SHELTERWOOD TREATMENTS FAIL TO ESTABLISH OAK REPRODUCTION ON MESIC FOREST SITES IN WEST VIRGINIA--10-YEAR RESULTS

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Abstract: The difficulty in regenerating oak on mesic forest sites is well known throughout the eastern and central United States, southern Ontario and Quebec, Canada. Research has shown that the establishment and development of oak seedlings prior to overstory removal, commonly referred to as advanced regeneration, is crucial for retaining oak species in the regenerated stand. The shelterwood reproduction method has been suggested as a means of developing the advance regeneration needed. In 1983, various shelterwood treatments were evaluated on the Fernow Experimental Forest in north-central West Virginia. Three overstory and two understory densities resulting in six treatment combinations were studied. Advanced red oak (*Quercus rubra*) regeneration was not abundant before treatment over most of the study area. Both natural regeneration and planted northern red oak and white ash (*Fraxinus americana*) seedlings were evaluated. Growth of planted seedlings was not significant after 5 years, though survival of red oak was improved significantly by both overstory and understory treatments. Natural regeneration of red oak was inadequate to recommend further overstory removal, and did not differ significantly by treatment combination. Overstory treatments stimulated abundant sweet birch (*Betula lenta*) regeneration, reducing the chances of establishing oak in the future. These results suggest that forest managers in the central Appalachian region may be unable to establish or develop advance regeneration of sufficient size and quantity when attempting to regenerate oaks on mesic sites with the shelterwood method as implemented here.

INTRODUCTION

The difficulty in regenerating northern red oak (*Quercus rubra*) on mesic sites is well known throughout the eastern and central United States and southern Ontario and Quebec, Canada (Smith 1993a; Wagner 1993). Early logging activities that cleared much of the old-growth deciduous forests throughout the range often were heavy but variable, and largely a function of local markets, terrain, and logging technology of the time. Yet, even with the variability of these harvests and a nearly total disregard for the regeneration potential of the stand, the oak component was largely retained in the newly established stands. More recently, retaining oak on these same sites following a regeneration cut has proven most difficult. A continuation of current management practices likely will result in a widespread reduction of oak on mesic sites throughout the region. Fewer oak trees on these sites could have far reaching economic and ecological consequences.

Research has shown that successful regeneration of oak on mesic sites, site index 70 at 50 years or greater, requires the establishment and development of oak seedlings of sufficient size and number, often referred to as advanced regeneration, prior to overstory removal (Carvell and Tryon 1961; Loftis 1990a; Merritt 1979). Variations of the shelterwood regeneration method have been suggested as a means of developing the advanced regeneration needed, and preliminary results where oak seedlings are present have been encouraging (Loftis 1990b; Schlesinger and others 1993).

Oak regeneration can be broken down into three components: establishment, development, and growth after overstory removal. Establishment refers to the germination of acorns and persistence of new seedlings. Development is the

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increase in height and basal diameter before overstory removal. Growth after overstory removal refers to the probability of advance regeneration maintaining a competitive position in the new stand.

The objective of this study was to determine the effect of several shelterwood treatments on the establishment and development of new oak seedlings before final overstory removal. Because oak seedlings were not abundant on most of the study areas, treatments were intended to "establish" new regeneration. The study design allowed us to test the hypothesis that stocking from overstory and understory components is the principal constraint to the establishment and development of oak seedlings. Manipulating overstory and understory density by the use of cutting and herbicides, enabled us to evaluate the effects of several levels of stocking on oak-seedling dynamics.

METHODS

This study was established on the Fernow Experimental Forest (39.03° N, 79.67° W), near Parsons, West Virginia, during the 1983-84 dormant season. Mean annual precipitation on the Fernow is about 58 inches and is distributed evenly throughout the year. Mean annual temperature is 48° F and the length of the frost-free season is approximately 145 days. The elevation of the study sites ranges from about 2,400 to 2,600 feet. The soils within the study sites are characterized by a Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) that developed on uplands in material weathered from sandstone and shale. The Calvin soils are well drained and strongly acid, moderately deep, and moderately permeable. The site index for the study area is about 70 for northern red oak. Overstory species in the study area included northern red oak, chestnut oak (*Q. prinus*), and white oak (*Q. alba*) in descending order of dominance as measured by basal area. Other overstory species included red maple (*Acer rubrum*), sugar maple (*A. saccharum*), sweet birch (*Betula lenta*), and yellow-poplar (*Liriodendron tulipifera*). The study area is part of the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest (McNab and Avers 1994).

The study design was implemented as a 2 x 3 factorial with three overstory treatments combined with two understory treatments for a total of six distinct shelterwood/herbicide treatments with two replications on 12 plots. An additional treatment with a 45-percent residual stocking was omitted from this analysis due to blowdown and salvage logging that occurred in those areas. All data were analyzed by analysis of variance using linear model procedures incorporating the factorial design and tested for significance at the 5-percent level unless otherwise noted. The Tukey-Kramer HSD was used for pairwise multiple comparisons; it is designed to maintain overall protection regardless of the number of comparisons.

The overstory treatments consisted of reducing residual stocking to 75 and 60 percent based on the upland-oak stocking guide (Gingrich 1967) plus an uncut control group (Fig. 1). Average stocking for all plots before treatment was 115 percent. All plots were marked for cutting by designating leave trees. Two guidelines were followed in selecting leave trees: 1) favor oaks for seed source purposes, and 2) achieve uniform spacing of residuals. Species and diameter at breast height (dbh) of each leave tree were tallied and stocking was calculated in the field. Trees less than 5.0 inches in dbh were ignored during marking even though they accounted for as much as 20 percent of stocking in some plots. Thus calculations of residual stocking level included only trees 5.0 inches and larger in dbh. In all plots except for the overstory control plots (no treatment), pole-size trees were either cut and removed, cut and left in place, or treated with herbicides.

The stocking guide for upland oak was selected for control of residual stocking to evaluate its suitability as a thinning guide in the central Appalachian region. The upland oak equations were based on more xeric site oaks such as white, black (*Q. velutina*), and scarlet (*Q. coccinea*), which tend to have smaller crowns relative to northern red oak. Thus, reductions to 75- and 60-percent residual stocking may be more severe than suggested by the residual stocking percentages. Residual stand structures are shown in Figure 2 for 75- and 60-percent residual stocking levels. Of the total number of stems after treatment, 71 and 83 percent were in oak species in the 75-percent and 60-percent residual stocking plots, respectively. Oak stems in both areas averaged 36 percent before treatment.

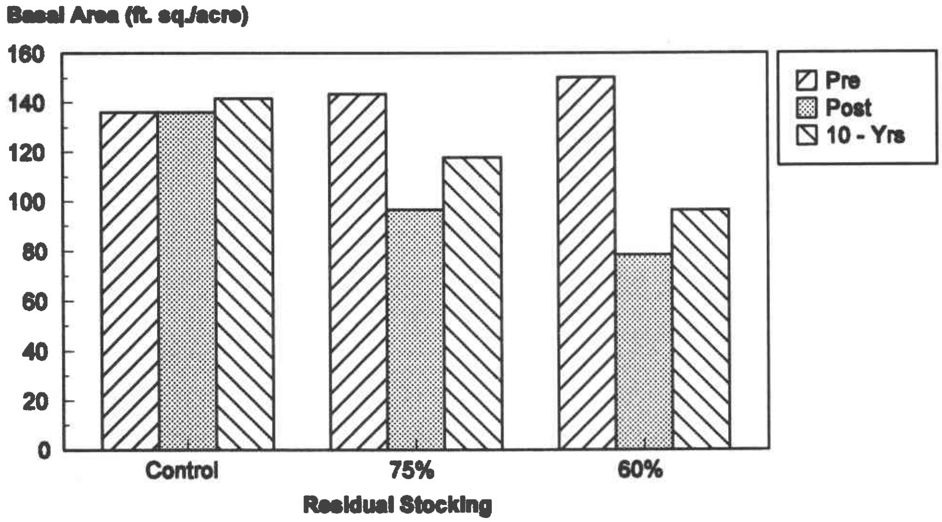

Figure 1. Average basal area per acre of trees 5.0 inches or larger in dbh before treatment (Pre), immediately after treatment (Post), and after 10 growing seasons (10-Yrs).

The understory treatments consisted of basal spraying a 2-percent solution of triclopyr (Garlon® 4) in oil on all stems less than 5.0 inches in dbh, plus an untreated control group. The herbicide treatment was designed to eliminate competition from existing shade-tolerant understory saplings, primarily striped maple and beech. This treatment was applied to two of the four replications for each overstory treatment.

Each treatment area was approximately 3 acres in size with a 0.5-acre growth plot in the center of the treatment area. Within each growth plot, all stems 5.0 inches and larger in dbh were permanently tagged (Lamson and Rosier 1984). Both small and large reproduction data were sampled. Data for small reproduction included the species, height class, and frequency of all woody vegetation observed within 20 0.001-acre sampling points distributed systematically in each plot. Sampling points were permanently marked. Height classes were defined as 0 to 6, 6 to 12, 12 to 36, 36 to 60, and more than 60 inches in total height but less than 0.99 inch in dbh. The results reported here focus on the establishment of seedlings larger than 1 foot tall due to an assumed ephemeral nature of smaller reproduction. Large reproduction was defined as woody species 1.0 to 4.9 inches in dbh observed within 10 0.01-acre sampling points and included all commercial and noncommercial woody species. The same plot centers were used to sample small and large reproduction with every other plot center used for large reproduction. Thus, data on small reproduction were obtained from 240 0.001-acre plots and large reproduction data were obtained from 120 0.01-acre plots.

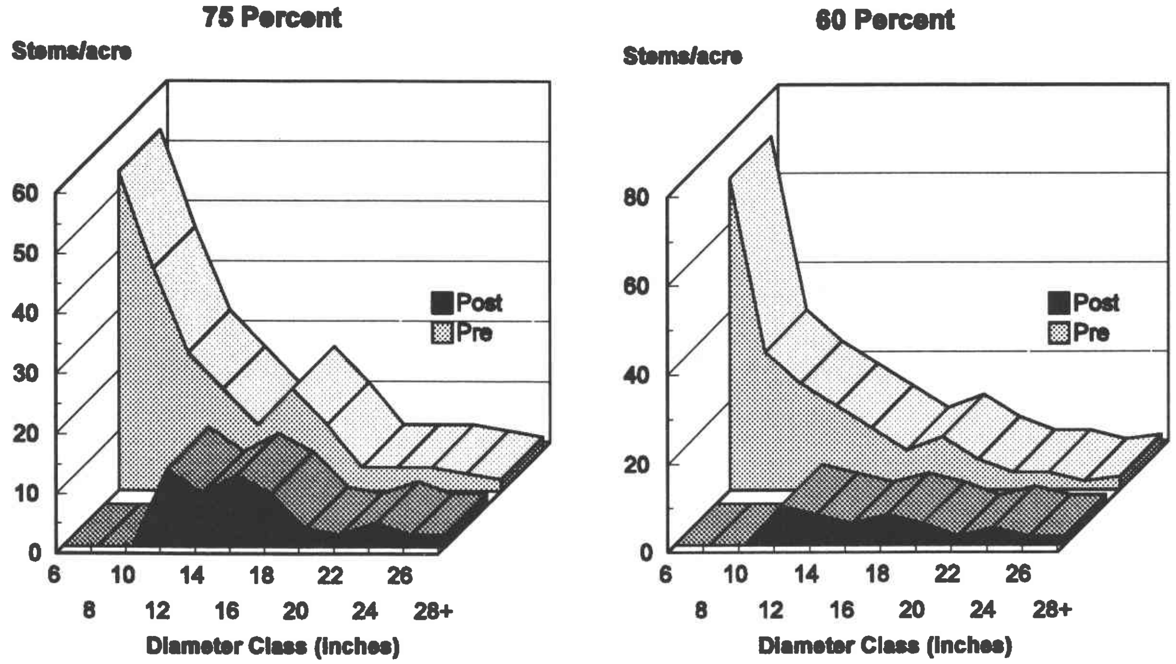

Figure 2. Characteristics of stand structure before treatment (Pre) and immediately after treatment (Post) for 75-percent and 60-percent residual stocking treatments.

All residual overstory trees were remeasured at the same interval as for the understory data. Reproduction plots and 0.5-acre growth plots were surveyed before and after logging prior to the first growing season and again 5, 7, and 10 years later. The most recent remeasurement was in the spring of 1994. During September 1991, near the completion of the eighth growing season, all of the treatment areas that received an initial understory herbicide treatment were mistblown with a 1-percent solution of glyphosate (Roundup®) herbicide. In 1991, understory vegetation ranged from 4 to 15 feet in height. Smaller red oak seedlings that germinated during the prior growing season were abundant when the understory was mistblown. The treatment was applied with backpack sprayers in such a way as to control undesirable vegetation without killing a significant portion of the red oak regeneration. Small-scale trials showed that this was achieved when glyphosate applied at a 45-degree upright angle and care was taken to avoid spraying the small desired vegetation.

In an attempt to ensure some seedling establishment, 50 red oak (2-0) and 50 white ash (*Fraxinus americana*) (1-0) seedlings were underplanted in each treatment area in the spring of 1984 following dormant-season logging. Seedlings were planted 10 feet apart so that the planting locations did not interfere with the reproduction plots. Mortality of planted seedlings was high and all seedlings were replanted before the start of the second growing season.

RESULTS

Natural Seedlings

After 10 growing seasons, the establishment of northern red oak seedlings more than 1 foot tall was low and did not differ for the overstory or understory treatment combination (Table 1). Results from a repeated measures uninvariate analysis of variance combining the results after 5, 7, and 10 growing seasons were similar and, again, demonstrated no significant differences for overstory ($P = 0.219$) or understory ($P = 0.426$) treatments. The repeated measures analysis of variance did suggest some differences in the number of large red oak seedlings within treatments over time ($P = 0.052$). Before treatment, the total number of small red oak seedlings less than 1 foot tall averaged 1,154 per acre and did not differ significantly by treatment area. Thus, some regeneration was present that had the potential to respond to the treatments even in the absence of new seedlings becoming established from acorns. After 5 growing seasons, many of these small oak seedlings were recruited into larger size classes. However, remeasurements after both 7 and 10 growing seasons showed that the total number of oak seedlings more than 1.0 foot tall declined at each measurement period. This decline coincided with increased competition from other species responding to the initial treatment (Fig. 3).

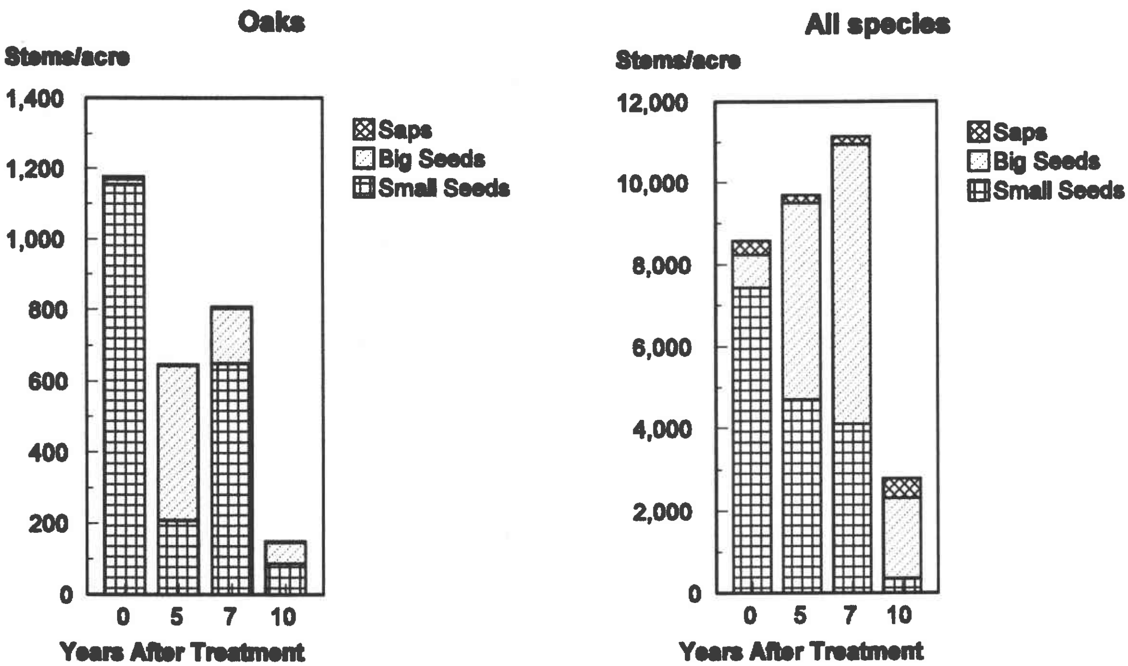

Figure 3. Characteristics of understory structure before the first growing season and 5, 7, and 10 years after treatment for oak and all species combined; "Saps" refers to trees 1.0 to 4.9 inches in dbh; "Big Seeds" includes stems taller than 1 foot but less than 1 inch in dbh; and "Small Seeds" includes stems less than 1 foot tall.

Table 1.--Statistical summary for northern red oak seedlings more than 1.0 foot tall and less than 1 inch in dbh 10 growing seasons after initial shelterwood/herbicide treatment combinations; sources of variation are denoted as OTREAT for overstory treatment and UTREAT for understory treatment

Source	Sum-of-squares	DF	Mean-Square	F-ratio	P
OTREAT	51666.667	2	25833.333	1.192	0.366
UTREAT	20833.333	1	20833.333	0.962	0.365
OTREAT*UTREAT	71666.667	2	35833.333	1.654	0.268

For species other than red oak, the abundance and species composition of small reproduction differed among treatments after 10 years. Perhaps most striking was the response of sweet birch. Analysis of variance indicated that the number of sweet birch seedlings, which are intermediate in shade tolerance (Trimble 1975), were significantly different with respect to overstory (P = 0.045) but not to understory treatment (P = 0.129). There were no significant interactions between overstory and understory treatments (P = 0.342). When overstory treatment alone was the grouping variable, the 60-percent stocking plots were significantly different according to the Tukey-Kramer HSD pairwise comparison (Table 2). Graphically, it appears that the threshold conditions necessary for birch regeneration were reached at 75-percent overstory stocking in combination with understory removal (Fig. 4). At higher levels of residual stocking, including the 75 percent overstory with no understory treatment, birch is a minor component of the understory.

Table 2.--Average number of seedlings per acre (1.0 foot tall to 0.99 inch in dbh) by overstory/understory treatment combination 10 years after treatment (standard error of treatment mean in parentheses)

		Species Group					
Overstory treatment (percent)	Understory treatment	Striped maple	Other tolerant	Birch	Other intermediate	Intolerant	Total
60	Yes	1,750 (200)	350 (300)	1,825 (775)a	1925 (975)	1,475 (425)a	7,325 (125)a
60	No	3,375 (25)	150 (160)	1,025 (225)a	175 (175)	75 (75)b	4,800 (200)a
75	Yes	2,450 (450)	175 (175)	1,075 (425)b	175 (175)	325 (175)b	4,200 (1400)b
75	No	2,750 (600)	100 (0)	50 (0)b	175 (175)	25 (25)b	3,100 (750)b
100	Yes	2,875 (1025)	175 (25)	100 (100)b	100 (100)	25 (25)b	3,275 (975)b
100	No	2,750 (100)	175 (75)	250 (250)b	50 (50)	0 (0)b	3,225 (125)b

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

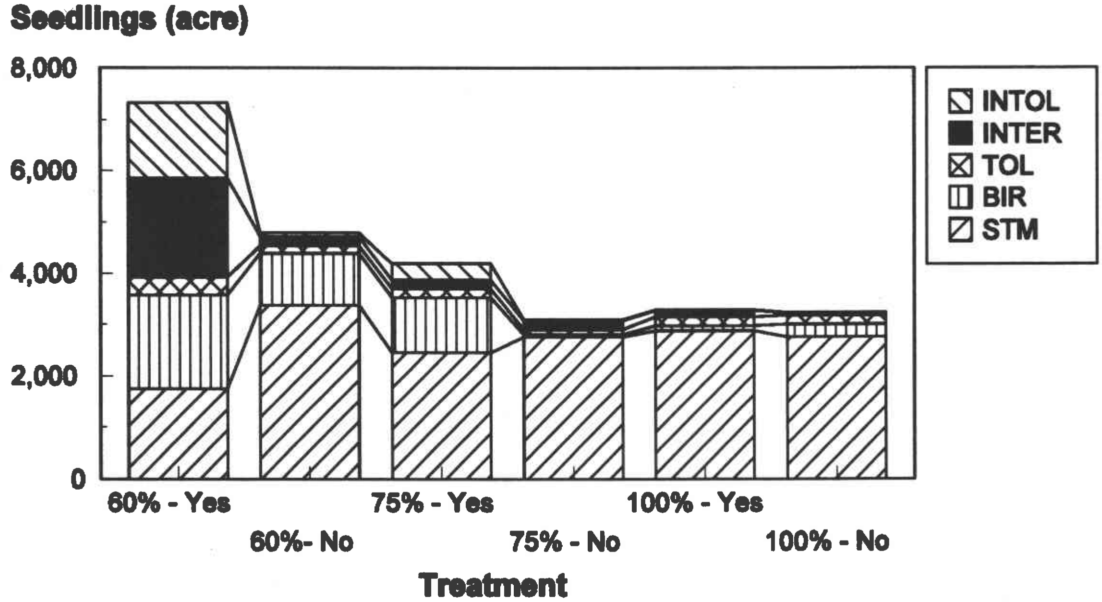

Figure 4. Number of stems per acre (1 foot tall to 0.99 inch in dbh) for each species group 10 years after treatment. "Yes" or "No" indicates understory treatment; species groups are striped maple (STM), sweet birch (BIR), shade-tolerant species excluding striped maple (TOL), intermediate shade-tolerant species excluding birch (INTER), and shade-intolerant species (INTOL).

Other intermediate shade-tolerant species demonstrated no significant differences among either overstory (P = 0.109) or understory treatments (P = 0.130). The small number of replications (n=2) and wide variability prevent a finding of significance, yet it appears that the combination of understory treatment and 60-percent residual overstory stocking promotes a variety of intermediate shade-tolerant species. This category included Fraser magnolia (*Magnolia fraseri*), cucumber (*Magnolia acuminata*), red oak, and white oak in descending order of abundance. The results also illustrate that these species are less shade tolerant than birch.

Intolerant species were significantly different among overstory (P=0.016) and understory (P=0.010) treatments. This was the only response variable that demonstrated significant differences for both types of treatments. However, only at the 60-percent residual stocking level in combination with understory removal were the intolerant species significantly more abundant. Species observed in this category included black cherry (*Prunus serotina*), yellow-poplar, sassafras (*Sassafras albidum*), and black locust (*Robinia pseudoacacia*).

Striped maple (*Acer pensylvanicum*) was isolated from other shade-tolerant species because of its relative abundance and influence on the regeneration of other species. Striped maple was abundant in all treatments, and not significantly related to overstory (P=0.880) or understory (P=0.212) treatments. The understory treatment designed to reduce competition, in part, from this noncommercial species was largely ineffective, possibly because seeds of striped maple ripen in September and October and are dispersed in October and November. The spring-applied triclopyr to existing stems did cause increased mortality of existing stems but did not negatively influence germination of striped maple from seed. The understory treatment may even have created conditions more suitable for survival of first year seedlings of striped maple whose seeds can remain viable for up to 2 years (Wilson and others 1979). Effective control of striped maple must include both existing stems and viable seed.

Other shade-tolerant species that were largely absent from the regeneration included red maple, sugar maple, American beech (*Fagus grandifolia*), eastern hophornbeam (*Ostrya virginiana*), black gum (*Nyssa sylvatica*), and eastern hemlock (*Tsuga canadensis*). This group did not exhibit differences for the overstory (P = 0.760) or understory treatment (P = 0.485).

The total number of all woody species combined was significantly different with respect to the overstory (P = 0.021) but not understory treatment (P = 0.099). However, from the results noted, the differences in this category are due primarily to differences in the number of intolerant and intermediate shade-tolerant species, including birch.

Analyzing the response to treatments was hindered by the confounding nature of the understory treatment applied at the end of the eighth growing season. This treatment was applied only on plots with an initial understory treatment, so we excluded all of these plots and repeated the analysis for overstory treatment only. Again, neither the response among overstory treatments (P=0.116) nor within treatments (P=0.256) was significant over time in a repeated measures design for large red oak seedlings.

In summary, the response to treatments can be characterized by an initial increase in red oak seedlings more than 1 foot tall at 5 years and a subsequent decline of the same due to an inability to maintain competitive positions with other species beyond 5 years. Greater reductions in basal area evoked greater response in recruitment of smaller oak seedlings into larger size classes, though the effect was ephemeral as the other faster growing species became established and surpassed oak seedling development in total height and competitive position. Beyond 7 years, recruitment of new individual stems greater than 1 foot tall has stopped and mortality within the new cohort began. Unless the small percentage of oak in the understory can become more dominate at a later stage of development, it would seem that the efforts to establish a new cohort of oak have been unsuccessful.

Planted Seedlings

Underplanted seedlings could serve as a source of regeneration if the seedlings respond to treatments. Survival of planted red oak seedlings was significantly different for both overstory (P = 0.004) and understory (P = 0.017) treatments. Survival was inversely related to percent stocking and further enhanced by understory removal. After 4 growing seasons, survival of red oak exceeded 90 percent for both the 60- and 75-percent stocking areas where the understory was removed (Table 3). Height growth of red oak was negligible and total height declined due to browsing by deer, and neither was significantly related to overstory (P = 0.065) or understory (P = 0.063) treatment.

Survival of white ash seedlings was not significantly related to overstory (P = 0.237) or understory (P = 0.438) treatment. Seedling total height was significantly related to overstory (P = 0.005) but not understory (P = 0.111) treatment. Both the 60- and 75-percent residual stocking treatments significantly increased height growth relative to no reduction in the overstory density. The practical significance of this may be minor as height growth averaged less than 1 foot in 5 years (Table 4). Further, survival of both species declined after 7 years, perhaps due to the reemergence of the treated understory. As a consequence, planted seedlings were not protected from the understory treatment that was applied at the end of eight growing seasons so survival rates after this period no longer can be considered valid.

Table 3.--Survival and height growth of planted northern red oak seedlings (2-0) 5 years after treatment (standard error of treatment means in parentheses)

Overstory treatment	Understory treatment	Number of seedlings	Initial height	5-year height	Survival
Percent			Feet	Feet	Percent
60	Yes	90	1.40	1.59 (.01)	90 (10)a
60	No	100	1.33	1.19 (.19)	65 (1)b
75	Yes	100	1.22	1.19 (.18)	91 (1)a
75	No	100	1.50	1.33 (.00)	50 (16)b
100	Yes	100	1.35	1.24 (.03)	32 (14)b
100	No	100	1.23	0.81 (.15)	20 (4)b

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

Table 4.--Survival and height growth of planted white ash seedlings (1-0) 5 years after treatment (standard error of treatment means in parentheses)

Overstory treatment	Understory herbicide	Number of seedlings	Initial height	5-Year height	Survival
Percent			Feet	Feet	Percent
60	Yes	110	0.67	1.39 (.17)a	94 (4)
60	No	100	0.70	1.25 (.21)a	78 (6)
75	Yes	100	0.66	1.67 (.10)a	91 (3)
75	No	100	0.73	1.25 (.15)a	83 (1)
100	Yes	100	0.66	0.77 (.12)b	64 (26)
100	No	99	0.67	0.70 (.05)b	55 (29)

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

DISCUSSION

The results of this study indicate that residual stocking levels alone may not affect the establishment of oak seedlings on mesic sites in the central Appalachian region. In fact, attempts to establish oak through partial overstory reductions could create conditions that favor the establishment of other species such as sweet birch that can regenerate well in partially shaded understories. Also, in this study, a range of conditions was created that favored the establishment of species from shade tolerant to shade intolerant. That red oak is classified as intermediate in shade tolerance demonstrates that while stocking and its influence on light reaching the forest floor may be a constraint to the establishment of red oak seedlings in some situations, there are other constraints that are even more limiting.

For the southern Appalachians, Loftis (1990b) cautioned that the goal of basal area reductions to regenerate oak on mesic sites should be to develop existing seedlings only. Our results clearly illustrate the basis for this warning. The greater the reduction in basal area, the greater the response by non-oak species to use that growing space. Others have suggested that competing non-oak species must be controlled with fire or herbicides to provide an opportunity for oak species to develop (Schlesinger and others 1993). However, understory treatments in this study were insufficient to retard the development of competing species.

Disturbance patterns in the presettlement forest that created conditions suitable for oak stands on mesic site may have differed greatly from existing patterns. For example, fires of varying intensity may have been much more common. Postfire mortality was highly correlated with tree size, fire severity, and species in Virginia 2 years after wildfire (Regelbrugge and Smith 1994). In the Virginia study, the relative basal area of chestnut oak increased following severe fires, indicating characteristics of species-specific fire resistance. In the Fernow study, birch quickly became established in the understory following reductions in basal area , apparently preventing further recruitment by other species. Yet birch is one of a group of species that are easily damaged by ground fires. Because of its thin bark, even light scorching at the base of a birch tree will lower its resistance to attacks by insects and diseases. And birch is not a prolific sprouter (Lamson 1990). These characteristics are consistent with theories that suggest that periodic ground fires created conditions that favored the development of oak in the understory while discouraging the development of birch and similar species (Crow 1988; Rouse 1986; Reich and others 1990).

Undisturbed stands were once thought to provide optimal conditions for the establishment of oak seedlings (Korstian 1927). In the southern Appalachians, establishment of new seedlings is seldom a management problem. Inventories usually encounter 1,000 or more small red oak seedlings per acre in undisturbed, mature stands, and abundant acorn crops, which usually occur about twice per decade, result in many more oak seedlings becoming established (Loftis 1988). Many of the mature oak stands of today appear undisturbed in the sense that they are fully stocked and no cutting has occurred for several decades. Fire has been controlled and records indicate an absence of fire in many of these stands for 50 to 60 years. Yet, deer population densities have risen to record levels and the impact of deer browsing can be profound (Marquis 1981, Michael 1988).

Results from underplanting seedlings after 5-years suggest little potential for this technique; most discouraging was the lack of height growth. Survival of natural red oak seedlings after overstory removal is a function of the abundance and the size of the advanced regeneration (Loftis 1990a; Sander and others 1976). Since densities of planted seedlings as high as several thousand per acre would be impractical, success with underplanting seem to hinge on the potential size of the individuals before overstory removal. Survival of underplanted red oak seedlings was significantly related to overstory treatment, but height growth was not. In the Ozarks, Johnson and others (1986) found that the survival and growth of underplanted red oak are correlated with initial size of the seedling. Our results may reflect inadequate size characteristics for underplanting red oak in the central Appalachian region.

In the buffer strips of the 60- and 75-percent stocking plots, 20 natural red oak seedlings were sheltered with 5-foot-tall tan Tubex® tree shelters in April 1990. Preliminary results showed that the use of these shelters in shelterwood environments is not encouraging as a method for stimulating the height growth of seedlings. Mortality rates were high and height growth negligible for both areas. Tree shelters reduce solar radiation within the shelter and may not be useful in shelterwood situations. Planting with tree shelters may have more potential when combined with other forms of management that expose the sheltered seedling to full sunlight (Smith 1993b).

The results presented here illustrate the difficulty that forest managers face when attempting to regenerate oak on mesic sites. Managers need to be aware that oak regeneration on mesic sites in the central Appalachians is not achieved through manipulation of stocking levels alone. A better understanding of the role of fire and other forms of disturbances that resulted in long-term dominance by oak seral communities is needed (Abrams 1992; Abrams and Nowacki 1992) before management guidelines can be recommended for natural oak establishment and development prior to overstory removal. Underplanting, as applied in this study, seems to have little potential when combined with reductions in stocking level. Growth of planted seedlings was not sufficient to improve survival probabilities given the limited number of seedlings that can be planted. Until reliable silvicultural guidelines can be developed for the regeneration of oak on mesic sites, prudence should be used when harvesting these stands. If desired ecological conditions include the presence of oak on these productive sites following harvesting activities, partial retention of the preharvest oak component may be the only reliable method to achieve this objective. An oak presence provides a continuous source of hard mast for wildlife, contributes to species diversity, and provides a suitable seed source for future regeneration. If an adequate oak component develops in the regenerated stand, the retained oak trees could be harvested as in the final cut of a shelterwood regeneration, incorporated into two-age management scenarios, or deferred for an additional rotation. If an oak component is not regenerated, future natural regeneration of oak still is possible and the benefits of oak on mesic sites can be retained in part from existing residual trees.

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