Effects of Fire Frequency on Tree Canopy Cover at Allison Savanna, Eastcentral Minnesota, USA

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ABSTRACT: Allison Savanna (bur oak–northern pin oak barrens) in eastcentral Minnesota has been managed since 1962 using prescribed burns conducted at different intervals in eight units. To evaluate fire management success, preburn tree canopy cover was digitized from aerial photos in 1938 and 1960 (prior to burning) and again in 1987 (following 25 years of burns). The fire return interval ranged from 1.6 to 5.0 years. Change in tree canopy cover was compared between 1938 and 1960, and between 1960 and 1987, to determine the relationship between fire interval and canopy cover. In all units, canopy increased between 1938 and 1960, prior to prescribed burning. In 1987, after 25 years of periodic burning, change in canopy cover showed a significant negative relationship with the number of burns. Percent area of wetland in each burn unit did not have a significant effect on changes in canopy cover. Three vegetation plots established in 1990 in unburned, low-, and high-burn frequency units showed that, with increased burns, fires limited oak recruitment. Mature bur oaks *(Quercus macrocarpa)* were more abundant than northern pin oak *(Q. ellipsoidalis)* in the high-burn unit. Age of bur oak stems ranged from 20 to 200+ years, whereas northern pin oak was usually < 30 years. Results of these small-scale burns should be interpreted cautiously at larger spatial and temporal scales because of the longevity of oaks and the interactions of fire with climatic conditions and topographic features.

INTRODUCTION

Oak savannas (including both mesic oak openings and dry oak barrens) in the Mid-west are now quite rare, totaling about 2600 ha in 1986 — approximately 0.02% of their estimated presettlement extent (Nuzzo 1986). Savannas were cleared for cropland, converted to pasture, or changed through succession into closed-canopy oak stands following fire protection (Auclair 1976). Extant, high-quality remnants are generally small, approximately 2–20 ha (Nuzzo 1986). Management of these remnants is affected by their small size, as there is little area in which to test prescriptions, and in almost all cases detailed descriptions of plant community structure and dynamics are lacking. Fire is often an important part of many management plans (White 1986) .

Managers have often relied on historical information, such as Native American ac-counts and early land survey notes, the paleoecological record, and contemporary research to define the need for some type of bum program. However, little long-term data exist with which to evaluate the effec-tiveness of fire management efforts. A broad number of biological and other criteria are needed to evaluate fire management (Chap-man et al. 1995). Our research focused on the woody component and, specifically, the relationship between fire frequency and changes in tree canopy cover.

The objective of this research was to exam-ine the effects of fire management in an oak barrens over a 25-year period. We ex-amined pre- and early settlement commu-nity structure; then, using aerial photos, we determined rates of change in tree canopy cover (1) from 1938 to 1962 without fire management, and (2) from 1962 to 1987 under both fire and no fire management.

STUDY AREA

Allison Savanna, a bur oak–northern pin oak *(Quercus macrocarpa* Michx.– *Q. ellipsoidalis* E.J. Hill) oak barrens (or sand savanna), is located in the eastern part of the prairie-forest transition in eastcentral Minnesota, USA (45°25'N, 93°10'W) (all nomenclature is based on Gleason and Cronquist 1991). The 20-ha barrens area includes scattered wetland depressions containing marshes and sedge meadows. The climate is continental, with hot, humid summers and very cold winters, and average annual precipitation is 66 cm (Tester and Greenland 1987). The site is on the Anoka Sand Plain on sandy out-wash, blowout, and low dune topography, with fine to medium sands (Cooper 1935, Grigal et al. 1974). The ground-water table is fairly flat (M. Basiletti, graduate student, University of Minnesota, St. Paul, pers. corn.), and upland areas may be 2–6 m above the water table, depending on topography.

In the stable sand areas, the tree layer is dominated by northern pin oak and bur oak. At the time this study was conducted, the herbaceous ground layer appeared fairly homogeneous throughout the burned and formerly unburned areas, dominated by graminoids such as *Stipa spartea*, *Cyperus filiculmis*, and *Carex pensylvanica* and forbs such as *Artemisia ludoviciana* and *Ambrosia coronopifolia*, and, in more moist places, by *Andropogon gerardii*, *Schizachyrium scoparium*, and *Sorghastrum nutans*. On the more active dunes, oaks were less prevalent and *Calamovilfa longifolia* was typical.

Prior to settlement in the 1850s, fires were frequent in southern Minnesota, ranging from annual to 30-year intervals, depending on topography and firebreaks (Grimm 1984, 1985). Fires were ignited primarily by Native Americans and secondarily by lightning (Grimm 1985). Ground fires were frequent in the Allison Savanna area up through the 1930s (Pierce 1954; M. Heinselman and F. Irving, adjunct professors, University of Minnesota, St. Paul, pers. corn.). J.R. Bray praised the Allison tract in 1957, calling it "Beautiful Savanna," following his work on savannas in Wisconsin (Bray 1960). A subsequent survey of the tract in 1957 listed, among other things, one old, charred stump; other records indicate horses were grazed there (Heitlinger 1978). Allison Savanna is jointly managed by The Nature Conservancy and the Minnesota Department of Natural Resources.

Fire Management at Allison Savanna

In 1962 a prescribed burn experiment was established to examine the effects of fire frequency on the vegetation (The Nature Conservancy

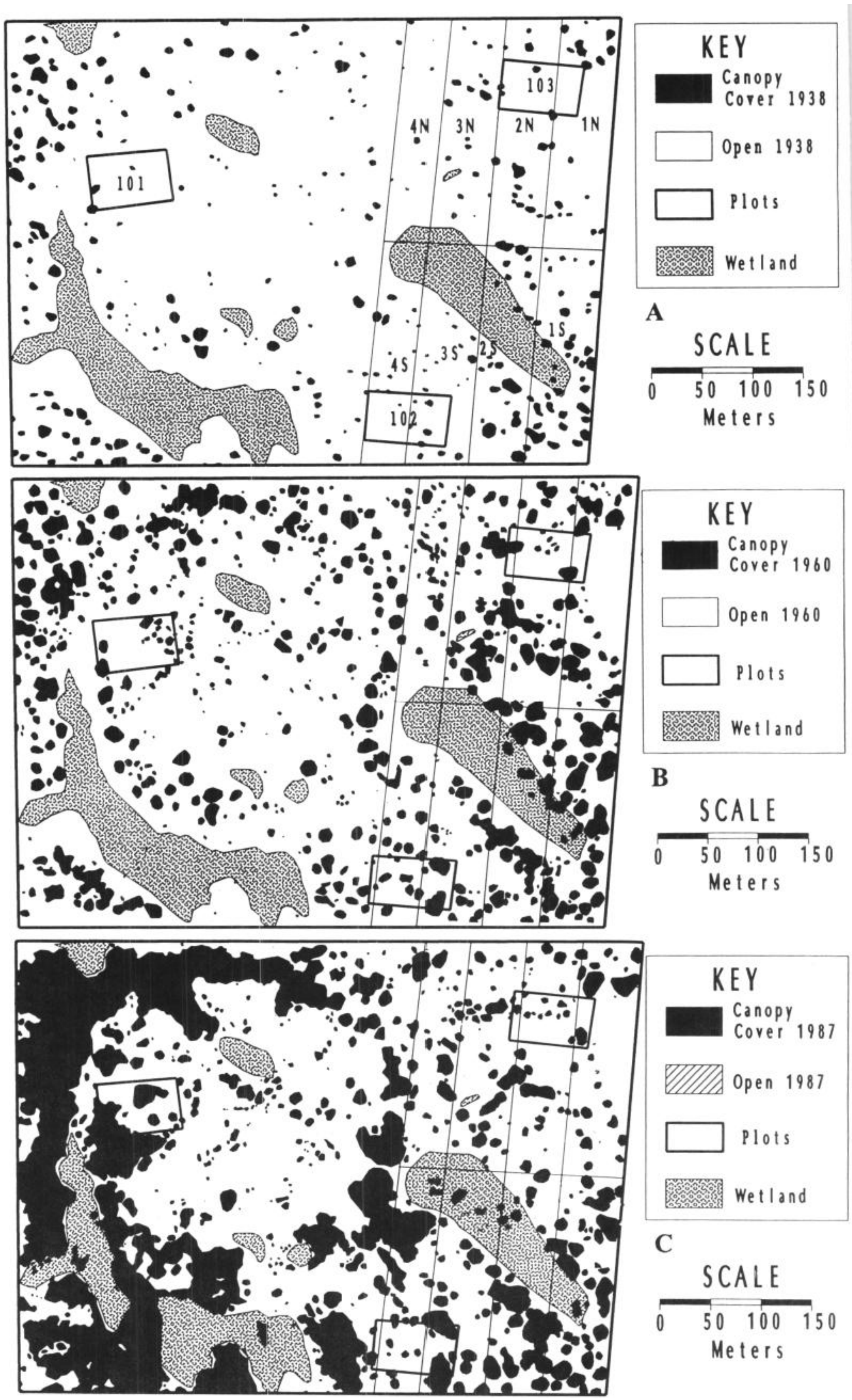

Figure 1. (A) A map of the oak savanna portion of Allison Savanna showing location of burn units (1N-4N, 1S-4S) in the eastern half and location of the western half, which was unburned until 1987. Tree canopy cover was digitized from the 1938 aerial photo. Vegetation plots are also shown, based on their placement using the 1987 aerial photo: 101-unburned, 102-I0w burn, 103-high burn. Open areas contain no tree cover. (B) Map showing the 1960 tree canopy cover. (C) Map showing the 1987 tree canopy cover.

1980). The oak savanna was divided into two halfs; the eastern half was further divided into eight units, each approximately 1 ha, which were burned in spring at different intervals (Figure 1). The western half was left unburned. Units in the east-ern half were burned from west to east; in the first year all eight units were burned, in the second year the easternmost six units were burned, and so on, such that fire intervals were systematically spaced in time. No preburn data were collected to describe the natural communities, although a series of photos were taken at permanently marked photo-stations by D.B. Lawrence. Over the course of the next 25 years, fire return intervals in the eight units varied from 1.6 to 5.0 years (Table 1). Little is known about the range of fire behavior or intensity during these burns.

In the 1980s, concern was expressed that frequent fires might be harmful to some of the species populations, in particular *Car-ex haydenii,* a wet meadow tussock sedge, and several lichen species (Wetmore 1983). At the same time, based on visual observations, The Nature Conservancy decided to introduce fire throughout the system. Hence, beginning in 1987, the eastern eight units were consolidated into one unit, to be burned every 4 years. The western half was burned for 3 consecutive years beginning in 1987, and is currently being burned every 4 years, alternating on a 2-year cycle with the eastern half.

METHODS Presettlement

Vegetation

Presettlement vegetation data were taken from the General Land Office survey records of 1854 that are deposited in the Minnesota State Archives (see Bourdo 1956). A section line map with all "bearing trees" was prepared. The north side of Allison Savanna is located along a section line, which was described as "scattering burr and black oak and oak brush." Section lines to the west and east of this north side were similarly described. The east side of Allison also follows a section line, which was described as "scattered black oak." The nearest section line to the west of Allison contained no description, probably because a small lake occupied the southern half of the line ("black oak" as used by the surveyors was interpreted to mean northern pin oak *[Q. ellipsoidalis]*, as Allison savanna is north of the range of black oak [Q. *velutina]).*

Tree Canopy Cover

Tree canopy cover was measured using aerial photos from '1938, 1960, and 1987, which were enlarged to 40-cm by 50-cm prints to compare pre- and post-burn cover changes. Tree canopy cover in the upland was digitized from these prints using ARC/INFO software (Environmental Systems Research Institute 1990). Burn units established in 1962 had been marked with stakes and their locations were identified on the 1987 print. Wetland areas, with or without tree canopy, were digitized as a separate overlay. The three photos were registered to identifiable landscape features, and ARC/INFO was used to measure tree canopy cover in the uplands of each burn unit. Wetland area (including areas with woody cover) was also measured in each unit.

Table 1. Percent woody canopy cover at Allison Savanna in 1938, 1960, and 1987, excluding wetland area. Change in canopy cover was calculated by subtracting the natural logarithm (L_o) of canopy area for each year. Prescribed burning began in 1962. The number of burns from 1962 to 1987, followed by the corresponding fire return interval, are indicated in parentheses for each unit. N = North Unit, S = South Unit (Figure la).

	Percent Woody Canopy Cover (m^2 canopy cover)			L_n Change in Cover	
	Preburn		Postburn		
	1938	1960	1987	1938–60	1960–87
West Half (unburned)	5.1 (5,966)	18.3 (21,568)	46.6 (54,870)	1.29	.934
East Half (8 units combined)	6.8	25.1	26.2		
East Half (# burns, fire return interval)					
4 S (5x, 5.0 yr)	3.4 (234)	17.4 (1,197)	32.6 (2,245)	1.63	.629
4N(6x,4.2yr)	1.2 (88)	13.7 (1,033)	20.1 (1,522)	2.46	.387
3S (8x, 3.1 yr)	4.4 (346)	22.8 (1,787)	30.4 (2,380)	1.64	.287
3N (10x, 2.5 yr)	4.2 (411)	28.9 (2,840)	19.1 (1,870)	1.93	–.42
2S (10x, 2.5 yr)	14.3 (1,005)	36.6 (2,559)	42.0 (2,943)	.935	.140
1S (11x, 2.3 yr)	14.6 (1,436)	39.8 (3,904)	41.7 (4,089)	1.00	.046
2N (13x, 1.9 yr)	6.1 (625)	21.8 (2,237)	15.5 (1,596)	1.27	–.34
1N (16x, 1.6 yr)	6.0 (633)	19.2 (2,175)	16.1 (1,834)	1.24	–.17

Canopy cover area was converted to its natural logarithm to linearize the area relationship. The value in 1938 was subtracted from that in 1960 (preburn canopy change) and the value in 1960 was subtracted from that in 1987 (postburn canopy change) (Table 1). The differences were standardized to a 25-year rate. Linear and multiple regression analyses (SAS Institute 1988) were used to determine if either fire frequency or percent wetland area (arcsine transformed) was a significant predictor of the rate of canopy cover change.

Tree Size and Age

To provide more detailed information on the effects of fire management on trees, three 0.375-ha plots (50 m by 75 m) were established in 1990: one in the western half of the study area, which was unburned through 1987 (Figure la: plot 101, no burn); one that spanned two burn units with low-burn frequencies (plot 102, 3.1-to 5.0-year fire return interval); and one that spanned two burn units with high burn frequencies (plot 103, 1.6- to 1.9-year fire return interval). Although fire management began in the western half in 1987, it is not known to have killed any trees >10 cm dbh, and there were no standing dead trees in 1990. Plots were subjectively located to represent the 1990 vegetation within each unit. The positions of the three plots were located on the 1987 photo, and the tree canopy cover within these plots was calculated in 1938, 1960 and 1987 using ARC/INFO.

In 1991, all trees >10 cm dbh were measured for diameter in each plot. Eighteen trees were randomly selected and cored at breast height in the unburned and high-burn plots (101 and 103, respectively). Cores were oven dried at 60° C for 24 hours, then mounted on blocks and sand-ed. Ring widths were measured under a microscope to the nearest millimeter. Where cores were incomplete for bur oak, the amount of core missing was estimated from tree diameter. A minimum age for each tree was calculated using a growth rate of 1.3 mm/year (based on the average growth rate of the fastest growing bur oak in the two plots).

RESULTS AND DISCUSSION

Burn Units: Changes in Tree Canopy Cover

In 1938, among the eight burn units in the eastern half and the large unit in the west-ern half, canopy cover varied from 1 to 15% (Table 1). From 1938 to 1960 (the unburned period), tree canopy cover in-creased from 7 to 25% in the eastern half and from 5 to 18% in the western half of Allison Savanna, suggesting that both halves were responding similarly to the absence of fire management. In 1960, prior to burning the eight units, canopy cover varied from 14 to 40%. Between 1960 and 1987, the western (unburned) half continued to increase in canopy cover, from 18 to 47%, whereas the eastern half, managed under a variety of burn intervals, remained virtually unchanged, from 25 to 26% canopy cover. In 1987, variation in canopy cover among the burn units was also similar to that in 1960, ranging from 16 to 47% (Table 1).

The number of burns was a significant predictor of canopy cover changes in the burn units between 1960 and 1987 (r = -0.85, p < 0.01, df = 8; Figure 2), with change in canopy cover decreasing as the number of burns increased. When the unburned western half of the savanna was removed from the regression, the significance of the number of burns decreased only slightly (*r* = -0.78, *p* = 0.02 df = 7). In general, canopy cover continued to in-crease with a 3- to 5-year fire return interval and declined with a 1- to 2-year fire return interval. When the fire return interval averaged between 2 and 3 years, changes in canopy cover were less predictable, with cover increasing in one unit, declining in one, and remaining the same in the third (Table 1, Figure 2).

Photographic records taken in 1960 and 1991 from the high frequency burn unit (IN) in the eastern half and from the unburned western half provide a striking illustration of the reduction in canopy cover caused by burning and of the slow rate of canopy closure in the absence of burning (Figures 3 and 4).

Changes in canopy cover in the uplands were not significantly predicted by the per-cent wetland area found in each burn unit (*r* = 0.57,p = 0.14, df = 7). Multiple regression, using the number of burns and percent wetland area, did not significantly improve the predictive power of the regression compared to using the number of burns alone.

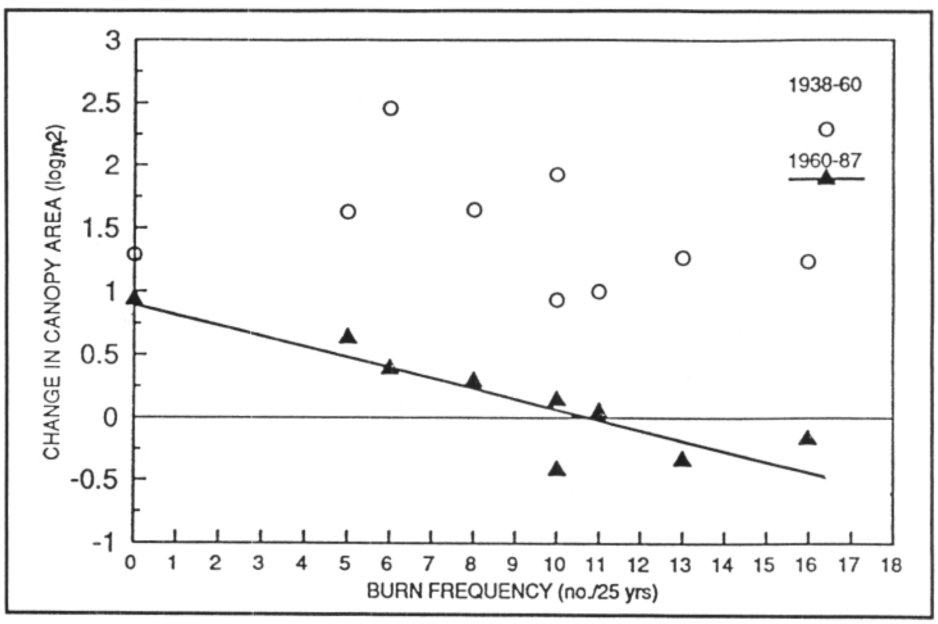

Figure 2. Change in tree canopy cover as a function of the number of burns in 25 years from 1962 to 1987 (closed circles). The equation for the linear regression was significant (r=-0.85,p<0.01). Change in tree canopy cover was insignificantly related to these units prior to burning (1938—1960; open circles). Change in canopy cover is the difference between the natural log of the area in 1938 vs 1960 and 1960 vs 1987 (Table 1).

Figure 3. Photographic record of burn management in unburned western half of Allison Savanna. Photos face due west. Top photo was taken in 1962 prior to burning. Bottom photo was taken in 1991; burning did not take place until 1987. Photos reproduced with permission of D.B. Lawrence.

Figure 4. Photographic record of burn management in Burn Unit 1N, with a fire return interval of 1.6 years, including part of plot 103. Photos face due west. Top photo was taken in 1962, prior to burning. Bottom photo was taken in 1991, the unit having been burned 15 times in 25 years. Note how canopy has been reduced to a scrub layer by burning. Photos reproduced with permission of D.B. Lawrence.

Two aspects of canopy-cover change at Allison Savanna are notable. First, the changes in canopy cover in the absence of fire were slower than those reported in more dry-mesic or mesic oak openings, which appear to succeed to oak forest more rapidly (Cottam 1949). In dry oak barrens at nearby Cedar Creek Natural History Area, using similar methods and over approximately the same time period (1959–1988), the average tree canopy coverage increased from 41 to 66% in the absence of fire (M.A. Davis et al., unpubl. data). The slower changes in the oak barrens when compared to the oak openings probably reflect the dry moisture conditions that slow tree establishment and growth (Whitford and Whitford 1971). Periodic droughts may be severe enough to kill large trees in open areas, thereby helping to maintain the open character of these sites (Faber-Langendoen and Tester 1993).

The second notable aspect of canopy-cover change is the rather slow decline in canopy coverage observed when frequent, low-intensity bums are used. Other studies at nearby Cedar Creek Natural History Area reported a similar slow decline in tree density with high-frequency fires (White 1983, 1986; Tester 1989). Once mature trees are established, they seem to be quite resistant to injury from ground fires. A decline in canopy coverage occurs when tree mortality outpaces canopy expansion and recruitment.

The very open character of the 1938 landscape, with only 6% tree cover, appears to resemble the landscape described by the early surveyors in the 1850s as they traversed the area (see "Methods"), with scattered bur and northern pin oak as the dominant features. Based on this limited data set, settlement between 1856 and 1938 apparently did not alter tree densities in this location. Consequently, canopy cover in 1938 may be used as a presettlement benchmark for restoration and management efforts in upland bur oak–northern pin oak barrens in eastern Minnesota.

Vegetation Plots: Changes in Canopy Cover and Other Variables

Tree canopy cover values in the three 0.375-ha plots in 1938, 1960, and 1987 were similar to the values found in the burn units and in the unburned western half within which they were placed. For example, in 1938, the unburned plot 101 had a canopy cover of 2%, similar to the 5°% found in the western half (Figures 1 and 5, Table 1). In 1987, the unburned plot had a canopy cover of 30% (western half = 47%), the low-burn plot had 26% (3S⁼30%), and the high-burn plot had 13% (1N=16%) (Figure 5).

Total tree densities in 1991 for stems > 10 cm dbh were 222, 141, and 80 stems/ha for unburned (until 1987), low-burn, and high-burn plots, respectively. Total basal area was 8.1, 8.3, and 4.2 m^z/ha for these same plots. The density of northern pin oak in the high-burn plot (24 stems/ha) was 21% of its value in the unburned plot (112), whereas the density of bur oak in the high-bum plot (53 stems/ha) was 50% of its unburned value (107). Thus the relative proportion of bur oak increased in the high-burn plot. Bur oak is considered to be the most fire-resistant oak because of its thick, corky bark (Cottam 1949).

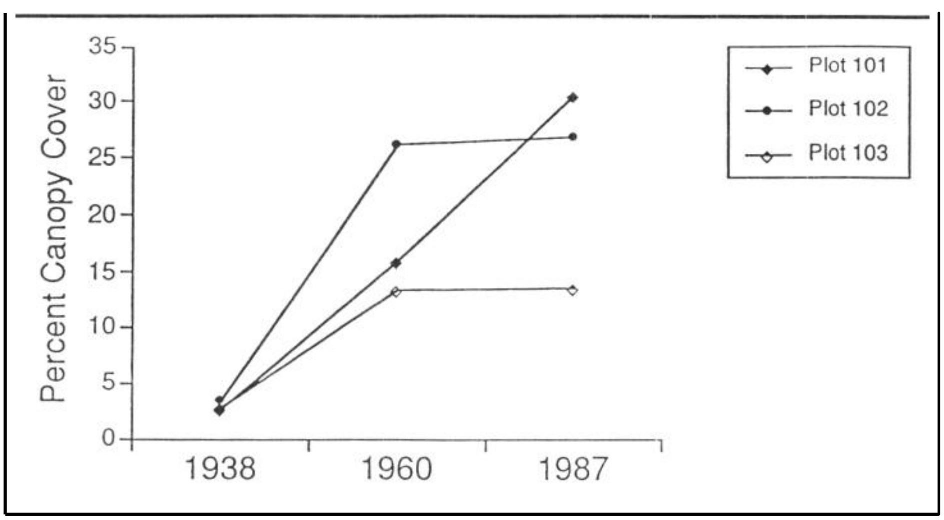

Figure 5. Tree canopy-cover changes in vegetation plots prior to management (1938 and 1960) and under three different burn frequencies from 1962 to 1987: no burn (plot 101), low burn (plot 102, 3.1- to 5.0-year fire return interval) and high burn (plot 103, 1.6- to 1.9-year fire return interval).

Despite recent burning in the unburned plot, shrub composition still reliably indicated some effects of long-term frequent burning. Three shrubs, *Spiraea alba*, *Amelanchier* spp., and *Rubus* spp., were completely absent in the low- and high-burn plots. *Corylus americana* and *Amorpha canescens* were more abundant in the burned plots; the *Corylus* was most abundant in the low-burn plot and the *Amorpha* was most abundant in the high-burn plot. There were few saplings or seedlings in the high-bum plot for either oak species, suggesting that future recruitment will be reduced.

Tree size distribution for each oak species varied with burning. In the unburned and low-burn plots, northern pin oak and bur oak were both abundant in the 10- to 25-cm dbh size classes (Figures 6a and 6b). Bur oaks were more abundant in the larger size classes (40- to 55-cm). Despite the overlap in the smaller size classes in the unburned plot, the age classes of the two species barely overlapped, with most of the northern pin oaks less than 30 years old, and the bur oaks ranging from 20 to greater than 200 years old (Figure 6d).

In the high-burn plot, both species showed gaps in size and age classes, but bur oak was more abundant than northern pin oak in all but the smallest (10-cm) size class (Figures 6c and 6e). Bur oaks were also absent from the younger age classes; all stems were older than 70 years (Figure 6e). Several of the bur oaks would have been 40 to 50 years old back in 1850, indicating that presettlement oaks are still present on the site. Bur oak recruitment was apparently very sporadic over the last 150 years. Northern pin oaks may have been present in 1850 but few or none survived. The northern pin oak regeneration in the 10- and 20-year age classes is primarily from sprouts of large dead trunks.

CONCLUSION

Experiments in fire management at Allison Savanna have demonstrated the effects of fire return intervals on changes in tree canopy cover in small burn units. After 25 years of low-intensity burning at 1- to 2-year fire return intervals, canopy area has been reduced (Table Figure 2), and recruitment by either bur oak or northern pin oak is limited. Burning at 2- to 3-year fire return intervals has prevented further canopy growth, but may or may not have reduced total canopy cover. Less frequent fires (3- to 5-year fire return intervals) may have increased canopy cover. The effect of different fire return intervals, however, was not strong, even after 25 years of burning.

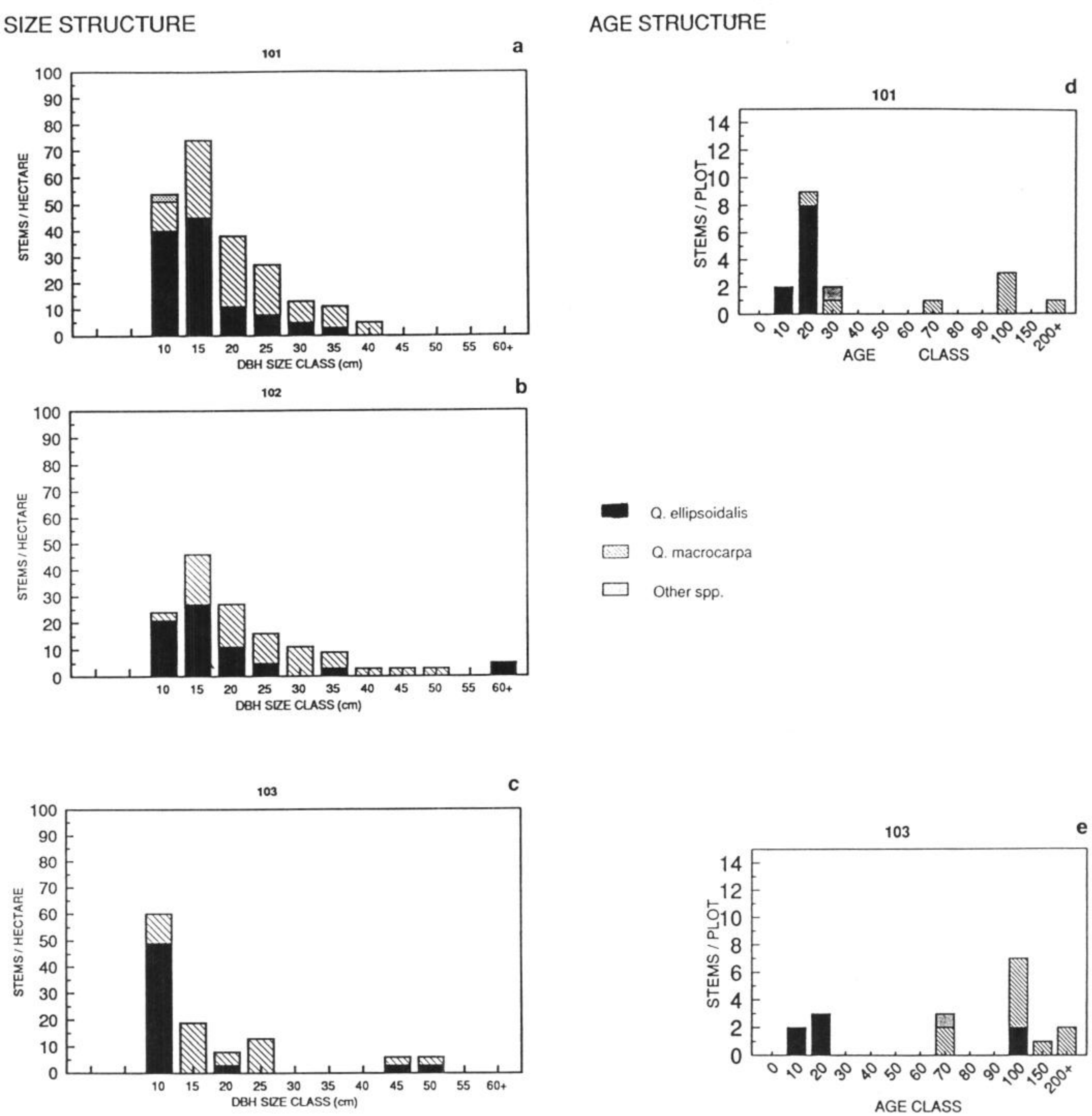

Figure 6. Tree size structure (a—c) and age structure (d, e) for plots at Allison savanna. Plot 101 (a, e) was established in 1990 in the western half where there was no burning until 1987, **plot 102 (b) was established in burn units that had been subjected to a** fire return interval of between 3.1 **and 5.0 years from 1962** to 1987, **and plot 103 (c,** e) was **established in burn units that had been subjected to a** fire return interval of 1.6 to 1.9 years.

The present management plan at Allison Savanna, which calls for burning every 4 years using 10-ha burn units, may not lead to the prescribed reduction in canopy cover. A simple extrapolation from the results of the small-scale burns conducted over a 25-year period would indicate that a 1- to 2-year fire return interval is required to reduce canopy cover. However, these data were collected over relatively short spatial and temporal scales, and extrapolations should be made cautiously. Several factors should be considered. The first is the longevity of the dominant oak species. Bur oak trees, once established, can persist through many fires and increase canopy area simply through the growth of existing crowns. However, if fire return intervals of 3 to 5 years reduce recruitment, as they appear to be doing, then eventually canopy area would decline as the older trees die. Thus 25 years is still a relatively short time frame with respect to judging the changes in oak canopy.

Second, at larger spatial scales, fire behavior may change. Fire intensity may increase and/or fires may be more patchy, depending on how fire management is conducted. Topographic features and landscape patterns have an important influence on fire dynamics (Leitner et al. 1991, Frelich et al. 1992, Bowles et al. 1994). Undue emphasis should not be placed on the fire return interval per se, because fire intensity and behavior may be equally important. Furthermore, fires may be more damaging to trees if they are allowed to occur during periodic droughts. Burning every 4 years may be very effective if at least every other burn is intense — that is, conducted under the following conditions: 60–80°F, 20–30% relative humidity, and 10 mph winds (B. Winter, steward, The Nature Conservancy, Minnesota Field Office, Minneapolis, pers. corn.). A 4-year cycle also may be appropriate once areas are reduced to 5—20% canopy cover, as is now the case for much of the eastern half of Allison Savanna. This part of the site now resembles more closely the surveyor's description: a "scattering burr and black oak" tree layer. Monitoring the effects of burning on the larger scale should provide more insight into the use of fire for savanna management.

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