S. Cox, Jarod H. Fogarty, and Janet C. Dewey[1]

Forested ecosystems have the capacity to sequester large amounts of carbon and are important reservoirs of the world's total carbon, both in the wood and in the soil. Forested wetlands, while composing a small portion of the earth's surface, contain a large portion of the terrestrial carbon pool. Deforestation and drainage of forested areas result in increased soil temperatures and decomposition, followed by carbon loss. The Lower Mississippi Alluvial Valley (LMAV) has undergone the most widespread loss of wetlands in the form of bottomland hardwood forests in the United States. Many thousands of acres deemed marginal for agriculture are now being afforested with assistance from Federal and state cost-share incentive programs. By 2040, an estimated 34 million acres of retired agricultural land will be planted with trees. In addition, many owners holding potentially viable bottomland hardwood lands for non-agricultural uses have become interested in merging their present land-use needs with reforestation programs.

This project is a partnership with the Carbon Fund, Entergy Corporation and Mississippi State University. Six hardwood species combinations by two fertilizer treatments by two competition treatments in two soil types in the LMAV are being studied to evaluate the impacts of fertilization and herbicides on bottomland hardwood establishment, growth, and above- and belowground carbon storage. The cost effectiveness of the treatments for sequestering carbon, wildlife interactions, and herbaceous plant species are also being evaluated.

The carbon data generated in the project will be analyzed on a cost per ton sequestered basis. The data generated by this study will serve as a basis for evaluating the cost effectiveness and expected financial returns for the proposed silvicultural regimes. Costs for each activity by prescription will be monitored, documented, and compared to the response variables for each silvicultural treatment. The cost efficiency will be calculated using the response variable information and cost of treatment. Financial criteria such as land expectation value (LEV) will be calculated to determine the optimal silvicultural regime. The LEV will be calculated on a before- and after-tax basis to more accurately reflect investment returns for private landowners at existing federal income tax brackets. In addition, carbon production capacity for each regime will be compared and evaluated for economic tradeoffs. This comparison will serve as a basis for evaluating the potential of governmental incentive programs to promote carbon sequestration and minimize inefficiencies in resource allocation.

Tree seedling herbivory, particularly due to white-tailed deer, and the factors influencing herbivory rates are important concerns in reforestation efforts. We will investigate effects of several factors on deer herbivory rates by monitoring tree seedling herbivory damage on plots treated with various combinations of herbicide, fertilizer, and tree species. Seedling survival may be maximized by identifying the best combination of treatments.

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Effects of reforestation over time on wildlife populations in treatment plots will be monitored by call counts for birds and anurans, area searches for herpetofauna, live-capture traps for small mammals, and digital motion cameras for large mammals. In relation to wildlife habitat use, relative abundance of wildlife food and cover plants will be measured among reforestation treatment types to identify those that most benefit wildlife, especially concerning threatened and endangered animals (e.g., Louisiana black bear).

Some forest regeneration practices have the potential to stimulate growth and spread of exotic plant species. Plant community characteristics (i.e., species richness, stem density, species dominance) will be monitored within 1-m^2 quadrants at each treatment plot. The effects of reforestation treatments on the spread of exotic plant species including cogon grass, Johnson grass, and kudzu will be monitored at the same time. These efforts will provide the basis for recommending best treatments that will maximize success of reforestation efforts, provide suitable habitat for wildlife, and inhibit exotic plant growth.

SURVEY OF WEST VIRGINIA FORESTRY CONSULTANTS: SERVICES PROVIDED AND FEES CHARGED TO THE PRIVATE FOREST LAND OWNERS IN THE STATE OF WEST VIRGINIA

Dheeraj Nelli, David W. McGill, Kathryn G. Arano, and Shawn T. Grushecky[1]

Many private landowners in West Virginia are unaware of the services and fee structures offered by consulting foresters. This information on services and fees allows landowners to anticipate how much they might have to spend to implement a forestry practice on their property with the assistance of a consulting forester. To develop a comprehensive list of services and fees charged for forestry services, we conducted a mail survey of West Virginia forestry consulting companies in the summer of 2005.

The survey response rate was 56 percent. In addition to collecting information on forestry services and fees, we also collected information pertaining to firm characteristics. The results of the survey indicate that most of the consulting forestry businesses (56 percent) in West Virginia are under sole proprietorship, with at least one full time forester and one employee. These consulting firms have also been in the business for an average of 15 years; averaging 39 clients per year, mostly small (less than 100 acres) NIPF landowners. The average minimum acreage requirement to consider a consulting job is 10 acres. Consulting foresters are willing to travel from 30 to 500 miles or 1 to 6 hours to offer their services.

Forestry services offered begin from management plan preparation to timber harvesting and sales. Services offered by more than 50 percent of the consulting foresters surveyed include timber sale administration, timber appraisals, timber inventory and cruising, expert witness testimony, and forest management plans and timber damage/trespass appraisals. Most forestry activities are charged on a dollar per hour basis with the exception of timber sale administration and forest stewardship plan preparation, which are commonly charged based on percent of sale revenues and dollar per acre, respectively.

Timber sale administration was the most common service offered, with an average consulting fee of 12 percent of timber sale revenues. Average hourly fees charged for most of the services ranged from $30 to $72 per hour. Expert witness testimony is the most expensive service, averaging $72 per hour. Services like financial analysis, safety seminars, real estate appraisals, accident investigation and land surveying are charged on an average of $50 to $70 per hour. About 21 services have average fees ranging from $40 to $50 per hour. Services such as hunting lease administration, soil mapping, forest management plans, reclamation of logging disturbances, NTFP assessments and management and wildlife habitat improvement are relatively cheaper, averaging less than $40 per hour.

The two major challenges currently faced by the consulting foresters are cost of doing business, which includes taxes, health insurance, fuel and transportation cost; and competition from service foresters, industry procurement foresters and moon-lighters.

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FIRE HISTORY OF A SOUTHERN ILLINOIS BOTTOMLAND FOREST

John L. Nelson, Charles M. Ruffner, and John W. Groninger[1]

Forest management strategies based on natural disturbance regimes require an understanding of fire's role across all landscape positions and cover types. Within the central hardwoods forest region, fire history research has centered on upland forests and conifer stands. However, little is known about the role of fire in bottomland forests with some suggesting that fire occurs rarely (Brinson and Rheinhardt 1998, Light and others 2002), and its importance is often discounted, except during periods of extreme drought. Others, however, believe prior to European settlement fire played an important role (Dey 2002, Nelson and Sparks 1998). In this paper, we present the fire history of a bottomland forest at Mermet Lake State Conservation Area in southern Illinois. We found fire to be common prior to the mid 1950's, before declining and becoming exceedingly rare after the mid 1960's.

The present study examines the fire history of two bottomland stands in southern Illinois. The stands are located at Mermet Lake State Conservation Area, in Massac County, Illinois. Drainage of the area and conversion to agriculture had occurred across much of the land comprising the conservation area prior to 1938. Forest conversion to row cropping continued until acquisition of the land by the State, with all agricultural usage ceasing by 1959 on lands included in this study. The entire study area supported mature hardwood forests prior to a 2003 stand-replacing tornado and salvage harvest.

Our analyses of fire scars from these two stands indicate fire was common during the first half of the 1900's. This corresponds to the common practice of burning crop residue and other vegetation prior to plowing in the fall of the year. These fires appear to have frequently encroached into the adjacent forest stands and abandoned fields. Fire frequency declined dramatically after the mid 1950's and was excluded by the end of the 1960's.

Results of a 2005 inventory indicate oaks, which were the dominant species in the pre-tornado stands, represent less than 2 percent (135 oaks/ha) of the regeneration class. Further research is needed to determine whether the lack of fire over the last 40 years contributes to or is merely coincidental with the decline of oak dominance following the stand-replacing tornado of 2003.

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THE SUCCESSIONAL STATUS OF TWO TABLE MOUNTAIN PINE (*PINUS PUNGENS*) STANDS IN THE SOUTHERN APPALACHIANS, TENNESSEE

Christopher M. Oswalt, Wayne K. Clatterbuck, and Brian T. Hemel[1]

Table Mountain Pine (*Pinus pungens*), a species endemic to the Southern Appalachian mountain chain, is experiencing successional replacement by mixed hardwood species and, in some cases, other *Pinus* species. *P. pungens* replacement over the past century is largely the result of altered natural and anthropogenic fire regimes due to fire suppression efforts. However, *P. pungens* replacement is also occurring through disturbance-mediated accelerated succession, due to recent Southern pine beetle (SPB) (*Dendroctonus frontalis*) outbreaks, on sites where the fire regime has only been moderately altered. *P. pungens* stands in the southern Appalachians have the potential to disappear altogether. Two *P. pungens* stands of differing age and structure at Horsehitch Gap on the Cherokee National Forest in Greene County, TN were analyzed using dendrochronology and stand reconstruction techniques. The stands represent colonization periods resulting from two stand replacing fires in 1941 and 1981. The 1941 stand has experienced disturbances caused by low intensity ground fires and SPB. In the 1981 stand, SPB appears to be accelerating the successional shift from a *P. pungens* dominated community to a hardwood community dominated by blackgum (*Nyssa sylvatica*) and sclerophyllous oak species. The 1981 stand has experienced multiple waves of density dependent mortality, yet currently appears stagnate. No disturbances of any kind were recorded in the 1981 stand, following stand initiation. Currently, both stands are in danger of being replaced by other species. Without management intervention, table mountain pine communities stand to be lost in the southern Appalachians.

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RESPONSE OF THE NON-NATIVE INVASIVE GRASS, *MICROSTEGIUM VIMINEUM* (TRIN.) A. CAMUS, TO THREE LEVELS OF CANOPY DISTURBANCE

Christopher M. Oswalt, Sonja N. Oswalt, and Wayne K. Clatterbuck[1]

We investigated the impacts of *Microstegium vimineum* (Trin.) A. Camus, on the composition and structure of native woody regeneration following a range of canopy disturbances. Our objectives were to (1) quantify the differences, if any, in mean end-of-season understory vegetation biomass between the undisturbed and disturbed sites, (2) to quantify the differences, if any, in *M. vimineum* percent cover and biomass by canopy disturbance severity, (3) to quantify the relationship, if any, between *M. vimineum* percent cover and native woody species regeneration density, and (4) to quantify the relationship, if any, between *M. vimineum* percent cover and native woody species regeneration diversity.

Understory vegetation biomass differed between the disturbed and undisturbed units (P=0.009). Total stems ha^{-1} of woody species declined with increasing *M. vimineum* cover values (P<0.001, r^2=0.81). Species richness of native woody species also decreased with increasing *M. vimineum* percent cover alone (P=0.0023, r^2=0.47). Our results indicate that *M. vimineum*, may have a negative impact on native woody species regeneration in southern forests.

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CORRELATIONS BETWEEN TREE CROWN CONDITION AND SHADE TOLERANCE, CROWN FORM, AND LIGHT AVAILABILITY

KaDonna C. Randolph[1]

Individual tree crown condition is the result of a combination of many factors including genetic traits, growing site characteristics, and past and present external stresses (e.g., drought, insect outbreaks, fire, etc.). Shade tolerance and the extent to which terminal buds control the length and orientation of lateral branches (epinastic control) are the two primary physiological characteristics affecting crown condition, while light availability is likely the most influential environmental factor. The general literature suggests that shade tolerant species maintain denser, wider, and longer crowns than shade intolerant trees, and that regardless of shade tolerance an increase in light availability allows all species to maintain larger, denser crowns.

Crown condition data collected by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Program were analyzed to clarify relationships between stand density variables, crown structure descriptors, and crown condition indicators. FIA measures a suite of crown condition indicators on its Phase 3 (or P3) forest inventory plots to aid the reporting of forest health conditions and trends in the United States. The crown condition indictors utilized were crown density, crown diameter, uncompacted live crown ratio, and crown light exposure. In addition, two stand density variables, number of live stems and total live basal area (trees $\geq$ 5.0 inches dbh), were calculated for each FIA P3 subplot. For the analyses, crown forms and shade tolerances were assigned to 34 hardwood species in 11 states in the Southern United States. Shade tolerances were divided into five groups: very intolerant, intolerant, intermediate, tolerant, and very tolerant. Crown form was partitioned into six classes: conical, columnar, oval, rounded, broad-spreading, and flat-topped. Spearman rank correlations (rho) among the crown condition indicators and stand density variables were calculated for all species combined. Analyses including crown diameter were completed with data collected in 1998 and 1999 (5,351 trees). All other analyses utilized data collected in 2000 and 2001 (4,931 trees).

The correlations among the crown condition indicators and stand density variables supported the suppositions in the general literature. Increased light availability was associated with larger and denser crowns regardless of shade tolerance. Spearman rank correlations between crown light exposure and crown diameter, live crown ratio, and crown density were 0.24, 0.10, and 0.15, respectively. Correlations between the number of live stems per subplot and crown diameter, live crown ratio, and crown density were -0.19, -0.26, and -0.08, respectively. Longer and wider crowns also were associated with increasing shade tolerance; however, denser crowns were not. Spearman rank correlations between shade tolerance and live crown ratio, crown diameter, and crown density were 0.10, 0.11, and -0.04, respectively.

The correlations also indicated that crown diameter and live crown ratio tended to increase as crown form shifted from conical to rounded to flat-topped (rho = 0.24 and 0.14, respectively). Crown density decreased as crown form shifted from conical to flat-topped (rho = -0.07).

Even though the correlations among the different variables were not exceptionally strong, they were generally consistent with expectations based on previous research. The variables considered here probably interact in ways that would provide further insight into the impact of physiological and environmental factors on tree crown condition; however, these simple relationships provide a starting point for understanding and modeling tree crown condition.

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EVALUATING THE DISTRIBUTION AND SHADE-TOLERANCE OF HAY-SCENTED FERN ACROSS A LIGHT GRADIENT

Alejandro A. Royo and Walter P. Carson[1]

Hay-scented fern (*Dennstaedtia punctilobula* (Michx.) Moore) is a native rhizomatous fern that spreads aggressively throughout oak-transition and northern hardwood forests understories when deer overbrowsing reduces the abundance of competing understory vegetation, and overstory disturbance increases understory light levels (Cody and others 1977, de la Cretaz and Kelty 1999). Under these conditions, hay-scented fern forms a dense, nearly impenetrable stratum that severely inhibits successful tree regeneration (George and Bazzaz 1999, Horsley 1993). Therefore, understanding its current distribution as well as the factors regulating its persistence is crucial in managing its spread and mitigating its impact across the forested landscape.

To assess current hay-scented fern abundance throughout the Allegheny National Forest, we surveyed 47 randomly located forest stands along existing roads and assessed percent cover using a stratified-random belt transects. Using an experimental approach, we measured changes in hay-scented fern frond density and height to alterations in light levels. In one set of experiments we altered light availability using shade cloth (control, 50, 27, 15, 10, and 5 percent) in an oak-northern hardwoods transition understory. In a related experiment, we transplanted fern monoculture pots to forested areas spanning a wide light gradient (< 1 to 100 percent of full sun).

We found hay-scented fern was present on 81 percent of the sites surveyed and reached potentially interfering levels of abundance on 47 to 59 percent of the sites. Both the shade cloth and transplanted pot experiments demonstrated that, once established, hay-scented abundance is resilient to strong light reductions. The shade cloth results show that light reductions of 73 percent (2.16 to 3.24 percent of full sun) and 85 percent (1.2 to 1.8 percent of full sun) were required to reduce frond density and height, respectively, below control levels after three growing seasons. Similarly, the transplant experiment indicated that altering light availability did not influence frond density or height in the short term (1 year).

These results demonstrate that hay-scented fern invasion is a more pervasive and intractable challenge than previously thought (e.g., McWilliams and others 1995). This survey suggests that 241,000 to 303,000 acres in the Allegheny National Forest alone are impacted by a dense hay-scented fern layer. The manipulations of light availability strongly suggest that ambient light levels in oak-transition and northern hardwood forests are sufficient to allow the continued monopolization of the understory by hay-scented fern. Furthermore, these manipulations demonstrate that fern abundance will gradually diminish only under the most severe light limitations (< 2 to 3 percent of full sun). Thus, the potential exists for a long-term control strategy if light available to the fern stratum decreases following succession towards later successional canopy species or if early successional shrubs can establish, grow, and displace fern (Horsley and Marquis 1983).

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NATURAL RESOURCE INTERPRETIVE PROGRAMS: AN EVALUATION

A.J. Stegmann and B.E. Cutter[1]

Most state and federal agencies involved in the management of natural resources offer educational programs that serve several purposes. In addition to providing the traditional public education programs, they provide benefits to the agency itself. Resource managers have an outlet through which they can communicate their management agendas and goals and then receive public feedback. Educational programs also provide a means of public outreach, allowing agency personnel to become familiar faces to local residents. Finally, these programs afford members of the public the opportunity to become informed about, and involved with, the resources available to them.

In Missouri, the Departments of Conservation and Natural Resources plays this vital role. This study evaluates the programs offered by four sites that serve schools in St. Louis and St. Charles counties. Opinions were gathered from interpreters and educators alike. Responses were compared both among classroom teachers and also between the interpretive staff and teachers.

In addition, as the Internet becomes a standard means of communication, new opportunities are available to disseminate information. This study makes use of traditional surveys in an untraditional way. Surveys were posted online instead of using traditional paper copies. This in turn presented some new challenges!

We had a response rate of nearly 50 percent for the entire study; however, there were some unexpected demographic differences. Homeschoolers in this area did not participate in the on-line survey. For at least one of the study sites, these students comprised a large share of their audience. The survey did point out areas in which each site could use improvement. Educators reported that the programs offered by the agencies met their required curricula and academic goals well. However, in some instances, those presenting the program had trouble connecting with and holding the attention of the audiences. Scheduling issues were also a concern at every site.

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USE OF NATIVE SEED MIXTURES TO IMPROVE EROSION CONTROL AND WILDLIFE HABITAT ON LOG LANDINGS FOLLOWING TIMBER HARVEST IN THE UPPER ELK WATERSHED OF WEST VIRGINIA

Lisa R. Tager, Shawn Grushecky, David W. McGill, William Grafton, and John Edwards[1]

The Upper Elk River is considered one of the highest quality cold-water fisheries in the mid-Atlantic region. The watershed is highly forested (>90 percent) and supports a large wood products industry. Due to the Upper Elk Rivers Category I status, efforts are underway to reduce nonpoint source pollution from timber harvests. Once logging sites are retired, timber companies are required to reclaim skid trails and log landings by reseeding them to prevent erosion off of retired sites. The seed mixtures used, however, are often filled with non-native plant species and may not create suitable wildlife habitat or forage.

We created a study to test three possible native seed mixtures to be used for reclamation that would provide erosion control as well as high quality habitat. We reclaimed eight retired log landings in the Upper Elk Watershed using four different seed mixtures. Three of the mixtures included only native species, while the fourth mixture was a standard reclamation mix used by timber companies. The three native mixes included a wildlife mix, a wildflower mix, and an erosion control mix. Species diversity was assessed through small mammal trapping and camera scent stations. Forage quality was measured by vegetation clipping and exclosure-related browse estimates. Silt fence sediment wells were constructed on each landing to measure erosion control effectiveness of each seed mixture.

After one season of research, there were distinct differences between the four seed mixtures. Small animal trapping and scent station surveys indicated that the wildlife mix was most successful in providing habitat and cover to small mammal populations in the area. Forage quality testing signified that the wildlife mix was also most efficient in providing high quality forage to wildlife. Biomass measurements from vegetation clipping showed that the standard reclamation mix grew the most biomass, with the wildlife mix coming in as the second best biomass producer. Erosion control effectiveness deemed difficult to measure, and therefore will be studied in a laboratory setting. However, biomass production is often a good indicator of erosion control effectiveness, which leads us to believe that the standard reclamation mix and the wildlife mix will provide the best erosion control in our laboratory studies. One more season of field research will be performed to verify present research findings.

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INFLUENCE OF IRON INDUSTRY CHARCOAL PRODUCTION ON FOREST COMPOSITION AND STRUCTURE ON A WESTERN HIGHLAND RIM FOREST, TENNESSEE

Saskia L. van de Gevel, Justin L. Hart, David F. Mann, and Wayne K. Clatterbuck[1]

Forests of the Western Highland Rim were heavily influenced by the iron industry during the 19th and 20th centuries. Production of iron required large amounts of charcoal. Timber was cut, burned in hearths to produce charcoal, and then transported to local furnaces and forges. The impacts of charcoaling (i.e. charcoal production) are still evident on the landscape today. We used forest inventory and tree-ring methods to investigate stand dynamics of ridgetop communities on the Western Highland Rim in Tennessee.

The study was conducted in Stewart State Forest (SSF), Stewart County, Tennessee, in the northcentral portion of the State. The 1371 ha that comprise SSF were acquired by the State of Tennessee in 1933. The study area is located within the Western Highland Rim section of the Interior Low Plateau physiographic province. The area is characterized by broad ridges, dissected by numerous streams. The soils of the area are moderate to well drained, thin silt loams which are underlain by cherty limestone of the Warsaw Formation. We sampled ten 0.04 ha circular plots on ridgetops of SSF, five that were located in areas previously used as charcoal hearths and five in areas not directly influenced by charcoal production.

The influence of charcoaling and associated fire frequency and severity, grazing, and agricultural clearing on forest development reflects a history of intense land use in Stewart County during the 19th and 20th centuries. There are 72 known charcoal hearths on the 1371 ha of SSF. The forest was clearcut at least once in its history for charcoal production. Charcoal hearths along the Western Highland Rim were generally used multiple times and as a result areas adjacent to hearths were cut over to generate fuel for charcoal production more than once. After charcoal production ceased (early 1900s) the area was cultivated and used for grazing of domestic livestock before the state of Tennessee acquired the land in 1933. In addition to anthropogenic disturbances during the past 200 years, SSF has been impacted by tornado events, including tornadoes in 1983, 1991, and 2000. The forest experienced salvage cuts following these disturbance events.

Anthropogenic fires in charcoal hearths were high intensity, concentrated events that permeated soil profiles at greater depths than would occur during typical surface fires. Organic matter was rapidly volatilized at the high temperatures resulting in nutrient poor, hydrophobic soils in charcoal hearth sites. The poor soil conditions caused by the charcoaling have influenced ridgetop forest communities. Based on importance values, hearth sites were dominated by *Quercus alba* L., *Q. rubra* L., and *Q. stellata* L. Non–hearth sites were dominated by *Q. alba* and *Q. rubra*, and did not contain *Q. stellata*. Distinct differences in tree establishment were found between hearth and non-hearth sites. All trees (n=81) within our study sites were established between 1890-1955. There was a more narrowly concentrated cohort establishment (1915-1940) of *Quercus* species in the non-hearth sites.

Differences in stand structure and species composition for hearth and non-hearth sites are attributed to differences in fire intensity altering soil characteristics between the sites. Future research should be directed towards a regional level study that incorporates historic records of operation and known hearth, furnace, and forge locations to appreciate the extensive influence of charcoaling on forest composition and structure on the Western Highland Rim.

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VALUE LOSS RATE FOR HARDWOOD TREES UPROOTED IN A SEVERE WINDSTORM ON THE ALLEGHENY PLATEAU

Janice K. Wiedenbeck and Susan Stout[1]

In July 2003, a severe straight-line wind storm caused a severe disturbance on approximately 32,400 ha of forest land on the Allegheny Plateau in western Pennsylvania. On affected land an estimated 15 to 40 percent of the trees were blown down. A suite of studies are being conducted to assess the ecological and economic effects caused by a disturbance of this magnitude. To assess the rate of loss in value of the timber resource affected by the disturbance, four plots were established on the Kane Experimental Forest on affected sites. Within these plots we sampled the tree grade, size, and condition class (broken tops, intact tops, on ground, off ground) of the trees 10 months after the storm. Sawmill recovery studies were conducted on similar log samples at intervals of 10 months, 15 months, and 23 months after the storm. The volume and value of the lumber recovered in the first two sawmill studies conducted on black cherry and red maple logs cut from trees that had been uprooted was not reduced from expected levels for logs of these two species. However, the value of veneer logs 15 months after the disturbance was reduced by an average $0.50 per board foot.

At the beginning of the second growth season after the storm (spring 2005), only 10 percent of the uprooted trees showed significant leaf flush. Sapwood stain was evident in all species. Significant ambrosia beetle boring was evident in ash and maple. In a forest where 22 percent of the cherry trees produce veneer logs, less than 3 percent of the affected trees produced veneer logs. Almost all of the ash and maple logs that would normally be sold as sawlogs were being sold as pulpwood.

Sawmill study results indicated that severe product value losses occurred in red maple and, to a lesser extent, black cherry. Measurements conducted on a set of logs that were harvested from a nearby ownership that was similarly impacted by the windstorm revealed lumber degrade levels 2 years after the storm. More than 95 percent of the red maple boards sawn from the uprooted trees had severe sapwood stain—a costly degrade in this species. Seven percent of the black cherry lumber was stained but only 3 percent of the lumber contained the most costly form of stain, heartwood stain.

In March 2006, the sample of cherry trees on the Kane Experimental Forest will be sawn on a portable sawmill along with a matched sample of standing cherry so that we can determine more precisely the rate of value loss for the affected trees and so that we may discover any differences in value loss associated with various condition factors noted in our forest plots for each affected tree (e.g., for trees that were broken versus those that tipped over and retained a substantial root ball).

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UTILIZATION OPTIONS FOR DECADENT EASTERN HEMLOCK TIMBER

Matthew F. Winn and Philip A. Araman[1]

The hemlock woolly adelgid (*Adelges tsugae* Annand) is a non-native pest that is damaging the eastern hemlock (*Tsuga canadensis* L.) in the Eastern United States. Nearly one-third of the area inhabited by native hemlocks in the Central Hardwoods region is infested with the insect. Once a tree is heavily infected, it usually dies within 3 years. Most of the current research effort focuses on preventing the spread of the adelgid. Unfortunately, the damage is already done in many areas and there has been little research on potential utilization of the dead hemlocks. The purpose of this study is to examine the current markets for hemlock, determine at what stages of decline hemlock wood can still be used for various products, determine how much product yield is lost when dead material is processed, and make management and harvesting recommendations based on the findings.

In order to assess the current markets for hemlock, a study area was first established in Virginia, West Virginia, and North Carolina. Primary wood manufacturers in the study area are currently being contacted to determine the use of hemlock timber. The following information is being collected from each mill: mill type, volume of hemlock processed, type of products purchased, type of products sold, delivered cost of products purchased, and end-product value. Preliminary results indicate that there is a demand for hemlock lumber for local construction, and there also appears to be a demand for hemlock logs in the log home industry.

Decadent hemlock timber cannot be marketed effectively until the decay rate of dead hemlock trees has been determined. Therefore, an effort is being made to determine the decay rate of dead hemlock trees measured as the wood's specific gravity loss over time since death. To this end, one-half inch increment cores are being collected from dead hemlock trees and adjacent live hemlock trees within the study area. Other information gathered from each tree includes breast-height diameter, branch and bole structures retained, GPS coordinates, aspect, and slope. In order to determine time since death, core samples of dead hemlock trees will be cross-dated with core samples from live, adjacent hemlock trees. Cross dating involves matching the annual growth rings in two different core samples. Theoretically, trees of the same species growing in the same area will have similar growth ring patterns. Once the rings are matched, an estimate of time since death can be made by counting the outer rings present in the live trees but missing in the dead trees.

Because of the physical deterioration associated with dead trees, the product yields from dead timber are expected to be lower than those from trees harvested while alive. In order to determine the volume of usable material lost when processing dead hemlock, a yield study will be conducted. Both live and dead hemlock trees will be followed from standing to final product. Final products will include lumber, log home timbers, and other items. Volume measurements will be taken at each stage of processing, from bucking the tree-length logs to the final product. Tree and log yields will be calculated for both live and dead timber and the average yield lost will be determined.

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GROUNDWATER NITROGEN AND PHOSPHORUS DYNAMICS IN GIANT CANE AND DECIDUOUS FOREST RIPARIAN BUFFERS

Chad M. Yocum, Karl W.J. Williard, Sara G. Baer, and James J. Zaczek[1]

Non-point source nutrient pollution from agricultural land is a growing concern in the United States and world, as agricultural production per unit land area intensifies. Vegetated riparian buffers have been promoted as a means to protect surface waters from the deleterious effects of excess nutrient inputs. Additionally, region-specific research is necessary to test the effectiveness of riparian buffers under a variety of physiographic, hydrologic, and vegetation regimes. The primary objective of our study was to compare groundwater ammonium-N, nitrate-N, and orthophosphate levels in giant cane (*Arundinaria gigantea*) and deciduous forest buffers along three southern Illinois streams in the sand and gravel aquifer of the Cache River watershed. We hypothesized that groundwater nitrogen and orthophosphate levels would decline through both riparian vegetation types in a similar manner. Transects of groundwater monitoring wells were established in giant cane and forest buffers at each of the three study sites. Groundwater was sampled at 0, 1.5, 3, 6, 9, and 12 m from the field edge from February 2004 to present. Groundwater samples were analyzed for ammonium-N, nitrate-N, and orthophosphate concentrations in the Department of Forestry's Water Quality Laboratory at Southern Illinois University Carbondale. Across the three riparian sites, groundwater ammonium-N concentrations were significantly reduced by 66percent within 1.5 m in the forest buffers and by 37 percent within 6 m in the giant cane buffers. However, these overall ammonium-N reductions were driven primarily by substantial reductions at one riparian site. Dihydrous ammonia was applied to the agriculture field adjacent to this site, whereas the other two study sites lacked this fertilizer application. Groundwater nitrate-N concentrations were not significantly reduced across giant cane and forest buffers at the three sites; however, the mean groundwater nitrate-N concentration was significantly ($p \leq 0.0001$) higher in the forest buffers (6.96 mg L^{-1}) compared to the giant cane buffers (0.67 mg L^{-1}). The difference in groundwater nitrate-N levels between the two vegetation types may be due to the preferential uptake of monovalent ions by monocotyledons such as giant cane. Groundwater orthophosphate concentrations were highly variable throughout the riparian buffers. Small orthophosphate amounts caused this high degree of variability in the overall study. Soil phosphorus fractionation analysis is being conducted to pinpoint the sources, amount, and movement of phosphate throughout these three dynamic systems. The relatively advanced age (~40years) of these riparian systems could be adversely affecting their nutrient uptake potential. Management and thinning of such established riparian areas should be considered to maintain them as nutrient sinks. The three sites sustained nonsignificant overall groundwater nutrient sequestration. Overall riparian zone effectiveness in the sequestration of dissolved groundwater nutrients needs further site specific study.

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SURVIVAL AND GROWTH OF NORTHERN RED OAK PLANTING STOCK TYPES THROUGH 17 YEARS AFTER PLANTING

James J. Zaczek, Kim C. Steiner, and Tim Phelps[1]

A northern red oak plantation was established in 1988 within a recently clearcut mixed-oak stand in Harry's Valley, Huntingdon County, Pennsylvania, to evaluate performance of nursery stock and planting methods. Twenty treatments were compared including various stock types of containerized (two gallon containers); 2-1, 1-1, 2-0, 1-0 bareroot; and direct-seeded acorns (same seed source); and nursery run 1-0 bareroot with factorial combinations of treatments of undercutting in the nursery and top-clipping when planting. Each treatment was planted with at least 33 replications in a totally random design. Tree shelters were installed on seedlings of two treatments at age 2. The plantation was surrounded by an electric fence and was maintained weed-free with herbicide for 3 years after which the fencing was removed and all cultural treatments were stopped.

Survival was 92 percent at age 3 and declined over time to 74 percent, 56 percent, and 39 percent at ages 6, 10, and 17, respectively. Treatments with highest survival at age 17 were containerized (73 percent) and 2-0 bareroot (58 percent). By then, survival was independent of nursery undercutting, top-clipping at planting, and treeshelters. Across and within treatments, trees still alive in 2004 tended to be taller or larger caliper stock at the time of planting. Surviving trees tended to be taller (all unclipped, mean of 44 cm vs 33 cm, respectively) and had larger mean stem caliper (8.3 mm vs 6.7 mm, respectively) at planting. Of 265 surviving trees, only three trees of top-clipped stock and two trees of unclipped stock had more than one living stem suggesting that top-clipping does not promote multiple stems. Mean height of surviving trees at age 10 was 5.4 m ranging from 5.9 m for containerized stock to 4.8 m for direct-seeded acorns. At age 17, mean dbh was 7.5 cm and ranged from 9.6 cm for containerized to 3.2 cm for direct-seeded acorns in treeshelters.

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Proceedings of the 15th central hardwood forest conference held February 27–March 1, 2006, in Knoxville, TN. Includes 86 papers and 30 posters pertaining to forest health and protection, ecology and forest dynamics, natural and artificial regeneration, forest products, wildlife, site classification, management and forest resources, mensuration and models, soil and water, agroforestry, and fire.

Keywords: Central hardwoods, silviculture, oak-hickory, upland hardwoods, bottomland hardwoods.

METRIC TO ENGLISH CONVERSION TABLE

Symbol	*When You Know*	*Multiply by*	*To Find*	*Symbol*
		LENGTH		
mm	millimeters	0.0394	inches	in
cm	centimeters	0.3937	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
cm^2	square centimeters	0.1550	square inches	in^2
m^2	square meters	1.196	square yards	yd^2
km^2	square kilometers	0.3861	square miles	mi^2
ha	hectares (10 000 m^2)	2.471	acres	
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
t	metric ton (1 000 kg)	1.102	short tons	
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
mL	milliliters	0.0610	cubic inches	in^3
L	liters	2.113	pints	pt
L	liters	1.057	quarts	qt
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	R^3
m^3	cubic meters	1.308	cubic yards	yd^3
		TEMPERATURE		
°C	degrees Celsius	multiply by 9/5, add 32	degrees Farenheit	°F

ENGLISH TO METRIC CONVERSION TABLE

Symbol	*When You Know*	*Multiply by*	*To Find*	*Symbol*
		LENGTH		
in	inches	25.40	millimeters	mm
in	inches	2.54	centimeters	cm
ft	feet	30.48	centimeters	cm
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	6.452	square centimeters	cm^2
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
mi^2	square miles	2.590	square kilometers	km^2
	acres	0.4047	hectares	h
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
	short tons (2,000 lb)	0.9072	metric tons	t
		VOLUME		
pt	pints	0.4732	liters	L
qt	quarts	0.9464	liters	L
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7646	cubic meters	m^3
		TEMPERATURE		
°F	degrees Farenheit	subtract 32, multiply by 5/9	degrees Celsius	°C