FIFTEEN YEARS OF PLANT COMMUNITY DYNAMICS DURING A NORTHWEST OHIO OAK SAVANNA RESTORATION

Scott R. Abella[1] and John F. Jaeger
Metroparks of the Toledo Area
5100 W. Central Ave.
Toledo, OH 43615

Lawrence G. Brewer[2]
Department of Botany
Miami University
Oxford, OH 45056

ABSTRACT

Midwest oak savanna communities are noted for their unusual plant assemblages, but these communities have been reduced by more than 98% because of changing land uses and conversion to closed-canopy forests. We initiated an ongoing 15-year experiment in 1988 to restore a 40-ha black oak (*Quercus velutina*) savanna by applying burn treatments that historically maintained this vegetation type. Groundlayer composition changed significantly for both the burn treatment and the control, with the burn treatment exhibiting slight increases in herbs such as wild lupine (*Lupinus perennis*) and hairy puccoon (*Lithospermum caroliniense*), both of which are species requiring greater insolation. Burn treatments differentially affected different plant community characteristics during the 15-year period, with some characteristics such as sapling density decreasing and other characteristics like species richness remaining comparatively unchanged. Oak overstory density was not affected by burn treatments, and reductions in oak density of 33-50% are needed for consistency with presettlement savanna structure to enhance the diversity of sunny and shady microsites characteristic of oak savannas. Results support the continuation of experimental restoration treatments in this savanna, and indicate further research is needed to clarify long-term patterns of temporal change in oak savanna vegetation.

INTRODUCTION

Oak savanna communities historically covered more than 11 million hectares in the midwestern United States (Nuzzo 1986). These fire-, drought-, or edaphic-maintained communities consisted of scattered oak canopies, brushy or open understories, and diverse groundlayers of both prairie and forest species (Bray 1960; Heikens & Robertson 1994; Leach & Givnish 1999). By 1985, changing land-uses and fire suppression had reduced oak savanna to 0.02% of its presettlement extent in the Midwest (Nuzzo 1986). Despite the sharp decline in the areal extent and quality of oak savannas, regions supporting oak savannas still contain notable plant diversity. For example, Leach & Givnish (1999) surveyed 22 savanna remnants (42 ha total) in southern Wisconsin and found that the remnants supported 507 native plant species (~ 27% of Wisconsin's native flora). Because of their unique floral assemblages and current rareness, there has been

[1]Author for correspondence: sra8@dana.ucc.nau.edu; present address: Ecological Restoration Institute and College of Ecosystem Science, Northern Arizona University, Box 15018, Flagstaff, AZ 86011

[2]Present address: Center for Applied Ecology, Northern Kentucky University, Highland Heights, KY 41076

increasing interest since the 1980s in restoring oak savannas to the Midwest landscape (White 1983; Anderson 1998; Jones 2000).

Since 1988, the Toledo Area Metroparks have been using experimental treatments to restore oak savannas in Oak Openings Preserve, within the Oak Openings region in northwest Ohio (Abella et al. 2001). The Oak Openings region occupies glacial lakeplain sands, and based on presettlement land survey records historically consisted of a mosaic of 44% oak savanna (4–43 trees ha^{-1}), 23% oak woodland (> 43 trees ha^{-1}), 7% oak barrens (1-3 trees ha^{-1}), and 27% wet prairie (< 1 tree ha^{-1}; Brewer & Vankat 2001). Oak savannas in this region not converted to other land uses became closed-canopy forests through the 1900s because of fire suppression, resulting in declines in ground-flora diversity (Abella et al. 2001). Restoration treatments by the Metroparks have entailed reducing canopy cover and sapling densities and reinstating disturbance regimes, such as fire, that historically maintained oak savanna plant communities (Nuzzo 1986). Despite the historic widespread distribution and floral diversity of oak savannas, there are few long-term data available on the temporal dynamics of savanna vegetation.

We have been studying the community dynamics of Mary's Savanna, a 40-ha black oak savanna in Oak Openings Preserve, during an ongoing 15-year restoration experiment initiated in 1988 (Brewer & Grigore 1993). This savanna, similar to other savannas across the Midwest (Nuzzo 1986), had become closed-canopy forest and lacked savanna structure before restoration. Prescribed burn treatments have been applied to 30 ha of this savanna since 1988 with a goal of achieving a community structure resembling that of a presettlement savanna in this region, while 10 ha of the savanna have served as a control. This study was undertaken in Mary's Savanna to document plant community dynamics over a 15-year period to better understand temporal changes of savanna vegetation and plant responses to reintroductions of disturbance regimes that historically maintained this vegetation type.

METHODS

Mary's Savanna is located in the southern section of Oak Openings Preserve (41°32′15″N, 83°51′00″W), western Lucas County, northwestern Ohio (Fig. 1). Soils in the savanna are mapped as mixed, mesic Aquic and Typic Udipsamments of the Ottokee and Oakville series (Stone et al. 1980). The mapped series were confirmed in 1988 by sampling soils at five locations in Mary's Savanna and comparing the soil characteristics to series descriptions in the soil survey (Stone et al. 1980). Based on increment cores collected from five dominant oaks, Mary's Savanna established about 1900, possibly following farm abandonment or cessation of livestock grazing (Moseley 1928). In 1821, the area supported oak savanna according to government land survey records (Brewer & Vankat 2001).

Five permanent 0.05-ha plots (20 m × 25 m) were established in Mary's Savanna in 1988 following methods documented in Brewer & Grigore (1993). Three plots were established in the burn treatment, and two plots were established in the control. Pre-treatment data were collected in 1988, and the plots were re-sampled at 1–4 year intervals in 1988, 1990, 1991, 1993, 1997–2000, and 2002. Burn treatments were applied at 1–4 year intervals in the following years and months: 1988 (November), 1989 (April), 1990 (April), 1993-1994 (November), 1997 (March), 1998 (November), and 2001 (November). Relative humidities at ignition times ranged from 32–72%, with winds typically < 16 km/hr out of the south.

On each plot, we determined the species and measured the diameter to the nearest cm at 1.37 m for each tree greater than 1 cm diameter. We determined average percent canopy cover using a den-

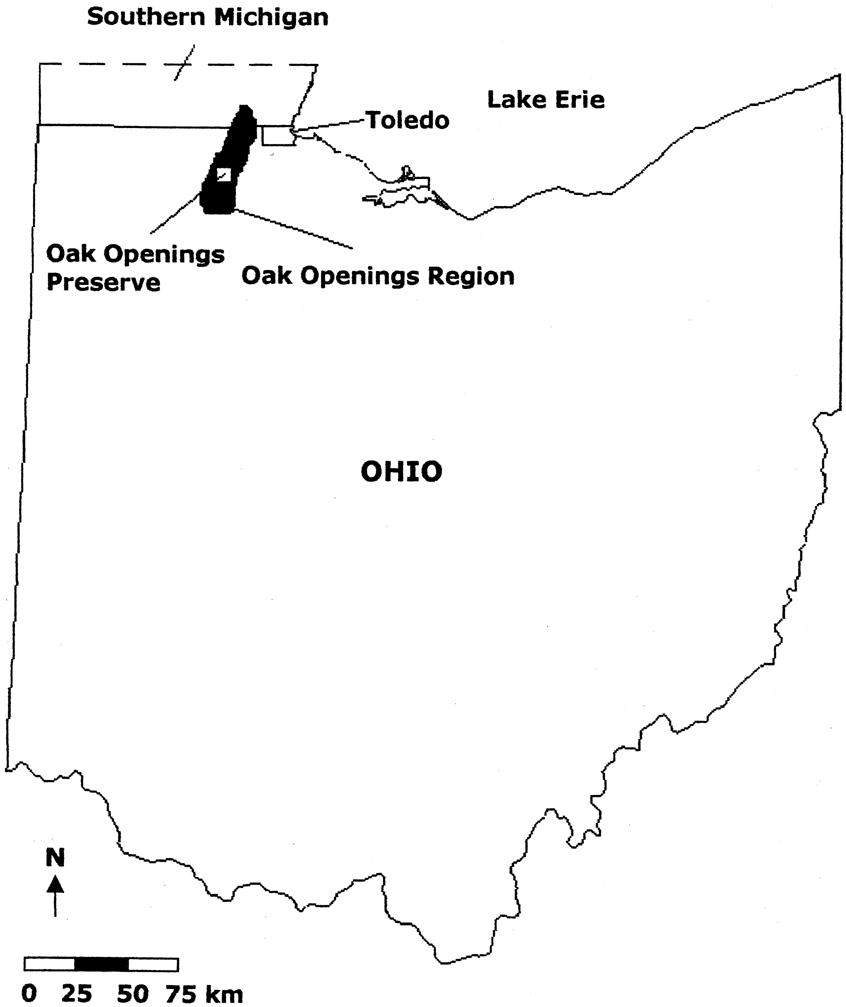

FIGURE 1. Location of the 1,496-ha Oak Openings Preserve and the 40,000-ha Oak Openings region of northwestern Ohio.

sitometer (Geographic Resource Solutions, Arcata, CA), based on measurements to the nearest 5% cover at eight locations at 5-m intervals along the plot diagonal. In six 1-m^2 subplots located at the plot corners and at the centers of the long plot axes, we categorized the areal percent cover of vascular plant species at 1% intervals up to 5% cover and then at 5% intervals for cover greater than 5%. We surveyed the entire 0.05-ha plot for species not occurring in subplots and categorized the percent cover of these species on a plot basis. In 2002, we increased the number of subplots per plot to 15 to refine plant frequency estimates. Plants not readily identifiable in the field were collected, pressed, and when possible identified to species. Nomenclature follows Voss (1972; 1985; 1996). We measured the thickness of the Oi and Oe+a soil horizons (Soil Survey Division Staff 1993), hypothesized to decrease following burn treatments, by excavating the layers with a 20-cm long handshovel at six locations along the perimeter of each plot.

To test the null hypothesis of no change in plant community characteristics between pre- (1988) and post-treatment (2002) within the burn and control treatments, we compared mean black oak basal area, species richness, Shannon's diversity index (H′; McCune & Mefford 1999), and thickness of the Oi and Oe+a horizons between years for each treatment using two-tailed paired *t*-tests. We evaluated the null hypothesis of no change in groundlayer composition between pre- and post-treatment for each treatment using blocked multi-response permutation procedure tests in the software PC-ORD (McCune & Mefford 1999). Multi-response permutation procedures are multivariate, non-parametric tests that evaluate the null hypothesis of no difference in species composition between groups using a randomization procedure (Zimmerman et al. 1985). We used the blocked test (Euclidean distance and medians aligned) variation of multi-response permutation procedures to accommodate our paired-sample data (McCune & Mefford 1999). The data matrix consisted of mean percent cover of each species, and data for each plot were relativized by the maximum species percent cover for that plot (McCune & Mefford 1999).

RESULTS AND DISCUSSION

Black oak comprised 21.9 ± 1.1 (mean ± 1 standard deviation) m^2 ha^{-1} basal area (94% relative basal area) in the burn treatment post-treatment in 2002, which was not significantly different ($t = 0.69$, $P = 0.56$) from 20.3 ± 3.1 m^2 ha^{-1} basal area (95% relative basal area) pre-treatment in 1988. Mean black oak basal area for the control also did not differ ($t = -2.76$, $P = 0.56$) between 2002 (18.0 ± 10.4 m^2 ha^{-1}; 93% relative basal area) and 1988 (21.5 ± 8.6; 95% relative basal area). Densities of overstory black oak (> 20 cm diameter) also did not change for either treatment (Fig. 2). Burn treatments in this savanna have not affected basal area or densities of overstory black oak presumably because of the thick bark of this species (Easterly 1969). These results are consistent with those of White (1983), who found that 13 years of annual burns did not decrease overstory oak density in a Minnesota savanna.

Burn treatments, however, have drastically changed the community structure of Mary's Savanna during the 15-year period by eliminating small-diameter trees (Fig. 2). In contrast, post-treatment density in the 1–5 cm diameter class of black cherry (*Prunus serotina*) and sassafras (*Sassafras albidum*) exceeded 500 trees ha^{-1} in control plots (Fig. 2). These densities are similar to those reported by Larch & Sakai (1985) for minimally disturbed oak stands of southeastern Michigan. Post-treatment community structure of the control includes several layers of large and small trees, while community structure of the burn treatment is two-layered and consists of a canopy and a groundlayer (Fig. 3). The relatively open understory structure of the burn treatment resembles descriptions of some presetttlement savannas in this region, although overstory oak densities are currently about twice as high as was typical of area presettlement savannas (Brewer & Vankat 2001).

Post-treatment groundlayers in both the burn and control plots are dominated by bracken fern (*Pteridium aquilinum*), Pennsylvania sedge (*Carex pensylvanica*), shrubs such as hillside blueberry (*Vaccinium pallidum*), and seedlings of black oak and other species (Table 1). Forbs like cinquefoil (*Potentilla simplex*), frostweed (*Helianthemum bicknellii*), flowering spurge (*Euphorbia corollata*), and wild lupine (*Lupinus perennis*) are present in the burn treatment but at relatively low frequencies (Table 1). Blocked multi-response permutation procedure

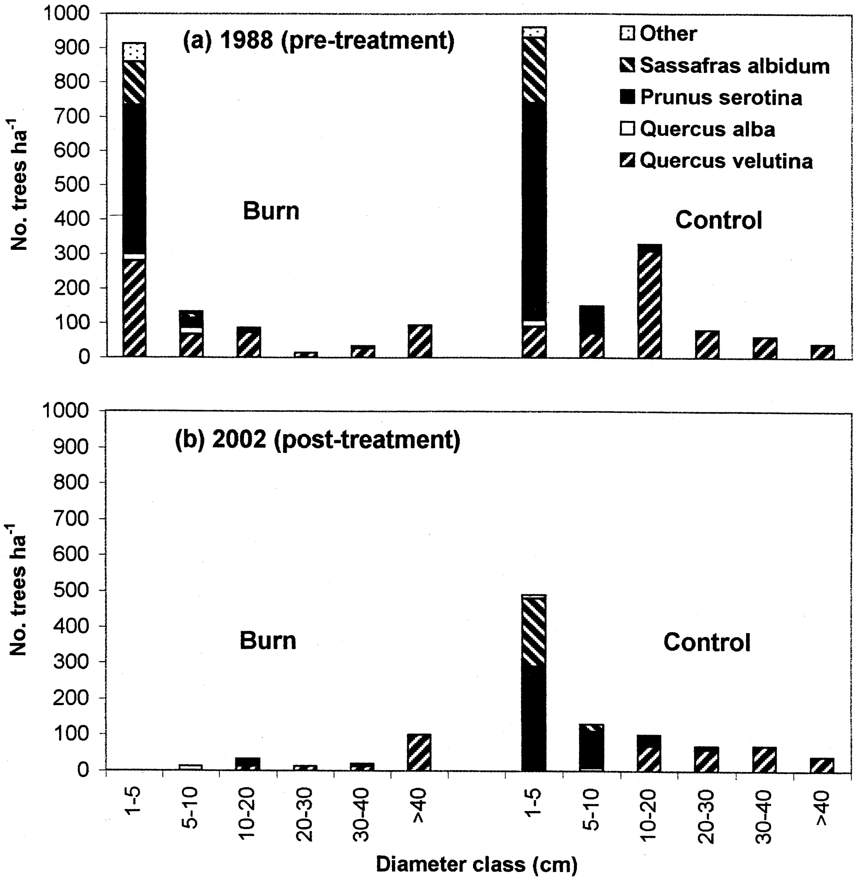

FIGURE 2. Pre- (1988) and post-treatment (2002) diameter distributions for burn and control treatments in Mary's Savanna, northwestern Ohio. Other species includes *Acer rubrum*, *Amelanchier arborea*, and *Pinus strobus*.

tests of pre- (1988) and post-treatment (2002) groundlayer composition within treatments indicated composition was weakly, but significantly different for both the burn ($T = -2.74$, $P = 0.02$) and control ($T = -2.62$, $P = 0.02$) treatments. However, causes for the compositional differences were disparate between treatments. Burn plots exhibited new occurrences or increases in percent cover of species requiring greater insolation such as wild lupine (33% plot occurrence increase and seven-fold increase in mean percent cover), while control plots exhibited decreases of species requiring greater insolation like hairy puccoon (*Lithospermum caroliniense*; 100% plot occurrence reduction) and increases of woody vegetation such as sassafras (4% mean cover increase) tolerant of shade (Larch & Sakai 1985). Based on the relatively small blocked multi-response permutation procedure T-statistic (McCune & Mefford 1999), however, burn

(a) control

(b) burn

(c) burn groundlayer

FIGURE 3. Post-treatment (2002) community structure of the control and burn treatments in Mary's Savanna, a 100-year-old black oak savanna in northwest Ohio. In the burn groundlayer (c), herbs requiring greater insolation such as *Baptisia tinctoria* (top center) and *Lupinus perennis* (bottom right) exhibited increases in cover during the 15-year experiment. (Photos by S. R. Abella, 12 June 2002).

TABLE 1. Mean percent frequency for fifteen 1-m^2 subplots per 0.05-ha plot in 2002 (post-treatment) of the most common plant species for burned (n = 3) and control (n = 2) plots in Mary's Savanna, northwest Ohio.

Growth form and species	Burn	Control
Seedlings	% Frequency (mean ± SD)	
Acer rubrum—red maple	4 ± 4	13 ± 0
Prunus serotina—black cherry	20 ± 18	33 ± 9
Quercus alba—white oak	4 ± 8	P †
Q. velutina—black oak	71 ± 4	70 ± 24
Sassafras albidum—sassafras	31 ± 4	17 ± 24
Shrubs		
Gaylussacia baccata—black huckleberry	9 ± 15	23 ± 14
Rosa carolina—pasture rose	27 ± 27	27 ± 9
Rubus allegheniensis—common blackberry	9 ± 15	—
R. flagellaris—northern dewberry	16 ± 17	3 ± 5
Rhus copallina—winged sumac	2 ± 4	—
Vaccinium angustifolium—low sweet blueberry	27 ± 31	10 ± 5
V. pallidum—hillside blueberry	58 ± 10	30 ± 14
Graminoids		
Andropogon gerardii—big bluestem	P	—
Carex pensylvanica—Pennsylvania sedge	100 ± 0	97 ± 5
Panicum spp.	9 ± 10	10 ± 5
Fern		
Pteridium aquilinum—bracken fern	93 ± 7	100 ± 0
Forbs		
Asclepias tuberosa—butterfly-weed	P	—
Baptisia tinctoria—false indigo	P	P
Comandra umbellata—bastard-toadflax	4 ± 8	—
Euphorbia corollata—flowering spurge	13 ± 18	P
Helianthemum bicknellii—frostweed	13 ± 7	3 ± 5
Lithospermum caroliniense—hairy puccoon	2 ± 4	—
Lupinus perennis—wild lupine	9 ± 15	—
Lysimachia quadrifolia—whorled loosestrife	9 ± 10	P
Phlox subulata—moss phlox	P	—
Polygonatum biflorum—Solomon's seal	7 ± 7	3 ± 5
Potentilla simplex—common cinquefoil	16 ± 4	P
Smilacina racemosa—false Solomon's seal	P	P
Tephrosia virginiana—goat's rue	P	7 ± 9
Viola pedata – birdfoot violet	P	—

† Species did not occur in a subplot but was present on a plot.

treatments have only subtly affected overall groundlayer composition of this savanna.

Groundlayer species richness per plot did not change significantly between pre- and post-treatment for either treatment (Fig. 4). Shannon's diversity index also did not differ between pre- and post-treatment for either the burn (2002 H′ = 1.96 ± 0.28; $t = 0.45$, $P = 0.70$) or the control (2002 H′ = 1.86 ± 0.33; $t = -0.23$,

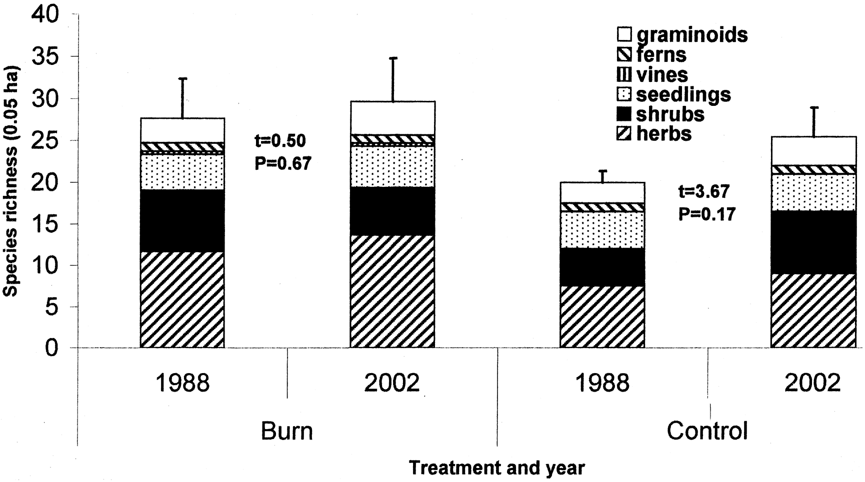

FIGURE 4. Mean species richness in 1988 (pre-treatment) and 2002 (post-treatment) for burn and control treatments in Mary's Savanna, northwestern Ohio. Error bars represent one standard deviation for total mean species richness, and *t*-statistics and probabilities represent year comparisons of means within treatments (two-tailed paired *t*-tests).

P = 0.86). No significant change in species diversity during the 15-year period associated with burn treatments in Mary's Savanna is consistent with the short-term (3-year) findings in other savannas without overstory reduction treatments in the Oak Openings region (Abella et al. 2001). These results suggest that the disturbance of burning alone is insufficient to significantly alter patterns of groundlayer diversity in Oak Openings savannas that had previously succeeded to closed-canopy forest as had Mary's Savanna.

Burn treatments reduced Oi horizon thickness by 4.7 cm, whereas thickness of the Oe+a horizon did not change significantly (Fig. 5). Many herbs of oak savannas, such as hairy puccoon, germinate and emerge most successfully on exposed mineral soil (Weller 1985). The relatively thick Oe+a horizon in Mary's Savanna may preclude the establishment of these savanna herbs (Facelli & Pickett 1991). Phillips et al. (2000) found that the Oe+a horizon remained 1.5 cm thick in a Tennessee oak stand after 35 years of burn treatments, and this study combined with our findings suggest that long-term burning in Mary's Savanna will not result in our hypothesized reduction in Oe+a horizon thickness. It is unclear if the 90-year period of fire suppression during which Mary's Savanna developed has resulted in an unusually thick Oe+a horizon not able to be readily reduced by burning, or if despite reductions in the Oi horizon annual inputs of plant litter exceeded levels consumed by the burn treatments.

During the 15-year duration of this study, some community characteristics of the burn treatment of Mary's Savanna have remained relatively constant, while other characteristics have changed considerably (Figure 6). Mean cover of bracken fern doubled to 25% in the first two growing seasons following the ini-

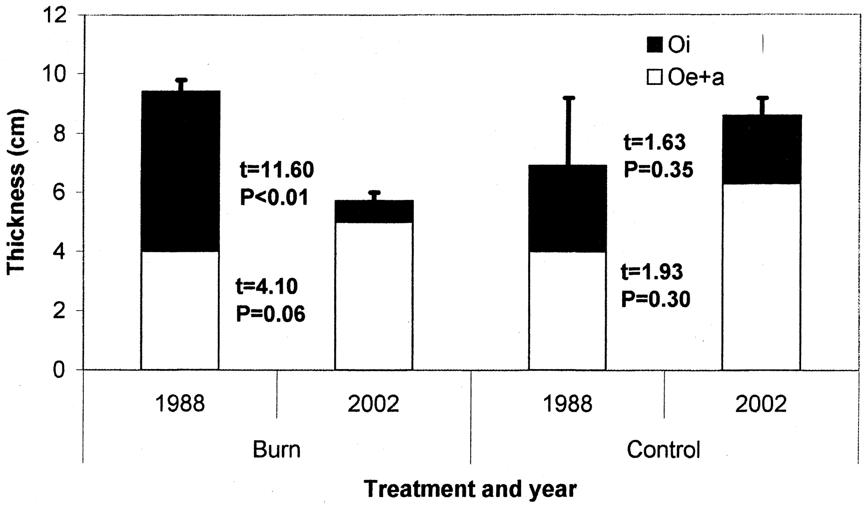

FIGURE 5. Mean Oi and Oe+a horizon thicknesses in 1988 (pre-treatment) and 2002 (post-treatment) for burn and control treatments in Mary's Savanna, northwestern Ohio. Error bars represent one standard deviation for total mean O-horizon thickness, and *t*-statistics and probabilities represent year comparisons of means within treatments for each of the Oi and Oe+a horizons (two-tailed paired *t*-tests).

tial 1988 burn treatment (Brewer & Grigore 1993), and then declined but remained above pre-treatment levels in 2002 (Fig. 6). Sapling density decreased sharply after the first burn treatment in 1988, recovered by 1993 after a four-year period without burning, and remained low for the rest of the study. In comparison, groundlayer species richness and overstory oak density varied little (Fig. 6). Results indicate that experimental burn treatments have differentially affected different community characteristics over the 15-year period, and demonstrate the utility of long-term permanent plot studies for directly detecting temporal changes of savanna vegetation.

Additional experimental treatments are needed to continue restoring historic vegetation composition and structure to Mary's Savanna (Brewer & Vankat 2001). Burn treatments could be continued at irregular intervals not more frequent than every two years to balance positive and negative effects of fire on different plant species (Grigore & Tramer 1996). Overstory oak density in Mary's Savanna presently is high (Fig. 2), and a reduction in density of 33–50% is necessary to approach the upper density of 43 trees ha^{-1} documented for historical savannas in this region (Brewer & Vankat 2001). This density reduction could decrease the current average canopy cover of 55 ± 4% in the burn treatment, possibly alleviating light limitations for the establishment of such herbs as wild lupine (Grigore & Tramer 1996), while enhancing the diversity of sunny and shady microsites characteristic of oak savannas (Leach & Givnish 1999). Higher light levels may also decrease the current dominance of bracken fern, a species susceptible to killing frosts in more open savanna structures (Cody & Crompton

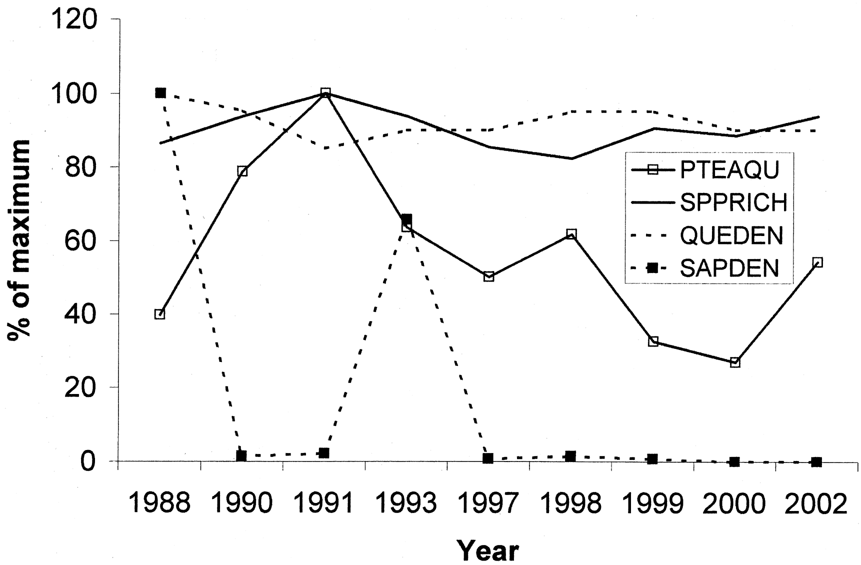

FIGURE 6. Community dynamics during a 15-year period for a burn treatment in Mary's Savanna, northwestern Ohio. Abbreviations and maximum mean values (in parenthesis) for variables are as follows: PTEAQU = *Pteridium aquilinum* % cover (31.9%), SPPRICH = species richness per 0.05 ha (32 species), QUEDEN = *Quercus* density greater than 30 cm diameter (133 trees ha^{-1}), and SAPDEN = total sapling density of all species in the 1–5 cm diameter class (913 trees ha^{-1}). Burn treatments were applied in 1988–1990, 1993–1994, 1997–1998, and 2001.

1975). Results of this study support the continuation of experimental plant community restoration treatments by the Toledo Metroparks, and indicate further research is needed to clarify long-term patterns of temporal change in oak savannas, once a dominant vegetation type of the midwestern landscape.

ACKNOWLEDGMENTS

We thank Tim Gallagher, Penny Wagner, Steve Nehls, Jerry Jankowski, Mark St. Mary, Ted Witham, Joe Croy, Denise Gehring, and Gary Horn for performing or coordinating restoration treatments. We also thank Bob Jacksy, Mark Plessner, Karen Menard, Jeff MacKenzie, Kim High, and Mary Huffman for assistance in the field during the period 1988–2000. Financial support for restoration in Mary's Savanna was provided by The Nature Conservancy and the U.S. EPA Great Lakes Project Office (grant GL 985592-01). Wally Covington and Neil MacDonald reviewed the manuscript.

LITERATURE CITED

Abella, S. R., J. F. Jaeger, D. H. Gehring, R. G. Jacksy, K. S. Menard, & K. A. High. 2001. Restoring historic plant communities in the Oak Openings region of northwest Ohio. Ecological Restoration 19: 155–160.

Anderson, R. C. 1998. Overview of midwestern oak savanna. Transactions of the Wisconsin Academy of Sciences, Arts and Letters 86: 1–18.

Bray, J. R. 1960. The composition of savanna vegetation in Wisconsin. Ecology 41: 721–732.
Brewer, L. G., & M. T. Grigore. 1993. Restoring oak savannas in northwest Ohio—monitoring the progress. *In* Proceedings of the 1993 Midwest Oak Savanna Conference, Chicago, Illinois.
Brewer, L. G., & J. L. Vankat. 2001. The vegetation of the Oak Openings of northwest Ohio at the time of Euro-American settlement. Map and text. Ohio Biological Survey, Columbus, Ohio.
Cody, W. J., & C. W. Crompton. 1975. The biology of Canadian weeds. 15. *Pteridium aquilinum* (L.) Kuhn. Canadian Journal of Plant Science 55: 1059–1072.
Easterly, N. W. 1969. The oaks of the Oak Openings. Castanea 34: 335–351.
Facelli, J. M., & S. T. A. Pickett. 1991. Plant litter: its dynamics and effects on plant community structure. Botanical Review 57: 1–32.
Grigore, M. T., & E. J. Tramer. 1996. The short-term effect of fire on *Lupinus perennis* L.. Natural Areas Journal 16: 41–48.
Hiekens, A. L., & P. A. Robertson. 1994. Barrens of the Midwest: a review of the literature. Castanea 59: 184–194.
Jones, J. 2000. Fire history of the bur oak savannas of Sheguiandah Township, Manitoulin Island, Ontario. Michigan Botanist 39: 3–15.
Larch, C. M., & A. K. Sakai. 1985. Oak forest succession in the Oakland University nature trails area, Oakland County, Michigan. Michigan Botanist 24: 21–32.
Leach, M. K., & T. J. Givnish. 1999. Gradients in the composition, structure, and diversity of remnant oak savannas in southern Wisconsin. Ecological Monographs 69: 353–374.
McCune, B., & M. J. Mefford. 1999. PC-ORD: multivariate analysis of ecological data. Version 4. User's guide. MjM Software Design, Gleneden Beach, Oregon. 237 pp.
Moseley, E. L. 1928. Flora of the Oak Openings. Proceedings of the Ohio Academy of Science, Volume 8, Special Paper Number 20: 79–134.
Nuzzo, V. A. 1986. Extent and status of Midwest oak savanna: presettlement and 1985. Natural Areas Journal 6: 6–36.
Phillips, D. H., J. E. Foss, E. R. Buckner, R. M. Evans, & E. A. FitzPatrick. 2000. Response of surface horizons in an oak forest to prescribed burning. Soil Science Society of America Journal 64: 754–760.
Soil Survey Division Staff. 1993. Soil Survey Manual. U.S. Department of Agriculture, Soil Conservation Service, Agricultural Handbook 18. U.S. Government Printing Office, Washington, D.C.
Stone, K. L., E. H. McConoughey, G. D. Bottrell, & D. J. Crowner. 1980. Soil Survey of Lucas County, Ohio. U.S. Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office, Washington, D.C. 139 pp.
Voss, E. G. 1972. Michigan Flora. Part I. Cranbrook Institute of Science, Bloomfield Hills, Michigan. 488 pp.
Voss, E. G. 1985. Michigan Flora. Part II. Cranbrook Institute of Science, Bloomfield Hills, Michigan. 727 pp.
Voss, E. G. 1996. Michigan Flora. Part III. Cranbrook Institute of Science, Bloomfield Hills, Michigan. 622 pp.
Weller, S. G. 1985. The life history of *Lithospermum caroliniense*, a long-lived herbaceous sand dune species. Ecological Monographs 55: 49–67.
White, A. S. 1983. The effects of thirteen years of annual prescribed burning on a *Quercus ellipsoidalis* community in Minnesota. Ecology 64: 1081–1085.
Zimmerman, G. M., H. Goetz, & P. W. Mielke. 1985. Use of an improved statistical method for group comparisons to study effects of prairie fire. Ecology 66: 606–611.