COMPARING SINGLE-TREE SELECTION, GROUP SELECTION, AND CLEARCUTTING FOR REGENERATING OAKS AND PINES IN THE MISSOURI OZARKS

Randy G. Jensen and John M. Kabrick[1]

Abstract.—In the Missouri Ozarks, there is considerable concern about the effectiveness of the uneven-aged methods of single-tree selection and group selection for oak (*Quercus* L.) and shortleaf pine (*Pinus echinata* Mill.) regeneration. We compared the changes in reproduction density of oaks and pine following harvesting by single-tree selection, group selection, and clearcutting during a 10-year period in the Missouri Ozarks. Inventories in permanent plots were completed preharvest (1995) and post-harvest (1998, 2002, and 2006). Prior to harvesting, advance oak regeneration densities (trees < 4.5 inches diameter at breast height [d.b.h.]) ranged from 144 to 173 trees per acre. Ten years after harvesting, oak density in clearcut stands increased to 1,049 trees per acre and was about two times greater than in group openings (514 trees per acre) and more than four times greater than where single-tree selection (236 trees per acre) was used. Pine (trees < 4.5 inches d.b.h.) averaged nine trees per acre prior to harvesting and decreased to eight trees per acre in clearcut stands. In stands harvested with group selection or single-tree selection, pine remained at about two to three trees per acre on average, but most stands had none. These findings suggest that both group and single-tree selection do regenerate oaks but not as well as clearcutting. None of these methods as currently practiced are regenerating pine.

INTRODUCTION

In the Ozarks Highlands even-aged regeneration methods such as clearcutting and shelterwood harvesting have proven to regenerate oaks successfully (Johnson and others 2002). However, forest managers in this region are increasingly interested in applying uneven-aged methods such as single-tree and group selection to oak stands for aesthetic reasons and for the habitat created by maintaining complex and nearly-closed forest canopies at both stand and landscape scales.

At one time, oak-dominated stands were considered unsuitable for uneven-aged silviculture (Roach and Gingrich 1968, Sander and Clark 1971). There is now evidence, however, that uneven-aged methods can sustain and recruit oaks in some stands in the Ozark Highlands (Larsen and others 1999, Loewenstein and others 2000). Still, it is not clear how successfully uneven-aged methods will work when applied in mature stands that are currently even-aged (Loewenstein and Guldin 2004). Moreover, few studies have experimentally compared the effectiveness of single-tree or group selection for regenerating oaks to clearcutting, the even-aged method most commonly used in the Missouri Ozarks. Managers were also interested in increasing the abundance of shortleaf pine, which was historically much more prevalent than in recent times.

OBJECTIVES

In 1989, the Missouri Ozark Forest Ecosystem Project (MOFEP) was initiated by the Missouri Department of Conservation (MCD) to compare the effects of even-aged, uneven-aged, and no-harvest

[1]Resource Staff Scientist (RGJ), Missouri Department of Conservation, RR2 Box 198, Ellington, MO 63638; Research Forester (JMK), USDA Forest Service, Northern Research Station, 202 ABNR Bldg, Columbia, MO 65211. RGJ is corresponding author: to contact, call (573)663-7130 or email at randy.jensen@mdc.mo.gov.

Table 1.—Basal area and number of trees per acre in the dominant and co-dominant crown classes before and after 1996 harvests using clearcut (twenty 0.5-acre plots), uneven-age selection (122 plots) and nonharvested (380 plots) stands located on ridges, southwest and northeast slopes on MOFEP sites

1995	Basal area (ft per acre)	Standard deviation	Range	Trees per acre	Standard deviation	Range
clearcut	69	9	53-84	71	15	50-98
uneven-age	72	13	42-100	89	26	38-160
no harvest	70	13	27-125	82	28	30-200
1998						
clearcut	6	7	0-22	7	7	0-40
uneven-age	53	15	14-85	71	15	24-150
no harvest	71	13	32-122	81	13	28-192

management of the flora and fauna of Ozark forests (Brookshire and Shifley 1997, Shifley and Kabrick 2002). This project afforded an opportunity to experimentally compare even-aged and uneven-aged methods for regenerating oaks and shortleaf pine.

METHODS

Study Area

The MOFEP study sites consist of nine compartments or sites ranging in size from 776 to 1,275 acres and are located mostly within the Current River Oak Forest Breaks and the Current River oak-pine woodland hills landtype associations of the Ozark Highlands section (37°00´- 37°12´N and 91°01´- 91°31´W) (Kabrick and others 2000). The compartments are located in the Current River and Peck Ranch Conservation Areas in Carter, Reynolds and Shannon counties in Southeast Missouri and are administered by the MDC. Before the start of the study, the compartments had received no management for the prior 40 years. In the study region, the annual temperature is 56 ˚F and the mean annual precipitation is 45 inches, with the majority of rain falling in the spring and fall. The study compartments occur at 560 to 1,180 feet elevation with slopes of 0 to 60 percent and dominant soil parent materials being hillslope sediments, loess, and residuum (Meinert and others 1997, Kabrick and others 2000). Preharvest inventories showed that oaks were the dominant trees and four oak species, white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), and post oak (*Q. stellata* Wangenh.) comprise 71 percent of the basal area. Other oaks found at MOFEP include chinkapin oak (*Q. muehlenbergii* Engelm.), blackjack oak (*Q. marilandica* Muench.), Shumard oak (*Q. shumardii* Buckl.), and northern red oak (*Q. rubra* L.), but in combination they comprise only 1 percent of the basal area. Shortleaf pine (*Pinus echinata* Mill.) (8 percent), pignut hickory [*Carya glabra* (Mill.) Sweet] (4 percent), black hickory (*C. texana* Buckl.) (4 percent), mockernut hickory (*C. tomentosa* Poir. Nutt.) (4 percent), flowering dogwood (*Cornus florida* L.) (3 percent), and blackgum (*Nyssa sylvatica* Marsh.) (2 percent) also are in the study area. Before harvest, trees in the dominant and co-dominant crown classes contributed from 69 to 72 square feet per acre basal area and 71 to 89 trees per acre (Table 1). Prior to the study, compartments were subdivided into stands averaging 12 acres in size with similar forest vegetation composition and age, and environmental characteristics (Brookshire and others 1997). Further descriptions of the MOFEP study can be found in Shifley and Brookshire (2000) and Shifley and Kabrick (2002).

Study Design and Harvest

The study sites were divided into three complete statistical blocks of three compartments each, which were in close proximity to one another. Three compartments within each block were randomly assigned one of three treatments: (1) even-aged management with harvesting by clearcutting and intermediate thinning; (2) uneven-aged management with harvesting using a combination of single-tree selection and group selection; and (3) no-harvest management. The management system was applied at the compartment level and management was implemented at the stand level. The MDC Forest Land Management Guidelines (Missouri Dept. of Conserv. 1986) and the guidelines for managing uneven-age stands (Law and Lorimer 1989) provided general recommendations for harvesting in even-age and uneven-age compartments at MOFEP. The MOFEP study design is described in detail by Sheriff and He (1997), and Sheriff (2002).

The even-aged management treatment uses clearcutting with reserves as the principal means of stand regeneration (Brookshire and others 1997). With this method approximately 10 percent of the area in a forest compartment was initially designated as "old growth" and excluded from future harvesting. During each harvest entry, stands covering about 10 to 15 percent of the remaining area in the compartment are clearcut, with a few trees left unharvested as reserves. Rotation lengths for even-aged compartments are approximately 100 years with a 15-year entry. Reserve trees are retained to provide food and cover for wildlife or, in the case of shortleaf pine, to provide seed for natural regeneration. Reserve trees usually number fewer than 4 to 8 per acre and are generally >12 inches d.b.h. Intermediate thinnings are conducted periodically within stands to improve quality and increase growing space for residual trees. The stands chosen for intermediate thinning usually have some mature and over-mature large sawtimber but also an abundance of quality poles and small sawtimber.

Uneven-aged treatment follows the guidelines developed by Law and Lorimer (1989) and includes a combination of group selection and single-tree selection on a 15-year cutting cycle for timber harvest and forest regeneration. As with even-aged management, approximately 10 percent of the forest compartment was initially designated as "old growth". The remaining area was grouped into stands of 8 to 32 ha. Within stands, group selection methods were used to create openings to regenerate shade-intolerant species. These group openings were approximately one to two tree heights in diameter, depending on aspect. At MOFEP, the group openings are 70 feet diameter (0.1 acre) on southwest-facing slopes, 105 feet (0.2 acre) on ridge tops, and 140 feet (0.35 acre) on northeast-facing slopes. The locations of the group openings were determined by forest managers based on where they would improve the stand quality the most. The total land area of openings was about 5 percent of the total harvested area. Elsewhere in the stand, single-tree selection was used with harvest objectives set by the desired residual basal area, the largest tree diameter to be left in the stand, and the q-value or change across consecutive diameter classes. At MOFEP, the target residual basal area was equivalent to B-level stocking (about 58 percent) with adjustments made for logging damage (Roach and Gingrich 1968). The target largest diameter was about 18 inches d.b.h. in stands of low site quality to 26 inches d.b.h. in stands of high site quality. The target q-value averages 1.5 but can range from 1.3 to 1.7. For all harvesting, re-entries coincide with those of even-aged treatments.

The no-harvest management treatment was not harvested but wildfires are suppressed. Natural events such as tornadoes, fires, and insect and disease outbreaks are treated the same as on any other forest land owned by the MDC, except that salvage harvests will not occur. This treatment serves as an experimental "control" to compare with the two other management practices.

The first MOFEP harvest was conducted from May through October 1996, with slashing being completed in May 1997. On even-aged compartments, 11 percent of the area (320 acres) was clearcut and 15 percent (411 acres) was thinned. On uneven-aged compartments, 57 percent of the area (2,124 acres) was harvested with single-tree selection and group methods. The three even-aged compartments produced 2.5 million board feet and three uneven-aged compartments yielded 3.4 million board feet (Kabrick and others 2002).

Data Collection

Woody vegetation was initially sampled in 1991 and has been re-inventoried approximately every 3 to 4 years since. Woody vegetation was sampled during the dormant season in 648 permanent, 0.5-acre plots distributed approximately equally among the nine compartments (Jensen 2000). At least one plot was established in each stand on all compartments. Live and dead trees ≥4.5 inches d.b.h. were inventoried on the 0.5 acre circular plots; trees between 1.5 and 4.5 inches d.b.h. were inventoried in four, 0.05-acre circular subplots; trees at least 3.3 feet tall and less than 1.5 inches d.b.h. were inventoried in four, 0.01-acre circular subplots nested within the 0.05-acre subplots. Characteristics recorded for each tree were species, d.b.h., status (i.e., live, dead, den, cut, blown-down), and crown class (i.e., dominant, co-dominant, intermediate, suppressed). Plot and subplot data were combined to obtain plot averages by d.b.h. and all values were converted to an acre basis.

Data Analysis

To evaluate the effects of the regeneration methods, we compared the oak reproduction density in 1995, prior to the first harvest entry, to the post-harvest densities determined from three consecutive inventories completed in 1998, 2002, and 2006. The landscape-scale nature of the MOFEP project also allowed us to examine the response to harvesting on different slope positions and aspects (hereafter slope-aspect). MOFEP is a designed, replicated complete block experiment. We conducted a randomized complete block analysis of split plots in space (i.e., slope-aspect classes within compartments) and time (i.e., repeated measures) as outlined by Steel and others (1997). Our primary interest was to examine the interaction between regeneration method and time and the interactions among regeneration method, slope-aspect, and time since harvest. To do this, we used PROC MIXED (SAS version 9.1, SAS Institute, Cary, NC). The four regeneration methods compared were (1) clearcutting; (2) single-tree selection; (3) group selection; and (4) no-harvest. Random effects in our analysis were block (i.e., the three MOFEP statistical blocks), block x treatment, block within treatment and slope-aspect, block x year, and block x treatment x year. Our analysis looked at stands within the three most common slope-aspect classes on moderately-deep or deep soils that were clearcut (24 stands) in the three even-aged compartments, harvested with single-tree selection (98 stands) or group selection (17 stands) in the three uneven-aged compartments, and the nonharvested stands (518 stands) within all nine compartments. Data were averaged at the plot (and stand) and statistical block level prior to analysis. Because the uneven-aged treatment included group openings surrounded by areas harvested with single-tree selection, some plots included subplots with group openings and single-tree selection. In these cases, we allocated data from the subplots into their respective harvest method (i.e., group opening, or single-tree selection). This situation did not occur with the even-aged treatment as all plots in clearcuts or nonharvested plots were in separate stands. For significant interactions ($\alpha = 0.05$), differences between individual (least square) means were determined using Fisher's least significant difference. Data were analyzed in size classes of 3.3 feet height to 1.5 inches d.b.h. and from 1.5 inches d.b.h. to 4.5 inches d.b.h. Grouping these two size classes did not change the results from the analyses conducted separately on these two size classes.

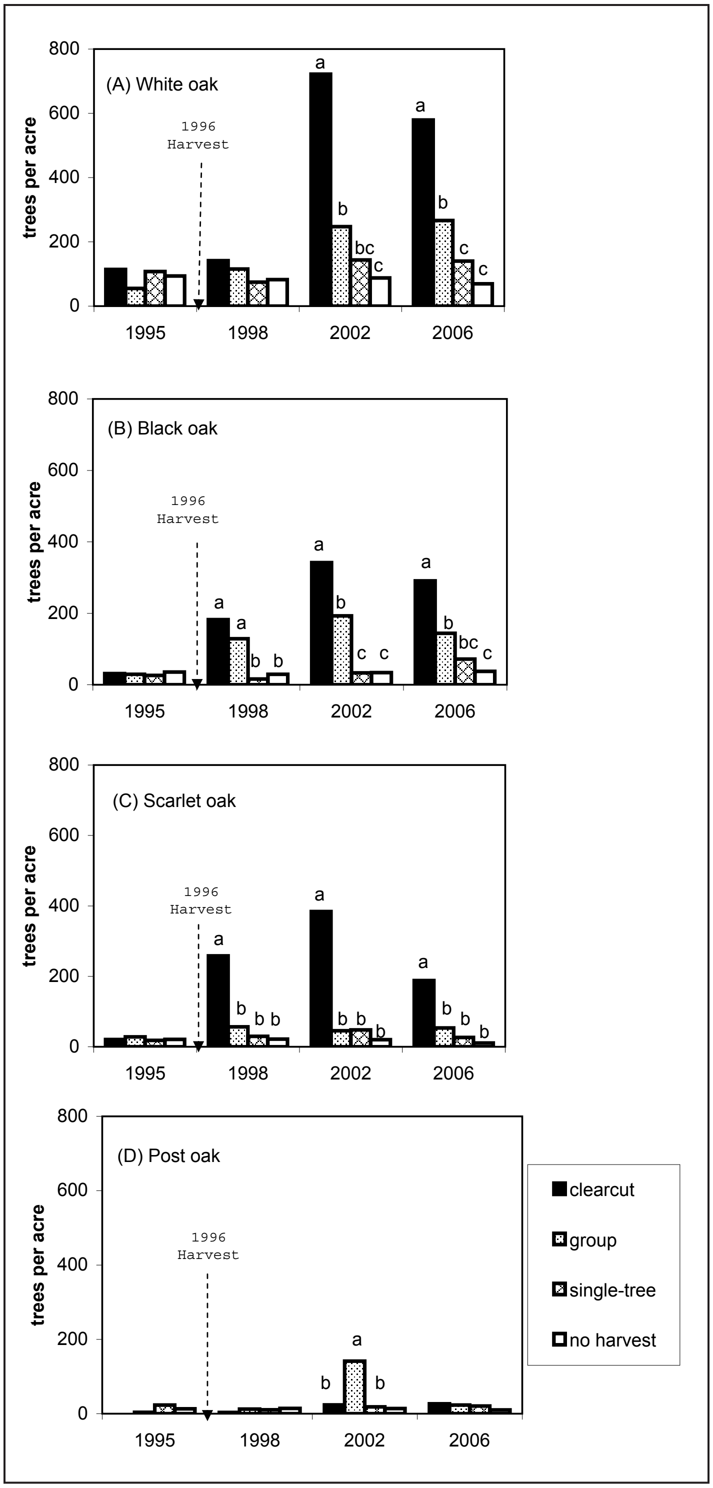

Figure 1.—White oak (A), black oak (B), scarlet oak (C), and post oak (D) regeneration densities of trees <4.5 in. d.b.h. before and after harvesting in 1996. Regeneration methods were clearcutting, group selection and single-tree selection compared to no-harvest management. For a given year, bars with the same letter(s) are not significantly different (α=0.05).

RESULTS

Response to Harvesting

Following the harvest, the basal area of dominant and co-dominant trees ranged from 6 square feet per acre on clearcuts to 71 square feet per acre on nonharvested stands, and seven trees per acre to 81 trees per acre, respectively (Table 1). The preharvest density of oaks (at least 3.3 feet tall and <4.5 inch d.b.h.) ranged from 144 to 173 trees per acre and oaks were 12 to 18 percent of all trees in that size class. White oaks (96 per acre) were the most abundant oak followed by black oak (28 per acre), scarlet oak (21 per acre) and post oak (9 per acre). Small shortleaf pine (<4.5 inch d.b.h.) were not abundant on any treatment preharvest and ranged from one to nine trees per acre.

The density of white oak remained similar to preharvest levels during the first two post-harvest years and then increased markedly in clearcuts (Fig. 1). By 2002, white oaks in clearcut stands exceeded 722 trees per acre compared to 247 per acre in group openings, 144 per acre in stands harvested with single-tree selection, and 88 per acre in nonharvested stands. By 2006, there was a 79 percent reduction in the number of white oaks in clearcuts (579 per acre) compared to 2002. These reductions were caused by competition-induced mortality as the trees entered the stem exclusion stage taking place in clearcut stands. In the same year, the density of white oaks in group openings had increased to 266 per acre, but remained constant in stands harvested with single-tree (140 trees per acre) and nonharvested stands (70 trees per acre).

Following harvesting, black oak densities increased gradually in clearcuts and in group openings and by 2002, there were more black oaks in clearcuts (342 per acre) than in group openings (193 per acre). By 2006, the black oak density in clearcuts remained higher than in group openings, but the density in stands harvested with single-tree selection had increased and was no longer different from group openings. Scarlet oak densities increased only in clearcuts (384 in 2002) and the densities in the other harvest treatments did not differ from each other during the study period. For both black oaks and scarlet oaks, we also observed the same competition-induced mortality in clearcut stands by 2006 as with white oaks.

Post oaks had low densities prior to harvesting and the densities remained low throughout the study period. In 2002, there were more post oak in group openings (142 per acre) than in clearcuts (24 per acre), stands harvested with single-tree selection (18 per acre), and nonharvested stands (14 per acre). This short-lived increase in post oaks resulted from the ingrowth of stems originally < 3.3 tall in two single group openings. These stems subsequently succumbed to competition-induced mortality prior to the final inventory in 2006.

Shortleaf pine was not analyzed statistically because it was absent from most of the plots, but we observed a few notable trends. For example, the density of shortleaf pine decreased after harvesting. By 2006 (year 10) shortleaf pine density decreased from nine to eight trees per acre in clearcut stands and from nine to seven trees per acre in no-harvest stands, but remained the same in stands harvested with single-tree selection (four trees per acre). The only exception to this trend occurred in group openings, where the shortleaf pine density increased from one tree per acre in 1995 to 34 trees per acre in 2006. However, this increase was due to the ingrowth of shortleaf seedlings in only one of the 20 plots sampled.

Response to Harvest by Slope-Aspect

White oak densities (<4.5 inch d.b.h.) were similar on ridges, northeast slopes, and southwest slopes in 1995 and 1998 (Fig. 2). By 2002, however, there were higher densities of white oaks on southwest slopes (1,022 per acre) than on ridges (780 per acre) and northeast slopes (364 per acres). In 2006, there was a slight reduction in white oaks on all slope positions, but densities were still higher on southwest slopes (938 per acre) than on ridges (450 per acre) and northeast slopes (349 per acre).

In group openings, preharvest densities of white oak ranged from 40 trees per acre on northeast slopes to 70 per acre on ridges. Densities in 1998 were similar. In 2002, there were more white oaks in openings on ridgetops (390 per acre) than on northeast (227 per acre) or southwest slopes (125 per acre). By 2006, white oak densities had increased on northeast slopes to 383 trees per acre, which was not significantly different from ridges (273 per acre), but was significantly higher than on southwest slopes (142 per acre). White oak densities were not different among slope-aspects in single-tree selection and nonharvested stands and they stayed at near preharvest densities through the years.

In 1995, black oak densities in clearcuts ranged from 8 trees per acre on ridges to 68 per acre on southwest slopes. In 1998, ridges had more black oak (418 per acre) than did southwest slopes (70 per acre) and northeast slopes (59 per acre; Fig. 3). In 2002, black oak densities increased to 468 trees per acre on ridges, but southwest slopes (340 per acre) now had similar densities. By 2006, southwest slopes (383 per acre) and ridges (308 per acre) had similar densities of black oak and more than northeast slopes (181 per acre).

Black oak densities in group openings followed a different trend than in clearcuts (Fig. 3). In 2002, there were more black oak on southwest slopes (298 per acre) and northeast slopes (228 per acre) than on ridges (53 per acre). This trend was similar in 2006 (256, 157, and 20 trees per acre, respectively). There were no differences between black oak densities among years for the three slope-aspect classes in single-tree selection and nonharvested stands.

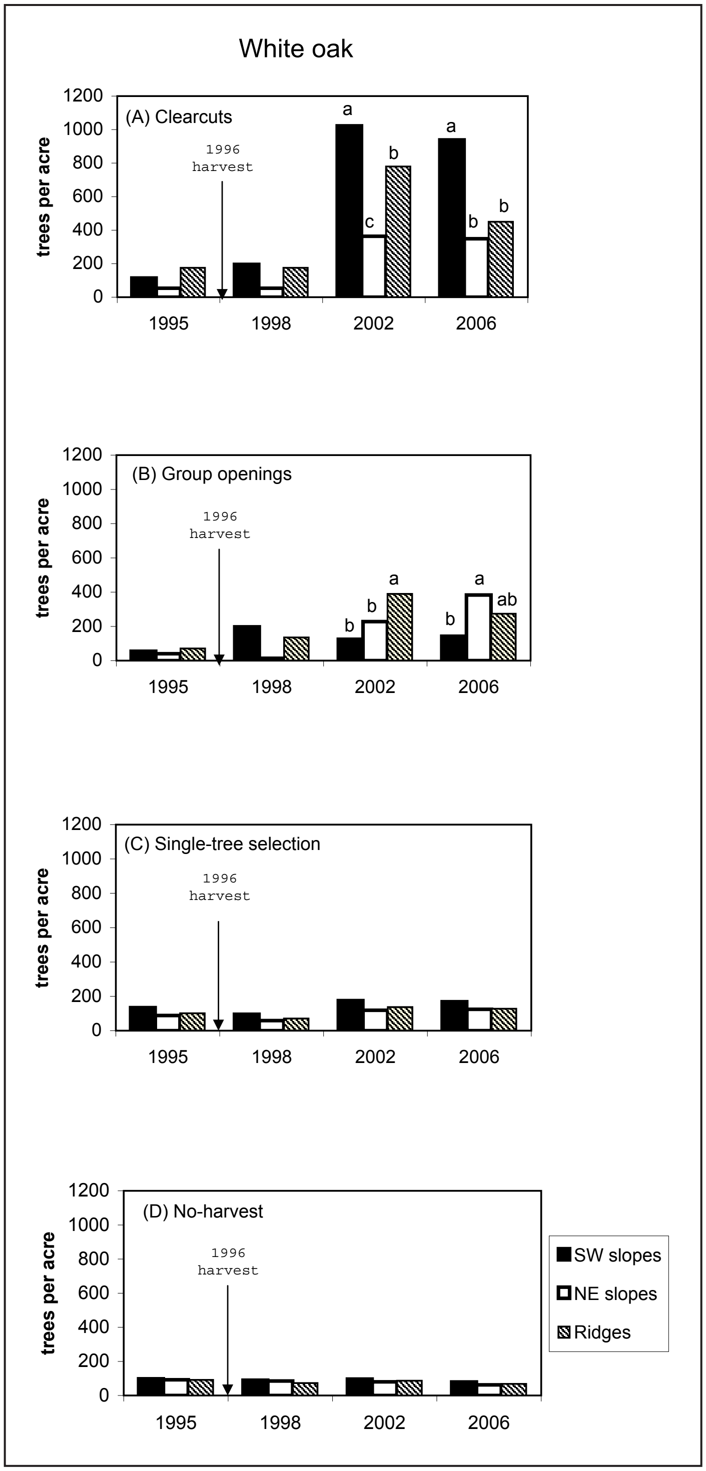

Figure 2.—White oak regeneration density of trees <4.5 in. d.b.h. by slope-aspect class before and after harvesting in 1996 by (A) clearcutting, (B) group selection, (C) single-tree selection, or (D) no-harvest management. For a given year, bars with the same letter(s) are not significantly different (α=0.05).

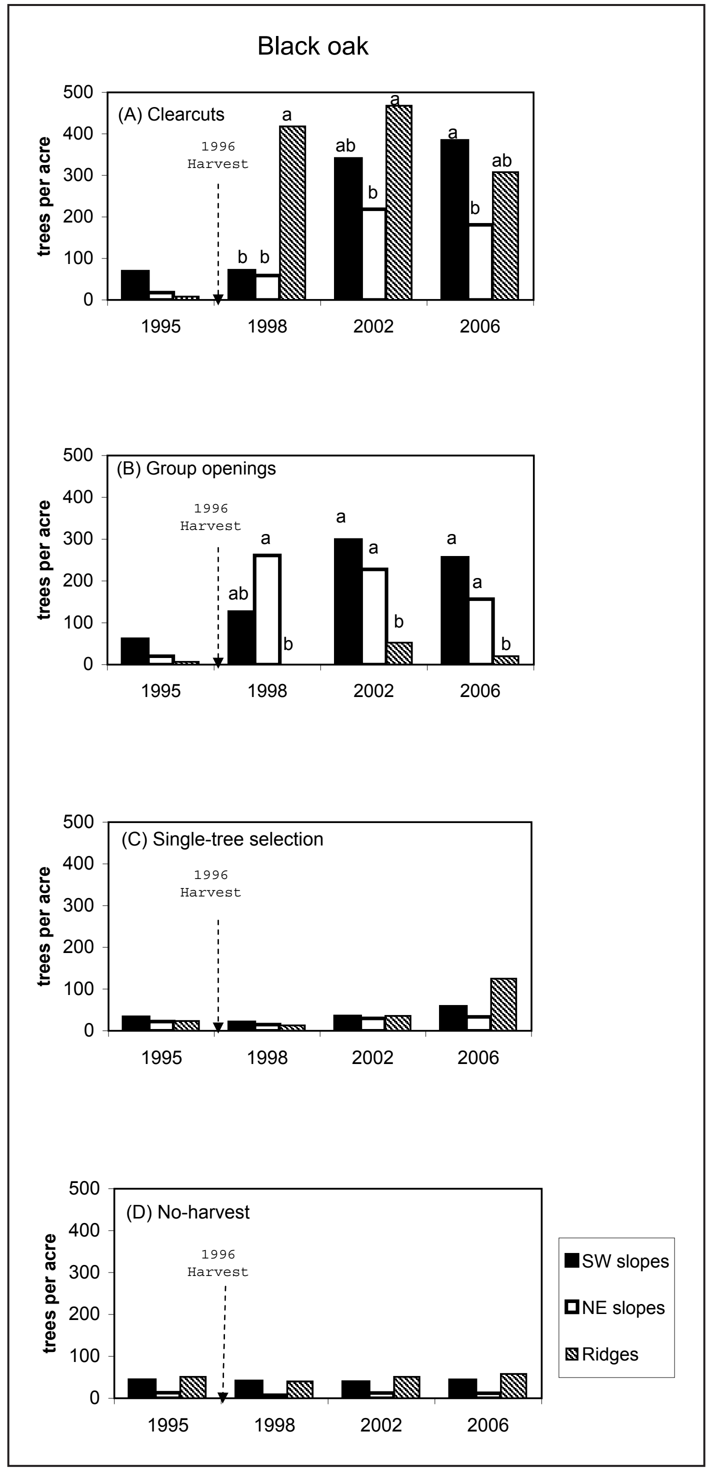

Figure 3.—Black oak regeneration density of trees <4.5 in. d.b.h.) by slope-aspect class before and after harvesting in 1996 by (A) clearcutting, (B) group selection, (C) single-tree selection, or (D) no-harvest management. For a given year, bars with the same letter(s) are not significantly different (α=0.05).

In 1998, scarlet oak densities in clearcuts were significantly higher on ridgetops (620 per acre) than southwest slopes (116 per acre); both had significantly higher densities than northeast slopes (38 per acre, Fig. 4). This trend was the same in 2002, with scarlet oak densities at 634, 341, and 178 trees per acre, respectively. Although scarlet oaks were at reduced densities on ridgetops (312 per acre) in 2006, they were still more abundant than on northeast slopes (147 per acre) or southwest slopes (105 per acre).

Ten years after group opening harvests, there were more scarlet oak on northeast slopes (107 per acre) and ridgetops (45 per acre) than on southwest slopes (10 per acre). There were no differences in scarlet oak densities on any slope-aspects in any of the years with single-tree selection harvests or in nonharvested stands.

The only difference detected in post oak densities among slope-aspect classes occurred in group openings in 2002 (Fig. 5). Post oak densities were estimated at 251 trees per acre on southwest slopes, which was similar to ridgetops (167 per acre) and significantly higher than on northeast slopes (7 per acre). This result, however, reflects large increases of post oak densities in only two plots.

DISCUSSION

White oak, black oak, and scarlet oak increased substantially in density with increasing harvest intensity (Fig. 1). The highest densities were found in clearcuts followed by group openings, single-tree selection harvests and nonharvested stands. By 1998, density increases had not yet materialized for most oak species because the majority of stems had not reached the minimum size threshold of 3.3 feet height by that time. In clearcuts, the tallest sprouts of sprouting stumps of white oak averaged 3.6 feet, scarlet oak 4.5 feet, and black oak 4.3 feet one growing season after harvest (Dey and Jensen 2002). In 1998, clearcuts had an average of 700 stump sprouts per acre, but plots harvested by a combination of single-tree selection and group openings had fewer than 120 stump sprouts per acre. There was an average of 42 stump sprouts per acre on plots harvested by single-tree selection and 7 sprouts per acre on nonharvested plots. Seedling sprouts and advance reproduction contributed to the rest of the regeneration (Kabrick and others 2002). Two years after harvest, clearcuts did have higher densities of scarlet oak than the other harvest types and had more black oak than single-tree selection and nonharvested stands. The highest densities of all of the four oak species occurred in 2002 and differences among harvest methods became apparent. Lower oak densities in 2006 were mostly due to the onset of stem exclusion due to competition, particularly in clearcuts and group openings.

The response of white oak, black oak, and scarlet oak to harvesting differed by slope position and aspect and these species attained highest densities in clearcuts located on southwest-facing slopes or on ridges. These findings clearly demonstrate that there is an interaction between harvest intensity and slope-aspect in the regeneration of oaks of different species. White oak densities in clearcuts were the highest after 10 years on southwest slopes but reached the highest densities in group openings on northeast slopes and ridgetops. Black oaks reached the highest densities on southwest slopes in clearcuts and group openings, but these densities were not statistically different from densities on ridges using clearcuts or densities on northeast slopes using group openings. Scarlet oak densities were highest on southwest slopes in clearcuts and group openings; however, densities in group openings were not different between southwest and northeast slopes.

Although the regeneration of shortleaf pine is an important issue for forest managers in the Missouri Ozarks, none of the forest harvesting methods applied in 1996 increased pine densities. We suspect that

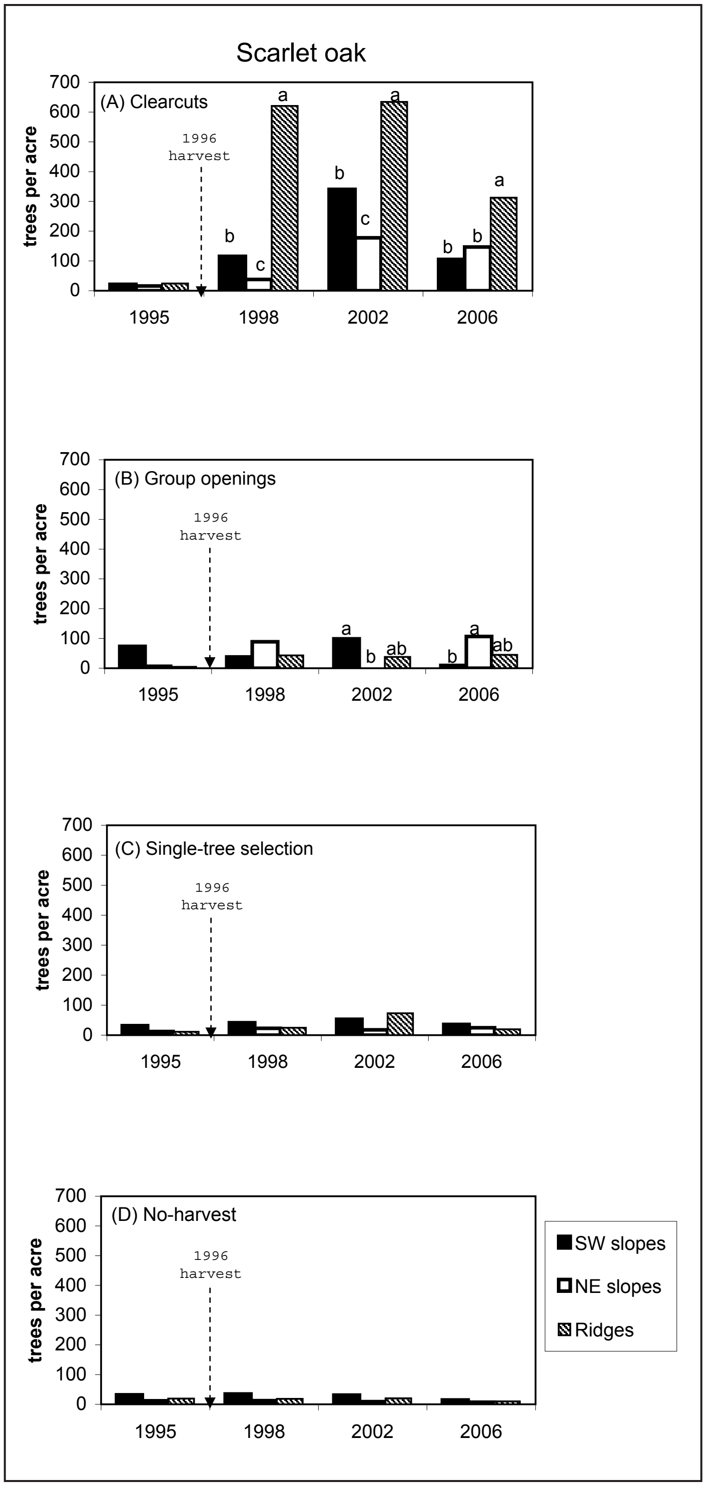

Figure 4.—Scarlet oak regeneration density of trees <4.5 in. d.b.h. by slope-aspect class before and after harvesting in 1996 by (A) clearcutting, (B) group selection, (C) single-tree selection, or (D) no-harvest management. For a given year, bars with the same letter(s) are not significantly different (α=0.05).

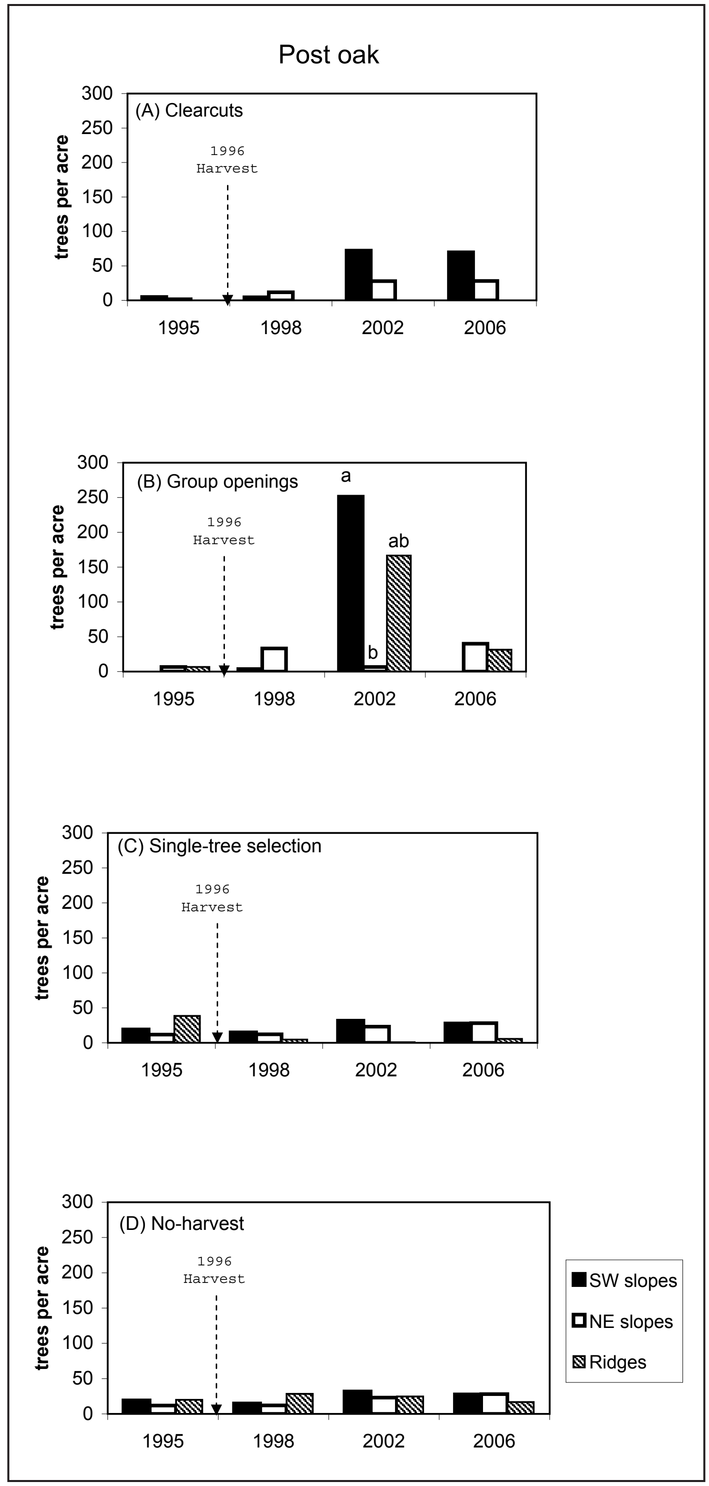

Figure 5.—Post oak regeneration density of trees <4.5 in. d.b.h. by slope-aspect class before and after harvesting in 1996 by (A) clearcutting, (B) group selection, (C) single-tree selection, or (D) no-harvest management. For a given year, bars with the same letter(s) are not significantly different (α=0.05).

the low light levels created by the high density of hardwood seedlings and seedling sprouts in clearcuts and group openings eliminated the shortleaf reproduction. Conversely, the canopy coverage may not have been reduced sufficiently in single-tree selection harvests to benefit the seeding of pine. The lack of scarification of the soil also may have made pine establishment more difficult. Other methods of site preparation and competition control will most likely be needed to increase pine densities.

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