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PRESCRIBED BURNING FOR OAK SAVANNA RESTORATION IN CENTRAL MINNESOTA

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Prior to European settlement, oak savannas dominated the prairie-forest ecotone in Minnesota (Drew 1973, McAndrews 1966, Pierce 1954) as well as in several other midwestern States (Cottam 1949, Curtis 1959, Finley and Potzger 1951-52, Potzger *et al.* 1956, Rohr and Potzger 1952, Stroessner and Habeck 1966). Now, however, oak savannas are rare because of agricultural land clearing, cattle grazing, and fire suppression (Curtis 1959). The purpose of this study was to evaluate an effort to restore oak savanna through prescribed burning.

The presettlement role of fire in the forest-prairie transition zone was twofold. Occasionally, fires spread from the prairie into the oak forests, killing all but the largest trees, thereby creating savannalike conditions (Curtis 1959). Frequent, low-intensity fires also maintained existing savannas (Curtis 1959, Drew 1973), presumably by reducing the number of oak sprouts and seedlings that survived or that made it into the overstory and by favoring the growth of herbaceous species that require high light levels. When the forest-prairie transition zone was settled, fires were suppressed and the savannas were quickly taken over by young oak trees and brush, which often resulted in a dense oak forest within 25 to 30 years (Curtis 1959).

Today, prescribed fire is being used at the Cedar Creek Natural History Area (CCNHA) in central Minnesota in an attempt to restore existing oak forests to oak savannas (Irving 1970), like those that occupied much of the area in presettlement times (Pierce 1954). The concept is that prescribed fire can be used as a restoration management tool to reduce oak overstory density, reduce shrub and sapling height and density, and encourage grasses and forbs. The objective of this study was to compare the vegetation on areas at CCNHA that had been subjected to various prescribed burning regimes since 1964. The results should be of use to land managers interested in restoring similar areas to oak savanna as well as to land managers using prescribed fire in oak forests for other purposes, such as range improvement.

STUDY AREA

The Cedar Creek Natural History Area is located approximately 32 miles north of St. Paul, Minnesota, and has a temperate, continental climate. The topography ranges from gently rolling to flat. Two soil series, Sartell and Zimmerman, dominate the prescribed burning area. Both series are sandy Entisols characterized by low fertility and high permeability (Grigal *et al.* 1974). According to the General Land Office survey notes of 1854, most of the uplands at CCNHA supported scattered, scrubby northern pin oak (*Quercus ellipsoidalis*)[1] and bur oak (*Q. macrocarpa*) (Pierce 1954). These same two species dominate the wooded sites in the prescribed burning area today, but in the unburned control sites they now form a closed-canopy oak forest.

METHODS

A prescribed burning program was initiated in 1964 on a portion of CCNHA (Irving 1970). The area was divided into blocks, some of which were subjected to varying prescribed burning schedules and some of which were maintained as unburned controls. Burns were conducted in April or May between the disappearance of snow and the leafing out of the oaks. Preferred burning conditions were 30 to 40 percent relative humidity, steady 8 to 12 mile per

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[1] *Nomenclature follows Gleason and Cronquist (1963).*

Table 1.—*Prescribed burning schedule, block size, and number of plots for blocks included in this study*

Block number	Total[1] size	Planned[2] burning schedule	Actual number of burns	First burn	Plots
	Acre			*Year*	*Number*
1a	6.5	2 yrs burn/2 yrs no burn	7	1967	3
1	33.6	4 yrs burn/2 yrs no burn	10	1964	6
3	28.7	Annual burns	14	1965	11
4	50.4	Annual burns	16	1965	19
5	39.5	3 yrs burn/3 yrs no burn	9	1965	15
6	20.0	2 yrs burn/1 yr no burn	10	1966	9
8	70.6	2 yrs burn/2 yrs no burn	7	1967	14
Control	--	Unburned	0	--	11

[1] Some units included old fields, which were excluded from this study The number of plots per block is proportional only to the wooded area.

[2] In some years burning was not possible because of lack of suitable burning conditions Consequently, actual burning schedules may deviate slightly from planned burning schedules (see White (1981) for a more detailed description)

hour winds, and constant wind direction (Irving 1970). These burning conditions were chosen to minimize the risk to people and structures and to decrease the probability of abrupt, undesirable effects on the existing plant communities.[2] Spring burns in Minnesota are often less severe than fall burns because in the spring high duff moisture limits available fuel and the downward transfer of heat, and because rapid growth of plants following spring fires reduces nutrient losses via leaching (McColl and Grigal 1975). Actual weather conditions at the time of each burn are on file at CCNHA.

Quantitative information on fire behavior at CCNHA is limited to studies on blocks 3, 4, and 6 (table 1). Oak litter consumption ranged from 0.04 (Wick 1966) to 0.67 tons per acre (Rimmel 1979), with percent consumption ranging from 9 percent (Wick 1966) to 72 percent (Rimmel 1979). Total consumption (litter, herbaceous, 1 hour timelag fuels) ranged from 0.62 to 1.00 tons per acre, with percent consumption ranging from 44 to 66 percent (Rimmel 1979). Rate of spread ranged from 8.5 (Wick 1966) to 55.1 feet per minute (White 1981).

Seven burning blocks and a control were included in this study (table 1). Excluded blocks were dominated by abandoned agricultural fields, occurred on rare soil types, or had very irregular burning schedules. Burning schedules varied according to the number of consecutive years of burning and the number of years between burns. Although blocks 1a and 8 had the same burning schedule, as did blocks 3 and 4, each block was considered a separate entity for analysis because some blocks occasionally were not burned on schedule due to unacceptable burning conditions. Also, although it was assumed that blocks were similar prior to initial burning, preburn information was not available.

Plot locations within blocks were established by stratified random sampling. Strata were defined by soil mapping unit, the only potential source of variation that was already mapped. This system ensured that all possible combinations of burning blocks and soils that occurred on the study area were sampled. Plot locations within each stratum were chosen by randomly generated coordinates at the sampling intensity of approximately one plot per 2.5 acres.

Each plot consisted of one 1,075 square foot circle and one 269 square foot circle, both centered on the same point, and ten 2.7 square foot circles distributed systematically within the 1,075 square foot circle (fig. 1). In the 1,075 square foot circle, all woody stems ≥2 in d.b.h. were recorded by species, d.b.h., and age at breast height. In the 269 square foot circle, all woody species with stems ≥0.4 in diameter at ground level (d.g.l.) and <2 in d.b.h. were recorded by percent cover. In each of the ten 2.7 square foot circles, woody species with stems <0.4 in dgl and all nonwoody species present were recorded. The number of 2.7 square foot circles (out of 10 possible) in which a species was present was used to calculate percent frequency for each species in each plot. Nonvegetation variables were recorded for the plot as a whole and included prescribed burning block, soil series, elevation, and slope. Data on the 1,075 square foot and 269 square foot plots were collected from late summer through early winter in 1978 and data on the 2.7 square foot plots were collected in June 1979. A preliminary sample of the 2.7

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[2] *Frank D. Irving, Professor, University of Minnesota: personal communication.*

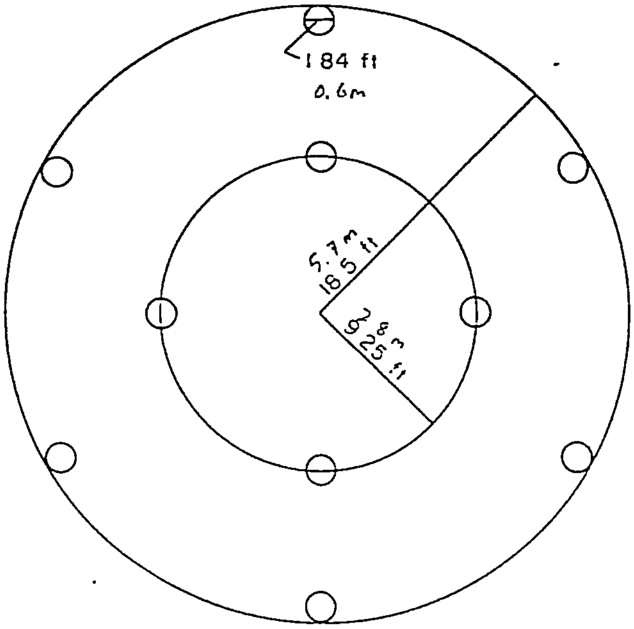

Figure 1.—*Plot design. The largest circle is 1,075 square feet, the inner circle is 269 square feet, and each of the smallest circles is 2.7 square feet.*

square foot plots taken in August 1978[3], indicated that species composition was similar regardless of whether sampling was done in June or August. The 1979 sampling occurred at the end of the burning cycle for blocks 1, 5, 6, and 8 but at the end of the rest period for block 1a (table 1). Blocks 3 and 4 are burned annually. For the sake of simplicity, data collected in the 2.7 square foot circle will be referred to as understory data, those in the 269 square foot circles will be referred to as shrub data, and those in the 1,075 square foot circles will be referred to as overstory data.

Prior to analysis, the number of understory species was reduced from 123 to 50 using the SCREEN program (Grigal and Ohmann 1975), which ranks each species on the basis of five criteria: occurrence over all plots, average frequency per plot, ratio of computed standard deviation to predicted standard deviation, information content based on species presence or absence by plot, and relative contribution of each species in the calculation of interstand distance in ordination space. Only a few species were recorded in the shrub and overstory plots; those occurring in ≥10 percent of the sites were included in subsequent analyses.

Data analysis involved two approaches. First, the relations between individual species and nonvegetation variables were analyzed with a nonparametric Kruskal-Wallis test (Conover 1971). This test was used because most of the species data were not normally distributed and could not be transformed to normality and because the nonvegetation variables were either nonordinal, categorical (prescribed burning block, soil series), or easily categorized (elevation, slope). The relations of the understory and shrubs to the overstory were analyzed using Spearman's Rank Correlation Coefficient, r_s (Siegel 1956).

Second, the plant community as a whole was analyzed in relation to the same nonvegetation variables. One approach was to group sites on the basis of similarity in species composition and abundance by using Orloci's (1967) agglomerative cluster analysis technique. Once groups of sites were formed, relations to the nonvegetation variables were investigated using contingency table analysis. This analysis determined whether or not sites with similar nonvegetation characteristics tended to group together on the basis of species composition and abundance. The other approach involved reciprocal averaging (Hill 1973), an ordination technique made available through the ORDIFLEX program by Gauch (1977). Reciprocal averaging (RA) places sites in relation to one another on the basis of similarity in terms of species composition and abundance. It differs from cluster analysis in that each site can be seen in terms of its relation to all other sites and no groups are automatically formed. Relations to nonvegetation variables were analyzed by inspecting the RA distribution to determine if sites with similar nonvegetation characteristics tended to occur together.

RESULTS

Individual understory species occurred in 5 to 94 percent of the plots while average frequency values per plot ranged from 1 to 77 percent. Shrub species were less widespread, their occurrence ranging from 10 to 15 percent of the plots, with average cover values per plot ranging from less than 1 percent to 2 percent. In the overstory, pin oak occurred in 60 percent of the plots with an average density of 127 stems per acre and an average basal area of 52 square feet per acre, while bur oak occurred in only 34 percent of the plots with an average density of 40 stems per acre and an average basal area of 13 square feet per acre.

In the understory, 36 species (72 percent of the total) had significantly different average frequen-

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[3] *Unpublished data on by Author.*

Table 2.—*Relations of species to blocks as indicated by a Kruskal-Wallis test. Table entries under each block are average frequencies (understory plots), average cover (shrub plots), and density and basal area (overstory plots). P indicates the probability that values were distributed randomly among blocks*

	Blocks								
Species	**P**	**1a**	**1**	**3**	**4**	**5**	**6**	**8**	**Control**
Understory plots									
Agropyron repens	0.001†	0	22	0	4	0	0	1	0
Ambrosia psilostachya	.002†	7	20	32	56	45	40	27	4
Amorpha canescens	.003†	0	3	9	3	4	19	9	0
Amphicarpa bracteata	.000†	93	92	32	19	25	8	47	41
Andropogon gerardi	.000†	0	12	44	5	26	26	4	5
Andropogon scoparius (*Schizachyrium scoparium*)	.071	0	0	12	7	3	14	3	0
Anemone spp.	.006†	0	0	2	1	3	11	4	0
Artemisia ludoviciana	.003†	0	0	20	9	8	13	17	0
Asclepias spp.	.008†	7	0	13	11	8	12	3	0
Bromus inermis	.000†	40	0	1	0	0	0	0	0
Calamagrostis canadensis	.467	30	0	4	4	5	0	2	0
Calamovilla longifolia	.001†	0	0	5	20	8	27	6	0
Carex spp.	.028†	37	17	33	24	25	10	22	44
Celastrus scandens	.001†	7	0	0	8	5	1	23	2
Chenopodium spp.	.177	0	0	3	2	1	0	0	6
Comandra richardsiana	.000†	0	2	26	3	23	24	24	0
Coreopsis palmata	.243	3	5	11	2	3	10	11	2
Corylus americana	.000†	0	7	18	11	13	2	29	37
Cyperus spp.	.001†	53	83	83	78	85	90	86	40
Fragaria virginiana	.583	0	3	6	5	9	3	6	5
Galium boreale	.000†	77	17	0	2	0	0	0	9
Helianthemum bicknellii	.001†	0	0	6	21	19	6	4	0
Helianthus laetiflorus	.213	0	2	20	5	5	3	6	4
Lathyrus venosus	.000†	3	32	0	9	0	40	0	2
Lespedeza capitata	.147	0	2	3	6	6	0	0	0
Lithospermum carolinense	.001†	0	0	1	3	11	1	4	0
Panicum oligosanthes	.002†	10	3	9	25	14	9	6	0
Panicum perlongum	.008†	0	0	1	12	6	10	2	0
Panicum cf. *praecocius*	.004†	0	0	12	23	14	13	8	2
Parthenocissus vitacea	.000†	40	38	14	21	25	6	44	65
Physalis virginiana	.000†	0	2	6	28	13	7	8	0
Poa spp.	.034†	40	17	15	31	15	7	4	16
Prunus cf. *virginiana*	.022†	0	0	1	2	3	0	6	7
Quercus ellipsoidalis	.142	3	13	23	32	17	23	21	21
Quercus macrocarpa	.027†	0	0	0	2	5	4	11	1
Rhus glabra	.010†	0	0	2	13	6	13	8	3
Rhus radicans	.001†	7	28	13	6	23	20	62	6
Rosa arkansana	.254	0	0	6	5	3	11	4	1
Rubus spp	.104	10	15	18	6	9	0	1	5
Scutellaria parvula	.012†	0	0	14	6	21	10	14	5
Smilacina stellata	.521	10	20	19	15	17	16	4	10
Solidago spp.	.000†	0	3	26	18	9	7	6	1
Solidago graminifolia	.023†	0	0	8	8	1	7	5	0
Sorghastrum nutans	.001†	0	0	25	11	33	31	9	1
Stipa spartea	.029†	13	23	27	25	35	32	24	6

(Table 2 continued on next page)

Table 2.—*Continued*

Species	Blocks								
	P	1a	1	3	4	5	6	8	Control
Tradescantia occidentalis	.000†	0	0	14	19	13	4	1	0
Vaccinium angustifolium	.069	0	0	4	1	0	0	0	11
Viola pedata	.006†	3	2	7	9	9	17	4	0
Viola pedatifida	.124	13	3	10	8	9	9	11	1
Viola sagittata	.082	0	0	11	7	7	4	0	2
Shrub plots									
Corylus americana	.000†	0	0	0	1	1	0	3	12
Quercus ellipsoidalis	.003†	0	0	0	1	1	0	0	1
Quercus macrocarpa	.470	0	0	0	1	1	1	1	1
Overstory plots									
Quercus ellipsoidalis density (stems ac)	.000†	81	250	177	49	40	153	46	353
Quercus ellipsoidalis basal area (ft^2 ac)	.001†	74	91	70	39	30	48	26	113
Quercus macrocarpa density (stems ac)	.002†	0	0	15	28	40	23	136	7
Quercus macrocarpa basal area (ft^2 ac)	.002†	0	0	4	9	13	9	39	4

† Significant ($P \leq 0.05$)

cies among the blocks (table 2).[4] Only four of those 36 species, however, had their highest average frequency per plot in the control block. Twenty-one of the remaining 32 species had peak average frequencies in the three most frequently burned blocks (3, 4, and 6). However, the range in number of species peaking in any one block was small, with one species peaking in block 1 and nine peaking in block 4.

In the shrub layer, American hazel (*Corylus americana*) peaked in the control block (table 2). Pin and bur oak did not exhibit noticeable peaks. In the overstory, pin oak had its highest density and basal area in the control block whereas bur oak had its highest values in burning block 8 (table 2).

Over half (52 percent) of the understory species had significantly different average frequency values with respect to soil series, with 19 peaking in the Sartell series and seven peaking in the Zimmerman series (table 3). American hazel in the shrub layer and pin oak in the overstory peaked in the Zimmerman series while bur oak in the overstory peaked in the Sartell series. Unfortunately, it was not possible to statistically separate the effects of soil from the effects of fire because not all burning blocks occurred on both soil series.[5] For example, the Sartell series dominated blocks 4, 5, 6, and 8, and the Zimmerman series dominated blocks 1a, 1, 3, and control.

Ten understory species had significantly different average frequency values with respect to elevation, with 6 of those 10 species peaking in the lowest elevation category (table 3). Because the total range in elevation was only 22 feet, elevation probably reflected differences in depth to water table.[6] Only one species, smooth sumac (*Rhus glabra*), showed significant differences with respect to slope, which was divided into four categories: ≤1 percent, >1 percent and ≤2 percent, >2 percent and ≤3 percent, and >3 percent. Given the very limited topographic variation at CCNHA, this result was not surprising.

The relations of understory species and shrubs to the overstory were analyzed using pin oak density and bur oak density separately as representative of

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[4] *A nonparametric equivalent to Tukey's multiple comparison tests (Zar 1984) proved to be weak, only showing where the differences between blocks occurred for less than half the species that had significant differences according to the Kruskal-Wallis test. Consequently, peak average values per block were used to make subjective inferences about the block in which a species was most common.*

[5] *This was due to the lack of information on soil series distribution at the time burning blocks were established in 1964 (Frank D. Irving, Professor, University of Minnesota; personal communication).*

[6] *David F. Grigal, Professor, University of Minnesota; personal communication.*

Table 3.—*Relations of all species to soil series and elevation and of understory and shrub species to overstory density. P indicates the probability that values were distributed randomly among soil series or elevation categories*

	Soil[1]		Elevation[2]		Correlation $(r_s)^c$ with overstory density	
Species	*P*	*Peak*	*P*	*Peak*	*Quercus ellipsoidalis*	*Quercus macrocarpa*
Understory plots						
Agropyron repens	0.315		0.637		0.10	0.08
Ambrosia psilostachya	.007†	Sartell	.203		−.51†	.12
Amorpha canescens	.106†	Sartell	.036†	M, H	−.14	.19
Amphicarpa bracteata	.016†	Zimmerman	.555		.37†	−.06
Andropogon gerardi	.450		.282		−.01	.01
Andropogon scoparius (*Schizachyrium scoparium*)	.584		.334		−.14	.05
Anemone spp.	.023†	Sartell	.199		−.09	.28†
Artemisia ludoviciana	.471		.527		−.25†	.05
Asclepias spp.	.032†	Sartell	.436		−.27†	−.04
Bromus inermis	.010†	Zimmerman	.001†	L	.09	−.15
Calamagrostis canadensis	.742		.001†	L	−.21†	−.01
Calamovilla longifolia	.002†	Sartell	.050		−.45†	.08
Carex spp.	.008†	Zimmerman	.021†	L	.06	.00
Celastrus scandens	.070		.049†	H	−.12	.28†
Chenopodium spp.	.145		.150		−.14	.22†
Comandra richardsiana	.040†	Sartell	.527		−.01	.18
Coreopsis palmata	.555		.051		.09	.03
Corylus americana	.025†	Zimmerman	.036†	L	.33†	.17
Cyperus spp.	.010†	Sartell	.025†	H	−.17	.07
Fragaria virginiana	.573		.776		−.10	.05
Galium boreale	.000†	Zimmerman	.165		.31†	−.29†
Helianthemum bicknellii	.025†	Sartell	.619		−.42†	−.09
Helianthus laetiflorus	.127		.493		−.20	.13
Lathyrus venosus	.756		.578		.16	−.14
Lespedeza capitata	.698		.178		−.32	−.14
Lithospermum carolinense	.000†	Sartell	.119		−.33†	.11
Panicum oligosanthes	.020†	Sartell	.480		−.35†	.08
Panicum perlongum	.035†	Sartell	.926		−.36†	−.07
Panicum cf. *praecocius*	.011†	Sartell	.833		−.31	.06
Parthenocissus vitacea	.284		.267		.48†	.16
Physalis virginiana	.005†	Sartell	.405		−.47†	.06
Poa spp.	.537		.961		.01	−.04
Prunus cf. *virginiana*	.515		.024†	H	.19	.17
Quercus ellipsoidalis	.300		.877		.09	.18
Quercus macrocarpa	.001†	Sartell	.363		−.26†	.31
Rhus glabra	.025†	Sartell	.310		−.29†	.11
Rhus radicans	.033†	Sartell	.054		.21	.24†
Rhosa arkansana	.357		.916		−.13	.02
Rubus spp.	.010†	Zimmerman	.004†	L	−.02	−.02
Scutellaria parvula	.153		.220		−.23†	.07
Smilacina stellata	.646		.130		−.32†	−.11
Solidago spp.	.353		.866		−.17	.03
Solidago graminifolia	0.685		0.696		−.17	.23†
Sorghastrum nutans	.040†	Sartell	.099		−.36†	−.02

(Table 3 continued on next page)

Table 3.—*Continued*

Species	Soil[1] P	Soil[1] Peak	Elevation[2] P	Elevation[2] Peak	Correlation (r_s)[3] with overstory density: *Quercus ellipsoidalis*	Correlation (r_s)[3] with overstory density: *Quercus macrocarpa*
Stipa spartea	.026†	Sartell	.102		−.20	.05
Tradescantia occidentalis	.958		.931		−.28†	−.02
Vaccinium angustifolium	.002†	Zimmerman	.201		.13	−.10
Viola pedata	.040†	Sartell	.957		−.17	.11
Viola pedatifida	.196		.334		−.17	−.10
Viola sagittata	.999		.027†		−.10	.03
Shrub plots						
Corylus american	.001†	Zimmerman	.244		.18	−.02
Quercus ellipsoidalis	.816		.593		−.12	−.06
Quercus macrocarpa	.329		.839		−.21	.05
Overstory plots						
Quercus ellipsoidalis density (stems/ac)	.001†	Zimmerman	.841		—	—
Quercus ellipsoidlis basal area (ft^2/ac)	.001†	Zimmerman	.926		—	—
Quercus macrocarpa density (stems/ac)	.002†	Sartell	.626		—	—
Quercus macrocarpa basal area (ft^2/ac)	.002†	Sartell	.723		—	—

[1] Where a species was significantly related to soil series, as indicated by a Kruskal-Wallis test, the series in which the species reached its peak value is indicated.

[2] Where a species was significantly related to elevation, as indicated by a Kruskal-Wallis test, the elevation category in which the species reached its peak value is indicated. Elevation categories are as follows: L (low = ≤924 ft), M (medium = 925-929 ft), H (high = >929 ft).

[3] Spearman Rank Correlation Coefficient (r_s).

† Significant ($P \leq 0.05$).

the overstory (table 3). The correlation of density and basal area for each species was very high ($r_s = 0.91$ for pin oak and $r_s = 0.98$ for bur oak); thus, using basal area in addition to density would have been redundant. Twenty-two of the understory species (44 percent of the total) had a significant correlation with pin oak density (17 were negative and five were positive). In contrast, seven species had a significant correlation with bur oak density; six of the correlations were positive. The absolute values of the correlations were typically low, ranging from 0.21 to 0.51.

The plots were clustered by species composition (fig. 2). Five groups of plots were designated (W1 to W5),[7] each of which was composed of plots that were more similar in species composition to other plots in the same group than to plots in other groups. Figure 2 shows that plots from certain burning blocks (e.g., block 8) tended to cluster together, but that in no case did all the plots from any one burning block occur in the same group.

The contingency table analysis showed that the groups formed from cluster analysis were significantly related to fire (burning blocks) and soil series (table 4); that is, certain groups contained more plots representative of one burning block or soil series than would be expected if such plots were distributed randomly among the five groups. Adjusted standardized residuals (Haberman 1973) from the contingency table analysis were used to make qualitative judgments as to which burning blocks or soil series were the most closely associated with which groups. Results indicated that plots from the control block and block 1a tended to occur together in W1, plots from block 8 tended to occur in W2 or W3, plots from block 6 tended to occur in W4, and plots from block

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[7] *The choice of what constitutes a group when cluster analysis is applied is arbitrary. I chose five groups that were relatively distinct from one another and that contained enough plots for contingency table analysis. Groups could have been chosen differently, which would have influenced the results of contingency table analysis.*

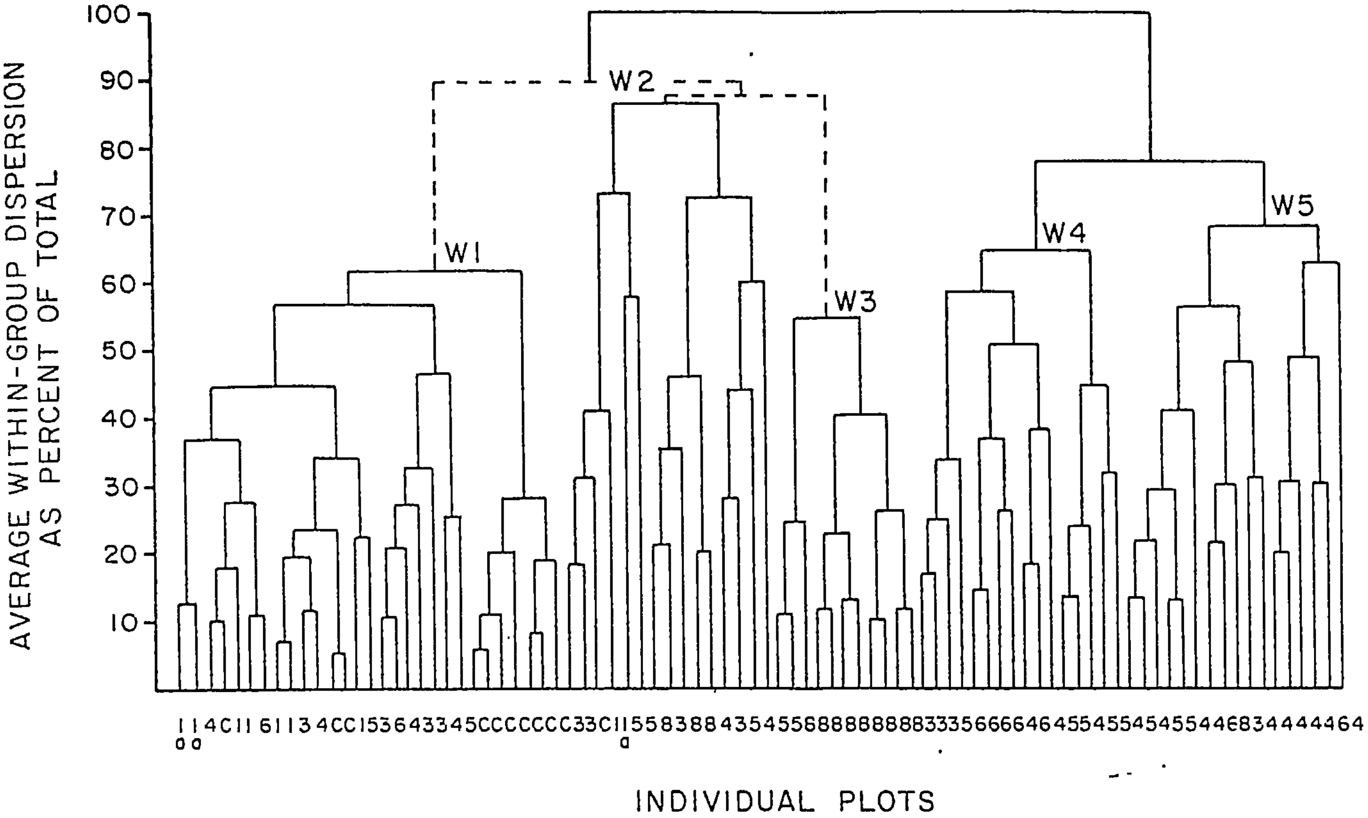

Figure 2.—*Grouping of plots from cluster analysis. Each plot is labled according to the block in which it is located. Five groups of plots are designated as W1 to W5. Dotted lines indicate a reversal, which is a geometric effect that results in a lowered average within-group dispersion when certain groups are joined in the hierarchy.*

4 tended to occur in W5 (table 4). Plots from blocks 1, 3, and 5 showed little association with any of the groups. Plots on Zimmerman soil dominated W1 whereas those on Sartell soil dominated W3, W4, and W5. The cluster groups were not significantly related to either elevation or slope. The same approach was used to evaluate which species were most strongly associated with which cluster groups (table 5).

Table 4.—*Relations of groups formed from cluster analysis (fig. 2) to fire (burning block), soil series, slope, and elevation. Relations were determined from contingency table analysis and subsequent examination of adjusted standardized residuals (Haberman 1973)*

	P	W1	W2	W3	W4	W5
Fire	0.000†	Control, 1[1]	8[2]	8	6	4
Soil series	.000†	Zimmerman	None	Sartell	Sartell[2]	Sartell[2]
Slope	.231	--	--	--	--	--
Elevation	.147	--	--	--	--	--

† Significant ($P \leq 0.05$)

[1] Where two category preferences were indicated by adjusted standardized residuals >2 00. they are listed here in order of preference

[2] Only a weak preference was indicated for any category by an adjusted standardized residual >1 00 and <2.00.

Because cluster analysis forms distinct groups of plots, it was not possible to determine the relations of individual plots to one another outside the group structure. Consequently, reciprocal averaging (Hill 1973) was used to look at all plots simultaneously and see their relations to one another. The resultant ordination of plots is shown in figure 3. From the ordination, it is apparent that plots from certain blocks (e.g., the control block) tended to be quite similar with respect to species composition, but that there was a considerable amount of overlap.

Thus, both cluster analysis and reciprocal averaging indicated that there was a tendency for plots in certain blocks to have similar species composition, and that no block had such a unique species composition that it was completely distinct from all other blocks. The control plots were apparently more similar to one another than were the plots in any of the burned blocks.

Table 5.—*Characteristic species of each group of plots formed from cluster analysis (see fig. 2.), determined from contingency table analysis and subsequent examination of adjusted standardized residuals (Haberman 1973)*

Group				
W1	**W2**	**W3**	**W4**	**W5**
Amphicarpa bracteata	*Amphicarpa bracteata*	*Celastrus scandens*	*Andropogon gerardi*	*Ambrosia psilostachya*
Galium boreale	*Carex* spp.	*Comandra richardsiana*	*Andropogon scoparius* (*Schizachyrium scoparium*)	*Asclepias* spp.
Parthenocissus vitacea	*Corylus americana*	*Coreopsis palmata*	*Asclepias* spp.	*Calamovilfa longifolia*
Quercus ellipsoidalis-overstory density, basal area	*Rhus glabra*	*Cyperus* spp.	*Cyperus* spp.	*Helianthemum bicknellii*
	Rubus spp.	*Parthenocissus vitacea*	*Lathyrus venosus*	*Lespedeza capitata*
		Prunus cf. *virginiana*	*Rhus glabra*	*Panicum oligosanthes*
		Quercus macrocarpa	*Smilacina stellata*	*Panicum perlongum*
		Rhus radicans	*Sorghastrum nutans*	*Panicum* cf. *praecocius*
		Scutellaria parvula	*Stipa spartea*	*Physalis virginiana*
		Quercus macrocarpa-overstory density, basal area	*Viola pedata*	*Poa* spp.
				Rhus glabra
				Tradescantia occidentalis

DISCUSSION

Although no distinct patterns in overall species composition could be found among the burned blocks, the majority of species in the understory, shrub, and overstory layers had significantly different distributions with respect to burned blocks versus the control block. However, the response of various groups of species was different. In the understory, 9 of the 12 grass species had significantly different average frequencies with respect to burning blocks. Although five grass species were found in the control plots, no grass species had its highest average frequencey in the control block. The sedges (*Carex* spp. and *Cyperus* spp.) were common throughout the study area, but *Carex* spp. had its highest average value in the control block whereas *Cyperus* spp. had its lowest average value in the control block. Forbs showed a similar pattern to grasses. Of the 25 forb species, 17 had significantly different distributions with respect to burning blocks; none of the 17 had its highest average values in the control block. Three of the 11 woody species in the understory layer had maximum values in the control block, whereas four had maximum values in the burned blocks; the four others showed no significant relationship to blocks. In summary, all grasses and forbs that showed a significant relationship to blocks had maximum average values in the burned blocks; approximately half the sedge and woody species also had maximum values in the burned blocks while the other half had maximum values in the control block.

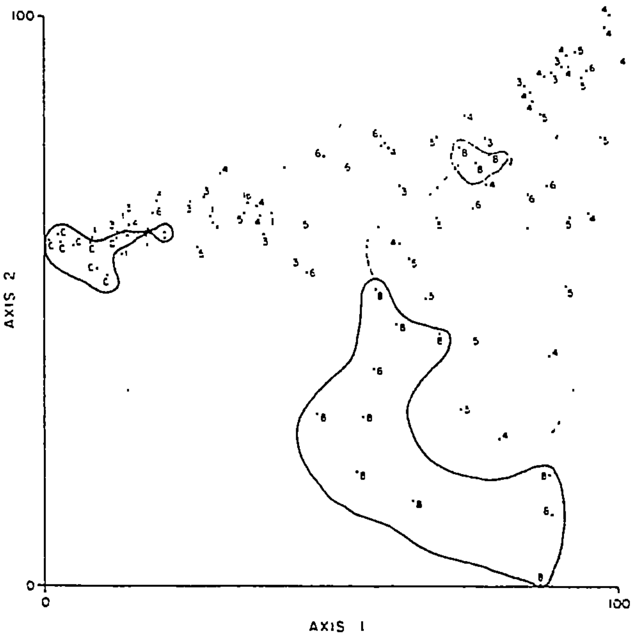

Figure 3.—*Distribution of plots on the first two axes from reciprocal averaging ordination. Each point is labeled according to the block in which it is located.*

Only three species (northern pin oak, bur oak, and American hazel) occurred frequently enough in the shrub layer to be analyzed. The most obvious result was that the shrub layer was virtually absent in the burned blocks (reaching a maximum of 4 percent cover in block 8) while reaching approximately 14 percent cover in the control block. In all blocks, American hazel was the single biggest contributor to shrub cover. Although American hazel was most prominent in the shrub layer of the control block, it is also able to maintain itself by sprouting following

Possibly these results suggest that heterogeneity within burn unit increases with fire freq.

fire, as evidenced by its occurrence in the understory plots of most burned blocks. This is consistent with other studies (Axelrod and Irving 1978, Buckman 1962), which have shown that although the average size of hazel stems may be reduced by low intensity burning, it is hard to eliminate hazel with such fires.

Northern pin oak was the most common overstory species in the study area. It had maximum average density (353 stems per acre) and basal area (113 square feet per acre) in the control block with minimum average density (40 stems per acre) in block 5 and minimum average basal area (26 square feet per acre) in block 8. Thus, even though blocks 5 and 8 have been burned periodically since 1965 and 1967 respectively (see table 1), the pin oak overstory has not been reduced to the 5 to 15 stems per acre levels of early oak savannas as reported by Bray (1955). Bur oak was not as abundant overall as pin oak, but it did occur in all blocks except 1 and 1a. In contrast to pin oak, bur oak had its maximum average density (136 stems per acre) and basal area (39 square feet per acre) in a burned block (8); in fact, block 8 was the only block in which bur oak was more abundant than pin oak in the overstory.

Differences in bur oak density and basal area among blocks were most likely related to preburn conditions because mature bur oak is quite fire resistant (Fowells 1965). The low-intensity prescribed burns resulted in little mortality to large diameter, thick-barked stems. Since small stems were rather rare, the fires probably had little influence on the advancement of such stems into the overstory.

Northern pin oak is less resistant to fire, possibly because of its thinner bark. In a specific comparison of block 3 and the 10 control plots immediately adjacent to block 3, White (1983) determined that pin oak density was 50 percent less in the annually burned block. These two areas were almost identical in environmental and preburn conditions (as determined from early air photos and average overstory age). Thus, it was assumed that the lower density in the burned block was due to considerable fire-caused mortality of small pin oak stems (White 1983). The current differences in density of pin oak among blocks is probably due in part to fire influence on smaller stems. Differences in preburn abundance of larger stems is also likely, since many of the burn blocks were not as similar to the unburned control as was block 3.

It is tempting to ascribe all the differences in individual species abundances among blocks to the influence of prescribed burning. However, this cannot be done for two reasons. First, it was not possible to statistically separate the effects of burning from the effects of soils because not all burning treatments were conducted on both soil series, as mentioned earlier. The influence of soil would appear to be relatively minor, however, because the two soil series are so similar in texture, pH, nutrient status, and water-holding capacity (see Grigal *et al.* (1974) for a more complete description of each series). A similar problem exists for differentiating the influences of fire and elevation. With only 10 species showing significant relationships to elevation, and with the range of elevation being small (≤22 feet), it is unlikely that elevational differences were of major importance.

Second, and more importantly, preburn stand structure and species composition were not known. Use of an unburned control block partially alleviated this problem, but it is not clear how well the control represented the pretreatment stands of each burned block. Although all the blocks were dominated by an oak canopy prior to burning, differences in structure and composition due to natural variation as well as occasional wood cutting, grazing, and burning most likely interacted with fire to produce the plant communities seen today.

Cluster analysis and reciprocal averaging were used in an attempt to discern differences among the blocks in terms of overall species composition. Although there was a tendency for certain blocks (e.g., control) to have similar composition among many of the plots in the block, no block had a distinctly unique species composition. This was not surprising given the relative uniformity of environmental conditions throughout the study area and the apparently individualistic (Gleason 1917, 1926) distribution of species with respect to blocks.

CONCLUSIONS

Several conclusions can be drawn from this study concerning the utility of prescribed burning for oak savanna restoration. First, fire has apparently altered the structure of the plant community. Grasses and forbs were more abundant in the burned blocks. Since many of these species are more common in prairies and savannas than in closed canopy forests (Curtis 1959), this effect was probably linked to the lower overstory densities and basal areas found in the burned blocks. Sedges and woody species in the understory had mixed responses to burning treatments. Species in the shrub layer were virtually absent in the burned blocks. Burning reduced the oak overstory, primarily by killing smaller diameter pin oak stems.

Second, it was not possible to distinguish among the prescribed burning regimes in terms of which was best suited for oak savanna restoration. In all the burned blocks, at least one species reached its maximum abundance; in five of the seven blocks, between four and eight species reached their maximum abundance. Although fire seemed to promote prairie and savanna species, different burning regimes could not be qualitatively separated. In other words, many different periodic burning schedules shifted the community towards oak savanna, but the development pattern differed in details.

Third, pretreatment community structure and composition probably influenced the effects of burning. Postfire structure and composition may best be predicted on a species-specific basis. By knowing what species are present on a site (or surrounding a site) prior to burning, and by knowing how each species responds to fire (e.g., by individual resistance, sprouting, germination of buried seeds or incoming seeds), one may predict the effects of fires of different characteristics (intensity, frequency, size, etc.). Relations between fire characteristics and the life history attributes of individual species are well-documented for some ecosystems (e.g., Keeley 1981, Noble 1981), but information is lacking on many species in many ecosystems.

Finally, although prescribed burning may promote savannalike conditions, it did not, even after 15 years, completely restore the CCNHA communities to presettlement conditions as described by Bray (1955). Part of the problem appears to be the resistance of large ($\geq$10 in. d.b.h.) stems to relatively low intensity fires and to fires with low residence times. Such trees were typically killed only when localized fuels were heavy, usually due to the presence of broken tops, or downed trees.[8] Varying the frequency of burning should have resulted in different burn intensities because of differential fuel buildup between fires. However, since the burns at CCNHA were conducted in the spring when fuels and/or soils were still relatively moist, and since fuel buildup may not have been very great with a maximum of 3 years rest between burns (table 1), larger trees were seldom killed. More intense burns, burns conducted under higher ambient temperatures and when root reserves are low, or burns with longer residence times would probably kill more of the large trees,[8] but might also increase the risk of a fire escaping and increase the risk of severely damaging more understory species. If the management objective is to reduce the overstory quickly and promote typical savanna/prairie understory species, perhaps overstory reduction by cutting or girdling, followed by prescribed burning, would best meet the objective. If more modest overstory reduction and understory promotion is the objective, any one of the regimes tried at CCNHA should be effective. Safety should, of course, always be a primary concern, and patience is necessary as immediate restoration is not likely. Also, the uses of prescribed fire for restoration and maintenance should be considered separately. The type of fire (frequency, intensity, season, etc.) needed for restoration of the savanna community may be quite different from the type of fire needed to maintain the savanna community once it is achieved.

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[8] *Frank D. Irving, Professor, University of Minnesota; personal communication.*

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