THE EFFECTS OF SHELTERWOOD HARVESTING ON OAK REGENERATION TWO YEARS AFTER HARVEST IN SOUTHERN OHIO

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Abstract.—This research examines the effects of two intensities of shelterwood harvesting (reduction of stocking levels to 50 and 70 percent of full stocking) on oak regeneration in southeastern Ohio 2 years after harvest. The main goal of this study is to develop an understanding of the relationship between residual stocking (harvesting intensity) and the successful release of oak regeneration. The silvicultural treatments were conducted during fall 2005 at Richland Furnace and Zaleski State Forests, which are located in the heavily forested, unglaciated Allegheny Plateau region of Ohio. Analysis of variance was used to compare stem densities of oaks and other woody vegetation among the two treatments and control. The results suggest that oak regeneration was successfully released following the implementation of shelterwood harvests at both residual percentages. Competing vegetation remained a problem, however; further management (such as prescribed fire) may be needed in these stands to increase the competitiveness of oak regeneration. We expect similar responses to shelterwood harvesting in other oak-hickory forests of the central hardwood region.

INTRODUCTION

Oak (*Quercus* spp.) has been the dominant component of the deciduous forests of the eastern United States for at least the past 5,000 years (Fralish 2004) and has been an important component for 10,000 years (Dolan and Parker 2004). During the past century, oak abundance has decreased while the abundance of red maple (*Acer rubrum*) and other hardwood species has increased (Griffith and others 1993, Van Lear 2004). This change in species composition is largely attributable to alterations of the local disturbance regimes and changes in land use. Periodic fires, once common across the forested landscape, favored the regeneration of oaks over red maple and other hardwoods, but the successful implementation of an aggressive national fire suppression policy has shifted forest stand composition toward fire-intolerant species (Abrams 1998). Forests in southern Ohio have not escaped the effects of this policy.

Most natural disturbances in forests reduce the amount of tree canopy and increase the available light for vegetative regeneration. Without canopy disturbance, shade-intolerant species cannot successfully regenerate. While oaks are intermediate in shade tolerance, prolonged shading can lead to seedling mortality (Crow 1988). When small canopy gap disturbances occur, oaks are often out-competed by more shade-tolerant species (Van Lear 2004). When major canopy disturbances occur, however, oaks are out-competed by faster-growing, more shade-intolerant species (Van Lear 2004). These patterns suggest that oaks require intermediate levels of disturbance. Studies by Sander (1979) and Loftis (1983) demonstrate that shelterwood

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cutting techniques, which produce intermediate levels of disturbance, often regenerate oaks on drier uplands. Therefore, the main objective of this study was to evaluate the effectiveness of two different intensities of shelterwood cutting on the establishment and growth of oak regeneration.

STUDY AREAS

Mixed oak hardwood forests located on upland sites in two of southeastern Ohio's state forests served as the locations for this study: (1) Richland Furnace State Forest, Jackson County (39°10'N, 82°36'W) ; and (2) Zaleski State Forest, Vinton County (39°15'N, 82°23'W). Both forests are in the unglaciated hill country of the Allegheny Plateau, where the topography is characterized by deeply dissected terrain (Kerr 1985). The topographic features create a gradient of moisture regimes and microclimates across the landscape (Kerr 1985). Both state forests contain large contiguous tracts of upland oak-dominated forests.

At Richland Furnace, 80 percent of the overstory basal area is composed of upland oak, primarily from the white oak group. Similarly, at Zaleski, 86 percent of the overstory basal area consists of oaks, with the majority of those species in the white oak group. White oak is the dominant tree species within both forests at 44 percent of the total trees per acre. Red maple is the second most common species in terms of trees per acre, 18 percent at Richland Furnace and 27 percent at Zaleski. The red oak group is the third most common tree species, representing 16 percent of the overstory stems at both study locations. Both upland oak stands selected for this study had stocking of approximately 100 percent, or stand density index values (SDI) of 215 (Williams 2003). The plots were located on medium sites (black oak site index 60-75 feet, base age 50 years) with slopes that ranged from 10-24 percent.

METHODS

Two different commercial harvest levels were implemented at each forest during fall 2005, reducing the stocking levels to 50 and 70 percent of full stocking (henceforth referred to as "50-percent treatment" and "70-percent treatment"), which represent the upper and lower bounds of previous management recommendations. These stocking levels are equivalent to SDI values of 110 and 150, respectively (Williams 2003).

The treatments were the first cut in a two-cut shelterwood method. A combined crown thinning and low thinning were implemented to reduce the stocking levels. Dominant and codominant oaks were the favored retention trees while all other species were selected for removal. Since this was a commercial harvesting operation, however, workers did little deliberate marking of noncommercial species. The harvesting in Richland Furnace was carried out via a cut-to-length logging system; Zaleski treatment areas were harvested using cable skidders.

At each state forest we set up three treatment areas: one 50-acre area reduced to 50-percent stocking, one 50-acre area reduced to 70-percent stocking, and one 25-acre control area. The primary reason for the larger size of the canopy reduction treatments compared to the control area is that this study is preliminary to a longer-term project. Eventually, 25 acres of the canopy reduction area at each of the two study locations will be treated with a growing-season prescribed fire and the other half of the areas will receive a dormant-season prescribed fire treatment.

VEGETATION PLOT ESTABLISHMENT AND MEASUREMENTS

Sixteen sample plots were established along transects within each canopy reduction area and eight sample plots were established in the control using a systematic sampling design. All transects were installed parallel to the slope wherever possible. During summer 2005, 40 vegetation plots were established before the silvicultural treatments were initiated to describe overstory and understory conditions. During summer 2007, two growing seasons after the silvicultural treatment, the plots were remeasured. Each sample plot was stratified into three subsample plots based on vegetation size category, and a tally of species was recorded: (1) sapling plot (0.05 acre)—all trees at least 4.5 feet tall and less than 4 inches diameter at breast height (d.b.h.), (2) large seedling plot (0.025 acre)—all woody stems 1 to 4.5 feet tall, and (3) small seedling plot (0.01 acre)—all woody stems less than 1 foot tall.

ANALYSIS

Although 38 species were identified within the vegetation plots, some similar species were grouped for the purpose of the analysis. Red maple (ACRU) was analyzed separately because of the large number of stems per acre, as well as because the competition between red maple and oak has been well documented (Abrams 1998, Fei and Steiner 2007, Nowacki and Abrams 2008). Three hickory species, shagbark, pignut, and mockernut, were placed into the same species group (CASP) because they belong to the same species guild (Sutherland and others 2000). Yellow-poplar was a group (LITU) by itself because few other shade-intolerant species were found in the understory. The non-commercial group (NONCOM) consisted of all woody shrub species. Blackgum was analyzed separately (NYSY) because evidence suggested that deer herbivory can significantly affect blackgum seedlings (Apsley and McCarthy 2004). The other group (OTHER) consisted of tree species with low stem densities. The white oak group (QUAL) consisted of both white oak and chestnut oak, which are both members of the white oak species guild and display similar seed dispersion and growth patterns (Sutherland and others 2000). The red oak group (QURU) consists of red oak, black oak, scarlet oak, and shingle oak. These species were a separate group because they belong to the same species guild and display similar life strategies (Sutherland and others 2000). Finally, sassafras (SAAL) was also analyzed separately due to its high density of regeneration in the preharvest plots.

The objective of the analysis was to determine whether the shelterwood treatments impacted the densities of woody species at each site. The regeneration data were analyzed using analysis of variance (ANOVA) to compare differences in stem densities among species groups within each size class among the three treatment types (50 percent, 70 percent, and control). Tukey's Studentized Range Test was used to indicate significant differences ($p < 0.05$) in mean stem densities among species and treatment groups for each size class. The two study areas were analyzed separately since the objective was not to directly compare the sites to one another. The results of the analysis were used to infer how the treatments impacted the growth of regeneration in terms of relative changes in stem density among species groups.

RESULTS

PREHARVEST DATA

The preharvest data, summarized in Table 1, were used to establish the initial conditions of the treatment plots at each site. The results of the analysis indicate that red maple was by far the most abundant species of regeneration at both sites for most size classes. The most notable exception was the dominance of sassafras large seedlings at Zaleski compared to all other species. Substantial densities (>100 stems/acre) of small and large seedlings were present for oaks and all other groups at both sites, apart from the few NYSY and LITU large seedlings observed at Zaleski. At both sites, however, densities of oak saplings were much lower than those of other species, especially red maple and black gum.

Analysis of the preharvest data also indicated that mean stem densities were similar across all treatments for most species groups (Table 1). The largest differences occurred for non-commercial and other species, which were of less interest in this study. The most notable difference was that the Zaleski control plots had significantly higher densities of oak seedlings and sassafras saplings than did the 50- and 70-percent treatments. Aside from a few minor differences, the results demonstrate that the initial plot conditions were relatively uniform across treatments; as such, any observed post-harvest differences can be attributed at least partially to effects of treatment.

Table 1.—Summary of preharvest small seedling, large seedling, and sapling stems per acre, by species for Richland Furnace and Zaleski State Forests. Please see text for species' abbreviations. Means followed by the same uppercase letter indicate no significant difference within species group between treatments. Means followed by the same lowercase letter indicate no significant difference between species groups within each treatment (for all tests, p =0.05).

Treatment	ACRU	CASP	LITU	NONCOM	NYSY	OTHER	QUAL	QURU	SAAL
Richland Small Seedling									
50	5,912 Ac	431 Aa	475 Aa	1,656 Ab	506 Aa	1,263 Aab	1,481 Aab	638 Aa	838 Ab
70	11,410 BC	233 Aa	460 Aa	727 Aa	113 Aa	213 Ba	3,513 Bb	1,300 Ba	1,100 Aa
Control	13,840 Be	213 Aa	700 Aab	2,020 Ab	100 Aa	175 Ba	2,850 ABb	738 Aa	1,100 Aa
Zaleski Small Seedling									
50	13,131 Ad	112 Aa	331 Aa	2,894 Ab	363 Aa	906 ABa	1,144 Aa	1,750 Aab	4,530 Ac
70	17,910 Ac	121 Aa	556 Aab	3,131 ABb	206 Ba	606 Aab	1,450 Aab	1,356 Aab	3,620 Ab
Control	8,700 Ac	50 Aa	25 Aa	2,487 Bb	13 Aa	1,975 Bab	2,863 Aab	1,113 Aab	2,900 Ab
Richland Large Seedling									
50	1,120 Ac	182 Aa	192 Aa	1,010 Bc	212 ABa	140 Aa	510 Aab	122 Aa	720 Abc
70	1,067 Ac	101 Aa	245 Aa	325 Aab	248 Ba	613 Ba	552 Abc	160 Aa	835 Ac
Control	1,244 Ab	125 Aa	190 Aa	350 Aa	85 Aa	180 Aa	370 Aa	155 Aa	1,104 Ab
Zaleski Large Seedling									
50	898 Aab	185 Ba	42 Ba	1,082 Ab	65 Aa	320 Aa	280 Aa	422 Aa	3,415 Bc
70	590 Aab	68 Aa	10 Aa	910 Ab	70 Aa	102 Ba	288 Aa	290 Aa	1,680 Ac
Control	720 Aab	170 Ba	0 Aa	1,140 Ab	40 Aa	320 Aa	1,130 Bb	670 Bab	1,795 Ac
Richland Sapling									
50	479 Ac	10 Aa	30 Aa	251 Ab	143 Aab	80 Aa	4 Aa	3 Aa	41 Aa
70	340 Ac	12 Aa	15 ABa	37 Ba	120 Ab	83 Ab	4 Aa	0 Aa	24 Aab
Control	53 Bb	8 Aa	0 Ba	8 Ba	55 Bb	55 Ab	3 Aa	3 Aa	18 Aa
Zaleski Sapling									
50	290 Ac	40 ABa	0 Aa	50 ABab	111 Ab	60 Aab	20 Aa	1 Ba	3 Ba
70	219 Ad	30 Aab	1 Aa	43 Aab	90 Ac	60 Abc	9 Aa	1 Ba	13 Ba
Control	175 Ac	65 Bab	0 Aa	103 Bb	23 Ba	215 Bc	13 Aa	23 Aa	70 Aab

TWO GROWING SEASONS AFTER HARVEST

Analysis of the post-harvest data illustrates the effects of the shelterwood treatments on stem densities for species groups compared to the control (Table 2). Comparison of post-harvest data with preharvest data shows a clear overall decrease in stem density across all small seedling groups for both treatments and the control. This change can be attributed to both seedling mortality and growth into the next class. In contrast with the preharvest data, there were significant differences in small seedling densities between treatment and control plots 2 years after harvest. At both sites, red maple, black gum, noncommercial, and other species were more abundant in the control plots than in the shelterwood treatments. The density of red oak small seedlings was higher for the 70-percent treatment at both sites, while white oaks were less dense. However, a higher density of white oaks in the control plots was also observed preharvest. Additionally, yellow-poplar small seedlings were more abundant in the 50-percent treatment compared to the control, while no changes were observed for blackgum or hickories.

Analysis of the large seedling data show somewhat similar trends. Red maple was the dominant species in all cases except for yellow-poplar in the 50-percent treatment at Richland. Significant differences in large red and white oak seedlings were not observed between treatments at either site, except for a greater number of red oaks in the Richland control. Higher densities of hickories and black gum were also observed in the shelterwood treatments.

The shelterwood treatments appeared to have an effect on sapling densities at both sites. Red maple remained the dominant species at both sites; densities were higher in the 50- and 70-percent treatments compared to the control. However, the density of oak saplings was also higher in the shelterwood treatments than in the control. White oaks were more abundant at both sites in the shelterwood treatments. The control plots at Richland Furnace and Zaleski had a relative absence of red oak saplings both preharvest and two growing seasons after harvest. No significant differences in sapling densities were observed for yellow-poplar, blackgum, or other species.

DISCUSSION

The results of this study demonstrate the effects of shelterwood cutting on woody regeneration in oak-hickory forests. The preharvest data record the overwhelming dominance of red maple regeneration compared to other species but also document the presence of red oak and white oak seedlings.

Overall densities of woody stems decreased 2 years post-harvest in both treatments and the control plots due to seedling mortality and growth into larger size classes. While the composition of the vegetation plots was relatively uniform within each study area during preharvest measurements, significant differences in stem density were observed 2 years after harvest. Red maple remained dominant in all size classes and for nearly all treatments. Additionally, red maple saplings were more abundant in the shelterwood treatments compared to the control. However, even though the treatments appeared to promote growth of red maple saplings, densities of oak saplings also increased significantly in the 50- and 70-percent treatment plots compared to the control.

These results suggest that the shelterwood cutting increased the survival of oak regeneration but did not eliminate competition from other species. Both the 50 and 70 percent of full stocking treatments allowed the oak seedlings to advance in size, which was a main objective of this study. However, the treatments were

Table 2.—Summary of 2 years post-harvest small seedling, large seedling, and sapling stems per acre, by species for Richland Furnace and Zaleski State Forests. Please see text for species' abbreviations. Means followed by the same uppercase letter indicate no significant difference within species group between treatments. Means followed by the same lowercase letter indicate no significant difference between species groups within each treatment (for all tests, p =0.05).

Treatment	ACRU	GASP	LITU	NONCOM	NYSY	OTHER	QUAL	QURU	SAAL
Richland Small Seedling									
50	1,213 Ab	194 Aa	4,931 Be	381 Aab	88 Aa	318 Aab	881 Aab	113 Aa	706 Aab
70	2,700 Ab	125 Aa	1,331 Ab	425 Aa	125 Aa	150 Aa	1,813 Ab	634 Ba	1,569 Bb
Control	12,412 Bc	538 Ba	700 Aa	2,087 Bab	38 Aa	300 Aa	3,413 Bb	938 Ba	1,175 ABa
Zaleski Small Seedling									
50	2,463 Ac	113 Aa	1,081 Aa	1,081 Aab	156 Aa	350 Aa	519 Ab	706 Aa	1,325 Aab
70	1,475 Ac	163 Aa	919 Ab	606 Aab	188 Aa	363 Aa	575 Aab	388 Ba	1,313 Ac
Control	4,125 Bc	100 Aa	25 Ba	1,875 Bb	100 Aa	613 Ba	3288 Ba	650 Aa	2,488 Bbc
Richland Large Seedling									
50	1,645 Ac	262 Aa	1,218 Abc	1,772 Ac	825 Aab	310 Aa	795 Aab	210 Aa	885 Aab
70	1,478 Ac	120 Ba	335 Bab	315 Bab	582 Ab	382 Aab	955 Ac	168 Aa	442 Bab
Control	1,325 Abc	100 Ba	165 Ba	685 Bb	30 Ba	225 Aab	530 Aab	300 Bab	1,000 Ab
Zaleski Large Seedling									
50	1,528 Ac	185 Aa	50 Aa	710 Ab	302 Aab	638 Ab	375 Ab	388 Aab	2,025 Ad
70	1,198 Bc	145 Aa	92 Aa	1,112 Ac	370 Aab	368 Bab	548 Ab	398 Aab	1,068 Bc
Control	310 Ca	115 Aa	0 Aa	885 Ab	50 Ba	110 Ca	655 Aa	440 Aab	930 Bb
Richland Sapling									
50	634 Bb	9 Aa	64 Aa	123 Ba	110 Aa	43 Aa	134 Ba	48 Ba	39 Aa
70	508 Bc	43 Ba	28 Aa	68 Abab	84 Aab	48 Aa	140 Bb	29 ABa	6 Aa
Control	88 Ab	3 Aa	15 Aa	8 Aa	60 Ab	83 Ab	0 Aa	0 Aa	65 Ab
Zaleski Sapling									
50	600 Cc	28 Ba	10 Aa	20 Aa	68 Ba	161 Ab	48 Ba	9 Aa	56 Aa
70	355 Bc	9 Aa	14 Aa	57 Aa	29 Aa	128 Ab	44 Ba	38 Aa	33 Aa
Control	143 Ab	40 Ba	0 Aa	260 Ba	45 Ac	60 Aa	3 Aa	33 Aa	45 Aa

also successful in generating substantial ingrowth of red maple and yellow-poplar. These species could retard the establishment and growth of oak regeneration in Zaleski and Richland State Forests. Consequently, other measures aimed at controlling competing vegetation may be necessary in conjunction with shelterwood cutting to secure the advance of oak regeneration. Oaks are highly fire-adapted species, and fire played an important role in the ecology of oak forests in the past, particularly in promoting the dominance of oak in the regeneration layers. Therefore, the use of prescribed fire could be justified to control the competitive vegetation after silvicultural harvesting (Artman and others 2001, Brose and VanLear 1998, Brose and others 1999).

Based on observations, the results from these silvicultural treatments should be typical for similar oak-hickory forests across the central hardwood region. However, it must be understood that before a particular silvicultural treatment is conducted, advance oak regeneration is vital to the overall success of the treatments. Managers should time their shelterwood cutting to coincide either with high levels of oak regeneration or with years of good acorn production. In some areas, shelterwood harvesting may not reduce competing vegetation enough to promote oak species, and the use of prescribed fire, in combination with a silvicultural prescription, should be considered.

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