Combined Session

CHANGES IN NATIONAL FOREST TIMBER SALES IN THE CENTRAL HARDWOOD REGION

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Abstract—National forests contain only a small percentage of the sawtimber inventory in the Central Hardwood Region but many have proportionately more high quality timber than adjacent private lands. As a result, these forests are important to sawmill and other primary processors in this region. In this paper we analyze timber sales from 14 national forests in the Central Hardwood Region to determine the impact of changing forest polices on the forest-products industry. Since the mid-1980's, sales of hardwood and softwood sawtimber have been declining steadily, while the relative volumes of higher value species have increased. Because of this change in the mix of products sold and increasing prices of higher valued hardwood species and pine, total revenue from timber sales have declined moderately, while physical volumes sold have declined by more than 50 percent.

INTRODUCTION

The National Forest System was established to provide timber and protect watersheds for the citizenry of the United States. In recent years timber sales from these forests have declined in large part because of increasing public and political pressures. Recent policy changes with respect to the management of national forests have placed greater emphasis on watershed health, sustainable forest ecosystems, and recreation.[2] Still, the eastern national forests may be an important source of quality timber for industries proximate to these forests (Luppold and others 1998). In this paper we analyze changes in timber sales from 14 national forests in the Central Hardwood Region to determine the impact of changing forest policies on the forest-product industry in this region.

Specifically we analyze the volume and value of sawtimber sold by the national forests in the Central Hardwood Region in 1997, the degree to which timber sales have changed since 1985, and whether the changes in sales volume and revenue are consistent among these forests. Although our primary focus is hardwood sawtimber sales, sales of pulpwood and softwood sawtimber also are examined as these products are part of the total mix of timber products sold.

THE DATA

The data used in this study were developed from reports on timber cut and sold on national forests under sales and land exchanges, issued by national forests in Region 8 (southern) and Region 9 (eastern). These reports contain timber sales volumes and revenue for sawtimber, pulpwood, and other products sold by species or species group. Sawtimber as defined by the USDA Forest Service is hardwood trees larger than 11 inches in diameter at breast height (dbh) and softwood trees greater than 9 inches dbh. Hardwood pulpwood is 6 to 11 inches dbh while softwood pulpwood is 5 to 9 inches dbh. The reports were collected for the period beginning in 1985 and ending in 1997. Inventory data were obtained from the Forest Service's Eastwide Forest Inventory Data Base and the Northeastern Research Station's Forest Inventory and Analysis Unit (Hansen and others 1992).

It should be noted that there are variations in the cut and sold reports. For this study reports, were obtained for separate forests except for the states of North Carolina and Georgia. Cut-and-sold reports for North Carolina contain sales from the Pisgah, Nantahala, Croatan, and Uwharrie National Forests. The Pisgah and Nantahala are large, predominantly hardwood forests located in the western mountains of North Carolina; the Croatan and Uwharrie are small and primarily softwood forests located in the Piedmont and Coastal Plain Region. The reports for Georgia combine the Chattahoochee and the Oconee National Forest. The Chattahoochee is primarily a hardwood forest while the Oconee is primarily pine.

All volumes from cut-and-sold reports are in thousand board feet (MBF) International scale though many products are sold using other units of measurement. Sawtimber traditionally has been sold using the Scribner or International scale and pulpwood has been sold by the cord or hundred cubic feet (CCF). Since 1996, most forests in Region 8 recorded sawtimber and pulpwood sales volumes in cubic meters (J. Kirk Eichenberger, pers. commun.). The exception is the Daniel Boone, which began reporting in cubic meters in 1997. During this transition, the conversion of pulpwood from CCF to MBF for the cut-and-sold report changed from 0.77 to 0.55 MBF/CCF. Thus pulpwood sales volumes in Region 8 since 1996 must be multiplied by 1.4 to be consistent with sales volumes prior to 1996.

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NATIONAL FORESTS OF THE CENTRAL HARDWOOD REGION

The Central Hardwood Region as defined by Hicks and others (1997), includes 14 national forests. These forests are listed geographically in Table 1 starting with the most southern forest on the eastern boundary of the region and ending with the most southern forest on the western boundary of the region. Although Ouachita National Forest in central Arkansas lies at the southwestern edge of the Central Hardwood Region, it was excluded from this study because it is predominantly southern pine. Also, the national forests in Virginia (Jefferson and George Washington) and North Carolina (Pisgah and Nantahala) were combined in Table 1 because parts of these forests overlap Forest Service survey regions.

The national forests of the Central Hardwood Region vary considerably with respect to species mix. Although the Chattahoochee has large volumes of red and white oak, eastern white pine is the most predominant species (single species or species group with the greatest volume). The Cherokee contains significant volumes of select red oak, white pine, and yellow-poplar. The combination of oak, yellow-poplar, and pine is also the composition of the North Carolina forests while the predominant species of the Virginia forests are the oaks and yellow-poplar. The Monongahela National Forest may be the most unusual national forest in the Central Hardwood Region because it includes relatively large volumes of black cherry, soft maple, and red spruce.

Although forest-survey statistics indicate that other red oaks (scarlet and southern red oaks) are the most predominant species group on the Daniel Boone, select white oak and yellow-poplar are the primary individual species. White oak and yellow-poplar also are the primary species on the Wayne while the Hoosier and Shawnee are oak/hickory forests with high proportions of select white oak.

The Mark Twain is the most fragmented forest in the Central Hardwood Region with nine noncontiguous districts. Although other red oaks account for 36 percent sawtimber volume, shortleaf pine is the most predominant species. Shortleaf pine is the most important species in the Ozark, though, select red and white oaks account for 34 percent of the sawtimber volume. The St. Francis is the only forest in the western portion of the Central Hardwood Region without a major pine component.

CHANGES IN NATIONAL FOREST TIMBER SALES

Volumes of hardwood timber sold from national forests in the Central Hardwood Region in 1997 are presented in Table 2.

Table 1—Sawtimber volume[a], hardwood component, and major species[b] of national forests in the Central Hardwood Region

National forest	State	Sawtimber volume	Hardwood component	Major species
		Million bf	*Percent*	
Chattahoochee[c]	GA	4311.1	63.7	WP[d], OWO, ORO, SRO
Cherokee	TN	3412.0	61.6	SRO, WP, YP, OP
Pisgah and Nantahala[e]	NC	7443.9	80.4	OWO, SRO, ORO, YP, SWO, WP, OP
Jefferson and G. Washington	VA	7803.0	83.9	OWO, SRO, ORO
Monongahela	WV	5181.6	83.7	SRO, BC, YP, SM, RS, OWO
Daniel Boone	KY	3437.2	85.0	ORO, SWO, YP, ORO
Wayne	OH	842.5	98.1	SWO, YP, OWO
Hoosier	IN	795.7	92.0	SWO, ORO, OWO, HK
Shawnee	IL	1020.0	95.9	ORO, SWO, HK
Mark Twain[f]	MO	3352.0	68.4	ORO, SLP
Ozark	AK	4030.2	70.9	SLP, SWO, SRO
St. Francis	AK	238.6	83.2	SWO, ORO, HK, YP

[a] Sawtimber volumes based on survey unit data extracted from the Eastwide Forest Inventory Data Base. Estimates are approximate since small portions of national forests may be in adjacent forest survey units.

[b] When combined, species equal or exceed 50 percent of the resource ranked in order of volume.

[c] Does not include the Oconee National Forest.

[d] SWO-select white oak, SRO-select red oak, OWO-other white oak, ORO-other red oak, YP-yellow-polar, HK-hickory, BC-black cherry, SM-soft maple, BE-beech, SLP-shortleaf pine, WP-eastern white pine, RS-red spruce, OP-other pine.

[e] Mountain survey region of North Carolina.

[f] Developed from Kingsley and Law 1991.

Table 2— National forest timber sales in 1997 and changes in sawtimber sales between 1985 and 1997 with respect to volume in the Central Hardwood Region

National forest	Volume of hardwood sawtimber sold in 1997	Change in volume of hardwood sawtimber sold	Volume of softwood sawtimber sold in 1997	Change in volume of softwood sawtimber sold
	MBF	*Percent*	*MBF*	*Percent*
Chattahoochee/ Oconee	1609.1	-73.5	2138.8	-92.7
Cherokee	3227.1	-75.6	7171.2	-36.7
Pisgah/Nantahala	6718.2	-74.7	7087.5	-38.5
Jefferson/ Washington	11136.5	-34.2	746.0	-88.0
Monongahela	9267.6	-50.1	211.4	-87.6
Daniel Boone	8070.0	-66.2	990.1	-87.2
Wayne/Hoosier	3802.2	-73.2	1870.3[a]	3116.3[a]
Shawnee	56.7	-96.1	8.4	-99.3
Mark Twain	25884.1	-36.9	12138.4	43.7
Ozark/St. Francis	5001.3	-30.5	34326.4	125.7

[a] Volume of softwood sold and increases in softwood sales were influenced by a salvage sale in 1997.

The Wayne and Hoosier National Forests are combined in Table 2 because they were operated as a single forest for 11 of the 13 years covered by this study. Similarly, timber sales on the Chattahoochee and Oconee and the Ozark and St. Francis National Forests are reported jointly.

Hardwood sawtimber sales on the Chattahoochee/Oconee, Cherokee and North Carolina (southern Appalachian) National Forests have declined by nearly 75 percent between 1985 and 1997. Except for the Cahattahoochee/Oconee, softwood sales have dropped less than hardwood sales. Much of the decline on the Chattahoochee/Oconee was caused by reduced sales on the Oconee. Although the southern Appalachian forests are predominantly hardwood, softwood timber was the major product sold from these forests in 1987.

Sales of hardwood sawtimber from the Jefferson/Washington, Monongahela, and Daniel Boone (mid Appalachian) also declined 34 to 66 percent. The volume of softwood sawtimber sold from these forests has declined by nearly 90 percent. In 1997, hardwood sales were 15 times greater than softwood sales in these forests.

Hardwood sawtimber sales for the Wayne/Hoosier declined by 73 percent while sales from the Shawnee have all but stopped. The large increases in softwood sawtimber from the Wayne/Hoosier resulted from salvage sales of uprooted and storm damaged trees. Prior to 1997, softwood sales were erratic but showed no downward or upward trend. Hardwood sawtimber sales also varied from year to year but have shown a decided downward trend; the decline was greatest in the Ohio (Wayne) section. Similar to the decline in the Wayne section of the Wayne/Hoosier, softwood sawtimber sales have all but ceased on the Shawnee National Forest.

The two Central Hardwood forests west of the Mississippi (Mark Twain and Ozark/St.Francis) have shown a moderate decline in hardwood sawtimber sales and large increases in softwood sawtimber sales. The increases in softwood were almost entirely those of shortleaf or other southern pines.

In the southern Appalachian forests, sales of hardwood pulpwood declined by 77 to 87 percent (Table 3). Sales of softwood pulpwood have declined by 27.3 percent on the Chattahoochee/Oconee and have increased more than 100 percent on the Cherokee. Pulpwood sales are influenced by sawtimber sales because sawtimber and pulpwood are sold together. The relative decline in hardwood pulpwood sales was greater than that for softwood pulpwood because of the greater decline in hardwood sawtimber sales. Still, the decline in relative sales of hardwood pulpwood has been greater than that of hardwood sawtimber and the decline in sales of softwood sawtimber was greater than that of softwood pulpwood.

Hardwood and softwood pulpwood sales have declined by 58 to 71 percent on the Virginia and West Virginia forests. Similar to other Mid- Appalachian forests, sawtimber and pulpwood sales from the Daniel Boone have declined by 49 to 87 percent; the decline was greatest in volume of softwood sawtimber and pulpwood.

Table 3— National forest timber sales in 1997 and changes in pulpwood sales between 1985 and 1997 with respect to volume in the Central Hardwood Region

National forest	Volume of hardwood pulpwood sold 1997	Change in volume of hardwood pulpwood sold	Volume of softwood pulpwood sold 1997	Change in volume of softwood pulpwood sold
	MBF	*Percent*	*MBF*	*Percent*
Chattahoochee/ Oconee	879.9	-87.5	8867.6	-27.3
Cherokee	2769.1	-72.2	4875.5	114.1
Pisgah/Nantahala	4932.8	-76.8	6248.1	29.5
Jefferson/ Washington	15943.2	-57.8	1640.0	-70.9
Monongahela	2702.7	-67.1	91.7	-86.0
Daniel Boone	2129.1	-49.3	646.3	-69.1
Wayne/Hoosier	1414.2	-77.4	2188.9	597.6
Shawnee	0.0	-100.0	3.2	-99.9
Mark Twain	0.0	-100.0	1320.2	192.3
Ozark/St. Francis	3779.2	-61.0	10991.3	-13.4

Similar to most other eastern national forests, hardwood pulpwood sales from the Wayne/Hoosier declined by nearly 80 percent; the 600-percent increase in softwood pulpwood sales for these forest is the result of a salvage sale. Sales of hardwood pulpwood have ceased on the Shawnee

Although sales of hardwood pulpwood have ceased on the Mark Twain, sales of softwood pulpwood have increased by more than 190 percent. Pulpwood sales volumes for both hardwood and softwood declined on the Ozark/St. Francis with the greatest decline in hardwood. Pulpwood sales from these forests vary from year to year, but the largest increase in sales of softwood pulpwood from the Mark Twain probably is abnormal because sales of this product had approached zero between 1989 and 1996.

CHANGES IN NATIONAL FOREST TIMBER SALES REVENUE

Although timber sales have declined sharply for most national forests, timber sales revenue has not declined as sharply and actually have increased on some forests (Table 4). Only sawtimber sales are shown in Table 4 because pulpwood's contribution to timber sales revenue is small for most forests in the Central Hardwood Region.

An examination of sales in the Appalachian portion of the Central Hardwood Region found that the change in revenue was related to the volumes of economically important species sold and the price growth of these species. The oaks are the most important species on the national forests in southern Appalachia. The sales volume of oak species from these forests decreased at a rate similar to that of total hardwood sales while price increased by 90 percent (North Carolina and Chattahoochee/Oconee) to 600 percent (Cherokee). These increases in price partially offset the decline in sales volume; still, revenues decreased by 30 to 54 percent between 1985 and 1997 (Table 4).

During the study period, red oak has been the most valuable species sold from national forests in Virginia. While total hardwood sawtimber sales declined by nearly 35 percent on these forests, sales of red and black oak increased by 44 percent. This increase in sales volume and a 391- percent increase in the price of red and black oak were the driving force behind the 191-percent increase in hardwood sawtimber revenues for these forests. Although red oak is the most predominant species on the Monongahela National Forest, most of the increases in sales revenue from this forest can be attributed to the steady sales volumes of black cherry and a 630-percent increase in the price of this species.

The oaks also are the most important species in the Daniel Boone National Forest, however, while the sales volume of white oak on these forests decreased by more than 50 percent, the sales volume of red oak increased by nearly 60 percent. The increase in red oak sales combined with increases of more than 300 percent in the prices of both red and white oak prices are the primary reasons why sales revenue did not decrease on the Daniel Boone.

The moderate increases in prices of red and white oaks on the Wayne/Hoosier and Shawnee forests were insufficient to offset a decrease in sales volume. By contrast, the 128-percent increase in the price of mixed oaks from the Mark Twain offset the 30-percent decline sales volume. The aggregate price of oak sold from the Ozark/St. Francis National Forests increased only slightly while prices of

Table 4—National forest sawtimber sales in 1997 and changes in sawtimber sales between 1985 and 1997 with respect to value in the Central Hardwood Region

National forest	Revenue of hardwood sawtimber sold in 1997	Change in revenue of hardwood sawtimber sold	Revenue of softwood sawtimber sold in 1997	Change in revenue of softwood sawtimber sold
	$1,000	*Percent*	*$1,000*	*Percent*
Chattahoochee/ Oconee	186.2	-38.3	254.4	-91.8
Cherokee	478.4	-30.1	973.1	8.6
Pisgah/Nantahala	658.9	-54.4	990.9	13.8
Jefferson/ Washington	2631.3	191.3	110.4	-64.6
Monongahela	3674.9	209.2	6.7	-85.1
Daniel Boone	872.1	6.3	78.1	-79.4
Wayne/Hoosier	589.1	-55.4	18.3	326.0[a]
Shawnee	6.4	-93.1	.3	-99.0
Mark Twain	3704.0	51.2	1500.3	158.5
Ozark/St. Francis	512.0	-32.6	9333.8	531.5

[a] Volume of softwood sold and increases in softwood sales were influenced by a salvage sale in 1997.

mixed hardwoods decreased by more than 50 percent. As a result, the decline in total sawtimber revenue was greater than that of sawtimber sales volume.

POTENTIAL IMPACT OF CONTINUAL REDUCTIONS IN SALES

A reduction or cessation of timber sales from national forests would seem to have little impact on the forest-products industry. In most of the states examined in this paper, the sawtimber volume on national forests is less than 10 percent of total sawtimber volume. However, national forest timber must be viewed not in aggregate but with specific users in mind.

Most of the national forests in the southern Appalachian Region are located near the North Carolina-Viginia wood-furniture industry. This industry is located in this region because of the availability of lumber. However, every southern Appalachian forest also is accessible by at least one interstate highway. Thus, the accessibility of these forests combined with their proximity to numerous urban centers may be another reason why this region has shown the greatest decline in timber sales.

Black cherry is the most valuable, commonly traded domestic hardwood species (Hardwood Market Report 1998) and rivals mahogany in importance in the manufacturing of traditional furniture. In the late 1980’s the Monongahela National Forest contained about 4 percent of the nation’s inventory of black cherry (Luppold and others 1998). All indications are that cherry has been harvested on private lands at a much faster rate than the national forests. As a result, the supply of cherry on these forests has increased.

The national forests in Ohio, Indiana, and Illinois contain large quantities of higher grade white oak timber (Luppold and others 1998). Although white oak is used by domestic secondary timber processors, much of the higher grade white oak from this region is exported to Europe and Asia. Reduced supplies of national forest timber from this region may not affect facilities that serve domestic customers as much as sawmills that sell to international customers.

The two national forests west of the Mississippi have substantial volumes of hardwood sawtimber. However, the market value of this timber is not as high as that of timber in other parts of the Central Hardwood Region. Still, flooring, pallet, and other industries may be dependent on sustained quantities of lumber from these forests.

SUMMARY AND CONCLUSIONS

The forests of the Central Hardwood Region range from the pine/oak forest of southern Appalachia to the primarily oak forest of the Central Plains to the pine/oak forest west of the Mississippi River. The southern Appalachian forests in Georgia, North Carolina, and Tennessee have shown greater declines in hardwood sawtimber sales than the forests of the mid-Appalachian Region of Virginia, West Virginia, and Kentucky. This difference may be a function of the proximity of the forests in southern Appalachia to large urban centers.

National forests in the Central Plains have shown large declines in hardwood sawtimber sales with the Shawnee showing the greatest decline. The only increases in timber product sales have resulted from a salvage sale of white pine on the Hoosier National Forest. The two national forests west of the Mississippi River have shown relatively moderate declines in sales of hardwood sawtimber sales and large increases in sales of softwood sawtimber.

Although timber sales have declined sharply for most national forests, timber revenues from these sales have not decreased nearly as much and have increased in some forests. These increases in revenue were greater on the Jefferson/Washington and Monongahela National Forests, the result of increased sales volume and prices of select red oak from the Jefferson/Washington and increased sales of black cherry from the Monongahela.

The reduction in timber sales on national forests has had an adverse economic impact on the industries that process and use timber products. This economic loss may be offset somewhat by gains that result from allocating timberlands to alternative uses such as watershed protection or recreation. It is important that policymakers understand economic tradeoffs associated with their decisions, and that future research focus on the impact of changing timber sales and management policies on recreational and ecological services. We believe that such analyses should be conducted on a forest-by-forest if not county-by-county basis to insure that the needs of rural communities located near national forests are considered.

REFERENCES

Hansen, M.H.; Frieswyk, T.; Glover, J.F.; Kelly, J.F. 1992. The eastwide forest inventory data base: user’s manual. Gen. Tech. Rep. NC-151. U.S. Department of Agriculture, Forest Service. 48 p.

Hardwood Market Report. 1998. Memphis TN: Henry Jones Publisher. 76(7): 40 p.

Hicks, R.R. 1997. A resource at the crossroads: a history of the central hardwoods. In: Proceedings 11th central hardwood forest conference. Gen. Tech. Rep. U.S. Department of Agriculture, Forest Service: 1-22.

Kingsley, N.P.; Law, J.R. 1991. Timber resource of the Mark Twain National Forest. Res. Bull. NC-129. U.S. Department of Agriculture, Forest Service. 31 p.

Luppold, W.G.; Baumgras, J.E.; Sheffield, R.M. 1998. A comparative analysis of hardwood sawtimber quality on national forests versus adjacent lands. Forest Products Journal. 45(5): 51-56.

OAK PLANTING SUCCESS VARIES AMONG ECOREGIONS IN THE CENTRAL HARDWOOD REGION

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Abstract—This paper compares the results of planting northern red oak (*Quercus rubra* L.) and white oak (*Q. alba* L.) in the Ozark Highlands of Missouri to planting northern red oak in the Shawnee Hills and Highland Rim of southern Indiana. In both regions, seedlings were planted beneath shelterwoods thinned to 60 percent stocking. Black oak site index for Missouri planting sites was 19 meters (at an index age of 50 years) and 23 meters for Indiana sites. A total of 5,120 seedlings were planted. Three years after planting the shelterwoods were removed. Six nursery treatments were applied to growing 2+0 northern red oak stock in which seedlings were: (1) not undercut nor top-clipped, (2) not undercut but top-clipped the spring before planting, (3) undercut the first year in the nursery but not top-clipped, (4) undercut the first year and top-clipped, (5) undercut both years in the nursery but not topped clipped, and (6) undercut both years and top-clipped. Those treatments plus two additional treatments were applied to growing 3+0 white oak nursery stock in which seedlings were: (1) undercut the second year but not top-clipped, and (2) undercut the second year and top-clipped. Thirteen years after planting, survival of northern red oak ranged from 13 to 26 percent in Indiana plantings and from 50 to 77 percent in Missouri plantings, depending on treatment. Eleven years after planting, survival of white oak in Missouri ranged from 40 to 85 percent. Because survival by itself may not accurately reflect planted tree success, logistic regression was used to derive dominance probabilities for planted oaks. Accordingly, a planted tree was deemed dominant (and thus competitively successful) if it attained 80 percent of the mean height of dominant competitors a specified number of years after planting. In the Missouri plantings, estimated dominance probabilities for northern red oak increased with time since shelterwood removal and with increasing initial basal caliper of seedlings. After 13 years, probabilities for red oak seedlings with an initial caliper of 15 millimeters ranged from 0.45 to 0.60, depending on nursery treatment. Estimated probabilities for white oak did not change significantly with time. After 11 years, probabilities for white oak seedlings with an initial caliper of 15 millimeters ranged from 0.36 to 0.77. In contrast, estimated dominance probabilities for red oaks planted in Indiana declined with time. After 13 years, probabilities for seedlings 15 millimeters in initial caliper ranged from 0.02 to 0.04, depending on nursery treatment. Although effects of undercutting and top-clipping varied by species and planting region, their joint effects generally resulted in higher success probabilities than when neither treatment was applied. Low dominance probabilities for trees planted on Indiana sites resulted from high mortality and slow growth related to suppression by yellow-poplar (*Liriodendron tulipifera* L.) and aspen (*Populus* spp). In addition to nursery treatment and initial seedling size effects, the results emphasize the importance of recognizing variation in the outcome of interspecific competition among ecoregions and associated temporal changes in dominance probabilities of planted oaks.

INTRODUCTION

Many forests of the Central Hardwood region are dominated by oaks. However, regenerating oaks naturally has often been unsuccessful (Crow 1988, Lorimer 1989). Planting may be one way to overcome this problem. Numerous papers have been presented in previous Central Hardwood Forest Conferences dealing with oak planting (e.g., Bardon and Countryman 1993, Lantagne 1995, Larrick and others 1997, McNeel and others 1993, Rathfon and others 1995, Teclaw and Isebrands 1993, Weigel and Johnson 1997).

The shelterwood method can be used to create conditions favorable to regenerating oaks (Dey and Parker 1996, Hannah 1987, Johnson and others 1989, Loftis 1990). Combining oak planting with the shelterwood method offers an alternative to relying exclusively on natural regeneration (Johnson and others 1986). Shelterwoods of appropriate density can provide planted oaks with sufficient light and time for them to reestablish and expand their root systems before final shelterwood removal (Dey and Parker 1996, 1997). The planted oaks then can successfully compete with other established tree reproduction after the shelterwood is removed. However, the success of the method depends on the size and type of nursery stock that is planted (Johnson 1984, Weigel and Johnson 1998a, 1998b).

The results from two oak planting studies are reported here. They deal with northern red oak (*Quercus rubra* L.) and white oak (*Quercus alba* L.) planted beneath a shelterwood and the subsequent removal of the shelterwood. The objective of the studies was to develop methods to increase success of planted northern red oak and white oak seedlings at different locations in the central hardwood region.

METHODS

Results were obtained from two studies that included 3,840 two-year-old northern red oak seedlings (study 1) and 1,280 three-year-old white oak seedlings (study 2). Seedlings were planted under oak or mixed oak stands thinned from below to 60 percent stocking based on Gingrich's (1967) stocking equation.

Nursery Phase

Half of the northern red oak seedlings were grown in the Vallonia State Forest Nursery in Indiana and half in the George O. White State Forest Nursery in Missouri. The

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planted trees represented 10 seed sources, 5 stand collections from Missouri and 5 stand collections from Indiana. White oak seedlings were grown in the George O. White State Forest Nursery in Missouri. The planted trees represented 10 seed sources, 5 stand collections from Missouri and 5 stand collections from Mississippi. The objective of including seed source as a source of variation was primarily to ensure some genetic diversity into the study and account for that variation. The objective was not to identify superior seed sources. Nursery and seed source for northern red oak, 13 years after planting, and seed source for white oak, 11 years after planting, did not have a significant affect on survival ($p > 0.05$) and where therefore combined during analysis.

Northern red oak seedlings received one of three undercutting treatments in the nursery bed: (1) not undercut (U_0), (2) undercut during the first growing season (U_1), and (3) undercut the first and second growing seasons (U_{12}). White oak seedlings received one of four undercutting treatments in the nursery: (1) not undercut (U_0), (2) undercut during the first growing season (U_1), (3) undercut during the second growing season (U_2), and (4) undercut during the first and second growing seasons (U_{12}). Seedlings were undercut at a depth of 15 centimeters during mid to late June after the completion of one or two flushes of shoot growth. Those undercut the second year were undercut at a depth of 20 centimeters.

After spring lifting in early April 1984 and before planting, the tops of half the northern red oak seedlings in each undercutting treatment were cut off (“top-clipped”) 20 centimeters above the root collar (C_1) and the other half were left intact (C_0). White oak seedlings were grown for 3 years and either fall lifted in November 1984 or spring lifted in early March 1985. Before planting, half the white oak seedlings in each undercutting treatment were top-clipped 20 centimeters above the root collar (C_1) and the other half left intact (C_0). Taproots and lateral roots of all seedlings were pruned to a common length of 25 centimeters below the root collar after lifting. The initial caliper (basal diameter measured 2.5 centimeters above the root collar) of each seedling was measured to the nearest 0.1 millimeter and recorded (table 1).

Planting Sites

Two Indiana sites were selected for planting northern red oak: Paoli Experimental Forest and the Pleasant Run Unit of the Hoosier National Forest. These sites were located in the Shawnee Hills and the Highland Rim, respectively, of the Interior Low Plateau as defined by McNab and Avers (1994). Sites were dominated by mixed oaks and yellow-poplar; black oak site index was 23 meters at an index age of 50 years based on Carmean’s (1971) site index curves. In southern Missouri, two sites were selected for the northern red oak plantings and two sites for the white oak plantings on the Sinkin Experimental Forest, which lies within the Central Plateau Subsection of the Ozark Highlands as defined by McNab and Avers (1994). The sites were dominated by black oak and white oak. Black oak site index was 19 meters at an index age of 50 years based on McQuilkin’s (1974) site index table.

Table 1—Mean, standard deviation, and range of initial seedling caliper for northern red oak and white oak

Species	Mean	Standard deviation	Minimum	Maximum
	--------------------	*mm*	--------------------	
Northern red oak	12.3	3.35	3.3	25.4
White oak	12.9	4.94	2.6	37.9

Outplanting

Northern red oak seedlings were outplanted in April 1984 at a spacing of 1- x 1-meter in a randomized block design with eight replications. Seedlings in Missouri were bar planted while those in Indiana were planted in auger holes. In April 1985 the white oak seedling were bar planted at 1- x 1-meter spacing. On all planting sites all woody stems between 2 and 4 centimeters d.b.h. and all stumps created by the shelterwood cut were treated with an herbicide (Tordon RTU) before planting. After three growing seasons (during the winter of 1986-1987 for northern red oak and during the winter of 1987-1988 for white oak), the shelterwood was completely removed. All stumps created by the final overstory removal were treated with an herbicide (Tordon RTU). Planted tree heights and survival were measured and recorded annually or biennially for 13 years for northern red oak and 11 years for white oak. For northern red oak in Indiana, the heights of dominant competitors were also measured in 1990, 1991, 1993, and 1996 (7, 8, 10, and 13 years after planting, respectively). In Missouri heights were not measured in 1993. For white oak, the heights of dominant competitors were also measured in 1990, 1992, 1993, and 1995 (6, 8, 9, and 11 years after planting, respectively). The tallest woody competitor, within a 1-meter radius of every fourth planted tree, was measured to determine mean heights of dominant competitors on each study area.

Data Analysis

Analysis of variance was used to determine influence of nursery treatments on survival and height growth. Mean separations were performed using Student-Newman-Keuls multiple range test. All treatment effects were tested at the 0.05 level. Logistic regression analysis (SAS 1989) was used to estimate the probability that a seedling of a given initial caliper would equal or exceed 80 percent of the mean height of dominant competitors. Models were developed for northern red oak in Indiana, northern red oak in Missouri, and white oak in Missouri. Analysis was done at 13 years for northern red oak and 11 years for white oak.

RESULTS

Survival after the first growing season for both species ranged from 100 percent to 87 percent (figure 1). Survival decreased for the 3 years while the oak seedlings were beneath the shelterwood. The U_0C_0 treatment, significantly different from all other treatments, showed the lowest survival for both species with white oak the lowest at 45

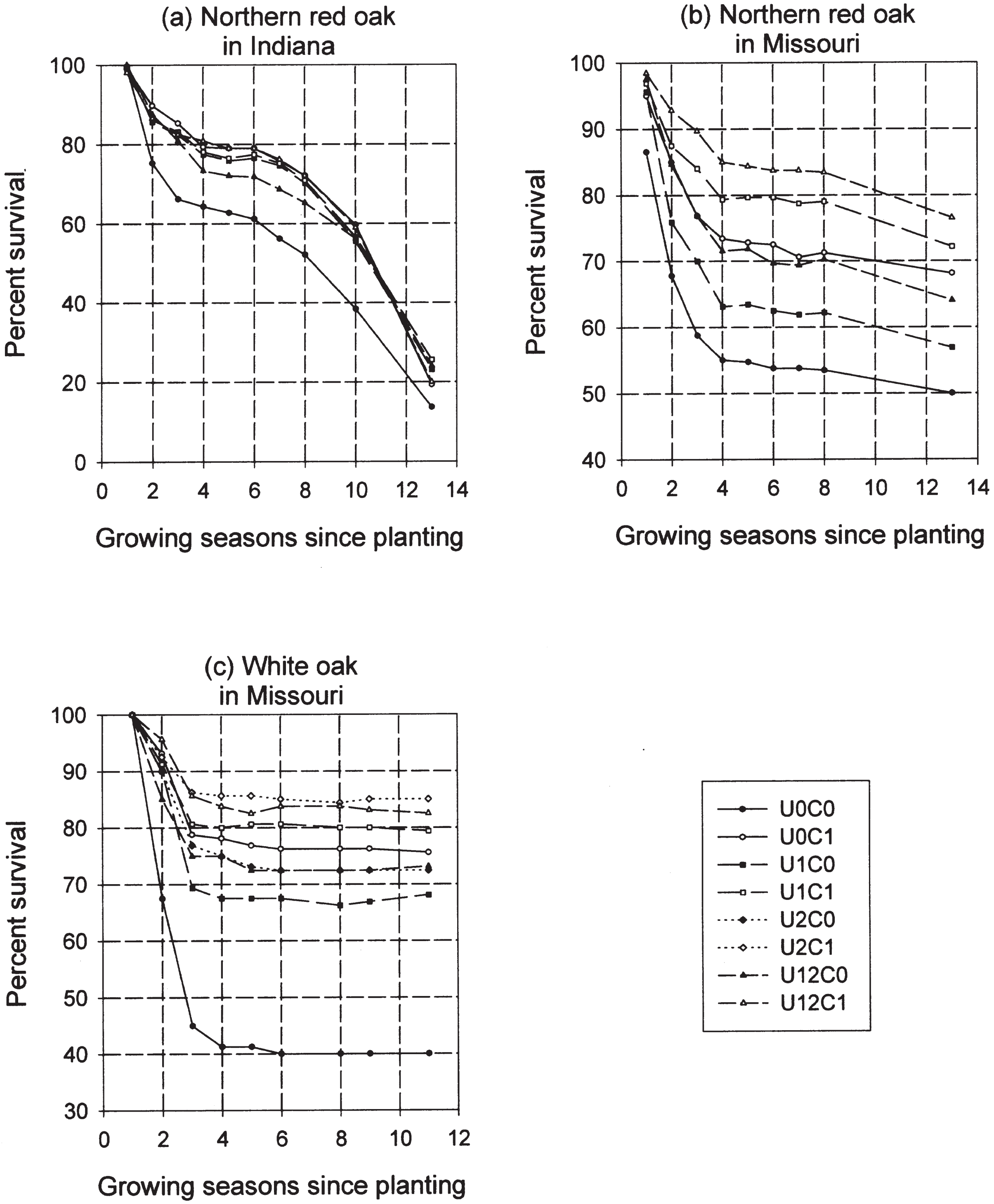

Figure 1—Survival trends for planted northern red and white oak. Seedling treatments: U_0C_0 = not undercut, not top-clipped; U_0C_1 = not undercut, top-clipped; U_1C_0 = undercut first year, not top-clipped; U_1C_1 = undercut first year, top-clipped; U_2C_0 = undercut second year, not top-clipped; U_2C_1 = undercut second year, top-clipped; $U_{12}C_0$ = undercut first and second year, not top-clipped; $U_{12}C_1$ = undercut first and second year, top-clipped.

percent. Survival for all remaining treatments for the two species was above 65 percent. Following complete overstory removal, survival remained constant for white oak ending between 40 and 85 percent 8 years after overstory removal with the U_0C_0 treatment once again significantly different from all other treatments. For northern red oak, survival remained fairly constant for the first 5 years but then decreased. In Indiana, 10 years after complete overstory removal, survival dropped to between 13 and 26 percent. The U_0C_0 treatment was significantly different for all treatments except U_0C_1 and $U_{12}C_1$. For Missouri the survival rate ranged from 50 to 77 percent with the U_0C_0 treatment significantly different for all treatments except U_1C_0.

During the early years, mean heights of survivors of white oak and northern red oak in both Missouri and Indiana differed by treatments. Those seedlings not top-clipped showed no net height growth during the first 3 to 5 years following outplanting (figure 2). However, seedlings top-clipped showed a positive height growth so that by the third to sixth growing season following outplanting there was no

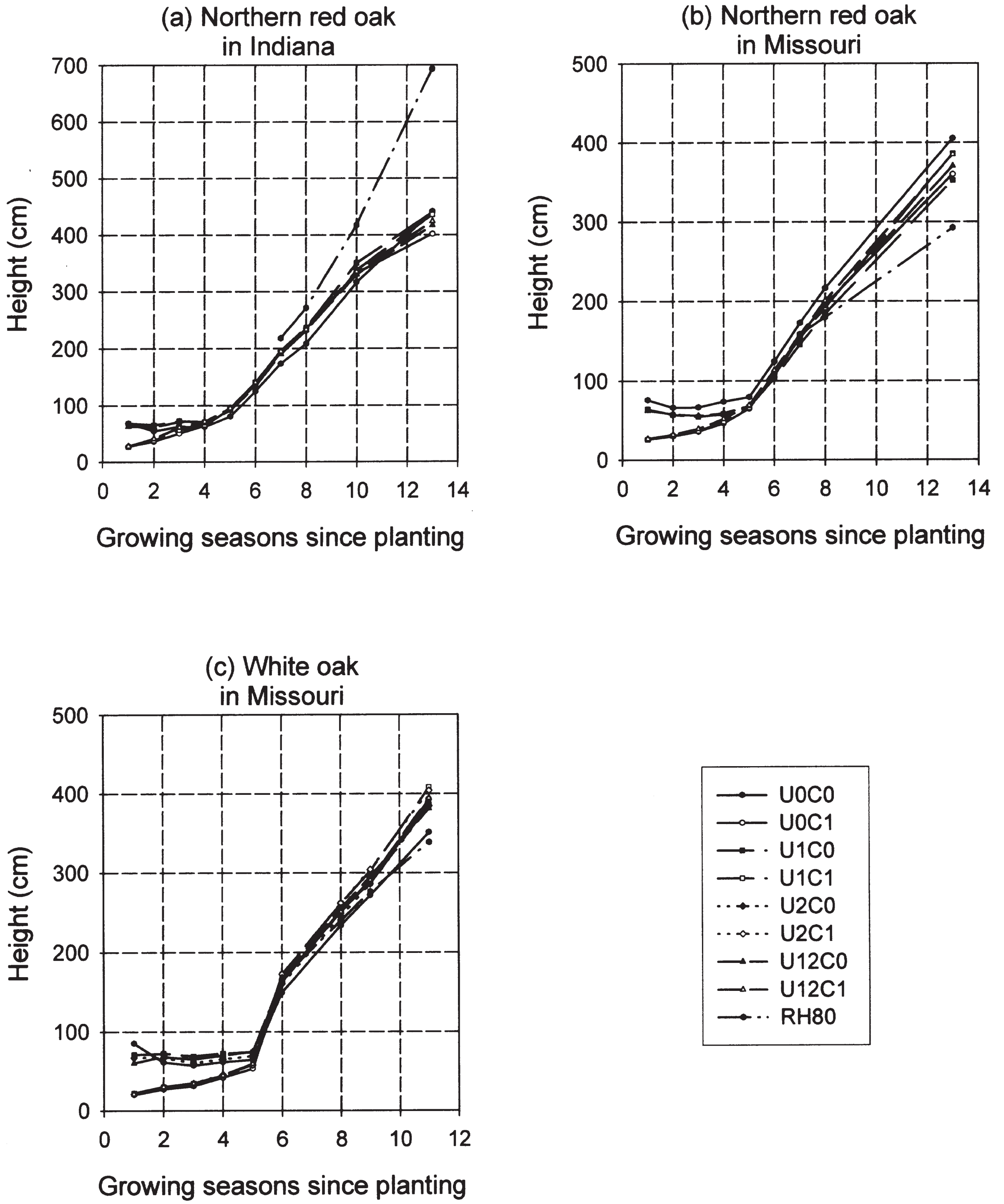

Figure 2—Mean heights of surviving planted northern red and white oak compared to the height of 80 percent of the competition height. Seedling treatments: U_0C_0 = not undercut, not top-clipped; U_0C_1 = not undercut, top-clipped; U_1C_0 = undercut first year, not top-clipped; U_1C_1 = undercut first year, top-clipped; U_2C_0 = undercut second year, not top-clipped; U_2C_1 = undercut second year, top-clipped; $U_{12}C_0$ = undercut first and second year, not top-clipped; $U_{12}C_1$ = undercut first and second year, top-clipped. RH80 (relative height 80) represents 80 percent of the mean height of dominant competitors.

significant difference ($p > 0.05$) in height between top-clipped and non-top-clipped seedlings.

Eight years after complete overstory removal (11 years after planting) white oak top-clipped treatments out grew non-top-clipped treatments ($p < 0.05$), with the U_0C_0 treatment showing the poorest performance ($p < 0.05$). For northern red oak, 10 years after complete overstory removal (13 years after planting), the U_0C_0 treatment outperformed all other treatments. Heights for northern red oak were not significantly different ($p > 0.05$). The difference between treatments for both species was less than 60 centimeters.

A planted oak was considered dominant if it attained 80 percent of the height of the competition. In Missouri, 8 years (white oak) and 10 years (northern red oak) after complete overstory removal all treatments were taller than 80 percent of the competition height. However, in Indiana all treatments for northern red oak were outgrown by woody competitors. The best treatment result was over 2.5 meters shorter than 80 percent of the woody competitor height.

Seedling survival and mean height of surviving trees do not always equate to seedling success. Moreover, such averages do not take initial seedling caliper into account. Logistic regression analysis therefore was used to estimate the probability that a seedling of a given initial caliper would equal or exceed 80 percent of the mean height of dominant competitors up to 10 years (northern red oak) or 8 years (white oak) following shelterwood removal. The resulting values were termed dominance probabilities because they express the likelihood that a planted seedling of a given treatment and initial size would be dominant or codominant (table 2).

Logistic regression results produced dominance probabilities that varied by species and ecoregion. Dominance probabilities increased with increasing initial seedling caliper for both species (figure 3). Northern red oak in Missouri showed increased dominance probabilities with time since shelterwood removal while in Indiana they showed decreased dominance probabilities with time since shelterwood removal. For white oaks in Missouri, dominance probabilities remained constant with time since shelterwood removal. Within a given undercutting treatment group, dominance probabilities for a given initial basal caliper are larger for clipped than for unclipped seedlings. The U_0C_0 treatment for both species produced the lowest dominance probabilities.

DISCUSSION

Survival rates after the first growing season were higher than that reported by Crunkilton and others (1989) for northern red oak in Missouri. Six years after outplanting, survival rates were similar to those reported by Gordon and others (1995). McGee and Loftis (1986) reported northern red oak and black oak survival, during a similar growing period, comparable to those reported here. Much of the mortality that did occur during the shelterwood period may have been attributable to suboptimal light levels, associated shoot dieback, and the death of seedlings of initially poor physiological quality.

Crunkilton and others (1989), Gordon and others (1995), McGee and Loftis (1986), and Zaczek and others (1993, 1997) reported height growth rates similar to or slightly less than those reported here. Possible logging damage following complete shelterwood removal could partially explain slow height growth.

Although survival and height growth of planted seedlings are important to their success, they do not always tell the complete story. The important end result is producing a competitively successful seedling; survival and height growth are not always indicators of a competitively

Table 2—Logistic regression models for dominance probabilities that a planted oak seedling will be dominant or codominant

	Parameter estimates[a]									
Species	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	p[b]	N[c]
White oak	-3.7414	1.1667	0.6984	0.9590	0.8022				0.10	5120
NRO in Missouri	-1.3070	0.5248		0.2484	0.3783			-3.2712	0.85	5760
NRO in Indiana	-1.7829	1.2593	0.4743	0.4060	0.2699	0.6659	-0.0825		0.21	7680

[a] Regression models are of the form $P = \{1+\exp[-(b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7)]\}^{-1}$, where P is the estimated probability that a planted oak seedling will produce a successful seedling; X_1 is the natural log of initial seedling caliper in millimeters; $X_2 = 0$ if not undercut, undercut second year, or both years, $= 1$ if undercut first year; $X_3 = 0$ if not undercut or undercut first year, $= 1$ if undercut second year or both years; $X_4 = 0$ if not top-clipped, $= 1$ if top-clipped; X_5 = years since shelterwood removal; X_6 = (years since shelterwood removal)^2; X_7 = 1/years since shelterwood removal. All parameter estimates differ significantly from zero at $\propto = 0.05$.

[b] The probability (p) that estimated dominance probabilities differ from the observed based on the Hosmer-Lemeshow chi-square test (Homer and Lemeshow 1989).

[c] N = number of seedlings planted • number of years competition measured (4 times for white oak and northern red oak in Indiana and 3 times for northern red oak in Missouri).

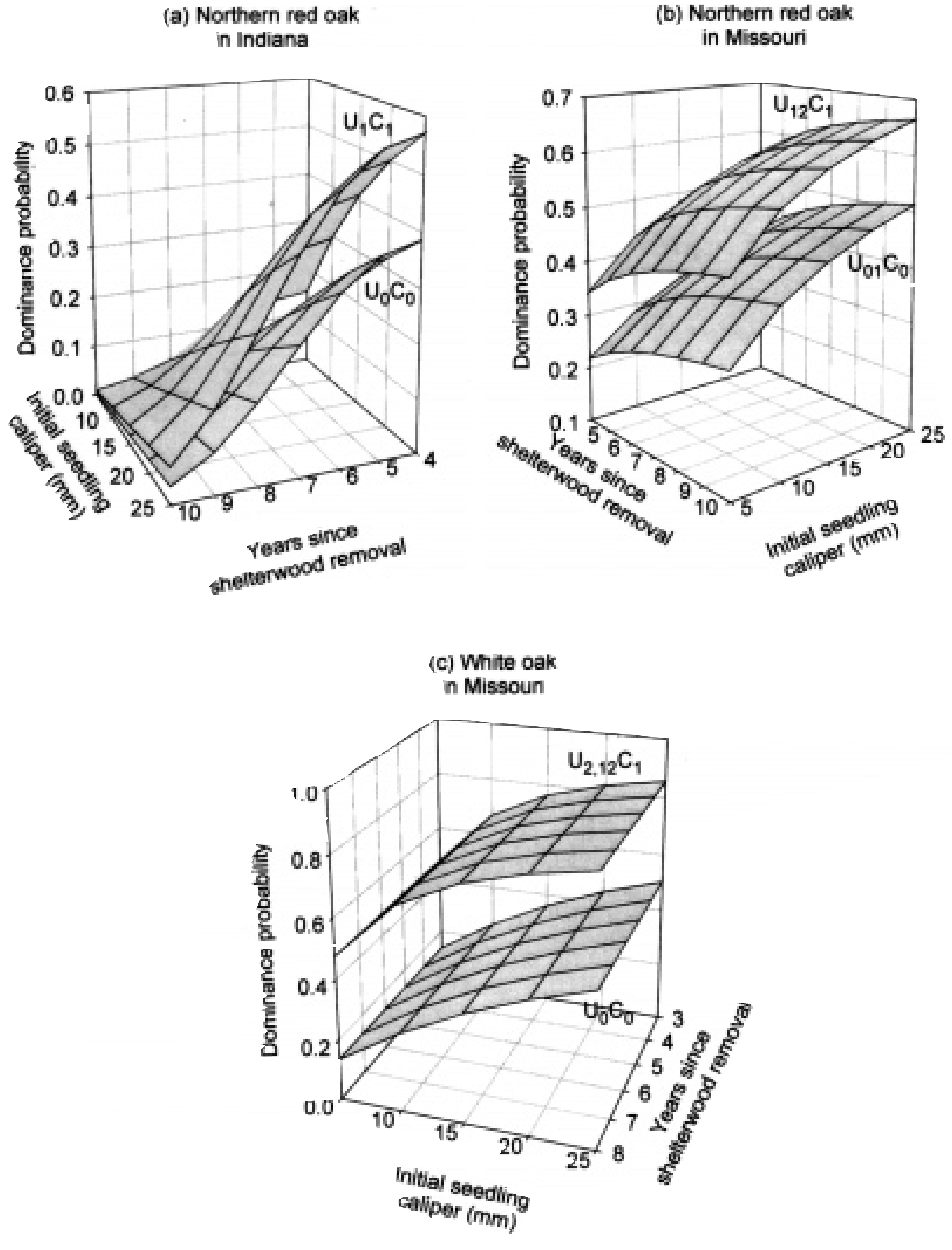

Figure 3—Dominance probabilities for planted northern red oak and white oak in relation to initial seedling caliper and years since shelterwood removal. For both regions and species, success probabilities are shown for the “best” and “worst” combination of undercut (U) and shoot clipping (C) treatments. Seedling treatments: U_0C_0= not undercut, not top-clipped; $U_{01}C_0$ = not undercut or undercut the first year, not top-clipped; U_1C_1 = undercut first year, top-clipped; $U_{12}C_1$ = undercut first and second year, top-clipped; $U_{2,12}C_1$ = undercut second year or first and second year, top-clipped. Note change in axis orientation between a and c and b.

successful seedling. Dominance probabilities give an indication of success by taking into account initial seedling caliper and seedling success against competition. Therefore, dominance probabilities integrate survival and growth into a single value which is silviculturally useful.

Different dominance probabilities between ecoregions can be explained by the relatively high site quality and the presence of rapid growing intolerant yellow-poplar (*Liriodendron tulipifera* L.) and aspen (*Populus* sp.) reproduction in Indiana. Those species comprised 75 percent of woody competitors on the Indiana planting sites.

Yellow-poplar (Beck 1990) and aspen (Perala 1990) are absent in the Ozark Highlands of Missouri. This height advantage of yellow-poplar and aspen over northern red oak in Indiana was at least 2.5 meters 10 years after shelterwood removal (figure 2). With the absence of yellow-poplar and aspen in Missouri, northern red oak was able to outgrow the competition and increase its dominance probabilities. Missouri woody competitors are characterized by low survival rates and limited size development relegating them to the sapling and reproduction layers (Dey and others 1996). However, in Indiana northern red oak was unable to compete with yellow-poplar and aspen which remain dominant throughout the rotation and thus its dominance probabilities decreased to near zero. Similar results were reported by McGee and Loftis (1986) in the southeast. White oak was able to compete successfully with woody competitors from time of shelterwood removal and thus its dominance probabilities remained constant.

Current results indicate that plantings in the Missouri Ozark Highlands will produce dominant and codominant trees. Successful plantings will not result in the two Indiana ecoregions. To improve planting results, in ecoregions dominated by rapid growing persistent woody competitors, post planting competition control may be needed. Burning the plantings while beneath the shelterwood (Brose and Van Lear 1998) or within 4 years following overstory removal should reduce the yellow-poplar competition. Application of herbicides to woody competitors 3-4 years following overstory removal should also provide the oaks with growing space. Repeated applications of competition control in these ecoregions may be necessary to maintain the planted oak in a dominant or codominant position.

The results of this research emphasize the importance of recognizing variation in competition among ecoregions where oak are to be planted. While a prescription for planting oak in one ecoregion may be successful, the same prescription in another ecoregion may result in entirely different results.

REFERENCES

Bardon, R.E.; Countryman, D.W. 1993. Survival and growth for the first-growing season of northern red oak (*Quercus rubra* L.) seedlings underplanted in mixed upland hardwood stands in south central Iowa. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. Proceedings, 9th central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. U.S. Department of Agriculture, Forest Service: 195-209.

Beck, D.E. 1990. Yellow-poplar. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 406-416. Vol. 2.

Brose, P.H.; Van Lear, D.H. 1998. Response of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. Canadian Journal of Forest Research. 28(3): 331-339.

Carmean, W.H. 1971. Site index curves for black, white, scarlet and chestnut oaks in the Central States. Res. Pap. NC-62. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)-a review. Forest Science. 34: 19-40.

Crunkilton, D.D.; Garrett, H.E.; Pallardy, S.G. 1989. Growth of northern red oak seedlings planted in a central Missouri clearcut and shelterwood. In: Miller, J.H., comp. Proceedings of the 5th biennial southern silvicultural research conference; 1988 November 1-3; Memphis, TN. Gen. Tech. Rep. SO-74. U.S. Department of Agriculture, Forest Service: 81-85.

Dey, D.C.; Johnson, P.S.; Garrett, H.E. 1996. Modeling the regeneration of oak stands in the Missouri Ozark Highlands. Canadian Journal of Forest Research. 26(4): 573-583.

Dey, D.C.; Parker, W.C. 1996. Regeneration of red oak (*Quercus rubra* L.) using shelterwood systems: ecophysiology, silviculture and management recommendations. For. Res. Info. Pap. 126. Sault Ste. Marie, ON: Ontario Ministry of Natural Resources; Ontario Forest Research Institute. 59 p.

Dey, D.C.; Parker, W.C. 1997. Overstory density affects field performance of underplanted red oak (*Quercus rubra* L.) in Ontario. Northern Journal of Applied Forestry. 14(3): 120-125.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. Forest Science. 13(1): 38-53.

Gordon, A.M.; Simpson, J.A.; Williams, P.A. 1995. Six-year response of red oak seedlings planted under a shelterwood in central Ontario. Canadian Journal of Forest Research. 25: 603-613.

Hannah, P.R. 1987. Regeneration methods for oaks. Northern Journal of Applied Forestry. 4(2): 97-101.

Hosmer, D.W.; Lemeshow, S. 1989. Applied logistic regression. New York: Wiley. 307 p.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Canadian Journal of Forest Research. 14(4): 536-542.

Johnson, P.S.; Dale, C.D.; Davidson, K.R.; Law, J.R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. Northern Journal of Applied Forestry. 3(1): 66-68.

Johnson, P.S.; Jacobs, R.D.; Martin, J.A.; Godel, E.G. 1989. Regenerating northern red oak: three successful case histories. Northern Journal of Applied Forestry. 6(4): 174-178.

Lantagne, D.O. 1995. Effects of tree shelters on planted red oaks after six growing seasons. In: Gottschalk, K.W.; Fosbroke, S.L., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. U.S. Department of Agriculture, Forest Service: 515-521.

Larrick, D.S.; Bowersox, T.W.; Storm, G.L.; Tzilkowski, W.M. 1997. Two-year survival and growth of artificial northern red oak regeneration at Gettysburg National Military Park. In: Pallardy, S.G.; Cecich, R.A.; Garrett, H.G.; Johnson, P.S., eds. Proceedings, 11th central hardwood forest conference; 1997 March 23-26; Columbia, MO. Gen. Tech. Rep. NC-188. U.S. Department of Agriculture, Forest Service. 349 p.

Loftis, D.L. 1990. A shelterwood method for regenerating red oak in the Southern Appalachians. Forest Science. 36(4): 917-929.

Lorimer, C.G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. For. Resour. Anal. 8, Publ. R3484. Madison, WI: University of Wisconsin, Department of Forestry. 31 p.

McGee, C.E.; Loftis, D.L. 1986. Planted oaks perform poorly in North Carolina and Tennessee. Northern Journal of Applied Forestry. 3(3): 114-116.

McNab, W.H.; Avers, P.E., comps. 1994. Ecological subregions of the United States: section descriptions. Admin. Publ. WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

McNeel, C.A.; Hix, D.M.; Townsend, E.C. 1993. Survival and growth of planted northern red oak in northern West Virginia. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. Proceedings, 9th central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. U.S. Department of Agriculture, Forest Service: 222-228.

McQuilkin, R.A. 1974. Site index prediction table for black, scarlet, and white oaks in southeastern Missouri. Res. Pap. NC-108. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Perala, D.A. 1990. Quaking aspen. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America. Agric. Handb. 654. U.S. Department of Agriculture, Forest Service: 555-569. Vol. 2.

Rathfon, R.A.; Kaczmarek, D.J.; Pope, P.E. 1995. Site preparation for red oak plantation establishment on old field sites in southern Indiana. In: Gottschalk, K.W.; Fosbroke, S.L., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. U.S. Department of Agriculture, Forest Service: 349-362.

SAS Institute Inc. 1989. SAS/STAT user's guide. Version 6, 4th ed. Cary, NC: SAS Institute, Inc. 846 p. Vol. 2.

Teclaw, R.M.; Isebrands, J.G. 1993. Artificial regeneration of northern red oak in the Lake States with a light shelterwood: a departure from tradition. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G.; eds. Proceedings, 9th central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. U.S. Department of Agriculture, Forest Service: 185-194.

Weigel, D.R.; Johnson, P.S. 1997. Planting oaks in the central hardwood region: a shelterwood approach. In: Pallardy, S.G.; Cecich, R.A.; Garrett, H.G.; Johnson, P.S., eds. Proceedings, 11th central hardwood forest conference; 1997 March 23-26; Columbia, MO. Gen. Tech. Rep. NC-188. U.S. Department of Agriculture, Forest Service. 151 p.

Weigel, D.R.; Johnson, P.S. 1998a. Planting white oak in the Ozark Highlands: a shelterwood prescription. Tech. Brief TB-NC-5. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Weigel, D.R.; Johnson, P.S. 1998b. Planting northern red oak in the Ozark Highlands: a shelterwood prescription. Tech. Brief TB-NC-6. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1993. Performance of northern red oak planting stock. Northern Journal of Applied Forestry. 10(3): 105-111.

Zaczek, J.J.; Steiner, K.C.; Bowersox, T.W. 1997. Northern red oak planting stock: 6-year results. New Forests. 13: 177-191.

EFFECTS OF FROST ON HARDWOOD REGENERATION IN NORTHERN WISCONSIN

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Abstract—In northern Wisconsin, frosts often occur during the early growing season when shoot and leaf development are beginning and trees are most susceptible to freezing temperatures. We measured the intensity and duration of frosts in late May and early June 1994 in a vertical, 10 meter temperature profile in a clearcut, a stand with 50 percent crown cover, and a control. In addition, we monitored shoot development of northern red oak (*Quercus rubra* L), white ash (*Fraxinus americana* L.), ironwood (*Carpinus caroliniana* Walt.), sugar maple (*Acer saccharum* Marsh.), and aspen—both trembling (*Populus tremuloides* Michx.) and big tooth (*Populus grandidentata* Michx.) in these stands and in a stand with 75 percent crown cover. We also assessed frost damage on a broader scale as it was related to overstory condition, distance from clearcut edge, and topographic position in two areas with clearcut and partially cut hardwood forests. The frost damage was more severe in the clearcut, less in the 50 percent crown cover, and did not occur in the 75 percent crown cover and control. Northern red oak and white ash shoots were severely affected by frost with death of all new growth in the clearcut; ironwood was slightly damaged; and sugar maple and aspen were apparently unaffected by frost. All trees with frost damage produced new shoots; the location of the buds that flushed depended on the severity of frost damage. In addition to differences among overstory treatments, frost damage differed with topographic positions and with depth-of-edge between areas with different temperature environments. Silvicultural implications of our observations are discussed.

INTRODUCTION

Forest succession patterns are determined by many interrelated factors acting at different spatial and temporal scales. The most obvious factors, such as site productivity, herbivory, plant species growth rates, vegetative reproduction, and seed availability, are commonly used to explain the variation in composition and development of forest ecosystems. Other physical and biological factors may also be important, but we know little about their occurrence in space and time. Late spring frosts are one factor that may be more important than expected for some species and sites. Frost has long been implicated as a factor in hardwood regeneration and growth, particularly for oaks (Buckley 1994, Crow 1992, Emerson 1846, Gordon and others 1995, Johnson 1979, McGee 1975, Ward 1964). However, there is little documentation of the frequency and severity of frost damage to oaks at varying scales of resolution, e.g., within and among individuals, stands, and landscapes, although Geiger (1965) described general spatial and temporal variation of frost in forests. Early growing season frosts result from the interaction between cold air masses that generally affect a region (advective frost), radiative heat loss, and pooling of cold air in areas with restricted air flow. The duration and severity of sub-freezing temperatures are related to the local topography, amount and type of forest cover, and weather conditions. The inability of vegetation to return to some northern Wisconsin sites after forest clearing in the early 1900s was due, in part, to the presence of frost pockets. Plant response to frost can vary significantly depending on the inherent ability of species to withstand frost, the stage of plant development when frost occurs, the severity of frost, and the ability to recover after frost damage (Kramer and Kozlowski 1979).

This paper describes frost damage in 2 regenerating hardwood stands in northern Wisconsin. The purpose of these observations is to better understand the short term effects of frost and determine if different forest structures resulting from silvicultural treatments reduced damage.

METHODS

Willow Springs

The Willow Springs site is located on the Chequamegon National Forest near Park Falls, WI (T38N R3E, Sections 13-14). Our most detailed observations were made at this site, which has a habitat type of *Acer/Viola - Osmorhiza* (Kotar and others 1988). The topography is level to gently sloping (0 to 5 percent) and the soil is a moderately well-drained, sandy loam. Early results of an artificial oak regeneration study on this site are available (Teclaw and Isebrands 1991).

The study area consists of 4, 8 hectare overstory blocks—0 (clearcut), 50 percent, and 75 percent canopy cover and an uncut control. Basal area was 17.0, 20.7, and 32.4 square meters/hectare, respectively in the 50 percent, 75 percent, and control blocks. Temperature was measured in the clearcut, 50 percent, and control blocks at the surface and 0.25, 0.50, 1.0, and 2.0 meters above ground every 10 minutes. Hourly average and daily maximum and minimum values were recorded with Campbell CR10 data loggers. Weather stations were located in the center of each overstory treatment and temperature measurements were replicated three times within each block.

Shoot elongation was measured on sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.),

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ironwood (*Carpinus caroliniana* Walt.), red oak (*Quercus rubra* L), aspen—both trembling (*Populus tremuloides* Michx.) and big tooth (*Populus grandidentata* Michx.), and raspberry (*Rubus idaeus* L.) in the overstory blocks in which they were present. The terminal shoot was measured on each of six plants for each species. Plants were located near the center of the block, as close to the weather stations as possible, and at least 150 meters from the edge of the block. Moreover, red oak acorn germination was observed on six artificially seeded plots in each overstory treatment block. Shoot elongation and germination observations were made every 7 to 14 days from May 1 through early July and in early August and September.

Two weeks after the temperature in the clearcut was recorded at -9.2 °C on Julian days 146-147 (May 26-27), we established three transects in all overstory treatments to determine the spatial variation in frost damage. Sample points were located at 10 meter intervals beginning at the edge of the clearcut block and going into the adjacent 50 percent and untreated blocks. The transects in the 50 percent block spanned the block and ended in the adjacent uncut forest. Transects were 150 and 300 meters long in the control and 50 percent blocks, respectively.

White ash and red oak were the only tree species severely affected by the frost. Because of the small number of red oak and the large number of uniformly distributed white ash seedlings that regenerated naturally, sample trees were only white ash. When oak seedlings were encountered, they were evaluated and the degree of damage was compared to adjacent white ash. Based on these observations, red oak and white ash were similarly affected by the frost. At each sample point, up to 20 white ash seedlings ranging in height from 0.25 to 1.5 meters were evaluated. Stump sprouts were also sampled in the clearcut because seedlings in that block were rare. In the control, most seedlings were 0.25 meter tall or less due to poor performance of seedlings in full shade. Frost damage was classified according to the following scale: class 1—no damage; 2—up to 20 percent of leaves damaged; 3—21 to 40 percent damage; 4—41 to 60 percent damage; 5—61 to 80 percent damage; 6—81 to 99 percent damage; 7—all leaves killed. In classes 2 to 5, there was little obvious damage to the current year's shoot. In class 6, the current year shoot was frost-pruned to varying lengths; in class 7, the entire current year shoot and all leaves were killed.

Bird Lake

The Bird Lake site is located near Lake Tomahawk, WI, on the American Legion State Forest (T38N R7E, Section 18) and has a habitat type of *Acer/Vaccinium - Viburnum* (Kotar and others 1988). The topography is typical of ground moraine deposits in the region with irregular slopes varying from 0 to as much as 60 percent over short distances (fig. 1). The mesoscale topography at this site was much more complex than at Willow Springs. The Bird Lake site consists of three replications of three overstory treatments—clearcut, and 25 percent and 50 percent crown cover (fig. 1). Residual basal area in the 25 percent and 50 percent plots was 7 and 14 square meters/hectare, respectively. Each overstory plot is 0.56 hectare. Teclaw and Isebrands (1993) have reported the early results of red oak artificial regeneration studies on this site.

Three weeks after the frost on Julian days 146-47, we made frost damage observations in all nine overstory treatment plots. Within each plot, 12 sample points were established. At each sample point, up to five red oak seedlings and three red oak sprout clumps were evaluated using the damage classes described above. In addition, we measured total plant height and height of frost damage.

The contour map of the site was developed using a hand-held abney level. All elevations in figure 1 are referenced from the starting point of the survey, which was designated as the 100 isoline. The total relief for the area is approximately 28 meters (relative height of 88 to 116).

RESULTS

Willow Springs

In 1994, sub-freezing temperatures were recorded on Julian days 131-133 (May 11-13), 136 (May 16), 146-147 (May 26-27), 152-154 (June 1-3), and 159 (June 8). The growing degree days (dd) for the clearcut based on 5 °C for the frost dates above were 97 to 111, 128, 243, 310 to 329, and 380, respectively. Degree days in the 50 percent and control blocks were slightly less. Bud break occurred between May 7 and 11, and there was measurable shoot elongation on May 22. Neither red oak nor white ash showed signs of frost damage on May 21; thus, frosts before this did not appear to affect development.

The sub-freezing temperatures on days 146-147 caused an immediate wilted appearance and green tissues turned black within a few days. Temperature regimes differed considerably among the three overstory treatments. Minimum temperatures in the clearcut, 50 percent crown cover, and 100 percent crown cover blocks were -9.2 °C, -2.5 °C, and -0.6 °C, respectively. The duration of the freezing conditions was 10 hours in the clearcut, 8 hours in the 50 percent crown cover block, and only 1 hour in the 100 percent crown cover block. The depth of freezing temperatures in the inversion layer was up to 10 meters above the ground in the clearcut and 50 percent crown cover blocks and only up to 0.5 meter in the 100 percent crown cover block (fig. 2).

Species differed in their ability to withstand frost. In the clearcut, red oak and white ash were equally susceptible. The current year shoot and associated leaves were killed on every seedling and sprout clump throughout the 8 hectare block (figs. 3A, 3B, 4A, and 5A). Frost damage did not differ between plants in open areas and those present in the understory of stands of dense young aspen suckers. About 20 percent of the red oak acorns on artificially seeded plots in the clearcut had germinated at the time of the frost. They were subjected to the coldest temperatures, and their above ground stems were killed. Red oak germinants on the artificially seeded plots in the 50 percent and 75 percent blocks were not damaged. Of the other common tree and shrub species present, ironwood and

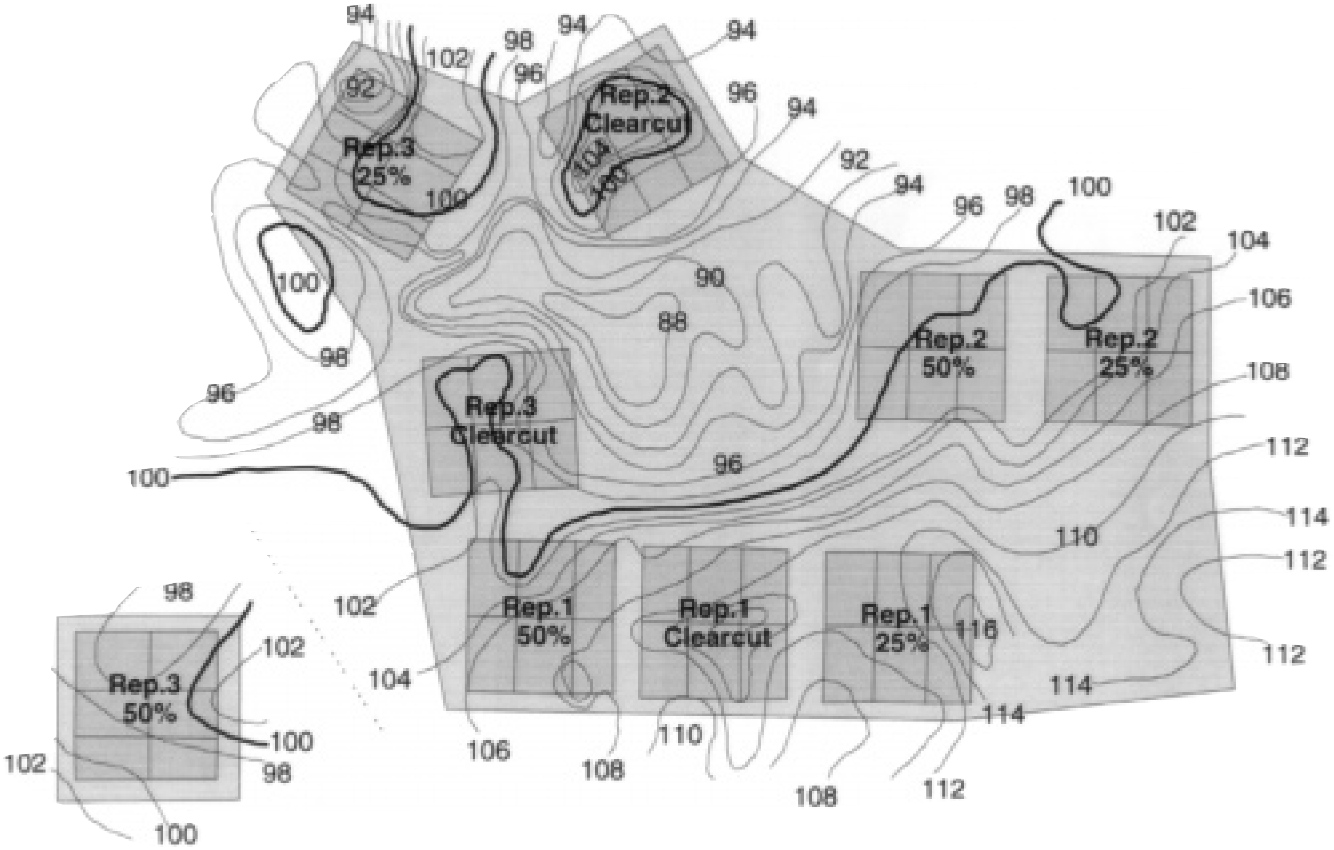

Figure 1—Contour map of the Bird Lake site with locations of clearcut, 25 percent crown cover and 50 percent crown cover plots. The elevations shown are in meters and relative to the 100 line (e.g., 88 indicates 12 meters lower than 100 and 116 indicates 16 meters higher). The total relief in the area is approximately 28 meters. Isolines in the Rep 3 - 50 percent plot are not continuous with other isolines in the figure as the plot is located several hundred meters away. See table 3 for estimates of frost damage in each treatment unit.

raspberry had some leaf and shoot damage. The damage to ironwood was not as immediately noticeable as in red oak and white ash. The most susceptible parts of the current growth of ironwood were killed by the frost, and there was a measurable reduction in shoot length (data not shown). In contrast, sugar maple and aspen did not exhibit signs of frost damage. Shoot growth patterns observed here were similar to those reported by Buech (1976) at another site in northern Wisconsin.

Severity of frost damage to white ash and red oak varied in the 50 percent and control blocks depending, in part, on the distance to the edge of the clearcut block. In the control, class 7 damage occurred to a minor degree up to 20 meters from the edge of the clearcut. From 30 to 150 meters from the edge, no damage was observed (table 1). In the 50 percent block, class 6 and 7 damage was common near the edge of the clearcut, but gradually declined with distance from the edge of the clearcut. Beyond 80 meters, class 7 damage did not occur and undamaged seedlings were most common, although class 2 damage occurred up to 210 meters from the clearcut (table 2). The damage from 80 to 190 meters from the edge of the clearcut block may be representative of that

Table 1—Percentage of frost damaged seedlings in the control block as related to distance from the edge of the clearcut

	Frost damage class						
Distance from edge	1	2	3	4	5	6	7
m							
0-10	24	-	6	-	9	1	60
11-20	88	2	-	7	-	-	3
21-30	96	-	2	-	2	-	-
31-150	100	-	-	-	-	-	-

Class 1 = no damage, 2 = up to 20 percent of leaves damaged, 3 = 21 to 40 percent damage, 4 = 41 to 60 percent damage, 5 = 61 to 80 percent damage, 6 = 81 to 99 percent damage, 7 = all leaves killed.

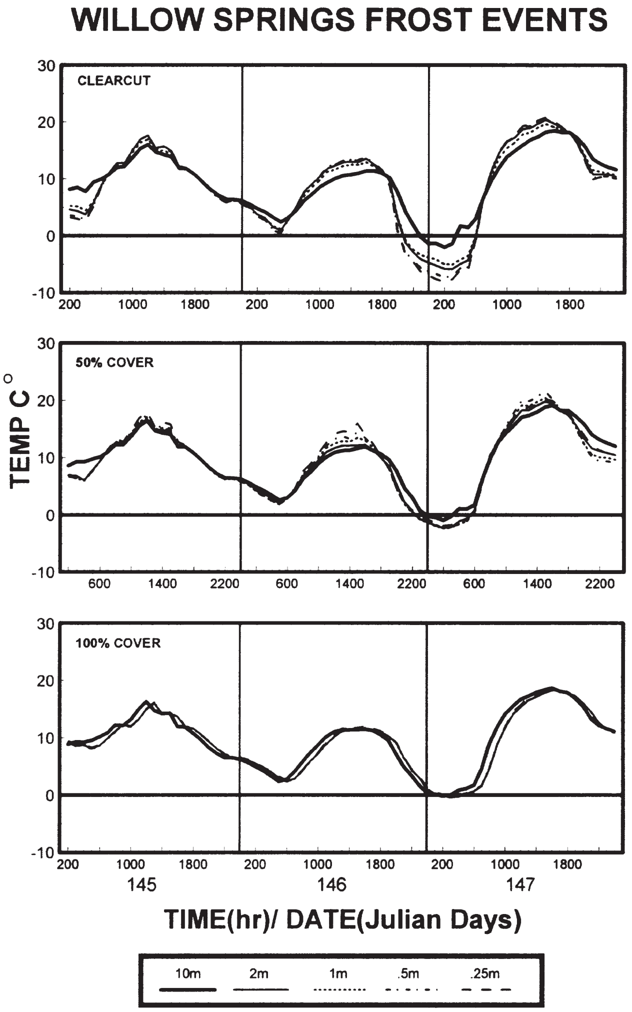

Figure 2—Temperature profiles in clearcut, 50 percent crown cover, and control blocks at the Willow Springs site on days 146 to 147.

Table 2—Percentage of frost damaged seedlings in the control block as related to distance from the edge of the clearcut

Distance from edge	Frost damage class 1	2	3	4	5	6	7
m							
0-10	-	-	-	-	-	-	100
11-20	-	-	-	-	-	-	100
21-30	-	-	-	-	10	-	90
31-40	-	-	-	-	8	-	92
41-50	2	-	6	2	6	10	74
51-60	25	14	7	4	10	14	25
61-70	29	19	12	9	12	12	7
71-80	61	19	5	5	4	5	2
81-90	74	18	4	4	-	-	-
91-100	93	6	-	1	-	-	-
101-110	78	19	-	3	-	-	-
111-120	93	6	-	1	-	-	-
121-130	82	18	-	-	-	-	-
131-140	100	-	-	-	-	-	-
141-150	87	13	-	-	-	-	-
151-160	78	22	-	-	-	-	-
161-170	80	20	-	-	-	-	-
171-180	89	11	-	-	-	-	-
181-190	73	27	-	-	-	-	-
191-200	87	13	-	-	-	-	-
201-210	96	4	-	-	-	-	-
211-280	100	-	-	-	-	-	-

Class 1 = no damage, 2 = up to 20 percent of leaves damaged, 3 = 21 to 40 percent damage, 4 = 41 to 60 percent damage, 5 = 61 to 80 percent damage, 6 = 81 to 99 percent damage, 7 = all leaves killed.

expected with a frost of this intensity (fig. 2) in larger blocks of continuous forest with these overstory conditions. Beyond 190 meters from the edge of the clearcut, the transect approached the uncut area and this may have affected microclimate (table 2). None of the other tree species or raspberry exhibited any evidence of frost damage in any part of the 50 percent block. The 75 percent block was surrounded by untreated forest and no damage to red oak, white ash or other species occurred.

The type of flushing after frost damage varied with the severity of damage. All plants with class 7 damage produced new flushes. Most commonly, the new shoot originated from dormant buds in the terminal bud cluster on the previous year's growth (fig. 3B) or from a dormant axillary bud on the previous year's growth or an axillary bud near the base of the seedling. Flushing in seedlings and stump sprouts was similar. Flushing began 1 to 2 weeks after the frost and was completed within about 2 weeks of budbreak. The post-frost flush was longer than the original flush in some trees (figs. 4 and 5).

Undamaged buds on the current year's shoot flushed (fig. 3C and 3D) on seedlings that sustained partial frost damage to leaves or shoots (e.g., red oak in the 50 percent block and ironwood in the clearcut block). Flushing occurred on stems with only damaged leaves and on those with damaged leaves and shoots pruned to varying lengths by the frost. For example, most of the leaves on the terminal shoot of tree 3 (fig. 4B) were killed and subsequently shed, but the shoot was not damaged. Following this damage, several axillary buds flushed, resulting in additional net shoot elongation for the year. Also, the tip of the shoot of tree 4 (fig. 4B) was killed and shoot length was reduced in the short-term; however, flushing of a bud on this shoot recovered the lost length and added an additional 10 centimeters.

Bird Lake

Red oak was the only species damaged by frost at Bird Lake. Other species present, but not damaged, were paper birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum*),

Figure 3—Examples of frost damage to northern red oak where (A) entire shoot and all leaves were killed, (B) close-up of frost killed shoot showing: (1) frost killed original flush and (2) new shoot formed by flush of dormant bud, (C) undamaged shoot with nodes where frost-damaged leaves have been shed and axillary buds flushing, (D) shoot with frost pruned tip and various degrees of leaf damage.

raspberry, and blackberry (*Rubus allegheniensis* Porter). Frost damage was not closely associated with any of the three overstory conditions in this area as it was at Willow Springs, but appeared associated with topographic position. However, seedlings and sprouts in 50 percent plots had the least damage (class 2-3), followed by the 25 percent plots and clearcuts, respectively. Although the number and size of plots in our study were not large enough to establish a definitive relationship between overstory condition and topographic position, frost damage and topographic position seem related. For example, in the clearcut plots, the least damage occurred in the plot with the highest relative elevation (clearcut plot 2, fig. 1, table 3). Seedlings and sprouts in the 25 percent and 50 percent plots tended to have more class 6 and 7 damage where the elevation was below 100 than in those with elevations greater than 100 (fig. 1, table 3).

The height on the plant to which frost damage occurred differed among the plots. Affected seedlings always exhibited damage over the entire plant, suggesting that they were completely within the portion of the inversion layer with temperatures low enough to freeze stem and leaf tissues. However, stump sprouts in 25 percent plot 2 and 50 percent plot 2 were of sufficient height so that their tops were above the freezing conditions of the inversion layer, while their lower branches were damaged by freezing conditions. Red oak trees along roads with the lower part of their crowns damaged and the upper part undamaged were common in this area. The oak stump sprouts in clearcut plot 2 and 25 percent plot 3 showed damage over their entire vertical structure.

We did not follow the post-frost flushing on this site. However, measurements made at the end of the growing season indicated that all seedlings had produced new shoots and no mortality was observed as a result of the frost damage.

DISCUSSION

In northern Wisconsin, frosts often occur during the early growing season when trees are most susceptible to freezing temperatures. Frost damage should be viewed at different scales of resolution and as variable in space and time. At Willow Springs and Bird Lake, frost damage differed among shoots on the same plant, among species and populations of the same species in an area, and among stands within a landscape. We also observed variation in frost damage related to a significant depth-of-edge (Chen and others 1995) between areas differing in temperature regimes as, for example, between the clearcut block and the adjacent 50 percent and control blocks at our Willow Springs site. The observed penetration of frost damage into the control and 50 percent blocks from the clearcut at Willow Springs may have important implications for silvicultural practices such as strip or group selection cuts. The patterns of frost damage that we observed substantiate the work of Geiger (1965) on the spatial variation in frost damage in forests, and they provide examples of how hardwood forests of the northern Great Lakes region are affected by frost.

Understanding the role of frost in determining the composition and structure of these forests requires long term observations. Several things do stand out, however, from short-term observations. First, there are great differences in susceptibility to frost among species, and the most susceptible species, e.g., oak and ash, are at a disadvantage on sites where growing season frosts are common. For example, at Willow Springs, red oak was affected by frost in each of the past 6 years in the clearcut. Stump sprouts appear to have an advantage over seedlings in that they grow faster and attain heights that are above the damaging inversion layer during frost events and may be the best way to maintain oak as a component of the forest where frost is a concern. Oak sprouts in lower Michigan recovered quickly from frost damage and there was little effect on net shoot elongation (Johnson 1979).

Frost is probably not a critical factor by itself in terms of seedling survival. Rather, it is one of a host of biotic and abiotic factors affecting survival and growth. Buckley (1994, 1998) found that frost damaged seedlings often died, but that a combination of frost and repeated browsing of the new shoots (produced after the frost) likely caused most of

Table 3—Percentage of frost damaged seedlings at the Bird Lake site relative to canopy cover and elevation

Frost damage class	Clearcut Plot 1	Clearcut Plot 2	Clearcut Plot 3	25 percent crown cover Plot 1	25 percent crown cover Plot 2	25 percent crown cover Plot 3	50 percent crown cover Plot 1	50 percent crown cover Plot 2	50 percent crown cover Plot 3
	----------Elevation (m) ---------			----------Elevation (m)----------			----------Elevation (m)----------		
	108-114	94-104	96-100	110-116	100-108	92-102	102-110	96-102	98-102
1	25	-	2	31	28	-	25	14	45
2	34	-	19	27	23	-	41	12	10
3	29	-	17	22	11	-	26	8	3
4	4	-	17	11	3	-	2	11	-
5	5	-	8	4	2	-	-	14	5
6	2	-	21	-	20	-	-	15	8
7	2	100	17	5	12	100	7	26	28

Class 1 = no damage, 2 = up to 20 percent of leaves damaged, 3 = 21 to 40 percent damage, 4 = 41 to 60 percent damage, 5 = 61 to 80 percent damage, 7 = all leaves killed.

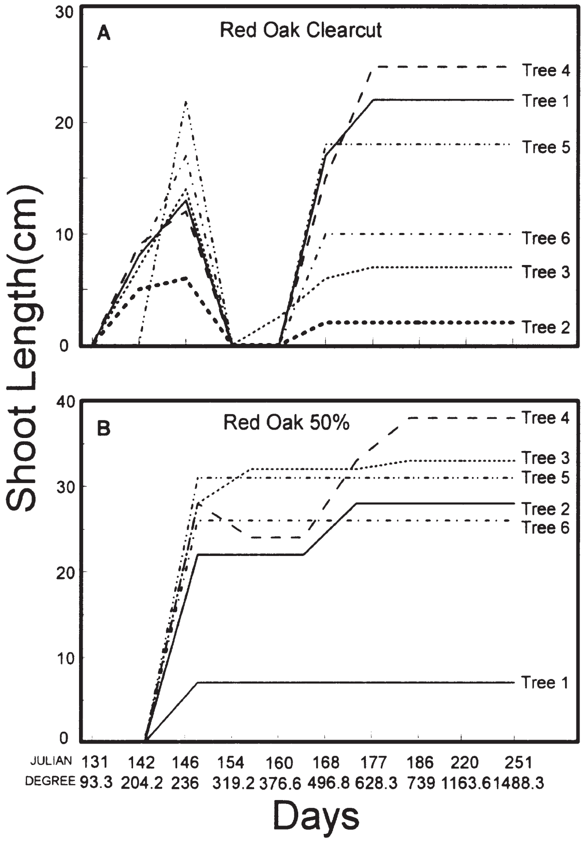

Figure 4—Shoot elongation of red oak in (A) clearcut, and (B) 50 percent crown cover block at the Willow Springs site. The frost on Julian days 146 and 147 killed all new shoot growth in the clearcut (fig. 3A), but affected only less mature tips of shoots in 50 percent crown cover (fig. 3C and 3D). Shoot growth of individual trees is shown for clearcut and 50 percent crown cover areas to better illustrate some of the variation within the seedling population. Note the effect of frost pruning on shoot length of tree 4 and on shoot elongation resulting from flushing in trees 2 and 4 in 50 percent crown cover.

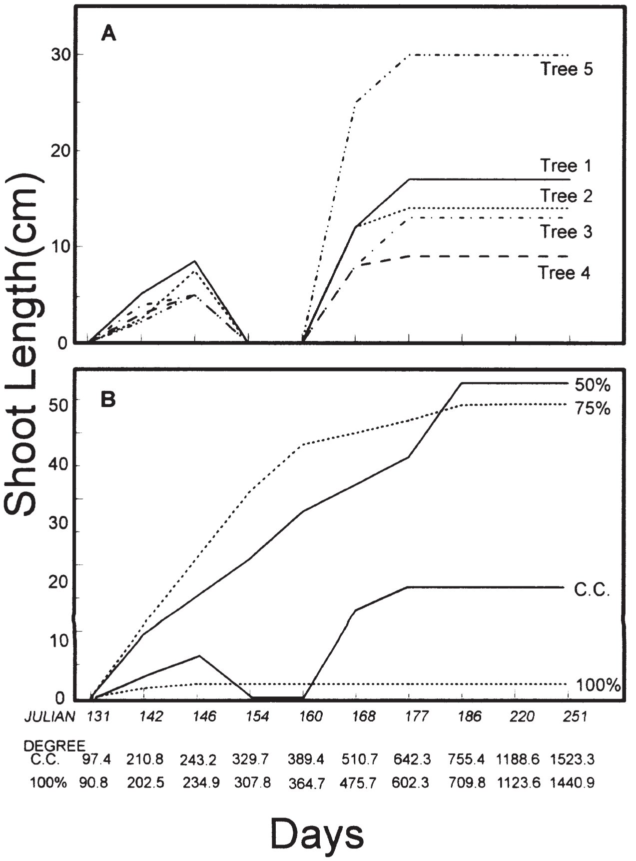

Figure 5—Shoot elongation of white ash (A) 5 individual trees in the clearcut, and (B) average of 5 trees in clearcut, 50 percent and 75 percent crown cover, and control blocks at Willow Springs.

the mortality. Where portions of terminal leaders are severely frost-pruned, reductions in height and photosynthate production may decrease growth rate and increase the period when a large proportion of the photosynthetic tissues of a seedling are susceptible to additional frosts, herbivory, and competition with understory vegetation.

Our work confirms the studies of Ringger (1972) on microclimate of forest gaps in northern hardwoods, as well as the broader experience of Geiger (1965) who found that silvicultural treatments significantly influence microclimate and more specifically the distribution, severity and effect of frost in the landscape. The importance of creating or maintaining an overstory to reduce frost damage to oak regeneration was recognized 150 years ago by Emerson (1846), Crow (1992), Buckley (1994, 1998), and Gordon and others (1995). The appropriate level of overstory cover and composition will depend on the local topography of the area and the frequency and severity of frosts in an area. For areas with relatively little relief, such as our Willow Springs site, it appears that a 50 percent canopy cover is at the lower end of a threshold for total prevention of frost. This agrees with observations from lower Michigan (Buckley 1994, 1998) of a significant decrease in frost damage as crown cover increased from 25 to 75 percent. However, on sites with more irregular topography, such as Bird Lake, there is a relationship between overstory condition, topographic position, and potential for frost. Small gaps or clearcuts in areas with highly irregular topography might best be situated on relatively higher areas where cold air drainage does not result in frost pockets. Because of the depth-of-edge between areas with substantially different microclimates, there could be considerable damage to susceptible species in stands that are not large enough to have a true interior (Chen and others 1995).

In summary, these two case studies provide insight into some aspects of how frost affects the development of hardwood forests and how silvicultural treatments can be used to ameliorate frost in northern hardwood forests. In areas subject to frequent late spring frosts, managers would benefit from increased information about the relationship of frost damage to canopy cover, canopy composition, and the size of canopy openings. Certainly more work is needed to characterize interactions between these factors and frost, and to understand the long-term impacts of frost on species in these forests.

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REFERENCES

Buckley, D.S. 1994. Relationships among competing vegetation, herbivores, and environmental conditions affecting northern red oak (*Quercus rubra* L.) regeneration. Houghton, MI: Michigan Technological University. 581 p. Ph.D. dissertation.

Buckley, D.S.; Sharik, T.L.; Isebrands, J.G. 1998. Ecology. 79(1): 65-78.

Buech, R.R. 1976. Tree shoot elongation in northern Wisconsin and relationships with temperature and precipitation. Canadian Journal of Forest Research. 6: 487-498.

Chen, J.; Franklin, J.F.; Spies, T.A. 1992. Growing season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. Ecological Applications. 5: 74-96.

Crow, T.R. 1992. Population dynamics and growth patterns for a cohort of northern red oak (*Quercus rubra*) seedlings. Oecologia. 9: 192-200.

Emerson, G.B. 1846. Report on the trees and shrubs growing naturally in the forests of Massachusetts report to the legislature. Boston: Dutton and Wentworth, State Printers.

Geiger, R. 1965. The climate near the ground. Cambridge, MA: Harvard Press. 611 p.

Gordon, A.M.; Simpson, J.A.; Williams, P.A. 1995. Six-year response of red oak seedlings planted under a shelterwood in central Ontario. Canadian Journal of Forest Research. 25: 603-613.

Johnson, P.S. 1979. Shoot elongation of black oak and white oak sprouts. Canadian Journal of Forest Research. 9: 489-494.

Kotar, J.; Kovanch, J.A.; Locey, C.T. 1988. Field guide to forest habitat types of northern Wisconsin. Madison, WI: University of Wisconsin, Department of Forestry. 153 p.

Kramer, P.J.; Kozlowski, T.T. 1979. Physiology of woody plants. New York: Academic Press. 811 p.

McGee, C.E. 1975. Change in forest canopy affects phenology and development of northern red oak and scarlet oak seedlings. Forest Science. 21: 175-179.

Ringger, D.L. 1972. The microclimate of various forest openings. Milwaukee: University of Wisconsin. 122 p. M.S. thesis.

Teclaw, R.M.; Isebrands, J.G. 1991. Artificial regeneration of red oak in the northern Lake States. In: Laursen, S.B.; DeBoe, J.F., eds. The oak resource in the upper Midwest—implications for management. Publ. NR-BU-5663-5. St. Paul, MN: University of Minnesota: 187-197.

Teclaw, R.M.; Isebrands, J.G. 1993. An artificial regeneration system for establishing northern red oak on dry-mesic sites in the Lake States. Annuls of Science Forestry. 50: 543-552.

Ward, W.W. 1964. Bud distribution and branching in red oak. Botanical Gazette. 125: 217-220.

RED MAPLE DYNAMICS IN APPALACHIAN HARDWOOD STANDS IN WEST VIRGINIA

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Red maple (*Acer rubrum* L.) is increasing in understory abundance in Appalachian Hardwood forests in the eastern United States. Partial cutting practices are typically used to harvest the mature, second generation forests. These partial overstory removals may increase the importance of red maple in the overstory of the next forest generation. The ability of understory red maple to respond to minor disturbances may give it a competitive advantage over new regeneration. The growth strategies red maple uses to attain overstory canopy positions were investigated on mesic and dry sites, in two West Virginia Appalachian hardwood stands. In both stands, red maple comprised a small percentage of overstory basal area but was the most abundant understory species. Stem analysis and increment cores were used to determine disturbance history and to examine height and diameter growth relationships among species. The stands originated after a stand-replacing disturbance around 1925. During stand initiation, red maple invaded the sites for 10-15 years longer than most other species, however, all of the codominant red maples sampled were similar in age to other codominant species. Even though stump sprouting is a typical regeneration mechanism for red maple and other species in the region, none of the sampled stems showed evidence of sprout origin. Red maple may have been a better competitor on the dry site because even though red maple grew faster on the mesic site, the drier site had a higher percentage of codominant red maples. Regardless of site, codominant red maples had height growth rates similar to codominant oaks (*Quercus* spp.) throughout stand development. The height growth rates of codominant yellow-poplars (*Liriodendron tulipifera* L.) were usually higher than other species, especially during the first 20 years of development. Only one sampled codominant maple achieved codominance after being overtopped for 20 years (Figure 1a). Stem analyzed understory maples showed fluctuating height growth rates in response to small disturbances in the overstory. Age did not appear to decrease red maple's ability to respond to canopy disturbance. Three understory maples showed significant height growth increases when they were 40-50 years old (Figure 1c,e). Red maple's shade tolerance, understory abundance, and ability to respond to minor canopy disturbances, suggests that partial harvesting increases the likelihood that future stands could have a higher overstory red maple component.

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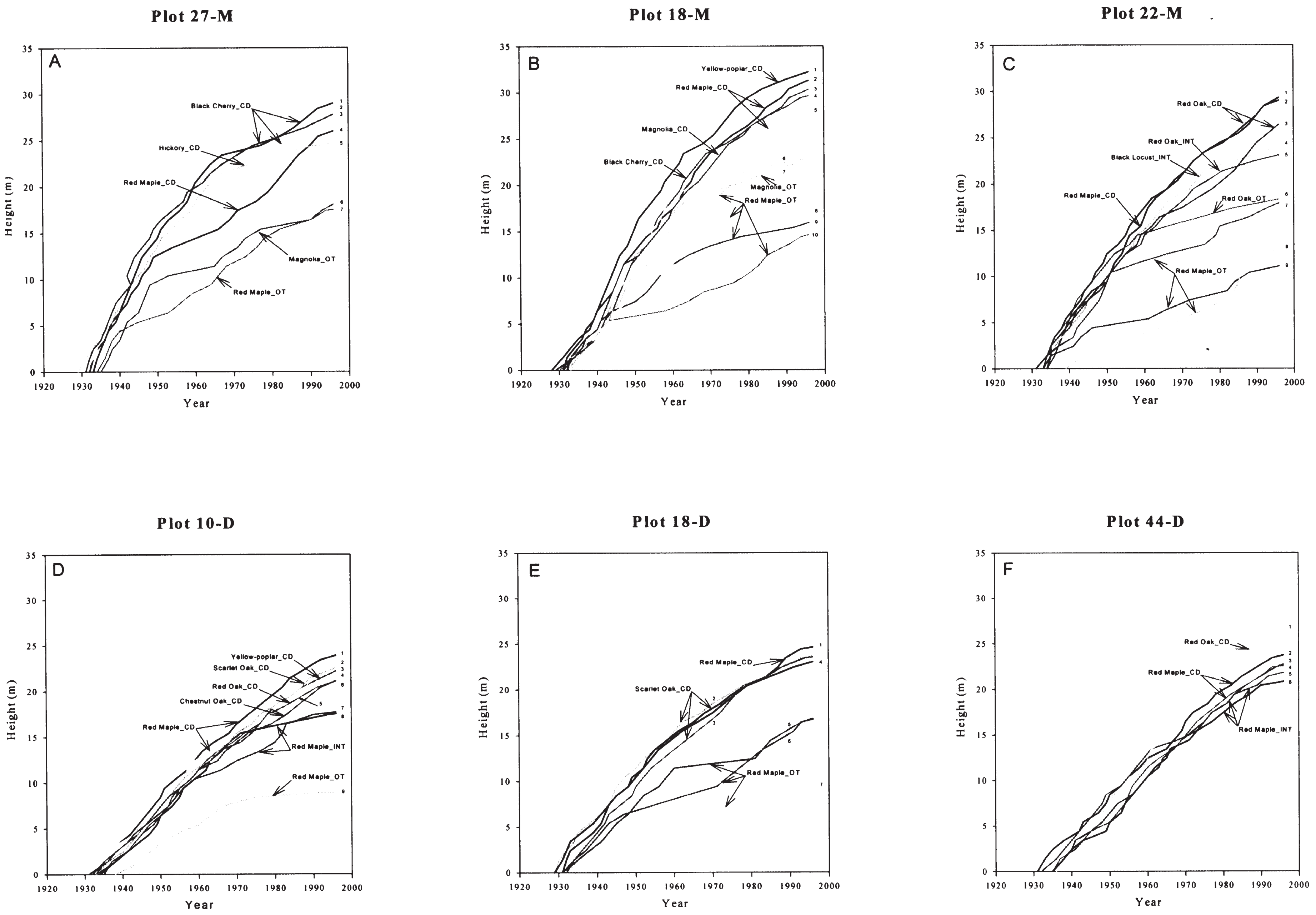

Figure 1— Height growth trajectories for stem analysis plots. Crown class designations CD-codominant, INT-intermediate, OT-overtopped.