Woody Vegetation Following Even-aged, Uneven-aged, and No-Harvest Treatments on the Missouri Ozark Forest Ecosystem Project Sites

John M. Kabrick[1], Randy G. Jensen[2], Stephen R. Shifley[3], and David R. Larsen[4]

Abstract.—The Missouri Ozark Forest Ecosystem Project (MOFEP) experimentally tests forest ecosystem response to (a) even-aged management with clearcutting, (b) uneven-aged management with single-tree and group selection, and (c) no-harvesting. The nine MOFEP experimental sites in the southeast Missouri Ozarks are small landscapes ranging from 772 ac (312 ha) to 1,271 ac (514 ha) in extent. In 1996-97, each of the nine sites received one of the three treatments. Clearcutting and thinning affected 26 percent of the total area on the three sites receiving the even-aged management treatment. Selection and group selection harvests affected 57 percent of the total area on the three sites receiving the uneven-aged treatment. The treatments significantly ($P<0.05$) reduced the mean number of trees, basal area, and canopy cover per acre on the harvested sites, but mean diameter was unchanged. Following treatment, the relative size distribution of trees by diameter class was virtually identical for each of the three treatments. Black oak (*Quercus velutina* Lam.) and scarlet oak (*Q. coccinea* Muenchh.) in combination comprised 60 percent of the harvested basal area; white oak (*Q. alba* L.) and post oak (*Q. stellata* Wangenh.) accounted for an additional 20 to 30 percent. On a percentage basis, harvested trees included more scarlet and black oak basal area and less white oak and shortleaf pine (*Pinus echinata* Mill.) basal area than the sites had prior to harvest. Between 1995 and 1998, the total basal area on no-harvest sites increased an average of 1 ft^2/ac (0.2 m^2/ha). Trees between 3.3 ft (1 m) tall to 0.5 in. (1.3 cm) d.b.h. increased in number only in stands that were harvested by single-tree and group selection methods. Small trees decreased in all other treatments except those that were not harvested or thinned. Trees between 0.5 in. (1.3 cm) and 1.5 in. (4 cm) d.b.h. decreased in all stands that were harvested; the greatest decrease occurred in clearcut stands. In either size class, differences in pre- and post-harvest abundance were small and species composition did not change consistently as a result of treatments. More than 700 stump sprouts per acre (1,700/ha) occurred in clearcuts; fewer than 120/ac (300/ha) occurred in areas harvested by a combination of single-tree and group selection. Single-tree selection harvests in the uneven-aged treatment and intermediate thinning in the even-aged treatments resulted in 42 and 36 sprouts per acre (104 and 89/ha), respectively. Stands without harvesting averaged fewer than 7 sprouts per acre (17/ha). Overall, the greatest changes in reproduction-sized trees occurred with stump sprouts of which nearly half were oaks. On all sites, white oak had the greatest basal area ingrowth. In addition to providing information on stand and site response to timber harvesting, the results reported in this paper provide information necessary to analyze how other components of the ecosystem (e.g., understory vegetation, animals, microclimate) responded to harvest treatments.

---

[1] Research Forester, Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; e-mail: kabrij@mail.conservation.state.mo.us.

[2] Research Forester, Missouri Department of Conservation, Route 2, Box 198, Ellington, MO 63638; e-mail: jenser@mail.conservation.state.mo.us.

[3] Research Forester, USDA Forest Service, North Central Research Station, 202 Natural Resources Building, University of Missouri, Columbia, MO 65211-7260; e-mail: sshifley@fs.fed.us.

[4] Associate Professor, Department of Forestry, 203 Natural Resources Building, University of Missouri, Columbia, MO 65211; e-mail: larsendr@missouri.edu.

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term, landscape-scale experiment to test effects of even-aged, uneven-aged, and no-harvest forest management practices on the flora and fauna of upland oak ecosystems (Brookshire and Hauser 1993, Brookshire and Shifley 1997). Because forest harvesting alters forest density, stand size structure, and species composition, identifying differences in pre- and post-harvest forest characteristics is critical for understanding forest change and for interpreting results of other MOFEP studies.

MOFEP was initiated because the impacts of forest management on songbirds and on other non-commodity forest attributes such as diversity of native plant and animal species have been poorly quantified in the Missouri Ozarks. MOFEP provides an opportunity to experimentally measure and statistically test the effects of forest management practices on a suite of ecosystem attributes.

Three management treatments were implemented on the MOFEP sites: (1) even-aged management with harvesting by clearcutting and intermediate thinning, (2) uneven-aged management with harvesting by single-tree selection and group selection, and (3) no-harvest management (see also Sheriff, this proceedings). Even-aged management, as practiced by Missouri Department of Conservation (MDC) managers, uses clearcutting as the principal means of stand regeneration. With this method approximately 10 percent of the acreage in a forest compartment (i.e., a MOFEP site) is clearcut every 10 years for forest regeneration. Thinnings (intermediate cuttings) are conducted periodically within stands to improve quality and increase growing space for residual trees. In the Ozarks, even-aged management is simple to employ, provides excellent regeneration of shade intolerant tree species such as upland oaks (*Quercus* L.) and pine (*Pinus* L.), and provides habitat for wildlife species that prefer early-succession vegetation.

In contrast, uneven-aged management, as practiced by MDC managers, is relatively new to upland oak ecosystems in the Ozarks. Uneven-aged management is commonly practiced in bottomland forests in Missouri and in mixed hardwood forests in the eastern United States where shade tolerant species are prevalent, competitive, and desirable. Forest management on the Pioneer Forest, a privately owned forest in the Ozarks, suggests that uneven-aged management may be a viable silvicultural alternative in Missouri's upland forests where soils and climate favor oak species and limit competition by undesirable species (Loewenstein 1996). As practiced by MDC managers, uneven-aged management includes single-tree selection and group selection for timber harvest and forest regeneration. Uneven-aged management is more complicated to implement than even-aged management because tree size (and age) distributions within individual stands must be carefully monitored and regulated. However, uneven-aged forests typically have a structurally diverse forest canopy containing both small trees and large-diameter overstory trees over a large contiguous area (Missouri Department of Conservation 1986). Forests managed with uneven-aged methods are thought to be more favorable for forest interior plant and animal species than forests managed with even-aged methods.

Sometimes, managers or land owners choose not to alter or manipulate forest vegetation. For example, managers may desire late-successional or old-growth forests on public lands, and private land owners may choose not to cut trees on their lands. At MOFEP sites, the no-harvest treatment serves two purposes. It demonstrates patterns of forest development that result from natural disturbances and successional processes, and it serves as an experimental control to compare with the two other management practices.

Our paper has four objectives. First, it summarizes the forest harvesting, including the stand-scale effects on tree species density, basal area, and composition. Second, it evaluates site-scale (landscape-scale) effects on tree species density and basal area. Third, it evaluates the effects of harvest treatments on forest regeneration. Finally, it evaluates site-level forest change since inventories began on MOFEP in 1990. Our results and discussion are focused on harvest effects on trees, but the findings are also directly relevant to the other studies in this volume that describe how other components of the forest ecosystem respond to the three forest management treatments.

METHODS

The MOFEP study design is described in detail by Brookshire *et al.* (1997), Sheriff and He (1997), and Sheriff (this proceedings). There are nine study sites (compartments) that range in size from 772 ac (312 ha) to 1,271 ac (514 ha). These were allocated into three "complete" statistical blocks of three sites each. Sites within each block were randomly designated to be managed as even-aged, uneven-aged, or no-harvest, yielding three replicates of each treatment (Sheriff and He 1997). The Missouri Department of Conservation Forest Land Management Guidelines (Missouri Department of Conservation 1986) and the guidelines for managing uneven-aged stands (Law and Lorimer 1989) provided the general recommendations for harvesting in even-aged and uneven-aged MOFEP sites. Also see Sheriff (this proceedings) for additional details on treatments.

Forest Vegetation Sampling and Data Sets

Shortly after MOFEP was initiated, each site was divided into areas of common slope and aspect. These were further divided into stands that averaged approximately 12 ac. Stands were used to stratify the placement of permanent vegetation plots (fig. 1). Vegetation plots were randomly located within stands, and each stand received at least one plot. There were 645 vegetation plots established between October 1990 and September 1992. Three additional vegetation plots were added in 1994 to intensify sampling in bottomland areas for a total of 648 permanent inventory plots. Plot center and subplot centers of all vegetation plots were permanently marked with steel rods. Since 1991, these permanent plots have been re-inventoried approximately every 3 years to document the condition of woody vegetation. During each re-inventory within permanent

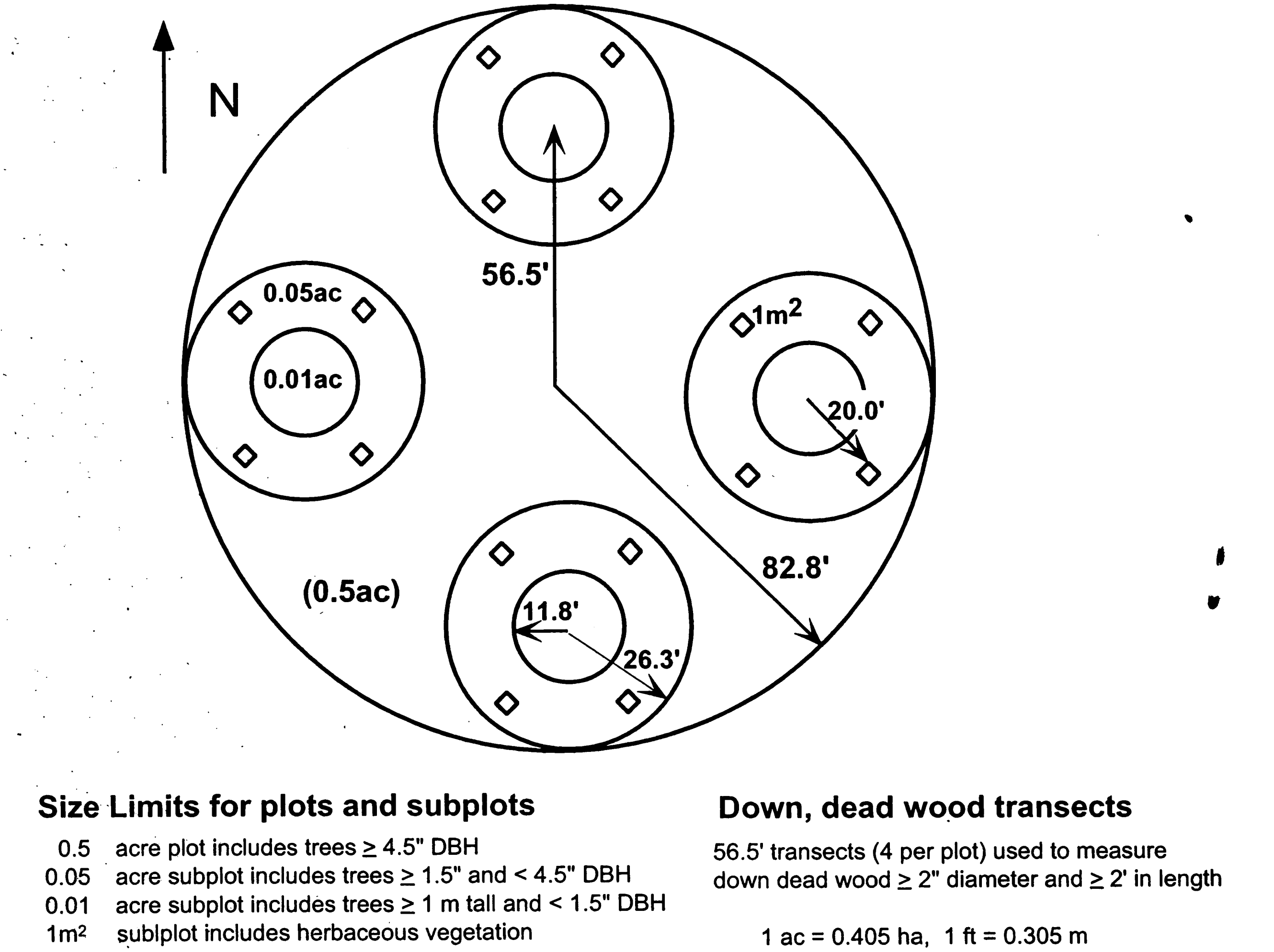

Figure 1.—*MOFEP vegetation plot design.*

plots, live and dead trees ≥ 4.5 in. (11 cm) diameter at breast height (d.b.h.) are sampled in 0.5-ac (0.2 ha) circular plots; trees between 1.5 in. (4 cm) and 4.5 in. (11 cm) d.b.h. are sampled in four 0.05-ac (0.02 ha) circular subplots; and trees at least 3.3 ft (1 m) tall and less than 1.5 in. (4 cm) d.b.h. are sampled in four 0.01-ac (0.004 ha) circular subplots nested within the 0.05-ac subplots. Characteristics recorded for each tree include species, d.b.h. (or size class for trees < 4.5 in. (11 cm) d.b.h.), and status (e.g., live, dead, den, cut, blow-down). Plot and subplot data are combined to obtain plot averages by d.b.h. or size class, and all values are converted to an acre basis for analysis. Additional details about vegetation data collection can be found in Shifley and Brookshire (2000).

We summarized information about the harvested stands (e.g., location, size, area, harvest regime) using spatial data compiled by MDC. We used two data sets to determine the effects of forest harvesting on trees. The first was collected between May 1994 and January 1995 (hereafter referred to as 1995). This inventory was conducted before the first forest harvest entry, which occurred from May 1996 to May 1997. The second data set was collected between October 1997 and June 1998 (hereafter referred to as 1998). We determined forest growth, ingrowth, and mortality during the entire course of MOFEP by comparing data collected in 1991-1992 (hereafter referred to as 1992) to data collected in 1998 in all stands and all MOFEP sites. Growth refers to basal area increases of existing trees ≥ 4.5 in. (11 cm) d.b.h., ingrowth refers to basal area increases for trees that have grown into the ≥ 4.5 in. (11 cm) d.b.h. size class, and mortality refers to all trees ≥ 4.5 in. (11 cm) d.b.h. that have died.

Statistical Analysis

We statistically evaluated pre- and post-treatment differences in the number of tree species per plot, number of trees per acre, quadratic mean diameter, basal area, and percent canopy cover. For quadratic mean diameter and basal area, analyses were conducted by combining data by size classes corresponding to sampling thresholds for vegetation plots and subplots: trees ≥ 3.3 ft (1 m) tall, trees ≥ 1.5 in. (4 cm) d.b.h., and trees ≥ 4.5 in. (11 cm) d.b.h. We also evaluated pre- and post-treatment differences in the number of trees per acre, quadratic mean diameter, and basal areas per acre for the most abundant tree species: white oak (*Quercus alba* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), shortleaf pine (*Pinus echinata* Mill.), and post oak (*Q. stellata* Wangenh.).

Pre- and post-treatment tree attribute differences were evaluated at the site level using analysis of variance with the following fixed effects model:

$$Y_{ij} = \mu + \text{block}_i + \text{treatment}_j + \varepsilon_{ij}$$

Where μ is the mean difference between the pre- and post-treatment attribute, block_i is the block effect, treatment_j is the treatment effect (i.e., harvest treatment), and ε_{ij} is the error effect N(0, σ^2). Blocks and treatments each received two degrees of freedom, leaving four degrees of freedom for error. For analyses that we conducted with this model, we used an α-level of 0.05. Where overall significance was found, we used a least significant difference test to identify attributes that differed significantly from those of no-harvest sites.

RESULTS AND DISCUSSION

Forest Harvesting

The acreage and volume harvested varied considerably between treatment types (tables 1 and 2). On even-aged treatment sites, approximately 320 ac (130 ha) (11% of the total area) were clearcut and 411 ac (166 ha) (15%) were thinned. Stands that were clearcut averaged 13 ac (5 ha) and stands that were thinned on the even-aged sites averaged 11 ac (4 ha). On uneven-aged sites, 2,124 ac (860 ha) (57%) received single-tree selection harvests, and group openings were created to regenerate the shade intolerant oaks and pine. Group openings 70 ft (21 m) in diameter (i.e., approximately one tree height) were created on south-facing slopes; openings 105 ft (32 m) were created on ridgetops; and openings 140 ft (43 m) in diameter were created on north-facing slopes (Law and Lorimer 1989). In uneven-aged sites, there were between 153 and 267 group openings. These covered a total area of 24 to 46 ac (10 to 19 ha) per site and occupied roughly 5 percent of the area in each cutting unit (table 3). Within group openings, all or nearly all trees were removed. The average cutting unit size averaged 21 ac (9 ha) in the uneven-aged sites. Overall, a greater volume was harvested from uneven-aged sites than from even-aged sites (3.4 million bd ft

Table 1.—*Total and percent area harvested and commercial volume harvested in even-aged and uneven-aged sites*

Site	Site area[1]	Area clearcut	Area clearcut	Area thinned[2]	Area thinned	Volume harvested[3]
	Acres	*Acres*	*Percent*	*Acres*	*Percent*	*Thousand bd ft*
Even-aged						
3	889	93	10	211	24	754
5	772	114	15	142	18	927
9	1,141	113	10	58	5	773
Even-aged total	2,802	320	11	411	15	2,454
Uneven-aged						
2	1,271	—	—	876	69	1,146
4	1,183	—	—	735	62	952
7	1,240	—	—	513	41	1,344
Uneven-aged total	3,694	—	—	2,124	57	3,442

[1] Metric conversions are 1 acre = 0.4047 ha.
[2] Includes intermediate thinning on even-aged management sites and single-tree selection and group selection harvest on uneven-aged management sites.
[3] This does not include cull or slash volume; from Brookshire *et al.* 1997.

Table 2.—*Number of stands (i.e., cutting units) and stand size for even-aged and uneven-aged sites*

Site	No. of stands clearcut	Mean stand size clearcut[1] (range)	No. of thinned stands[2]	Mean stand size thinned[1] (range)	No. trees ≥4.5" d.b.h. harvested[1]	Basal area for trees ≥4.5" d.b.h. harvested[1]
		Acres		*Acres*	*Trees/acre*	*ft²/ac*
Even-aged						
3	8	12 (2-32)	22	10 (1-31)	22	16
5	7	16 (7-25)	14	10 (4-27)	29	19
9	9	13 (7-23)	4	15 (12-17)	13	10
Even-aged total	24	13 (2-32)	40	11 (1-31)	21	15
Uneven-aged						
2	—	—	27	32 (3-80)	21	14
4	—	—	55	13 (3-26)	30	20
7	—	—	28	18 (6-51)	12	12
Uneven-aged total	—	—	110	21 (3-80)	21	15

[1] 1 acre = 0.4047 ha, 4.5 in. = 11 cm, 1 tree/ac = 2.47 trees/ha.
[2] Includes intermediate thinning on even-aged management sites and single-tree selection and group selection harvest on uneven-aged management sites.

Table 3.—*Number, total size, and percent area of group openings in uneven-aged cutting units*

Site	No. of group openings	Total area of openings[1]	Total area of openings
		Acres	*Percent*
2	267	46	5
4	221	37	5
7	153	24	5
Uneven-aged total	641	107	5

[1] 1 acre = 0.4047 ha.

vs. 2.5 million bd ft) because more of the total area on the uneven-aged sites was treated with selection and group selection harvests than was thinned or clearcut on the even-aged sites. Moreover, by chance, the total area of the three sites treated with uneven-aged management was about 30 percent greater than the total area of sites treated by even-aged management.

The number of residual trees, the residual basal area, and residual overstory canopy cover within harvested stands or cutting units also differed by treatment (table 4). As expected, very few residual trees ≥ 1.5 in. (4 cm) d.b.h. remained in clearcut stands except those left to produce seed for forest regeneration or to provide wildlife food and shelter. The residual basal area of clearcut stands was 6 ft^2/ac (1.5 m^2/ha) compared to 97 ft^2/ac (22 m^2/ha) prior to harvest; canopy cover was reduced from 86 to 3 percent. Thinned stands in even-aged sites and cutting units harvested by the selection method in uneven-aged sites had roughly a 25 percent reduction in both trees per unit area and basal area; overstory canopy cover was reduced from 86 to 56 percent.

Table 4.—*Pre- and post-treatment tree density, basal area, and canopy cover in harvested stands or cutting units*

	Trees per acre[1] (*standard deviation*)						Basal area ($ft.^2$ / ac)[1] (*standard deviation*)				Canopy coverage (*standard deviation*)	
	≥ 3.3 ft tall		≥ 1.5 in. d.b.h.		≥ 4.5 in. d.b.h.		≥ 1.5 in. d.b.h.		≥ 4.5 in. d.b.h.		(%)	
	1995	1998	1995	1998	1995	1998	1995	1998	1995	1998	1995	1997
Clearcut stands (even-aged treatment)	1,305 *(349)*	1,277 *(230)*	437 *(138)*	17 *(9)*	136 *(13)*	8 *(2)*	97 *(4.6)*	6 *(0.5)*	85 *(4.9)*	6 *(0.7)*	86 *(3.3)*	3 *(1.0)*
Intermediate thinning (even-aged treatment)	1,350 *(356)*	911 *(201)*	491 *(42)*	354 *(46)*	158 *(23)*	133 *(14)*	100 *(11.0)*	71 *(7.5)*	86 *(13.0)*	62 *(9.2)*	86 *(3.6)*	55 *(8.1)*
Selection cutting units (uneven-aged treatment)	1,228 *(84)*	968 *(240)*	475 *(101)*	332 *(61)*	158 *(19)*	127 *(16)*	100 *(6.2)*	76 *(5.8)*	87 *(2.7)*	67 *(3.8)*	85 *(3.8)*	57 *(12.7)*

[1] 3.3 ft = 1 m, 1.5 in. = 4 cm, 4.5 in. = 11 cm, 1 tree/ac = 2.47 trees/ha, and 1 ft^2/ac basal area = 0.2296 m^2/ha.

In combination, black oak, scarlet oak, white oak, post oak, shortleaf pine, and hickories (*Carya* spp. Nutt.) comprised 95 percent of the live basal area immediately prior to harvest and 96 percent of the harvested basal area. Together, black oak and scarlet oak comprised approximately 60 percent of the harvested basal area; white oak and post oak accounted for an additional 20 to 30 percent of the harvest (fig. 2). Compared to the species composition of the sites prior to harvest, the harvested trees included a greater percentage of scarlet and black oak basal area and a lesser percentage of white oak and shortleaf pine basal area. In the even-aged treatment, the harvested basal areas of scarlet and white oak were nearly equal. However, in the uneven-aged treatment, harvest of scarlet oak was proportionately greater than that of white oak (33 vs. 21% of total). Shortleaf pine was 3 percent of the harvested basal area although it was 9 percent of the total basal area prior to the harvest.

Both harvest treatments removed trees ranging from 5 to more than 29 in. (13 to 74 cm) in diameter. The size distribution of diameters for harvested trees was similar to that of the live trees that were retained (fig. 3). Snags (i.e., standing dead trees) also had a diameter size distribution similar in form to that of live trees. Diameter distributions for live, cut, and standing dead trees each had a negative exponential (reverse-J) shape. However, compared to the inventory of live trees, the population of snags included a greater proportion of small diameter trees (less than 7 in. [18 cm] d.b.h.) and fewer trees in size classes between 10 and 20 in. d.b.h., regardless of harvest treatment.

Relative to the size distribution of live trees that remained following harvest treatments harvested trees included proportionately more trees greater than 10 in. (25 cm) d.b.h. for even-aged treatments and greater than 15 in. (38 cm) d.b.h. for uneven-aged treatments (fig. 3). Clearcut stands in the even-aged treatment were typically older and included more large trees than the average for untreated stands. Following harvest, the diameter distribution of the live trees was nearly identical for the three treatments (fig. 3).

The q-value is a measure of the shape of a negative exponential (reverse-J) diameter distribution, and it is often used in uneven-aged management to describe desired stand structure. For tree diameter distributions with a negative exponential form, the q-value corresponds to the ratio of the number of trees in a given diameter class to the number of trees in

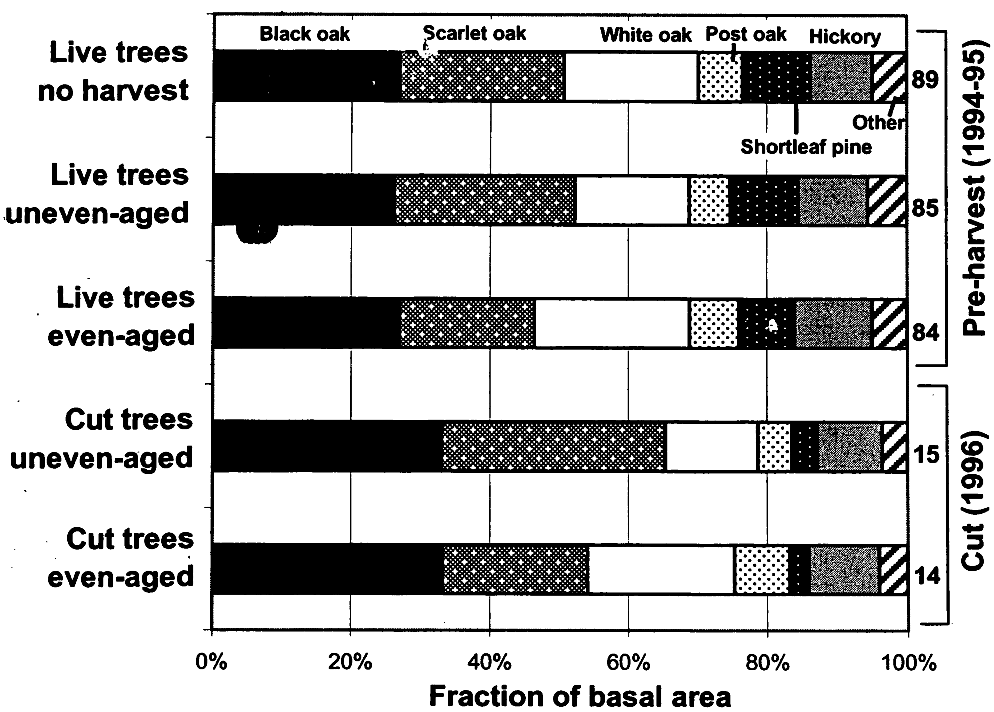

Figure 2.—*Proportion of live basal area by species and treatment prior to harvest (1994-95), and proportion of cut basal area by species (1997-98) for the even-aged and uneven-aged treatments. Values are means for three sites in each treatment group. Mean basal area per acre for each category is shown to the right of each bar.*

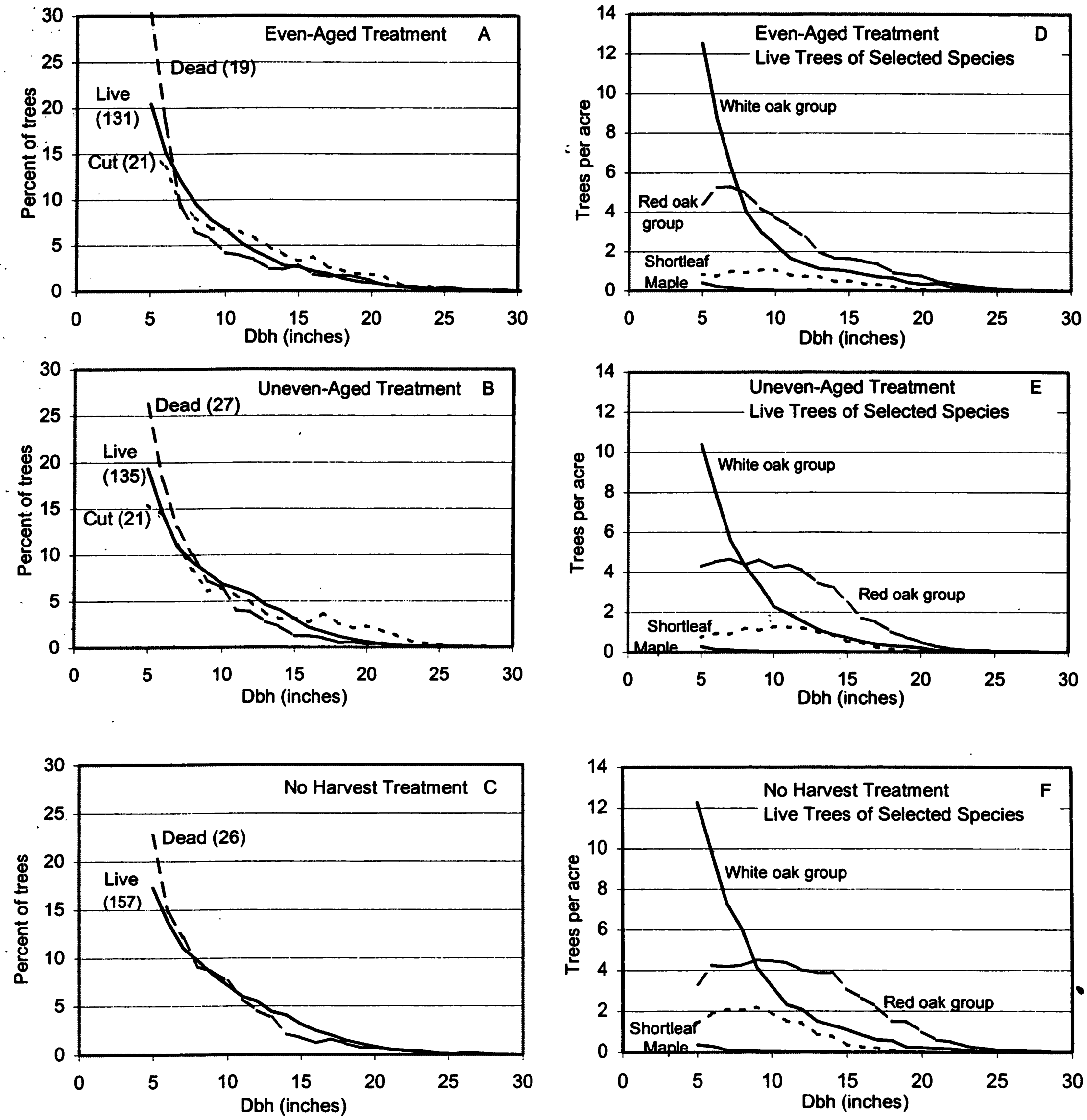

Figure 3.—*(A) to (C). Proportion of trees $\geq$ 4.5 in. (11.4 cm) d.b.h. by diameter class for live, dead, and cut trees, 1998. The mean number of trees per acre for the live, cut, and dead categories is shown adjacent to the live, cut, and dead labels. Values are a composite for all plots in each treatment. All diameter distributions shown follow a negative exponential form. Distribution curves for live trees are virtually identical for each of the three treatments; the q-value for each of the three live tree distributions is 1.2. (D) to (F). Number of live trees by diameter class for the white oak group (white and post oak), the red oak group (black and scarlet oak), the maple group (red and sugar maple), and shortleaf pine, 1998.*

the next larger diameter class. When all plots in a treatment were combined, the live tree diameter distributions following harvest were nearly identical for each of the three management treatments. Each had a q-value of 1.2 (computed using 1-in. diameter classes). Individual live tree diameter distributions for maples (*Acer rubrum* L. and *A. saccharum* Marsh.) and for white oaks (white oak and post oak) also had negative exponential diameter distributions (fig. 3). Of the four species groups illustrated, the white oak group (white oak and post oak) dominated the size classes between 5 and 7 in. (13 and 18 cm) d.b.h. The red oak group (black oak and scarlet oak) and shortleaf pine were unimodal in form, and the red oak group had a greater proportion of trees in the larger diameter classes at all sites. We attribute this pattern to greater shade tolerance of white oak and maples, and to the comparatively rapid growth of the shortleaf pines and trees in the red oak group. The data for smaller diameter classes (fig. 3) show that maple is not increasing.

These results help illustrate that even-aged and uneven-aged forest management systems create very different forest structures (fig. 4). Clearcutting is an intensive tree harvesting method that removes nearly all trees in a treated stand; most large trees that do not have commercial value are cut down in post-harvest "slashing" operations that facilitate regeneration of desirable trees. However, MDC guidelines specify that clearcuts be small in area (a range of 2 to 20 ac [1 to 8 ha] is recommended) to protect water and soil resources and to ensure that different size classes of trees are represented across the forest (Missouri Department of Conservation 1986). Even when the total acres clearcut and thinned are combined, only one-fourth of the total land area was affected by harvest in the even-aged treatment. In contrast, uneven-aged management by the single-tree selection and group selection methods was much more extensive. Harvests occurred over a larger proportion (57%) of uneven-aged sites, explaining why nearly 40 percent more merchantable volume was harvested from uneven-aged sites than from even-aged sites.

The scarlet oak harvest was disproportionately large in the uneven-aged treatment because MDC foresters purposely marked uneven-aged cutting units to retain longer lived tree species such as white oak over the comparatively short-lived tree species such as scarlet oak. In the Ozarks, scarlet oaks are often short lived because they are particularly susceptible to oak decline, largely caused by Armillaria root disease (Johnson and Law 1989). Compared to even-age methods, single-tree selection methods used in uneven-aged sites provide greater flexibility to favor long-lived species during timber marking.

Treatment Effects Among Sites

One of MOFEP's strengths is that it was designed to be a long-term, landscape-scale investigation. Although we can address only short-term results at this early stage of the experiment, we can begin assessing some short-term landscape-scale effects. MOFEP sites (or compartments) serve as contiguous forest "landscapes." For all species combined in our study, there were detectable treatment-level effects for five of nine woody vegetation variables (table 5). Values of variables that changed significantly after harvesting were usually for the larger size classes of trees. For example, there were no significant reductions in the total number of trees per acre although significant decreases were detected for trees ≥ 1.5 in. (4 cm) d.b.h. in the uneven-aged treatment and for trees ≥ 4.5 in. (11 cm) d.b.h. in both even-aged and uneven-aged treatments. One exception was basal area, which decreased significantly in all size classes on harvested sites. As expected, the average canopy cover of harvested sites decreased following harvesting and was significantly lower than the no-harvest sites. We note that the average canopy cover of no-harvest sites also decreased. However, we do not know if this decrease was simply sampling variation or a decrease in canopy cover (e.g., due to tree blowdown, mortality, defoliation), or both. Changes in numbers, diameters, and basal areas for the most abundant species were similar to those of all species combined (table 5). White oak, black oak, and especially scarlet oak stems per acre and/or basal areas of the larger size classes were decreased significantly by harvesting, especially in uneven-aged sites. We found small, but significant changes in post oak basal area for trees ≥ 4.5 in. d.b.h. There were no changes in shortleaf pine abundance, diameter, and basal area.

Even though individual cutting units and stands were impacted by harvesting in both even-aged and uneven-aged sites, we found relatively few site-scale treatment effects. When averaged across an entire site, many vegetation characteristics were not significantly different from those in no-harvest sites. Most changes were detected only for the numbers of trees and basal area per acre. Clearly, both even-aged and uneven-aged harvest treatments impacted the sites, and did so in very different ways (see fig. 4). The first even-aged harvest treatments left mature forests containing large patches (stands) where few mature trees remain. The first uneven-aged harvest treatments left a mature forest having slightly lower density than the pre-harvest forest and containing small patches (group openings) where few trees remain.

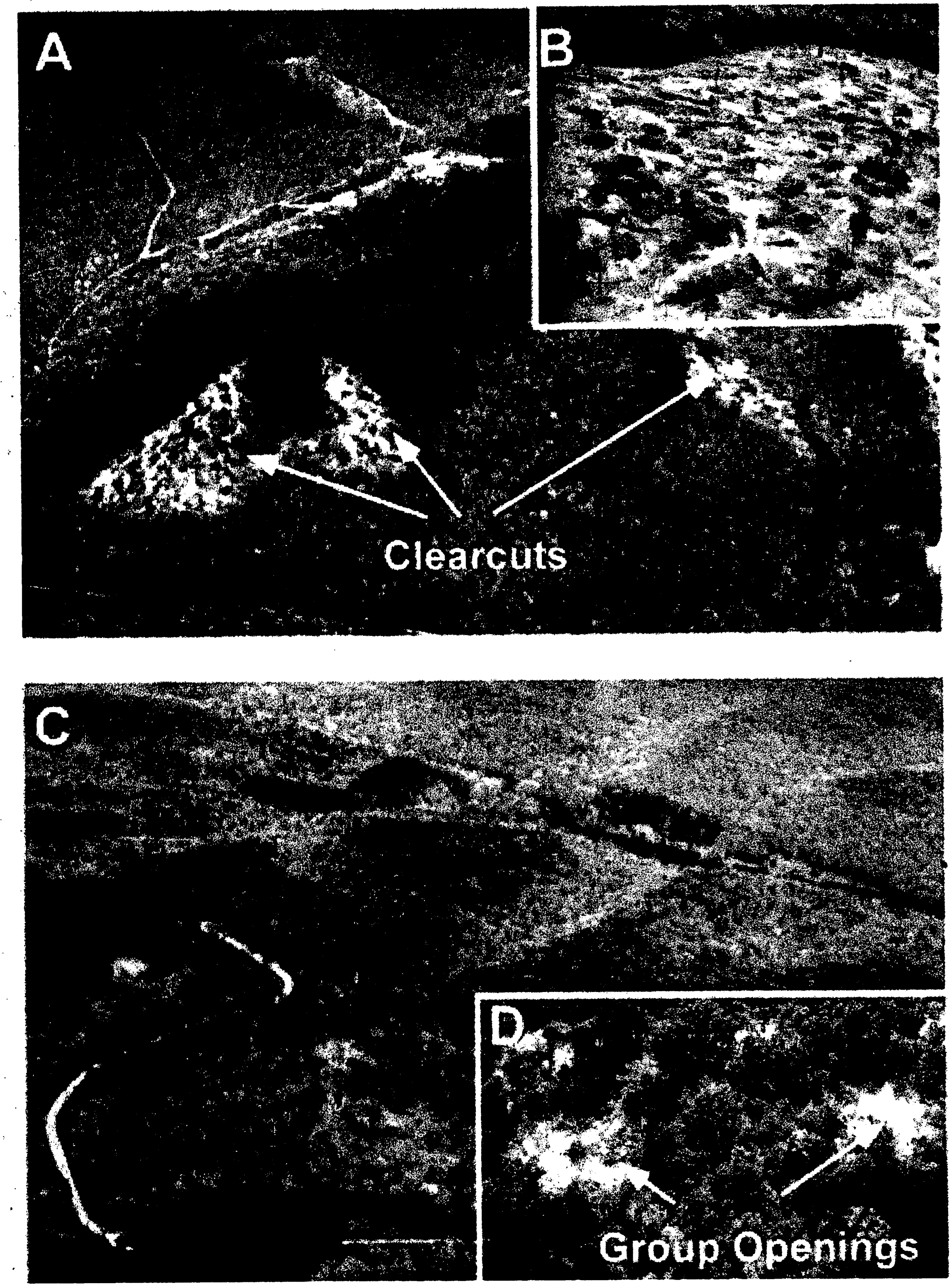

Figure 4.—*(A) to (D). Different forest structures are created by even-aged and uneven-aged management. These photographs were taken in April 1997, nearly 1 year after harvesting began. (A). Even-aged MOFEP site 9 illustrating clearcuts. (B). Close-up photograph of a clearcut. Note that few residual trees remain and that a large volume of slash was left on the ground. (C). Uneven-aged MOFEP site 7 illustrating single-tree selection and group openings. (D). Close-up photograph of an area harvested with single-tree selection and group openings. Few trees per acre were removed within single-tree selection cutting units, leaving a nearly closed-canopy forest. Within group openings, all trees were harvested, and some slash remains on the ground.*

Table 5.—*Pre- and post-treatment means and differences for attributes of all tree species and for white oak, black oak, scarlet oak, shortleaf pine, and post oak. Values differing significantly (α = 0.05) from the no-harvest treatment are shown in bold.*

Species and attribute[a,b]	No-harvest (sites 1, 6, 8) 1995	No-harvest 1998	No-harvest diff.	Even-aged (sites 3, 5, 9) 1995	Even-aged 1998	Even-aged diff.	Uneven-aged (sites 2, 4, 7) 1995	Uneven-aged 1998	Uneven-aged diff.	F-value[c] (for difference)	P-value (for difference)
All trees											
No. of species per plot	12.7	13.0	0.3	14.5	14.1	-0.4	14.0	14.5	0.5	6.3	0.06
No. of trees > 0 in. d.b.h.	1,180	1,167	-13	1,282	1,183	-99	1,268	1,132	-136	0.3	0.76
No. of trees ≥ 1.5 in. d.b.h.	409	403	-6	451	385	-66	453	362	**-91**	**7.1**	**0.05**
No. of trees ≥ 4.5 in. d.b.h.	155	157	2	149	132	**-17**	157	135	**-22**	**11.5**	**0.02**
Qmd ≥ 1.5 in. d.b.h.	6.7	6.7	0.0	6.3	6.3	0.0	6.3	6.4	0.1	0.5	0.62
Qmd ≥ 4.5 in. d.b.h.	10.3	10.3	0.0	10.2	10.0	-0.2	10.0	9.9	-0.1	2.3	0.21
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	99	100	1	96	82	**-14**	97	81	**-16**	**22.6**	**0.01**
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	89	90	1.0	84	71	**-12**	85	71	**-14**	**25.0**	**0.01**
Canopy cover (%)	82	69	-13	85	59	**-26**	84	60	**-24**	**21.9**	**0.01**
White oak											
No. of trees > 0 in. d.b.h.	117	120	3	137	137	0	134	110	**-24**	10.6	**0.03**
No. of trees ≥ 1.5 in. d.b.h.	89	93	4	105	101	-4	94	76	-18	5.0	0.08
No. of trees ≥ 4.5 in. d.b.h.	40	43	3	41	38	**-3**	35	32	**-3**	7.3	**0.05**
Qmd ≥ 1.5 in. d.b.h.	6.4	6.4	0.0	6.2	6.0	-0.2	5.7	6.0	0.3	6.1	0.06
Qmd ≥ 4.5 in. d.b.h.	8.9	8.8	-0.1	9.2	9.0	-0.2	8.6	8.5	-0.1	1.4	0.33
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	20	21	1.0	22	20	**-2**	17	15	**-2**	11.9	**0.02**
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	17	18	1.0	19	17	**-2**	14	13	**-1**	14.2	**0.02**
Black oak											
No. of trees > 0 in. d.b.h.	57	62	5	58	62	4	60	58	2	0.7	0.57
No. of trees ≥ 1.5 in. d.b.h.	32	37	5	38	36	**-2**	37	38	1	7.0	**0.05**
No. of trees ≥ 4.5 in. d.b.h.	28	26	-2	29	23	-6	30	24	-6	6.1	0.06
Qmd ≥ 1.5 in. d.b.h.	11.8	10.9	-0.9	10.5	9.7	-0.8	10.6	9.3	-1.3	0.2	0.80
Qmd ≥ 4.5 in. d.b.h.	12.5	12.8	0.3	12.0	11.9	-0.1	11.6	11.4	-0.2	6.0	0.06
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	24	24	0	23	19	**-4**	23	18	**-5**	14.1	**0.02**
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	24	23	-1	23	18	**-5**	22	17	**-5**	10.7	**0.02**
Scarlet oak											
No. of trees > 0 in. d.b.h.	44	51	7	45	62	17	58	60	2	2.1	0.24
No. of trees ≥ 1.5 in. d.b.h.	32	39	7	35	37	**2**	43	41	**-2**	18.3	**0.01**
No. of trees ≥ 4.5 in. d.b.h.	27	26	-1	25	21	**-4**	32	25	**-7**	16.3	**0.01**
Qmd ≥ 1.5 in. d.b.h.	11.0	10.1	-0.9	9.4	8.2	-1.2	9.8	9.0	-0.8	0.6	0.60
Qmd ≥ 4.5 in. d.b.h.	12.0	12.1	0.1	10.9	10.6	-0.3	11.3	11.2	-0.1	5.4	0.07
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	21	22	-1	17	14	**-3**	23	18	**-5**	21.7	**0.01**
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	21	21	0	16	13	**-3**	22	17	**-5**	21.2	**0.01**
Shortleaf pine											
No. of trees > 0 in. d.b.h.	26	51	25	18	37	19	19	29	10	1.8	0.28
No. of trees ≥ 1.5 in. d.b.h.	22	47	25	15	35	20	16	26	10	1.4	0.34
No. of trees ≥ 4.5 in. d.b.h.	17	17	0	10	10	0	13	12	-1	4.8	0.09
Qmd ≥ 1.5 in. d.b.h.	8.6	6.3	-2.3	9.1	6.4	-2.7	9.8	7.7	-2.1	0.0	0.99
Qmd ≥ 4.5 in. d.b.h.	9.6	9.7	0.1	11.0	11.1	0.1	10.8	10.9	0.1	0.2	0.80
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	9	10	1	7	8	1	8	9	1	2.4	0.21
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	9	9	0	7	7	0	8	8	0	1.6	0.31
Post oak											
No. of trees > 0 in. d.b.h.	22	33	11	15	25	10	30	37	7	0.1	0.94
No. of trees ≥ 1.5 in. d.b.h.	15	25	10	13	22	9	16	28	12	0.1	0.91
No. of trees ≥ 4.5 in. d.b.h.	10	10	0	8	7	-1	10	8	-2	4.1	0.11
Qmd ≥ 1.5 in. d.b.h.	8.5	6.9	-1.6	9.4	6.8	-2.6	7.9	5.8	-2.1	0.4	0.72
Qmd ≥ 4.5 in. d.b.h.	10.2	10.2	0.0	11.7	11.3	-0.4	9.7	9.9	0.2	6.2	0.06
Basal area (ft²/ac) ≥ 1.5 in. d.b.h.	6	7	1	6	6	0	5	5	0	3.8	0.12
Basal area (ft²/ac) ≥ 4.5 in. d.b.h.	6	6	0	6	5	**-1**	5	4	**-1**	21.7	**0.01**

[a] Reported values are per acre except as noted. Metric conversions are 1.5 in. = 4 cm, 4.5 in. = 11 cm, 1 tree/ac = 2.47 trees/ha, and 1 ft²/ac basal area = 0.2296 m²/ha basal area.
[b] Qmd = quadratic mean d.b.h. (in inches) for trees in the specified size class.
[c] For ANOVA of treatment effects, F has (2,4) degrees of freedom.

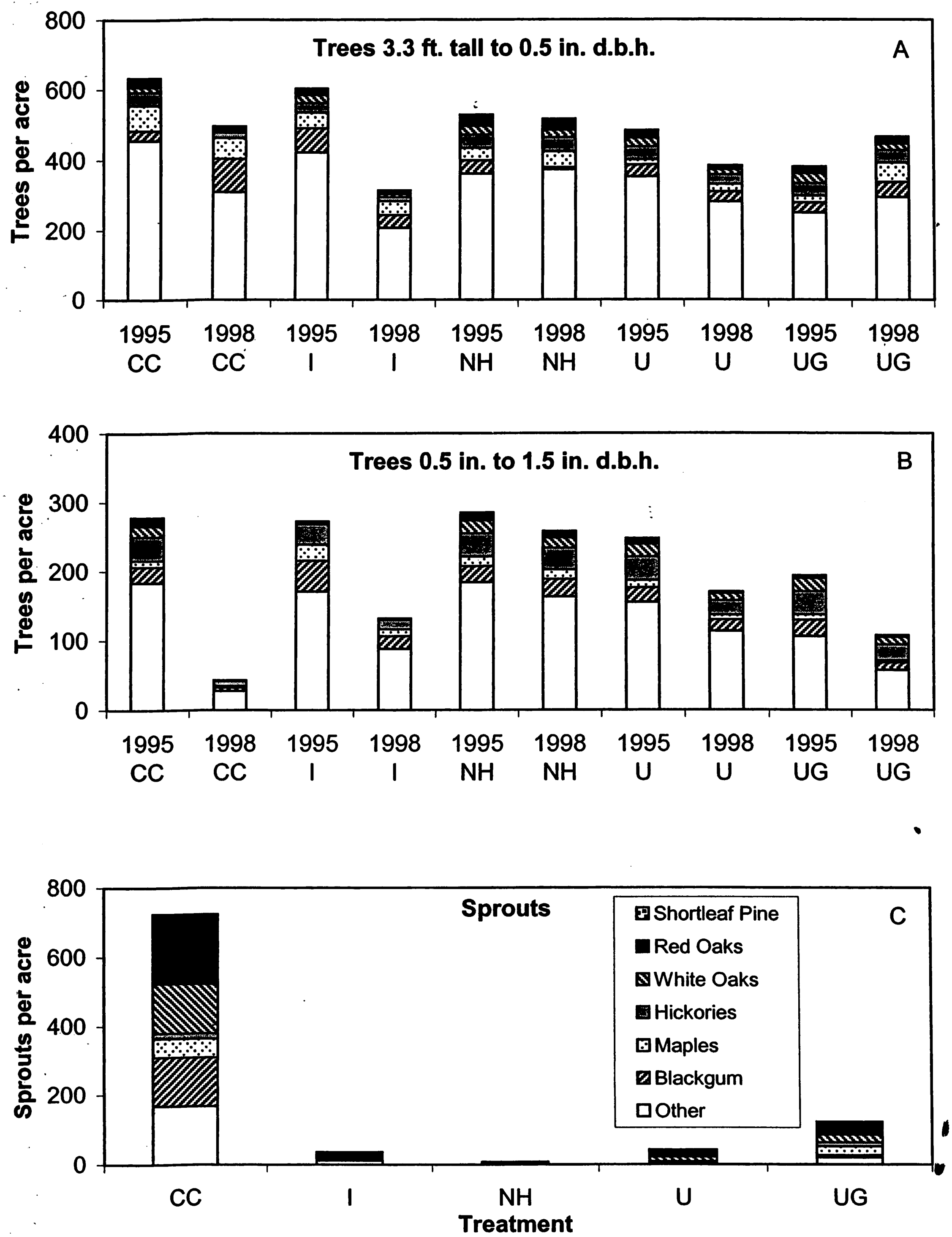

Figure 5.—*Number of small trees and sprouts per acre before and after harvest treatments (1995 and 1998). Summaries are for individual plots that were clearcut (CC), received an intermediate harvest as part of the even-aged treatment (I), were left unharvested (NH), received single-tree selection harvest as part of the uneven-aged treatment (U), or received both single-tree and group selection harvesting as part of the uneven-aged treatment (UG). Species shown are: the white oak group (white and post oak); the red oak group (black and scarlet oak); the maple group (red and sugar maple); the hickory group (black, mockernut, pignut, and bitternut hickory); blackgum; shortleaf pine. Values are for (A) trees from 3.3 ft (1 m) tall to 0.5 in. (1.3 cm) d.b.h.; (B) trees ≥ 0.5 in. (1.3 cm) to 1.5 in. (4 cm) d.b.h.; and (C) recent sprouts of any diameter. The bars show the proportion attributable to each species group; order of species groups (top to bottom) matches vertical order shown in the legend. One acre = 0.4047ac.*

However, it is clear that the impact of these treatments on forest structure at site scales (i.e., approximately 1,000-ac compartments) cannot be fully described or understood by evaluating the forest vegetation data with analysis of variance. To better quantify site-scale effects of the different treatments, we need to apply other descriptive measures of the forest structure. These measures should include quantifying the number, area, perimeter, and spatial arrangement of patches of forest having contrasting diameter and/or height distributions (e.g., clearcut stands, group openings, and the matrix of forest between these patches). These statistics would provide a different perspective on the treatment effects.

Forest Reproduction

An important purpose of harvesting by either even-aged or uneven-aged methods is to regenerate a future stand. Therefore, it is important to determine the effects of harvesting on species composition, abundance, and total numbers of trees in the reproduction size class. Trees from 3.3 ft (1 m) tall to 0.5 in. (1.3 cm) d.b.h. increased in number only on plots that were harvested by single-tree and group selection. Small trees decreased on plots in other treatments except those that were not harvested or thinned (fig. 5A). Trees between 0.5 in. (1.3 cm) and 1.5 in. (4 cm) d.b.h. decreased in all treatments; the greatest decrease occurred in clearcut plots (fig. 5B). In either size class, differences in pre- and post-harvest abundance were small, and species composition did not change consistently as a result of treatments. Most trees in these size classes were in the "other" category; of trees in this category, most were dogwoods (*Cornus florida* L.) and sassafras (*Sassafras albidum* [Nutt.] Nees). Neither of these is an overstory species in Ozark forests. More than 700 stump sprouts per acre (1,700/ha) occurred in clearcuts; fewer than 120/ac (300/ha) occurred in areas harvested by a combination of single-tree and group selection (fig. 5C). Single-tree selection harvests in the uneven-aged treatment and intermediate thinning in the even-aged treatments resulted in 42 and 36 sprouts per acre (104 and 89/ha), respectively. Stands without harvesting averaged fewer than 7 sprouts per acre (17/ha). Overall, the greatest changes in reproduction-sized trees occurred with stump sprouts of which nearly half were oaks. Blackgums (*Nyssa sylvatica* Marsh.) also sprouted prolifically in clearcuts and sprout numbers were similar to those of white oak. The order of sprout abundance followed the expectations for available light at the forest floor: clearcut > group opening > single-tree section or thinning > no harvest (fig. 5C).

Although it is too early to draw definitive conclusions with the data collected only 2 years after harvesting, cutting apparently has had very little effect on the species composition or abundance of the reproduction layer. During the next few years, we anticipate that oaks will become more abundant in the reproduction layer within harvested areas, especially in clearcuts and group openings, primarily because of oak stump sprouting.

Oak stump sprouting is an important source of regeneration in upland hardwood forests throughout the Central Hardwood region (Dey and Jensen, this proceedings; Johnson 1992; Sander *et al.* 1984; Weigel and Johnson 1998). In clearcuts, stump sprouts may provide most of the oaks that will later grow into dominant or codominant canopy positions (Johnson 1975, Weigel and Johnson 1998). The contribution of stump sprouts to oak regeneration depends upon many factors. Some important factors are parent tree species, age, and diameter (Sander *et al.* 1984, Weigel and Johnson 1998). Large (> 8 in. [20 cm] d.b.h.) black oaks and scarlet oaks are more likely to stump sprout than large white oaks (Sander *et al.* 1984). Younger oaks sprout more readily than older ones and smaller diameter oaks sprout more readily than larger ones (Weigel and Johnson 1998).

We do not know the exact number of reproduction-sized oak trees needed to ensure adequate regeneration, but oak regeneration is seldom a problem in even-aged stands in this part of the Missouri Ozarks. However, it is not clear to what extent oak regeneration will be successful in uneven-aged stands because oak seedlings require about one-third full sunlight for maximum photosynthesis (Law and Lorimer 1989) and uneven-aged stands may not provide enough sunlight for oak seedlings to compete with other tree species. For Missouri Ozark forests, Larsen *et al.* (1999) recommended a residual basal area of about 50 ft^2/ac (12 m^2/ha) to ensure adequate oak regeneration in stands harvested only by single-tree selection methods. On MOFEP sites, the residual basal area in selection harvest cutting units was 67 ft^2/ac (15 m^2/ha), considerably higher than recommended by Larsen *et al.* (1999) for single-tree selection if used alone. However, uneven-aged harvesting at MOFEP followed the guidelines of Law and Lorimer (1989), who recommended using group openings nested within single-tree selection cutting units to encourage oak regeneration. Accordingly, MOFEP single-tree selection cutting units within uneven-aged sites contained from 153 to 267 group openings (or about 5% of the area of cutting units) to enhance oak regeneration. Moreover, the residual basal area within single-tree selection cutting units (excluding the group openings) is within the recommendations made by Law and Lorimer (1989). Our analysis was conducted too soon after harvesting to determine how successful the combination of single-tree selection and group openings will be over the long term in providing adequate oak regeneration on MOFEP sites. Monitoring the regeneration dynamics of all MOFEP treatments will continue in order to measure effects on forest regeneration.

Forest Dynamics

Forest species composition is always changing. Some trees continue to grow while others die and are eventually replaced. Human-caused disturbances such as timber harvesting often create the most striking short-term changes in species composition, but natural disturbances and succession also alter species composition over time. To evaluate some of these changes for the most abundant tree species on MOFEP sites, we compared the growth, ingrowth, and mortality of individual tree species and species groups for trees ≥ 4.5 in. (11 cm) d.b.h. in each treatment and site.

From 1992 to 1998, white oak had the greatest net basal area growth on no-harvest sites and a net basal area increase on three of six sites receiving harvest treatments despite substantial white oak removal (fig. 6). We attribute this greater net growth rate to white oak's initial high abundance, moderate growth rate, high ingrowth rate, and low natural mortality (fig. 6). Because white oak is moderately shade tolerant (Rogers 1990), the steady increase of white oak net growth in no-harvest sites and moderate losses of white oak in harvested sites were expected. Its moderate shade tolerance allows some white oak regeneration to persist in the forest's partial shade. Once regeneration is established, white oak seedlings can be recruited into larger size classes in natural canopy gaps or in openings created by harvesting. Recruitment of white oaks into the ≥ 4.5 in. (11 cm) diameter class explains the large amount of white oak ingrowth shown in figure 6. Moreover, white oaks are less susceptible to disease or decline than the common red oak species, and they often live longer than red oaks (Hicks 1998, Rogers 1990), explaining the low white oak mortality on all MOFEP sites. Shortly after MOFEP was initiated, Pallardy (1995) predicted that white oak would become more important in the overstory. His prediction was based upon analysis of the first MOFEP inventory data set that showed that white oak was much more abundant in the understory compared to species in the red oak group and shortleaf pine (Pallardy 1995). Data collected on MOFEP thus far support Pallardy's prediction.

Black oak had low to moderate net basal area growth increases on no-harvest sites 1 and 6 but a net loss on no-harvest site 8 (fig. 6). Scarlet oak had modest net basal area growth on all no-harvest sites. Both black oak and scarlet oak had net basal area losses on all sites that received harvest treatments (fig. 6) because of low ingrowth rates, high mortality rates, and substantial harvesting. We expected greater black oak ingrowth than we observed because of its moderate shade tolerance and moderate growth rate (Sander 1990). Even though black oak is considered moderately shade tolerant, black oak seedlings and saplings must not be as shade tolerant as those of white oak or else we would have observed greater black oak ingrowth. We did not anticipate much scarlet oak ingrowth because it is shade intolerant (Johnson 1990); substantial regeneration and recruitment of scarlet oak would typically require a major canopy-removing disturbance.

High mortality of both black oak and scarlet oak was not surprising. Both species are susceptible to oak decline and to *Armillaria mellea* (Bruhn *et al.* 2000). As indicated previously, oak decline is often attributed to Armillaria root disease in the Missouri Ozarks (Bruhn *et al.* 2000, Johnson and Law 1989). The abundance of *Armillaria mellea*, the most virulent of the *Armillaria* species documented in the study area, is positively correlated with black oak and scarlet oak abundance on MOFEP sites and is correlated with very gravelly and drought-prone

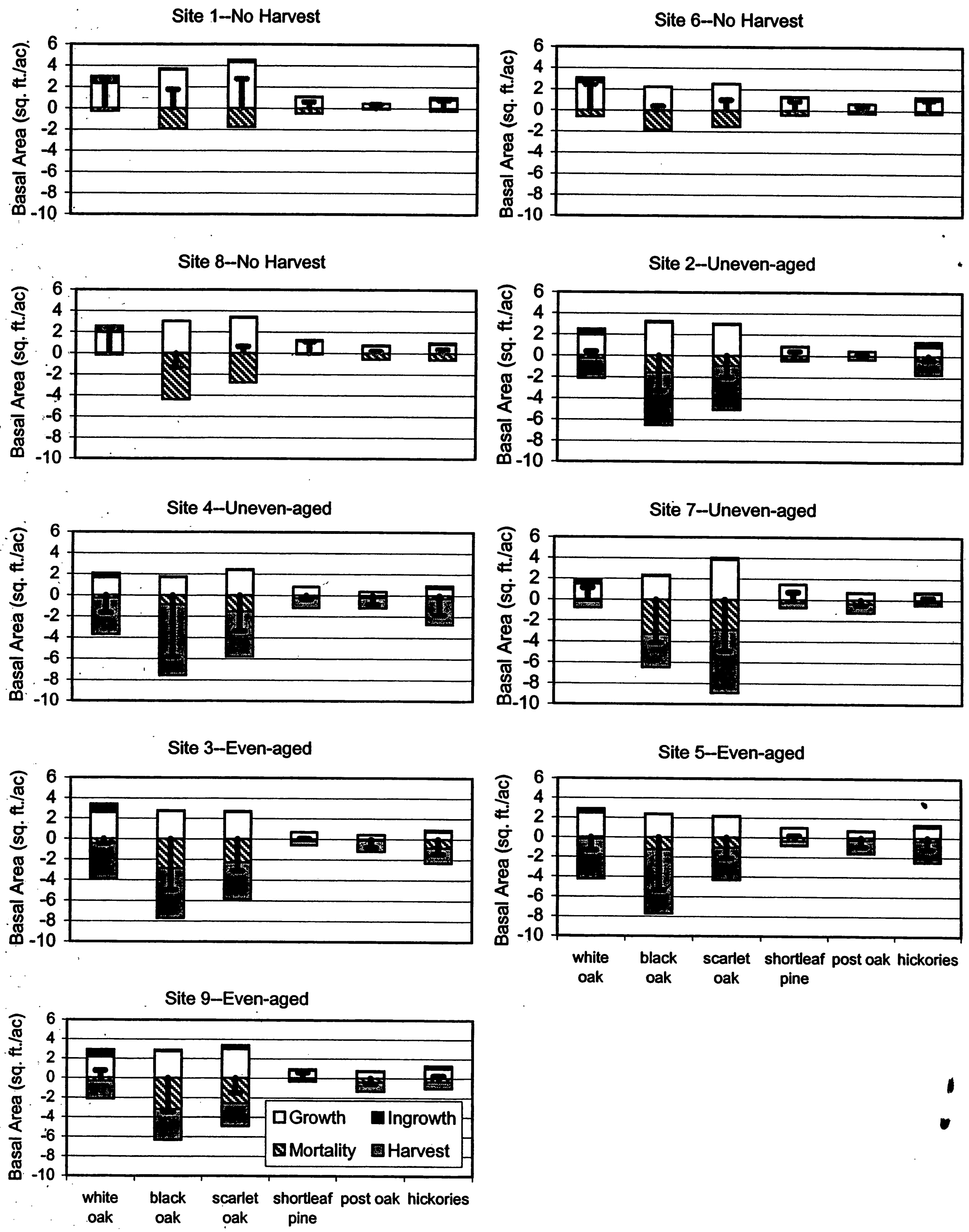

Figure 6.—*Growth of initial trees, ingrowth, mortality, and harvest of trees ≥ 4.5 in. (11 cm) d.b.h. for the most abundant trees species. Values show mean basal area change per acre for trees on each site. The line within the bar of each species shows the net change in basal area when mortality and harvest are subtracted from growth and ingrowth. The hickory group includes black, mockernut, and pignut hickory. One ft^2/ac of basal area = 0.2296 m^2/ha.*

and acidic soils associated with summit, shoulder, and shoulder ridge landform positions and with gravelly hillslope sediments from the Roubidoux and upper Gasconade bedrock formations (Bruhn *et al.* 2000). Soils having these characteristics are much more extensive on MOFEP sites 7 and 8 (Meinert *et al.* 1997), thus explaining the greater black oak and scarlet oak mortality observed on these two sites.

Shortleaf pine had negligible ingrowth and little mortality during the sampling period and maintained a modest, positive net growth on nearly every site (fig. 6). This modest positive net growth of shortleaf pine was also found on harvested sites because relatively few shortleaf pine trees were removed. The hickory group, which includes pignut hickory (*C. glabra* Mill.), mockernut hickory (*C. tomentosa* Nutt.), and black hickory (*C. texana* Buckl.), had modest but positive net growth on no-harvest sites and negligible or modest net basal area decreases on harvested sites (fig. 6).

These findings have implications for MOFEP overstory vegetation composition in the future. On no-harvest sites, we expect white oak to become much more abundant over time because the absence of harvest disturbances will favor the growth of longer lived, more shade-tolerant species such as white oak. Similarly, we also expect white oak to become more abundant on uneven-aged sites because single-tree selection harvesting favors species that are more shade tolerant and because more scarlet oak was harvested on uneven-aged sites. However, we do expect some eventual recruitment of black oak and scarlet oak in uneven-aged group openings. Overstory composition will likely change the least on even-aged sites: clearcutting leaves behind very few residual trees so there is little opportunity to alter species composition except through thinning. Moreover, most of the forest regeneration on even-aged sites appears to be from both white oak group and red oak group sprouts. It is difficult to predict composition changes for the other species because their abundances are so low. However, it appears that shortleaf pine basal area will increase on all treatments because of modest but positive net growth.

SUMMARY

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term, landscape-scale experiment to test effects of even-aged, uneven-aged, and no-harvest forest management practices on the flora and fauna of upland oak ecosystems. Three management treatments have been implemented on the MOFEP sites: (1) even-aged management with harvest by clearcutting and intermediate thinning, (2) uneven-aged management with harvest by single-tree selection and group selection, and (3) no harvest.

On even-aged treatment sites, approximately 320 ac (130 ha) (11%) were clearcut and 411 ac (166 ha) (15%) were thinned. Stands that were clearcut averaged 13 ac (5 ha) in size, and stands that were thinned on the even-aged sites averaged 11 ac (4 ha). In uneven-aged treatment sites, 2,124 ac (860 ha) (57%) were harvested. On uneven-aged sites, stands were grouped into cutting units that averaged 21 ac (9 ha) in size. Clearcutting removed more trees per cutting unit than thinning or single-tree selection, although a greater total merchantable volume was cut on uneven-aged sites.

Black oak and scarlet oak in combination made up approximately 60 percent of the harvested basal area; white oak and post oak accounted for an additional 20 to 30 percent of the harvest. In the even-aged treatment, the harvested basal areas of scarlet and white oak were nearly equal. In the uneven-aged treatment, however, harvest of scarlet oak was proportionately greater than that of white oak.

On both even-aged and uneven-aged sites for all species combined, there were decreases in trees per acre and in basal area per acre. Changes that differed significantly from those of the no-harvest control were usually detected for the larger size classes of trees. One exception was basal area, which decreased significantly in all size classes on harvested sites. The average canopy cover of all sites decreased, and decreased significantly more on harvested sites. Changes in numbers, diameters, and basal areas for the most abundant species were similar to those for all species combined.

Abundance in reproduction-sized trees did not change consistently as a result of treatments. We found that the greatest changes in reproduction occurred with stump sprouts. Clearcuts had the greatest number of sprouts, followed by areas harvested by a combination of single-tree and group selection. Some sprouting occurred in thinned and selectively harvested stands. Few sprouts were found in non-harvested stands.

From 1992 to 1998, white oak had the greatest net basal area growth on no-harvest sites. Black oak had low to modest net basal area growth increases on no-harvest sites 1 and 6 but a net loss on no-harvest site 8. Scarlet oak had modest net basal area growth on no-harvest sites. Both black oak and scarlet oak had net basal area losses on all sites that received harvest treatments because of a low ingrowth rate, a high mortality rate, and substantial harvesting. Shortleaf pine had negligible ingrowth during the sampling period, but maintained a modest, positive net growth, even on sites that received harvest treatments because relatively few shortleaf pines were removed. Among the other most abundant tree species, there was little net growth during the sampling period on all sites regardless of harvest treatment.

LITERATURE CITED

Brookshire, B.L.; Hauser, C. 1993. The Missouri Forest Ecosystem Project. In: Gillespie, A.R.; Parker, G.R.; Pope, P.E.; Rink, G., eds. Proceedings, 9th Central hardwood forest conference; 1993 March 8-10; West Lafayette, IN. Gen. Tech. Rep. NC-161. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 289-307.

Brookshire, B.L.; Jensen, R.G.; Dey, D.C. 1997. The Missouri Ozark Forest Ecosystem Project: Past, present, and future. In: Brookshire, B.L.; Shifley, S.R., eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 1-25.

Brookshire, B.L.; Shifley, S.R., eds. 1997. Proceedings of the Missouri Ozark Forest Ecosystem Project Symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 378 p.

Bruhn, J.N.; Wetteroff, J.J., Jr.; Mihail, J.D.; Kabrick, J.M.; Pickens, J.B. 2000. Distribution patterns of Armillaria species in upland Ozark Mountain forests with respect to site, overstory species composition, and oak decline. Forest Pathology. 30: 43-60.

Dey, D.C.; Jensen, R.G. 2002. Stump sprouting potential of oaks in Missouri Ozark Forests managed by even- and Uneven-aged silviculture. In: Shifley, S.R., Kabrick, J.M., eds. Proceedings of the second Missouri Ozark Forest Ecosystem Project symposium: Post-reatment results of the landscape experiment; 2000 October 17-18; St. Louis, MO. Gen. Tech. Rep. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 102-113.

Hicks, R.R. 1998. Ecology and management of central hardwood forests. New York, NY: John Wiley and Sons. 412 p.

Johnson, P.S. 1975. Growth and structural development of red oak sprout clumps. Forest Science. 21: 413-418.

Johnson, P.S. 1990. Scarlet oak. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America, Vol. 2, Hardwoods. Agric. Handb. 654. Washington, DC: United States Department of Agriculture, Forest Service: 625-630.

Johnson, P.S. 1992. Sources of oak reproduction. In: Loftis, David L.; McGee, Charles E., eds. Symposium proceedings, oak regeneration: serious problems, practical solutions; 1992 September 8-10; Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

Johnson, P.S.; Law, J.R. 1989. A five year record of change for a declining scarlet oak stand in the Missouri Ozarks. In: Rink, G.;

Budelsky, C.A., eds. Proceedings of the Seventh Central hardwoods conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 103-107.

Larsen, D.R.; Loewenstein, E.F.; Johnson, P.S. 1999. Sustaining recruitment of oak reproduction in uneven-aged stands in the Ozark highlands. Gen. Tech. Rep. NC-203. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 11 p.

Law, J.R.; Lorimer, C.C. 1989. Managing uneven-aged stands. In: Clark, F.B.; Hutchinson, J.G., eds. Central hardwood notes. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 6.08: 1-6.

Loewenstein, E.F. 1996. Size- and age-structure of an uneven-aged oak forest. Columbia, MO: University of Missouri. 167 p. Ph.D. dissertation.

Meinert, D.; Nigh, T.; Kabrick, J. 2000. Landforms, geology, and soils of the MOFEP study area. In: Shifley, S.R.; Brookshire, B.L.; eds. Missouri Ozark Forest Ecosystem Project site history, soils, landforms, woody and herbaceous vegetation, down wood, and inventory methods for the landscape experiment. Gen. Tech. Rep. NC-208. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 56-68.

Missouri Department of Conservation. 1986. Forest management guidelines. Missouri Department of Conservation. 81 p.

Pallardy, S.G. 1995. Vegetation analysis, environmental relationships, and potential successional trends in the Missouri Ozark Forest Ecosystem Project. In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings of the 10th Central hardwoods forest conference; 1995 March 5-8; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 551-562.

Rogers, R. 1990. White oak. In: Burns, RM.; Honkala, B.H., eds. Silvics of North America, Vol. 2, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 605-613.

Sander, I.L. 1990. Black oak. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America, Vol. 2, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 744-750.

Sander, I.L.; Johnson, P.S.; Rogers, R. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: United States Department of Agriculture, Forest Service, North Central Experiment Station. 11 p.

Sheriff, S.L. 2002. Missouri Ozark Forest Ecosystem Project: the experiment. In: Shifley, S.R.; Kabrick, J.M. 2002. Proceedings of the second Missouri Ozark Forest Ecosysem symposium: Post-treatment results of the landscape experiment; 2000 October 17-18; St. Louis, MO. Gen. Tech. Rep. NC-227. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 1-25.

Sheriff, S.L.; He, Z. 1997. The experimental design of the Missouri Ozark Forest Ecosystem Project. In: Brookshire, B.L.; Shifley, S.R.; eds. Proceedings of the Missouri Ozark Forest Ecosystem Project symposium: An experimental approach to landscape research; 1997 June 3-5; St. Louis, MO. Gen. Tech. Rep. NC-193. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-40.

Shifley, S.R.; Brookshire, B.L., eds. 2000. Missouri Ozark Forest Ecosystem Project site history, soils, landforms, woody and herbaceous vegetation, down wood, and inventory methods for the landscape experiment. Gen. Tech. Rep. NC-208. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 314 p.

Weigel, D.R.; Johnson, P.S. 1998. Stump sprouting probabilities for southern Indiana oaks. Tech. Brief TB-NC-7. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.