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THE EFFECTS OF THIRTEEN YEARS OF ANNUAL PRESCRIBED BURNING ON A *QUERCUS ELLIPSOIDALIS* COMMUNITY IN MINNESOTA[1]

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Abstract. A *Quercus ellipsoidalis* community in central Minnesota has been prescribed burned annually since 1965 in an attempt to restore the area to its presettlement oak savanna structure and composition. By 1979 density and basal area of the overstory were significantly lower in the burned area than in an adjacent unburned area but were still higher than estimated savanna values because of the persistence of stems ≥25 cm diameter at breast height (dbh). A tall-shrub/small-tree layer was totally lacking in the burned area but averaged 19% cover in the unburned area. Understory richness was significantly higher in the burned area than in the unburned area. Most of the species that showed a significant difference between the two areas peaked in the burned area; this was especially true for grasses and forbs. These results indicate that annual prescribed burning is gradually restoring the area to savanna but that the restoration is not yet complete. Complete restoration may not be possible with annual burning because such burning seems to have little effect on large-tree (≥25 cm dbh) mortality.

Key words: fire; Minnesota; oak; prescribed burning; Quercus ellipsoidalis; *restoration; savanna.*

INTRODUCTION

In the past few decades research has shown that fire was a natural component of many plant communities (Heinselman 1978). However, effective fire suppression since the early 1900s has altered the structure and composition of many of these communities, particularly those communities which were originally subjected to frequent fires (Sando 1978). Because of the changes caused by fire suppression, reintroduction of natural burning into a system involves two steps: (1) restoration of the plant community to its presuppression structure and composition and (2) maintenance of that community structure and composition once it is attained.

Controlled burning was first introduced to a portion of the Cedar Creek Natural History Area (CCNHA) in east-central Minnesota in 1964. The purpose of the prescribed burning was to return the area to its presettlement oak savanna structure and composition. It is generally agreed that fire played an important role in the maintenance of oak savanna communities that occurred along the forest-prairie transition zone in Minnesota (Drew 1973) and Wisconsin (Curtis 1959) prior to European settlement. Fire probably occurred frequently in these communities. After 10 yr of fire exclusion the savanna openings were often filled with small trees and shrubs, and after 30 yr they had become dense oak forests (Curtis 1959). The purpose of this research was to determine vegetation differences between an area prescribed burned annually for 13 yr and an adjacent unburned area.

STUDY AREA

The Cedar Creek Natural History Area is located ≈51 km north of St. Paul, in east-central Minnesota. The 2300-ha reserve has a typical temperate, continental climate. Mean monthly temperature peaks in July (22°C) and reaches a low in January (−11.5°); mean monthly precipitation follows a similar pattern, peaking in June (11.4 cm) and reaching a low in January (2.2 cm) (Grigal et al. 1974).

The Cedar Creek area is part of the Anoka Sand Plain. The uniform texture of the outwash sand which dominates the uplands of CCNHA (Grigal et al. 1974) was probably the result of sorting by melt-water streams as they flowed over the ice surface (Cooper 1935, Cushing 1963).

Both the burned and unburned study areas are on a sandy Entisol soil (Zimmerman series) characterized by low fertility and high permeability (Grigal et al. 1974). Analysis of a representative Zimmerman pedon showed a maximum cation exchange capacity of 5.6 (range from 1.3 to 5.6 among different horizons sampled) and a maximum field capacity of 14.3% (range from 6.8 to 14.3% among different depths sampled) (Grigal et al. 1974).

Presettlement land survey notes (1854) for the Cedar Creek Natural History Area revealed that the upland primarily supported scattered, scrubby northern pin oak (*Quercus ellipsoidalis*; nomenclature follows Gleason and Cronquist [1963]) and bur oak (*Q. macrocarpa*); prairies were noted in the area but were of limited extent (Pierce 1954). The tree species at CCNHA

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TABLE 1. Overstory characteristics of burned and unburned study areas.

	Mean (SD)			
	Burned area	Unburned area	df	t
Age (yr)				
Quercus ellipsoidalis only	39 (11)	37 (4)	136	0.86
Diameter (cm)				
All stems	19 (9)	18 (7)	144	0.79
Q. ellipsoidalis only	20 (9)	18 (7)	138	1.31
Density (stems/ha)				
All stems	473 (408)	940 (433)	19	2.55*
Q. ellipsoidalis only	436 (398)	920 (416)	19	2.72*
Basal area (m²/ha)				
All stems	16.1 (15.4)	26.8 (12.8)	19	1.72
Q. ellipsoidalis only	15.9 (15.3)	26.7 (12.7)	19	1.75*

* Significant ($P \leq .05$) for a one-tailed t test.

have not changed much since presettlement days, but the types of vegetation have changed, most notably from oak scrub to oak forest (Pierce 1954). Pierce's interviews with long-time residents of the area and his investigation of oak stands supported the idea that fires in the area were frequent in the early days of settlement and that the changes from scrub oak to oak woods coincided with the cessation of those frequent fires. Disturbance of the study area since settlement has been limited primarily to selective logging and light grazing (A. Peterson, *personal communication*).

PRESCRIBED BURNING PROGRAM

In 1964 the area was divided into 15 blocks of different sizes, each of which was subjected to different frequencies and schedules of prescribed burns (Irving 1970). The blocks chosen for this study were an unburned control block (10 ha) and an annually burned block (11 ha).

The burned block was first burned in 1965 and has been burned every year since, except for 1970 and 1975. Each year the burning was conducted in April or May, at some time between the disappearance of snow and the leafing-out of the oaks. Burning was done under conditions that favor low- to moderate-intensity fires, good smoke dispersal, and easily controlled burns. Lack of suitable burning conditions prevented burning in 1970 and 1975. All burns in this block have been conducted with a strip headfire technique (Irving 1970, Mobley et al. 1973). In an early study, Wick (1966) measured average oak litter consumption by prescribed fire as 0.44 Mg/ha (average preburn litter mass was 1.25 Mg/ha and average postburn litter mass was 0.81 mg/ha) in this block. His rate-of-spread measurements in 1966 ranged from 2.6 to 5.4 m/min, while my rate-of-spread measurements in 1979 ranged from 7.8 to 16.8 m/min.

METHODS

The vegetation was sampled in 1979, using a nested plot design. All stems ≥5 cm dbh within a 100-m² circle were recorded by species, dbh, and age. Age was determined by counting annual rings on an increment core taken at breast height. A 25-m² circular inner plot was used for estimation of percent cover of stems ≥1 cm diameter at ground level (dgl) and <5 cm dbh. Percent frequency was determined for woody species with stems <1 cm dgl and for all nonwoody species. This determination was made by counting the number of times a species occurred in 10 systematically placed 0.25-m² circular plots within the 100-m² plot.

Nested plot centers were randomly located at a sampling intensity of 1 nested plot/ha: this resulted in 11 nested plots (11 100-m² plots, 11 25-m² plots, and 110 0.25-m² plots) in the burned area and 10 nested plots (10 100-m² plots, 10 25-m² plots, and 100 0.25-m² plots) in the unburned area.

Student's t test for normally distributed data and the Mann-Whitney U test for nonnormally distributed data were used to test for significant differences between the burned and unburned areas. In all cases a result was considered statistically significant at $P \leq .05$.

RESULTS AND DISCUSSION

Quercus ellipsoidalis dominated the overstory (as measured in the 100-m² plots), comprising 98% of the stems in the unburned area and 92% of the stems in the burned area. The few remaining stems were *Q. macrocarpa*. With the exception of age, results in Table 1 are reported for total stems and for *Q. ellipsoidalis*; with only six *Q. macrocarpa* stems, it was not possible to treat *Q. macrocarpa* separately.

Table 1 shows that the average age of *Q. ellipsoidalis* was 39 yr in the burned area and 37 yr in the unburned area, an insignificant difference. Thus, overstory differences between the burned area and unburned area are not related to age of stand.

Density and basal area were the major overstory differences between the burned and unburned areas (Table 1). The density of *Q. ellipsoidalis* stems in the unburned area was more than twice the density of *Q. ellipsoidalis* stems in the burned area (920 vs. 436 stems/

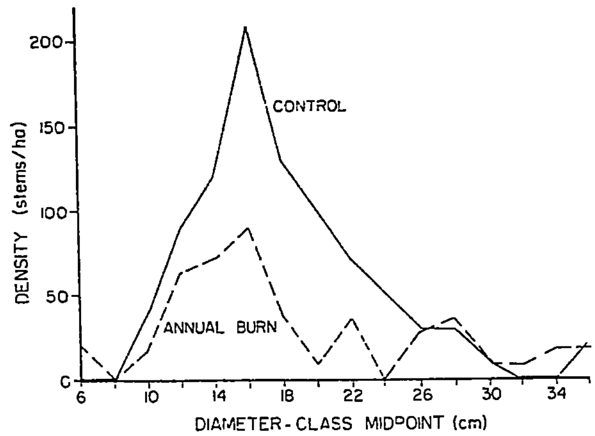

FIG. 1. The diameter distribution of *Quercus ellipsoidalis* stems on burned and control (unburned) plots.

ha). Difference in basal area of *Q. ellipsoidalis* was not as dramatic (27 m²/ha in the unburned area vs. 16 m²/ha in the burned area) but was significant. These differences were not related to differences in average diameters between the two areas (Table 1) but rather were related to reduction in the number of stems between 5 and 25 cm dbh (Fig. 1). Almost two-thirds (63%) of the total difference in density (484 stems/ha) was due to higher densities in the unburned area in the 15–17, 17–19, and 19–21 cm dbh-classes. Thus, prescribed burning seems to be doing an effective job of killing small-diameter *Q. ellipsoidalis*. However, average density in the burned area was still considerably higher than the densities of early savannas reported by Bray (1955), which ranged from 13 to 36 stems/ha. Some of the differences in densities may be due to differences in minimum tree size included in the calculations, but most trees in my study area were >11 cm dbh (Fig. 1) and thus were probably large enough to be included in the data Bray (1955) reported.

Differences in the shrub layer (stems ≥1 cm dgl and <5 cm dbh) between the burned and unburned area were visually dramatic and statistically significant (Table 2): there simply was no shrub layer in the burned plots. Total percent cover by the shrub layer averaged 19% in the unburned area. Sixty-six percent of that cover was by *Corylus americana* and 16% by *Rhus glabra*; the contribution by *R. glabra*, however, was due entirely to high percent cover in one plot. The Mann-Whitney *U* test indicated that total shrub cover was significantly higher in the unburned area than in the burned area (Table 2).

Besides the differences in total percent cover by the shrub layer, *Amelanchier* spp. and *Corylus americana* had significantly higher average percent cover values in the unburned area than in the burned area (Table 2). Small *Amelanchier* spp. stems (<1 cm dgl) also occurred in the understory plots in the unburned area but not in the burned area: although this difference was too small to be significant, it appears that *Amelanchier* spp. may be adversely affected by fire. In contrast, *Corylus americana* occurred in over 80% of the understory burned plots as well as in all of the understory unburned plots. Thus, it appears that annual spring burns prevent *C. americana* from attaining the size it might in the absence of fire but that its sprouting ability allows it to maintain itself in the community. The significantly lower average frequency of *C. americana* in the burned plots, however, may indicate that fire is gradually reducing *C. americana*. These results are consistent with those of Buckman (1962), who found that only repeated, hot (summer) burns would reduce the abundance of *C. americana*, and with the results of Axelrod and Irving (1978), who found that the prescribed burns at CCNHA reduced the average height of *C. americana* stems. Alban (1977) showed fire to have similar effects on *Corylus cornuta* in a *Pinus resinosa* stand in Minnesota.

Testing of individual understory species was restricted to the 40 species that occurred more than twice in either the burned plots or the unburned plots. Differences in percent frequency were tested with the Mann-Whitney *U* test, which uses ranks rather than actual values.

Table 3 shows that 14 of the 40 species tested (35%) showed a significant difference between the unburned and burned sites; 12 of those 14 (86%) had higher values on the burned site. However, different groups of plants reacted differently. Of the 9 grass and sedge species, 5 had significantly higher frequency values in the burned area than in the unburned area, while 4 showed no significant difference between the two; none had significantly higher values in the unburned area. Of the 24 forb species, 7 had significantly higher values in the burned area, none had a significantly higher value in the unburned area, and 17 showed no significant difference between the two. The situation was reversed for the 7 woody species: 2 had significantly higher frequency values in the unburned area, while 5 showed no significant difference between the two areas. Thus, herbaceous plants that showed a significant difference between burned and unburned areas almost

TABLE 2. Average percent cover values for shrubs in unburned area. No shrubs occurred in the burned-area sample plots.

Species	Mean percent cover (SD)
Acer rubrum	0.5 (1.6)
Amelanchier spp.	2.3 (3.4)*
Corylus americana	12.7 (13.7)*
Prunus serotina	0.4 (0.7)
Prunus virginiana	0.1 (0.2)
Quercus ellipsoidalis	0.2 (0.4)
Quercus macrocarpa	0.1 (0.2)
Rhus glabra	3.0 (9.5)
Total	19.5 (20.0)*

* Significantly ($P \leq .05$) greater than zero (Mann-Whitney *U* test).

TABLE 3. Average species frequency values (%) in the burned area and the unburned area.

Species	Frequency (%)	
	Burned area	Unburned area
Ambrosia cf. *psilostachya*	31.8	2.0*
Amorpha canescens	9.1	0.0
Amphicarpa bracteata	31.8	39.0
Andropogon gerardi	43.6	6.0*
Andropogon scoparius	11.8	0.0
Arenaria lateriflora	0.9	6.0
Artemisia ludoviciana	20.0	0.0*
Asclepias spp.	12.7	0.0
Asclepias tuberosa	6.4	0.0
Calamovilfa longifolia	4.5	0.0
Carex spp.	32.7	47.0
Chenopodium spp.	2.7	7.0
Comandra richardsiana	26.4	0.0*
Corylus americana	18.2	39.0†
Cyperus spp.	82.7	38.0*
Fragaria virginiana	6.4	5.0
Galium boreale	0.0	10.0
Helianthemum bicknellii	6.4	0.0
Helianthus laetiflorus	20.0	3.0
Panicum oligosanthes	9.1	0.0
Panicum cf. *praecocious*	11.8	2.0*
Parthenocissus vitacea	13.6	69.0†
Physalis virginiana	6.4	0.0
Poa spp.	14.5	15.0
Prunus virginiana	0.9	8.0
Quercus ellipsoidalis	22.7	21.0
Rhus radicans	12.7	5.0
Rosa arkansana	6.4	1.0
Rubus spp.	6.4	1.0
Scutellaria parvula	13.6	6.0*
Smilacina stellata	15.5	11.0
Solidago spp.	26.4	1.0*
Solidago graminifolia	8.2	0.0
Sorghastrum nutans	25.5	1.0*
Stachys palustris	6.4	0.0
Stipa spartea	27.3	6.0*
Tradescantia occidentalis	13.6	0.0*
Viola pedata	7.3	0.0*
Viola pedatifida	10.0	1.0
Viola sagittata	10.9	3.0

* Showed a significantly ($P \le .05$) higher value in the burned area.
† Showed a significantly ($P \le .05$) higher value in the unburned area.

always had higher values in the burned areas, whereas the opposite was true for woody plants. This may be due to the general life cycle of these groups of species. Most perennial grasses and forbs die back at the end of their growing season; thus, early-spring fires would consume primarily dead material. This would be especially true for warm-season species (which dominate the study area) because such species do not initiate growth until late spring or summer. In contrast to perennial grasses and forbs, deciduous woody species do not die back at the end of the growing season, although most will experience a translocation of carbohydrates and nutrients from aboveground portions of the plant to belowground portions at the end of the growing season. Thus, early-spring fires damage living portions of woody plants, which must eventually stress the plants, especially if the burning is annual.

Most of the grasses and forbs that had significantly higher frequency values on the burned site are well suited to take advantage of recent burns because they can reproduce vegetatively or by seed (Weaver 1954, Anonymous 1963, Gleason and Cronquist 1963, Hitchcock 1971). However, these reproductive options are available to most of the understory species examined, including many of those showing no significant difference between the burned and unburned areas. Those species may be responding primarily to factors other than fire, factors which may not differ significantly between these very similar sites. Another possibility is that the relatively small sample size rendered the statistical tests insensitive to small differences in percent frequency.

If the species in Table 3 are analyzed in relation to Curtis's (1959) classification of species, an interesting trend emerges. Nine species that showed a significant difference between my burned and unburned areas were included in Curtis's study. Of the seven species peaking in my burned area, three showed maximum abundance in Curtis's prairie categories, and two showed maximum abundance in his oak barrens category. One species peaked in his sand barrens category, and one peaked in his cedar glades category. In contrast, both species having higher values in my unburned area were most common in his southern dry forests category. This fits well with Curtis's observation that oak barrens are quickly converted to southern dry forests in the absence of fire.

The understory was also analyzed in terms of species richness (the number of species found in each plot); for this analysis, all species that occurred in the 0.25-m^2 plots were included, not just the 40 species tested individually. The burned area had a significantly higher number of species in the understory ($\bar{x}$ = 25.4 species/plot, SD = 4.5) than did the unburned area ($\bar{x}$ = 13.0 species/plot, SD = 4.9). The burned area also had a larger total number of species present than did the unburned area (70 species occurred in the burned area understory vs. 44 in the unburned understory). Of the 81 species that occurred in the understory, 33 were found in both the burned area and the unburned area, 37 were unique to the burned area, and 11 were unique to the unburned area. Thus, it appears that annual prescribed burns have provided a suitable habitat for far more species than are present in the absence of fire.

This study shows that reversing the trend from oak savanna to oak woods may take >13 yr using annual spring burns. Under a spring prescribed burning program, it appears that fire intensity is not sufficient to kill large (dbh ≥25 cm) *Quercus ellipsoidalis* quickly. Whether this burning regime will ever kill these larger oaks is unknown, but it does seem that they are being stressed by the fires (A. S. White, *personal observa-*

tion). The current density of *Q. ellipsoidalis* appears too high for a true oak savanna to develop fully. Most savanna species increase with an increase in light intensity (Bray 1958, Whitford and Whitford 1978) and thus would not reach their maximum abundance until overstory density was considerably reduced. Other prescribed burning blocks at CCNHA currently have lower overstory density than this annually burned block, but their understories are also somewhat different in relative species composition (White 1981), which might suggest individualistic species responses to prescribed burning. However, all the burned areas at CCNHA have lower overstory densities, less shrub cover, and higher frequency of grasses than the unburned area (White 1981). Similar structural changes, then, may be obtained with a variety of spring-burning frequencies, but composition changes may vary considerably with the type of burn.

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