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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Citation for proceedings: Stringer, Jeffrey W.; Loftis, David L., eds. 1999. Proceedings, 12th central hardwood forest conference; 1999 February 28-March 1-2; Lexington, KY. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 293 p. [Peer-reviewed paper].

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

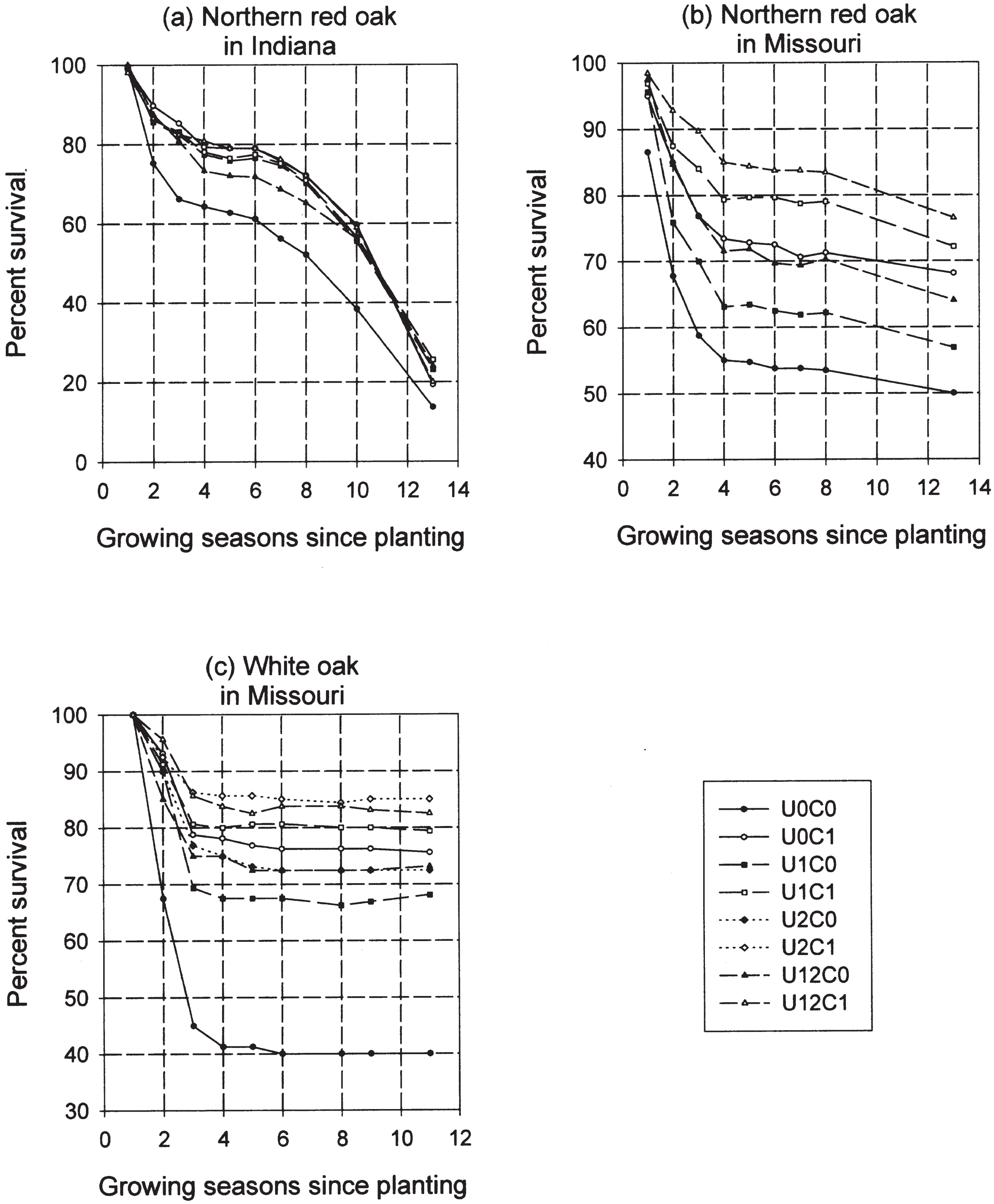

Figure 1—Survival trends for planted northern red and white oak. Seedling treatments: U_0C_0 = not undercut, not top-clipped; U_0C_1 = not undercut, top-clipped; U_1C_0 = undercut first year, not top-clipped; U_1C_1 = undercut first year, top-clipped; U_2C_0 = undercut second year, not top-clipped; U_2C_1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

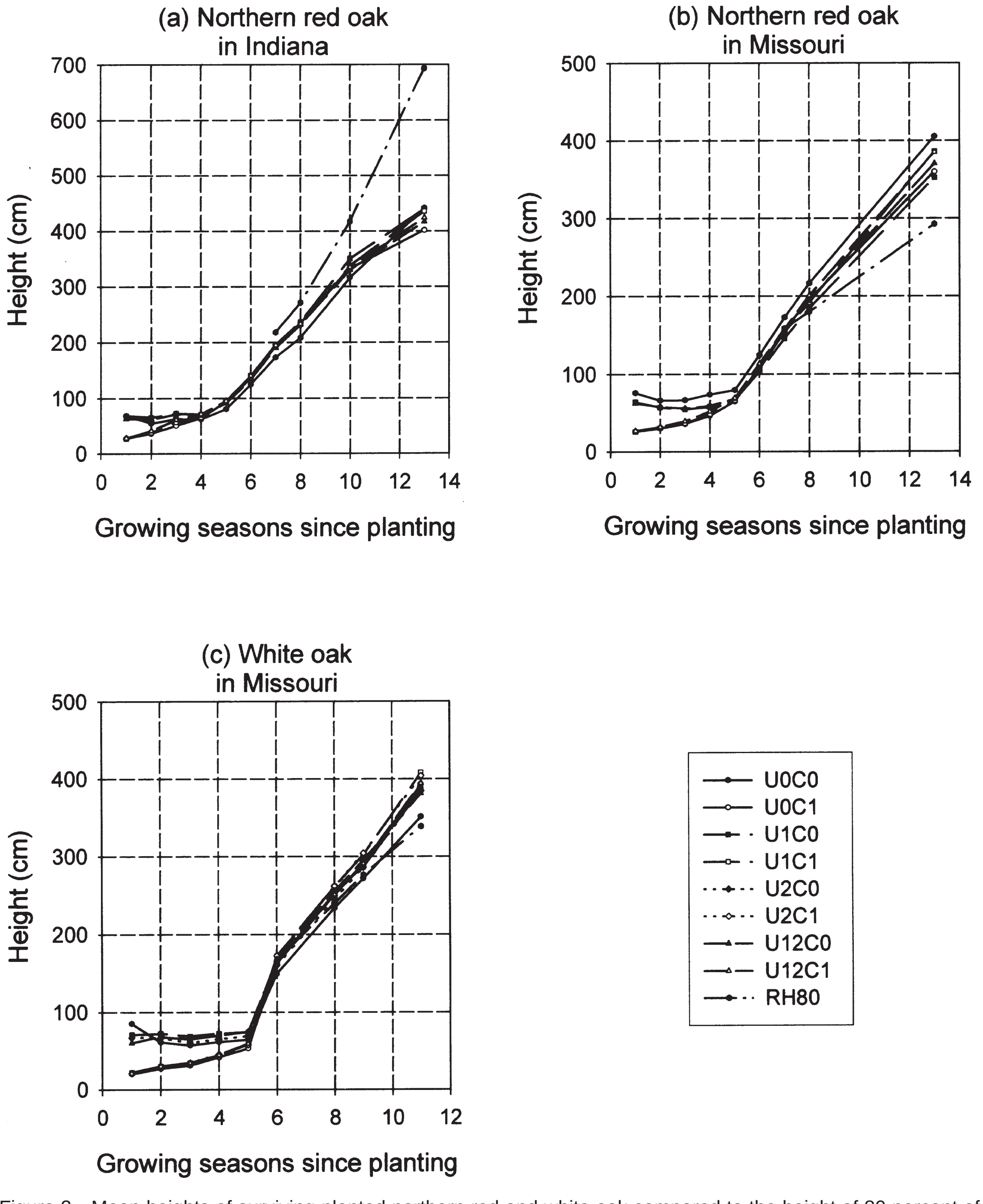

Figure 2—Mean heights of surviving planted northern red and white oak compared to the height of 80 percent of the competition height. Seedling treatments: U_0C_0 = not undercut, not top-clipped; U_0C_1 = not undercut, top-clipped; U_1C_0 = undercut first year, not top-clipped; U_1C_1 = undercut first 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).

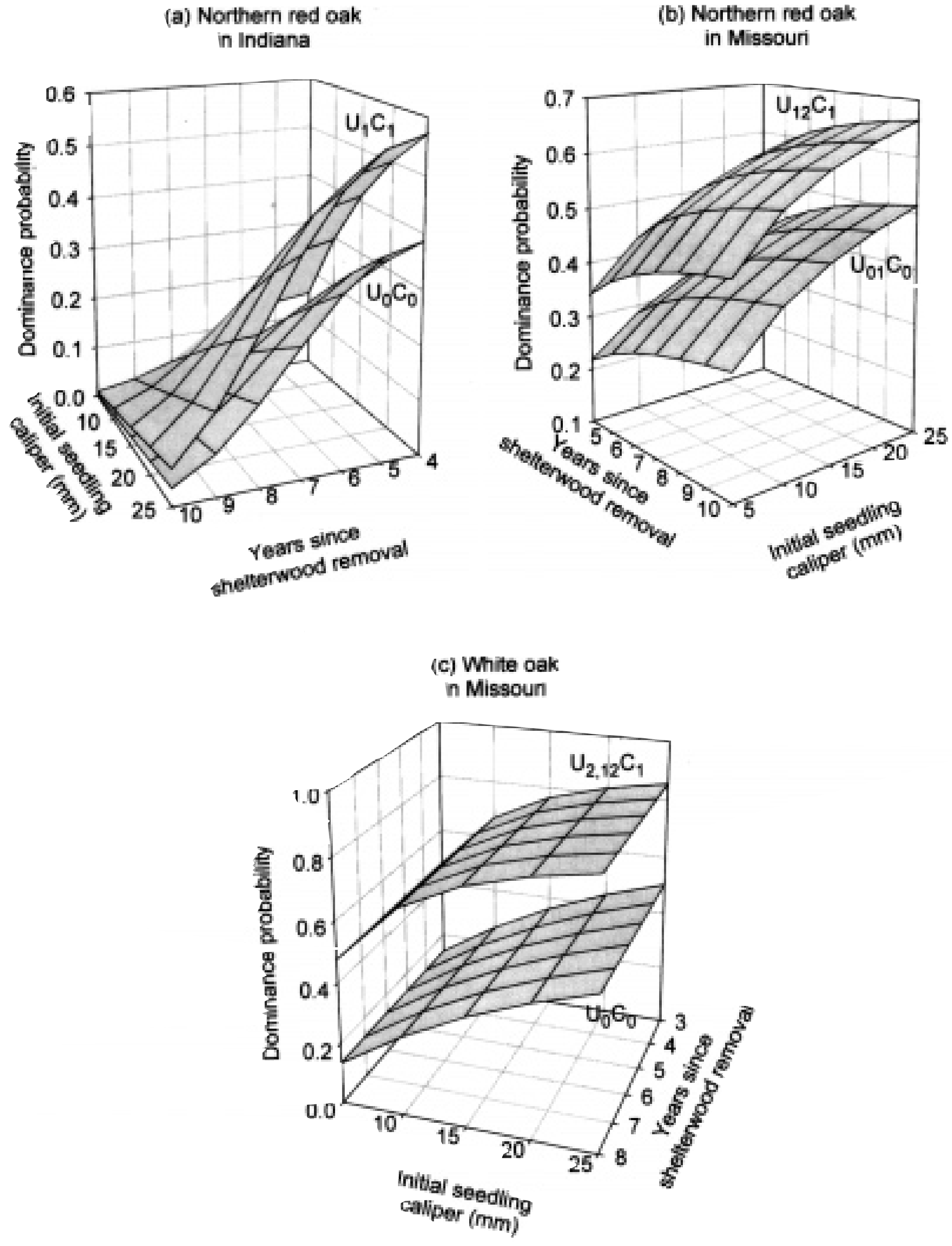

Figure 3—Dominance probabilities for planted northern red oak and white oak in relation to initial seedling caliper and years since shelterwood removal. For both regions and species, success probabilities are shown for the "best" and "worst" combination of undercut (U) and shoot clipping (C) treatments. 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.

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