TEN-YEAR RESPONSE OF COMPETING VEGETATION AFTER OAK SHELTERWOOD TREATMENTS IN WEST VIRGINIA

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Abstract.—Successful oak regeneration depends on the relative status of advanced oak reproduction and associated competing woody vegetation present when harvests or other stand-replacing disturbances occur. This study was installed to quantify the effect of microsite light availability and deer browsing on the development of advanced northern red oak (*Quercus rubra*) seedlings and competing vegetation in 80-year-old, mixed mesophytic Appalachian hardwood stands dominated by northern red oak. Advanced oak seedlings and competing woody species were monitored in forty-eight 0.4-acre permanent plots for 10 years. Microsite light was manipulated with herbicide injection and cut-stump treatments to stems in the intermediate and suppressed crown classes. Twelve plots were randomly assigned to four microsite light levels: Control, Low, Medium, and High. Eight plots in each treatment were randomly assigned to receive protection from deer browsing by a woven wire fence. The major competing vegetation included black cherry (*Prunus serotina*), American beech (*Fagus grandifolia*), sweet birch (*Betula lenta*), red maple (*Acer rubrum*), striped maple (*A. pensylvanicum)*, and yellow-poplar (*Liriodendron tulipifera*). The development of competing vegetation in each treatment combination was compared 1, 3, 5, 7, and 10 years after treatment. Both microsite light level, as measured by photosynthetically active radiation (PAR), and fencing had a significant effect on the abundance and height class of competing vegetation. Competing vegetation increased at higher PAR levels and within fenced plots at a moderate pace for the first 5 years after treatment, followed by a surge in height growth in the second 5 years after treatment. After 10 years, sweet birch was the most aggressive competitor in the treated plots, with nearly 10,000 stems per acre ≥3 feet tall in fenced plots with the highest PAR levels. Guidelines for prescribing similar preparatory treatments and a discussion of management implications for long-term oak regeneration success are provided.

INTRODUCTION

Regenerating northern red oak (*Quercus rubra*) on high-quality growing sites is a continuing problem in the central Appalachian region. New stands that develop after overstory harvests often contain fewer oaks than the preceding stand. The basic problem is that overstory harvests are applied when an insufficient number of competitive advanced oak seedlings are present to compete with other hardwood species after the harvest. As a result, few oaks ascend into the canopy of the new stand to replace the parent trees that were removed. Instead, competing species occupy a greater proportion of the new stand and the proportion of oaks in the overstory falls short of management objectives.

Successful oak regeneration is related to the size and number of advanced seedlings present when harvests occur (Loftis 1990a, Sander et al. 1984). 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

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become dominant or codominant 20 years after a harvest is essentially zero (Loftis 1990a). Although numerous small seedlings may be present before a harvest, very few will compete successfully after the harvest because of their small initial size. This probability increases to 1 percent for a 0.2-inch basal diameter, and to 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 preharvest 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).

The species composition of a new stand is determined by competition among the species present in various forms at the time of the disturbance, following the "initial floristics composition" model suggested by Egler (1954). After the overstory harvest, numerous woody and herbaceous species compete for the available sunlight, water, and nutrients. The sources of 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 1983b, Sander 1988). As a result, successful oak reproduction on mesic sites comes primarily 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).

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. As mixed oak stands in the central Appalachians approach maturity, adequate advanced oak reproduction usually does not develop due to several factors: (1) acorns are consumed or damaged by deer, insects, rodents, and birds; (2) advanced oak seedlings and sprouts are browsed by deer; and (3) cohorts of new seedlings are suppressed and killed by excessive shade from dense interfering vegetation in the midstory and understory strata. These conditions call for preparatory 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 the parent trees are removed (Lorimer 1992, Marquis 1981, Marquis et al. 1976, Tilghman 1989).

Forest managers can increase the probability of successful oak regeneration by prescribing preparatory treatments that enhance the size and competitiveness of advanced oak seedlings several years before a planned overstory harvest (Beck 1988, Carvell and Tryon 1961, Gottschalk 1983, Hannah 1987, Leak et al. 1987, Loftis 1990b, Marquis et al. 1992, Sander and Clark 1971). Shelterwood treatments reduce stand density and increase the amount of sunlight and other site resources available to advanced oak seedlings. The added sunlight increases both survival and growth of advanced oak seedlings, thus increasing the abundance and competitiveness of advanced oaks in the next stand. 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*) and yellow-poplar (*Liriodendron tulipifera*), particularly where canopy gaps were created (Loftis 1983a). Alternative shelterwood treatments that removed only 30 percent of stand basal area from below the overstory canopy, with no canopy gaps, increased survival and growth of advanced oak seedlings without stimulating the development of competing species (Loftis 1988). Although similar treatments have not been tested in the central Appalachians, advanced oak reproduction was found to be more abundant in mature stands where the overstory canopy is closed and the subcanopy density is relatively sparse (Miller 1997, Schuler and Miller).

An important factor to consider in prescribing a shelterwood treatment is the amount of sunlight needed to enhance the survival and growth of advanced oak without overstimulating their competitors. At very low levels of microsite light, the oak seedlings will not respond. At very high levels of microsite light, the response of competing species may surpass that of the oaks. If prescribed fire or other remedial treatments are not available to control competing vegetation several years after a heavy shelterwood removal cut (Brose et al. 1999), a gentler approach may be necessary. Forest managers in the central Appalachian region need a reliable and efficient treatment for developing adequate advanced oak reproduction before harvest operations that does not require a followup prescribed fire. In many cases, prescribed fire may be inconsistent with landowner objectives or policy constraints. A relatively light-handed shelterwood treatment is needed to enhance the survival and growth of advanced oak seedlings while limiting the response of their competitors.

This study examined the effect of various light levels and deer fencing on the development of competing woody vegetation after noncommercial shelterwood treatments that reduced only the midstory density as described by Loftis (1990b). The overstory canopy was left intact, thereby increasing sunlight on the forest floor by relatively small increments.

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. Yellow-poplar, black cherry (*Prunus serotina*), American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), sugar maple (*A. saccharum),* and cucumbertree (*Magnolia acuminata*) 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) (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 (trees ≤10 inches diameter at breast height [d.b.h.]) were present in the suppressed and intermediate crown classes before treatments were applied. This vegetation included striped maple (*A. pensylvanicum*), 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.

METHODS

In 1998, a total of 48 square treatment plots were installed on the study site. Each plot was 0.4 acre in size and included a 0.1-acre measurement plot surrounded by a similarly treated buffer. Within each measurement plot, the initial stand inventory included species, d.b.h., and crown class of all trees ≥1 inch d.b.h.

Within each 0.1-acre measurement plot, competing woody vegetation was tallied in each of nine circular 0.001-acre subplots, whose center points were marked with a steel rod. The tally included the number of stems by species and the following five height classes: height <0.5 feet, 0.5 to 0.9 feet, 1 to 2.9 feet, 3 to 4.9 feet, and ≥5 feet. Competing woody vegetation was tallied before treatment and again 1, 3, 5, 7, and 10 years after treatment.

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. It was measured with synchronized Accupar® Ceptometers (Decagon Devices, Inc., Pullman, WA) 3 feet above the ground at a fixed location in a nearby open field and at 10 designated points within each measurement plot. Measurements in the open were compared to mean measurements within the plots at synchronized times to determine percent PAR associated with each plot (Gendron et al. 1998, Parent and Messier 1996).

Treatments

The treatments included three levels of the shelterwood method described by Loftis (1990b). This method removes trees from below the overstory canopy, starting with the smallest trees and including trees in progressively larger d.b.h. classes until a desired threshold for removal is reached. Trees were removed by using an approved herbicide applied to the cut stumps of trees <1 inch d.b.h. or injected by using a hack-and-squirt method for larger trees. The herbicide solution used in all treatments was 41 percent glyphosate active ingredient diluted to 50 percent of full strength in water (20.5 percent glyphosate active ingredient). Each injected tree received one incision 1.75 inches long and 1.5 ml of herbicide solution per inch of d.b.h. Twelve plots were randomly assigned to each of the three treatments described below for a total of 48 plots. Oaks were not removed in any treatment as they serve as a desired source of reproduction for the future. The herbicide treatments were applied in late July 1999.

Control

No vegetation was cut or treated with herbicide.

Low

All woody stems ≥2 feet tall and <1 inch d.b.h. were severed near the ground and their stumps were sprayed with herbicide. In addition, woody stems ≤2 inches d.b.h. were injected with herbicide.

Moderate

This treatment included all stems removed in the Low treatment. In addition, all stems ≤7 inches d.b.h. were injected with herbicide.

High

This treatment included all stems in both the Low and Moderate treatments plus all remaining stems in the suppressed and intermediate crown classes.

Fenced or Unfenced

Eight plots in each of the Control, Low, Medium, and High treatments were protected from deer by a 6.5-foot-tall woven wire fence, and four plots in each treatment were not protected. The fences were erected in August 1998 and maintained until the conclusion of the study in 2009.

Data Analysis

Statistical analyses were completed to provide insight into two important relationships: (1) the effect of the herbicide treatments on microsite light as measured by percent PAR and (2) the effect of the herbicide treatments and fencing on the development of competing woody vegetation as measured by the number of stems present in three height classes.

A one-factor repeated measures analysis of variance (ANOVA) was used to examine the effect of the 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 the herbicide treatment,
β = the effect of time, and
ε = the random error.

A two-factor repeated measures ANOVA was used to examine the effect of the herbicide treatments (factor 1) and fencing (factor 2) on the number of stems of competing woody vegetation in each height class. 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 = the number of stems in a given height class,
μ = the overall mean,
α = the effect of the herbicide treatment,
β = the effect of fencing,
θ = the effect of time, and
ε = the random error.

The remaining terms represent the interaction of factors in the full model. The general linear models procedure in SYSTAT 13 (Systat Software Inc., Chicago, IL) was used for all statistical analyses. The Tukey-Kramer HSD mean separation test was used for all multiple comparisons. Treatment effects were considered to be significant when $p < 0.05$. For each analysis, the residuals were tested for normality by using the Shapiro-Wilk test and for homogeneity of variance by using the Levene test.

Table 1.—Average number of stems removed in each treatment and the resulting effects on basal area and photosynthetically active radiation (PAR), Monongahela National Forest

Treatment	Plots	Stems removed		Reduction in basal area		Residual stand PAR
	no.	----- number/acre -----		ft^2/acre	percent	percent
		≥1.0 in. d.b.h.	<1.0 in. d.b.h.			
Control	11	–	–	–	–	2.3
Low	11	270	1,154	5	2.7	4.4
Medium	10	400	1,172	23	13.5	8.7
High	10	440	1,139	46	22.8	12.4

RESULTS

A severe wind storm in the 2003-04 dormant season caused several overstory trees to fall over in one section of the study area. As a result, 6 of the original 48 plots were dropped from the study because there was a significant increase in percent PAR in those plots the following growing season. The number of plots retained in the study is presented in Table 1.

The average basal area on all study plots including stems ≥1.0 inch d.b.h. was 185 square feet per acre before treatment. The herbicide treatments reduced stand basal area by 3, 14, and 23 percent in the Low, Medium, and High treatments, respectively (Table 1). In addition, each treatment removed approximately 1,150 stems per acre <1.0 inch d.b.h. The basal area reductions in this study were equal to or less than those recommended for stands of similar site index in the southern Appalachians (Loftis 1990b).

Microsite Light Measurements

Before treatment, the low levels of microsite light beneath the dense subcanopy vegetation were not conducive to oak seedling survival and growth. The average percent PAR was 1.9 percent before treatment, and none of the plots were receiving the minimum amount of light needed for oak seedling survival. When seedlings do not receive enough light, as is 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). Levels of PAR in all plots before treatment were below the threshold level needed for oak seedlings to achieve a positive carbon balance (Hanson et al. 1987). 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 after the herbicide treatments were applied, there was a significant increase in percent PAR in all treatments ($p < 0.01$). The Low, Medium, and High treatments increased microsite light to 4.4, 7.7, and 12.4 percent PAR, respectively (Fig. 1). 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 treated plots compared to control plots remained intact throughout the 10-year study period. In the fenced plots, there were significant differences in percent PAR among the treatments for all years except the fourth and sixth years. In those years, percent PAR in the High and Medium treatments appeared to be similar, whereas differences among the other treatments remained intact. In the unfenced plots, there were significant differences in percent PAR

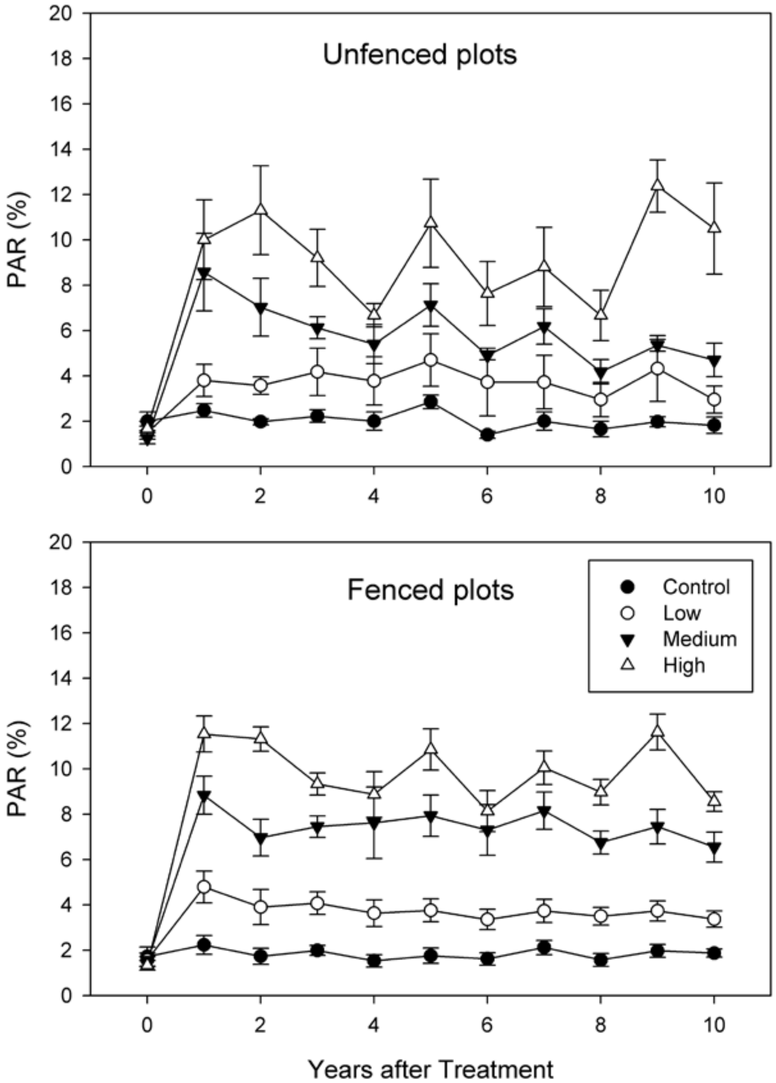

Figure 1.—Average percent photosynthetically active radiation (PAR) before and 10 years after herbicide treatments on Monongahela National Forest sites with one standard error shown above each point.

among the treatments in the 2nd, 3rd, 5th, 7th, and 10th years, again indicating that increases in percent PAR remained intact throughout the study period. There were no apparent differences in percent PAR between fenced and unfenced plots.

Changes in Competing Woody Vegetation

The repeated measures ANOVA indicated a significant effect of treatment ($p < 0.01$), fencing ($p < 0.01$), time ($p < 0.01$), and the interaction of treatment, fencing, and time ($p < 0.01$). As expected, there was a significant difference between the treated and control plots as early as the first year after treatments were applied. Later, the number of stems of competing woody vegetation in the Medium and High treatment plots was significantly greater than that observed in the Control and Low plots. In general, the number of stems of competing woody vegetation increased as both sunlight and time increased. In addition, this relationship was more pronounced in fenced plots, where the effect of deer species preference did not influence the composition of the competing woody vegetation. A brief comparison among the treatment and fencing combinations is presented in the following sections to chronicle the response of the competing woody vegetation over the 10-year study period.

Table 2.—Pretreatment average number of stems per acre <1 inch d.b.h. by species and height class, Monongahela National Forest

Species	Height class <6 in.	6 in. to 1 ft	1 ft to 3 ft	3 ft to 5 ft	≥5 ft	Total
	number/acre					
Black cherry	18,556	0	0	0	0	18,556
American beech	222	333	444	111	222	1,333
Sweet birch	333	0	0	0	0	333
Red maple	16,889	0	0	0	0	16,889
Red oak	2,889	667	0	0	0	3,556
Striped maple	1,222	556	556	111	333	2,778
Yellow-poplar	0	0	0	0	0	0
Other commercial	222	0	0	0	111	333
Noncommercial	889	0	111	0	0	1,000
Total	41,222	1,556	1,111	222	667	44,778

Pretreatment

Before treatments were applied, American beech and striped maple made up virtually all of the competing woody vegetation ≥1 foot tall in the understory (Table 2). Both species are classified as very shade tolerant in the central Appalachians (Trimble 1973). American beech stems were primarily root sprouts from poletimber and sawtimber parent trees distributed throughout the study area. The striped maple competition was a combination of seedling and sprout origin stems, and all of it was <2 inches d.b.h. It was apparent as the study was installed that the American beech and striped maple competition had developed over several decades as the stand approached maturity. These species had developed into low, dense interference, and it was assumed that numerous cohorts of oak seedlings had come and gone under the dense shade over many years.

Black cherry and red maple seedlings <1 foot tall were common and abundant throughout the study area before treatments were applied. Seed sources for both species were present in the overstory canopy. Although black cherry seedlings are somewhat shade tolerant when they are very small, there was not enough sunlight for them to grow and develop into larger size classes (Marquis et al. 1992). Moreover, black cherry is not a preferred deer browse when other foods are present. Red maple is considered shade tolerant, yet no seedlings ≥6 inches tall were found in the pretreatment inventory of competing species (Table 2). Although red maple was present in the sapling, poletimber, and sawtimber size-classes, low levels of sunlight and deer browsing may have prevented red maple from growing into larger advanced reproduction.

The pretreatment distribution of competing woody vegetation by height class and treatment is presented in Figure 2. Most stems were found in the 1- to 3-foot height class, followed by the ≥5-foot height class. The number of stems in the 3- to 5-foot height class was significantly lower than in the other two height classes before treatment ($p < 0.01$), and the number of stems within each height class was not significantly different by the assigned treatment.

First Year after Treatment

Almost all stems in the height classes ≥3 feet tall and many stems in the 1- to 3-foot height class were removed in the treated plots. By design, oaks were not removed in the treated plots to provide a future source of reproduction; thus, some plots had a few oak seedlings in the 3- to 5-foot height class 1 year after treatment. At this relatively early stage of development, the number of stems of competing woody vegetation was not significantly different among the treatments. The control plots remained unchanged, and the effect of increased sunlight and protection from deer browsing in the treated plots was not yet apparent (Fig. 3).

Third Year after Treatment

After three growing seasons, there was a significant increase in competing woody vegetation in the 3- to 5-foot height class within the fenced plots ($p < 0.01$) that received the Low and High treatments, and in the unfenced plots that received the Low treatment ($p < 0.01$) (Fig. 4). In the fenced plots, the increases included red maple seedlings responding to greater levels of sunlight and protection from deer browsing. In the unfenced plots, the increases included only striped maple seedlings responding to greater levels of sunlight. It was assumed that deer browsing continued to hold back the development of red maple seedlings for several years in the unfenced plots.

Fifth Year after Treatment

There was a surge in the development of competing woody vegetation in the 1- to 3-foot height class by the fifth year after treatment in all treated plots, particularly those in the fenced plots (Fig. 5). Within the fenced plots, the number of sweet birch and red maple stems in the Medium and High treatment plots was significantly greater than in all other treatments ($p < 0.01$), averaging >10,000 stems per acre in the High fenced plots. Within the unfenced plots, the surge in the number of stems in the 1- to 3-foot height class was primarily red maple. Deer prefer to browse sweet birch over red maple where both species are present (Tilghman 1989); thus, red maple was the primary beneficiary of the increase in sunlight in the unfenced plots. Note that few sweet birch seedlings were present before treatments were applied (Table 2). By the fifth year after treatment, thousands of birch seedlings had emerged from seed and grown into the 1- to 3-foot height class inside the fenced plots.

Seventh Year after Treatment

After the seventh year, the numbers of stems in the 1- to 3-foot and 3- to 5-foot height classes in the Medium fenced and High fenced treatments were significantly greater than those in the Control plots ($p < 0.01$). Sweet birch was the most abundant species in the 1- to 3-foot height class, although red maple and yellow-poplar were also important components. Sweet birch was the dominant species in the 3- to 5-foot height class. In the unfenced plots, the number of seedlings in the Medium and High treatments was significantly greater than in the Low treatment (Fig. 6), with sweet birch as the dominant species. It was also clear that the number of stems in the 3- to 5-foot and ≥5-foot height classes had not recovered to pretreatment conditions after 7 years, indicating that the herbicide treatments provided a somewhat sustained reduction in competition overtopping the desired advanced oak seedlings.

Tenth Year after Treatment

After the 10th year, there were more than 7,000 stems per acre in both the 3- to 5-foot and ≥5-foot height classes in the High fenced treatment (Fig. 7). There was also a slight decrease in the number of stems in the 1- to 3-foot height class, likely due to the effect of overtopping vegetation. The number of stems in the ≥5-foot height class in Medium fenced and High fenced plots exceeded that found in

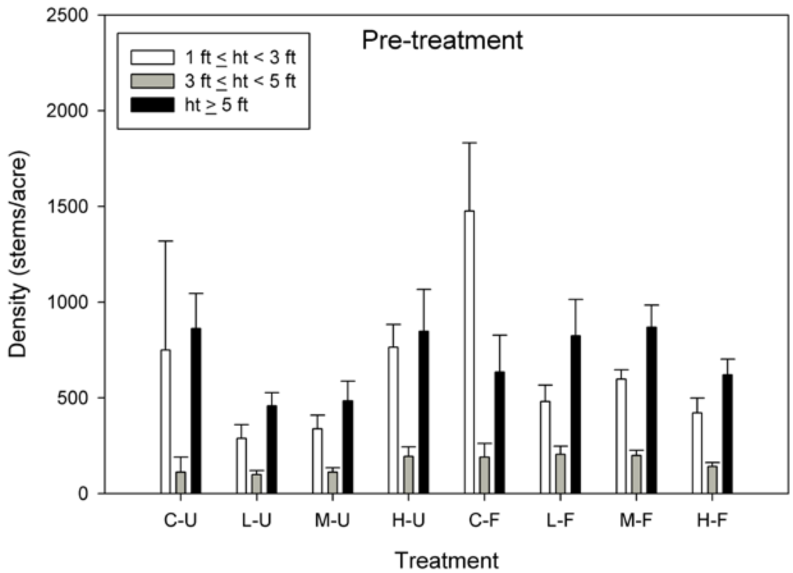

Figure 2.—Pretreatment distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

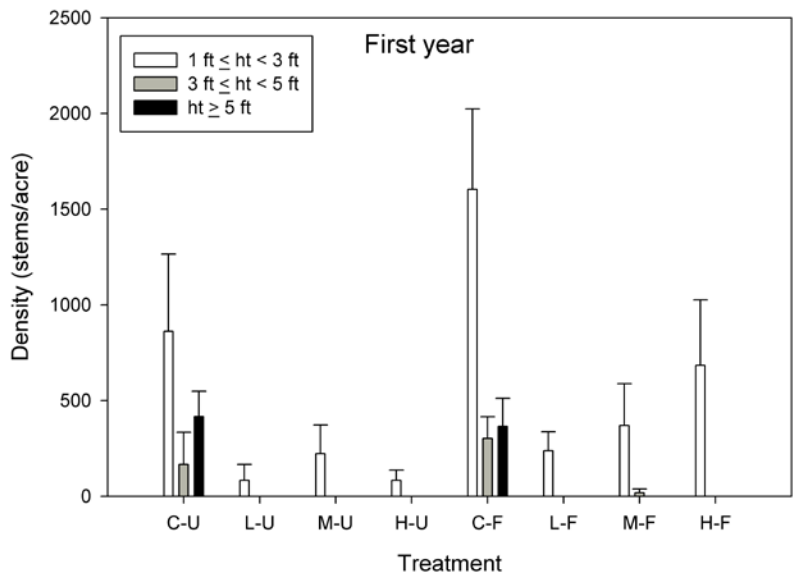

Figure 3.—First-year distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

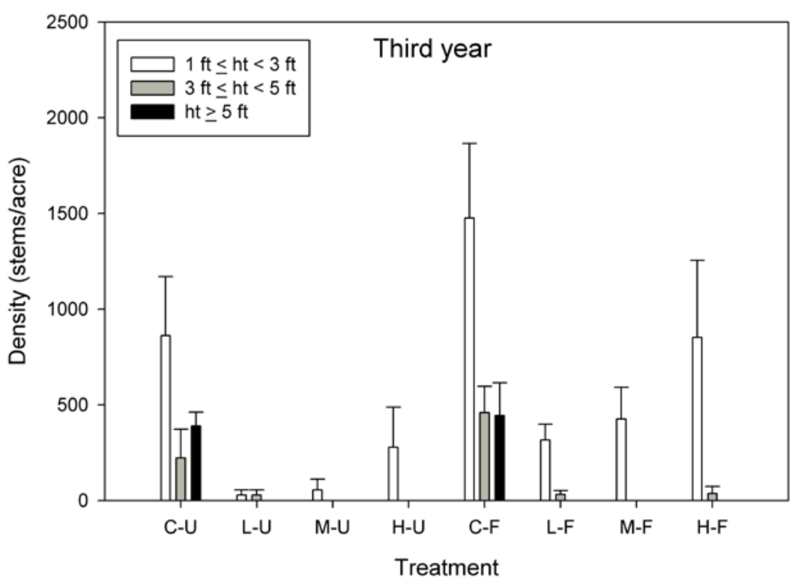

Figure 4.—Third-year distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

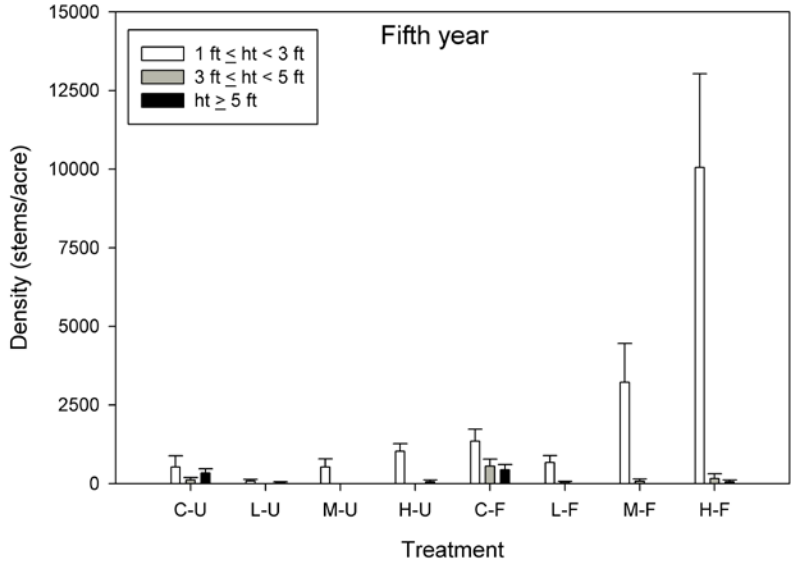

Figure 5.—Fifth-year distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

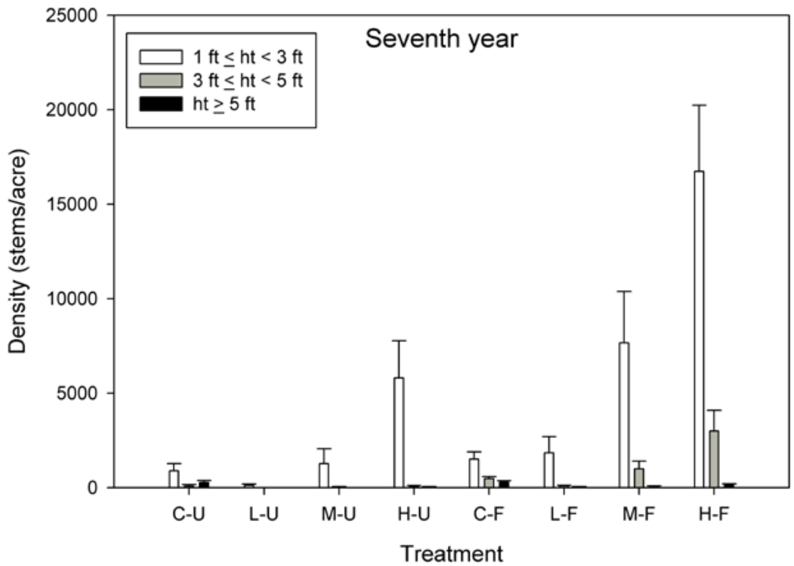

Figure 6.—Seventh-year distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

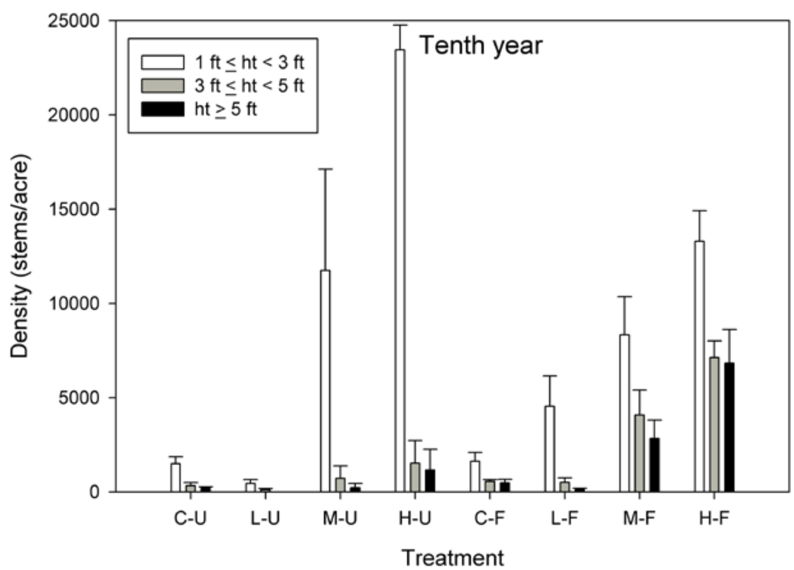

Figure 7.—Tenth-year distribution of competing woody vegetation by height class and treatment, where C = Control, L = Low, M = Medium, H = High, U = Unfenced, and F = Fenced, on Monongahela National Forest sites. One standard error is shown above each bar.

all other treatments ($p < 0.1$). In the fenced plots, the competing woody vegetation was dominated by sweet birch. Black cherry, red maple, and yellow-poplar were also important components. In the unfenced plots, sweet birch was the dominant species in all height classes in the Medium treatment. In the High unfenced treatment, sweet birch was also dominant, with some red maple and black cherry stems present in the 1- to 3-foot height class. By the 10^{th} year, the number of stems in the 3- to 5-foot and ≥5-foot height classes had surpassed pretreatment conditions in the Medium and High treatments in both fenced and unfenced plots ($p < 0.1$).

DISCUSSION

The response of advanced oak seedlings to the shelterwood treatments applied in this study will be analyzed in a separate report. A brief summary is provided here to add context to information presented on the development of competing woody vegetation. Based on more than 2,300 tagged seedlings, the initial average height of advanced oak seedlings was 0.4 foot (Miller et al. 2004). After 10 years, average height increased to 0.5 foot in the Control unfenced plots and 1.5 feet in the High fenced plots. Oak seedling survival ranged from 2 percent in the Control unfenced plots to 46 percent in the High fenced plots. Basal diameter in the Control unfenced and High fenced plots averaged 0.08 inches and 0.24 inches, respectively. In general, dominance probabilities applied to the oak seedlings present after 10 years indicated that both the Medium and High treatments were predicted to yield an acceptable number of codominant oaks in the next stand to meet management objectives.

This analysis focused on the development of competing woody vegetation in height classes ≥1 foot tall because regeneration in smaller height classes can be ephemeral, varying with factors such as periodic seed crops, weather conditions, and subtle changes in the availability of alternative deer food from year to year. The three height classes recognized in this study represent increasing degrees of competition that influence the long-term survival of a cohort of advanced oak seedlings. Although much of the competing woody vegetation reached heights that exceeded that of the advanced oak seedlings, previous research on dominance probabilities indicated that oak seedlings of sufficient size will reach codominant status after an overstory harvest (Loftis 1990a). This study showed that competing woody vegetation did not become abundant in the ≥5-foot height class until 7 to 10 years after treatment (Figs. 6 and 7). This result implies that advanced oak seedlings had at least 10 years to develop into larger size classes in preparation for competing in the next stand.

A key decision for land managers is whether to incur the expense of the deer fence in preparation for more successful oak regeneration in the next stand. In this study, fencing produced both positive and negative effects. Oak seedling survival and growth were greater within fenced plots, but the absence of browsing also allowed the rapid development of competing woody vegetation, particularly sweet birch in the Medium and High treatments (Figs. 7 and 8). Advanced reproduction of other desirable species such as black cherry, yellow-poplar, and red maple became established inside the fenced plots; red maple and sweet birch dominated the unfenced plots. Deer impact in the study area was deemed to be moderate based on the observed response of competing woody vegetation and the appearance of certain herb species inside the fenced plots in the latter years of the study (Brose et al. 2008). At higher levels of deer impact, protection from deer browsing may be necessary to promote a competitive cohort of oak seedlings. At lower levels of deer impact, the deer fence may not be needed. The decision to install a deer fence is a function of the desired proportion of oak in the future stand

and the ambient level of deer impact when the oak regeneration process is initiated. The results of this study indicated that a moderate level of oak regeneration success was possible in the unfenced plots that received the Medium and High treatments.

Although percent PAR remained elevated in the 10th year (Fig. 1), it is expected that the sunlight available to desired advanced oak seedlings will diminish rapidly in future years, particularly in the fenced plots that received the High treatment. Measurements were taken at 3 feet above the ground, and there was a surge in competing woody vegetation ≥3 feet tall in the latter years of the study. It is expected that a similar response—although delayed several more years—will occur in the Medium-fenced plots and in the unfenced plots that received the Medium and High treatments.

The time interval between applying the treatment and the surge in the development of competing woody vegetation has implications for scheduling the eventual removal of the overstory to initiate the regeneration of a new stand. The results of this study indicated that overstory removal before the seventh year would likely yield unsatisfactory oak regeneration success in the next stand. Within the High treatment plots, percent PAR averaged 12.4 percent (Table 1), which is adequate for survival and growth of oak seedlings. Still, previous research has shown that oak seedlings require at least 6 years to attain a root-shoot ratio equal to 1.0 under a range of sunlight conditions (Brose 2011). Considering the rapid development of competing woody vegetation in the fenced plots between the 7th and 10th years, it would be necessary to schedule the overstory harvest during that period to release the advanced oak seedlings. In the unfenced plots, the overstory harvest could be delayed a few more years. The precise timing of the overstory harvest in both situations would depend on the size and number of advanced oak seedlings present, dominance probabilities associated with those seedlings, and the desired proportion of oak in the next stand (Loftis 1990a).

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, preharvest herbicide treatments allowed 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. Preharvest herbicide treatments provide such conditions, in that interfering plants are eliminated quickly and 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.

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