THE APPLICATION OF SINGLE-TREE SELECTION COMPARED TO DIAMETER-LIMIT CUTTING IN AN UPLAND OAK-HICKORY FOREST ON THE CUMBERLAND PLATEAU IN JACKSON COUNTY, ALABAMA

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ABSTRACT

Cumberland Plateau region upland oak forests have undergone a myriad of disturbances (including periods of few and minor disturbances). Traditional timber harvesting practices such as diameter-limit cutting have negatively altered species composition and skewed stand structure, especially on medium-quality sites. We assessed the ability of single-tree selection to improve stand characteristics by comparing species structural and compositional responses, and assessing changes in productivity and quality with stands harvested by diameter-limit cutting. The single-tree selection marking guidelines specified a minimum diameter at breast height (d.b.h.) of 6 inches, a maximum d.b.h. of 30 inches, and a q-value of 1.4. The diameter-limit cut targeted stems 14 inches d.b.h. and greater. Both treatments had a target residual basal area of 65 square feet per acre, a density level that approximates the B-level stocking for upland oaks. All stands were harvested in 2005. Observed residual basal area averaged 61.5 square feet per acre with 66 stems per acre in the single-tree selection stands. The diameter-limit cut left a residual basal area of 39 square feet per acre with 64 stems per acre; there were no residual trees 16 inches d.b.h. and greater. The single-tree selection targeted all species, and the proportion of hickory and yellow-poplar declined following the harvest. For the diameter-limit cut, all chestnut oak and most white oaks were removed.

Keywords: Cumberland Plateau , diameter-limit cut, single-tree selection, uneven-aged management

INTRODUCTION

The upland oak forests of the Cumberland Plateau region have undergone a myriad of disturbances. These past disturbances (and sometimes lack of disturbance) on medium-to-high quality sites have resulted in stands of less desirable species compositions and stand structures that indicate populations of desirable species are unsustainable. Although generally considered even-aged systems, the majority of these stands contain a mixed or irregular age structure: old, cull trees remain from prior entries and young, intolerant species capitalized on openings created in "high-grade" harvests, where the most desirable stems were removed. The lack of adequate oak regeneration, and the desired future condition of a predominance of oak, makes managing these stands a challenge.

Even-aged systems are recommended for regenerating oak forests. The shelterwood method of regeneration continues to be touted as the preferred method for accomplishing oak regeneration on higher quality sites (Sander 1979; Smith 1986; Hannah 1987; Loftis 1983; Loftis 1990; Beck 1991). Reducing overstory and midstory densities alters light levels so that mid-tolerant species such as oak will respond while the establishment of highly intolerant species such as yellow-poplar will be limited. The response of tolerant species such as sugar maple may be stimulated under these light conditions. For example, Goodburn and Lorimer (1999) found that sugar maple reached close to its maximum height growth under light intensities of 2-15 percent full sunlight. In a study in forested stands typical in the Cumberland region, a shelterwood method that targeted the deadening of midstory structure increased light levels to 16 percent of that in open conditions, and sugar maple seedlings present pre-treatment showed a height response one year post-treatment (Schweitzer 2004). It is also well established that disturbances on productive sites where yellow-poplar is present will enhance its regeneration potential, as it readily seeds in as new individuals.

The response of Cumberland Plateau forests to varying levels of overstory and midstory disturbance is currently under assessment in several studies (Schweitzer and others 2004; Schweitzer 2004; Schweitzer 2010). Shelterwood harvests of various basal area retentions are being tested to relate differing levels of understory light and competition and the response of desired species. All studies in this area thus far have been under the auspices of even-aged management. This case study of single-tree selection will allow for the comparison of light levels and seedling and sapling recruitment, growth, and survival between it and several other studies of even-aged methods of regeneration.

An uneven-aged management system is one that contains stands with trees of three or more distinct age classes (Society of American Foresters 1998). Regeneration

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prescriptions that drive uneven-aged management include single-tree selection and group selection. In the Cumberland Plateau region, which is dominated by private forest landowners, diameter-limit cutting is often alluded to as “selection” cutting, and some are confused by the semantics of “selection.” Diameter-limit cutting has resulted in the degradation of many stands, due to the removal of the majority of the commercially valuable trees, the retention of small, old trees that do not respond to the disturbance, and the increase in the percentage of poor quality and traditionally low value species. True uneven-aged management is not common in the Cumberland Plateau region. The lack of the use of uneven-aged management is driven by several factors, including the difficulty of implementation, the expense related to maintaining road infrastructure for multiple entries, and the inability to commercially sell hardwoods of smaller stem diameters. Creating conditions for regeneration of desirable species, which includes oaks, is also a challenge. However, the potential for a land owner to have more frequent income flows via timber sales, and the aesthetics associated with partial harvests, are appealing to some landowners.

Single-tree selection has been reported as inappropriate for managing upland oak forests in Southern Appalachian upland hardwood forests, as canopy gaps are deemed too small to allow enough light for oak reproduction (Sander and Clark 1971; Sander and Graney 1993; Loftis 2004). However, it has been recently reported in an oak-hickory forest in the Missouri Ozarks that after 40 years of applied single-tree selection, stand quality and vigor were improving, and there was sufficient recruitment to perpetuate the oak-hickory type (Lowenstein and others 1995). The use of uneven-aged management is receiving heightened attention in the Cumberland region by mostly private land owners and environmental groups who wish to avoid the visual impact associated with clearcutting, as well as the desire to create unique forest stand structures.

Another difficulty in implementing single-tree selection in Cumberland Plateau stands is that we often do not know the developmental history of the stands. We assume the stands are of the same age, although we also know that diameter-limit cutting is rampant, and many stands have been partially harvested using this type of cutting practice. So the use of stem diameters as a surrogate for age in developing single-tree selection prescriptions may be even more exaggerated in our forests. Nevertheless, we are interested in the applicability of single-tree selection, including implementation procedures in our mixed species, and mixed shade tolerance, stands. We examined residual stand structure and composition following the first entry of a single-tree selection harvest and compared this to that obtained with a diameter-limit cut. We are interested in documenting the light levels and canopy conditions under each treatment, and the initial regeneration response.

METHODS

STUDY REGION

Forested stands chosen for this study are owned by the Stevenson Land Company, Stevenson, AL. The stands are located near Blue Spring, Jackson County, on strongly dissected margins and sides of the Cumberland Plateau (the escarpment). On the escarpment study sites, soils are characterized as deep to very deep and loamy. They are considered well-drained, with moderate to moderately low soil fertility. Slopes range from 15 to 30 percent. Upland oak site index is 75 to 80, and yellow-poplar (*Liriodendron tulipifera* L.) site index is 100 [base age 50 years, Smalley Landtype 16, Plateau escarpment and upper sandstone slopes and benches – north aspect (Smalley 1982)]. Canopies are dominated by oaks, including black, northern red, white and chestnut (*Quercus velutina* Lamarck, *Q. rubra* L., *Q. alba* L., *Q. prinus* L.), yellow-poplar, hickories (*Carya* spp.), and sugar maple (*Acer saccharum* Marsh.), with a lesser proportion of white ash (*Fraxinus americana* L.) and blackgum (*Nyssa sylvatica* Marsh.). Depending on the site, dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* DC.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), and eastern redbud (*Cercis canadensis* L.) are common understory species. Beneath mature stands oak reproduction is small and sparse, and competition by yellow-poplar and sugar maple is great.

TREATMENTS

This area was chosen as a study site because of its typical stand history and composition for the region. Our assumption was that these stands were essentially even-aged at approximately 80-100 years old. A history of site disturbance does not exist. Two case studies of approximately 30 acres each are being implemented on this site as a response to results observed in a larger stand manipulation study also located in Jackson County, Alabama.

To begin the process of moving these stands towards an uneven-aged stem distribution, we set our harvest parameters to control the growing stock so that we would have a progression of stems of various sizes. The residual stocking level was set at 60 ft^2/a of basal area (BA), the diameter of the largest tree was 30 inches, and the number of trees desired in each diameter class was determined by the diminution quotient (q) of 1.4. The q expresses the ratio of the number of trees in any diameter class to the number of trees in the next higher diameter class. We also had a minimum diameter of 6 inches, a merchantable constraint for our systems. A 65 BA density level approximates the B-level stocking for upland oaks (Gingrich 1967). Smith and Lamson (1982) recommended a 1.3 q-value for sawtimber production and higher q-values for smaller product objectives.

Residual structure was obtained by marking trees after division into four size classes: (1) small poletimber (6-8 inches d.b.h.) (2) large poletimber (9-11 inches d.b.h.) (3) small sawtimber (12-15 inches d.b.h.) and (4) large sawtimber (>15 inches d.b.h.). Target residual basal area for each class was calculated and the stand marked to meet these targets. Removal tree priority followed (1) large cull and defective trees (2) competing trees of poor form and quality (3) intermediate and suppressed tress of lower quality and value.

The diameter-limit cut was implemented by removing all trees 14 inches d.b.h. and larger. All harvesting was done by chainsaw felling and cable skidding by Chisenall Timber in the summer of 2005.

FIELD METHODS

Prior to treatment, 25 measurement plots were systematically located in the treatment area. These plots were used to collect pre-prescription data in order to develop the single-tree selection marking criteria. All trees 5.6 inches d.b.h. and greater on 0.2-acre plots were tallied by species and diameter.

We then randomly chose 5 of these plots to use as measurement subplots, which consisted of three concentric circles. Five plots were also established in the diameter-limit cut stand. Subplot centers were permanently marked with a 2-foot piece of reinforcing steel, and geographic coordinate pairs were recorded using a hand GPS receiver. A hand-held spherical densiometer was used to measure canopy cover. Densiometer counts were made in four cardinal directions from each permanent plot center and averaged.

Regeneration was sampled on 0.01-acre circular plots. Seedlings were tallied by species in each regeneration plot by 1-foot height classes, up to 1.5 feet d.b.h., and then by diameter.

Using the same plot center, a 0.025-acre plot was established and all trees 1.6 inches d.b.h. and greater were monumented (distance and azimuth measured and recorded from plot center, each tree tagged with a numbered aluminum tag) and species and d.b.h. recorded. An additional 0.2-acre plot, located concentrically, was established, and all trees 5.6 inches d.b.h. were measured and monumented as described previously. We measured all plots prior to harvesting in 2005, and then remeasured them in 2009

RESULTS

OVERSTORY COMPOSITION AND STRUCTURE

Twenty-five dominant or codominant tree species were tallied in the stands. Oak species included black, white, northern red, chestnut, scarlet (*Q. coccinea* Muench.) and post (*Q. stellata* Wang.), and hickory species included mockernut (*Carya tomentosa* Nutt.), pignut (*C. glabra* Sweet.), red (*C. ovalis* Sarg.) and shagbark (*C. ovata* K. Koch.). A gradient of shade tolerance of canopy species included extremely tolerant sugar maple, intermediately tolerant red maple (*A. rubrum* L.) and extremely intolerant yellow-poplar. For the single-tree selection stand, the pretreatment basal area was 121 BA with 123 stems per acre (SPA), and this stand was dominated by oaks, hickories and yellow-poplar (Table 1). The diameter-limit cut stand had a similar structure and composition, with 108 BA and 117 SPA, also dominated by oaks and hickories (Table 1). Both stands contained a number of other species, including white ash, American beech (*Fagus grandifolia* Ehrh.), sourwood, common persimmon (*Diospyros virginiana* L.), Eastern redcedar (*Juniperus virginiana* L.) and elms (*Ulmus* spp.).

An examination of the diameter distribution of the single-tree selection stand shows that this mixed species stand had a diameter distribution curve that resembled the uneven-aged system, with more stems in the smaller size classes (assumed to be "younger") and fewer stems in the larger (assumed to be "older") diameter class (Figure 1). Thus the potential to harvest and maintain a reversed J-shaped diameter distribution existed in this even-aged stratified mixture stand. Following harvest, we had 6 fewer SPA than desired in the 10-inch d.b.h. class, and 4 greater SPA than desired in the 18-inch d.b.h. class. After 32.8 ft^2/a of BA was removed from the stand, oak was still a significant overstory species, accounting for 37.7 of the of the residual basal area (57.7 ft^2/a). There were 64 SPA in the residual stand, of which oak comprised 59 percent comprised of the stems (Table 1). The distribution of oak across diameter classes is show in Figure 2a; except for the 12-inch d.b.h. class, there is balance in the distribution of oak residual BA with diameter (Figure 2b).

The diameter-limit cut successfully removed all trees greater than 14 inches d.b.h. (Figure 3a). The residual BA was 39.0 ft^2/a, with 49.5 BA of oak removed and a residual oak BA of 12.3 (Figure 3b). The diameter-limit cut had 64 SPA in the residual stand with 32 percent of these stems oaks (Table 1).

Canopy cover was similar between the two stands, with the single-tree selection stand having an average 83.4 percent cover (standard deviation 13.9) and the diameter-limit cut having an average cover of 80.9 (std 10.8). The range of recorded cover was 30.3-97.9 percent for the single-tree selection and 47.0-99.0 percent for the diameter-limit cut.

REGENERATION COMPOSITION AND STRUCTURE

The regeneration cohort, which included all stems from 1 foot tall to 1.5 inches d.b.h., contained 44 different species. Several of these were shrubs that included devil's walking stick (*Aralia spinosa* L.), beauty berry (*Callicarpa americana* L.), *Euonymus* spp., oak-leaf hydrangea (*Hydrangea quercifolia* Bartram), Vaccinium spp., and maple-leaf viburnum (*Viburnum acerifolium* L.). Also present were many midstory tree species, including blackhaw (*V. prunifolium* L.), Carolina buckthorn, Eastern hophornbeam (*Ostyra virgniana* (Mill.) K. Koch), Eastern redbud, flowering dogwood and winged sumac (*Rhus copallina* L.). Potential canopy species were also present and included black, white, northern red, scarlet, chestnut and Chinkapin oak (*Q. muehlenbergii* Engelm.), hickories (mockernut, pignut and red), yellow-poplar, white ash, blackgum, sourwood, red maple and sugar maple.

For all stems considered in the regeneration cohort (including shrubs and midcanopy species), total numbers increased after both harvests. For the single-tree selection, SPA changed from 6,880 pre-harvest to 13,740 post-harvest, and for the diameter-limit cut stand, SPA changed from 8,760 pre-harvest to 12,400 post-harvest. The single-tree selection stand had increased SPA in all size classes; for the diameter-limit cut stand, regeneration less than one foot tall decreased by 3,840 SPA; all other size classes increased, with the 4-ft tall to 1.5 inch d.b.h. class having the greatest increase, from 420 SPA to 3,200 SPA. The largest increase by size class for the single-tree selection was in the 2-3 ft class, which increased from 220 to 2,440 SPA.

Total oak SPA declined post-harvest for both treatments (Table 2). Small (less than one foot tall) oak regeneration was impacted most by both harvesting treatments, declining by 860 SPA in the single-tree selection and by 1,580 SPA in the diameter-limit cut stand. The single-tree selection also resulted in a decline of oak in the 1-to-2-ft height class, from 440 to 320 SPA. However, both the 2-3 ft height class and the 3-4 ft height class of oak increased by 160 and 40 SPA, respectively. There were no oak tallied greater than 4 ft tall in the single-tree selection stand. For the diameter-limit cut stand, oak increased in all other size classes, with the largest increase occurring in the 2-3 ft height class. Oak regeneration that was 4 ft tall-to 1.5 inch d.b.h. increased by 40 stems to a total of 120 SPA post-harvest in the diameter-limit cut stand.

Sugar maple, red maple and white ash all experienced a decline in the smallest regeneration class for both treatments (Table 2). The single-tree selection had 440 SPA of sugar maple regeneration compared to 80 in the diameter-limit cut. Post-harvest, there were also more white ash regeneration in the single-tree selection compared to the diameter-limit cut, with 520 SPA compared to 40 SPA, respectively. Red maple SPA declined overall for the single-tree selection and increased for the diameter-limit cut. Both treatments had an increase in the largest regeneration size classes, resulting in 440 SPA of red maple in the single-tree selection and 800 SPA in the diameter-limit cut. The most prominent change in the regeneration cohort was observed for yellow-poplar. Yellow-poplar increased in all size classes for both treatments, resulting in 4080 SPA for the single-tree selection and 2060 for the diameter-limit cut. Yellow-poplar regeneration in both treatments was well represented in all size classes post-treatment.

DISCUSSION

We used stem diameter as a surrogate for tree age in designing a prescription to initiate the process of moving an assumed even-aged upland hardwood forest towards an uneven-aged system. The initial diameter distribution lent itself well towards this goal, as we had adequate numbers of stems of desirable species across size classes to both conduct a commercial harvest and to produce a residual stand that has adequate growing stock. Implementing the prescription was difficult. Following an intensive cruise of the entire stand, a spreadsheet was used to determine the desired residual stand and harvest component, by size class and then species. Although we marked the cut stand and had some checks in place, most of the 12-inch trees were removed (from 15 SPA to 2 SPA), and more 16 and 18 d.b.h. trees were left than prescribed. In contrast, the diameter-limit cut did not remove trees consistently in all diameter classes, but did remove most stems that were greater than 14 inches d.b.h. Only 6 stems per acre of 14 inch d.b.h. trees remained, and these were blackgum, yellow-poplar and hickory.

When single-tree selection is applied in stands that contain shade intolerant species, a shift in species composition can occur. It is difficult to discern this response after only one harvest entry, but we did attempt to remove trees of all species. Following the initial harvest, the overstory species composition retained a dominance of oak, remained consistent with both BA and SPA of hickory, and decreased in the proportion of sugar maple, red maple and yellow-poplar. For the diameter-limit cut stand, the residual stand was depleted of oak, with no oak equal to or greater than 16 inch d.b.h. in the residual stand, and only 2 SPA of oak in the 14 inch d.b.h. class. Although both stands are projected to have enough commercial volume to sustain at least one more harvest entry, without substantial recruitment and growth of the oak growing stock in the diameter-limit cut stand additional harvesting may have to be subsidized.

Stem quality may respond negatively to these partial harvests. With high stand densities, branchless boles are encouraged. The decrease in density in these stands may affect a few individual trees in the canopy, but these trees of higher vigor left in the single-tree selection stand should be less prone to epicormic branching (Trimble and Seegrist 1973; Meadows 1995). Inferior crown classes, especially overtopped white oak, may have the propensity to form epicormic branches (Miller 1996). Because only diameter was considered in the diameter-limit cut (not residual stand species composition or vigor), this practice could severely contribute to stand degradation via epicormic branching.

Few examples of sustained single-tree selection management have been reported for upland hardwood systems. In Missouri, on more xeric oak sites, uneven-aged management with single-tree selection has been shown to be viable if overstory density is maintained at 63 BA over a 20-year cutting cycle (Larsen and others 1999). In the Pioneer Forest of Missouri, Loewenstein and others (2000) have shown that over 40 years of single-tree selection management, there has been no discernable shift in species composition and the diameter distributions have remained stable for dominant species groups, especially oaks. In contrast, Della-Bianca and Beck (1985) and Loftis (2004) have reported that on a productive, mesic upland hardwood site, following 50 years and four cutting cycles, a diameter distribution approximating uneven-aged structure is present, but the majority of the smaller diameter stems are noncanopy, shade tolerant species. On our site, we have the potential to develop a commercially valuable species that is shade tolerant, sugar maple, under single-tree selection management. However, maintaining species composition congruent with the original stand, dominated by oak, is a primary management goal. How this stand continues to develop over time, with subsequent harvest entries, will rely on the ability of desirable species to recruit into larger size classes.

As a regeneration method, single-tree selection promotes shade-tolerant species. The initial disturbance in our stands allowed for an ephemeral increase in the amount of light beneath the main canopy. This increase pulse of light was around 20 percent of full sunlight, below the 30-50 percent of full sunlight needed to promote oak reproduction (Dey and Parker 1996; Hodges and Gardiner 1993, Ashton and Berlyn 1994, Gottschalk 1994). Oak reproduction between 2-to-4 ft in height increased in both the single-tree selection and diameter-limit harvest stands. A cohort of sugar maple in the reproduction exists, as does the potential for these stems to either remain viable over time, or respond to the next disturbance and occupy growing space in intermediate to dominant canopy positions. In another study on the Cumberland Plateau escarpment, in which the midstory was deadened to allow growing space and light to promote oak, sugar maple regeneration responded positively (Schweitzer 2004). She observed that the amount of full sunlight was 16 percent, similar to that in the single-tree selection stand in this study. The disturbances created by both the single-tree selection and diameter-limit cutting resulted in a variable light environment across the stands. In response, we observed a pulse of reproduction for shade intolerant yellow-poplar, as well as red maple and white ash. The potential for this cohort of mixed species to develop into mid- and overstory canopy species will be followed. We are also interested in how stump sprouting, especially oak stump sprouts, may contribute to sustained oak densities. Dey and others (2008) found that under single-tree selection in the Missouri Ozarks recruitment of oak stump sprouts into the overstory was reduced.

CONCLUSION

On productive sites on the Cumberland Plateau escarpment, managing for a suite of species presents some interesting challenges. In reality, forested stands that are primarily owned by non-industrial private landowners are being high-graded using diameter-limit cutting disguised as "selection" harvesting. Contrasting this practice with true single-tree selection will allow us to discern how these stands respond to these practices, and provide insight on how sustainable these practices are in terms of overstory species composition and regeneration recruitment. Constructing resultant stand structures that allocate sufficient growing space to all ages with representation across all desirable species is challenging. For example, we do not know the proper length of the cutting cycle for uneven-aged management in these systems, so this study will serve as a template to assist in developing prescription parameters. Residual stand degradation as determined by tree grade will assist in determining the economic feasibility of these practices.

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Table 1—Relative stems per acre (SPA) and basal area (BA) presented as a percentage of total, for single-tree selection and diameter-limit cut stands in Jackson County, AL

	Single-tree selection				Diameter limit cut			
	% SPA	% SPA	% BA	% BA	% SPA	% SPA	% BA	% BA
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Oaks	44	48	58.3	58.9	42	28	57.2	31.5
Hickories	13	7	12.7	6.3	14	19	11.2	17.2
Red maple	2	3	1	2	1	2	0.2	0.5
Sugar maple	6	6	2	2	8	13	3.3	10
Yellow-poplar	12	6	14	5	3	6	3.3	6.9
Others	33	30	12	25.8	22	22	24.8	33.9

oak species included red (*Quercus rubra*), black (*Q. velutina*), white (*Q. alba*), and chestnut (*Q. prinus*)
hickory species included mockernut (*Carya tomentosa*), pignut (*C. glabra*), red (*C. ovalis*), and shagbark (*C. ovata*)

Table 2—Average regeneration stems per acre (standard deviation) by 5 size classes for selected species in a stand subjected to Single-tree selection (STS) and a stand cut using a diameter-limit (DLC)

		<1' ht		1' to 2' ht		2' to 3' ht		3' to 4' ht		4' ht-1.5 " d.b.h.	
		pre	post	pre	post	pre	post	pre	post	pre	post
Oaks	STS	1520 (1880)	660 (168)	440 (632)	320 (120)	20 (38)	180 (81)	0 (0)	40 (18)	0 (0)	0 (0)
	DLC	2520 (3168)	940 (302)	580 (1004)	740 (257)	40 (76)	220 (82)	0 (0)	60 (25)	80 (136)	120 (54)
Sugar maple	STS	580 (496)	240 (280)	20 (32)	180 (216)	0 (0)	0 (0)	0 (0)	0 (0)	20 (32)	20 (32)
	DLC	60 (48)	20 (32)	20 (32)	40 (48)	20 (32)	20 (32)	0 (0)	0 (0)	60 (96)	0 (0)
White ash	STS	520 (792)	60 (96)	180 (248)	100 (128)	60 (72)	200 (320)	0 (0)	60 (96)	80 (128)	100 (160)
	DLC	60 (32)	0 (0)	60 (32)	0 (0)	0 (0)	20 (32)	0 (0)	20 (32)	0 (0)	0 (0)
Red maple	STS	1220 (102)	660 736)	40 (48)	60 (96)	20 (32)	40 (64)	0 (0)	0 (0)	80 (96)	440 (624)
	DLC	600 (760)	160 (192)	40 (64)	180 (216)	40 (48)	120 (64)	40 (48)	80 (64)	420 (472)	800 (680)
Yellow-poplar	STS	60 (72)	2100 (520)	60 (96)	900 (640)	0 (0)	700 (840)	0 (0)	240 (248)	0 (0)	140 (168)
	DLC	40 (64)	580 (696)	0 (0)	800 (704)	0 (0)	340 (472)	0 (0)	160 (168)	20 (32)	180 (184)

oak species included red (*Quercus rubra*), black (*Q. velutina*), white (*Q. alba*), and chestnut (*Q. prinus*)

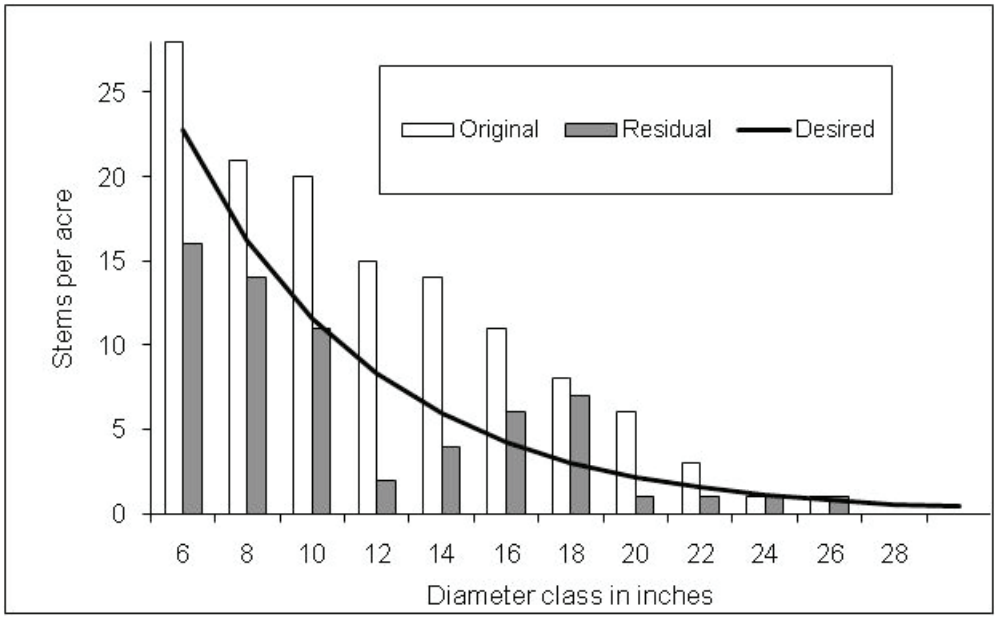

Figure 1—Diameter distribution of stems per acre by size classes for the single-tree selection stand, depicting the original stand's diameter distribution, the desired stand's distribution using the parameter of 65 ft2 of basal area, maximum stem diameter of 30 inches, and a q of 1.3, and the resultant residual stand's distribution.

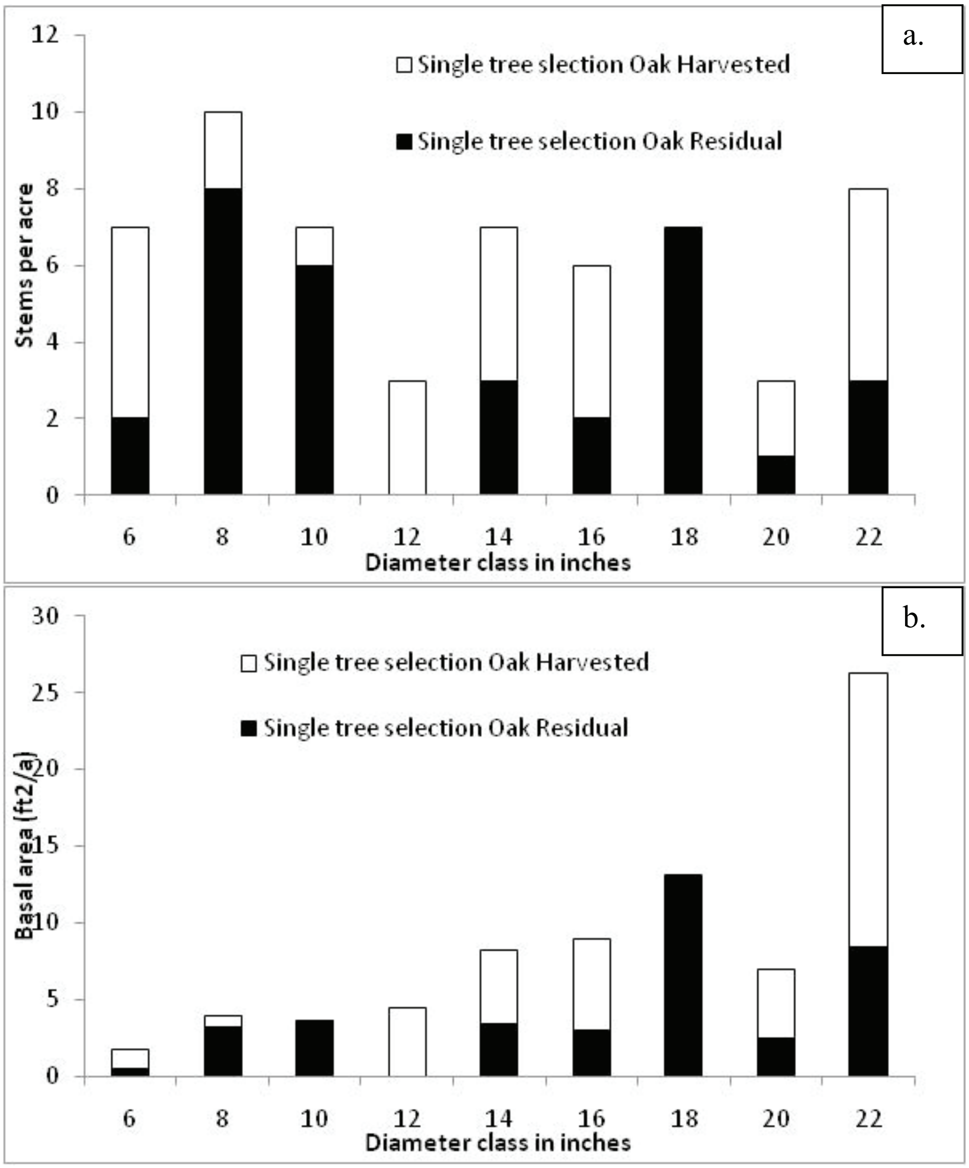

Figure 2—Distribution of all oak (*Quercus rubra, velutina, alba* and *prinus*) in the single-tree selection stand by stems per acre (a) and basal area (b) by diameter classes showing the harvested and residual stand.

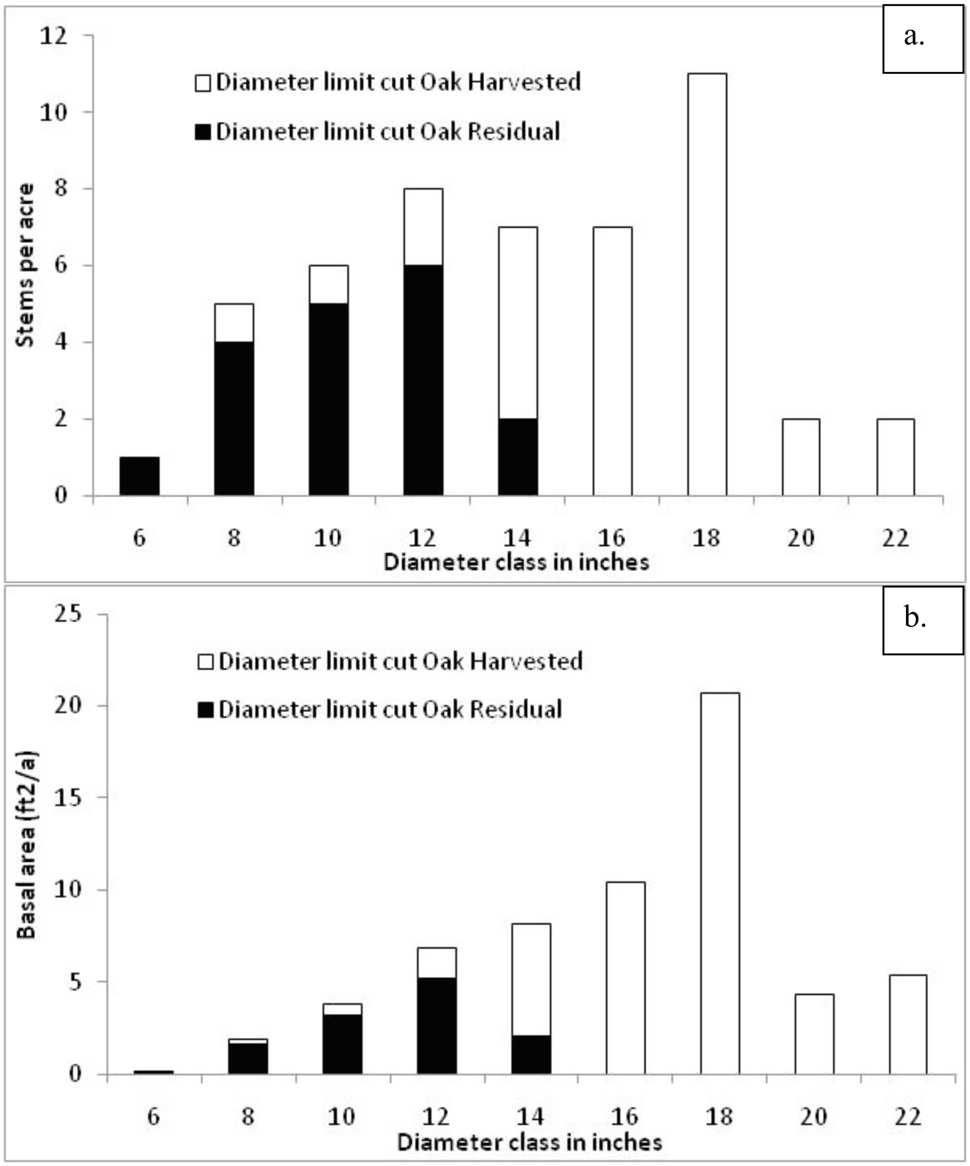

Figure 3—Distribution of all oak (*Quercus rubra, velutina, alba* and *prinus*) in the diameter-limit cut stand by stems per acre (a) and basal area (b) by diameter classes showing the harvested and residual stand.