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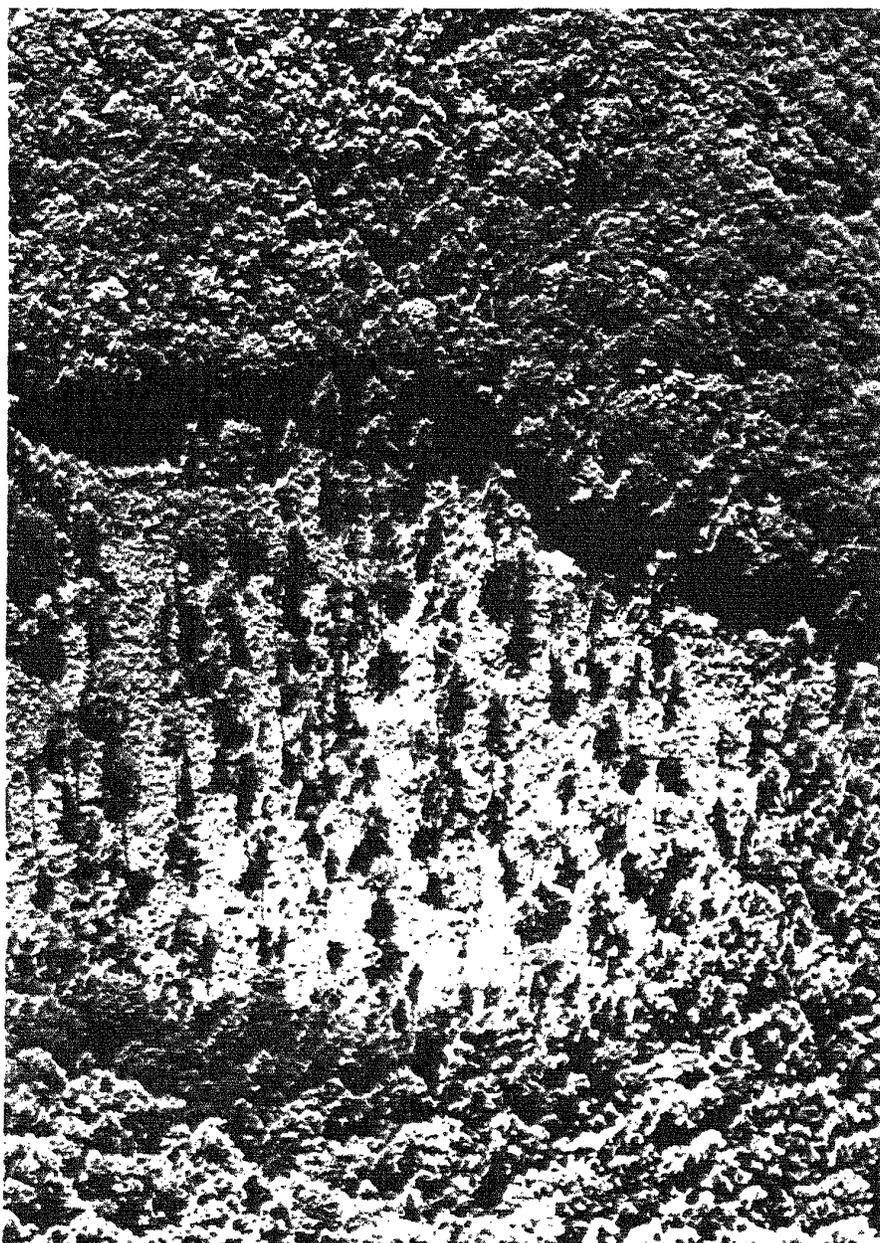
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Proceedings

10th Central Hardwood Forest Conference

Morgantown, West Virginia
March 5-8, 1995



CONTINUING FORESTRY EDUCATION

For attending this conference, each registrant was eligible for 12 hours of Continuing Forestry Education (CFE) credit offered by the Society of American Foresters.

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Cover Photo: This 1984 aerial photograph was taken from a helicopter three years after deferment cutting in 80-year-old central Appalachian hardwoods on the Fernow Experimental Forest near Parsons, West Virginia. (Photo by James N. Kochenderfer, USDA Forest Service.)

USDA FOREST SERVICE
5 RADNOR CORP CTR STE 200
PO BOX 6775
RADNOR, PA 19087-8775

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10TH CENTRAL HARDWOOD FOREST CONFERENCE

Proceedings of a Meeting

Held at

Lakeview Resort and Conference Center

Morgantown, WV

March 5-8, 1995

Edited by

Kurt W. Gottschalk and Sandra L. C. Fosbroke

SPONSORED BY:

Division of Forestry, West Virginia University

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FOREWORD

This conference is the tenth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, University of Tennessee, Southern Illinois University with the North Central Forest Experiment Station (NCFES), Pennsylvania State University with the Northeastern Forest Experiment Station, and Purdue University with NCFES. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the biology and management of central hardwoods by forest scientists from throughout the Central Hardwood Region of the eastern United States. As with previous Proceedings, a wide range of topics that represent the broad array of research programs in this area is represented.

The social and biological characteristics of the Central Hardwood Region make it unique in comparison with other forest regions of the United States. For example, one-fourth of the United States human population resides in this region. Approximately 90% of the land is in private ownership and public lands tend to be small and fragmented with private inholdings. These and related conditions play critical roles in the practice of forestry in this region. The information presented in this Proceedings is important to the long-term management of the forest resources of this unique region.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two (usually three) scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and content of their papers.

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RED SPRUCE/HARDWOOD ECOTONES IN THE CENTRAL APPALACHIANS

Harold S. Adams¹, Steven L. Stephenson², David M. Lawrence³, Mary Beth Adams⁴, and John D. Eisenback⁵

Abstract: We are currently investigating patterns of species composition and distribution, ecologically important population processes, and microenvironmental gradients along ten permanent transects (each consisting of a series of contiguous 10 x 10 m quadrats) established across the typically abrupt and narrow spruce/hardwood ecotone at seven localities in the mountains of central West Virginia and western Virginia. Primary emphasis of our research is directed toward testing three basic hypotheses: (1) red spruce communities in the central Appalachians are decreasing in areal extent due to encroachment of surrounding hardwood communities, (2) stress-induced growth decline in red spruce is a factor in this decrease, and (3) the direction and rate of successional change can be predicted from models developed from quantitative data obtained from field studies of red spruce/hardwood ecotones. Preliminary data obtained during the 1992, 1993, and 1994 field seasons suggest that central Appalachian red spruce communities presently exist at least in static equilibrium with respect to surrounding hardwoods and exhibit, at some localities, advance regeneration into the hardwood communities. (Supported in part by funds provided by the USDA Forest Service).

¹Dabney S. Lancaster Community College, Clifton Forge, VA 24422.

²Department of Biology, Fairmont State College, Fairmont, WV 26554.

³Department of Environmental Science, University of Virginia, Charlottesville, VA 22903.

⁴USDA Forest Service, Timber and Watershed Laboratory, Parsons, WV 26287.

⁵Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

NITROGEN DYNAMICS IN OAK FOREST SOILS ALONG A HISTORICAL DEPOSITION GRADIENT

Ralph E.J. Boerner¹ and Elaine Kennedy Sutherland²

Abstract: This study quantified soil nutrient status and N mineralization/nitrification potentials in soils of oak-dominated, unmanaged forest stands in seven experimental forests ranging along a historical and current acidic deposition gradient from southern Illinois to central West Virginia, U.S.A. Among these seven sites (that spanned 8.5° of longitude) soil pH and Ca²⁺ decreased and soil organic C and extractable Al³⁺ increased from west to east. In general, initial soil solution NO₃⁻, total N mineralization potential and net NO₃⁻ accumulation over 30 days of incubation (as measured by aerobic laboratory incubations) also decreased from west to east, whereas initial soil solution NH₄⁺ was uncorrelated with longitude. The Fernow Experimental Forest (W.Va.), the eastern-most site, was the exception to this trend. Soils from the Fernow had the highest concentrations of both NO₃⁻ and NH₄⁺ in the soil solution, and the greatest N mineralization potential. Stepwise regressions of N mineralization rate, net NO₃⁻ accumulation, and proportional nitrification on initial soil properties produced models with overall r² of 0.705, 0.772, and 0.708, respectively. Rates of N turnover were positively correlated with initial NO₃⁻, pH, and Ca:Al ratio and negatively correlated with extractable Al³⁺ concentrations. Differences in oak growth and mortality may be related to the differences in soil chemical status and soil N dynamics among these seven experimental forests.

INTRODUCTION

Most mature, upland forests of eastern North America are nitrogen (N) limited (Aber et al. 1989). In such ecosystems, the processes that regulate the availability of inorganic N to roots and soil microbes are those involved in the mineralization of low molecular weight organic compounds containing N (e.g. amino acids, polypeptides, nucleotides) to NH₄⁺ (i.e. ammonification or N mineralization) and, in some cases, subsequently to NO₃⁻ (i.e. nitrification). Once the N is in inorganic form, it is subject to competition between roots and microbes, both of which result in the inorganic N being reconverted to biomass N.

Rates of nitrogen mineralization and nitrification are affected by a variety of environmental factors, including soil solution pH, temperature, and moisture (Plymale et al. 1987; Robertson 1982), as well as the rate at which nitrogenous substrates are supplied. Thus, modification of soils by anthropogenically-generated deposition has the potential to alter the rates and patterns of organic N turnover in forest soils, and thereby, to alter the basic functioning of the forests those soils support (Bondietti and McLaughlin 1992).

Over the last 50 years, some forest soils in eastern North America have experienced decreases in pH, increases in NO₃⁻ deposition and soil solution concentration, increased soil solution Fe³⁺ and Al³⁺ concentrations, and lowered Ca:Al ratio (Bondietti and McLaughlin 1992), all of which have the potential to affect key ecosystem processes (Aber et al. 1989). In N-poor ecosystems, the activity of autotrophic nitrifiers may be inhibited and soil NO₃⁻ concentrations remain low because of a number of factors, including the inability of such bacteria to compete well against plant roots and heterotrophic soil microbes for NH₄⁺ and the direct inhibition by low pH (van Miegrot et al. 1992) and relatively high Fe³⁺ and Al³⁺ availability (Liang and Tabatabai 1978). Although the activity of heterotrophic N-mineralizing bacteria and fungi may not be as sensitive to changes in soil chemistry as that of autotrophic nitrifiers (Legge and Crowther 1987), N-mineralization rates are generally lower on acidified soils (Plymale et al. 1987).

¹Professor, Department of Plant Biology, Ohio State University, 1735 Neil Avenue, Columbus, OH 43210.

²Research Ecologist, Northeastern Forest Experiment Station, USDA Forest Service, 359 Main Road, Delaware, OH 43015.

N-limited forest ecosystems (i.e. ones with low rates of mineralization and little nitrification) are typically dominated by tree species which are dependent on ectomycorrhizae (Vogt et al. 1991) such as oaks (*Quercus* spp.), pines (*Pinus* spp.), and spruces (*Picea* spp.). Because of the ability of their ectomycorrhizae (ECM) to forage for NH_4^+ , reduce NO_3^- , and degrade low molecular weight organic N substrates, these tree species can maintain growth even under very low N conditions (France and Reid 1983, Jansen 1991). Heavy, chronic N deposition may greatly alter the N status of forest soils, through its effect on leaching of Ca^{2+} , mobilization of Al^{3+} , and removal of N limitation for tree growth. Under such conditions, ECM-dependent species may decline and be replaced by tree species dependent on vesicular-arbuscular mycorrhizae (VAM) more typical of N-rich forest sites (Jansen 1991; Arnolds 1991) (e.g. maples, *Acer* spp. and yellow-poplar, *Liriodendron tulipifera*). Thus acidic deposition with a significant N component has the potential to affect eastern forest ecosystems over the long term, both in soil chemical status and in tree species composition.

As part of a larger study of the relationship between forest management, tree drought responses/mortality, historical deposition rates, and ecosystem function along the Ohio River Valley of eastern North America, this study was specifically designed to: (1) measure potentials for conversion of organic nitrogen to inorganic forms by soil microbial assemblages in forest soils differing in their historical deposition rates and in site quality; (2) determine relationships between differences in nitrogen mineralization/nitrification potentials and other soil properties (including both static properties such as texture and deposition-related properties such as Ca:Al ratio); and, (3) relate forest soil ecosystem processes such as the ones measured here to variations in tree crown condition, mortality, and drought response among these forests sites. This paper discusses the results of our analyses of the first two of those three objectives.

METHODS

Study Sites and Field Sampling

Seven experimental forests located in the Ohio River Valley were selected for study (Figure 1). These seven sites spanned 8.5° of longitude (Table 1) along a gradient of historical atmospheric deposition which increased from west to east (Work Group One 1983, Lovett 1992). In each experimental forest, two unmanaged, oak-dominated plots on NW-NE facing 15%-25% slopes on non-calcareous substrates were selected. In each plot we established two random quadrats, and took seven random soil samples from each quadrat along a transect running parallel to the contour of the slope during a ten day period in July 1993. Before taking a sample, the forest floor (litter + unconsolidated humus) was cleared from the mineral soil surface over an area of approximately 0.25 m². A 2 cm soil corer was then used to extract A-horizon cores of 5-20 cm in length, depending on the forest site. Each sample was a composite of 5-15 such A-horizon cores totalling at least 200 g fresh mass of soil. We limited our sampling to the A-horizon because rates of N-mineralization and nitrification are typically much greater in the A-horizon than in the B-horizon and unconsolidated litter (Boerner and Koslowsky 1989). All samples were transported to the laboratory under refrigeration.

Table 1. Experimental Forest study site names, abbreviations, and locations.

Name (Abbrev.)	State	Latitude	Longitude	Elevation Range
Kaskaskia (KAS)	Illinois	37°32' N	88°20' W	460-500'
Bald Rock (BDR)	Kentucky	36°59' N	84°16' W	1060-1080'
McKee (MCK)	Kentucky	37°27' N	83°59' W	1180-1270'
Robinson (ROB)	Kentucky	37°15' N	83°20' W	1050-1150'
Mead (MEX)	Ohio	39°15' N	83°00' W	760-800'
Raccoon (RAC)	Ohio	39°10' N	82°23' W	790-860'
Fernow (FER)	West Virginia	39°03' N	79°41' W	2650-2730'

N MINERALIZATION

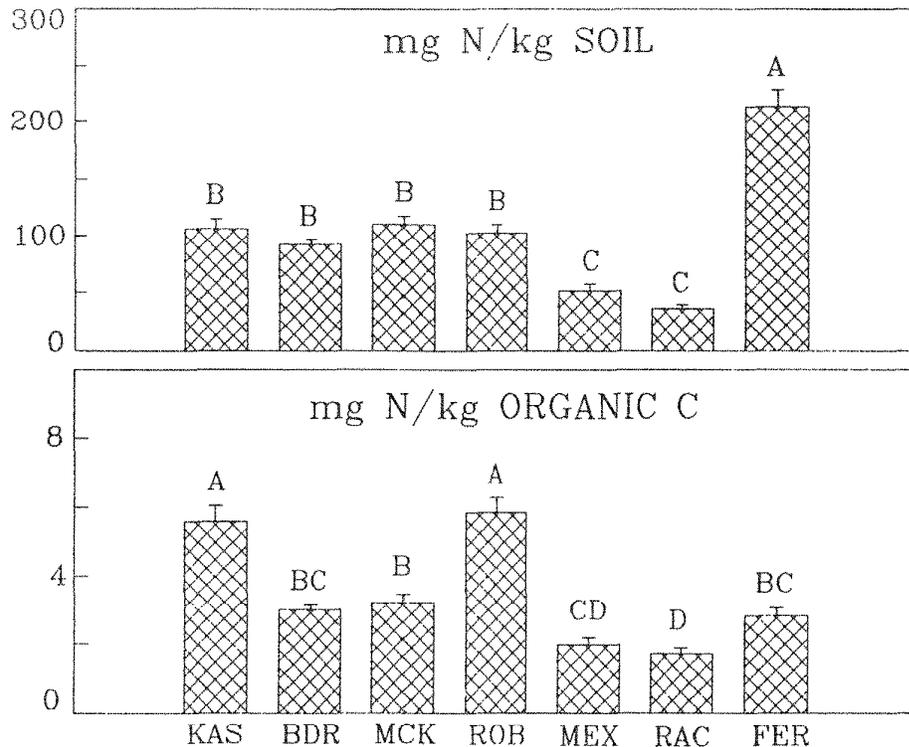


Figure 1. A-horizon N mineralization on a mass basis (mg N/kg dry soil) and on an organic matter basis (mg N/kg organic C), in soils from seven experimental forests along the Ohio River corridor. Forests are arrayed from west to east along the x-axis. Histogram bars represent the mean of N=14, and the error bars represent one standard error of the mean. Bars with the same lower case letter were not significantly different at $p < 0.05$ following analysis of variance and Ryan-Einot-Gabriel-Welsch Modified F Test. Forest codes follow Table 1.

Laboratory Methods

Each sample was subdivided into two subsamples. One was sent to Micro-Macro International, Inc., Athens, GA for analysis of soil texture by hydrometer, pH in water, Ca^{2+} , Mg^{2+} , K^+ , and Na^+ in 1 M NH_4OAc extracts, and NO_3^- , PO_4^{3-} , and Al^{3+} in 1 M KCl extracts. Methods followed Jones (1992). The second subsample was air-dried for 10-14 days, then analyzed for organic C content by Walkley-Black wet oxidation (Allison 1965).

The third subsample was then subdivided into two portions. One portion of approximately 10 g was extracted with 1 M KCl and the extract frozen pending analysis. The second portion was air-dried for 10-14 days, then passed through a 6 mm sieve to remove stones, roots, and leaf fragments. Approximately 100 g of the sieved soil was weighed, placed in a 300 ml styrofoam cup, and brought to 70% of field capacity with "Hubbard Brook Recipe" artificial rainwater (Lee and Weber 1979). We used artificial rainwater rather than deionized water to better simulate field conditions and to prevent the excessive leaching of the soil samples that might occur if deionized water were used throughout the incubation period.

All samples were incubated under aerobic laboratory conditions for 30 days at 23-28° C. Samples were weighed every 2-3 days, and were maintained at 50-70% of field capacity by adding artificial rainwater as needed. At the end of the incubation period, approximately 10 g (dry mass) of soil was taken from each incubated sample and extracted as above.

NH_4^+ and NO_3^- concentrations of each initial and final sample extract were determined colorimetrically on a LaChat QuikChem Autoanalyzer. Relative nitrogen mineralization was calculated as the difference between total inorganic N (i.e. $\text{NH}_4^+ + \text{NO}_3^-$) in the initial vs final extracts, less the N added in the rainwater solution. Net NO_3^- accumulation was calculated as the difference between initial and final NO_3^- concentrations in each sample. To correct for differences in soil organic matter content among forest sites, we expressed both N mineralization and net NO_3^- accumulation as mg N/g organic C. Percent nitrification was calculated as the percent of the total nitrogen mineralized which was converted to NO_3^- during the incubation period (Campbell et al. 1993).

Initial soil parameters and rates of N turnover were compared among experimental forests, stands within forests, and sample plots within stands by analysis of variance, using the Ryan-Einot-Gabriel-Welsch Modified F Test to post-test differences among means (SAS 1985). Regression models of N turnover rates as a function of initial soil conditions were constructed by maximum- r^2 , forward selection stepwise regression (SAS 1985). Significant differences were at $p < 0.05$ except where otherwise indicated.

RESULTS

Soil Physical and Chemical Properties

Five of the seven soil chemical parameters we measured varied linearly with longitude (Table 2). Organic carbon content, NH_4^+ and Al^{3+} all increased from west to east, whereas pH and the molar Ca:Al ratio decreased from west to east (Table 2). In contrast, Ca^{2+} was significantly greater in soils from the Kaskaskia E.F. (IL) and Robinson E.F. (KY) than in soils from the other five sites, and NO_3^- concentration was greatest in the two sites at the ends of our longitude gradient, Kaskaskia (IL) and Fernow (WV).

There was no consistent variation in soil texture with longitude (Table 3). The soils of the Mead (OH) E.F. had the greatest proportion of clay of the seven sites sampled, and there was little variation in clay content among the soils of the other six sites. The percentage of sand varied more than did the clay fraction, with the soils of the Fernow E.F. (WV), Bald Rock E.F. (KY), and McKee E.F. (KY) having greater relative sand content than the soils of the Mead E.F. (OH), Raccoon E.F. (OH) or Kaskaskia E.F. (IL) E.F.s. The dominant textural classes ranged from silty clay through silty clay loam and clay loam.

Nitrogen Mineralization and Nitrification

Without considering the Fernow E.F., total N mineralization decreased linearly from west to east, with the soils from the Raccoon E.F. (OH) and the Mead E.F. (OH) mineralizing significantly less ($p < 0.0001$) total organic N per unit soil mass than the soils from the four sites to the west (Figure 1). On a mass basis, soils from the Fernow E.F. mineralized >2X as much N over 30 days as did the soils from any of the six other sites, and did not fit the linear longitudinal pattern of the other six sites. When N mineralization was adjusted for the differences in initial soil organic C among sites, the rate of N mineralization at the Fernow E.F. was no longer greater than those from the sites to the west. The lowest rates of total N mineralization/g organic C were still recorded at the Raccoon E.F. (OH) and the Mead E.F. (OH).

Net NO_3^- accumulation on a mass basis was significantly greater at the Kaskaskia E.F. and the Fernow E.F. than at the other five sites (Figure 2). The soils from the other five experimental forests accumulated an order of magnitude less NO_3^- , and did not differ significantly from each other in NO_3^- accumulation rate. When NO_3^- accumulation rate was adjusted for difference in organic C content, the rate observed in the soils from the Fernow E.F. became more similar

Table 2. Chemical properties of A-horizon soils from unmanaged, oak-dominated forest plots in seven experimental forests. Within a column, means followed by the same lower case letter were not significantly different at $p < 0.05$. $N = 28$ for each experimental forest and standard errors of the means are given in parentheses. All parameters except pH and organic carbon (%) are in mg/kg dry soil. Experimental forests are listed from west to east.

Experimental Forest	pH	Org. Carbon	NO_3^-	NH_4^+	Ca^{2+}	Al^{3+}	Ca:Al Molar Ratio
Kaskaskia (IL)	5.14a (0.18)	1.91cd (0.30)	17.33b (2.28)	22.42c (1.78)	683.5a (48.1)	10.5e (3.3)	136.20a (22.65)
Bald Rock (KY)	4.50b (0.17)	3.08bc (0.30)	0.59c (0.16)	26.58bc (1.70)	70.6b (8.8)	147.4c (9.7)	0.32c (0.05)
McKee (KY)	4.28b (0.06)	3.42b (0.52)	2.34c (0.32)	25.41bc (1.90)	64.3b (4.4)	190.9bc (15.2)	0.23c (0.03)
Robinson (KY)	4.88a (0.11)	1.76d (0.05)	1.96c (0.48)	24.12c (1.53)	345.4a (42.0)	83.8d (22.4)	27.20b (12.00)
Mead (OH)	4.25bc (0.03)	2.64bcd (0.27)	0.51c (0.13)	33.91b (2.58)	113.3b (14.3)	311.3a (17.9)	0.27c (0.06)
Raccoon (OH)	4.07c (0.07)	2.10bcd (0.32)	0.39c (0.06)	24.01c (1.85)	59.7b (7.8)	212.5b (11.3)	0.19c (0.03)
Fernow (WV)	3.79d (0.06)	5.59a (0.31)	50.57a (6.94)	50.58a (3.97)	146.3b (19.2)	244.3a (13.5)	0.48c (0.14)

to, though still significantly different from, those at the five intermediate sites (Figure 2). The percent of total N mineralization which was subsequently nitrified to NO_3^- followed the same pattern (Figure 2).

If one does not consider the Fernow E.F., two general patterns emerged: (1) on a mass basis, total N mineralization decreased 66% over 8.5° of longitude from west to east, and (2) nitrification, measured either as net NO_3^- accumulation or percent of newly mineralized N nitrified, was significantly greater in the site with Ca:Al ratio > 135 than in the other five sites. When N turnover rates were adjusted for initial organic C content of the soils, the east-west trend of decreasing total N mineralization existed among all seven sites, including the Fernow E.F.; however, even when differences in organic C were accounted for, the soils from the Fernow E.F. (WV) still accumulated significantly more NO_3^- and nitrified a significantly greater percentage of NH_4^+ than would be predicted by longitude.

Regression Analysis of N Turnover Rates

Because of the inherent weakness in assuming that field plots such as those analyzed here are truly replicates, one must interpret the results of analyses of variance with considerable caution. Given the large variation in initial soil conditions among sites, we felt a multiple regression approach which explicitly addressed the differences among study sites would be a more effective inferential tool in analyzing situations such as this one.

Table 3. Texture of A-horizon soils from unmanaged, oak-dominated forest plots in seven experimental forests. Within a column, means followed by the same lower case letter were not significantly different at $p < 0.05$. $N=28$ for each experimental forest and standard errors of the means are given in parentheses. Experimental forests are listed from west to east.

Experimental Forest	Sand (%)	Silt (%)	Clay (%)	Prevalent Texture
Kaskaskia (IL)	12.0d (1.1)	64.8a (2.2)	23.1b (1.8)	Silty Clay Loam
Bald Rock (KY)	48.8ab (2.5)	27.5c (2.0)	23.7b (0.8)	Clay Loam
McKee (KY)	43.8b (3.5)	31.9cd (2.6)	24.3b (1.2)	Clay Loam
Robinson (KY)	35.3c (3.6)	35.6c (2.5)	29.2ab (1.7)	Clay Loam
Mead (OH)	18.0d (1.9)	47.2b (1.4)	34.8a (1.0)	Silty Clay
Raccoon (OH)	18.9d (1.5)	54.5b (1.2)	26.6b (0.8)	Silty Clay Loam
Fernow (WV)	56.9a (1.7)	21.8e (2.0)	21.3b (1.3)	Clay Loam

Regression of the rate of N mineralization per unit soil mass on the soil chemical and physical properties analyzed produced a linear model significant at $p < 0.0001$ with overall model $r^2 = 0.705$ (Table 4). This model attributed the variance in N mineralization rates among samples and sites to, in declining order, initial NO_3^- concentration in the soils, soil texture, and soil pH, with initial NO_3^- and pH having positive slope coefficients and silt+clay content a negative sign. The robustness of the model can be appreciated when one considers that the highest N mineralization rates were recorded at the Fernow E.F., the site with the lowest pH and silt+clay content of the soil. Without the Fernow E.F. in the model, the r^2 would improve considerably. Organic carbon content was not a significant variance component in this regression, and a similar regression done on mineralization rate per unit organic matter produced essentially identical results.

Regression of the net rate of NO_3^- accumulation on soil properties produced a linear model with equal significance ($p < 0.0001$) and even closer fit ($r^2 = 0.772$) (Table 4). In this model, the initial concentration of NO_3^- and the Ca:Al molar ratio contributed the largest partial r^2 to the model, both with positive sign for the slope coefficient. Thus, net NO_3^- accumulation increased with increasing initial NO_3^- and Ca:Al ratio. Soil pH (+), initial Al^{3+} concentration (-), and silt+clay content (+) contributed less, but still significantly to model fit. The percent of newly mineralized N which was subsequently nitrified during the 30 day incubation period was also directly proportional to initial NO_3^- concentration and the Ca:Al ratio (Table 4). Adding in initial soil Al^{3+} concentration (-) and silt+clay content produced a linear model with $r^2 = 0.708$.

NET NITRATE ACCUMULATION

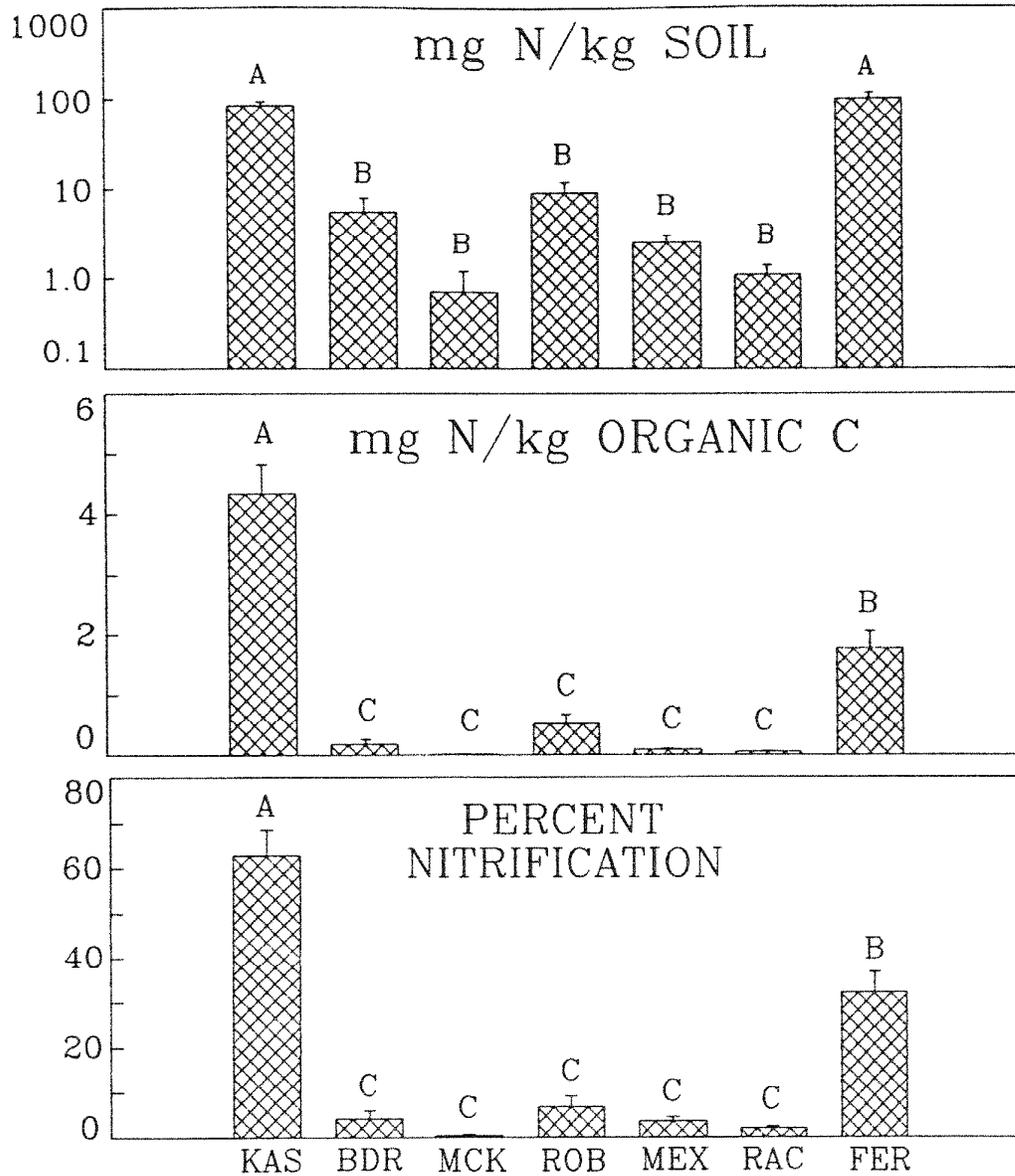


Figure 2. NO_3^- accumulation on a mass basis ($\text{mg NO}_3^- \text{-N/kg dry soil}$) and on an organic matter basis ($\text{mg NO}_3^- \text{-N/kg organic C}$), and percent nitrification of mineralized N in soils from seven experimental forests along the Ohio River corridor. Note the logarithmic y-axis for the two NO_3^- plots. Forests are arrayed from west to east along the x-axis. Format follows Figure 1.

Table 4. Forward selection, maximum r^2 regression of N turnover components on initial soil parameters. All independent variables with slope components significantly different from 0 at $p < 0.05$ are given, and variables are listed in declining contribution to the total model r^2 . $N=167$ for each regression.

Independent Variable	Slope Coefficient/ Significance of Slope
<u>N Mineralization (mg N/kg soil), total model $r^2=0.705$, $p < 0.0001$</u>	
Initial NO_3^-	+2.10 $p < 0.0001$
% Silt+Clay	-1.36 $p < 0.0001$
pH	+12.76 $p < 0.026$
<u>Net NO_3^- Accumulation (mg N/kg soil), total model $r^2=0.772$, $p < 0.0001$</u>	
Initial NO_3^-	+1.94 $p < 0.0001$
Ca:Al Ratio	+0.26 $p < 0.0001$
pH	+7.83 $p < 0.048$
Al	-0.07 $p < 0.014$
% Silt+Clay	+0.27 $p < 0.048$
<u>Percent Nitrification, total model $r^2=0.708$, $p < 0.0001$</u>	
Initial NO_3^-	+0.66 $p < 0.0001$
Ca:Al Ratio	+0.18 $p < 0.0001$
Al	-0.05 $p < 0.0007$
% Silt+Clay	+0.24 $p < 0.0019$

Thus, all three measures of organic N turnover were directly proportional to and strongly affected by the initial NO_3^- concentration in the soil samples. Soil texture was also a significant variance component for all three measures of N turnover; however, N mineralization was inversely proportional to the silt+clay content of the soil whereas net NO_3^- accumulation and percent nitrification were directly proportional to that property. Total N mineralization was not affected by Al^{3+} or Ca:Al molar ratio; in contrast both net NO_3^- accumulation and percent nitrification were directly proportional to Ca:Al ratio and inversely proportional to Al^{3+} concentration.

DISCUSSION

As a result of changes in the patterns of fossil fuel use over the last two decades, the relative proportions of NO_3^- and SO_4^{2-} in precipitation and dry deposition have shifted away from predominately S deposition to relatively greater deposition of N. Currently, upper elevations of the Appalachian Mountains receive as much as 27 kg N/ha/yr in precipitation (Lovett 1992), a level almost an order of magnitude greater than that in pristine precipitation (Aber et al. 1989; Lovett 1992). The geographic range of our seven study sites was designed to encompass a gradient of historical deposition of NO_3^- , SO_4^{2-} , and H^+ increasing from west to east, and a more recent NO_3^- deposition gradient increasing from 2.7-5.6 kg N/ha/yr in Illinois to 13.5-18.1 kg N/ha/yr in West Virginia (Work Group One 1983).

Chronic NO_3^- deposition can have a range of effects on forest soils, including enhanced leaching of Ca^{2+} , increased Al^{3+} solubility, and decreased Ca:Al ratio (Aber et al. 1989; Foster et al 1989). This pattern emerged clearly among our six study sites west of the Appalachian Plateau (i.e. excluding the Fernow Experimental Forest, West Virginia): Ca^{2+} decreased, Al^{3+} increased, and Ca:Al ratio decreased by two orders of magnitude between southern Illinois and southern Ohio. This spatial pattern was consistent with the temporal pattern of change in soil and leachate chemistry

reported from a sugar maple (*Acer saccharum*) forest in Ontario over 1981-1986 caused presumably by heavy N deposition in acidic precipitation (Foster et al. 1989).

Aber et al. (1989) hypothesized that chronic high NO_3^- deposition could reduce microbial activity and, thereby, reduce the rates of N mineralization and nitrification. Although this hypothesis was supported by the rates we observed in our six study sites west of the Appalachian Plateau, the longitudinal patterns of variation in N mineralization and nitrification differed. N mineralization decreased gradually and linearly with longitude, and the pattern of change correlated most strongly with pH. Over the 8.5° of longitude represented by our gradient, the rate of N mineralization decreased by 66%. In contrast, nitrification was significant only in the two study sites in which the Ca:Al ratio was >20; in all other sites nitrification was negligible. These data were consistent with *in vitro* studies demonstrating strong inhibition of nitrification by Al^{3+} and Fe^{3+} , even in the presence of high NH_4^+ concentrations (Liang and Tabatabai 1978), and supported the notion that nitrification is more susceptible to inhibition by low pH and high Al^{3+} than is N mineralization (Legge and Crowther 1987).

The soils of the Fernow Experimental Forest (WV) departed in a number of respects from the patterns which emerged among the other six sites. Extractable NO_3^- and NH_4^+ concentrations and organic matter content were greatest in this site. The greater organic matter accumulation may have been a function of the of higher elevation (therefore lower mean temperature) of this site. Similarly, the higher concentrations of inorganic N in the A-horizon may have been a function of greater mean annual precipitation, higher elevation (therefore lower primary productivity), and differences in the concentration of N in precipitation.

The rate of N mineralization per unit soil mass at the Fernow E.F. was considerably greater than those we observed in soils from the other six sites. However, this appears to have been primarily a function of differences in organic matter content. When N mineralization was expressed on a per unit organic matter basis, the activity of the soils of the Fernow became consistent with the longitudinal pattern suggested by the other six sites. This was not true, however, for either net NO_3^- accumulation or proportional nitrification: both remained higher than would be predicted on the basis of longitude even when expressed on an organic matter basis. This greater production and accumulation of NO_3^- indicates that the degree to which mineralization of organic N to NH_4^+ exceeded uptake by plants, fungi, and bacteria was greater at the Fernow than at all of the other study sites except Kaskaskia. Again, this is likely due to the higher elevation and cooler climate of Fernow producing lower uptake demands. Thus, we feel the departure of the soils of the Fernow from some of the longitudinal patterns we observed among the other six sites was the result of direct and indirect effects of differences in elevation.

Both mineralization and nitrification were strongly correlated with initial soil NO_3^- concentrations. This may have been the result of a simple feedback loop: soils which support high rates of mineralization are likely to produce sufficient NH_4^+ to allow for significant NO_3^- production. Thus, high rates of mineralization correlate well with high concentrations of the products of prior mineralization (i.e. NO_3^- and NH_4^+). Thus, we feel our finding of strong correlations between organic N turnover and soil pH, Ca:Al ratio, and soluble Al^{3+} have greater significance than does the demonstration of the autocorrelation between activity rates and product accumulation.

The ramifications of these changes in soil N turnover may have significant effects on oak growth and mortality. Oaks, like many other ectomycorrhiza-dependent species, dominate N-poor and N-limited ecosystems (Vogt et al. 1991). Although these tree species may lack the ability to reduce significant amounts of NO_3^- to amine for protein biosynthesis, they can dominate in strongly N-limited conditions because of the ability of their ectomycorrhizal symbionts to forage actively for NH_4^+ and readily mineralizable, low molecular weight N compounds and because of the ability of ectomycorrhizae (ECM) to reduce modest amounts of NO_3^- . Under N-enriched conditions, where P may be as limiting as N, or more so, species of trees which rely on vesicular-arbuscular mycorrhizae (VAM) and which are capable of much greater relative growth rates, such as maples and yellow poplar, may assume dominance (Vogt et al. 1991). Thus, any process which shifts the balance of inorganic N in the soil solution towards a greater $\text{NO}_3^-:\text{NH}_4^+$ ratio and increases overall N availability, may negatively affect the competitive ability of oaks and other ECM-dependent species. Furthermore, if the low Ca:Al ratio and high soluble Al^{3+} concentrations we observed in the eastern portion of our gradient can affect ECM fungi directly, then the ECM-dependent oaks would be at even a

greater disadvantage. This sequence of events has been implicated in the decline of ECM-dependent spruces and pines in Europe (e.g. Jansen 1991; Arnolds 1991). Further experimental analysis of the linkages between organic N turnover, soil solution $\text{NO}_3^-:\text{NH}_4^+$ ratio, Ca:Al ratio, ECM fungi, and oak growth/mortality in the eastern U.S. is clearly warranted.

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TEMPORAL VARIATION IN PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)
IN MESIC SOUTHERN APPALACHIAN HARDWOOD FORESTS
WITH AND WITHOUT *RHODODENDRON* UNDERSTORIES

Barton D. Clinton¹

Abstract: Understanding spatial and temporal variation in the understory light regime of southern Appalachian forests is central to understanding regeneration patterns of overstory species. One of the important contributors to this variability is the distribution of evergreen shrub species, primarily *Rhododendron maximum* L. We measured photosynthetically active radiation (PAR) in the understory of closed forest canopies in areas with and without *R. maximum*. Measurements were taken from March through November 1993 with a frequency of approximately 3 weeks. In 1994 measurements resumed from March through May. PAR under sub-canopies of *R. maximum* averaged 77% (e.g., 14 vs. 65 $\mu\text{mol m}^{-2}\text{s}^{-1}$) lower than in areas without *R. maximum* during the growing season, and 70% (e.g., 179 vs. 641 $\mu\text{mol m}^{-2}\text{s}^{-1}$) lower in the dormant season. Variation in PAR during the growing season ranged from 73% to 86% lower in *R. maximum* versus non-*R. maximum* understories. During the growing the season, light levels beneath *Rhododendron* were observed to be < 2% of full sun. Low-light environments associated with *R. maximum* understories are extremely limiting with respect to regeneration of important hardwood species.

INTRODUCTION

The structure of forest canopies is extremely heterogeneous and the spatial distribution of light at the forest floor is a consequence of this heterogeneity (Pukkala and others, 1991). Although soil nitrogen availability commonly limits productivity in most temperate forests (Vitousek and others, 1982), light is typically the most limiting resource under closed canopies in southern Appalachian forests (Wayne and Bazzaz, 1993).

The quantity of light in the understory is a function of the rate of light extinction through the canopy. Utilization efficiency of the residual radiant energy in the understory depends upon the understory tolerance levels of woody plant species and determines their ability to survive and develop under light-limited conditions. It is this difference in understory tolerance among species which determines the compositional and structural characteristics of forests in the southern Appalachians.

The evergreen shrub *Rhododendron maximum* L. is an important component of mesic forest sites in the central and southern Appalachians. This species has been recognized for its influence on microclimatic conditions (Romancier, 1971) and understory composition (Clinton and others, 1994; Monk and others, 1985; Phillips and Murdy, 1985). Even though the mechanisms (eg., competition for water and nutrients, allelopathy, litter depth and quality, light extinction) of its influence on above and belowground conditions are not completely understood, there is little doubt that this species impacts the light environment beneath it. The purpose of this paper is to present data on the temporal variation in the light environments of open versus *Rhododendron* occupied understories in mesic southern Appalachian forests.

¹Research Ecologist, USDA Forest Service, Southeastern Forest Experiment Station, Coweeta Hydrologic Laboratory, 999 Coweeta Lab Road, Otto, NC 28763

METHODS

Study Design

Sampling was conducted in mature stands of mixed-hardwoods at the Coweeta Hydrologic Laboratory located in the Southern Appalachian physiographic province of western North Carolina. Basal area of these stands is approximately $25 \text{ m}^2\text{ha}^{-1}$ most of which is accounted for by *Quercus prinus*, *Q. coccinea*, and *Acer rubrum*. The basal area of *Rhododendron* is approximately $2 \text{ m}^2\text{ha}^{-1}$. All plots are mid-elevational (800 - 1100 m) and generally have a northerly aspect. Photosynthetically active radiation (PAR) was measured on sunny days between the hours of 1030 and 1330 in open understories and in understories containing continuous *Rhododendron* sub-canopies. Measurements were made on each of 8 plots (6 non-*Rhododendron* and 2 *Rhododendron* plots). Plots were approximately 300 m^2 each containing a permanently marked transect. Along each transect were permanently marked measurement points approximately 2 m apart. Using a portable light meter (Sunfleck Ceptometer, Decagon Devices, Pullman, WA, USA), four measurements of PAR (400 - 700 nm) taken approximately 1 m above the forest floor were averaged and recorded at each point. Measures of full-sun were taken before and after each set of measurements and averaged. Measurements were made at approximate 3-week intervals beginning early in the growing season of 1993 and continuing into the spring of 1994.

Data Analysis

Comparisons were made for PAR between the two understory conditions using PROC ANOVA (SAS, 1987). Significant differences were evaluated at the 0.05 level.

RESULTS

Variability for a given measurement period within each understory condition was low, particularly within *Rhododendron* understories (Fig. 1). However, considerable variability exists between the two understory conditions (Table 1). For each measurement date, total PAR was significantly higher in the non-*Rhododendron* understory (Table 1; Fig. 1). Maximum PAR was observed during the spring before full leafout when non-*Rhododendron* areas had PAR fluxes from $600 - 900 \mu\text{m m}^{-2}\text{s}^{-1}$ (Table 1). *Rhododendron* areas showed maxima during the same period, but PAR was considerably less ($125 - 200 \mu\text{m m}^{-2}\text{s}^{-1}$) (Table 1). Light levels were most similar, both in terms of PAR and percent full sun during the months of September and November (Table 1; Fig. 1 and 2), and the highest degree of variability occurred during the month of July as evidenced by the high C.V. for those dates (Table 1). Over the entire sampling period, PAR in *Rhododendron* areas ranged from 12% - 33% of observed PAR in non-*Rhododendron* areas. Throughout the growing season, light levels in non-*Rhododendron* areas were observed to be <10% full sun (Fig. 2). Furthermore, levels under *Rhododendron* sub-canopies were less than 2% of full sun (Fig. 2). PAR levels early in the growing season (Fig. 1) may be sufficient for a limited number of species to germinate during that period.

Table 1. Means and associated test statistics for PAR in rhododendron versus non-rhododendron understories by measurement date. Values in parentheses represent the fraction of full-sun.

Date	PAR($\mu\text{mols}/\text{m}^2/\text{s}$)		F	P>F	C.V.
	non-Rhodo	Rhodo			
Apr 16	613.7 (0.393)	206.4 (0.131)	35.07	0.0001	59.32
Apr 4	663.7 (0.440)	169.7 (0.148)	41.88	0.0001	62.4
Jun 2	85.2 (0.052)	12.2 (0.007)	12.06	0.0006	135.56
Jun 22	55.3 (0.043)	14.0 (0.011)	10.99	0.0017	86.51
Jul 6	92.7 (0.060)	13.9 (0.011)	4.46	0.0398	159.81
Jul 21	87.0 (0.076)	23.4 (0.016)	6.64	0.0114	153.38
Aug 16	39.8 (0.031)	10.8 (0.007)	22.67	0.0001	82.70
Sep 1	37.7 (0.027)	10.1 (0.007)	21.95	0.0001	84.44
Nov 22	189.9 (0.324)	22.2 (0.028)	47.43	0.0001	72.65
Mar 4	463.2 (0.392)	127.5 (0.103)	45.18	0.0001	58.15
Apr 1	734.6 (0.496)	191.2 (0.133)	76.8	0.0001	45.73
Apr 18	789.0 (0.539)	126.6 (0.103)	139.8	0.0001	39.68
May 2	396.4 (0.220)	55.2 (0.043)	33.56	0.0001	83.60

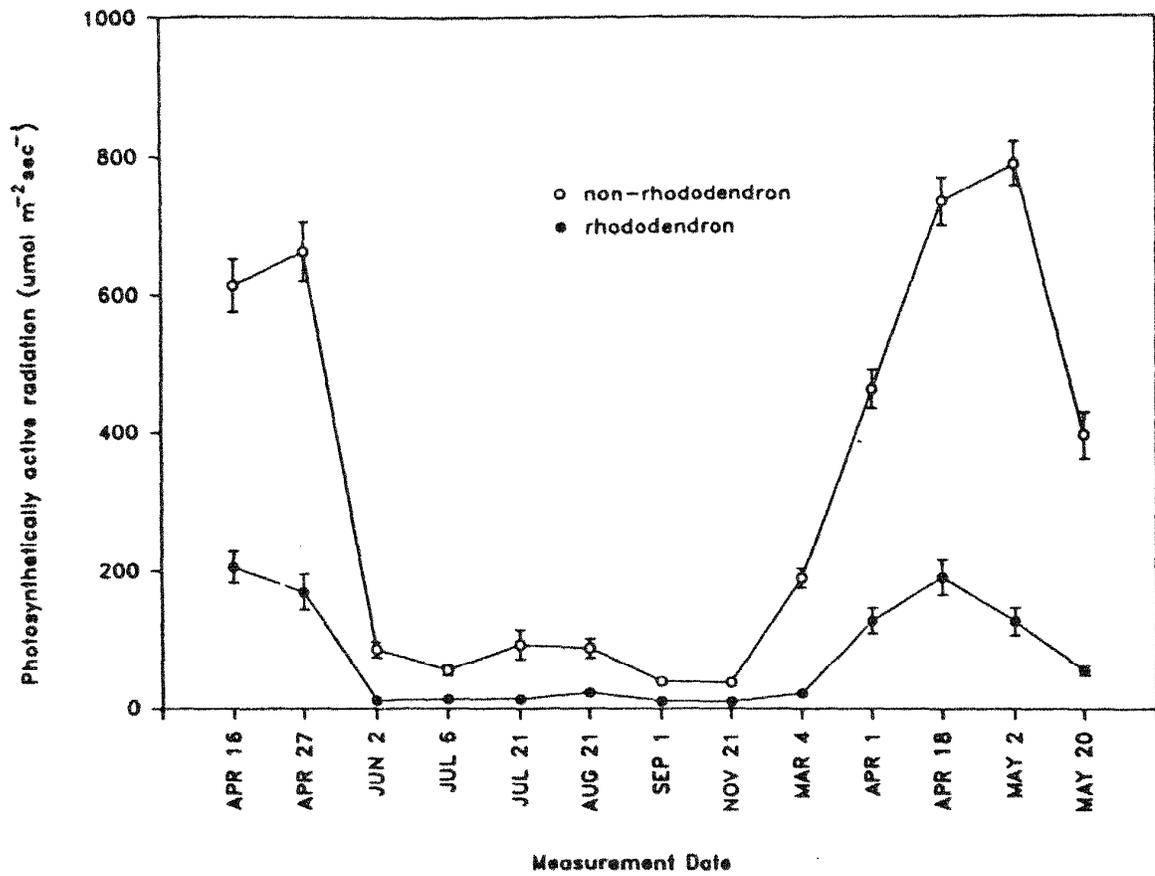


Figure 1. Measured photosynthetically active radiation (PAR) in *Rhododendron* versus non-*Rhododendron* understories. Error bars represent ± 1 standard error.

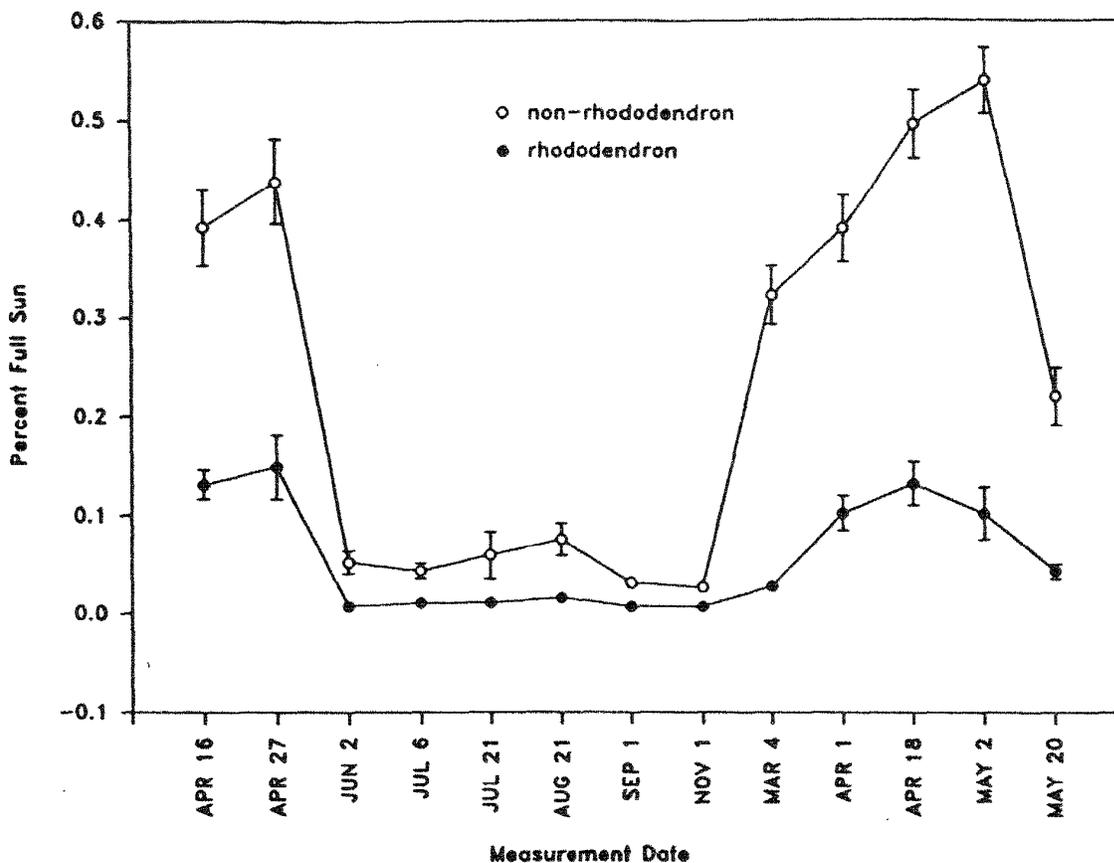


Figure 2. Percent full sun in *Rhododendron* versus non-*Rhododendron* understories. Error bars represent ± 1 standard error.

DISCUSSION

The light environment beneath *Rhododendron* sub-canopies was observed to be significantly different from non-*Rhododendron* understories throughout the sampling period. These differences may account for the general lack of hardwood regeneration in areas occupied by this species. The light compensation point for most woody species is usually about 2% full-sun (Salisbury and Ross, 1978) which was the level observed for *Rhododendron* areas during most of the growing season in this study. This result suggests that most woody species would simply be unable to become established in such light-limited environments. A few extremely shade tolerant species (e.g., *Acer saccharum* Marsh., *Tsuga canadensis* [L.] Carr.) have limited success in regenerating under *Rhododendron* (Clinton and others, 1994); however, they are not important components of mid-elevation southern Appalachian overstories (Day and others, 1988).

Phillips and Murdy (1985) found that tree regeneration on permanent plots at Coweeta was lower in areas containing heavy *Rhododendron* and that the difference in regeneration between *Rhododendron* and non-*Rhododendron* areas

increased with time. Clinton et al. (1994) observed hardwood seedling density to be significantly less in *Rhododendron* versus non-*Rhododendron* areas (0.5 vs. 2.1 stems m⁻²). In a germination experiment, Clinton and Vose (unpublished data) found that only 3% of planted *Acer rubrum* L. seed germinated under *Rhododendron* compared with 15% in non-*Rhododendron* areas. Although the low light levels observed under *Rhododendron* in this study may account for these differences, other sources of inhibition may also exist. For example, during the brief period in early spring preceding overstory foliar development, PAR may be adequate, but temperature requirements for germination of important oak species may not be satisfied.

SUMMARY

Rhododendron maximum is an important structural and functional component of southern Appalachian forests. The ecological implications associated with low light environments beneath *Rhododendron* are substantial. Its influence on tree replacement could impact overstory composition (Clinton and others, 1994; Phillips and Murdy, 1985), in addition to potential impacts on nutrient cycling processes. Most overstory species in the southern Appalachians are intolerant to intermediately tolerant to shade. Where loss of the overstory through natural mortality occurs in areas occupied by *Rhododendron*, what is the probability that the pre-mortality composition of the overstory will be replaced? Given the apparent influence of this species on tree regeneration either due to low light or other phenomena, and the recent observed increase in overstory mortality in the southern Appalachians (Clinton and others, 1993; Starkey and others, 1989; Tainter and others, 1984), it is not likely that overstory composition will be maintained in areas occupied by *Rhododendron*.

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SHORT TERM EVALUATION OF HARVESTING SYSTEMS FOR ECOSYSTEM MANAGEMENT

Michael D. Erickson¹, Penn Peters², and Curt Hassler¹

Abstract: Continuous time/motion studies have traditionally been the basis for productivity estimates of timber harvesting systems. The detailed data from such studies permits the researcher or analyst to develop mathematical relationships based on stand, system, and stem attributes for describing machine cycle times. The resulting equation(s) allow the analyst to estimate productivity and thereby cost, over a range of conditions, as set forth in the mathematical model. The traditional weakness in this process has been the time it takes to collect, synthesize, analyze, and implement the results of the study. For field applications, the turnaround time is such that the original problem or concern often goes unsatisfied or is dealt with by some other means well before the analysis can offer a solution.

The purpose of this study was to develop a methodology for estimating productivity that provides reasonable estimates with quick turnaround time on the analysis. The goal is to collect data in one day and to provide answers almost immediately. The ability to assess productivity of harvesting systems quickly and reliably and to then tie system performance to site impacts, can aid immeasurably in ecosystem management.

¹Research Associate and Associate Professor, Appalachian Hardwood Center, West Virginia University, PO Box 6125, Morgantown, WV 26506-6125.

²Research Engineer, Northeastern Forest Experiment Station, USDA Forest Service, 180 Canfield St., Morgantown, WV 26505-3101.

HERBACEOUS VEGETATION IN THINNED AND DEFOLIATED FOREST STANDS
IN NORTH CENTRAL WEST VIRGINIA

S. L. C. Fosbroke, D. Feicht, and R. M. Muzika¹

Abstract: Herbaceous vegetation was inventoried in 1992 and 1993 in eight Appalachian mixed hardwood stands (< 50% basal area/acre in oak species) and eight oak stands (> 50% basal area/acre in oak species) in north central West Virginia. Vegetation was sampled on 20 6-foot radius plots per stand twice each growing season (once during late spring to sample spring ephemeral species, and later in mid summer). Stand disturbance prior to herbaceous sampling included 1) a silvicultural thinning (8 stands) in the winter/spring of 1990, and/or 2) moderate to heavy gypsy moth defoliation (6 stands) in 1990 and 1991. Most overstory mortality occurred within three years of the first defoliation. By the fall of 1993, residual overstory basal area ranged from 30 - 74 ft² / acre for (3) thinned, defoliated stands; from 38 - 66 ft² / acre for (3) unthinned, defoliated stands; from 78 - 104 ft² / acre for (5) thinned, undefoliated stands; and from 117 - 132 ft² / acre for (5) unthinned, undefoliated stands.

In 1992, species richness ranged from 22 - 65 in mixed hardwood stands and from 19 - 38 in oak stands. In 1993, species richness ranged from 24 - 70 in mixed hardwood stands and from 23 - 42 in oak stands. Regardless of thinning or defoliation disturbance, the dominant herbaceous species (i.e. the species that had the highest average percent cover) consisted of common greenbrier (*Smilax rotundifolia*), Hayscented Fern (*Dennstaedtia punctilobula*), or New York Fern (*Thelypteris noveboracensis*); the one exception was stand #6, a mixed hardwood stand with the highest species richness values recorded in the study. From 1992 to 1993, 9 of the 11 disturbed stands showed an increase in average percent cover of the dominant herbaceous species; stand #6 (a thinned, undefoliated stand) switched its dominant cover species, and stand #8 (an unthinned, defoliated stand) had its dominant species' coverage drop 0.4% between 1992 and 1993. Four of the five undisturbed stands had no change or a decrease in the average percent cover of the dominant herbaceous species from 1992 to 1993. Stand #12 was the only exception; its dominant herbaceous species increased 1.4% from 1992 to 1993. Detrended Correspondence Analysis (DCA) was used to further examine relationships among herbaceous species and stand/site characteristics.

¹Forestry Technician, Forester, and Research Ecologist, Northeastern Forest Experiment Station, USDA Forest Service, 180 Canfield St., Morgantown, WV 26505-3101.

DEFOLIATION AND MORTALITY PATTERNS IN FORESTS SILVICULTURALLY MANAGED
FOR GYPSY MOTH

Kurt W. Gottschalk and Rose-Marie Muzika¹

Abstract: Mixed hardwood forests of the Appalachian region support one of the most diverse communities of woody plants in North America, but the composition and relative dominance of the forest changes substantially with slight changes in physiography, soil type, or microclimate. Composition of oak and other species highly preferred by the gypsy moth determines the susceptibility of forests to defoliation. As composition of these species increases, the susceptibility increases. Silvicultural treatments were developed to minimize the effects of gypsy moth defoliation on forests. A research study was conducted to determine the effectiveness of two preoutbreak silvicultural treatments that are applied in different susceptibility stands. Presalvage thinning is designed to reduce the mortality that occurs in stands by taking out the trees with highest estimated probabilities of mortality and increasing the growth and vigor of the residual trees. It is applied in high or very highly susceptible stands (>50 percent oak). Sanitation thinning is designed to reduce the defoliation level (and subsequent mortality) in medium susceptibility stands (20 to 50 percent oak). This reduction is obtained by decreasing oaks and other susceptible species to 20 percent of the stand basal area and increasing vigor of the residual trees. Four replications of each treatment were established in 1989-90, with a paired untreated control stand for every treated stand.

Defoliation and mortality patterns over a five-year period appear to be stand dependent. While the general trend indicates that heavy defoliation of susceptible species occurred in 1990 and 1991, only six of the 16 stands sustained heavy defoliation. Defoliation patterns were nearly identical for both thinned and unthinned stands in a pair, although the thinned stands averaged slightly lower defoliation across all species. Mortality, expressed as percent of original basal area, was greater in the unthinned stands versus the thinned stands of each pair of the six stands that were defoliated. Mortality in stands that were presalvage thinned was 33.8 percent and 63.5 percent as opposed to 69.0 percent and 68.1 percent in the unthinned counterparts. The sanitation thinning mortality was 29.8 percent versus 41.4 percent for the unthinned stands. The majority of the defoliation and mortality occurred in oak and other susceptible species; very little occurred in resistant and immune species. These results represent worst case tests of the silvicultural treatments, as the treatments were completed in April 1990 and defoliation began in May 1990, so the stands had no time to adjust to the treatments and for the residual trees to increase in vigor. The results are encouraging in that they do show potential for silvicultural treatments to minimize gypsy moth effects on forest stands.

¹Project Leader and Research Ecologist, Northeastern Forest Experiment Station, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505-3101.

A GENERALIZED INGROWTH MODEL FOR THE NORTHEASTERN UNITED STATES

Linda S. Gribko¹, Donald E. Hilt², and Mary Ann Fajvan¹

Abstract: Ingrowth, the number of trees that periodically grow into the smallest inventoried diameter class, has long been recognized as a basic element of multicohort or, uneven-aged, stand development. However, very little information is available to aid forest managers in the estimation of ingrowth. The purpose of this study was to develop a generalized ingrowth model for the northeastern United States. The model was developed in two stages. First, annual ingrowth trees per acre into the 5-inch dbh class was modeled as a function of average stand diameter, overstory trees per acre, and a generalized stocking percent. Generalized stocking percent and overstory species composition, as a function of relative shade tolerance, were then used in a multivariate logistic model to predict the species composition of the ingrowth trees.

¹Assistant Professor of Forest Management and Assistant Professor, Division of Forestry, West Virginia University, P.O. Box 6125, Morgantown, WV 26506-6125.

²(Deceased) Research Forester, Northeastern Forest Experiment Station, USDA Forest Service, 359 Main Rd., Delaware, OH 43015.

BLACK WALNUT RESPONSE TO SUBSOILING, IRRIGATION, AND VEGETATION MANAGEMENT
ON A SITE WITH A SHALLOW FRAGIPAN

F. D. McBride and J. W. Van Sambeck¹

Abstract: Vegetation management with glyphosate and simazine proved to be more effective than preplant subsoiling or irrigation for achieving acceptable walnut biomass growth on an upland old field site (SI = 70 for white oak). In 1980, we direct seeded germinating black walnut seed on an upland, slightly eroded, old field ridge with a 45 to 60 cm deep fragipan. We tested all combinations of with and without preplant subsoiling (75 cm deep); with and without irrigation for 6 years, and with and without chemical weed control for 7 years. The only treatment effect still persisting after 14 years was vegetation management reducing the tall fescue competition. Preplanting ripping showed benefits for 4 to 8 years after planting only. Irrigation either reduced biomass growth or had no effect in combination with weed control. Our results continue to confirm that with intensive management black walnut can sustain acceptable growth and produce nuts above a 3-m long veneer log on agricultural lands with low site index for black walnut.

¹Forestry Technician and Research Plant Physiologist, USDA Forestry Sciences Laboratory, Mailcode 4630, Southern Illinois University, Carbondale, IL 62901-4630.

DISTRIBUTION, DISPERSAL AND ABUNDANCE OF HAYSCENTED
FERN SPORES IN MIXED HARDWOOD STANDS

Larry H. McCormick and Kathy A. Penrod¹

Abstract: A study was conducted in 1992 to assess the abundance and distribution of viable hayscented fern spores in the forest floor of central Pennsylvania hardwood stands before and after seasonal spore dispersal. Intact soil samples were collected at various distances and directions from established fern communities and placed in a greenhouse to effect spore germination. Spore abundance was estimated by counting the number of gametophytes which developed. Results indicate that a large viable sporebank exists in many central Pennsylvania hardwood forests. Viable spores were present in over 97% of pre- and post-dispersal samples with estimates of upward to 160,000 viable spores per square meter. Viable spores occurred at all distances within the 50 m from source zone sampled. The number of viable spores generally decreased with distance from the source with the highest abundance occurring within 10 m of the source. There was evidence of directional effects on spore abundance at some sampling locations, however, the effect was variable between sites. These data indicate the potential exists for the establishment of hayscented ferns from a viable sporebank in central Pennsylvania hardwood stands.

¹ Associate Professor and Graduate Student, respectively, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802.

IDENTIFICATION OF CANOPY STRATA IN ALLEGHENY HARDWOOD STANDS

David W. McGill¹, Stephen B. Jones¹, and Christopher A. Nowak²

Abstract: Allegheny hardwood stands typically develop vertical canopy layers, or strata, due to differential species-specific growth rates and tolerance to shade. Across the Allegheny Plateau, black cherry dominates the main canopy, while sugar maple, American beech, and red maple are relegated to subcanopy strata.

Stratification of Allegheny hardwoods is critical in forest management. For example, diameter-limit cutting of the larger and more valuable black cherry results in a residual stand that consists of sugar maple and beech, compromising the economic potential of the site. In addition, because these stands are stratified by species, where each stratum usually consists of not more than two species, the number and arrangement of the strata influence the diversity of and the regeneration potential in these stands.

This study compares several methods used to identify and characterize individual canopy strata, canopy profiles depicting tree silhouettes along horizontal transects, histograms showing the frequency of trees by diameter or height classes, and structural contour charts expressing the distribution of trees by both height and diameter classes. Structural contour charts represent a novel approach to depicting and evaluating canopy strata.

¹School of Forest Resources, The Pennsylvania State University, University Park, PA 16802.

²USDA Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 928, Warren, PA 16365.

A METHOD FOR APPLYING GROUP SELECTION IN CENTRAL APPALACHIAN HARDWOODS

Gary W. Miller and Thomas M. Schuler¹

Abstract: Public concern over the adverse visual impact of clearcutting has heightened interest in developing and testing alternative regeneration practices for central Appalachian hardwoods. When applied properly, group selection, which entails making small openings within a timber stand at regular intervals, can meet aesthetic goals while providing suitable light conditions to reproduce shade-intolerant species. Volume control and residual stand density are used to regulate periodic cuts, which include volume removed to create openings plus volume removed between openings to improve the quality and distribution of the residual stand. In central Appalachian hardwoods, openings must have a minimum size of 0.4 acre; all stems 1.0 inch d.b.h. and larger are cut to reproduce desirable shade-intolerant species. Maximum opening size is based on aesthetic requirements or other management constraints. Where reproduction of shade-tolerant species is acceptable, openings can be as small as a space occupied by a few trees. Openings should be located using the *worst first* approach to give the growing space occupied by mature trees or risky trees to faster growing, desirable regeneration. The residual stand between openings should be improved by cutting poor-quality or high-risk trees. The recommended residual basal area in sawtimber-size trees (11.0 inches d.b.h. and larger) is related to northern red oak site index (SI): 70 to 85 ft²/acre for SI 80, 55 to 70 ft²/acre for SI 70, and 40 to 55 ft²/acre for SI 60. These field-tested methods can help forest managers initiate group selection in second-growth Appalachian hardwoods. Guidelines are presented for computing the cut, determining size, location, and number of openings, and marking the stand.

¹Research foresters, Northeastern Forest Experiment Station, USDA Forest Service, Timber and Watershed Laboratory, P.O. Box 404, Parsons, WV 26287.

FIFTY-YEAR RESPONSE OF A 135-YR-OLD WHITE PINE STAND TO PARTIAL
THINNING IN CONNECTICUT

Darryl S. Nicholson and Jeffrey S. Ward¹

Abstract: In the early 1930s a series of plots were established throughout Connecticut to study the effects of thinning on stand growth. Gold's Pine plot (1.0 acre) was established in 1932 to study partial thinning in a mature 125-yr-old white pine/eastern hemlock stand. The plot is located within Housatonic State Forest in western Connecticut. In 1932 the stand volume was estimated to be 49 Mbf, 75% was white pine and the remainder was hemlock. The stand was thinned in 1944 and 1961. Approximately 4 Mbf/acre and 3 Mbf/acre were harvested in 1944 and 1961, respectively. Stand volume in 1994 was estimated to be 53 Mbf/acre. Mean diameter of white pines has increased from 20.7 to 28.8 inches. Over the 60-yr period the height of codominants and dominants has increased from 110 to 128 ft. There were 42 stems/acre in the understory (2-7 inches dbh) in 1932 consisting of eastern hemlock (64%), black birch (24%), white pine (2%), yellow birch (2%), white ash (2%), black cherry (2%), and sugar maple (2%). In 1994 there were 440 stems/acre in the understory consisting of eastern hemlock (55%), black birch (32%), yellow birch (4%), striped maple (4%), and sugar maple (4%). This case study suggests that mature white pine stands can be partially thinned to recover declining material and release stagnating trees without sacrificing continued volume growth and "Big Tree" stand characteristics.

¹Department of Forestry and Horticulture, Connecticut Agricultural Experiment Station, P.O. Box 1106, New Haven, CT 06504.

FOREST STAND DEVELOPMENT ON 6-26 YEAR-OLD
CLEARCUTS IN SOUTHEASTERN OHIO¹

Eric R. Norland and David M. Hix²

Abstract: Clearcutting, a commonly-used cutting practice in southeastern Ohio, often results in a forest stand with a different species composition than the parent stand. The time frame during which species shifts occur is unclear. While some studies have documented species composition at specific points in time, none have attempted to examine changes throughout the first decades of stand development. This study focused on examining the early-successional dynamics of young, mixed-species forests of southeastern Ohio. Species compositions were examined across a chronosequence of sixteen stands that developed 6-26 years following clearcutting. The sample was limited to dry-mesic hardwood forest ecosystems found on southerly aspects and on soils derived from residuum or colluvium. Over the 20-year period, stand density decreased from 17,636 stems/ha at age 6 to 2,759 stems/ha at age 26. During the same period, basal area increased from 8.2 m²/ha to 22.1 m²/ha. Oaks (*Quercus* spp.) declined from 3,386 stems/ha to 581 stems/ha. When considered as a proportion of the total stand, however, their proportion was relatively stable, averaging 21.3%. Oak importance value (IV=[relative density + relative basal area]/2) in the upper canopy (dominant and codominant crown classes) increased from 33.9 to 77.4% over the 20-year chronosequence. Chestnut oak (*Quercus prinus* L.) was the major species throughout the chronosequence. White oak (*Quercus alba* L.) and black oak (*Quercus velutina* Lam.) were minor components by age 26 years, although they dominated a comparison sample of six mature stands of the same ecosystem type. Yellow-poplar (*Liriodendron tulipifera* L.) was abundant 6-8 years after clearcutting, but nearly absent by age 26 years. Red maple (*Acer rubrum* L.) was the major species in both the intermediate and overtopped crown classes throughout the chronosequence. Predictive models were developed for stand density and basal area. A multiple logit model predicted increasing proportions of shade-tolerant species, although the predicted trends differed between crown classes. Models based on data from a chronosequence of forest stands can be used by resource managers to predict future composition and structure of an individual stand during its early decades of development. By anticipating what a stand may look like 20 years hence, management practices can be prescribed when it is desirable to alter the course of natural development.

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²Assistant Professors, School of Natural Resources, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210-1085.

VEGETATION ANALYSIS, ENVIRONMENTAL RELATIONSHIPS,
AND POTENTIAL SUCCESSIONAL TRENDS IN THE
MISSOURI FOREST ECOSYSTEM PROJECT

Stephen G. Pallardy¹

Abstract: The vegetation data set of the Missouri Forest Ecosystem Project (MOFEP, initiated by the Missouri Department of Conservation) in the Ozark Mountains of southeastern Missouri was ordinated by Detrended Correspondence Analysis (DCA) to identify vegetation gradients and potential environmental influences. The first DCA axis represented a strong gradient in black oak importance and segregation of this species from white ash, black walnut, eastern redcedar, sugar maple and bitternut hickory. Some Spearman rank correlation coefficients between Axis 1 and measured environmental variables were significant but not high, suggesting that unmeasured factors (e.g., disturbance history, soil pH) were associated with species distribution along the first axis. The second axis clearly separated mesic species (bitternut hickory, black walnut, white ash and sugar maple) from xeric species (shortleaf pine, eastern redcedar, post oak and blackjack oak). Aspect and aspect x slope variables correlated strongly with Axis 2 scores and species importance, suggesting that this axis represented a habitat moisture gradient. Potential canopy replacement in MOFEP forests was examined by analysis of overstory-understory relationships and density vs. size class distributions. White oak likely will become more important in MOFEP forests with time, as this species is relatively abundant in the understory, while relative abundance of red oak group species and shortleaf pine is substantially reduced compared to that in the overstory.

INTRODUCTION

The Missouri Forest Ecosystem Project (MOFEP) in the Ozark Mountains of southeastern Missouri represents one of the most extensive and comprehensive long-term ecological studies undertaken in the eastern United States (Brookshire and Hauser 1993). There have been few quantitative studies of the vegetation in the region and none of this extent (Nigh and others 1985, Read 1952, Ware and others 1992, Zimmerman and Wagner 1979). The baseline vegetation data set collected for this project offered an opportunity to provide an initial, coherent view of the nature and condition of this ecosystem and its plant population dynamics. Specifically, this study was undertaken to provide an ecological analysis of MOFEP forests with regard to tree species composition and dominance, vegetation-environment relationships, and potential successional trends.

METHODS

Data Analysis

The nine MOFEP study sites are located in Carter, Ripley and Shannon counties in the southeastern Missouri Ozarks and range in size from 260 and 527 ha. Study areas, vegetation plot design and data collection were described in detail by Brookshire and Hauser (1993). For the purposes of the present study, data consisted of 644 0.2 ha circular "tree" plots on which species and diameter of all individuals ≥ 11.4 cm (4.5 in) dbh were recorded. Additionally, within the boundary of each tree plot, species and diameter were recorded on four nested 0.02 ha plots for woody

¹School of Natural Resources, 1-31 Agriculture, University of Missouri, Columbia, Missouri 65211.

plants ("saplings") that were between 3.8 and 11.3 cm (1.5-4.5 in) dbh. Within each 0.02 ha plot, "seedling" data were recorded by species on a concentric 0.004 ha plot for plants > 1 m tall and < 3.8 cm (1.5 in) dbh.

Indirect gradient analysis of overstory species was conducted using tree plot data and Detrended Correspondence Analysis (DCA) (Hill and Gauch 1980). Tree Importance Value (IV = relative density + relative basal area) by species for each plot was used as an indicator of abundance. As employed in this study, output of the DCA procedure provides gradients in overstory species composition in two or more dimensions. Composition of major forest types on MOFEP study sites was assessed by averaging IV data across plots of the same Ecological Land Type (ELT) (Miller 1981). TWINSpan analysis (Hill 1979) of the MOFEP data set also was conducted, but provided no detectable advantage in forest classification over that offered by the ELT system (data not shown).

The relationships among DCA axis scores, species importance value and environmental factors were explored by Spearman rank correlation analysis using the CORR procedure of SAS (SAS Institute 1988). Correlation analysis allowed identification of: (1) species that contribute to vegetation gradients extracted in the ordination process and (2) environmental factors that may influence species distribution and dominance across ordination gradients. Spearman rank correlation was used instead of Pearson linear correlation to free the analysis of assumptions of linearity in relationships between species importance and environmental factors and of normality in distribution of vegetation across the ordination gradients (Dollar and others, 1992). Environmental data were obtained from data sets supplied by the Missouri Department of Conservation that contained information for each 0.2 ha plot indicating slope %, aspect (° azimuth) and slope position (1= floodplain, 5=ridgetop). For correlation analysis, aspect was transformed trigonometrically using a function that provided a maximum value (+1) for NE aspects (45°) and minimum value (-1) for SW aspects (225°) (Beers and others 1966):

$$\text{Transformed aspect} = \cos(\text{Aspect} - 45^\circ)$$

This transformation provides a representation of the "mesicness" continuum of topographic orientation, with NE aspects providing the most "mesic," SW aspects the most "xeric" environments, and other aspects being assigned intermediate values along this microenvironmental continuum. Another variable was derived from transformed aspect by multiplying it by slope % based on the tendency of microclimatic influences to be accentuated by the slope of the land (Frank and Lee 1966).

Potential successional trends in these forests were investigated through overstory-understory and size class analysis on groups of plots segregated by ELT classification. Data from the overstory plots mentioned previously and those of the four 0.02 ha sapling plots were merged, and differences between understory (≤ 19.05 cm dbh) and overstory (> 19.05 cm dbh) relative densities of important species of each ELT were assessed by t-tests after arcsin square root transformation (Dollar and others 1992, Sokal and Rohlf 1981).

Plot density (#/ha) of seedlings (from 0.004 ha plots), saplings and trees (as mentioned above) was assembled and segregated by ELT, and data for each species were plotted by diameter class [< 1.5 in (3.8 cm), 1.5-4.5 in (3.8-11.4 cm), 4.5-7.5 in (11.4 cm-19.1 cm), 7.5-10.5 in (19.1-26.7 cm), 10.5-13.5 in (26.7-34.3 cm), 13.5-16.5 in (34.3-41.9 cm), 16.5-19.5 in (41.9-49.5 cm), 19.5-22.5 in (49.5-57.2 cm), 22.5-25.5 in (57.2-64.8 cm), > 25.5 in (64.8 cm) dbh] for further analysis of population structure and potential replacement of canopy trees (Harcombe and Marks 1978, Harcombe 1987, Johnson 1992, McCarthy and Wistendahl 1988). Density vs. size class relationships for different species were compared visually and statistically (using χ^2 -based comparison of frequency distributions across size classes) (Sokal and Rohlf, 1981).

RESULTS AND DISCUSSION

Ordination and Classification

Seventy percent of the variation in vegetation composition was displayed in the first two (of four total) DCA ordination axes. The sample ordination graph, using the first two axes, displayed a dense cloud of plots toward the lower left-hand corner, with a far more scattered and sparse distribution of plots to the right and upper portions of the graph (Fig. 1). The DCA species ordination graph (Fig. 2) and correlation analysis of DCA plot scores with

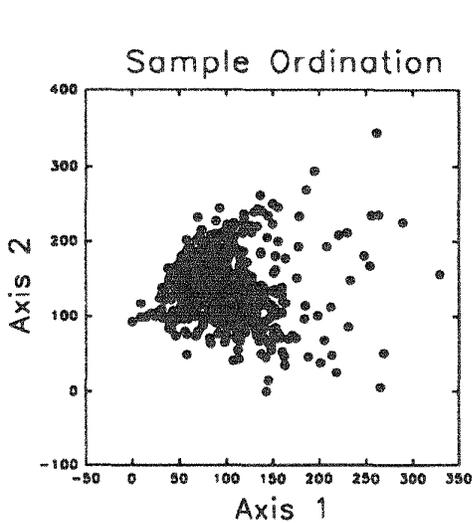


Figure 1. Distribution of plots across two-dimensional ordination space derived from DCA ordination of tree importance values of 644, 0.2 ha plots.

species IV (Table 1) indicated that the first DCA axis represented a strong gradient in black oak (*Quercus velutina* Lam.) importance and segregation of this species from species such as white ash (*Fraxinus americana* L.), black walnut (*Juglans nigra* L.), eastern redcedar (*Juniperus virginiana* L.), sugar maple (*Acer saccharum* Marsh.) and bitternut hickory (*Carya cordiformis* (Wangenh.) K. Koch). Black oak was more abundant in plots with low Axis 1 scores while the latter group of species was important in plots with high Axis 1 scores. In a similar fashion, the second DCA axis clearly separated mesic species such as bitternut hickory, black walnut, white ash, and sugar maple (high Axis 2 scores) from xeric species such as shortleaf pine (*Pinus echinata* Mill.), eastern redcedar, post oak (*Quercus stellata* Wangenh.) and blackjack oak (*Quercus marilandica* Muenchh.) (low Axis 2 scores).

When Axis 1 scores were correlated with environmental factors, some relationships were apparent, with the strongest correlations shown between axis scores and slope position (Table 2A). In practical terms, this correlation indicated that black oak was more important on ridgetop positions. However, in general, environmental correlations with Axis 1

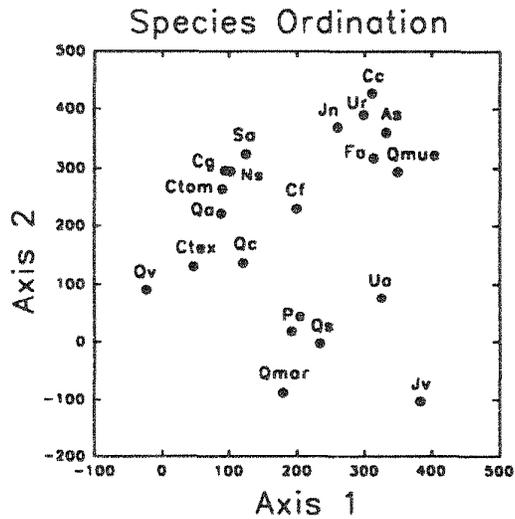


Figure 2. Scatter plot of species across two-dimensional ordination space derived from DCA ordination of tree importance values. Species key: Pe= shortleaf pine; Qc= scarlet oak; Qv= black oak; Qs= post oak; Qa= white oak; Qmue= chinkapin oak; Qmar= blackjack oak; Ns= black gum; Cg= pignut hickory; Cc= bitternut hickory; Ctex= black hickory; Ctom=mockernut hickory; Sa= sassafras; Cf= flowering dogwood; Jv= eastern redcedar; Ur= slippery elm; Ua= winged elm; Fa= white ash; As= sugar maple; Jn= black walnut.

Table 1. Spearman correlation coefficients between DCA axis scores and species importance values. ** $p \leq 0.01$;
* $p \leq 0.05$

Species	Ordination Axis	
	Axis 1	Axis 2
ACERSAC*	0.24**	0.25**
CARYCOR	0.18**	0.25**
CARYGLA	-0.11**	0.46**
CARYTEX	-0.24**	0.06
CARYTOM	-0.08*	0.42**
CORNFLO	0.02	0.25**
FRAXAME	0.29**	0.25**
JUGLNIG	0.16**	0.39**
JUNIVIR	0.32**	-0.04
NYSSSYL	-0.02	0.42**
PINUECH	0.44**	-0.53*
QUERALB	-0.03	0.57**
QUERCOC	0.12**	0.02
QUERMAR	0.12**	-0.48*
QUERMUE	0.47**	0.19**
QUERSTE	0.31**	-0.57*
QUERVEL	-0.89**	-0.25*
SASSALB	-0.03	0.27**
ULMUALA	0.39**	0.08
ULMURUB	0.28**	0.35**

*Species codes for Tables 1, 2 and 3. ACERSAC = sugar maple; CARYCOR = bitternut hickory; CARYGLA = pignut hickory; CARYTEX = black hickory; CARYTOM = mockernut hickory; CORNFLO = flowering dogwood; FRAXAME = white ash; JUGLNIG = black walnut; JUNIVIR = eastern redcedar; NYSSSYL = black gum; PINUECH = shortleaf pine; QUERALB = white oak; QUERCOC = scarlet oak; QUERMAR = blackjack oak; QUERMUE = chinkapin oak; QUERSTE = post oak; QUERVEL = black oak; SASSALB = sassafras; ULMUALA = winged elm; ULMURUB = slippery elm.

were not strong (i.e., less than 0.3), suggesting that some unmeasured factor likely was important in determining species composition across this axis. Plausible candidates are disturbance history and soil factors (especially pH, Nigh and others 1985, Ware and others 1992). In contrast to these relatively weak Axis 1-environment correlations, the transformed aspect and aspect x slope variables correlated more strongly ($r = 0.43$ to 0.46) with Axis 2 DCA sample scores. This result is consistent with the distribution of species shown in the species ordination graph (Fig. 2). Hence Axis 2 of the DCA ordination appeared to represent a habitat moisture gradient.

MOFEP Forest Composition

Forests of the two most common ELT classifications (17 and 18) (Table 3) consisted of nearly equal abundances of black and scarlet oak. White oak (*Quercus alba* L.) was somewhat greater in importance on ELT 18 plots (side slopes N/E aspects; deep soils; Miller, 1981) than on 17 plots (side slopes S/W aspects; deep soils). In contrast, shortleaf

Table 2. Spearman correlation coefficients (with probability level below) between DCA ordination axis scores and environmental variables (A) and between environmental variables and species Importance Values (B). For species codes see Table 1.

(A)		Axis 1	Axis 2
	Slope (%)	0.001 0.98	0.08 0.04
	Slope position	-0.29 <0.01	-0.25 <0.01
	Aspect*	-0.22 <0.01	0.43 <0.01
	Aspect x slope*	-0.19 <0.01	0.46 <0.01

(B)		ACERSAC	CARYCOR	CARYGLA	CARYTEX	CARYTOM	CORNFL0	FRAXAME	JUGLNIG	JUNIVIR	NYSSSYL
Slope (%)	-0.02 0.59	-0.08 0.04	-0.10 0.01	-0.07 0.10	0.02 0.69	0.15 <0.01	0.001 0.98	-0.07 0.07	0.09 0.03	0.12 <0.01	
Slope position	-0.13 <0.01	-0.14 <0.01	0.01 0.76	0.07 0.10	-0.12 <0.01	-0.16 <0.01	-0.13 <0.01	-0.05 0.25	-0.05 0.23	-0.22 <0.01	
Aspect*	0.01 0.94	0.03 0.46	0.29 <0.01	0.15 <0.01	0.19 <0.01	0.26 <0.01	0.03 0.43	0.10 <0.01	-0.07 0.06	0.22 <0.01	
Aspect x Slope*	0.01 0.90	0.05 0.24	0.33 <0.01	0.15 <0.01	0.21 <0.01	0.28 <0.01	0.07 0.07	0.12 <0.01	-0.10 0.01	0.23 <0.01	

		PINUECH	QUERALB	QUERCOC	QUERMAR	QUERMUE	QUERSTE	QUERVEL	SASSALB	ULMUALA	ULMURUB
Slope (%)	0.10 <0.01	0.12 <0.01	0.15 <0.01	-0.04 0.32	0.01 0.81	-0.26 <0.01	-0.07 0.06	0.01 0.99	0.04 0.34	-0.04 0.36	
Slope position	-0.01 0.97	-0.20 <0.01	-0.14 <0.01	0.17 <0.01	-0.25 <0.01	0.13 <0.01	0.37 <0.01	-0.07 0.07	-0.22 <0.01	-0.16 <0.01	
Aspect*	-0.40 <0.01	0.19 <0.01	0.04 0.37	-0.32 <0.01	-0.09 0.03	-0.30 <0.01	0.04 0.32	0.18 <0.01	-0.04 0.35	0.04 0.37	
Aspect x Slope*	-0.45 <0.01	0.17 <0.01	0.02 0.66	-0.32 <0.01	-0.06 0.12	-0.27 <0.01	0.01 0.87	0.19 <0.01	-0.04 0.33	0.04 0.26	

* Aspect transformed trigonometrically (see text).

Table 3. Mean Tree Importance Values of MOFEP plots classified by Ecological Land Type (ELT). (n= number of plots in ELT)

n= SPECIES	ELT*												
	1	5	6	7	11	15	17	18	19	20	21	22	23
ACERSAC*		1.46	4.10		0.02		0.15	0.10	3.00	1.13			0.42
CARYCOR		3.81	7.70		0.03	0.38	0.05	0.14	0.76				
CARYGLA	19.40	11.77	32.15	6.15	10.87	5.60	3.80	10.98	3.14	5.85	0.55	0.70	1.55
CARYTEX	10.70	9.59	14.10	11.75	12.35	8.14	7.06	8.87	6.28	14.65	8.92	4.13	4.47
CARYTOM	10.80	9.96	15.05	35.15	7.52	5.86	6.22	10.01	4.76	5.77		2.73	0.98
CORNFLO	11.50	1.45		1.56	0.43	0.32	0.97	2.55	2.13	0.48		4.30	0.94
FRAXAME		2.27	2.65		0.22		0.34	0.37	3.89	2.21		1.70	1.36
JUGLNIG		2.92	12.80	1.31	1.71		0.39	0.97	2.59	0.75			
JUNIVIR							0.37	0.03	1.78		10.10	0.60	9.58
NYSSSYL	26.10	6.21	16.40	12.31	1.42	1.04	2.42	4.45	1.35	7.32	0.80	1.03	
PINUECH		11.04		9.41	12.75	9.32	25.25	7.45	31.35	15.36	22.17	13.03	25.35
QUERALB	63.70	43.03	45.95	28.23	30.03	16.58	38.98	47.40	32.63	66.61	20.62	21.16	10.72
QUERCOC	26.10	28.53	24.30	36.00	28.79	14.68	46.88	47.96	35.05	40.26	40.52	15.30	35.76
QUERMAR		0.33		0.36	2.88	9.08	3.05	0.24	0.87	0.47	33.55	17.46	15.52
QUERMUE		5.71	2.40	3.16			0.89	0.49	25.23	3.13	4.15	15.13	20.77
QUERSTE	6.40	25.58		15.56	18.15	16.38	12.48	7.09	29.20	9.97	11.42	46.30	40.67
QUERVEL	20.70	20.80	10.95	30.01	71.80	112.44	49.13	48.28	8.93	18.65	34.00	29.56	26.76
SASSALB		0.49		2.85	0.16		0.15	0.53	0.11	0.85			
ULMUALA		1.52	1.15	0.55	0.01		0.35	0.21	2.56	0.80	13.22	0.73	1.53
ULMURUB		5.82	3.40	0.68	0.25		0.27	0.40	1.77	0.22		0.56	0.23

*Species code: see Tab. 1. ELT Codes (Miller, 1981): 1-Low flood plains/foamy and mixed alluvial soils; 5,6-Upland waterways/deep cherty soils; 7-Toe slopes/deep loamy soils; 11-Narrow ridges/deep cherty soils; 15-Broad ridges/deep loamy and clayey soils; 17-Side slopes/South and West aspects/deep soils; 18-Side slopes/North and East aspects/deep soils; 19-Side slopes/South and West aspects/shallow soils; 20-Side slopes/North and East aspects/shallow soils; 21-23-Side slopes/very shallow limestone soils

pine was more important on ELT 17 plots. Other tree species on these plots generally had importance values greater than 1 and less than 15 and included pignut, black and mockernut hickories (*Carya glabra* (Mill.) Sweet, *C. texana* Buckl., *C. tomentosa* (Poir.) Nutt.), black gum (*Nyssa sylvatica* Marsh.) and post and blackjack oak. These hickory species and black gum tended to be more important on ELT 18 plots, while blackjack and post oaks were more important on ELT 17 plots. Plots of ELT 11 (narrow ridges/deep cherty soils) were dominated by black oak with smaller contributions by scarlet (*Quercus coccinea* Muenchh.), white and post oaks. Lower importance values were associated with shortleaf pine, the three above-mentioned species of hickory, and black gum. Plots of ELT 19 (side slopes S/W aspects; shallow soils) were characterized by the highest shortleaf pine and chinkapin oak (*Quercus muehlenbergii* Engelm.) importance values among all ELT classes, with similar contributions by scarlet, white, and post oaks. Most important on plots characterized as "Upland Waterways" (ELT 5, 6) was white oak, followed by scarlet, post and black oak, and shortleaf pine and previously-mentioned species of hickory. Moreover, there was a small, but notable, contribution on ELT 5 plots of mesic species such as black walnut, black gum, sugar maple bitternut hickory, and slippery elm (*Ulmus rubra* Mühl). Although the sample sizes of remaining ELT classes were quite small, it is worth noting that white oak importance was quite high on ELT 20 (side slopes N/E aspects; shallow soils) and those species that prefer soil high in calcium, such as eastern redcedar and chinkapin oak (Fowells 1965), were important on ELT 21-23 plots.

Correlation of species importance values with environmental parameters (Table 2B) reinforced the qualitative relationships noted above between ELT-based environmental characterizations and species distribution and abundance. Species associated with ELTs categorized as having South and West-facing slopes (shortleaf pine and

blackjack and post oaks) tended to be negatively correlated with the transformed aspect and aspect x slope % variables. In contrast, species that were more important on ELTs associated with North- and East-facing slopes (white oak, species of hickory, black gum, and black walnut) tended to be positively and significantly correlated with these two parameters. Black oak correlated most highly with slope position, being most important on ridgetop positions and showing little correlation with aspect. In contrast, more mesic-site species (for this region) such as sugar maple, bitternut hickory, white ash, black gum, white oak, and winged (*Ulmus alata* Michx.) and slippery elm were associated with lower slope positions.

MOFEP plots show species composition and abundance typical of the generally xeric forests of the region (Braun 1972, Nelson 1985, Read 1952, Ware and others 1992). On ridgetop and upper slope forests a combination of black, scarlet, post and white oaks and shortleaf pine dominate, with relative importance shifting among black oak (ridgetops), scarlet, black and post oaks and shortleaf pine (S- and W-facing slopes), and white oak and hickories (N- and E-facing slopes). On lower slopes white oak tends to attain an importance similar to that associated with mesic (North and East) aspects on upper slopes. On the relatively infrequent mesic sites associated with upland draws and ephemeral streams, mesic species of the region such as sugar maple, bitternut hickory, black gum and black walnut, along with more abundant white oak may be found.

According to Nelson's (1985) scheme, MOFEP forests would appear to variously fit the classifications of xeric to dry-mesic forests on limestone/dolomite, chert and sandstone substrates. This conclusion is consistent with that of Brookshire and Hauser (1993). MOFEP forests similarly fit into Braun's (1972) categorization of Oak-Pine and southern division Oak-Hickory forests. There were some exceptions to Nelson's and Braun's descriptions, however. Particularly noteworthy was the scarcity of northern red oak (*Quercus rubra* L.) in MOFEP forests despite its inclusion in forests of the region by both Nelson and Braun. Similarly, Ware and others (1992) identified northern red oak as a common constituent of upland forests near the Current River in the same general area. Secondly, is the abundance of scarlet oak in the MOFEP study sites and its restriction to the Oak-Chestnut Region by Braun (1972) (she nowhere mentions it as occurring in Oak-Hickory forests). Scarlet oak also fails to appear in the species lists of Ware and others (1992). It might be speculated that, given the morphological similarity of scarlet oak to northern red and black oaks, variation in species identification might be responsible for these discrepancies.

Overstory-Understory Relationships

Figures 3-7 illustrate differences between overstory (>19.05 cm dbh) and understory (\leq 19.05 cm dbh) relative densities of major species of common ELTs. Some trends were apparent: (1) In every ELT examined, there was evidence of substantial depletion of understory populations of shortleaf pine and major red oak group species (scarlet and black oak); (2) In three of five major ELT classes (11, 17, 18, representing 92% of plots) white oak relative density in the understory was significantly greater than that in the overstory; (3) A number of other species that currently are not very important in the overstory show greater relative abundances in the understory [i.e., black gum, mockernut hickory, black hickory and sassafras (*Sassafras albidum* (Nutt.) Nees)].

Overstory-understory relationships varied somewhat with ELT classification. The understory relative densities of red oak group species and shortleaf pine tended to be greater in plots of ELTs that were more xeric in character (especially ELT 11 and 17, Figs. 4 and 5) compared with more mesic ELTs (5 and 18 Figs. 3 and 6). However, understory relative densities of these species were substantially reduced on ELT 19 plots, which also presumably were quite xeric. As mentioned above, relative density of understory white oak was greater than that in the overstory in three ELTs (11, 17 and 18, Fig. 4, 5 and 6). In the other two abundant ELTs (5 and 19) relative density of understory white oak was less than that in the overstory, but because there were few black or scarlet oak and shortleaf pine plants in the understory of forests of these ELTs, white oak was still the most common understory tree species. Other species that tended to show increased relative density in the understory (black gum, black and mockernut hickory, sassafras) showed little apparent relationship between relative abundance and ELT (and hence microenvironment). Post oak was relatively less abundant in the understory than in the overstory in all ELTs, but the differences were substantially less than those shown by red oak group species and shortleaf pine.

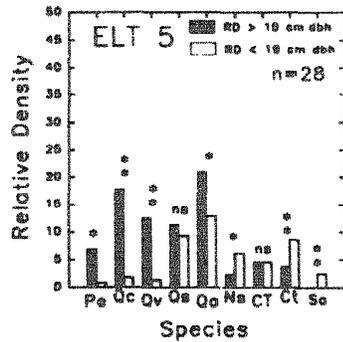


Figure 3. Overstory and understory relative density for major species on ELT 5 plots. Asterisks above each pair of histogram bars indicate highly significant (** $p \leq 0.01$) and significant ($p \leq 0.05$) differences between overstory and understory pairs. Bar pairs with "ns" are not significantly different ($p > 0.05$). Species codes: Pe-shortleaf pine, Qc-scarlet oak; Qv-black oak; Qs-post oak; Qa-white oak; Ns-black gum; CT-black hickory; Ct-mockernut hickory; Sa-sassafras..

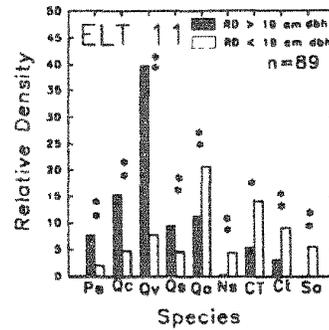


Figure 4. Overstory and understory relative density for major species on ELT 11 plots. Asterisks above each pair of histogram bars indicate highly significant (** $p \leq 0.01$) and significant ($p \leq 0.05$) differences between overstory and understory pairs. Bar pairs with "ns" are not significantly different ($p > 0.05$). Species codes: see legend for Fig. 3.

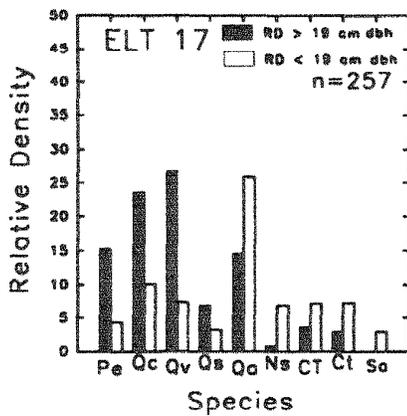


Figure 5. Overstory and understory relative density for major species on ELT 17 plots. All bar pairs are significantly different ($p \leq 0.01$). Species codes: see legend for Fig. 3.

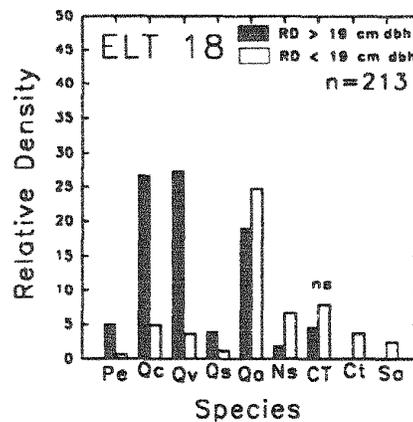


Figure 6. Overstory and understory relative density for major species on ELT 18 plots. All bar pairs except that marked with "ns" are significantly different ($p \leq 0.01$). Species codes: see legend for Fig. 3.

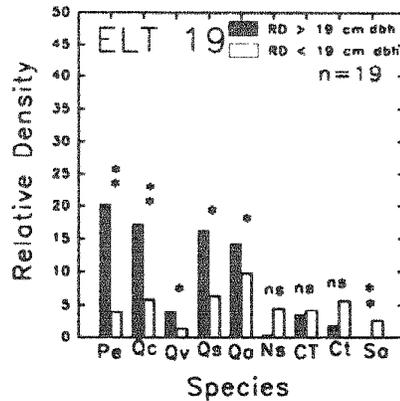


Figure 7. Overstory and understory relative density for major species on ELT 19 plots. Asterisks above each pair of histogram bars indicate highly significant (** $p \leq 0.01$) and significant (* $p \leq 0.05$) differences between overstory and understory pairs. Bar pairs with "ns" are not significantly different ($p > 0.05$). Species codes: see legend for Fig. 3.

Density-Size Class Distribution Relationships

χ^2 -tests of distribution differences across size classes indicated that there were highly significant ($p \leq 0.01$) differences among species in every ELT (data not shown). Density vs. size class plots were constructed for major species and ELTs [see Fig. 8 for an example (ELT 17)]. In general, the results offered further confirmation of previously-noted patterns of species dominance and potential replacement across ELTs.

However, several new distribution patterns were shown in these plots and not elsewhere: (1) In all ELTs white oak abundance was greatest in the 1.5-4.5 in (3.8-11.4 cm) dbh size class, decreasing in all larger and the one smaller size class; (2) Most other abundant species in the understory (black gum, sassafras, black hickory, mockernut hickory) had greatest density in the smallest size class; (3) Some species that currently are abundant in the overstory (black, scarlet, and post oak and shortleaf pine) showed shallow negative slopes; (4) Density of red oak group species and shortleaf pine were much reduced in smaller size classes compared with those of white oak and other understory species, supporting the general trends and conclusions shown by overstory-understory analysis (see above). However, red oak group species are present in densities $> 50/\text{ha}$ even in smaller size classes in certain ELTs, particularly those that are more xeric (e.g., 17, Fig. 8). Density of shortleaf pine is everywhere less than 25/ha; (5) The differences between ELT 17 and 18 in relative density of red oak group species and shortleaf pine vs. white oak were attributable to differences in absolute abundance in the former group. Absolute density of white oak in the understory was quite similar on both ELTs (data not shown; see also Brookshire and Hauser 1993).

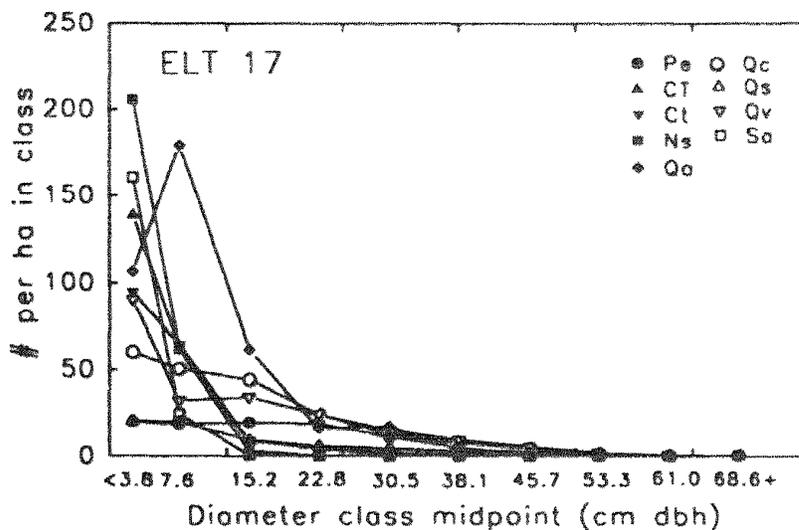


Figure 8. Mean density vs. size class relationships for important species on ELT 17 plots. Species codes: see legend for Fig. 3.

These data are consistent with trends we have seen elsewhere in the Ozarks (Jenkins and Pallardy, 1993). There is strong evidence in the MOFEP data set and from other research in the Missouri Ozarks that white oak has the potential to increase in importance throughout the region. The ecological basis of this potential change *may* be ascribable to white oak's greater longevity and shade tolerance (Dougherty and others 1980, Fowells 1965). The size class distributions further indicate that white oak apparently has experienced a "pulse" of recruitment, with the greatest abundance of this species found in the next-to-smallest size class. Other species, particularly black gum, some of the hickories, and sassafras show great abundance in the smallest size class. One might speculate that observers of long-term forest succession in the Ozark region might see these species becoming more important, but it is debatable whether they (except perhaps for the hickories) have canopy potential given the xeric environment of the Ozarks and the greater microclimatic stress associated with ascent to an unprotected canopy position (Nigh and others 1985, Pallardy and others 1988). On the other hand, the current position of white oak as a canopy dominant throughout much of the MOFEP study area indicates that its short-term increase in abundance is nearly certain.

Future trends in abundance of scarlet and black oak in MOFEP site forests may differ somewhat from those of shortleaf pine. In the former pair there is still sufficient regeneration to anticipate a continuing, if less prominent, contribution of both red oak species to future forest overstories. This is especially true on xeric ELT 11, 17, and 19 sites. In contrast, seedlings and saplings of shortleaf pine are nowhere abundant and one might predict a uniform decline in the abundance of this species through time in canopies of undisturbed forests of the MOFEP project.

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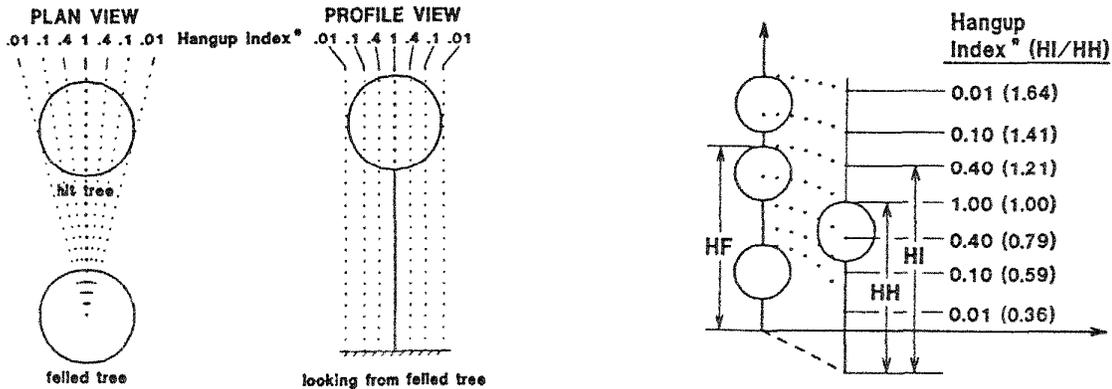
TIMBER MARKING GUIDELINES TO MINIMIZE CHAINSAW FELLING ACCIDENTS

Penn A. Peters¹, Michael D. Erickson², and Curt D. Hassler²

Abstract: Trees are marked by foresters for retention or harvest to satisfy landowner objectives for timber sale revenues, stand improvement, wildlife habitat, water quality, and aesthetics. Another consideration when marking trees is the safety of the chainsaw feller. Can the tree that has been marked for harvest be felled safely? Will the feller be able to select and control a direction of fall such that the felled tree does not produce a hazardous reaction?

When marking timber, the following will have a positive effect on chainsaw feller safety: 1. mark trees to be cut on two sides (for example, uphill-downhill), so the feller can easily see the trees to be cut and can make a safe selection of the felling order. 2. when selecting one cut tree from a pair of trees -- mark the tree that can be felled safely, 3. assume a heavily leaning tree will fall in the direction of lean and assess for hazards, and 4. learn the three factors that affect the likelihood of a hangup, viz., lateral offset, impact height (HI), and felled tree to hit tree dbh ratio. The lateral offset is the perpendicular distance from the direction of fall plane to the centerline of the hit tree. The impact height (HI) is the vertical distance from the base of the hit tree to the top of the falling tree as the falling tree intersects the lateral plane containing the hit tree (see figure). Felled tree height (HF) and hit tree height (HH) are defined in the figure also.

Effect of diameter	
Hangup Index*	dbh of hit tree/ dbh of felled tree
0.9	2.07
0.7	1.29
0.5	.99
0.3	.80
0.1	.62
0.01	.48



*A tree with a hangup index of 0.4 is four times as likely to hang up as one with a hangup index of 0.1.

¹Research Engineer, Northeastern Forest Experiment Station, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505-3101.

²Research Associate and Associate Professor, Appalachian Hardwood Center, West Virginia University, Morgantown, WV 26506.

MATING PARAMETER ESTIMATES OF BLACK WALNUT
BASED ON NATURAL AND ARTIFICIAL POPULATIONS

George Rink¹, Guoqiang Zhang², Zuo Jinghua², and Fan H. Kung²

Abstract: Horizontal starch gel electrophoresis was performed on six polymorphic loci in black walnut (*Juglans nigra* L.) embryos from open-pollinated nut collections made in 1987 in a Missouri half-sib progeny test, and Indiana seed orchard and a natural population in southern Illinois. Allozyme data disclosed very high levels of variation (75.0-87.5%), mean heterozygosity (0.198-0.215) and outcrossing (0.880-0.928 in all three seed populations. Mating parameters from seed orchard populations were not significantly different from those of the natural population. The mean fixation index was less than 0.1 in all three seed populations, suggesting very low rates of inbreeding in this species in seed orchards as well as in a natural setting.

¹North Central Forest Experiment Station, Forestry Sciences Laboratory, Southern Illinois University, Carbondale, IL 62901-4630.

²Department of Forestry, Southern Illinois University, Carbondale, IL 62901-4630.

VARIATION AMONG NORTHERN RED OAK PROVENANCES IN BARK THICKNESS:DBH RATIOS

Matthew S. Russell and Jeffrey O. Dawson¹

Abstract: Differences in bark thickness in relation to diameter at breast height were observed in a 30-32 year old Illinois planting of 32 provenances of northern red oak (*Quercus rubra*) from throughout its natural range. Bark thickness by itself is often a good indication of relative cambial insulation from fire. Fire resistance in trees can largely be attributed to thickness and low thermal conductivity of bark. Western and southern provenances tended to have greater average bark thickness to dbh ratios than northern or eastern provenances because we tested latitude and longitude separately. One possible explanation is that provenances located in the western or southern areas of the range may have developed greater fire resistance through natural selection of genotypes that produce thicker bark at a given dbh.

INTRODUCTION

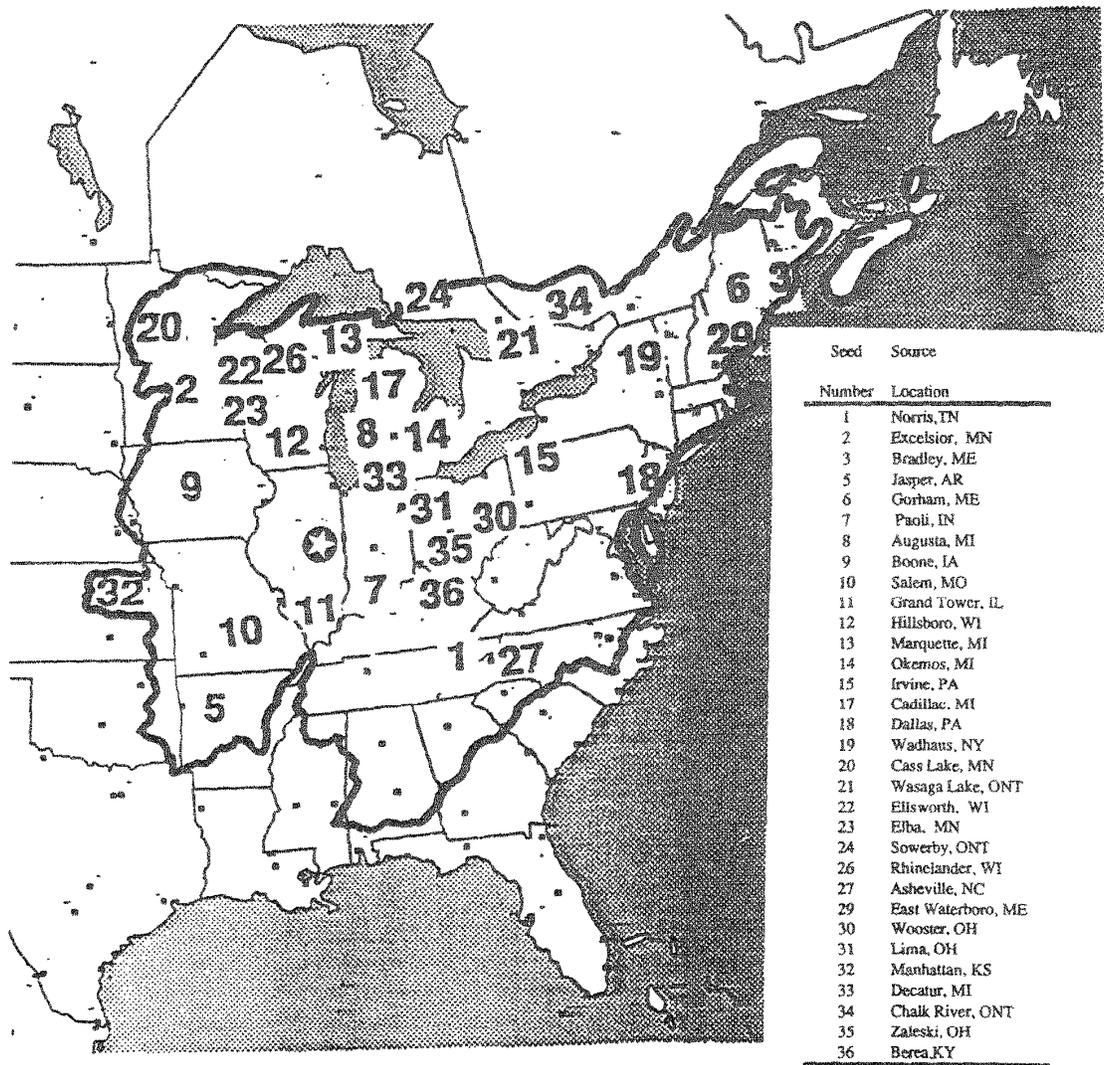
In mesic deciduous forests of Eastern North America, fires have historically been thought of as detrimental to the quality of standing timber. However, exclusion of fire from these forests has been implicated in the gradual post-settlement replacement of dominant early to mid-successional *Quercus* species with late-successional more shade tolerant *Acer* species (Wuenschel and Valiunas 1967; Abrams 1992). Pallardy and others (1991) noted significant changes in species composition over a 22 year period for three distinct forest types in Missouri. Increases in the prevalence of sugar maple (*Acer saccharum*) and decreases in *Quercus spp.* were attributed to exclusion of fire and succession towards more mesic environments. The continuing trend towards late successional stages has led many resource managers to reconsider fire as a management tool to manipulate natural processes of succession and to control forest species composition.

Northern red oak (*Quercus rubra*) is a commercially valuable species which is widely distributed throughout eastern North America and into southern Canada (Figure 1). The range of this species includes most states east of the Mississippi River except parts of states located in the coastal plains of the South and Florida. Northern red oak is intermediate in shade tolerance and can be found on a variety of topographical locations and soil types. The best development of this species occurs in the Ohio River Valley on deep, well drained loam to silty, clay loam soils (Sander 1990).

Very little is known about the effects of fire on central hardwoods. It is difficult to quantify the effects of fire due to confounding variables such as duration and intensity of burn. Several methods have been developed to delineate factors contributing to fire tolerance of various tree species (Kayll 1963; Vines 1968; Hare 1964; Gill and Ashton 1968; Uhl and Kauffman 1990). There is a consensus among researchers that the vascular cambium of trees will be killed at temperatures in excess of 60°C (Hare 1961). Temperatures at the surface of tree stems often exceed 60°C in prescribed fires (Fahnestock and Hare 1964). Knowledge of the specific effects of fire on individual trees is necessary if fire is to be used efficiently in management. A recent study by Hengst and Dawson (1994) has shown that greater bark thickness and lower thermal conductivity moderate hardwoods' cambial temperature increases resulting from artificial burning. In the same study northern red oak from central Illinois had one of the lower bark thickness:dbh ratios of the common native oak species.

Bark has long been recognized as a factor which provides fire resistance to trees (Starker 1934; Hare 1965; Martin 1963; Vines 1968). Numerous air-filled cells in bark provide excellent insulation and prevent rapid fluctuation of

¹Department of Forestry, W-503 Turner Hall, University of Illinois, Urbana, IL 61801.



★ = Location of provenance study near Monticello, Illinois.

Figure 1. The native range of *Quercus rubra* and locations of 32 seed sources used in an East Central Illinois provenance study.

temperatures at the vascular cambium. Martin (1963) conducted a laboratory experiment examining the thermal conductivity of the bark of several species. His results demonstrated the good insulating qualities of bark and identified some factors contributing to variation in heat conductance between and within the bark of different species.

Northern red oak has been observed to exhibit considerable geographic genetic variation for a variety of traits in past observations of provenance trials (Kriebel and others 1976). McMahon (1988) conducted a study examining the performance of different provenances of Northern red oak in the same plots used in this study. He observed variation and significant differences among provenances for a variety of characteristics such as survival, growth rate, forking, and phenology. The purpose of our study was to determine whether northern red oak provenances differ in bark thickness:dbh ratios.

METHODS

Study Design

Variation in bark thickness was determined in the summer of 1993 in a northern red oak provenance study near Monticello, Illinois (40.1° N latitude; 88.5° W longitude). The planting was one of several established as the U.S.D.A. North Central Cooperative Regional Project (NC-51) entitled "Tree Improvement through Selection and Breeding of Trees of Known Origin." The 1-0 stock was planted during spring of the years 1962-1964. Individual tree seed sources were not separated into families for this study. Bulked seedlots were the source of planting stock. The experimental design encompassed 32 seed sources within 7 replicates of a randomized complete block experimental design. Each replicate contained at least 16 trees from each source upon establishment with a spacing of 3.0 x 2.4m. A double border row of common seed source trees surrounded the plots.

Six trees were measured from 4 x 4 plots in each of 3 replications of each source. Bark thickness measurements were made to the nearest millimeter using a metric bark gauge. Diameter at breast height was measured to the nearest millimeter 1.4m above the ground. Trees that were measured were randomly selected from the total number of surviving trees present. The trees were consecutively assigned a number, and a random number table was then used to select 6 trees. Two bark thickness measurements were made on the north and south sides of each randomly selected tree at a height of 1.4m.

Data Analysis

In a previous study, bark thickness of northern red oak and 15 other hardwood species from a single locale was positively linearly correlated with dbh for each species (Hengst and Dawson 1994). The ratio of bark thickness to dbh was used in analysis rather than bark thickness alone to eliminate the confounding influence that tree size has on bark thickness. The rationale for using the ratio of bark thickness to dbh as opposed to some other function of the two variables is geometrically motivated and is supported by a simple linear regression (Figure 2). Here we see that apart from some residual variance, attributable to seed sources, bark thickness is essentially a multiple of dbh offset by a small intercept very near the origin. Also, in order to avoid the consequences that outliers and violations of the usual assumptions of the standard linear regression model may have on statistical inference, a nonparametric index was used to measure the association of the variables of interest. The mean bark thickness:dbh ratio was associated with latitude and longitude using this ordinal method. Specifically Kendall's tau, a nonparametric index of ordinal association that can be interpreted much like the usual correlation coefficient, was used along with its corresponding test of statistical significance. It should be noted that the usual adjustment to Kendall's tau for data containing ties was used, because there were some ties in the bark thickness:dbh ratio. Though standard linear regression was not used for statistical inference, it was used to provide graphical summaries of the data. Statistical analyses were conducted using S+ (Statistical Science Inc. 1994) and SAS version 6.0 (SAS Institute Inc. 1989). Variation among bark thickness:dbh ratios was also examined for all provenances using ANOVA. The ANOVA was followed by a t-test to examine geographic variation among disjunct seed sources (Table 1).

Table 1. Provenance means for bark thickness:dbh ratios for a 30-32 year old range wide provenance trial of *Quercus rubra* grown in East Central Illinois. A T-grouping was constructed to illustrate statistical differences among seed sources by mean bark thickness:dbh ratios ranked from greatest to least. Means followed by the same letter are not significantly different ($\alpha = .05$).

Seed	Source	Mean	# of	T-grouping
Number	Location	bark thickness: dbh ratio	observations	
1	Norris, TN	0.047	17	A
36	Berea, KY	0.045	18	A
2	Excelsior, MN	0.045	12	A
10	Salem, MO	0.045	18	AB
35	Zaleski, OH	0.044	17	ABC
34	Chalk River, ONT	0.042	18	BCD
5	Jasper, AR	0.041	16	CD
9	Boone, IA	0.041	18	CD
23	Elba, MN	0.041	18	CD
27	Asheville, NC	0.040	14	D
12	Hillsboro, WI	0.040	18	D
8	Augusta, MI	0.040	18	D
11	Grand Tower, IL	0.040	18	DE
7	Paoli, IN	0.040	18	DE
32	Manhattan, KS	0.039	34	DEF
6	Gorham, ME	0.039	18	DEFG
15	Irvine, PA	0.036	13	EFGH
33	Decatur, MI	0.036	18	FGH
31	Lima, OH	0.036	18	FGHI
30	Wooster, OH	0.036	13	FGHI
22	Ellsworth, WI	0.035	18	GHIJ
20	Cass Lake, MN	0.035	18	HIJ
21	Wasaga Lake, ONT	0.035	18	HIJ
17	Cadillac, MI	0.035	18	HIJ
29	East Waterboro, ME	0.035	18	HIJ
18	Dallas, PA	0.034	18	HIJK
26	Rhineland, WI	0.034	18	HIJK
19	Wadhaus, NY	0.033	18	HIJK
14	Okemos, MI	0.033	14	IJK
13	Marquette, MI	0.032	18	JKL
3	Bradley, ME	0.032	18	KL
24	Sowerby, ONT	0.030	12	L

RESULTS

Among the 32 seed sources in the provenance study, the Kendall's tau index of correlation between latitude and the mean provenance ratio of bark thickness to dbh was equal to -0.438, revealing that a negative association exists between bark thickness:dbh ratio and latitude. In other words, trees with seed sources in the south tend to have higher relative bark thickness for a given dbh, a finding consistent with our hypothesis. A central limit theorem based test of the statistical significance of the observed value of Kendall's tau had an association probability value of 0.0002. The mean values of the ratio of bark thickness:dbh are plotted against latitude (Figure 3) along with the least squares regression line. The negative slope of the regression line illustrates the trend.

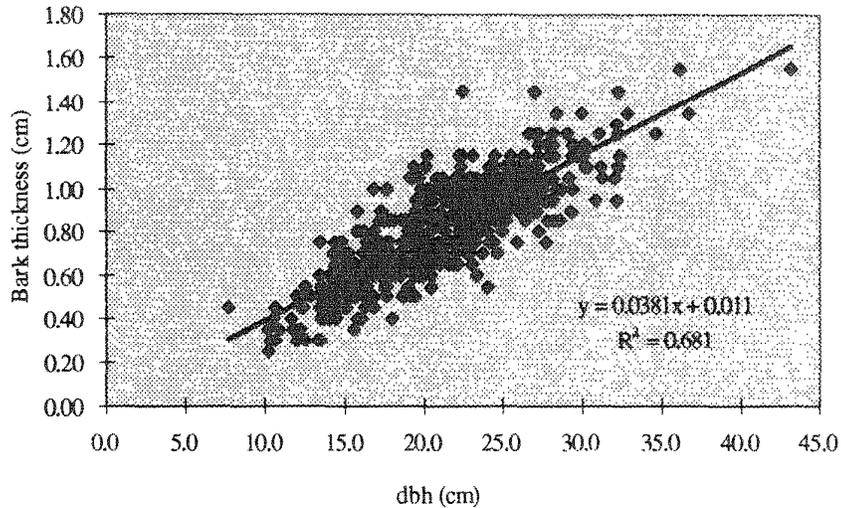


Figure 2. Dbh vs. barkthickness for 32 seed sources planted in a central Illinois provenance trial of *Quercus rubra*. Individual tree data were used to plot the regression (n=589).

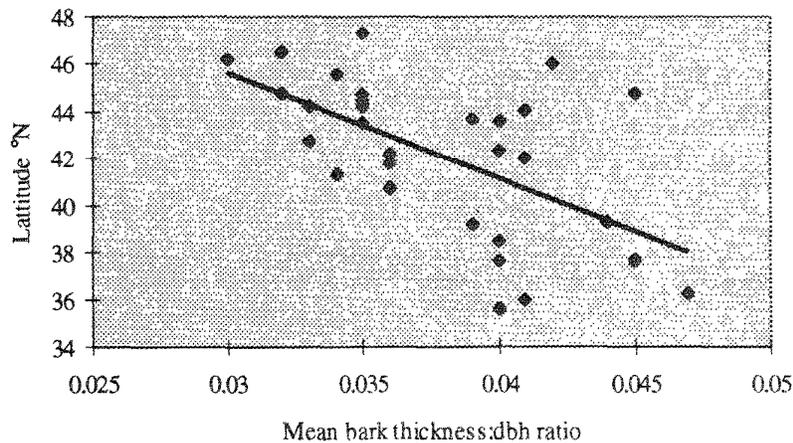


Figure 3. Mean provenance bark thickness:dbh ratios by seed source vs. latitude.

Kendall's tau was also computed to examine the association between longitude and bark thickness:dbh ratio, and was equal to 0.304. While the degree of association implied by this index suggests that latitude is more closely associated with bark thickness:dbh than is longitude, the positive value of Kendall's tau supports our hypothesis that western seed sources tend to produce trees with relatively thicker bark for a given dbh. A test of significance in this case resulted in a probability value of 0.007, once again lending support to our assertion. The mean values of the ratio of bark thickness:dbh are plotted against longitude (Figure 4) along with the least squares regression line. The positive slope of the regression line illustrates the trend.

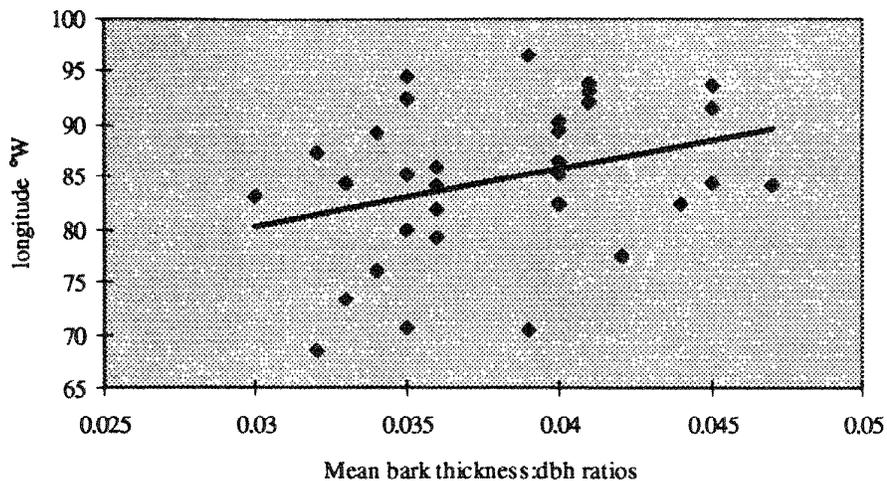


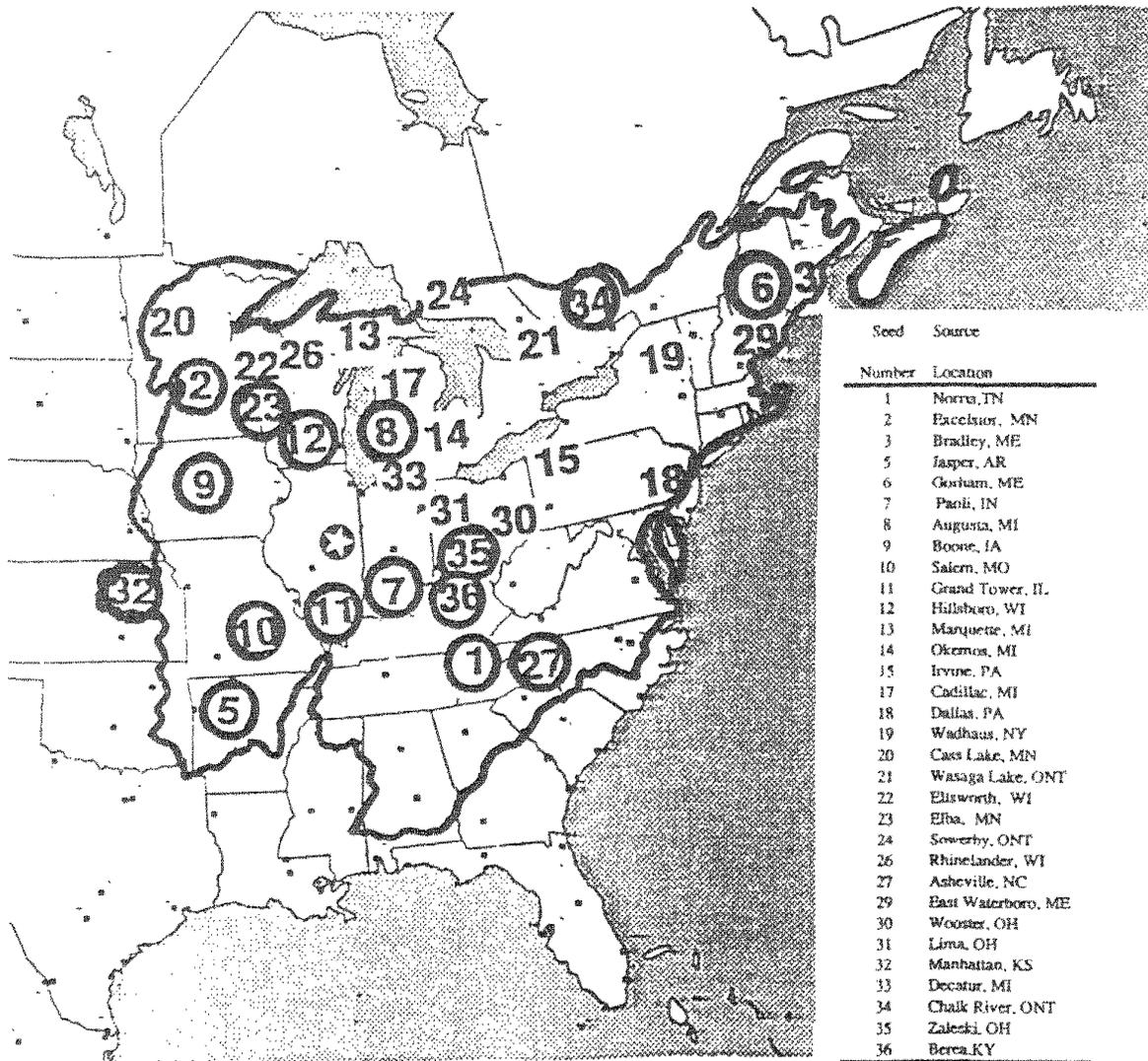
Figure 4. Mean bark thickness:dbh ratios by seed source vs longitude.

Analysis of variance indicated that different mean values for bark thickness:dbh ratios for provenances of northern red oak were significantly different ($\alpha = 0.05$). A T-grouping illustrates specific statistically significant differences in bark thickness:dbh ratios among provenance means (Table 1).

DISCUSSION

The median value of bark thickness:dbh ratios (0.038) for all provenances was used as a division point to separate the two size classes in figure 5. Results indicate that provenances associated with western and southern areas of the range generally had greater bark thickness for a given dbh according to Kendall's tau. Exceptions to the trend are source 6 from Gorham, Maine and source 34 from Chalk River, Ontario. We do not have explanations for these exceptions, though there is a possibility that fire frequented these areas prior to European settlement.

Fire was probably most prevalent in western and southern portions of the range of northern red oak in the millennia following the retreat of continental glaciers from the northern part of its range 12,000 years ago (Abrams 1992). In these areas long term exposure to increased fire frequency may have led to the natural selection of tree genotypes with greater bark thickness:dbh ratios which consequently could better resist cambial damage from fire. Other factors such as long term patterns in conditions conducive to the prevalence of bark boring insects also may have influenced ecotypic variation in bark characteristics of northern red oak.



★ = Location of provenance study near Monticello, Illinois.

Figure 5. Contrast between bark thickness:dbh ratios in the western and southern portions with those in the northern and eastern portions of the native range of *Quercus rubra*. Seed source ratios above the median value of 0.038 are enclosed in a circle.

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PRELIMINARY GUIDELINES FOR THE USE OF TREE SHELTERS
TO REGENERATE NORTHERN RED OAK AND OTHER HARDWOOD SPECIES
ON GOOD TO EXCELLENT GROWING SITES

Thomas M. Schuler¹, Gary W. Miller¹, and H. Clay Smith²

Abstract: Regenerating northern red oak (*Quercus rubra* L.) on good to excellent growing sites is a serious problem for forest managers throughout the eastern and central United States. Natural regeneration using shelterwood methods are still being refined and are dependent on existing natural seedlings, an uncommon situation in many of today's forests. A possible alternative to natural regeneration is the use of plastic tree shelters in conjunction with a planted seedling. Research has shown that tree shelters promote a period of rapid seedling height growth followed by a period of much slower growth after emerging from the top of the shelter. Because the use of tree shelters represents a significant financial investment, judicious use of this technique is warranted. Preliminary guidelines are presented to maximize the likelihood of early seedling survival, growth, and potential competitiveness in the regenerated stand. Recommendations are based on research in the use of tree shelters conducted since 1988 on the Fernow Experimental Forest in north central West Virginia. Considerations include the age and origin of planting stock; size, color, style, and height of the tree shelter; stake material; planting location, density, and timing in relation to overstory removal; the use of herbicides or mulch to retard competing vegetation; maintenance schedules; and costs for installation.

¹Research foresters, Northeastern Forest Experiment Station, USDA Forest Service, Timber and Watershed Laboratory, P.O. Box 404, Parsons, WV 26287.

²Retired project leader and research forester, Northeastern Forest Experiment Station, USDA Forest Service, Timber and Watershed Laboratory, P.O. Box 404, Parsons, WV 26287.

THE EFFECT OF SITE DISTURBANCE ON NITROGEN AND PHOSPHORUS AVAILABILITY
IN INDIANA OAK-HICKORY FORESTS

D. Andrew Scott, Phillip E. Pope, Donald J. Kaczmarek, and Karyn S. Rodkey¹

Abstract: Nitrogen (N) and phosphorus (P) are nutrients often limiting forest site productivity. Soil water availability, soil temperature, and litter substrate quality interact to control the availability of these mineral nutrients and these factors can be directly altered by site disturbance. This study will examine the effects of site disturbance at three oak-hickory dominated forests of varying productivity. The study will utilize both field and controlled environment experiments. The objectives of the study are: 1) to determine the effects of disturbance on N and P availability, 2) to determine how sites of varying productivity respond to site disturbance, and 3) to determine the effects of varying soil water availability on N and P mineralization rates. The disturbances created are: (1) removal of litter and forest floor organic layers to the mineral soil, (2) incorporation of the forest floor with the mineral soil to a depth of 20 cm, (3) ground fire, i.e. burning the forest floor, and (4) an undisturbed control. N and P availability will be determined using mixed bed anion/cation ion exchange resins. In the field, resins will be buried in the mineral soil at a depth of 20 cm. In the controlled environment study, intact soil monoliths measuring 15 cm in diameter and 30 cm in length will be maintained at either high or low soil water potentials to determine the effects of water availability on N and P mineralization rates as determined by ion exchange resins. Temporal changes in ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{2-}) availability in response to these site disturbance treatments will be determined.

¹Undergraduate Honors Student, Professor of Forestry, Graduate Research Instructor, and Laboratory Coordinator, Purdue University, Department of Forestry and Natural Resources, 1159 Forestry Building, West Lafayette, IN 47907-1159.

SALAMANDER ABUNDANCE IN SMALL CLEARCUTS

Dana A. Soehn and Dr. Edwin D. Michael¹

Abstract: Recent research has shown that some timber harvesting methods adversely impact salamander populations. Researchers have documented the virtual disappearance of salamanders in large clearcuts with population recovery times estimated from 20-60 years. The purpose of this study was to determine salamander abundance in small, 3-year old clearcuts at Cooper's Rock State Forest in northern West Virginia. Salamanders were sampled inside and outside 16 clearcuts (0.5, 1.0, 1.5, and 2.0 ha), using a nondestructive monitoring technique. A total of 152 sampling stations were established, each consisting of 12 boards (12" x 6" x 1") placed in a 3 x 4 configuration with 0.5 inches separating individual boards. From April through November of 1994, all boards were lifted and checked for salamanders every 2 weeks. Captured salamanders were given a unique toe clip, sexed, measured, and released. Individual recognition of salamanders allowed for monitoring of movements throughout the season and also a population estimate using a multiple mark-recapture technique. Microhabitat features, including soil temperature, surface temperature, soil moisture, litter moisture, litter mass, and soil pH, were measured at each station. Preliminary results indicate that salamanders are present in the three year old clearcuts, but estimated abundance is less than in the adjacent mature forest. Microhabitat conditions in these small patch cuts may more rapidly allow for recolonization of salamander populations to predisturbance levels, than would occur in larger clearcuts. A total of 742 individual salamanders were captured, with the redback salamander (*Plethodon cinereus*) being most abundant (85% of total captures).

¹Graduate Research Assistant and Professor of Wildlife and Fisheries, Division of Forestry, West Virginia University, P.O. Box 6125, Morgantown, WV 26506-6125.

PRODUCTION AND TRADE FLOWS OF MICHIGAN FOREST PRODUCTS

Dr. James Stevens¹

Abstract: Michigan hardwoods are an important contributor to the Michigan State economy yet the flow of wood and wood products is poorly documented. This project is an on-going survey of primary and secondary wood processing firms in Michigan. The objective is to determine wood flow from stump to point of final processing (if in Michigan) or to the point where it leaves the state with the intent of evaluating the potential for increasing value-added production in the state. Preliminary data indicate that the flow of raw materials and products is very dynamic. As timber prices have risen in the past few years, firms have tried to capture a larger profit margin by eliminating the use of brokers. The final report will be complete by the end of 1994 and the results will be available for the March conference.

¹Assistant Professor, Department of Forestry, Michigan State University, East Lansing, MI 48824.

ECOSYSTEMS MANAGEMENT RESEARCH IN HARDWOOD FORESTS DOMINATED BY DEER

Susan L. Stout, David S. deCalesta, Stephen B. Horsley, Christopher A. Nowak, and James C. Redding¹

Abstract: Forest ecosystems of the Allegheny Plateau region of Pennsylvania have become impoverished as a result of over-browsing by white-tailed deer for more than 50 years. Research conducted in this region shows a strong, negative relationship between deer density and diversity of woody and herbaceous plant species and intermediate canopy nesting songbirds. This research also shows that deer are strongly associated with difficulties in establishing diverse regeneration of commercially important species. Research to date has been conducted on the stand level, and this research suggests that manipulation of deer forage, through managing at the landscape level, offers some hope of reestablishing diversity in forest ecosystems. Scientists have designed a landscape-level study to test this hypothesis generated from stand-level research. A study design combining observations and experimental manipulation on blocks of 500-1000 acres of forest land has been selected, and initial measurements will be collected before the Conference. While Pennsylvania's forests have suffered over-browsing for more than 50 years, this research has wide regional importance, as many other states are approaching the conditions currently found in Pennsylvania, and mitigation strategies are needed throughout the region.

¹U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratory, P.O. Box 928, Warren, PA 16365.