EFFECT OF PRE-HARVEST SHADE CONTROL AND FENCING ON NORTHERN RED OAK SEEDLING DEVELOPMENT IN THE CENTRAL APPALACHIANS

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Abstract—Successful oak regeneration is related to the size and number of advanced seedlings present when harvests occur. This study was installed to quantify the effect of microsite light availability and deer on the development of advanced northern red oak (*Quercus rubra* L.) reproduction in mesic Appalachian hardwood stands. Microsite light was manipulated with pre-harvest herbicide treatments. Twelve 0.4-acre plots were randomly assigned to each of three microsite light levels and an untreated control for a total of 48 plots. A woven wire fence was erected around 8 plots in each treatment. Approximately 1,500 individual seedlings were tagged for long-term study. An additional 200 seedlings were tagged for annual destructive tests to measure shoot and root development. Three years after treatment, survival averaged 74 percent in fenced/high-light plots compared to 22 percent in unfenced/untreated plots. Fencing had a much stronger influence on survival than microsite light. Treatments also increased shoot length by 30 percent, root length by 39 percent, shoot weight by 145 percent, root weight by 337 percent, and basal diameter by 26 percent compared to controls. Practical considerations and long-term implications are discussed.

INTRODUCTION

Regenerating northern red oak (*Quercus rubra* L.) on high-quality growing sites is a continuing problem in the central Appalachian region. New stands that develop after harvests often contain fewer oak stems than the preceding stand, and the proportion of oak in the new stand usually does not meet management objectives. The basic problem is that harvests are often applied when there is a lack of competitive advanced oak seedlings present, thus the probability of successful oak regeneration is relatively low.

Competition among various species on a given site determines future species composition. After a significant disturbance to the forest canopy, numerous woody and herbaceous species compete for the light, water, and nutrients freed by the removal of overstory trees. The sources of new woody regeneration include: (1) new seedlings from seed stored in the forest floor, (2) sprouts from cut stumps, wounded roots, and broken shoots, and (3) advanced seedlings that developed before the disturbance. Species that compete with oaks on mesic sites often exhibit faster initial height growth than new oak seedlings and small advanced oak seedlings. If the oaks are not able to keep pace with competing species in the early stages of development, they usually die as the new overstory canopy closes above them (Trimble 1973). Oak stump sprouts are usually competitive with other species, but they contribute relatively few new stems on mesic sites (Loftis 1983a, Sander 1988). As a result, the primary source of successful oak reproduction on mesic sites comes from relatively large advanced oak seedlings. If large advanced oak seedlings are lacking before the harvest, then competing species usually dominate the composition of new stands (Beck and Hooper 1986).

Successful oak regeneration is related to the size and number of advanced seedlings present when harvests occur (Sander and others 1984, Loftis 1990a). For example, on northern red oak site index 80 (base age 50 years), the probability that an advanced oak seedling with a 0.1-inch basal diameter will become dominant or codominant 20 years after a harvest is essentially zero (Loftis 1990a). Even if thousands of such small seedlings are present before a harvest, very few will compete successfully after the harvest due to their small initial size. This probability increases to 1 percent for a 0.2-inch basal diameter, and 8 percent for a 0.75-inch basal diameter. As the seedling size and probability of success increase, fewer seedlings are needed to obtain adequate regeneration after a harvest. A pre-harvest inventory of advanced oak seedlings is recommended to determine if there will be a sufficient oak component in the new stand (Loftis 1990a). If projected oak regeneration is insufficient, silvicultural treatments may be needed to increase the growth and survival of advanced seedlings before the overstory is removed (Loftis 1990b).

In undisturbed mature oak stands, advanced oak seedlings usually exhibit both poor survival and slow growth. In one study, the survival of a cohort of northern red oak seedlings that germinated after a good acorn crop steadily declined from 60 percent after 1 year to only 10 percent after 10 years (Beck 1970). Similarly, the average total height of survivors was less than 1 foot after 1 year and generally did not increase over the next 10 years. In the southern Appalachians, shelterwood treatments that removed more than 50 percent of the stand basal area stimulated the growth of advanced oak seedlings, but also stimulated the development of competing species such as sweet birch (*Betula lenta* L.) and yellow-poplar (*Liriodendron tulipifera* L.), particularly where canopy gaps were created (Loftis

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Citation for proceedings: Spetich, Martin A., ed. 2004. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS–73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 311 p.

1983a). Alternative shelterwood treatments that removed only 30 percent of stand basal area from below, with no canopy gaps, increased survival and growth of advanced oak seedlings without stimulating the development of competing species (Loftis 1988). Similar treatments have not been tested in the central Appalachians.

In most central Appalachian hardwood stands, adequate advanced oak reproduction does not develop due to several factors: (1) predation of acorns by deer, insects, rodents, and birds, (2) browsing of seedlings and sprouts by deer, and (3) excessive competition from dense interfering vegetation in the midstory and understory strata. These conditions call for pre-harvest silvicultural treatments that reduce acorn predation, reduce deer browsing of established seedlings, and reduce interfering plants so that advanced oak seedlings can grow to sufficient sizes before overstory removal (Lorimer 1993, Marquis 1981, Marquis and others 1976, Tilghman 1989).

Preparing for successful regeneration requires proper management of stand structure in the overstory, midstory, and understory for many years before a harvest (Carvell and Tryon 1961, Sander and Clark 1971, Gottschalk 1983, Beck 1988, Leak and others 1987, Loftis 1990b, Hannah 1987, Marquis and others 1992). Forest managers in the central Appalachian region need a reliable and efficient treatment for developing adequate advanced oak reproduction before harvest operations. Preliminary results in the region indicate that advanced oak reproduction is more abundant in stands where the canopy is closed and the subcanopy density is reduced (Schuler and Miller 1995, Miller 1997). A key to preparing for successful reproduction is a clearer understanding of the relationship between subcanopy stand density and the survival, growth, and development of oak seedlings and their competitors. This study was installed to quantify the effect of microsite light availability and deer on the development of advanced oak reproduction in mesic Appalachian hardwood stands.

STUDY SITES

The study was installed in 80-year-old second-growth central Appalachian hardwood stands on the Monongahela National Forest in northern Randolph County, West Virginia. Overstory trees in the study area regenerated after landscape-scale logging operations that were conducted between 1915 and 1920. In 1998, northern red oak accounted for 59 percent of the basal area, while yellow-poplar, black cherry (*Prunus serotina* Ehrh.), American beech (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), and cucumbertree (*Magnolia acuminata* L.) also occupied significant proportions of the overstory. Annual precipitation in the study area averages 59 inches and is evenly distributed throughout the year. Soils are described as Dekalb channery loam (loamy-skeletal, mixed, mesic Typic Dystrochrept) (USDA Soil Conservation Service 1967). The study area is located on site index 80 for northern red oak (base age 50). Several layers of dense subcanopy vegetation were present before treatments were applied. This vegetation included striped maple (*Acer pensylvanicum* L.), American beech, red maple, and sugar maple. There were approximately 20 to 25 white-tailed deer (*Odocoileus virginianus*) per square mile in the study area. The stands contained an average of 5,000 2-year-old advanced northern red oak seedlings per acre when the study was installed.

METHODS

Microsite light on the forest floor was manipulated by treating selected subcanopy stems with an approved herbicide. A 50 percent solution of glyphosate as Accord 41.5 percent SL in a water carrier was used in all herbicide applications. The treatments included three microsite light levels plus a control defined as follows:

Control—no stems were treated

Low—all stems greater than 2.0 feet tall and less than or equal to 2.0 inches in diameter at breast height (d.b.h.) were cut near the ground, and the surfaces of cut stumps immediately were wetted with herbicide solution

Medium—in addition to stems included in the Low treatment, all stems greater than 2.0 inches and less than or equal to 7.0 inches in d.b.h. were injected

High—in addition to stems included in the Low and Medium treatments, all remaining stems that were in the intermediate or suppressed crown classes were injected.

The hack-and-squirt method was used to inject herbicide into target stems in the Medium and High treatments. A hatchet with a 1.75-inch wide blade was used to make the incisions, and incisions were spaced 1.5 inches apart on each target tree. A squirt bottle was used to dispense about 1.5 ml of herbicide into each incision.

In all three herbicide treatments, oak stems were neither cut nor injected in order to retain them as possible sources of advanced reproduction or sprouts.

Each treatment was applied to 12 square plots, resulting in a total of 48 plots, and each plot was 0.4-acre in size. A 6.5-feet tall woven wire deer fence was erected around 8 plots in each of the treatments, for a total of 32 fenced plots. A square 0.1-acre measurement plot was centered within each treatment plot, thus providing a buffer around each measurement plot, and all data were collected within the measurement plots. The fences were erected in July 1998, and the herbicide treatments were applied in late July 1999.

Species, d.b.h., and crown class were recorded for all stems greater than or equal to 1.0-inch d.b.h. before treatment within the 0.1-acre measurement plots. A post-treatment inventory was completed a year later to determine the percent reduction in basal area achieved in each plot. Photosynthetically active radiation (PAR) was measured within each plot in late July before treatment and each year after treatment to quantify changes in microsite light. PAR was measured with synchronized Accupar Ceptometers placed 1 meter above the ground at a fixed location in a nearby open field and at 9 designated points within each plot. Measurements in the open were compared to mean measurements within the plots at synchronized times to determine percent PAR associated with each plot (Parent and Messier 1996, Gendron and others 1998).

Approximately 1,500 individual oak seedlings were tagged for long-term study. Survival and total height of live seedlings were recorded in late summer before treatment and each year after treatment.

An additional 50 seedlings in each treatment were tagged within fenced plots to perform annual destructive tests to measure root and shoot response to each microsite light level. All seedlings tagged for the destructive tests germinated in the spring of 2000. Approximately 10 seedlings were extracted from each treatment in September of 2000, 2001, and 2002, thus providing growth response data for each of the first three growing seasons. Measurements taken on extracted seedlings included shoot length, root length, dry shoot weight, dry root weight, and basal diameter.

DATA ANALYSIS

Statistical analyses were completed to provide insight into four important relationships: (1) the effect of herbicide treatments on microsite light, (2) the effect of herbicide treatments and fencing on survival and height of tagged red oak seedlings, (3) the effect of herbicide treatments on third-year shoot and root characteristics of extracted seedlings, and (4) the effect of herbicide treatments on basal diameter of extracted seedlings over 3 growing seasons.

A one-factor repeated measures ANOVA was used to examine the effect of herbicide treatments on microsite light.The fixed effect model has the form:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij}$$

where

Y = percent PAR

μ = the overall mean

α = the effect of herbicide treatment

β = the effect of time

ε = the random error.

A two-factor repeated measures ANOVA was used to analyze the effect of the herbicide treatments (Factor 1) and fencing (Factor 2) on seedling survival and height. The fixed effect model has the form:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \theta_k + (\alpha\beta)_{ij} + (\alpha\theta)_{ik} + (\beta\theta)_{jk} + (\alpha\beta\theta_{ijk}) + \varepsilon_{ijk}$$

where

Y = survival proportion or height

μ = the overall mean

α = the effect of herbicide treatment

β = the effect of fencing

θ = the effect of time

ε = the random error.

The remaining terms represent the interaction of factors in the full model.

For third-year shoot and root response, data were analyzed using a one-factor ANOVA. The fixed effect model has the form:

$$Y_i = \mu + \alpha_i + \varepsilon_i$$

where

Y = shoot length, root length, shoot dry weight, or root dry weight

μ = the overall mean

α = the effect of herbicide treatment

ε =the random error.

For seedling basal diameter, means were compared for each of the first three growing seasons after treatment. Basal diameter data were collected from the same seedlings used to compare shoot and root development. It was not possible to conduct a repeated measures analysis of basal diameter since the subjects were destroyed each year. Instead, the data were analyzed as a two-factor ANOVA and the fixed effect model used has the form:

$$Y_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij}$$

where

Y = basal diameter

μ = the overall mean

α = the effect of herbicide treatment

β = the effect of time

ε = the random error.

The general linear models procedure in SAS was used for all statistical analyses (SAS Institute Inc. 1998). The Tukey-Kramer HSD mean separation test was used for all multiple comparisons. Treatment effects were considered to be statistically significant when $P < 0.05$. For each analysis, the residuals were tested for normality using the Shapiro-Wilk test and for homogeneity of variance using the Levene test.

RESULTS AND DISCUSSION

The average basal area on all study plots was 180 ft^2 per acre before treatment. The herbicide treatments reduced basal area by an average of 22, 10, and 2 percent for the High, Medium, and Low treatments, respectively (table 1). Loftis (1990a) recommended reducing basal area by 30 to 35 percent when applying similar pre-harvest shelterwood treatments in stands on site index 80 in the southern Appalachians. The basal area reduction in this study ranged from 1 to 35 percent, thus all treatment levels were equal to or less than those recommended for stands in the southern Appalachians (table 1).

Microsite Light

Before treatment, the low levels of microsite light beneath the dense subcanopy vegetation were not conducive to oak seedling survival and growth. The average PAR was 1.9 percent before treatment, and none of the plots was receiving the minimum amount of light needed for oak seedling survival. When seedlings do not receive enough light, as is

Table 1—Summary of shade control treatments and effects on basal area and microsite light availability

Treatment	Plots	Stems treated		Reduction in basal area		Residual stand PAR	
	no.	*no./ac*		*- - - - - - - - - - percent - - - - - - - - - -*			
		Mean	Range	Mean	Range	Mean	Range
Control	12	—	—	—	—	2	1 – 3
Low	12	209	70 – 450	2	1 – 13	4	3 – 8
Medium	12	360	180 – 600	10	3 – 25	8	4 – 16
High	12	410	270 – 640	22	16 – 35	12	8 – 25

PAR = photosynthetically active radiation.

common in stands with a dense subcanopy layer, photosynthesis produces less carbohydrates than are used in respiration, thus the seedlings eventually die (Hodges and Gardiner 1993). Hansen and others (1987) found that small northern red oak seedlings need PAR ≥ 30 µmol $m^{-2}s^{-1}$ to achieve the necessary positive carbon balance. All measures of PAR in untreated plots were below this threshold level. It was clear that low microsite light levels on the forest floor had prevented the development of any large advanced oak seedlings for many years.

One year later, the herbicide treatments resulted in a significant increase in microsite light reaching the forest floor (fig. 1). The High, Medium, and Low treatments increased microsite light to 12, 8, and 4 percent PAR, respectively. The repeated measures ANOVA indicated a significant effect of treatment (P <0.01), time (P <0.01), and the interaction of treatment and time (P <0.01). The differences among the treatments were still intact after the third growing season, although the subtle changes in microsite light that occurred each year appear to differ by treatment. By the end of the third year, slight reductions in microsite light were evident in the High and Medium treatments, probably due to crown expansion among overstory trees into small canopy gaps. Microsite light in the Low and Control treatments remained relatively stable for the first three growing seasons. As this study continues, more information about the longevity of treatment effects on microsite light will become available.

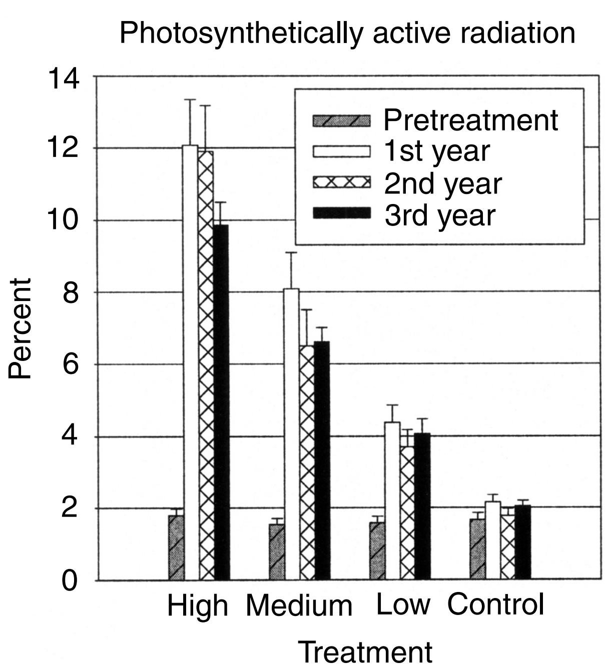

Figure 1—Mean percent of photosynthetically active radiation before and 3 years after shade control treatments, with one standard error bar shown above each mean.

Seedling Survival and Height

This comparison of survival and height included all 1,076 tagged seedlings that were still alive after 3 years. The repeated measures ANOVA with two factors indicated that time (P <0.01), microsite light (P = 0.02), and fencing (P <0.01) had a significant effect on the 3-year survival of oak seedlings. There was no evidence of interaction between microsite light and fencing (P = 0.78). At each level of microsite light, fencing increased survival by more than 20 percent (fig. 2). Note that survival was 22 percent in untreated plots, and the addition of a fence increased survival to 44 percent. Also, in fenced plots, each increase in microsite light further increased survival by 10 percent. For example, the Low treatment increased survival to 54 percent, the Medium treatment increased survival to 64 percent, and the High treatment resulted in maximum survival of 74 percent (fig, 2). Repeated measures ANOVA are robust to violations of multivariate normality and homogeneity of covariance matrices, thus applying the arcsine square root transformation to the observed survival proportions yielded similar results. A similar repeated measures ANOVA for seedling height indicated that time (P <0.01) and fencing (P <0.01) significantly affected seedling height, but height did not differ significantly by microsite light treatment (P = 0.46). Seedling height in fenced plots averaged 4.7 inches, while those in unfenced plots averaged 3.5 inches after 3 years.

Shoot and Root Response After 3 Years

This comparison is based on a relatively small sample, approximately 10 seedlings per treatment, extracted from fenced plots for laboratory analysis of shoot and root development. Shoot length, root length, shoot weight, and root

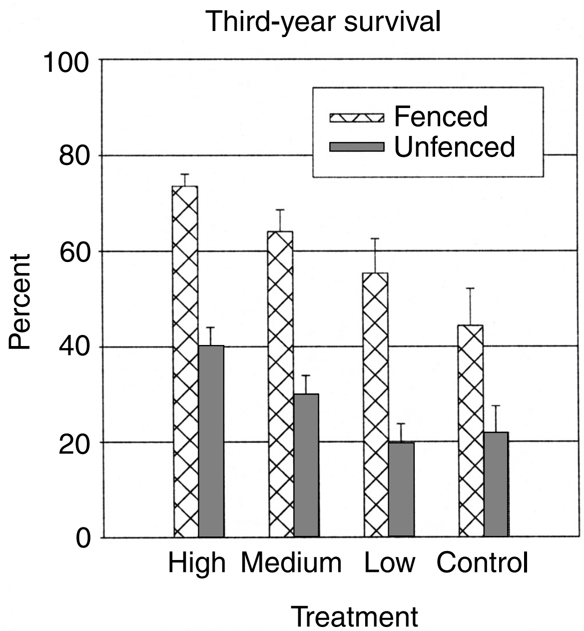

Figure 2—Mean survival of advanced northern red oak seedlings 3 years after shade control treatments and fencing, with one standard error bar shown above each mean.

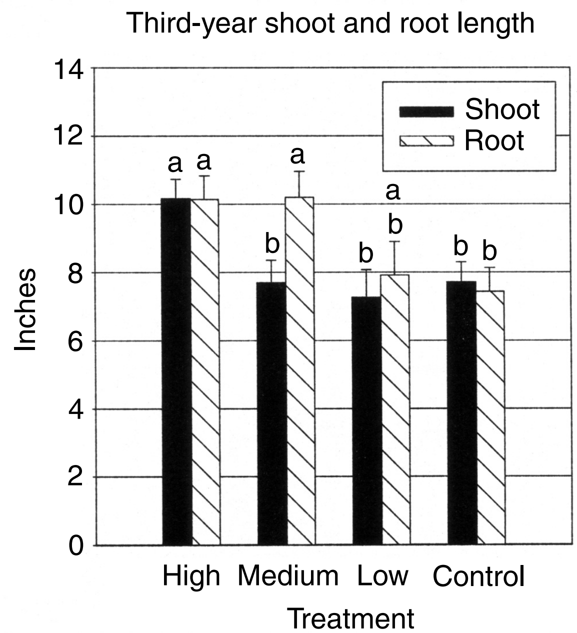

Figure 3—Mean shoot and root length of seedlings extracted 3 years after treatments, with one standard error bar shown above each mean. For each variable, means with the same letter are not significantly different based on Tukey-Kramer HSD multiple comparison test at the 0.05 level.

weight were significantly related to microsite light resulting from the herbicide treatments. In addition, the analysis of residuals exhibited no evidence to reject assumptions of normality or homogeneity of variance in any of the comparisons. Multiple comparisons of treatment means following each ANOVA showed that significant root responses occurred at lower microsite levels than that observed for shoot responses. Shoot length in the High treatment was significantly greater than in other treatments, while shoot length among the Medium, Low, and Control treatments was not significantly different. Shoot length averaged over 10 inches in the High treatment compared to less than 8 inches in the other treatments (fig. 3). By contrast, root length in both the High and Medium treatments was significantly greater than that observed in the Control treatment. Root length averaged over 10 inches in the High and Medium treatments compared to less than 8 inches in the Low and Control treatments (fig. 3). The High treatment increased shoot length and root length by 30 and 39 percent, respectively, compared to controls. Shoot weight in the High treatment was significantly greater than in other treatments, and shoot weight among the Medium, Low, and Control treatments was not significantly different. Average shoot weight in the High treatment was 145 percent greater than that observed in control plots (fig. 4). Root weight in the High and Medium treatments was significantly greater than in the Control treatment. Average root weight in the High treatment was 337 percent greater than that observed in the control plots (fig. 4).

Seedling Basal Diameter

Both time (P <0.01) and microsite light treatment (P <0.01) were significantly related to seedling basal diameter, although there was no evidence of interaction between time and treatment (P = 0.67). The residuals were consistent

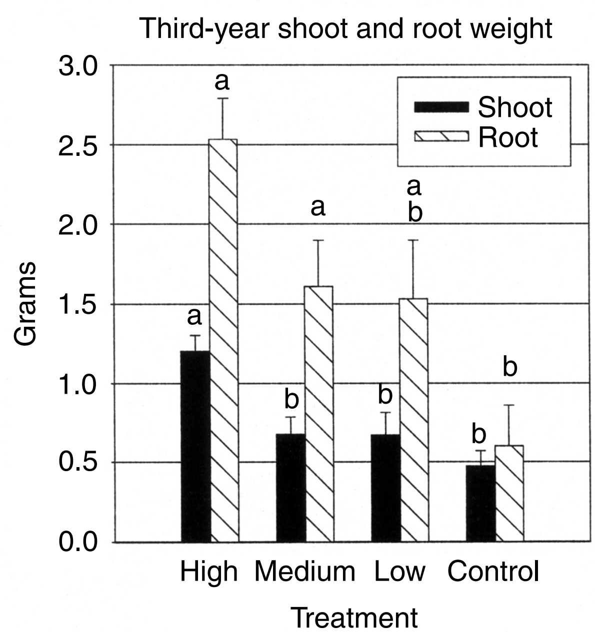

Figure 4—Mean shoot and root dry weight of seedlings extracted 3 years after treatments, with one standard error bar shown above each mean. For each variable, means with the same letter are not significantly different based on Tukey-Kramer HSD multiple comparison test at the 0.05 level.

with normality and homogeneity of variance assumptions. The High treatment led to an increase in basal diameter each of the first three growing seasons, with the greatest increase occurring in the third growing season (fig. 5). After three growing seasons, the Medium and Low treatments

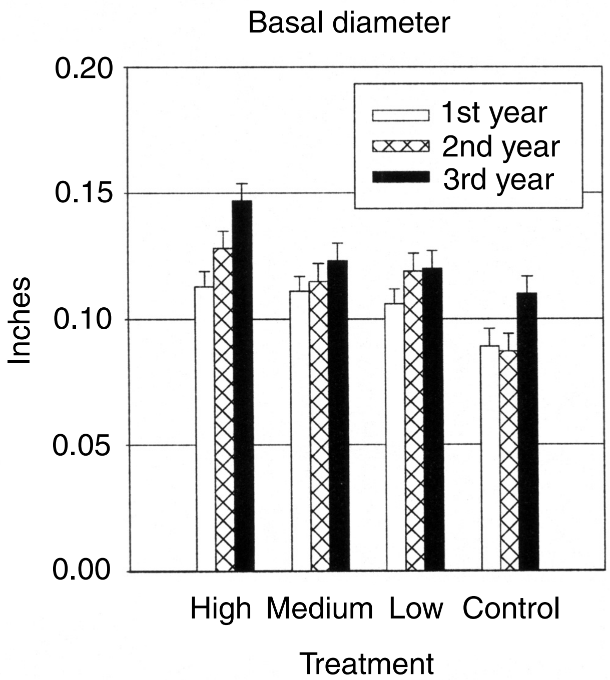

Figure 5—Mean basal diameter of seedlings extracted 1, 2, and 3 years after treatments, with one standard error bar shown above each mean.

did not produce significant increases in basal diameter compared to controls. Basal diameter in the High treatment averaged 0.146 inches, approximately 26 percent greater than that observed in the controls.

In general, the data indicated that enhanced root development occurred in the High and Medium treatments, with some evidence of faster stem development in the High treatment (figs. 3 and 4). Oak seedlings typically exhibit a conservative growth strategy in which surplus photosynthate resources are allocated to root development before notable shoot development occurs (Hodges and Gardiner 1993). Apparently the Medium treatment resulted in enough photosynthate to enhance root development within 3 years after treatment, but increases in shoot development may not be evident for a few more years.

Practical Implications

An example is presented in table 2 to illustrate the practical implications of the results presented here. The example is based on 20-year dominance probabilities for red oak seedlings presented by Loftis (1990b). This approach predicts the number of dominant/codominant (D/C) stems 20 years after overstory removal based on the number and size of seedlings present when the overstory is removed. The number of D/C stems projected to develop in the new stand

Table 2—Predicted number of dominant/codominant oak stems in the new stand based on the size and number of advanced oak seedlings present when harvest occurs

Time between treatment and harvest	Pre-harvest basal diameter	Dominance[a] probability	Survival rate	Pre-harvest oak seedlings	D/C stems 20-yr after harvest
year	*inches*	*- - - - - percent*	*- - - - -*	*- - - - - - number per acre*	*- - - - - -*
		Predicted outcome with high shade control and fencing			
0	0.089	0.0	100.0	5000	0
1	0.113	0.0	88.2	4410	0
2	0.128	0.6	83.5	4175	25
3	0.146	0.7	73.5	3675	26
4	0.167	0.8	68.0	3400	27
5	0.191	0.9	63.0	3150	28
6	0.218	1.2	58.0	2900	32
7	0.248	1.4	53.0	2650	37
8	0.281	1.7	48.0	2400	41
9	0.317	2.1	44.0	2200	46
10	0.356	2.5	40.0	2000	50
11	0.398	3.1	36.0	1800	56
12	0.443	3.7	32.0	1600	59
		Predicted outcome with no shade control and no fencing			
0	0.089	0.0	100.0	5000	0
1	0.089	0.0	69.6	3480	0
2	0.089	0.0	41.2	2060	0
3	0.116	0.0	21.8	1090	0
4	0.120	0.5	11.0	550	3
5	0.124	0.5	6.0	300	1
6	—	—	0.0	0	0

D/C = dominant/codominant.

[a] Loftis 1990a.

is found by multiplying the dominance probability for a given seedling size by the number of such seedlings present. Note that the dominance probability increases as seedling size increases because larger advanced seedlings can compete more successfully against other species as the new stand develops.

The example compares two silvicultural alternatives. One alternative includes fencing and shade control as applied in the High treatment. The other alternative includes no fencing and no shade control. Computations for the first three years are based on actual survival rates and average basal diameters observed in the High and Control treatments. Computations beyond the third year were estimated as a linear projection of basal diameter growth and a negative exponential projection of survival based on the observed 3-year trends in each of the two silvicultural alternatives.

With shade control and fencing—The treatments increased the projected number of successful D/C oaks within 3 years, and continued increases are expected for several years into the future. After 3 years, the survival rate was 73.5 percent and the average basal diameter was 0.146 inches (table 2). Applying the corresponding dominance probability indicates that 0.7 percent of the surviving 3675 seedlings, or 26 stems per acre, would become D/C in the new stand if the overstory were removed after the third year. Postponing overstory removal for several additional years would allow advanced seedlings to grow larger, thus introducing a greater dominance probability and a greater projected number of successful D/C oaks in the next stand. However, natural mortality will also reduce the number of seedlings each year. Projections of both decreasing survival and increasing growth indicate that the projected number of successful D/C oaks generally increases for at least 10 years after pre-harvest treatments were applied. If treatments are applied 8 to 10 years before removing the overstory, projections indicate that the new stand will contain 40 to 50 D/C oaks per acre when the new stand is 20 years old.

With no shade control and no fencing—In the absence of pre-harvest treatments, the projected number of successful D/C oaks remained near zero, and no improvement is expected in the future. After 3 years, the survival rate was only 21.8 percent, and the average basal diameter was 0.116 inches (table 2). These trends suggest that few seedlings will remain after 5 years, and those that survive have little chance of becoming dominant or codominant after the overstory is removed. Even if the overstory had been removed immediately, when there were 5,000 seedlings per acre, the dominance probabilities indicate that none would compete successfully after the harvest because of their small initial size.

For simplicity, this example was based on applying the appropriate dominance probability to a single size class, the mean basal diameter observed in each alternative. In real-world applications, a population of advanced oak seedlings often exhibits a distribution of size classes and each size class has a corresponding dominance probability. It is more accurate to estimate the projected number of successful D/C oaks by applying dominance probabilities to the number of advanced seedlings in each size class and summing the results (Loftis 1993).

SUMMARY

The example illustrates three important results of this study. First, pre-harvest shade control and fencing increased survival and stimulated faster shoot and root growth. Successful oak regeneration is related to the size and number of advance seedlings present before a harvest, thus the treatments tested in this study increased the probability of successful oak regeneration. In the absence of pre-harvest treatments, especially fencing, the probability of successful oak regeneration remained near zero. Second, significant shoot and root development occurred in the first 3 years, but more time is needed to allow seedlings to fully respond to the treatment. As the seedlings develop larger basal diameters, their corresponding dominance probability will also increase. Data from this study indicated that treatments should be applied at least 8 to 10 years before a planned harvest to assure that seedlings attain at least a 2 to 3 percent probability of becoming dominant or codominant once the overstory is removed. Third, annual measurements of PAR showed only slight decreases in microsite light each year, indicating that observed survival and growth rates will continue for several years. In the High treatment, it is expected that enhanced microsite light will be available for 10 to 12 years after treatment. This extended response period provides a practical window of opportunity for scheduling future activities such as commercial shelterwoods and/or removal of the overstory once competitive advanced oak seedlings develop.

Periodic control of undesirable vegetation can be a valuable long-term practice in forest management. Zedaker (1986) reasoned that applying herbicide treatments at opportune times in the life cycle of hardwood stands is an effective means of allocating site resources to desirable species. In this case, pre-harvest shade control treatments allow advanced northern oak seedlings to acquire the site resources necessary to become competitive with other species and enhance the probability of successful oak regeneration. Oaks are notorious for slow height growth in the early stages of development (Hodges and Gardiner 1993). Small seedlings need at least 8 to 10 years of desirable growing conditions before overstory removal to develop into competitive advanced seedlings. Pre-harvest herbicide treatments provide such conditions, in that interfering plants are eliminated quickly and they do not become reestablished for many years. Forest managers should consider maintaining relatively low levels of undesirable subcanopy vegetation in hardwood stands, even many years before a planned harvest, to keep interfering species in check and continually allocate resources to preferred species.

ACKNOWLEDGMENTS

The authors thank David L. Loftis, Thomas M. Schuler, John P. Brown, Fekedulegn Desta, and Stephen P. Satterfield for providing helpful review comments; and James H. Knibbs for assisting with the NEPA process on the Monongahela National Forest.

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