SINGLE-TREE HARVESTING REDUCES SURVIVAL AND GROWTH OF OAK STUMP SPROUTS IN THE MISSOURI OZARK HIGHLANDS

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Abstract.—Regeneration and recruitment into the overstory is critical to the success of using uneven-aged systems to sustain oak forests. We evaluated survival and growth of white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Muenchh.) stump sprouts 10 years after harvesting Ozark forests by the clearcut, group selection, or single-tree selection method. After 10 years, the percent of stumps with live sprouts was high for all species in clearcuts (75 percent) and group selection openings (ranging from 60 to 78 percent depending on species), but was substantially less in single-tree selection units (ranging from 32 to 50 percent depending on species). Stump sprout 10th-year height and diameter at breast height (d.b.h.) was largest in clearcuts, intermediate in group selection openings, and smallest in single-tree selection units. White oak and black oak growth was not significantly different between clearcut and group openings, but it was significantly less in single-tree selection units. Scarlet oak growth in clearcuts was significantly more than either uneven-aged method, and differences between group and single-tree selection were significant. Single-tree selection harvesting as conducted in this study has lowered survival and growth of oak stump sprouts, and slowed their recruitment into the overstory. Inadequate light levels in the understory are probably limiting oak development. Long-term ability of this regeneration method to sustain oak stocking in these forests needs further study.

INTRODUCTION

Forest managers throughout eastern North America often desire to maintain current levels of oak (*Quercus* spp.) stocking for timber, wildlife, and conservation biology reasons. Even-aged methods such as clearcut and shelterwood harvesting are recommended to regenerate eastern oak species; uneven-aged methods such as single-tree and group selection are not considered appropriate for sustaining oak ecosystems (Roach and Gingrich 1968, Sander and Graney 1993). Oak forests managed by the single-tree selection method typically transition to more mixed mesophytic, shade-tolerant species, with substantially reduced levels of oak stocking (Schlesinger 1976, Della-Bianca and Beck 1985, Smith and Miller 1987). The group selection method promotes the regeneration of more shade-intolerant species such as the oaks, but small openings (< 0.1 acre) are often dominated by shade-tolerant species, and larger openings are captured by fast-growing shade-intolerant species such as yellow-poplar (*Liriodendron tulipifera* L.) and black cherry (*Prunus serotina* Ehrh.) (Smith 1981, Weigel and Parker 1997, Jenkins and Parker 1998). However, concerns from certain environmental groups about forest harvesting have led state and federal agencies to experiment with or adopt uneven-aged systems (single-tree or group selection) for managing eastern oak forests.

In the Missouri Ozark Highlands, however, uneven-aged management has been practiced on the privately owned Pioneer Forest for more than 40 years, and the practice has been used on state and federal land for more than a decade. Johnson and others (2002, p. 358) recognized that "[t]here is substantial evidence that the single-tree selection method can be used to sustain oak stands in the Ozark Highlands." Their evidence is based on analysis of Pioneer Forest continuous forest inventory (Loewenstein 1996, Loewenstein and

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others 2000). However, they do qualify this optimistic report by noting that the long-term sustainability of this method needs to be verified.

Stump sprouts are the most competitive source of oak reproduction (Johnson and others 2002) and an evaluation of their development after uneven-aged harvesting would be indicative of the method's ability to sustain current oak stocking levels. Of particular interest is the effect of a partial overstory and small group openings on oak stump sprout survival and growth. Most studies of oak stump sprouting address how sprouts develop in clearcuts, or openings larger than 0.5 acres (Wendel 1975, Lynch and Bassett 1987, Dey and others 1996). Less is known about the persistence and competitiveness of oak stump sprouts that develop in single-tree gaps and in small (<0.5 acres) group openings. Gardiner and Helmig (1997) studied survival and growth of water oak (*Q. nigra* L.) stump sprouts in young (i.e., ≤30 years old), thinned bottomland plantations in Louisiana. They found that substantial reductions in stand density, i.e., removing 60 percent of basal area, increased survival of oak stump sprouts after 7 years. Lockhart and Chambers (2007) reported that removing half of the overstory basal area did not increase fifth-year survival of cherrybark oak (*Q. pagoda* Raf.) stump sprouts in a Louisiana plantation. However, they suggested that sprout survival was compromised by 2 years of drought. Long and others (2004) reported that survival of upland oak stump sprouts was 93 percent 2 years after reducing basal area by 29 percent by thinning from below in southern Ohio forests.

OBJECTIVES

The purpose of this study was to determine the effect of regeneration method: clearcut, group selection, and single-tree selection on the survival and growth of oak stump sprouts in the Missouri Ozark Highlands. We present a 10-year assessment of sprouting capacity and growth performance in three oak species, white oak (*Q. alba* L.), black oak (*Q. velutina* Lam.), and scarlet oak (*Q. coccinea* Muenchh.).

METHODS

We monitored stump sprouting of oak trees in stands harvested by the clearcut, group selection, or single-tree selection regeneration method located in Shannon, Carter, and Reynolds Counties, MO. The study stands are located within the Current River oak forest breaks and the Current River oak-pine woodland hills landtype associations (Nigh and Schroeder 2002). Before harvesting, study stands were fully stocked, mature forests dominated by white oak, black oak, scarlet oak, and post oak (*Q. stellata* Wangenh.), which comprised 71 percent of the basal area (Kabrick and others 2004). Shortleaf pine (*Pinus echinata* Mill.) was 8 percent of original basal area. The remaining species included pignut hickory (*Carya glabra* (Mill.) Sweet), black hickory (*C. texana* Buckl.), mockernut hickory (*C. tomentosa* Poir. Nutt.), flowering dogwood (*Cornus florida* L.), and blackgum (*Nyssa sylvatica* Marsh.). Initial stand density averaged about 84 ft^2 per acre, 150 trees per acre, and 84 percent crown cover for trees greater than 4.5 inches d.b.h.

This study was part of the Missouri Forest Ecosystem Project (MOFEP) that was designed as a randomized complete block study (Sheriff and He 1997). Each management treatment (even-aged, uneven-aged, and no harvesting) was randomly assigned to large, approximately 1,000-acre, forest compartments within each of three blocks. Blocks were landscapes large enough to accommodate three 1,000-acre treatments and were subjectively chosen to maximize homogeneity in site and stand conditions within a block. A total of 648 half-acre permanent plots were randomly located across all blocks and management treatment compartments, and were apportioned to each ecological landtype as they occurred within the study area.

Table 1.—Distribution of oak stumps by species and harvest treatment sampled on the Missouri Ozark Forest Ecosystem Project

Species	Clearcut	Group Selection	Single-tree selection	Total
White oak	158	93	131	382
Scarlet oak	65	21	56	142
Black oak	69	49	60	178
Total	292	163	247	702

Single-tree and group selection harvesting was implemented according to the guidelines presented in Law and Lorimer (1989). In single-tree selection units, the target residual basal area was chosen to be B-level stocking, i.e., about 58 percent stocking, according to Gingrich (1967). The target largest diameter was set at 18 inches d.b.h. in stands of low site quality and 26 inches d.b.h. where site quality was high. The target q-value averaged 1.5, but ranged between 1.3 and 1.7 at the stand level depending on the actual distribution of tree diameters. Group openings were 0.1 acre (one tree height in diameter, about 75 feet) on south and west aspects, 0.2 acres on ridges, and 0.4 acres (two tree heights in diameter, about 150 feet) on north and east aspects. The cutting cycle for uneven-aged units was set at 15 years. Ten percent of the stands in each compartment were harvested in the initial treatment, which was completed in the fall of 1996. Immediately following the timber harvest, all unmerchantable stems in clearcuts and group openings were cut by chainsaw in the winter of 1996-1997. In single-tree units, unmerchantable stems in over-stocked diameter classes were cut or double-girdled. Woody vegetation was inventoried after the harvest treatments were applied (Grabner 2000, Jensen 2000). The post-harvest overstory in clearcuts averaged 7 ft^2 per acre, eight trees per acre and 3 percent crown cover. No overstory was left within group selection openings. In contrast, stand density after harvest in single-tree selection units averaged 62 ft^2 per acre, 122 trees per acre, and 58 percent crown cover.

Within the harvested stands, we randomly selected oak stumps in clearcuts (292 trees), group selection openings (163 trees), and single-tree selection units (247 trees). We limited the number of trees selected at any given point to less than five per species to distribute the sample across all MOFEP compartments. Stumps were chosen to represent the range of diameters present and were located far enough from each other so they could be considered independent of one another. A total of 702 stumps were selected (Table 1).

Stumps were identified to species and tagged with a unique number, and the diameter of each stump was measured (initial stump diameter). Stumps were referenced to a permanent marker by azimuth and distance. Stumps averaged 9.3 inches in diameter (range 1.7 inches to 33.3 inches) and 61 years in age (range 38 to 192 years). In the fall of 2006, 10 growing seasons after harvesting, stumps were revisited to measure the height and d.b.h. of the tallest sprout.

For each species, we used analysis of variance (ANOVA) (PROC GLM, SAS Version 9.1, SAS Institute, Inc., Cary, NC) to test for significant differences in the logit of proportion of stumps with at least one live sprout 10 years after harvesting by block and harvest treatment (clearcut, group selection, single-tree selection). Similarly, we used ANOVA to test for significant differences in height and d.b.h. of the dominant sprout at year 10 by block, harvest treatment, initial stump diameter class (class 1: <6 inches; class 2: 6 to <11 inches; class 3: ≥11 inches), and the interaction of harvest treatment, and initial stump

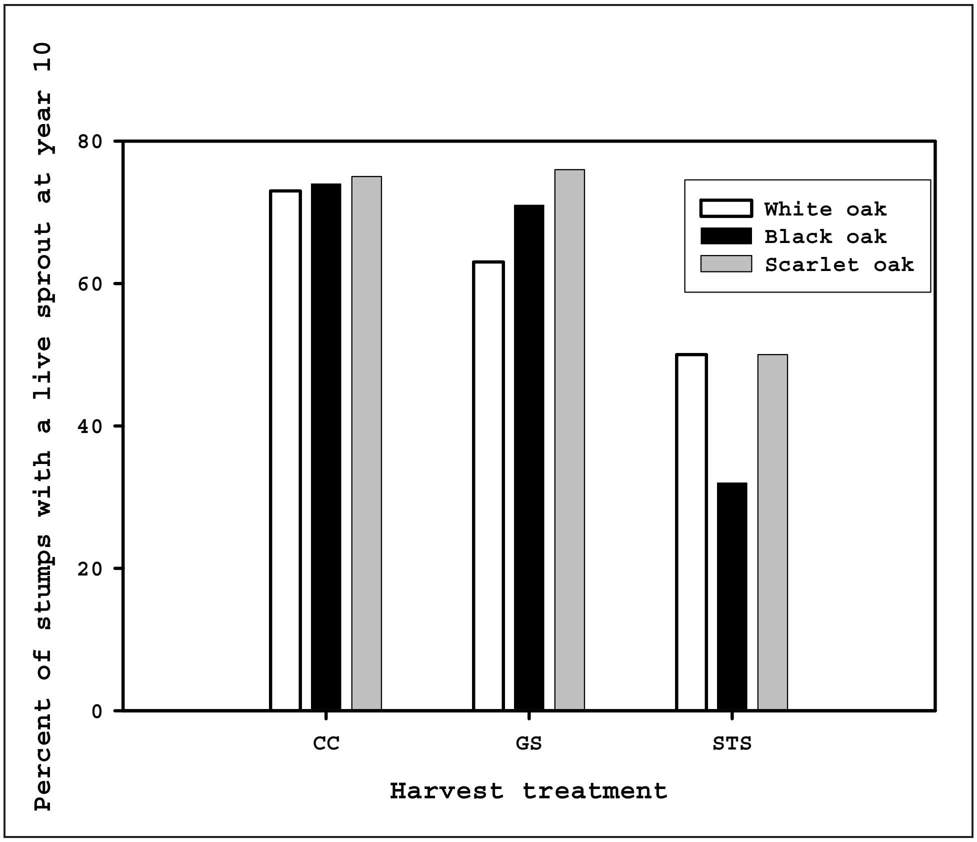

Figure 1.—Percent of stumps that had at least one live sprout 10 years after harvesting by species and harvest treatment (CC = clearcut; GS = group selection; STS = single-tree selection). For each species, differences among harvest treatment are not significantly different (α = 0.05).

diameter class for each species. We treated block, harvest treatment and stump diameter class as random effects in all analyses. For significant main effects and interactions (α = 0.05), differences between least squares means were determined by pairwise comparisons.

RESULTS

Proportion of Sprouting Stumps

Ten years after harvesting, we found that the percent of stumps with at least one live sprout was high (e.g. 75 percent) in clearcuts and group selection openings for all species, but was only 32 percent (black oak) and 50 percent (white oak and scarlet oak) in single-tree selection treatments (Fig. 1). Despite the absolute differences in average percent of stumps with live sprouts by harvest treatment, there was no evidence that the logit of proportion of stumps with a live sprout was significantly affected by block or harvest treatment within a species at year 10.

Height and Diameter

Ten years after harvesting, we found that the dominant sprout was tallest in clearcuts, intermediate in group openings, and substantially smaller in single-tree units (Table 2). Height differences among the harvest treatments were greatest for black oak and scarlet oak. White oak in clearcuts and group selection openings were similar in height. Among the species, scarlet oak stump sprouts were nominally the tallest, on average, in clearcuts at 10 years. Height of white oak and black oak stump sprouts was statistically

Table 2.—Mean 10th-year height and diameter (d.b.h.) of dominant stump sprout by species and harvest treatment. For a species, mean heights or diameters among harvest treatments with different letters are significantly different at α=0.05.

Regeneration method	Height (feet)	d.b.h. (inches)
White oak		
Clearcut	15.5 a	2.2 a
Group selection	13.6 a	1.5 a
Single-tree selection	5.2 b	0.4 b
Scarlet oak		
Clearcut	25.0 a	3.1 a
Group selection	13.2 b	1.4 b
Single-tree selection	6.5 c	0.7 b
Black oak		
Clearcut	18.6 a	2.3 a
Group selection	12.5 a	1.3 b
Single-tree selection	5.1 b	0.4 c

similar in clearcuts and group selection openings, but significantly reduced in single-tree selection treatments. For scarlet oak, height of stump sprouts in clearcuts was significantly greater than in group and single-tree selection openings; height in group selection openings was significantly greater than in single-tree harvest treatments.

Tenth-year d.b.h. of the dominant stump sprout was greatest in clearcuts for all oak species, intermediate in group openings, and smallest in single-tree treatments (Table 2). Stump sprout d.b.h. averaged about 2.0 inches larger in clearcuts than in single-tree selection treatments. Scarlet oak stump sprouts were the largest, averaging 3.1 inches in clearcuts, almost an inch larger than either white oak or black oak. In general, d.b.h. of the dominant sprout was significantly larger in clearcuts than either of the uneven-aged harvest treatments for all oak species. One exception was white oak, whose d.b.h. was statistically similar in clearcuts and group openings. Black oak and white oak d.b.h. in group selection openings was significantly greater than in single-tree treatments, but there was no statistically detectable difference between scarlet oak d.b.h. in group and single-tree selection treatments.

In general, sprouts from smaller diameter stumps grew taller in height and larger in d.b.h. for all oak species in 10 years (Table 3). Average sprout height was nominally the largest for stumps that were <6 inches in diameter. The average height of the dominant stump sprout was significantly greater for sprouts arising from smaller stumps (<12 inches in diameter for all oak species). For white oak, sprout height was significantly greater for stumps that were < 6 inches compared to sprouts from larger stumps after 10 years. Similarly, sprout d.b.h. was significantly greater for stumps <12 inches in diameter than for sprouts from larger stumps for all oak species. Sprouts from stumps that were <12 inches d.b.h. were usually an inch larger in d.b.h. than sprouts from larger oak stumps after 10 years. There were no significant interactions between harvest treatment and stump diameter class on stump sprout height or d.b.h. for any of the oak species.

Table 3.—Mean 10th-year height and diameter (d.b.h.) of dominant stump sprout by species and stump diameter size class. For a species, mean heights or diameters among stump diameter size classes with different letters are significantly different at α=0.05.

Stump diameter (inches)	Height (feet)	d.b.h. (inches)
White oak		
<6	16.2 a	1.9 a
6 to <11	11.6 b	1.5 a
≥11	6.4 c	0.7 b
Scarlet oak		
<6	19.2 a	2.1 a
6 to <11	16.8 a	2.0 a
≥11	8.6 b	1.1 b
Black oak		
<6	13.9 a	1.6 a
6 to <11	15.6 a	1.7 a
≥11	6.7 b	0.7 b

DISCUSSION

Stumps in this study averaged 9 inches in diameter and 61 years in age, which places them in prime sprouting condition for these oak species (Johnson and others 2002). Gardiner and Helmig (1997) also observed very high initial sprouting (100 percent) in young (28-year-old), small-diameter water oak under a partial overstory created by thinning a bottomland plantation in Louisiana. Lockhart and Chambers (2007) found that 85 to 95 percent of cherrybark oak stumps (average d.b.h. 11 inches) produced sprouts after thinning to either 50 or 75 percent stocking in a 30-year-old Louisiana bottomland plantation. In a mature bottomland oak forest in southeast Missouri, Kabrick and Anderson (2000) reported that stumps of pin oak (*Q. palustris* Muenchh.), cherrybark oak, and willow oak (*Q. phellos* L.) in single-tree gaps sprouted as readily as stumps of upland oaks in clearcuts. Their sprouting frequencies were also comparable to open-grown stump sprouts in this study. McGee (1978) reported no difference in the ability of white oak stumps to produce sprouts when growing in small canopy gaps and forest openings.

We observed that percent of stumps with any live sprouts remained high among species in clearcuts (75 percent on average) and group openings (ranging from 63 to 76 percent) 10 years after harvesting. Oak stump sprouts are vigorous and competitive in these Ozark forests, and are able to survive relatively well when given sufficient growing space and light. The percent of stumps with a live sprout was much lower in single-tree units where the residual overstory averaged 62 ft^2 $acre^{-1}$ and 58 percent crown cover. Under these overstory densities, light levels begin to limit oak reproduction survival and growth (Larsen and others 1997, Dey 2002).

Gardiner and Helmig (1997) found that survival of water oak stump sprouts remained relatively high (80 percent) 7 years after a moderate thinning that reduced plantation basal area by 60 percent, and that this survival was 23 percent higher than that of stump sprouts in plots where only 40 percent of the basal area was removed. No doubt greater reductions in stand density permitted additional light to reach the oak sprouts in the years immediately following thinning, thus improving their survival for up to 7 years. In another bottomland plantation thinning study, Lockhart and Chambers (2007) reported initially very high stump sprouting in cherrybark oak after a heavy (50 to 55 percent reduction in stocking) and light (25 to 30 percent reduction in stocking) thinning. But over the next 5 years, they noticed that stump sprout survival dropped to 30 to 40 percent and there was no difference between thinning treatments. Benefits to stump sprout survival and growth that were expected in the heavy thinning may have been reduced by a 2-year drought.

Height and diameter growth of oak stump sprouts was greatest in clearcuts after 10 years. The reduction in height and diameter as a result of harvest treatment (clearcut < group opening << single-tree selection) was least in white oak, intermediate for black oak, and substantial for scarlet oak, which probably mirrors the difference in shade tolerance among these species (Burns and Honkala 1990). Scarlet oak is one of the most shade-intolerant oak species found in the Missouri Ozark Highlands. Lockhart and Chambers (2007) noted that height growth of cherrybark stump sprouts growing under partial overstory shade were consistently higher with lower residual stand densities for 5 years after thinning, but differences were insignificant primarily because of a 2-year drought that occurred following thinning. Gardiner and Helmig (1997) reported that height and diameter growth of water oak stump sprouts were significantly greater for 5 years after thinning under the lower stand density treatment, but by year 7 and with canopy closure, stump sprout heights were statistically similar among the thinning treatments.

Managers have been discouraged from using uneven-aged systems in oak forests largely because of oak's inability to survive and grow in moderate to high levels of shade under high residual forest overstory densities, or because oak do not compete well with fast growing shade-intolerant species, such as yellow-poplar and black cherry in larger group selection openings.

It is commonly reported that light levels in forest understories and regeneration openings should be between 30 and 50 percent of full sunlight to promote development of oak reproduction (Hanson and others 1987, Hodges and Gardiner 1993, Ashton and Berlyn 1994, Gottschalk 1994). Shelterwood harvesting should leave a residual stocking of ≤60 percent, and the diameter of group selection openings should be a minimum of one to two times the height of the adjacent dominant trees to produce 30 percent or more of full sunlight in the regeneration environment (Minckler and others 1973, Sander 1979, Dey and Parker 1996).

In this study, group openings, which varied in size from one tree height in diameter on south-west aspects to two tree heights on north-east aspects, initially provided the one-third or more of full sunlight recommended for good oak growth according to the literature. Position of oak reproduction in the group opening is important for survival and growth. Trees growing in the center of group openings grow at rates similar to trees in clearcuts, but oaks along the edges of openings are inhibited by the shade from the adjacent stand. Our survival and growth results for oak stump sprouts in group openings are averages of the sample trees regardless of their location in the group. In the single-tree selection units it is doubtful that oak stump sprouts received more than one-third of full sunlight, probably less in many cases given the residual stand basal area. Single-tree selection harvest in mature, closed-canopied hardwood forests may not appreciably increase light levels at the forest floor (Fischer 1979).

Overstory density was important for developing large oak advance reproduction in Missouri Ozark (Larsen and others 1997) and Lower Michigan (Johnson 1992) xeric oak ecosystems, where the probability of having large oak reproduction was greatest at stocking levels between 30 and 60 percent (Gingrich 1967). Larsen and others (1999) recommended maintaining overstory density at less than 63 ft^2 $acre^{-1}$ on average over a 20-year cutting cycle to favor oak recruitment in forests managed to produce an uneven-aged structure in the Missouri Ozarks. The overstory in our single-tree selection stands, which was at the upper limit of residual overstory density recommended by Larsen and others (1999), did reduce the height of the tallest stump sprout. The long-term survival and recruitment success of these sprouts remains unknown.

In the xeric oak forests of the Missouri Ozark Highlands, there is hope that uneven-aged systems can be devised to sustain these oak dominated ecosystems. In the case of Pioneer Forest, implementation of the regeneration method has changed over time, and residual stand densities have increased from about 30 to 60 ft^2 $acre^{-1}$, making it difficult to draw conclusions about the sustainability of the system (Loewenstein 1996, Loewenstein and others 2000). More monitoring is needed on public lands managed under uneven-aged systems to determine the future of these forests. In addition, it has been noted elsewhere that there are subtle shifts in species dominance in Ozark forests harvested by uneven-aged methods, with white oak increasing in importance, black oak and scarlet oak decreasing because of problems with regeneration, and loss of shortleaf pine following complete failure to regenerate under moderate to high residual stocking (e.g., 60 ft^2 $acre^{-1}$) in single-tree selection harvested stands, or in small canopy gap openings (Stambaugh 2001, Sasseen 2003, Kabrick and others 2007).

Harvest method and, in particular, management of overstory density are important in determining oak regeneration and recruitment success, i.e., long-term survival and growth of oak stump sprouts and advance reproduction into maturity as codominant and dominant trees. Recruitment into the overstory of oak stump sprout and large oak advance reproduction is critical to success of uneven-aged management of oak forests in the Missouri Ozarks. We have seen by this study that, as implemented in the MOFEP, single-tree selection harvesting greatly reduces the overstory recruitment potential of oak stump sprouts. Timing of future harvest entries will be crucial to promoting development of oak stump sprouts and other reproduction and continuing their recruitment into the overstory. These results may suggest modifications be made to target tree d.b.h., q-values, and target residual stand basal area to provide more light to oak reproduction in the understory. The length of the cutting cycle may need to be rethought because it can be crucial in stopping the decline in oak stump sprout development, which is also indicative of what is happening to oak advance reproduction. Oak reproduction can be released earlier by shortening the cutting cycle, but this approach must be balanced with other concerns, stand growth and yield, and the economics of harvesting.

There is flexibility in how the many even-aged and uneven-aged systems are applied to sustain oak forests in the Missouri Ozark Highlands. How these methods are implemented is critical to meeting the variety and complexity of management goals. Further monitoring of sprouts in this study will provide valuable insight on how we should manage regeneration and recruitment processes. Managers can use these results to help determine when uneven-aged management is appropriate and to develop detailed stand prescriptions that consider the full range of silvicultural systems.

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