USING SILVICULTURE TO SUSTAIN UPLAND OAK FORESTS UNDER STRESS ON THE DANIEL BOONE NATIONAL FOREST, KENTUCKY

Callie Jo Schweitzer, Kurt W. Gottschalk, Jeff W. Stringer, Stacy L. Clark, and David L. Loftis[1]

Abstract.—We used a large-scale silvicultural assessment designed to examine the efficacy of five stand-level prescriptions in reducing the potential impacts of gypsy moth infestations and oak decline on upland hardwood forests in Kentucky's Daniel Boone National Forest. Prescriptions involved a mix of intermediate stand treatments aimed at increasing residual tree vigor and regeneration treatments aimed at maintaining regeneration diversity. Prescriptions were as follows: (1) shelterwood with reserves, (2) shelterwood with midstory removal through herbicide, (3) B-line thinning, (4) creation of an oak woodland, and (5) untreated control. Thirty stands were chosen, half originally classified as sub-mesic and half classified as sub-xeric oak forest types. Prescriptions were replicated three times on each site type. Moisture classification index classified 24 stands as sub-xeric and 6 as sub-mesic. Stand basal areas were reduced to 22.9, 80.6, and 68.3 square feet per acre, in the shelterwood with reserves, thinning, and oak woodland treatments, producing reductions equivalent to 81, 39, and 52 percent, respectively. Early assessment showed a slight increase in tree vigor as determined by crown cover and position for residual trees in these three treatments. In the oak shelterwood treatment, oak seedlings greater than 1 foot in height increased from 191 to 325 stems per acre following herbicide treatment that targeted non-oak mid-canopy trees such as red maple, yellow-poplar, and blackgum.

INTRODUCTION

The Cumberland Plateau, the southernmost section of the Appalachian Plateau's physiographic province, comprises more than 9 million acres of forest land (Fenneman 1938; Smalley 1979, 1982, 1986). Kentucky's Daniel Boone National Forest (DBNF), London District, lies in the heart of the Cumberland Plateau. On the Plateau uplands, mixed hardwood forests dominate, and oaks are the most widespread genus, with the most common being white oak (*Quercus alba* L.), scarlet oak (*Q. coccinea* Muench.), black oak (*Q. veluntina* Lamarck), northern red oak (*Q. rubra* L.), post oak (*Q. stellata* Wang.), and chestnut oak (*Q. montana* L.) (Braun 1950, Hinkle 1989). On the most xeric sites, oaks such as chestnut oak and scarlet oak dominate, and on less xeric sites, northern red oak and white oak are more common. These stands also contain myriad other species, including hickories (*Carya* spp.), maples (*Acer* spp.), yellow-poplar (*Liriodendron tulipifera* L.), sourwood (*Oxydendrum arboretum* DC), sassafras (*Sassafras albidum* [Nutt.]Nees.), and scattered pine (*Pinus* spp.). Stands are considered stressed due to site conditions, management histories, competition between species, and other disturbances. Another potential stressor on Kentucky's forests is the encroachment of the gypsy moth (*Lymantria dispar* L.).

[1]Research Forester (CJS), Southern Research Station, U.S. Forest Service, P.O. Box 1568, Normal, AL 35762; Project Leader (KWG), Northern Research Station, U.S. Forest Service, 180 Canfield St., Morgantown, WV 26505; Extension Professor (JWS), Department of Forestry, University of Kentucky, Lexington, KY 40546; Research Forester (SLC), Southern Research Station, U.S. Forest Service, Knoxville, TN 37996; Research Forester (DLL), Southern Research Station, U.S. Forest Service, Asheville, NC 28806. CJS is corresponding author: to contact, call (256) 372-4230 or email cschweitzer@fs.fed.us.

Gypsy moth currently infests 25 percent of its potential range in eastern North America and is spreading at a rate of 13 miles per year (Liebhold and others 1989, 1992). A national management program was initiated in 2000 to slow the spread of gypsy moth and has reduced the spread rate by 50 percent. It is estimated that gypsy moth will spread to the DBNF over the next 15 to 30 years with trap catches of gypsy moth males occurring in northeastern Kentucky over the last couple of years. In other stands defoliated by gypsy moth, silvicultural treatments that increased tree and crown vigor were found to reduce mortality (Gottschalk and others 1998).

This study examines treatments that DBNF management might use to increase overall stand vigor and to regenerate stands while maintaining a high oak component. Silviculture regimes for oak-dominated stands and for oak regeneration methods have been described in similar systems (Loftis 1983, Sander and others 1984, Loftis 1990a, Dey 1991, Johnson and others 2002, Brose and others 2008). We manipulated stand structure in two primary forest types (sub-xeric and sub-mesic oak forests) to sustain or increase stand vigor, while giving appropriate attention to how such disturbances influence the competitiveness of oak regeneration. This study will assess the alteration in species composition and stand structure with respect to vulnerability to gypsy moth and oak decline. We will also assess the projected regeneration outcomes. As part of this study, researchers will examine the costs, operational performance, and forest floor disturbance impacts of an integrated mechanized forest operation used to implement the treatments. In this paper, we will present preliminary data detailing sub-xeric and sub-mesic site characterization, and changes in forest structure post-treatment, including basal area reduction, relative stand density reduction, species composition changes, and canopy cover and class differences.

METHODS

SITE DESCRIPTION

The study area is located on the Cold Hill Area of the London Ranger District of the DBNF, Kentucky. The treatment stands are located on the Central Escarpment (221 Hb) land-type association, as described in the Land and Resource Management Plan (2004: 1-8). All treatment stands are located on broad ridges. Treatment stands were relatively similar prior to treatment and uniform within stand boundaries, and are best described as upland hardwood forests dominated by oak species. Total basal area ranges from 100 to 120 square feet per acre, relative stand density from 60 to 104 percent, and ages from 70 to 150 years old. The stands have been subjected to various silvicultural treatments, including harvesting and prescribed burning, since the National Forest acquired the land, but the stands are representative of fully stocked upland hardwood forests on the Cumberland Plateau. Stand boundaries were delineated based on several factors, including administrative constraints, proximity to road infrastructure, stand history, ownership boundaries, topography, soil type, and species composition.

TREATMENTS

The field structure for this study was a quasi-randomized design, 2 X 5 factorial with three replications. Replications were not blocked. Stands, which equal treatments, were randomly chosen from a pool of potential stands located across the landscape. Forest types were randomly distributed but represented fixed factors: sub-mesic (site index for upland oaks estimated at 65-80 feet at base age 50) and sub-xeric (site index 50-65 feet) oak forests (Smalley 1986). The other factor was silvicultural treatment with five levels: (1) shelterwood with reserves, (2) oak shelterwood, (3) thinning, (4) oak woodland, and (5) a control. Fifteen stands from each of the two forest types were randomly assigned a treatment. Thus, 10 treatment conditions were replicated across the study area. The following is a description of each of the silvicultural treatments:

1. **Shelterwood with reserves.** This treatment will leave a residual basal area of 10 to 25 square feet per acre. Residual trees will be selected to promote increased forest health conditions and to improve habitat for wildlife and plant species that benefit from open, low basal area forest conditions. Oak species will be favored. A new stand will regenerate beneath the reserve trees and eventually create a two-aged stand structure.
2. **Oak shelterwood.** This treatment will not initially impact the overstory basal area. All basal area will be removed from the midstory and understory without making canopy gaps in the overstory. Undesirable tree species less than 3 inches diameter at breast height (d.b.h.) will be treated with a thinline basal bark treatment using triclopyr ester. Trees greater than 3 inches d.b.h. in the midstories and understories will be treated with a stem injection method using triclopyr amine. Undesirable tree species include those specifically in competition with oaks, such as red maple (*A. rubrum* L.), yellow-poplar, and trees with unhealthy stems and/or crowns. When sufficient advanced oak regeneration is present, the overwood will be removed to create a new even-aged oak stand (Loftis 1990b).
3. **Thinning.** This treatment will utilize the Gingrich stocking chart to thin to B-level stocking (Gingrich 1967). Reducing tree density will allow the residual trees to take advantage of improved growing conditions. The result should be increased tree vigor, larger crown diameters, continued or improved diameter growth, and increased capacity to survive defoliation. The thinning treatment was marked using crown vigor guidelines as well as stocking goals to match the presalvage thinning prescription (Gottschalk and MacFarlane 1992, Gottschalk 1993).
4. **Oak woodland.** This treatment will be conducted by first thinning to 45 to 70 square feet per acre followed by prescribed burning every 3 to 5 years. White oaks will be favored as residual trees to increase hard mast production and bat habitat. An objective of the treatment will be spatial and vertical heterogeneity. Another objective is to increase the native ground flora of forbs and grasses that depend on fire. Prescribed burns will be operational spring burns conducted by DBNF personnel.
5. **Control.** This treatment will not receive a silvicultural prescription and will be used to compare and evaluate the results of change from the above treatments.

A mechanical tree-length harvesting system was used to harvest all units. The system consisted of a feller buncher, grapple skidder, and a knuckleboom loader. Trees larger than 23 inches d.b.h. were felled with a chainsaw. All limbing and topping were performed with a chainsaw in the stand. Products removed from the stands included hardwood sawtimber and biomass logs. A biomass log was any material greater than 3 inches d.b.h., reasonably straight, and at least 10 feet long, and that did not qualify as a saw log. Harvesting began in November 2007 and was completed for all 18 stands in September 2009. Herbicide treatment for the oak shelterwood was done between October 2008 and March 2009.

DATA COLLECTION

We established twenty 0.1-acre vegetation measurement plots in each stand and measured plots prior to and just after treatment implementation. All plot centers are permanently marked with rebar, flagging, and global positioning system coordinates. We permanently labeled all trees 4.6 inches and greater d.b.h. We measured and recorded tree species, d.b.h., crown condition, tree grade, canopy cover, and tree height. In each plot, we also created a 0.01-acre plot where we enumerated regeneration (trees < 1.5 inches d.b.h.) by species and height class. We randomly selected five vegetation plots in each unit, and on those plots we tagged five representative seedlings per regeneration plot and recorded species and measured height and basal diameter (immediately above the root collar). Overstory data were collected following one growing season for all stands and regeneration data were collected following one growing season for all stands except those treated in late summer 2009, which were excluded from this analysis. For post-treatment in the oak shelterwood treatment only, we surveyed status, species, and d.b.h. for all stems 1.6 inches and greater on five 0.025-acre plots to assess this treatment, which targeted smaller-diameter stems.

STATISTICS

The combination of the two factors (2 X 5) and three replications will result in 30 treatment stands. The general statistical analysis model for categorical and continuous variables measured in the study is a mixed model analysis of variance for factorial designs. Because treatment stands were chosen from the larger population of stands within the Cumberland Plateau, they will be treated as random within the analysis. Forest type will be treated as fixed. Due to the relatively large area occupied by each treatment stand, the assumption of independence between treatments is warranted. Treatment stands were assigned randomly within each replication and replications were assigned randomly. Statistical significance of the F-value at the 0.05 significance level for a factor or interaction between factors would initiate further analyses. We used Tukey's Honestly Significant Difference (HSD) tests for means separation. All analyses were carried out using SAS® Version 8.01 (SAS Institute Inc., Cary, NC).

RESULTS

SITE CLASSIFICATION

We used a moisture classification index (MCI) devised by McNab and others (2002) to classify each stand as sub-xeric or sub-mesic. The initial classification was done by DBNF personnel based on broad characterization of each stand's topography and edaphology, and through an estimated site index based on limited tree core analysis and soil surveys. McNab and others (2002) classification uses a stand-level species list, assigns a moisture weight to each species listed, and then calculates an average MCI by summing all weights and dividing by the total number of species listed. The MCI scale is from 0 to 4, with a species such as red maple having a weight of 0 (indicative of neither xeric nor mesic conditions), a post oak having a weight of 1 (xeric classification if value is <1.5), and a basswood (*Tilia glabra* Vent.) having a weight of 4 (mesic classification if value is >3.5). Moisture weights from McNab and others' (2002) were used, and species tallied in DBNF stands not listed in theirs paper were assigned a value by McNab (W.H. McNab, Southern Research Station, U.S. Forest Service, 1577 Brevard Road, Asheville, NC 28806, personal communication). MCI for each of the 30 stands in this study are given in Table 1. In summary, for the 30 stands, the MCI ranged from 1.63 to 2.63, with 24 stands falling within the sub-xeric range (between 1.5 and 2.4) and six stands classified as sub-mesic (between 2.5 and 3.4). Four of the sub-mesic stands had values at 2.5.

OVERSTORY COMPOSITION AND STRUCTURE

We measured 9,032 trees with d.b.h. that ranged from 4.6 to 46 inches. Thirty different species were identified in these stands. There were three *Pinus* species, dominated by shortleaf pine (*P. echinata* Mill.), with a smaller proportion of Virginia pine (*P. virginiana* Mill.) and pitch pine (*P. rigida* Mill.). There were also, on average, four eastern hemlock trees (*Tsuga canadensis* [L.] Carr.) per acre, with the majority in the pole-size class. Other species included upland oaks (chestnut oak, white oak, northern red oak, scarlet oak, southern

Table 1.—Moisture Classification Index (MCI) for each study stand on the Daniel Boone National Forest, KY. Stand numbers followed by an 'm' indicate initial mesic designation. Stand numbers followed by an 'x' indicate xeric. MCI between 1.5 and 2.4 indicates sub-xeric. MCI between 2.5 and 3.4 indicates sub-mesic. Bold, italicized text indicates stands that differed between initial and MCI classifications.

Treatment	Stand	MCI
Control	1m	2.63
Shelterwood with reserves	***2m***	***1.63***
Oak shelterwood	***3m***	***2.33***
Oak woodland	4m	2.53
Control	***7m***	***2.35***
Oak shelterwood	***10m***	***2.29***
Thinning	***11m***	***2.45***
Shelterwood with reserves	***12m***	***2.31***
Control	***13m***	***2.21***
Oak shelterwood	14m	2.54
Oak woodland	***15m***	***2.41***
Shelterwood with reserves	***16m***	***2.23***
Thinning	***17m***	***2.11***
Thinning	18m	2.54
Oak woodland	***19m***	***2.36***
Oak woodland	20x	2.47
Thinning	***21x***	***2.58***
Oak woodland	22x	2.17
Oak woodland	23x	2.29
Oak shelterwood	24x	2.44
Thinning	25x	2.39
Control	26x	2.33
Oak shelterwood	27x	2.45
Control	28x	2.50
Shelterwood with reserves	29x	2.37
Oak shelterwood	31x	2.33
Shelterwood with reserves	32x	2.31
Thinning	33x	2.12
Control	34x	2.27
Shelterwood with reserves	35x	2.30

red oak [*Q. falcata* Michx.], blackjack oak [*Q. marilandica* Muench.], post oak, and black oak), hickories (shellbark hickory [*C. laciniosa* Schneid.], shagbark hickory [*C. ovata* K. Koch.], and mockernut hickory [*C. tomentosa* Nutt.]), red maple, sourwood, and lesser amounts of species such as yellow-poplar and blackgum (*Nyssa sylvatica* Marsh.). We found no significant differences for basal area (BA, in square feet per acre) (P = 0.072) and stems per acre (SPA) (P = 0.20) among the five treatments prior to treatment implementation (Table 2). Basal area in these study stands ranged from 103.6 to 120.0 (standard deviation [std] 0.3-9.2), and SPA were 143-159 stems per acre (std 8-20). There were no significant differences for BA (P = 0.4282) and SPA (P = 0.08370) for stands originally identified as sub-mesic, which had average BA of 113.5 (std 9) and 146 (std 1.5) SPA compared to sub-xeric stands, which had BA of 110.7 (std 7.2) and 156 (std 4) SPA. There were no treatment-by-site interactions.

Table 2.—Basal area (BA, in square feet per acre) and stems per acre (SPA, minimum d.b.h. 4.6 inches) values for all five treatments, pretreatment and post-treatment, on the Daniel Boone National Forest, KY. Values with different letters within the same column are significantly different at the 0.05 level.

	Pretreatment		Post-treatment	
	BA (std)	SPA (std)	BA (std)	SPA (std)
Shelterwood with Reserves	103.6 (0.3) a	149 (13) a	22.9 (1.1) d	19 (2) d
Oak Shelterwood	106.6 (0.4) a	143 (20) a	107.5 (0.9) a	115 (11) b
Thinning	119.3 (9.2) a	150 (11) a	80.6 (7.9) b	61 (7) c
Oak Woodland	120.0 (3.2) a	153 (8) a	68.3 (4.2) c	49 (4) c
Control	110.0 (4.3) a	159 (14) a	118.2 (5.0) a	159 (14) a

Although not necessarily the goal of these treatments, four significantly different BA and SPA regimes post-treatment (Table 2) were created. As expected, control and oak shelterwood stands did not differ because the goal of the oak shelterwood treatment was to target midstory trees without creating canopy gaps. There was significantly greater residual BA in the thinning treatment compared to the oak woodland and shelterwood with reserves treatments; however, residual SPA for the thinning treatment was not significantly different from SPA in the oak woodland. The shelterwood with reserves treatment had significantly less BA and SPA compared to the other four treatments. The change in BA was greatest for the shelterwood with reserves treatment (80.8), followed by the oak woodland (51.8) and the thinning (38.7). SPA change was also greatest for the shelterwood with reserve treatment (SPA change = 130), but the amount of change did not differ from that of the oak woodland treatment (105). The oak woodland SPA change did not differ from that of the thinning (SPA change = 89 . Oak BA increased from 70 to 88 percent of the total basal area for the oak woodland treatment, and from 61 to 74 percent in the shelterwood with reserves. Diameter distributions of each treatment, for the cut or herbicided and residual stand, are presented in Figure 1.

In the oak shelterwood treatment, pretreatment and post-treatment BA for the overstory trees did not differ, as the treatment targeted midstory species. We added supplemental plots in these treatments to assess those smaller-diameter trees that were subjected to the herbicide treatment. Using all stems with d.b.h. 1.6 inches or greater, we found BA changed from 100.0 pretreatment to 85.8 post-treatment, and SPA changed from 333 pretreatment to 139 post-treatment. We herbicide-treated, on average, 176 SPA that had an average d.b.h. of 3.0 inches and a range of d.b.h. of 1.6 to 9.1 inches. Of the 176 SPA treated with herbicide, 106 were red maple, 13 were yellow-poplar, and the rest included blackgum, sourwood, sassafras, bigleaf magnolia (*Magnolia macrophylla* Michx.), and serviceberry (*Amelanchier aborea* [Michx. f.] Fern.). The residual stands comprise primarily oaks, hickories, and red maple, with a lesser component of shortleaf pine, yellow-poplar, sourwood, and flowering dogwood (*Cornus florida* L.).

The thinning treatment reduced BA from 119 to 81, and SPA changed from 150 to 61. According to the Gingrich guide (1967), our stands were taken from nearly 100 percent stocked (A-line) to just above 60 percent stocked, B-line, as was the objective (Fig. 2). The majority of the removed stems were taken from the 5.5- to 9.5-in. diameter class (53 SPA), although stems were removed from all diameter classes (Fig. 1.d.). The percentage of total basal area dominated by oak species changed from 54 percent pretreatment to 64 percent post-treatment.

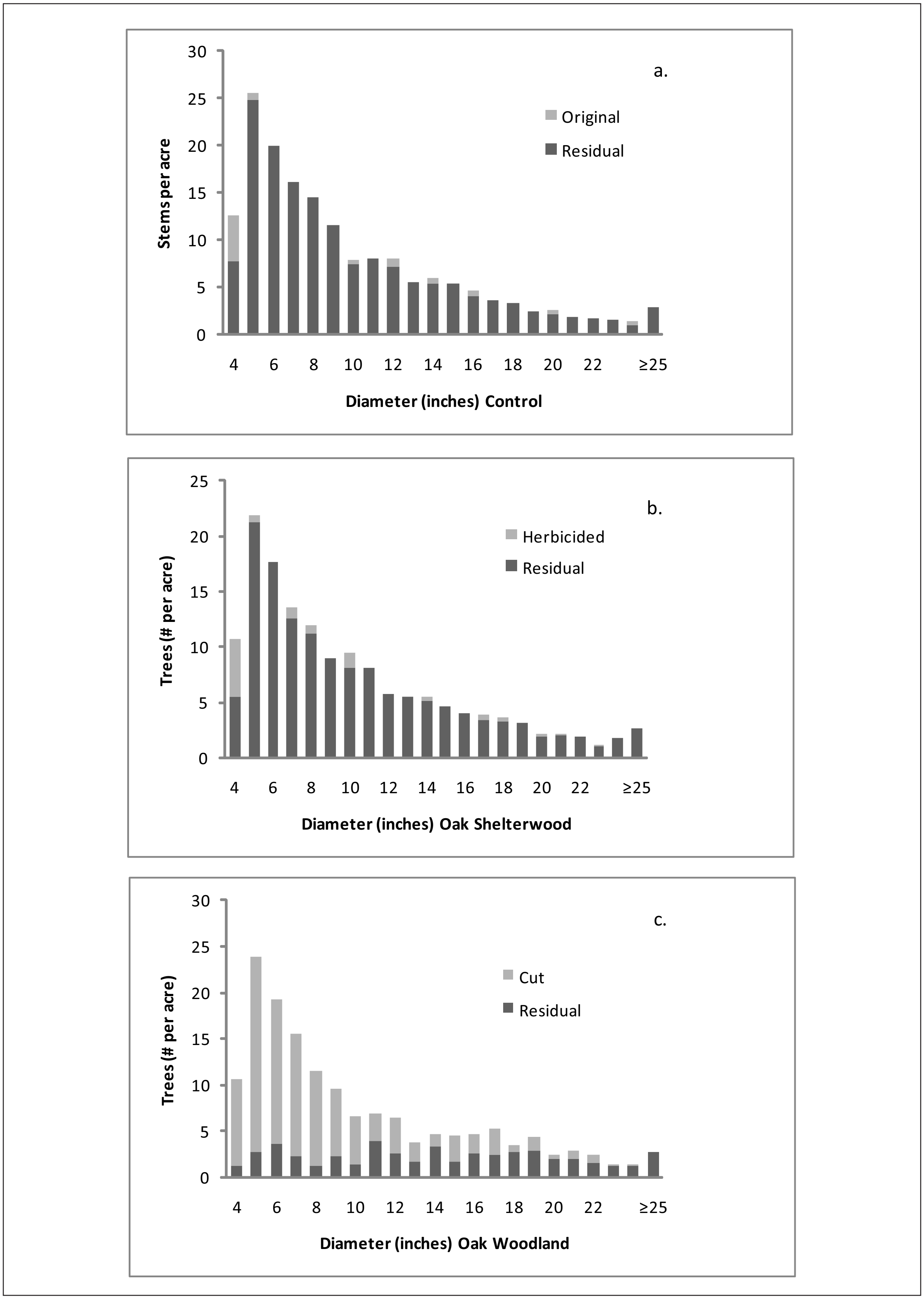

Figure 1.—Treatment diameter distributions for cut and residual trees, Daniel Boone National Forest, KY; lettered graphs depict treatments as: a. Control, b. Oak shelterwood, c. Oak woodland, d. Thinning, and e. Shelterwood with reserves. (Figure 1 continued on next page.)

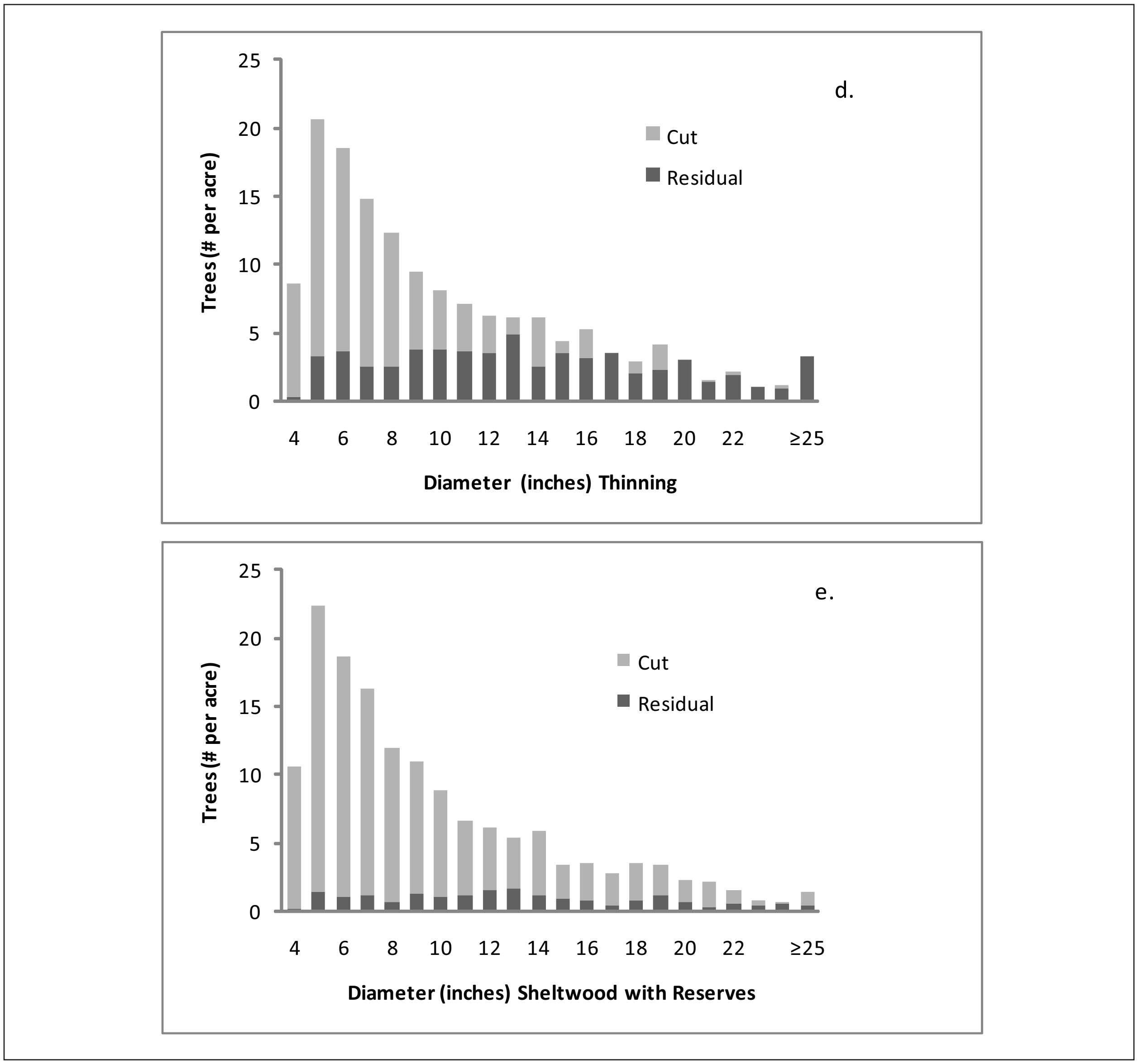

Figure 1 (continued).—Treatment diameter distributions for cut and residual trees, Daniel Boone National Forest, KY; lettered graphs depict treatments as: a. Control, b. Oak shelterwood, c. Oak woodland, d. Thinning, and e. Shelterwood with reserves.

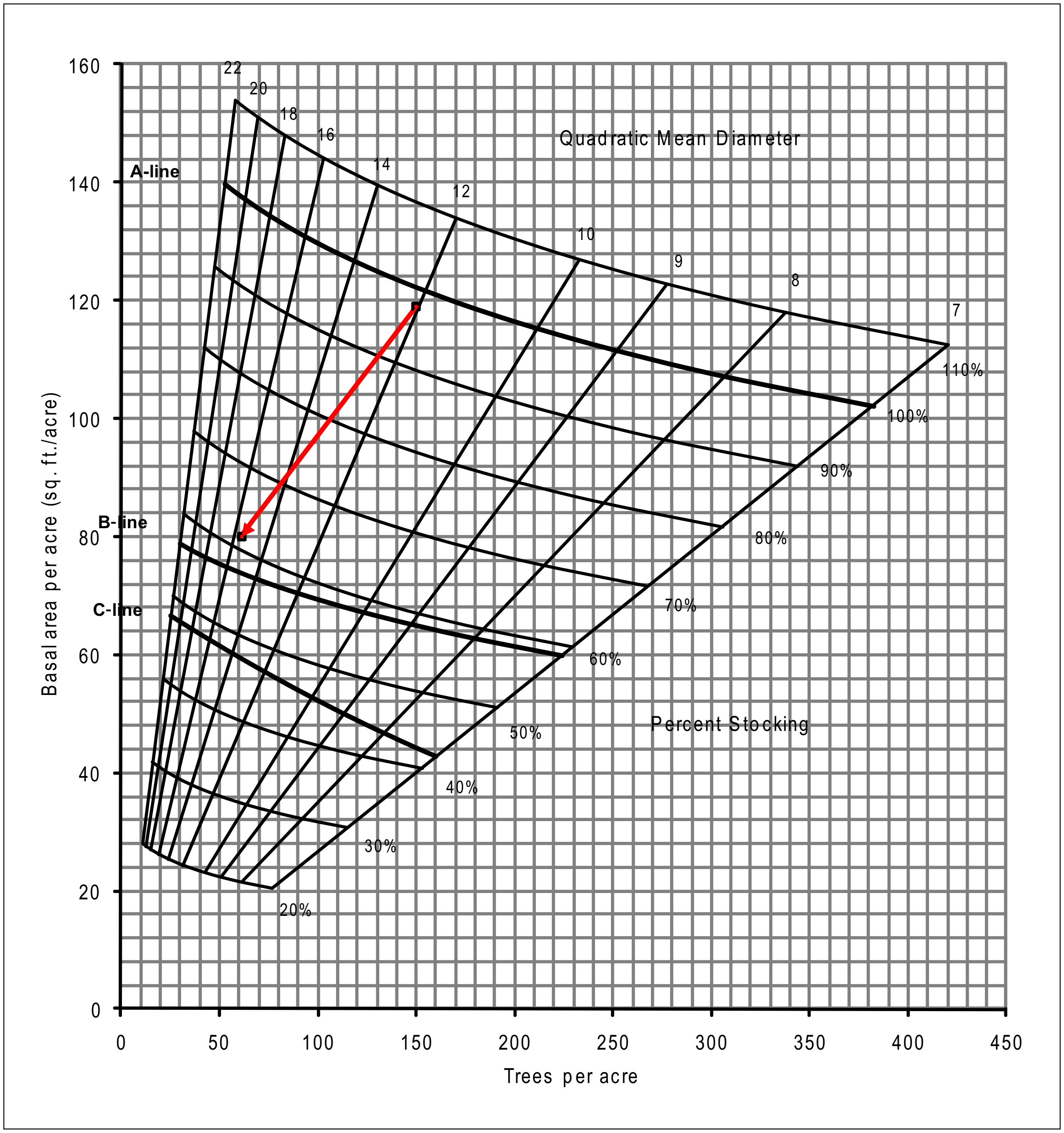

Figure 2.—Plot of stand data from six thinned stands on the Daniel Boone National Forest, KY, superimposed on Gingrich's (1967) stocking guide for central hardwood forest stands. The arrow represents the direction of stocking from pretreatment to post-treatment levels.

VIGOR, CROWN CLASS, TREE CLASS, AND DAMAGE

In the shelterwood with reserves treatment, there were on average two large sawtimber trees per acre (d.b.h. class 23.6 inches and greater), and these trees had a vigor class of 2.0 and a crown class of 3.0 (see Table 3 for vigor ratings and Table 4 for treatment values). The residual stands had only eight large sawtimber trees total; one residual white oak, which was co-dominant with a crown vigor of 1.0, had more than 200 epicormic branches post-treatment and two other residual trees had large bole wounds (600 and 18 1-square inch wounds, respectively). Medium sawtimber trees had few boles with epicormic branches (less than one tree per acre), and little damage was noted.

In the thinning treatment, medium and large sawtimber dominate the residual stand; their vigor class increased slightly, a result of the removal of lower-vigor trees, and these co-dominant trees will now receive more light from the sides (Table 4). Few epicormic branches were noted in these tree classes; less than one large sawtimber tree per acre had an average of four epicormic branches per tree, and three medium sawtimber trees per acre had two epicormics per tree. The majority of the medium sawtimber trees displaying epicormic branching were white oak, black oak, and scarlet oak. Few wounds were found on the lower boles of residual trees; three small sawtimber trees per acre had 2 to 1,000 1-square inch wounds, and less than one tree per acre was wounded in the medium and large sawtimber classes.

The oak woodland residual stands showed an increase in vigor class for all sizes except saplings (Table 4). Incidence of epicormic branching increased from one residual tree per acre to between four and six residual trees per acre in the large, medium, and small sawtimber classes. The trees displaying epicormic branching were again primarily white oak, black oak, and scarlet oak. Residual pole-sized trees had the greatest bole damage, with five SPA damaged; four SPA were damaged in the small sawtimber class, three SPA were damaged in the medium sawtimber class, and less than one SPA was damaged in the large sawtimber class.

REGENERATION

We tallied 52 woody species in the regeneration plots, which included shrubs such as *Vaccinium* spp., *Euonymus* spp., and *Viburnum* spp. Because we tallied only up to 25 stems in any one height class, our sums are not a true total of the stems per acre. On average across all stands, prior to treatment, we tallied 2,624 SPA less than 1 foot tall, 1,403 SPA greater than 1 foot in height but less than or equal to 1.5 inches d.b.h., and 85 stems greater than 1.5 inches d.b.h. For the stands that underwent a harvest, these values changed to 2,002 SPA less than 1 foot tall, 1,720 SPA greater than 1 foot tall and less than 1.5 inches d.b.h., and 50 SPA greater than 1.5 inches d.b.h. For the control and oak shelterwood treatments, seedlings less than 1 foot tall were 2,503 SPA, stems greater than 1 foot tall but less than 1.5 inches d.b.h. were 1,269 SPA, and stems over 1.5 inches d.b.h. were 83 SPA

In the oak shelterwood treatment, oak seedling SPA were 628 (<1 foot), 191 (>1 foot tall but ≤1.5 inches d.b.h.), and 24 (>1.5 inches d.b.h.) prior to the midstory herbicide treatment, and 594, 325, and 19 SPA for the same classes, respectively, post-treatment. We will continue to follow this increase in the intermediate-sized regeneration because it is this stem size where the treatment response is expected. Red maple stems also slightly increased in this size class, from 463 SPA to 486. Red maple greater than 1 foot tall and less than 1.5 inches d.b.h. also increased in the three harvest treatments by 97 SPA in the thinning (547 SPA total post-treatment), 131 SPA in the oak woodland (621 SPA total post-treatment), and 202 SPA in the shelterwood with reserves (464 SPA total post-treatment). In this same size class, oak SPA increased to 218 in the thinning

Table 3.—Vigor rating based on tree crown and bole condition, adopted from Gottschalk (1993) to assess tree vigor on the Daniel Boone National Forest, KY.

	Vigor				
Class	% dead branches	Crown assessment	Foliage description	Epicormic branching	Stump sprouts
1 - Healthy	0-10	Healthy	Dense; green	None	None
2 - Good	11-25	Good	Density subnormal	Few	None
3 - Fair	26-50	Fair	Density and color subnormal	Some	None
4 - Poor	51-80	Poor	Density, color, and size subnormal	Heavy	None
5 - Very poor	81-100	Very poor, apparently dying	Extremely sparse	Tree living on sprouts	None
6 - Top-killed	100	Tree above ground completely dead	Does not exist	None	Live present
7 - Dead	100	Tree completely dead	Does not exist	None	None

Table 4.—Pretreatment and posttreatment stems per acre (SPA), basal area (BA in ft²/acre), tree vigor, and crown class rating by sawtimber sizes for three treatments (shelterwood with reserves, thinning, and oak woodland) on the Daniel Boone National Forest, KY. A description of vigor classes is given in Table 3.

	Large sawtimber (d.b.h 23.6. inches and greater)	Medium sawtimber (d.b.h. 17.6-23.5 inches)	Small sawtimber (d.b.h. 11.6-17.5 inches)	Pole timber (d.b.h. 5.6-11.5 inches)	Saplings (d.b.h. 1.8-5.5 inches)
Shelterwood with Reserves					
SPA-pre	2	12	23	32	23
SPA-post	<1	3	5	6	1.0
BA-pre	8.6	27.0	25.2	26.5	3.3
BA-post	2.3	5.9	5.3	2.6	0.2
Vigor class-pre	1.9	1.8	1.7	1.9	2.2
Vigor class-post	1.5	1.3	1.3	1.8	2.1
Crown class*-pre	2.8	2.7	3.2	4.2	4.7
Crown class-post	3.3	2.7	2.8	3.9	4.2
Thinning					
SPA-pre	4	15	28	67	18
SPA-post	4	12	19	17	2
BA-pre	17.7	33.1	21.3	24.2	2.6
BA-post	14.3	26.1	21.8	7.5	0.3
Vigor class-pre	1.5	1.6	1.5	1.8	2.1
Vigor class-post	1.0	1.1	1.1	1.5	1.5
Crown class-pre	2.9	3.0	3.3	4.3	4.7
Crown class-post	2.9	3.0	3.2	4.1	4.7
Oak Woodland					
SPA-pre	4	17	24	70	23
SPA-post	3	11	13	14	3
BA-pre	14.2	38.6	27.3	24.8	3.2
BA-post	12.7	24.7	15.1	5.7	0.4
Vigor class-pre	2.1	2.0	2.0	2.1	2.3
Vigor class-post	1.2	1.2	1.2	1.4	2.2
Crown class-pre	2.8	2.8	3.1	4.1	4.6
Crown class-post	2.9	2.9	3.1	4.1	4.9

*Crown classes are defined as 1-Open Grown, 2-Dominant, 3-Co-dominant, 4-Intermediate, 5-Overtopped and 206 in the oak woodland treatments. Red maple stems greater than 1.5 inches declined in all three harvest treatments, by 31 SPA in the thinning, 35 SPA in the oak woodland, and 43 SPA in the shelterwood with reserves, resulting in post-treatment SPA of 7, 6, and 2, respectively.

DISCUSSION

Although the study was initially designed to assess forest management response on two site types, our analysis (conducted post-stand selection) showed that the average MCI did not differ among most stands, with the majority classified as sub-xeric. The two stands that had the highest MCI were stands 1 and 28. Stand 1 had a mix of water tupelo (*Nyssa aquatic* L.), hemlock, northern red oak, and yellow-poplar, and had the only sweet birch (*Betula lenta* L.) tallied. All of these species had moisture gradient values between 3.0 and 3.5. Stand 28 had a similar species composition, minus the sweet birch. The other stands with MCI values near 2.5 contained hemlock, yellow-poplar, and flowering dogwood. In these stands, few black walnut (*Juglans nigra* L.) but many bigleaf magnolia trees were present. An examination of soil series, by measurement plot, did not reveal any predominant soil series in sub-xeric or sub-mesic stands, and most series were broadly represented across the study.

Of the primary growth factors for forest trees (site quality, stand density, and species composition), density is more easily affected by management decisions, while species composition is more minimally controlled by management. Thinning can improve average tree quality by removing defective trees or undesirable species. Gingrich's (1967) B-line stocking uses open-grown crown radius to define minimal full stocking. This release should improve future tree quality by maintaining the vigor of individual trees and allowing resources to be directed to the chosen residuals. By achieving the desired residual stocking, we expect the desired residual trees to respond to release.

Crown vigor and crown class most likely have not had enough response time since treatment implementation (1-year post-treatment assessment) to show differences from pretreatment values. However, the management regimes under study favored the retention of higher-vigor trees in all size classes, with minimal bole damage and sporadic epicormic branching. These parameters will be followed as indicators of tree vigor and potential resiliency to defoliation stress.

Although this study employed a variety of silvicultural treatments, all harvesting disturbances should be planned to provide for successful recruitment of desired species. We currently have three scenarios in which the canopy has been subjected to partial harvesting. These individual residual trees will influence the development of the next stand, and we will follow this process over time. In particular, we question whether intolerant and mid-tolerant species can exhibit sufficient height growth to survive and maintain a competitive position (Trimble 1973). Miller and others (2006) showed that low-density residual stands allowed species of all tolerances to compete as a new cohort for years, but over time reserve trees retarded the growth of reproduction in proportion to their distance from the reserve tree. For the shelterwood with reserves treatment, planning is underway to release desirable regeneration using herbicide to control competition within three growing seasons of the initial harvest. For the oak woodland treatment, periodic prescribed fires will greatly influence the regeneration. Once a decision is made to regenerate oak woodland stands, an assessment of the regeneration will be used to prepare the stand for reproduction of desired species.

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