SUCCESS OF UNDERPLANTING NORTHERN RED OAKS

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Abstract—We summarize results of the growth and survival of northern red oak (*Quercus rubra* L.) seedlings 11 years after planting in shelterwoods in the Boston Mountains of Arkansas. Shelterwood overstories were harvested 3 years after underplanting > 4,000 northern red oak seedlings. Woody vegetation that was competing with planted seedlings received two, one, or no competition control treatment(s). Results are expressed as the probability that a planted tree will live to attain a favorable competitive position at a specified year. These probabilities depend on initial seedling stem caliper before planting, site quality, weed control intensity, and shelterwood percent stocking. These probabilities of success increase with decreasing shelterwood stocking, decreasing site quality, increasing initial stem caliper, and increasing intensity of weed control. The reciprocals of the dominance probabilities provide silviculturally useful estimates of the numbers of trees that would need to be planted to obtain, on the average, one competitively successful tree in the future. Based on these results, we provide practical management methods to optimize success of underplanted northern red oak seedlings and to reach future stocking goals.

INTRODUCTION

Oaks are important to wildlife and, in turn, in forest energetics. Wildlife species that utilize oak mast include white-tailed deer (*Odocoileus virginianus*), black bear (*Ursus americanus*), turkey (*Meleagris gallopavo*), blue jays (*Cyanocitta cristata*), squirrels (*Tamiasciurus* spp., *Sciurus* spp., and others), and mice (*Peromyscus* spp.). For instance, a study by Harlow (1975) found that acorns made up an average of 76 percent of the diet of white-tailed deer during November and early December. Fluctuations in wildlife populations often follow fluctuations in oak mast production (McShea and Schwede 1993, Nixon and others 1975, Wentworth and others 1990). Major declines in the population of oaks could lead to similar declines in the populations of associated wildlife species where alternative resources are not available.

Over the last several years, oak decline has had a major impact throughout the Ozark Highlands. Mortality over large forest areas has led to the creation of shelterwood-like conditions. However, previously dense overstories have left many of these sites without oak regeneration or regeneration of sufficient size to survive competition from more shade-tolerant competitors. To address restoration of these sites, management methods are needed that can place oaks in a desirable position in relation to their interspecific competitors so that they may survive to become part of the future forest.

One option for restoring oak to these sites may be to plant oak seedlings under a shelterwood. For instance, Dey and Parker (1997) found that 99 percent of northern red oak seedlings were alive 2 years after underplanting in a shelterwood (50 percent crown cover) while only 90 percent survived in a closed-canopied undisturbed stand. Additionally, root volume, area, and dry mass were significantly greater for the shelterwood-planted seedlings. In a study comparing overstory density and understory competition, Teclaw and Isebrands (1993) found that underplanted northern red oak performed better in shelterwoods with 25 percent crown cover than those with 50 percent crown cover. In this study we summarize the success of shelterwood-underplanted northern red oak (*Quercus rubra* L.) seedlings relative to interspecific competitors and provide management recommendations to optimize underplanting success.

The objectives of this paper are (1) to summarize the 11-year success of planting northern red oak seedlings under shelterwoods from which they were released 3 years after planting and (2) to recommend management methods to optimize successful underplanting of northern red oak based on these results.

SITES

The study sites were located in the Boston Mountains of Arkansas in the southern lobe of the Central Hardwood Region (Merritt 1980). The Boston Mountains are the highest and most southern member of the Ozark Plateau physiographic province. They form a band 30 to 40 miles wide and 200 miles long from north-central Arkansas westward into eastern Oklahoma. Elevations range from about 900 feet in the valley bottoms to 2,500 feet at the highest point. The plateau is sharply dissected; most ridges are flat to gently rolling and are generally < 0.5 mile wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults). They are derived from sandstone or shale residuum, and their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults). They developed from sandstone and shale colluvium, and their productivity is medium to high. Rocks in the area are

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alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 inches; March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

METHODS

A total of 4,320 2-0 seedlings, undercut the first year in the nursery, were planted in early April 1987 at a 7.9- by 7.9-foot spacing in a split-split plot experimental design with five replicates (locations). The later loss of two main plots resulted in 4,128 seedlings being available for this study. Site index for red oaks (northern red and black oaks) ranged from 60 to 79 feet based on indirect estimation from soil and topographic factors (Graney 1977). Planted trees and competition were measured after the 1st, 3rd, 4th, 6th, 8th, and 11th growing seasons. This manuscript summarizes the 11th-year performance (8 years free of the shelterwood) of planted trees.

Designed study variables fall into two major categories: (1) those related to planting environment and (2) those related to nursery production. The former include shelterwood residual overstory density (40, 60, and 80 percent stocking) and three different competition control treatments (no competition control, one competition control treatment, and two competition control treatments). Designed to control woody stems > 1 foot tall and ≤ 1.5 inches in diameter at breast height (d.b.h.), competition control treatments consisted of applying herbicide to cut stem surfaces. The latter designed study variables include time of lifting, shoot clipping, and four local seed sources (table 1).

In addition to the designed study variables, initial basal stem diameter (caliper) of each seedling was measured 0.8 inch above the root collar to 0.004 inch. Initial caliper averaged 0.43 inch and ranged from 0.16 to 0.89 inch. The height of the dominant woody competitor was measured on a 33.8-square-foot plot centered at every fourth planted tree location. The dominant competitor species, most abundant competitor species, and the density of all tree reproduction ≥ 11.8 inches tall also were recorded for each competition plot. More detailed methods can be found in Spetich and others (2002).

Through logistic regression, we were able to ascertain important environmental and management variables necessary to determine planted tree success. The logistic model allows us to integrate the combined effects of these variables into

Table 1—Designed study variables defined (independent variables)[a]

Variable category	Independent variable name	Variable description
Planting environment	Preharvest overstory stocking—stocking after thinning from below (shelterwood creation)	Three levels: shelterwoods were thinned to 40, 60, or 80 percent stocking before planting. The overstory was removed 3 years after planting.[b]
	Competition control treatments[c]	Three levels: (1) control,[d] (2) one herbicide treatment (the winter before spring planting) plus mechanical weeding the winter before overstory removal, (3) two herbicide treatments. In both number 2 and 3 above, the first herbicide application (Tordon 101R or Roundup) was applied to cut stems the winter prior to planting. In number 3 above, the second herbicide application (Garlon-4) was applied to cut stems the winter before overstory removal.[e]
Nursery production	Shoot clipping treatments	Three levels: (1) shoots not clipped, (2) shoots clipped 8 inches above the root collar in the fall (November to December) before planting, and (3) shoots clipped 8 inches above the root collar in the spring (March) before planting.
	Time of lifting	Two levels: (1) seedlings lifted in November, and (2) seedlings lifted in March.
	Seed source	Four sources: collected from local stands distributed across the Buffalo Ranger District of the Ozark National Forest

[a] The dependent variable is the success probability. The success probability is the likelihood that a planted tree will live to attain a favorable competitive position, i.e., at least 80 percent of the mean height of dominant competitors, at a specified year.
[b] Overstory trees were defined as stems > 1.5 in. d.b.h. When harvests occurred, the cut surfaces of harvested trees were treated with an herbicide.
[c] Competition control treatment refers to stems that were1 foot tall or taller and ≤ 1.5 in. d.b.h.
[d] Stems ≤ 1.5 in. d.b.h. not treated
[e] Overstory shelterwood removal occurred during the winter of 1989–90.

a single expression. This expression not only indicates the likely success of a planted tree (where a successful tree is one that survives, plus attains and maintains at least 80 percent of the height of dominant competitors) under specific conditions, but its reciprocal is also a practical tool. Using these reciprocals, resource managers can determine the number of trees to plant to achieve a desired future stocking level of oak.

RESULTS AND DISCUSSION

Between year 6 and year 11, mortality of planted oaks increased by 21 percent. Overall, mortality was highest for oak seedlings with stems of 0.16 to 0.47 inch caliper. By year 11, the highest survival rate, 79 percent, was observed for seedlings with the largest initial caliper (0.67 to 0.87 inch). The survival rate was second highest (74 percent) for seedlings with calipers between 0.47 to 0.67 inch, and the lowest survival (67 percent) was recorded for seedlings in the 0.16- to 0.47-inch class.

We examined the field performance of individual planted trees and their competitors because competitive position in relation to surrounding vegetation is an important determinant of seedling survival. Rating of the most significant competitor results in a competition-centered approach to tree planting. More than 50 percent of the competition plots had dominant competitors represented by four species; sassafras (*Sassafras albidum* Nutt.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and black cherry (*Prunus serotina* Ehrh.) were found in 16.6, 15.3, 12.5, and 10.8 percent of the plots, respectively. The four most abundant competitors were flowering dogwood (*Cornus florida* L.), blackgum, sassafras, and red maple, representing 23.2, 19.7, 12.7, and 10.7 percent of competitors, respectively (table 2). We further evaluated competitive success and variables important to that success using logistic regression.

Spetich and others (2002) found that planted tree success at year 11 increased with initial seedling stem caliper, decreasing site index, lower shelterwood stocking levels, increased woody vegetation competition control, and shoot clipping. Variables that increased success probabilities the most were percent shelterwood stocking, woody vegetation competition control, and initial caliper of seedlings. In figure 1A we show the relationship of initial caliper, site index, and success probability for two woody competition control treatments (based on models by Spetich and others 2002). Figure 1B illustrates decreased probability of seedling success when no woody competition control is applied. Figure 2 illustrates the relationship of percent shelterwood stocking and initial caliper, where larger caliper and lower stocking results in a higher probability of seedling success.

The reciprocals of success probabilities provide silviculturally useful estimates of the number of trees that would need to be planted to yield, on the average, one competitively successful tree in year 11. In table 3 we present these reciprocals as a practical tool to help managers make underplanting decisions.

Table 2—Percent of competition plots[a] in which a given species occurred as the dominant competitor or most abundant competitor in 1997 (8 years after shelterwood overstory removal)

	Dominant competitor				Abundant competitor			
	Density[b] (%)			Total	Density[b] (%)			Total
Species	40	60	80		40	60	80	
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Sassafras (*Sassafras albidum* Nutt.)	6.0	3.8	6.7	16.6	8.6	5.9	8.7	12.7
Blackgum (*Nyssa sylvatica* Marsh.)	3.8	5.6	5.8	15.3	3.9	7.5	8.3	19.7
Red maple (*Acer rubrum* L.)	3.9	4.9	3.7	12.5	4.8	3.0	4.9	10.7
Black cherry (*Prunus serotina* Ehrh.)	3.5	3.7	3.6	10.8	4.3	3.6	2.8	4.4
Flowering dogwood (*Cornus florida* L.)	2.4	2.1	3.2	7.8	1.9	2.2	1.2	23.2
Carolina buckthorn (*Rhamnus caroliniana* Walt.)	2.9	1.0	2.6	6.5	1.7	1.5	1.3	3.1
Oaks[c] (*Quercus spp.*)	2.6	2.3	1.2	6.1	1.9	0.7	0.9	5.4
Hickories (*Carya spp.*)	2.5	1.0	1.2	4.7	1.7	0.8	1.0	3.4
Eastern hophornbeam (*Ostrya virginiana* Mill.)	0.7	2.8	0.2	3.7	1.6	0.6	1.0	2.8
Sumac (*Rhus spp.*)	1.9	0.4	0.6	2.8	0.8	1.9	0.1	3.4
Sugar maple (*Acer saccharum* Marsh.)	0.4	0.6	1.3	2.2	0.3	0.6	1.3	2.1
Paw paw (*Asimina triloba* (L.) Dun.)	1.3	0.8	0.0	2.0	1.1	1.1	0.0	2.1
White ash (*Fraxinus Americana* L.)	0.3	1.0	0.7	1.9	0.4	1.3	0.4	2.0
Witch hazel (*Hamamelis virginiana* L.)	0.3	0.6	0.4	1.3	0.3	0.9	0.4	1.6
Other[d]	2.0	2.1	1.6	5.7	1.6	1.2	0.7	3.4

[a] Based on 1,027 plots, 33.8-ft^2 in size where woody competitors occurred.
[b] Represents percent stocking in the shelterwood phase.
[c] Includes white oak, northern red oak, and black oaks.
[d] Species that represent < 1.0 percent of the total and include American elm, American beech, black locust, serviceberry, wild plum, redbud, hackberry, mulberry, cucumber tree, Ozark chinkapin, black walnut, umbrella magnolia, eastern redcedar, and devils walkingstick.

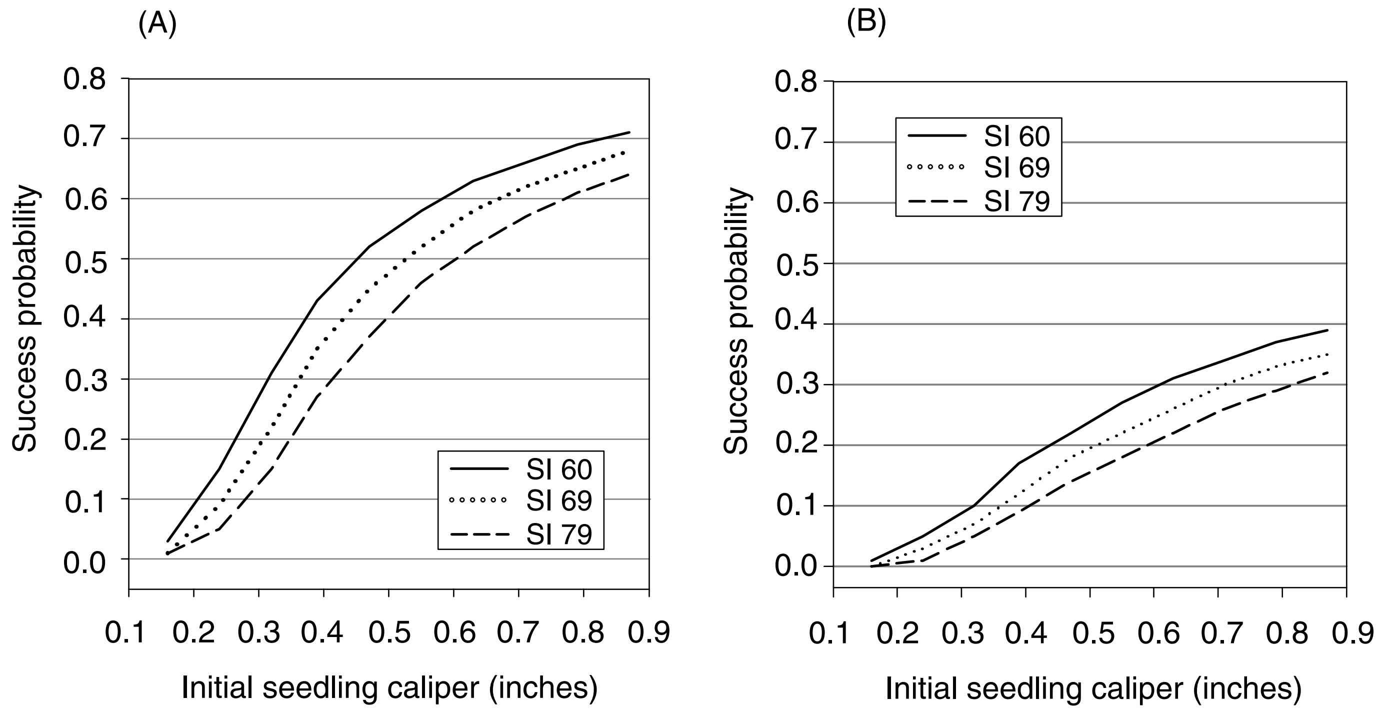

Figure 1—Success probability by initial seedling caliper and site index (SI) for top-clipped trees planted under shelterwoods with 40 to 60 percent stocking. (A) Two competition control treatments. (B) No competition control (based on Spetich and others 2002).

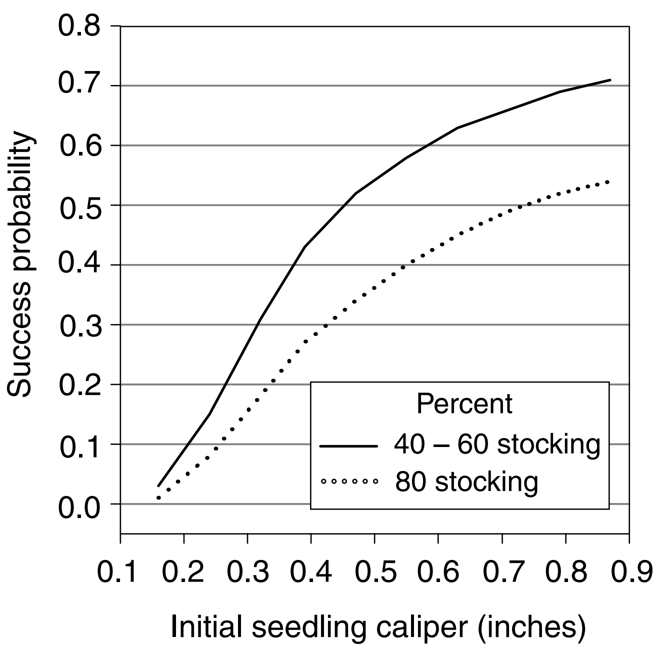

Figure 2—Success probability by initial seedling caliper and percent shelterwood stocking (based on Spetich and others 2002).

This study was not installed under oak decline conditions, so the recommendations below are best applied to healthy stands. However, reductions in stocking levels in stands affected by oak decline can approximate reductions in stocking imposed by a harvest. Following the recommendations below could result in similar oak underplanting success in these stands also.

RECOMMENDATIONS

To take maximum advantage of investments in site preparation, oaks could be planted at densities within treated areas that assure those areas are fully occupied at maturity, where "fully occupied" is the desired oak stocking at maturity necessary to meet management goals. Estimated dominance probabilities can facilitate decisions on an appropriate planting density. A reasonable goal might be at least 100 competitively successful trees per acre at stand age 11. This density would allow for some losses to mortality and suppression beyond 11 years, yet provide reasonable assurance that the oaks, by themselves, would ultimately occupy most of the growing space within treated areas. Using this method, the high per acre planting and site preparation costs associated with the planted area could be spread across the entire stand. For example, limiting planting to 20 percent of stand area would effectively reduce costs of $400 per acre actually planted (nursery stock plus planting plus site preparation costs) to $80 per acre prorated across the entire stand. Where possible, the unplanted portion of the stand (80 percent) could be regenerated naturally. Regeneration would be deemed successful if the

Table 3—Number of trees to plant in order to obtain one successful tree in year 11[a]

	Woody competition control[b]					
	None		Once[c]		Twice	
	Density[d] (*percent*)					
Caliper[e]	40 – 60	80	40 – 60	80	40 – 60	80
inches	*percent*					
	Site index 60 feet					
0.16	126.0	259.8	67.7	139.1	33.9	69.1
0.24	21.9	44.3	12.2	24.1	6.5	12.4
0.32	9.6	18.7	5.6	10.4	3.3	5.7
0.39	6.0	11.4	3.7	6.5	2.3	3.7
0.47	4.5	8.2	2.9	4.9	1.9	2.9
0.55	3.7	6.6	2.4	4.0	1.7	2.5
0.63	3.2	5.6	2.2	3.5	1.6	2.2
0.71	2.9	5.0	2.0	3.1	1.5	2.1
0.79	2.7	4.5	1.9	2.9	1.5	1.9
0.87	2.6	4.2	1.8	2.7	1.4	1.8
	Site index 69 feet					
0.16	306.5	633.7	164.0	338.6	81.4	167.5
0.24	38.9	79.6	21.2	42.9	11.0	21.7
0.32	14.4	28.7	8.1	15.8	4.5	8.3
0.39	8.2	15.8	4.8	8.9	2.9	4.9
0.47	5.7	10.8	3.5	6.2	2.2	3.6
0.55	4.5	8.2	2.9	4.9	1.9	2.9
0.63	3.8	6.8	2.5	4.1	1.7	2.5
0.71	3.4	5.9	2.3	3.6	1.6	2.3
0.79	3.0	5.2	2.1	3.3	1.5	2.1
0.87	2.8	4.8	2.0	3.0	1.5	2.0
	Site index 79 feet					
0.16	748.0	1,547.9	399.6	826.5	197.6	408.1
0.24	69.9	143.6	37.7	77.1	19.1	38.5
0.32	21.9	44.3	12.2	24.1	6.5	12.4
0.39	11.2	22.2	6.5	12.3	3.7	6.6
0.47	7.3	14.1	4.4	8.0	2.7	4.5
0.55	5.5	10.4	3.4	6.0	2.2	3.5
0.63	4.5	8.2	2.9	4.9	1.9	2.9
0.71	3.9	6.9	2.5	4.2	1.8	2.6
0.79	3.4	6.1	2.3	3.7	1.6	2.3
0.87	3.1	5.4	2.1	3.4	1.6	2.2

[a] (Eight years after shelterwood overstoryremoval): calculated by dividing 1 by the success probability. To determine the number of trees per acre to plant, multiply the number of trees per acre that you would like to have at year 11 (11 years after planting) by a number below. To locate this number use the one where your specific site index, competition control plans, and overstory density intersect with the caliper of trees you wish to plant.

[b] In all three cases of none, competition control once and competition control twice: stems > 1.5 inches d.b.h. were cut with the overstory and treated with herbicide.

[c] Includes a mechanical weeding before shelterwood removal.

[d] Represents percent stocking in the shelterwood phase.

[e] This is the initial basal stem diameter of seedlings measured 0.8 inches above the root collar.

Source: Spetich and others 2002.

combined planted and natural reproduction produces an adequate standwide representation of oak and other acceptable growing stock. Adequacy and acceptable growing stock would be defined by the management goals; e.g., wildlife hard mast needs, species diversity, forest restoration, maintenance of this keystone species, or any reasonable management objective. Specific steps to follow to optimize planted seedling success include:

1. Select upland sites within the site index range of 60 to 79 feet for red oaks.
2. Create a shelterwood by reducing overstory density to 40 to 60 percent stocking by thinning from below; i.e., concentrating removals on subcanopy trees down to 1.5 inches d.b.h. Treat the cut surface of cut stems of competitors with an effective herbicide.
3. Before planting, cut all competing woody plants 1 foot or taller and 1.5 inches or less d.b.h., then apply an effective herbicide to the cut surface.
4. Plant 2-year-old undercut seedlings with clipped tops that average at least 0.5 inch in caliper measured 0.8 inch above the root collar (seedlings should be grown from a local seed source).
5. Apply a second competition control treatment (herbicide) before shelterwood removal.
6. Remove the shelterwood three growing seasons after planting. Treat the cut surface of cut stems of competitors with an effective herbicide.

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This publication reports research involving herbicides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of herbicides must be registered by appropriate State and/or Federal Agencies before they can be recommended.

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