TIMBER HARVESTING, PRESCRIBED FIRE AND VEGETATION DYNAMICS IN THE MISSOURI OZARKS

A.N. Sasseen and R.M. Muzika†

ABSTRACT.—Little is known about the response of Missouri Ozark ground flora to silvicultural treatment. In this project, we examined herbaceous and woody species response to various thinning regimes and prescribed burns over several years at the Missouri Ozark Forest Ecosystem Project (MOFEP) and the Chilton Creek Management Area (CCMA). On MOFEP, ground flora and woody species regeneration data were collected across nine sites and three harvest treatments: 1) uneven-aged management, 2) even-aged management, and 3) no-harvest management. On CCMA, ground flora and woody species regeneration data were collected across burn units with different fire frequencies: 1) burned in 1998 and 2002, and 2) burned annually since 1998. Ecological Landtype Phase (ELTp) was used to stratify plots and for comparison and contrast among treatments. For woody regeneration up to 1 m, seedling and sapling development was greater on units that have been burned twice than units burned annually. For both fire frequencies and across ELTps, white oak (*Quercus alba)* dominated regenerating species. White oak regeneration was also abundant in most of the areas on MOFEP, particularly the uneven-aged plots. Successional trajectories were developed to examine treatment and ELTp effect on species change over time. The trajectories appear to be influenced by treatment as well as ELTp. Burning homogenized the ground flora vegetation on the sites, and decreases variability among ELTps, creating a consistent trajectory across ELTp. The effects of thinning and clearcutting, however, seem to be related to ELTp, therefore these ecological units can be used to understand and possibly predict the influence of specific management on vegetation.

Long-term studies of sufficient spatial extent are critical for understanding response of the vegetation communities associated with areas under active forest management. Furthermore, management for forested lands continues to develop as data reveal the consequences of various silvicultural approaches. Several large-scale studies have been conducted in attempts to characterize effects of forest management. For example studies in the Pacific Northwest (e.g., Halpern and Spies 1985, Franklin and others 2002), the Appalachians (Gilliam and others 1995, Meier and others 1995), and the Lake States (Metzger and Schultz 1984) underscore the need to include long time periods, realistic management objectives and large physical scale when examining effects of forest management activity.

Ecological land classification, a hierarchically structured, multi-factor approach for mapping ecological units at multiple scales, has been shown to be helpful in quantifying variation in ecological processes (Host and others 1987). As such, it may be valuable as a framework to examine the long term influences of management. This classification system characterizes the landscape by ecological variables including vegetation structure and composition. Management units 10's to 100's of acres (approximately 5-50 ha) in size can be defined by soil, aspect, geology and vegetation (Ecological Land Type phases [ELTps]), and represent a typical management level unit. Although few studies have incorporated the use of Ecological Classification Systems or specifically ELTp as an approach to understanding the effects of management, evaluation of the ecological units and their ability to describe variation in ground flora structure and composition, and response to management will contribute to the overall utility of an Ecological Classification System (ECS).

Numerous research efforts have examined the effect of silvicultural practices on important timber species, woody regeneration, and to a more limited extent, ground flora species. Changes in herbaceous species composition can provide a sensitive measure of ecologically relevant changes in the environment

†Plant Ecologist (ANS), National Park Service, Wilson's Creek National Battlefield, Republic, MO 65738; and Associate Professor (RMM), Department of Forestry, 203 Natural Resources Building, University of Missouri, Columbia, MO 65211. RMM is the corresponding author: to contact, call (573) 882-8835 or e-mail at muzika@missouri.edu

(Daubenmire 1952, Phillippi and others 1998). Analysis in an ECS framework would disclose more about the responses at the classification unit level and may make results more understandable and useful to areas outside the study sites.

In order to develop a greater understanding of the role of forest management in forest dynamics of the Missouri central hardwoods forests, the Missouri Department of Conservation (MDC) initiated the Missouri Ozark Forest Ecosystem Project (MOFEP) in the southeast Missouri Ozarks in 1989. MOFEP is a 100-year project designed to study the effects of traditional silvicultural methods of forest management (unevenaged, evenaged and no-harvest [control]) on various ecosystem components (Brookshire and others 1997). While the effects of even-aged management on regeneration have been studied to some degree in the Missouri Ozarks, attempts to examine the effects of uneven-aged management on regeneration are relatively new. Uneven-aged methods are significantly varied, often with site factors determining which uneven-aged method and to what extent it is used (Smith and others 1997, Larsen and others 1999, Loewenstein and others 2001).

Nearby to the MOFEP study, the Nature Conservancy initiated a case study at the Chilton Creek Area to determine the effects of fire-based ecosystem management, with the management of the site aimed at restoring and sustaining the native biota of the site through prescribed burning (The Nature Conservancy 1996). Dendrochronological and cultural evidence suggests fire interval in the Missouri Ozarks varied substantially during the last several centuries (Guyette and others 2002). In the Missouri Ozarks the reduction in fire intensity and frequency followed extensive logging of forests, many of which were dominated by shortleaf pine (*Pinus echinata*). Despite a resource that once accounted for millions of acres, short leaf pine now accounts for fewer than 200,000 hectares. Implications for management of the hardwood resource in Missouri, obviously encompasses potential for understanding and managing the pine resource in the region, as well. The recognition that both oak and pine dominated Ozark forests may rely on fire has increased the used of prescribed fire in Missouri forests. Although there have been recent efforts of re-introducing fire, the effect of fire on plant species composition, regeneration, succession, diversity, habitat, or wood quality remains unknown. The Chilton Creek study makes use of MDC's Ecological Classification System to organize hierarchical management units based on soil, geology, landform and vegetation; these units presumably represent stand-sized systems that would respond similarly to management. Thus, CCMA provides an ideal opportunity to directly link classification units to response.

The objective of this project was to explore how prescribed fire, timber harvest and ELTps influence ground flora composition, and explain forest dynamics. Although the harvesting treatments and burning treatments represent independent studies, we used ELTp as a sampling framework. We examine woody species response to treatment and overall richness, as well as examining how these change over time using ordination. ELTPs are used not only to stratify and compare silvicultural treatments, but also to examine the interaction of silvicultural treatments and ELTps. We examined response of herbaceous and woody species for 1) specific ELTps by treatment, and 2) within a treatment by ELTp. We contrast two long-term projects, which characterize typical forest management in the Missouri Ozarks. Although the study uses ELTp to stratify the plots, this project does not represent a test of the ECS *per se*, or the classification of ELTs and ELTps

Study Area

Both study areas, MOFEP and CCMA, are located in the southeast portion of the Ozark Highlands The physical boundaries of the Ozark Highlands are often open to debate, but in general, the region includes greater relief and steeper slopes than surrounding areas with exposed rock being older than outside the region (Rafferty 1980). Geologically, there is more dolomite, as opposed to limestone, and a prevalence of hard chert nodules (Rafferty 1980, Meinert and others 1997) when contrasted with adjacent areas.

MOFEP and CCMA are in the Current River Hills subsection, an area dissected by the Black, Current and Eleven Point rivers with local relief ranging from 61 to 183 meters (Nigh and Schroeder 2002). A subsection is an ecological classification level that can be > 1,000 acres (>400 ha). The Current River Hills subsection is mostly second growth forests of oak, oak-pine and mixed hardwood timber types. MOFEP is composed of nine sites, each at least 240 ha and relatively free of manipulation for no less than 40 years. There are thirteen ELTps on MOFEP with 43 soil map units. Five ELTps,comprising a majority of the landscape of interest to land managers. These have been characterized by Nigh and others (2000) (numbers indicate ELTp designations):

- high, ultic shoulders (2.1)
- exposed, ultic, Roubidoux/upper Gasconade backslopes (3.1)
- protected, ultic, Roubidoux/upper Gasconade backslopes (4.1)
- exposed, alfic, lower Gasconade/Eminence backslopes (5.2)
- protected, alfic, lower Gasconade/Eminence backslopes (6.2).

Local relief at CCMA ranges from 24 to 103 m (80 to 340 ft) with elevation ranging from 152 to 299m (500 to 980 ft). There are fifteen ELTps on CCMA, four of which are further characterized by this project:

- high, ultic shoulders (2.1)
- exposed, ultic, Roubidoux/upper Gasconade backslopes (3.1)
- protected, ultic, Roubidoux/upper Gasconade backslopes (4.1)
- exposed cherty and non-cherty variable depth to dolomite units, upper and lower Gasconade/ Eminence, multiple landforms (7.12).

For this paper, we will focus on the ELTps common to the two sites: 2.1, 3.1, 4.1 as well as 7.12.

Methods

On MOFEP, the nine sites are grouped into three replicated blocks. Each block (about 400 ha) contained one even-aged, one uneven-aged and one no-harvest (control) unit. All units were randomly allocated. Stratified random sampling was used to locate 70 to 76 vegetation plots, each 0.2 ha in size, in each of the nine sites for a total of 648 plots (Brookshire and others 1997). Each plot contains four 0.02 ha subplots, with four 1- m^2 quadrats within each subplot.

Treatments tested include plots located in clearcuts (CC) and intermediate harvest (I) as evenaged management (EAM); group openings (UG) and select harvesting (U) as unevenaged management (UAM) and one control (L) as no-harvest management (NHM). The first harvest began in 1996. Stands with site index ≥55 were managed with intermediate cutting. Harvest prescriptions follow Roach and Gingrich (1968), with approximately 10 to 12 percent of the site in clearcuts. Clearcutting and thinning affected 26% of the total area of the three even-aged sites with 15% (166 ha) and 11% (130 ha) respectively.

For uneven-aged management approximately 10 percent of each site was designated as “old growth” and the remaining 90 percent managed using group openings and select harvest (Shifley and Brookshire 2000). Approximately 57 percent of the total area of uneven-aged sites received single-tree selection harvests. There were between 153 and 267 group openings on each of the UAM sites, with group openings on south-facing slopes 21m in diameter (i.e. approximately one tree height), north-facing slopes 42m in diameter and ridge tops 32m in diameter (Law and Lorimer 1989). This allowed for a total of 10 to 19 ha per site in group openings.

The 2,268 ha Chilton Creek site is divided into five units for treatment, one of which is burned annually. The other four units are burned on a random 1-4 year return interval. The first prescribed burn occurred spring 1998, and the most recent data included in this analysis is from 2002. Each unit has then burned on a schedule based on random return intervals generated for each unit, independent of the other units. The result is a project area that has one annually burned unit and 0-4 units burned in any given year. A total of 250 plots were established randomly after stratification using ECS structure. Plot design and vegetation sampling follows MOFEP criteria for circular 0.2 ha plots (Brookshire and others 1997). For this paper, we will focus on plots that were annually burned and plots that have been burned twice in the five year period.

Ground flora vegetation sampling on both MOFEP and CCMA occurred from May to August. Within in each 1m^2 quadrat, all vascular species <1 m tall with live foliage were identified and percent cover to the nearest 1 percent estimated. Stems were counted for all tree seedlings less than 1m in height that were rooted in the quadrat. Woody species data were also collected from the 0.02 ha subplots and the 0.004 ha subplots. The circular subplots are nested within the 0.2 ha plot, with four of each subplot. In the 0.004 ha subplot, live trees at least 1m tall and less than 4 cm d.b.h. were tallied by species and size class.

Statistical Analysis

For MOFEP and CCMA, richness was calculated as the number of species per plot (16m^2). Plot richness was evaluated with a combination of ninety-five percent confidence intervals and pairwise t-tests. Pairwise t-tests were used to test for treatment effect, year effect and ELT effect on richness. Upper and lower confidence intervals were calculated using SPSS version 11.0.

Temporal patterns were examined by plotting ELTp ordination scores obtained through Detrended Correspondence Analysis (DCA). Ordination of community samples through time reveals successional trajectories (Halpern 1988). Mean ELTp scores were plotted in two dimensional species space. Detrended correspondence analysis was chosen because of its computation efficiency with large data sets and its ecologically interpretable and intuitive results.

DCA scores were used to obtain measures of resistance and resilience, or the degree to which community composition changes and recovers after disturbance. Euclidean distance was used in two-dimensional ordination space to measure compositional dissimilarity between the initial and each post-disturbance ELTp sample. Resistance to disturbance was defined as inversely proportional to the maximum Euclidean distance between pre- and any year post-disturbance samples (Halpern 1988). Resilience, or the recovery of a community to pre-disturbance conditions, was defined as inversely proportional to the Euclidean distance between pre-disturbance and the final post-disturbance sample for each ELTp (Halpern 1988).

Successional trends were examined using trajectory analysis (McCune and Grace 2002). Vectors of change over time from pre-treatment to last year post-treatment were standardized by subtracting tail from head and tail. PC-ORD version 4.14 (McCune and Mefford 1999) was used to perform multivariate analyses.

Results

Regenerating species

CCMA – the effect of burning. Woody tree species regeneration was examined for five tree species: black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.), post oak (*Quercus stellata* Wangenh.), scarlet oak *Quercus coccinea* Muenchh.), and shortleaf pine (*Pinus echinata* Miller). These species were sampled in various size classes from ground flora layer (<1m tall) to small sapling layer ($\geq$1m tall and <3.81cm dbh) and large sapling layer ($\geq$3.81cm to <11.43cm dbh). This paper will focus on the two larger size classes.

Across all ELTps, in the small sapling layer, annual burning resulted in a reduction of an average of 2600 stems per ha and 1316 stems per ha in the twice-burned plots. On annually burned and twice burned plots, the large sapling layer decreased by 229 and 183 stems per ha, respectively.

There was little change in shortleaf pine regeneration relative density in any size class from pre-treatment (1997) to post-treatment (2001) on CCMA (figs. 1a, b). The exception, however was a drastic decrease in twice burned ELTp 3.1 in the small sapling class. Overall abundance of post oak, scarlet oak, white oak and black oak showed little change as a result of prescribed burning. Scarlet oak exhibited decline in 2001 in the small sapling class, annually burned plots across all ELTps (fig. 1a). In the large sapling layer, this reduction occurred on annually burned 7.12s and on twice burned 2.1s and 3.1s .

There was no effect of prescribed burning on post oak regeneration. White oak relative density changed on specific ELTps, but overall was not significantly affected by burning. In the small sapling layer (fig. 2a) white oak had significantly reduced relative density on annually burned 7.12s. However in the larger sapling class (fig. 1b), relative density of white oak increased on twice burned 3.1s.

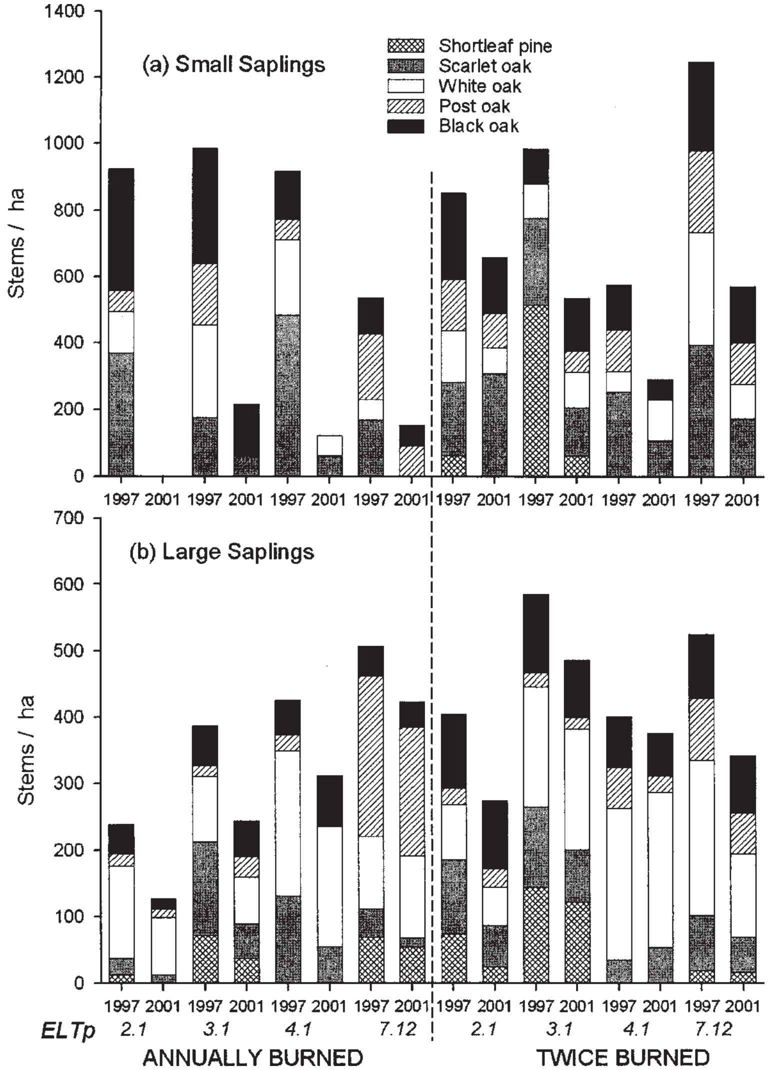

Figure 1a, b.—Mean number of stems per ha for (a) small sapling layer ≥ 1 m and< 3.81 cm dbh) and (b) large sapling layer (≥ 3.81 cm and< 11.43 cm dbh) on CCMA pre-treatment (1997) and post treatment (2001) for shortleaf pine, black oak, white oak, post oak and scarlet oak.

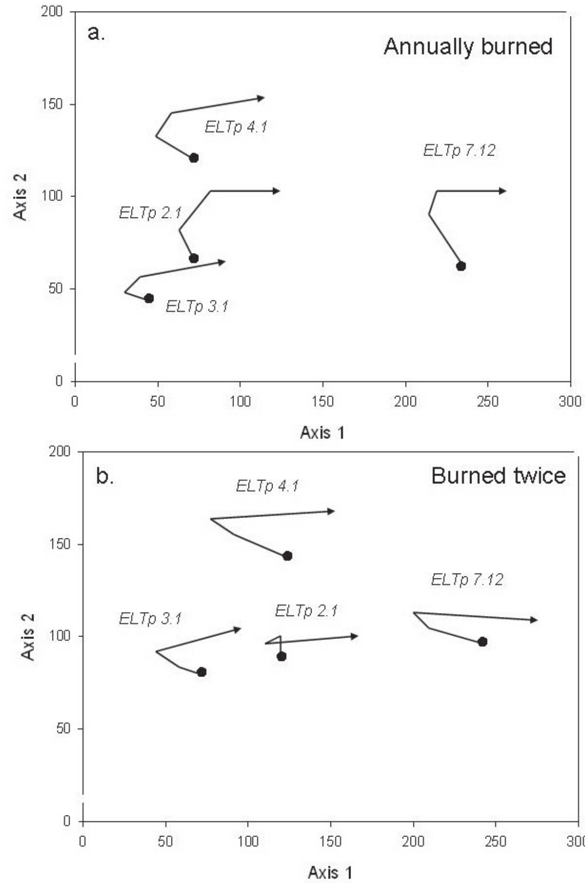

Figure 2a, b.—Detrended correspondence analysis (DCA) ordination through time representing understory communities of ELTps on CCMA annually burned (since 1998) sites (a) and sites burned twice in a five year period (b). Symbol endpoints indicate predisturbance communities (1997); lines connect the same ELTp in subsequent years post-disturbance (1998, 2001, 2002); arrowheads coincide with the final sample and indicate the direction of change through time.

MOFEP—the effect of harvest. Generally, regardless of treatment, there were declines in the 5 species of interest, through the course of the study. With the exception of the clearcut sites, harvest treatments on MOFEP had little effect on the relative density of many species. Relative density of black oak did not change the sapling layers. Over the course of the study, white oak decreased generally except in clearcut ELTp 2.1 (table 1 and table 2). However, density in the small sapling class had not decreased from pre-treatment and had increased in clearcuts on ELTp 4.1 and group opening 2.1s (table 1). The large sapling class had significant increases in white oak relative density for all treatments and most ELTps, with the exceptions of clearcuts on ELTp 3.1 and group opening on ELTp 4.1 (table 2). Shortleaf pine was common on certain ELTps, namely 3.1 and 2.1 only in the small sapling class. Clearcutting appears to have reduced pine saplings.

In general, there were more saplings in harvested plots for select ELTps than NHM. Indicative of the current overstory vegetation (Sasseen 2003), post oak was more abundant on control sites in the ground flora layer, than other treatments. Post oak is also the most common large sapling in clearcuts.

Table 1.—Stems per hectare of small sapling (>1 m tall and <3.81 cm DBH) on MOFEP during pretreatment (1994) and most recent sampling (2002) following treatment on select ELTps. Treatments include CC=clearcut (EAM), I=intermediate (EAM), L=No harvest (NHM), U=select (UAM), UG=group openings (UAM).

Treatment	ELTp	Year	Shortleaf pine	Scarlet oak	White oak	Post oak	Black oak
CC	2.1	1994	0	0	0	0	0
		2002	0	1482.6	1420.8	0	988.4
	3.1	1994	92.7	30.9	216.2	61.8	293.4
		2002	92.7	756.7	1776.0	339.8	1050.2
	4.1	1994	0	10.3	8.8	0	26.5
		2002	0	483.9	626.6	308.9	485.4
I	2.1	1994	0	0	92.7	0	30.9
		2002	0	0	154.4	0	154.4
	3.1	1994	61.8	46.3	20.6	0	61.8
		2002	0	61.8	103.0	61.8	144.1
	4.1	1994	0	123.6	0	0	0
		2002	0	61.8	329.5	0	61.8
L	2.1	1994	0	20.6	150.0	61.8	113.3
		2002	0	103.0	150.0	226.5	113.3
	3.1	1994	185.3	103.0	44.1	123.6	154.4
		2002	370.7	92.7	79.4	0	61.8
	4.1	1994	0	61.8	108.1	0	92.7
		2002	0	0	77.2	0	61.8
U	2.1	1994	30.9	37.1	101.1	0	69.5
		2002	61.8	74.1	213.4	0	193.0
	3.1	1994	0	51.5	88.3	41.2	154.4
		2002	0	72.1	432.4	267.7	144.1
	4.1	1994	0	20.6	113.3	0	0
		2002	0	61.8	123.6	0	144.1
UG	2.1	1994	0	92.7	46.3	0	0
		2002	0	30.9	339.8	0	61.8
	3.1	1994	0	82.4	77.2	247.1	123.6
		2002	1482.6	329.5	378.4	617.8	347.5
	4.1	1994	0	0	74.1	0	0
		2002	0	123.6	259.5	0	164.7

Composition

CCMA. Generally, plot level species richness was significantly different from pretreatment on annually burned plots over time (table 3). The exception is ELTp 7.12, which differed only immediately following first year of burning. Plots that were burned twice in ELTps 2.1, 3.1, and 4.1 differed significantly after burning, but the distinction in richness became less evident over time. In general, richness was greater over time in all ELTp and treatment combination.

DCA plot scores in species space for successive years were plotted as successional trajectories in two dimensional ordination space. Both treatments had similar patterns for all ELTps (fig. 2a, b). CCMA showed distinct separation of ELTps along both axes. ELTp 7.12 was distinctly distanced from the other three ELTps on axis one. Along axis 2, ELTp 4.1 (protected, upper backslope) was separate from other ELTps. For all the ELTps, however the trajectory was almost identical. Initially, ELTps changed along axis 1, but then the trajectory increased along axis 2, before finally reversing direction along axis 1 and returning almost to pre-treatment conditions. On CCMA, successional trajectories were not significantly different between treatments, but within a treatment annually burned 3.1s and 4.1s were significantly different.

DCA scores were also used to calculate relative resistance and resilience of each ELTp after treatment. CCMA ELTp 7.12 was the most resistant to disturbance and also the most resilient, i.e. it did not change as much after treatment as other ELTps and it returned to pre-treatment conditions rapidly (table 4).

Table 2.—Stems per hectare of large sapling (>3.81 cm DBH and <11.43 cm DBH) on MOFEP during pretreatment (1994) and most recent sampling (2002) following treatment on select ELTps. Treatments include CC=clearcut (EAM), I=intermediate (EAM), L=No harvest (NHM), U=select (UAM), UG=group openings (UAM).

Treatment	ELTp	Year	Shortleaf pine	Scarlet oak	White oak	Post oak	Black oak
CC	2.1	1994	0	49.4	432.4	0	37.1
		2002	0	210.0	506.6	0	185.3
	3.1	1994	144.1	58.7	163.7	12.4	101.9
		2002	78.2	216.2	129.7	6.2	98.8
	4.1	1994	0	38.8	102.4	18.5	22.7
		2002	0	81.2	95.3	0	61.8
I	2.1	1994	0	12.4	37.1	12.4	0
		2002	0	4.1	12.4	0	0
	3.1	1994	24.7	12.4	105.0	0	16.5
		2002	24.7	6.2	71.0	0	12.4
	4.1	1994	0	61.8	190.3	0	12.4
		2002	0	0	116.1	0	0
L	2.1	1994	18.5	16.5	119.8	64.9	22.2
		2002	6.2	8.2	113.7	68.0	17.3
	3.1	1994	40.2	51.9	111.2	46.3	35.0
		2002	46.3	49.4	117.4	34.0	20.6
	4.1	1994	0	0	103.8	0	0
		2002	0	12.4	82.8	24.7	0
U	2.1	1994	30.9	24.7	120.5	12.4	29.7
		2002	18.5	12.4	88.5	12.4	14.8
	3.1	1994	24.7	46.3	143.0	16.5	6.2
		2002	6.2	6.2	95.3	0	30.9
	4.1	1994	0	18.5	119.4	12.4	12.4
		2002	0	12.4	66.9	0	0
UG	2.1	1994	0	12.4	126.6	0	12.4
		2002	0	0	89.6	12.4	12.4
	3.1	1994	34.6	83.7	174.3	29.7	84.9
		2002	22.2	20.6	137.3	24.7	54.1
	4.1	1994	0	15.4	164.7	0	0
		2002	0	12.4	82.4	0	0

MOFEP. Differences in plot level richness for MOFEP were apparent in every ELTp with at least one treatment effect, but of the hundreds of possible combinations and potential contrasts in the MOFEP project, however only a few were significant (Table 5). ELTp 2.1 had the fewest significant differences, however there were fewer treatments in these ELTps. Treatment differences within ELTps were not consistent. Contrast with clearcuts provided a significant difference in each ELTp except 2.1. In many cases, the significance persisted and was evident throughout the years sampled, e.g. CC-L contrasts on ELTp 3.1 and 4.1. All treatments except control influenced species richness (Table 5).

The MOFEP trajectories were very different than CCMA trajectories for the same ELTps (example trajectory fig. 3). The ELTps separated in the same pattern for each treatment and the ELTps showed patterns of response. All ELTps in NHM are increasing on axis two while in clearcuts, all ELTps decreasing along axis two. In UAM and intermediate harvest, ELTps are showing a similar pattern. ELTps 3.1 and 4.1 are increasing along axis two, while ELTps 2.1 is decreasing along axis two.

Trajectory analysis showed clearcuts had significantly different successional trajectories from NHM for 3.1 and 4.1 Intermediate harvest had significantly different trajectories from NHM for all ELTps except 4.1, while select harvest was significantly different from NHM only for ELTp 4.1. However, intermediate and select harvest differed significantly for 2.1,but group openings trajectories differed significantly from NHM for ELTp 3.1.

Table 3.—P-values of CCMA treatment differences in mean richness by ELTp. Pairwise t-test of year effect on mean plot richness in annually burned and twice-burned plots by ELTp. Year contrast is post-treatment year specified minus pre-treatment year (1997). In 1998, annually burned and burned-twice areas had only been burned once.

ELTp	Contrast year	Annually Burned Pr > | t |	Twice Burned Pr > | t |
2.1	1998	0.2674	0.0302
	2001	0.0318	0.933
	2002	0.009	0.1154
3.1	1998	0.7327	0.0379
	2001	0.3185	0.0017
	2002	0.2984	0.4005
4.1	1998	0.2084	0.0522
	2001	0.2797	0.0309
	2002	<0.0001	0.0943
7.12	1998	0.0045	0.1311
	2001	0.3194	0.8966
	2002	0.8211	0.5071

Table 4.— Relative resistance and resilience measures on CCMA, derived from Euclidean distances (ED) between pre- and post disturbance samples in a two-dimensional ordination space. Distances are in standard deviation units.

Treatment	ELTp	Maximum ED (SD Units)	Relative resistance (rank)	ED at final sampling (SD units)	Relative resilience (rank)
Annual	2.1	0.61	3	0.61	3
	3.1	0.52	1	0.52	1
	4.1	0.54	2	0.54	2
twice	2.1	0.34	1	0.34	1
	3.1	0.361	2	0.361	3
	4.1	0.363	3	0.358	2

ELTp 3.1 appeared to have overall high resistance and resilience, while ELTp 4.1 had low resistance and resilience (table 6). On MOFEP, ELTps in clearcuts had a similar resistance and resilience pattern to NHM, while intermediate (EAM), select harvest (UAM) and group openings (UAM) were similar (Table 6). Within clearcuts, ELTp 3.1 had the highest resistance and resilience. In NHM, ELTp 2.1 was the most resistant followed by 3.1 and 4.1. However, the resilience rankings were 4.1, 3.1 and 2.1.

Discussion

CCMA

The short term and immediate effect of fire is a considerable reduction in seedlings and saplings. According to the findings of this study, annual burning may be too frequent to sustain an overstory. Fire did not appear to promote shortleaf pine. Shortleaf pine did not show up in the small sapling class at all on annually burned plots and was reduced on plots that were burned twice. Fire frequency for promotion of shortleaf pine must still be resolved if there is an interest in restoring this once common forest type to the Missouri Ozarks.

Although not reported here, both fire frequencies resulted in increased forbs, legumes and woody shrub and tree species and a decrease in woody vines and graminoid species (Sasseen 2003), a response similar

Table 5.—MOFEP treatment differences in mean richness by ELTp. Harvest occurred 1996. Bold denotes significant difference from pre-treatment species richness. Only treatment comparisons with at least on significant year difference are shown. CC=clearcut (EAM), I=intermediate (EAM), L=No harvest (NHM), U=select (UAM), UG=group openings (UAM).

Treatment	ELTp	Year	Shortleaf pine	Scarlet oak	White oak	Post oak	Black oak
CC	2.1	1994	0	49.4	432.4	0	37.1
		2002	0	210.0	506.6	0	185.3
	3.1	1994	144.1	58.7	163.7	12.4	101.9
		2002	78.2	216.2	129.7	6.2	98.8
	4.1	1994	0	38.8	102.4	18.5	22.7
		2002	0	81.2	95.3	0	61.8
I	2.1	1994	0	12.4	37.1	12.4	0
		2002	0	4.1	12.4	0	0
	3.1	1994	24.7	12.4	105.0	0	16.5
		2002	24.7	6.2	71.0	0	12.4
	4.1	1994	0	61.8	190.3	0	12.4
		2002	0	0	116.1	0	0
L	2.1	1994	18.5	16.5	119.8	64.9	22.2
		2002	6.2	8.2	113.7	68.0	17.3
	3.1	1994	40.2	51.9	111.2	46.3	35.0
		2002	46.3	49.4	117.4	34.0	20.6
	4.1	1994	0	0	103.8	0	0
		2002	0	12.4	82.8	24.7	0
U	2.1	1994	30.9	24.7	120.5	12.4	29.7
		2002	18.5	12.4	88.5	12.4	14.8
	3.1	1994	24.7	46.3	143.0	16.5	6.2
		2002	6.2	6.2	95.3	0	30.9
	4.1	1994	0	18.5	119.4	12.4	12.4
		2002	0	12.4	66.9	0	0
UG	2.1	1994	0	12.4	126.6	0	12.4
		2002	0	0	89.6	12.4	12.4
	3.1	1994	34.6	83.7	174.3	29.7	84.9
		2002	22.2	20.6	137.3	24.7	54.1
	4.1	1994	0	15.4	164.7	0	0
		2002	0	12.4	82.4	0	0

to comparable studies (Arthur and others 1998, Paulsell 1957). However, Paulsell also found an increase in grasses after burning, which did not occur on CCMA. This discrepancy may be due to a shift in species from fire-sensitive grass and sedge species to fire-tolerant species. The fire-tolerant species of grasses and sedges may also need a more open canopy than is resulting from the initial burning on CCMA, which has been burned since 1998. Grass and sedge abundance may increase in future when fire tolerant species gain dominance.

There has been much evidence to suggest that oak dominance is dependent upon fire in oak-hickory forests (Blake and Schuette 2000, Brose and others 2001). Four years after burning on CCMA, relative density of oak species is decreasing. Black oak appears to be the least tolerant of fire, with decreases in relative density in all layers. However, the more fire tolerant, white oak also decreased in the sapling layers for most ELTps, with the exception of a large increase in the annually burned 2.1. This may be due to sprouting of saplings since all five tree species were reduced on annually burned 2.1 in the small and large sapling layers. White oak relative density increased in the large sapling layer on annually burned 4.1 and twice-burned 3.1, suggesting future recruitment into the overstory, especially given the reduction in competition due to sapling mortality of other species such as black oak. Given differences in fire tolerance between the white oak and black oak group, there will likely be a shift in the future to more white oak and post oak on CCMA.

Table 6.—Relative resistance and resilience measures on MOFEP, derived from Euclidean distances (ED) between pre- and post disturbance samples in a two-dimensional DCA ordination space. Distances are in standard deviation units.

Treatment	ELTp	Maximum ED (SD units)	Relative Resistance (rank)	ED at final sampling (SD (units)	Relative Resilience (rank)
Control	2.1	0.2	1	0.18	3
	3.1	0.52	2	0.16	2
	4.1	0.79	3	0.06	1
Clearcut (EAM)	3.1	0.45	1	0.41	1
	4.1	0.62	2	0.5	2
Intermediate Harvest (EAM)	2.1	0.82	2	0.21	3
	3.1	0.5	1	0.11	1
	4.1	0.87	3	0.12	2
Select Harvest (UAM)	2.1	0.65	3	0.082	2
	3.1	0.243	1	0.07	1
	4.1	0.45	2	0.11	3
Group Opening (UAM)	2.1	0.54	2	0.04	2
	3.1	0.22	1	0.01	1
	4.1	0.63	3	0.28	3

Exploratory DCAs confirmed the importance of ELTps based on environmental factors but also demonstrated the control of certain disturbances. DCAs showed a separation of ELTps along axis 1, representing the influence of dolomite on the ground flora vegetation (fig. 3). Dolomite close to the surface results in soils with higher base percentages (35 to >50%) and typically supports a more diverse ground flora (Nigh 2000). Grabner (2002) found that unique assemblages of species resulted from the dolomite located at or near the soil surface. Variable depth to dolomite areas on CCMA (ELTp 7.12) had the highest richness and diversity of all ELTps and showed distinct separation from other ELTps on DCAs, indicating a distinct plant community. The effect of fire on the DCA and trajectory indicate that there can be a homogenizing effect and the fire frequency can determine consistent successional patterns. Halpern (1988) found that floras with greater community fidelity resulted in more distinct successional pathways. For CCMA, fire may create conditions suitable to a select suite of vegetation, and therefore trajectories can become more consistent over time.

The resistance and resilience measures correspond with successional theory equating diversity with stability (Lawton 1994). The annually burned sites had higher richness and diversity than the twice-burned and also had higher relative resistance and resilience scores. This substantiates the theory that high levels of diversity essentially buffer the effects of disturbance. ELTp 7.12, which had the highest richness and diversity, had the greatest resistance and resilience. It changes less than other ELTps and can return to pre-disturbance conditions more quickly.

MOFEP

The increases in richness after harvest (and decrease on control) on MOFEP are similar to other studies and therefore expected (Beese and Bryant 1999, Halpern and Spies 1995, Collins and Pickett 1988). In this study on the MOFEP sites, the first post-harvest sampling season occurred three years after treatment and may have missed the initial response of vegetation to harvest. The immediate response to treatment, therefore, remains unknown.

Change in richness on MOFEP corresponded with intensity of treatment. Clearcuts had the highest richness and the greatest increases, followed by group openings, select harvest, intermediate harvest and

NHM. This pattern suggests a gradient of responses determined by the amount of light reaching the forest floor. When stratifying by ELTp, 4.1 consistently demonstrated changes in richness between pre- and post-treatment. ELTp 4.1 is protected in aspect, with slightly greater moisture levels, so the influx of light due to harvest may have a greater effect than exposed ELTps.

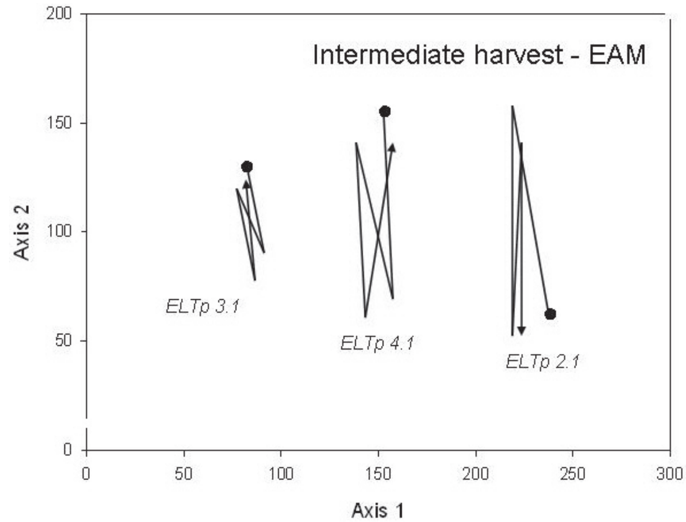

Figure 3.—Detrended correspondence analysis (DCA) ordination through time representing understory communities of ELTps on MOFEP intermediate harvest sites (EAM). Symbol endpoints indicate predisturbance communities (1995); lines connect the same ELTp in subsequent years (post-disturbance 1999, 2000, 2001, 2002); arrowheads coincide with the final sample and indicate the direction of change through time.

White oak consistently decreased across treatments except for clearcut 2.1, while black and scarlet oak increased across harvested sites. The small and large sapling layers were dominated by white oak, with the exception of clearcuts, which had large scarlet oak components (table 2). White oaks were dominant in the sapling layers for all ELTps and treatments including NHM. The oak forests of the Ozark Highlands are generally xeric landscapes where shade tolerant tree species are not major competitors.

Over time, tree species composition may shift to greater white oak density as light levels are reduced. White oak is moderately shade tolerant even in the sapling or seedling stage. Black oak is also moderately shade tolerant, but appears to have less shade tolerance than white oak at the seedling or sapling stage (Kabrick 2002). Black oak is also shorter-lived than white oak and may eventually be replaced by white oak. Scarlet oak, though comprising a significant portion of regeneration in clearcuts, is not expected to have significant in-growth into canopy layers due to its shade intolerance.

Exploratory DCAs on MOFEP data were not as consistent as CCMA. The axes represented a possible light gradient on axis 2 and an influence of dolomite gradient on axis 1, as they did for CCMA. However, plotted successional trajectories for MOFEP were very different from CCMA. There were large variances along axis 2, even for NHM, but the ELTps separated in the same order along axis 1 across treatments. While there was great variance, successional trends did emerge. All ELTps on NHM are moving towards a species composition associated with a closed-canopy. The changes along axis 2 for NHM suggest dynamic natural succession occurring with a trend towards more shade tolerant species.

All ELTps in clearcuts are moving towards species associated with a more open canopy. While the stand as a whole undergoes the long process of stand initiation, the ground flora undergoes rapid floristic change. Gilliam and others (1995) found that the degree to which forest management alters species diversity and long-term succession patterns depends upon the level of "decoupling" of the relationship between understory and overstory. In the Appalachians, single-tree harvest decreased plant species diversity less than clearcutting. Meier and others (1995) found that clearcutting decreased the vernal-herb diversity in the Appalachians, because of modification of the forest floor and eliminating gap-phase succession. It is likely the processes in the Missouri Ozarks are distinct from most areas in the Eastern Deciduous forest.

MOFEP relative resistance and resilience scores were similar in range to the scores on CCMA, but with less consistent patterns. NHM had both the lowest and highest scores for resistance. Clearcuts were more similar to NHM than other harvest treatments in respect to ELTp resistance and resilience values. The microclimatic changes caused by natural successional conditions and/or intense harvest were less pronounced on ELTps that were more xeric before treatment (i.e. ELTp 3.1).

ELTps in intermediate harvest, select harvest and group openings were similar in ELTp response to harvest treatments. ELTp 3.1 had the greatest resistance on these treatments, thereby supporting the diversity/stability theory. It had only moderate to low resilience however. The rankings for these three treatments were more similar to CCMA rankings, in terms of ELTps resistance to disturbance. ELTp 3.1 was consistently resistant and resilient and 4.1 was generally not resistant or resilient. Intermediate harvest, select harvest and group openings may not have been intense enough to cause lasting microclimate changes and may be more dependent on existing abiotic and biotic conditions to determine successional changes.

Successional trajectories in ordination space remained ordered along light (moisture) and geology gradients, suggesting the influences of initial species composition and local environment may persist through catastrophic disturbance. There were also differences between treatments that were very similar (i.e. intermediate and select harvest) that may have more to do with stochastic events such as immediate response of initial vegetation and buried seed or soil disturbance factors. Successional trajectories are determined through an interaction of both deterministic site factors and stochastic disturbance factors. In the short term successional trajectory apparent on MOFEP and CCMA, treatment effects may be most evident, but after initial response to disturbance deterministic site factors may dominate.

In general, the response at MOFEP is very different from the response at CCMA, but as expected since the treatments differ in intensity, frequency and magnitude. The predictability within an ELTp for understanding the effects of treatment may be greater for the harvested plots rather than the burned plots. Using prescribed fire may override the effects of site that could be controlling succession on the MOFEP sites. It is not possible to know if there will long-term differences in species richness, composition, abundance or successional trajectories as a result of management.

Literature Cited

Arthur, M.A.; Paratley, R.D.; Blankenship, B.A. 1998. **Single and repeated fires affect survival of woody and herbaceous species in an oak-pine forest.** Journal of the Torrey Botanical Society. 125:225-236.

Barnton, A.G. 1993. **Atlas of frequency distributions, auto-correlation and cross correlation of daily temperature and precipitation at stations in the U.S.: 1948-1991.** Camp Springs, MD: USDC NOAA Atlas NO. 11 m.

Beese, W.J.; Bryant, A.A. 1999. **Effect of alternative silvicultural systems on vegetation and bird communities in coastal montane forest of British Columbia, Canada.** Forest Ecology and Management. 115: 231-242.

Blake, J.G.; Schuette, B. 2000. **Restoration of an oak forest in east central Missouri, early effects of prescribed burning on woody vegetation.** Forest Ecology and Management. 139: 109-126.

Brookshire, B.L.; Jensen, R.; 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: 169-197.

Collins, B.S.; Pickett, S.T. 1988. **Demographic responses of herb layer species to experimental canopy gaps in northern hardwoods forest.** Journal of Ecology. 76: 437-450.

Daubenmire, R. 1952. **Forest vegetation of northern Idaho and adjacent Washington and its bearings on concepts of vegetation classification.** Ecological Monographs. 22: 301-330.

Franklin, J.F.; Spies, T.A.; VanPelt, R.; Carey, A.B.; Thornburgh, D.A.; Berg, D.R.; Lindenmayer, D.B.; Harmon, M.E.; Keeton, W.S.; Shaw, D.C.; Bible, K.; Chen, J. 2002. **Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir as an example**. Forest Ecology and Management. 155(3): 399-423.

Gilliam, F.S.; Turrill, N.L.; Adams, M.B. 1995. **Herbaceous-layer and overstory species in clear-cut and mature central Appalachian hardwood forests.** Ecological Applications. 5: 947-955.

Guyette, R.P.; Muzika, R.; Dey, D.C. 2002. **Dynamics of an anthropogenic fire regime.** Ecosystems. 5: 472-486.

Halpern, C.B. 1988. **Early successional pathways and the resistance and resilience of forest communities**. Ecology. 69: 1703-1715.

Halpern, C.B.; Spies, T.A. 1995. **Plant species diversity in natural and managed forests of the Pacific Northwest.** Ecological Applications. 5(4): 913-934.

Host, G.E.; Pregitzer, K.S.; Ramm, C.W.; Hart, J.B.; Cleland, D.T. 1987. **Landform- mediated differences in successional pathways among upland forest ecosystems in Northwestern Lower Michigan.** Forest Science. 33(2): 445-457.

Kabrick, J.M.; Jensen, R.G.; Shifley, S.R.; Larsen, D.R. 2002. **Woody vegetation following even-aged, uneven-aged, and no-harvest treatments on the Missouri Ozark Forest Ecosystem Project (MOFEP).** In: Proceedings of the second Missouri Ozark Forest Ecosystem Project 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 Forest Experiment Station: 84-101.

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 Forest Experiment Station. 11 p.

Lawton, J.H. 1994. **What do species do in ecosystems?** Oikos. 71:367-374.

Loewenstein, E.F.; Johnson, P.S.; Garrett, H.E. 2001. **Age and diameter structure of a managed uneven-aged oak forest.** Canadian Journal of Forest Research. 30(7): 1060-1070.

McCune, B.; Grace, J.B. 2002. **Analysis of ecological communities.** MjM Software Design, Gleneden Beach, OR. 300 p.

McCune, B.; Mefford, M.J. 1999. **PC-ORD: Multivariate analysis of ecological data.** Version 4.0, MjM Software Design, Gleneden Beach, OR.

Meier, A.J.; Bratton, S.P.; Duffy, D.C. 1995. **Possible ecological mechanisms for loss of vernal-herb diversity in logged eastern deciduous forests.** Ecological Applications. 5(4): 935-946.

Nigh, T.A.; Buck, C.; Grabner, J.; Kabrick, J. 2000. **A manual of ecological units in the current river hills subsection.** Unpublished report of the Missouri Department of Conservation.

Nigh, T.A.; Schroder, W.A. 2002. **Atlas of Missouri ecoregions.** Missouri Department of Conservation. 212 p.

Paulsell, L.K. 1957. **Effects of burning on Ozark hardwood timberlands.** Research Bulletin 640, University of Missouri, College of Agriculture, Agricultural Experimental Station, 24 pp.

Phillippi, T.E.; Dixon, P.M.; Taylor, B.E. 1998. **Detecting trends in species composition.** Ecological Applications. 8(2): 300-308.

Rafferty, M.D. 1980. **The Ozarks Land and Life. 1st edition.** Norman, Oklahoma: University of Oklahoma Press. 282 p.

Roach, B.A.; Gingrich, S.F. 1968. **Even-aged silviculture for upland central hardwoods.** Agric. Handbk. 355. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p.

Sasseen, A.N. 2003. **Using Ecological Landtype Phase (ELTp) to evaluate the effect of management on Missouri Ozark vegetation.** Columbia, MO: University of Missouri. 185 p. MS thesis.

Smith, D.M; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. **The practice of silviculture.** John Wiley and Sons, Inc. 527 p.

The Nature Conservancy. 1996. **Chilton Creek management area, Shannon and Carter counties, Missouri: A case study of the effects of fire-based ecosystem management.** Project plan, unpublished.