

Twenty-year Changes in Burned and Unburned Sand Prairie Remnants in Northwestern Illinois and Implications for Management

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ABSTRACT.—Few data are available that compare long-term changes in burned and unburned prairie remnants in the eastern part of the tallgrass prairie region. To assess effects on species richness and composition, in 1996 we resampled three dry and four dry-mesic sand prairie remnants that were originally sampled in 1976. Three of these sites were managed with burning over the 20 y period and four were not, allowing a comparison of temporal change among burned and unburned sites. Mean richness of native species per plot increased only in burned sites and declined only in unburned sites. In contrast, richness of alien species increased only in unburned sites and declined only in burned sites. In unburned dry-mesic sand prairies, an increase in the alien grasses *Bromus inermis* and *Poa pratensis* was accompanied by a decline in the native grasses *Schizachyrium scoparius* and *Stipa spartea*, and the forbs *Echinacea pallida*, *Helianthus rigidus* and *Coreopsis palmata*. Railroad rights-of-way prairies bordering agricultural fields were most vulnerable to invasion of alien grasses. These findings underscore the need to use fire to prevent invasion of alien grasses and to maintain native species richness and composition of prairie.

INTRODUCTION

Prairie covered >60% of the pre-European Illinois landscape but disappeared rapidly owing to conversion to agriculture and suppression of fires that maintained this vegetation (Robertson and Schwartz, 1994). Less than 0.07% of the original Illinois prairie remains undisturbed by humans, primarily in small (<5 ha) fragments that are isolated from natural fire (White, 1978). These remnants support a large number of species, many of which are restricted to few sites (Betz and Lamp, 1989; Betz and Lamp, 1992; Collins and Glenn, 1991). Thus, protection and fire management of as many remnants as possible is necessary to maintain the regional prairie flora. However, few studies have examined temporal changes among burned and unburned prairie remnants east of the Mississippi River. In this study we assessed 20-y changes in native and alien species richness and composition in burned or unburned sand prairie remnants in northwestern Illinois.

Forbs comprise most of the richness in prairie, occurring as interstitial species in a fuel matrix of dominant bunch grasses (Gleason, 1910; Collins, 1987; Collins and Glenn, 1988; Collins and Gibson, 1990). The timing and frequency of burning regulate dominant grass cover and species richness (Collins and Glenn, 1988; Collins and Gibson, 1990), and spring fires also reduce abundance of alien cool season grasses such as *Poa pratensis* (Svedarsky *et al.*, 1986; Abrams and Hulbert, 1987; Henderson, 1992). Establishment and growth of prairie species is generally thought to be stimulated by fire and its removal of litter, as well as by patch disturbance (Hulbert, 1969, 1988; Biondini *et al.*, 1989; Collins, 1989; Evans *et al.*, 1989). Fire exclusion allows accumulation of litter (Weaver and Rowland, 1952), which reduces forb growth and survivorship, thereby decreasing native richness and increasing

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alien richness (Kucera and Koelling, 1964; Collins, 1987; Gibson and Hulbert, 1987; Collins and Gibson, 1990). In their study of Wisconsin prairies originally examined by Curtis (1959), Leach and Givnish (1996) attributed a decrease in species richness to absence of fire, as well as effects of fragment size and moisture gradient position; but they did not compare burned and unburned sites.

In 1996 we resampled seven small sand prairie remnants originally sampled by the Illinois Natural Areas Inventory (INAI) in western and northwestern Illinois in 1976 (White, 1978). Three of these sites were managed by burning over the 20-y period. Because of known burning effects on prairie, we expected native species richness to increase or remain stable in burned sites and to decrease in unburned sites and alien richness to increase in unburned sites and to decrease in burned sites. We also sought to determine compositional changes that might accompany changes in species richness and to identify species sensitive to burning or to lack of burning.

METHODS

Study areas and data collection.—The study areas were three dry and four dry-mesic sand prairies located between 40°35' and 42°20' latitude and between 89°35' and 91°10' longitude in Carroll, Henderson, Henry and Whiteside counties, Illinois (Table 1). Each site was sampled for species presence by the INAI in 1976, using 20 or 30 circular 0.25 m² plots located along transects that were mapped (but not field marked) on aerial photo overlays. The dry sand prairies have shallow A horizons and dominant species that are usually restricted to sand soils, whereas dry-mesic sites have deeper A horizons and support mixtures of silt-loam and sand prairie species (Betz and Lamp, 1992). Characteristic species sampled in the dry sand prairies in 1976 included the grasses *Schizachyrium scoparius*, *Koeleria macrantha*, *Dicanthelium oligosanthes* var. *scribnerianum* and *Dicanthelium villosissimum*, and the sedge *Cyperus schweinitzii*, as well as the prickly pear cactus *Opuntia humifusa*. Nomenclature follows Mohlenbrock (1986). Characteristic grasses of the dry-mesic sand prairies also included *Schizachyrium scoparius*, along with *Stipa spartea* and *Sporobolus heterolepis*. In 1996 we used the original aerial photo overlays and vegetation maps to resample the original transect lines as precisely as possible. In some cases, we used multiple transects and greater numbers of plots to insure adequate coverage of the original sample area 1976 (Table 1).

Landscape context and fire histories.—With the exceptions of Henderson-572, which occurs in a State Forest, and Whiteside-1076, which is adjacent to the Thompson-Fulton Natural Area, these sites are isolated in an agricultural matrix that is becoming urbanized. Three of the sites had been burned (Table 1). Whiteside-880, a dry-mesic prairie located in an undisturbed portion of a pioneer cemetery, was burned biennially for >20 y (T. Keller and R. F. Betz, pers. comm.). Illinois Department of Natural Resources records indicate that Carroll-402 was burned two consecutive years before resampling in 1996 and Henderson-572 was burned at least two out of nine years before resampling. Earlier prescribed burns also occurred at these sites (J. Heim, pers. comm.; M. L. Bowles, pers. obs.). These management burns are usually spring fires timed to reduce early growing, cool-season alien grasses such as *Poa pratensis* or *Bromus inermis* (e.g., Willson, 1992), while avoiding impact on native spring-flowering species. No evidence of recent wildfire was observed on the unmanaged sites (M. Jones, pers. obs.) and there are no DNR records of wildfires on the sampled portions of these areas.

Three of the sites are comparatively large (>10 ha), while the remaining sites are small (<1.2 ha). Four of the sites are in railroad rights-of-way (ROW). Many such ROW prairies

TABLE 1.—Study site location and burn treatment, sample size and habitat characteristics

INAI County—Site number	Size ha	No. of plots sampled		Moisture gradient	Type of area
		1976	1996		
Burned					
Carroll—402	19.4	30	42	Dry	Prairie remnant
Henderson—572	1.1	20	40	Dry	Railroad ROW
Whiteside—880	0.6	20	31	Dry-mesic	Cemetery Prairie
Unburned					
Henderson—357	56.2	30	66	Dry	Prairie remnant
Henry—574	0.7	20	25	Dry-mesic	Railroad ROW
Henry—575	0.6	20	46	Dry-mesic	Railroad ROW
Whiteside—1076	13.4	20	36	Dry-mesic	Railroad ROW

persisted until the early 1960s, after which railroad companies ceased using fire to manage their rights-of-way (Harrington and Leach 1989, R. F. Betz, pers. comm.). One of these ROW prairies (Whiteside-1076) comprises multiple tracks and rights-of-ways.

Statistical analysis.—We used a nested ANOVA in a General Linear Model to test if mean native or alien plot species richness differed between 1976 and 1996 among burned ($n = 3$) and unburned ($n = 4$) sites. The model used a split plots in time and space design, with nested sites split between burn or unburn treatments (Steel and Torrie, 1960). We used this analysis in a manner similar to the Before-After Control-Impact (BACI) analysis strategy (Green, 1979). A significant interaction with time is used to test for environmental impacts; but, other undetectable events may affect temporal change (Stewart-Oaten *et al.*, 1986; Underwood, 1994). In this analysis, only the interaction is of interest, for which residual (error) degrees of freedom and mean square values do not enter into calculation of the F statistic, thus avoiding inflated P values associated with large degrees of freedom (Underwood, 1994). The Tukey-Kramer multiple range test was used to determine which sites differed within treatments, with significance adjusted to $\alpha = 0.025$ following the Bonferroni technique (Sokal and Rohlf, 1998). Based on expected uni-directional changes, we used one-tailed tests (Zar, 1974, Sokal and Rohlf, 1998) to assess whether species richness increased or decreased between 1976 and 1996 depending upon burn or unburn site treatments. We used *t*-tests for native richness and Mann-Whitney tests for alien richness because of the large number of zero values in the 1976 data. For these tests, significance was adjusted to $\alpha = 0.007$ (Sokal and Rohlf, 1998).

Temporal compositional changes in sites were also examined using multivariate analysis. We ordinated the 1976 and 1996 transects on PCORD software (McCune and Mefford, 1999) using Nonmetric Multidimensional Scaling (NMS) of species frequencies with a Bray-Curtis distance measure (Bray and Curtis, 1957) and a Varimax rotation. Ordinations align community data along floristic gradients and can indicate temporal trajectories of vegetation change (Hill and Gauch, 1980; Dunn and Sharitz, 1987; Gibson and Hulbert, 1987; Biondini *et al.*, 1989; Bowles *et al.*, 1996). With the ordination data, we also tested whether the dry and dry-mesic sites differed between 1976 and 1996 by using Multi-response Permutation Procedures (MRPP) with a Bray-Curtis distance measure on PCORD. This nonparametric procedure tested the *a priori* hypothesis of no differences between 1976 and 1996 among the three dry sand prairies and among the three unburned dry mesic sites (*e.g.*, Zimmerman *et al.*, 1985; Biondini *et al.*, 1989). For sites that differed over time, in this case the unburned dry-mesic sites, we correlated species frequencies with the first ordination axis

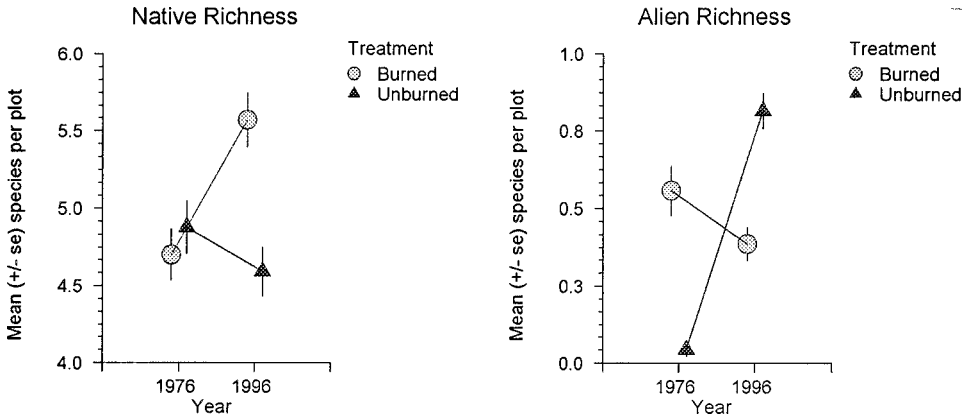


FIG. 1.—Temporal change in mean native and alien plot species richness in burned and unburned sand prairies. Error bars represent standard errors. Nested ANOVA: native interaction $F_{1,5} = 2.64$, $P = 0.165$; alien interaction $F_{1,5} = 7.11$, $P = 0.045$

to identify how composition had changed. We used chi-square analysis of 2×2 contingency tables with a Yates correction factor to test whether species with high positive or negative correlations differed significantly in their number of occupied or unoccupied plot occurrences between 1976 and 1996. The Fisher exact test was used for cell counts of <5 . For this analysis, species occurrences were pooled (*see* Table 1 for sample sizes) because of strong similarities among the unburned dry-mesic sites within years.

RESULTS

Effects on species richness.—In 1976 overall mean native species richness was $4.7 (\pm 0.17 \text{ SE})$ species per 0.25 m^2 plot. By 1996 plot native species richness averaged $5.6 (\pm 0.18 \text{ SE})$ in burned sites and $4.5 (\pm 0.18 \text{ SE})$ in unburned sites, but the interaction over time was not significant (Fig. 1). Within sites, native richness increased significantly in one burned dry sand prairie and declined significantly in one unburned dry-mesic site (Table 2). In the single burned dry-mesic site, native richness increased from $4.75 (\pm 0.31 \text{ SE})$ to $5.74 (\pm 0.27 \text{ SE})$ species per plot, but this increase was not significant ($P = 0.02$), and other sites remained unchanged (Table 2). Between 1976 and 1996 overall mean alien species richness declined to <0.5 species per plot in burned sites but increased from $0.05 (\pm 0.035 \text{ SE})$ to $0.84 (\pm 0.027 \text{ SE})$ species per plot in unburned sites with a significant interaction over time (Fig. 1). Within sites alien richness increased significantly in three of four dry-mesic unburned sites, and declined in the burned dry-mesic site (Table 2).

Compositional changes.—As tested with MRPP, dry sand prairies did not differ over time ($t = -0.1367$, $P = 0.47$). However, unburned dry-mesic sites shifted significantly along the first ordination axis (Fig. 2) due to compositional changes of alien and native species (Table 3). Species with positive correlations along the first axis and significant temporal increases in abundance were the alien grasses *Bromus inermis* and *Poa pratensis*, the native grasses *Andropogon gerardii*, *Dicanthelium oligosanthes* var. *scribnerianum* and *Leptoloma cognatum*, and the forbs *Tradescantia ohiensis* and *Ambrosia psilostachya*. Seven native species had negative axis correlations and significant declines, including the grasses *Schizachyrium scoparius*, *Danthonia*

TABLE 2.—Mean (\pm SE) native and alien species richness per plot in 1976 and in 1996 in burned and unburned sand prairies. Moisture gradient: D = dry, DM = dry-mesic. P values between temporally paired means are one-tailed test probabilities of no difference between means. The Bonferroni adjustment for $\alpha = 0.05$ significance is $\alpha = 0.007$. Sites with similar lower case letters (in columns) across burned and unburned groups have similar means (Tukey-Kramer multiple range comparison at $\alpha = .025$)

Site number & characteristics	Native richness			Alien richness		
	1976	1996	P	1976	1996	P
Burned						
402 (D)	4.53 (.25)a	5.79 (.33)a	0.006	0.53 (.11)b	0.52 (.11)b	0.393
572 (D)	4.90 (.33)a	5.22 (.29)a	0.506	0.00 (.00)a	0.05 (.03)a	0.808
880 (DM)	4.75 (.31)a	5.74 (.27)a	0.020	1.15 (.13)c	0.65 (.09)b	0.002
Unburned						
357 (D)	5.27 (.31)a	5.35 (.28)a	0.846	0.00 (.00)b	0.06 (.03)a	0.117
574 (DM)	4.15 (.33)a	4.40 (.50)ab	0.696	0.05 (.05)b	0.80 (.11)b	<.001
575 (DM)	5.45 (.37)a	3.09 (.16)b	<.001	0.00 (.00)b	1.24 (.09)c	<.001
1076 (DM)	4.45 (.27)a	4.89 (.41)a	0.370	0.15 (.08)b	1.25 (.21)c	<.001

spicata and *Stipa spartea*, the shrub *Rosa carolina* and the forbs *Echinacea pallida*, *Helianthus rigidus* and *Coreopsis palmata*.

In the single burned dry-mesic site (No. 880), significant declines occurred for the alien forb *Achillea millefolium* and grass *Poa pratensis*, as well as the native forb *Tradescantia ohimensis* and grass *Dicanthelium villosissimum*. The native forb *Brickellia eupatorioides* and native grasses *Dicanthelium oligosanthes* var. *scribnerianum* and *Sporobolus heterolepis* increased significantly at this site.

DISCUSSION

Fire and site effects on species richness.—Although the scarcity of undisturbed sand prairie remnants with historic data sets prevented full site replication in this study, our results are ecologically relevant as they support findings that fire is an important factor in the maintenance of native species richness and control of alien species in prairie (e.g., Gibson and Hulbert, 1987; Biondini *et al.*, 1989; Collins and Gibson, 1990; Leach and Givnish, 1996). Our data show that small-scale native richness increases or remains stable in burned sites and declines or remains stable in unburned sites, whereas alien richness increases in unburned sites and declines in burned sites.

Habitat characteristics also affect change in native richness and may interact with burning frequency (Gibson and Hulbert, 1987). For example, although the dry and dry-mesic sites had similar levels of native species richness, the dry-mesic site had more frequent (biennial) burns. A plausible explanation for this similarity is that drier habitats need less frequent burning because they have lower rates of species loss with fire exclusion (Henderson, 1992; Leach and Givnish, 1996). Dry sand prairies may be less sensitive than dry-mesic sand prairies to burning and to fire exclusion because drier habitats have more open sand and less fuel, and greater rates of erosional and animal patch disturbances that help maintain native species richness (Gleason, 1910; Loucks *et al.*, 1985; Plumb-Mentjes, 1990; Fulk and Ebinger, 1999). Climatic variation, especially drought, could have affected native species richness during the study period (e.g., Gibson and Hulbert, 1987; Biondini *et al.*, 1989). Most dry sand prairie vegetation died back by midsummer in a severe drought in 1988 (M. Bowles

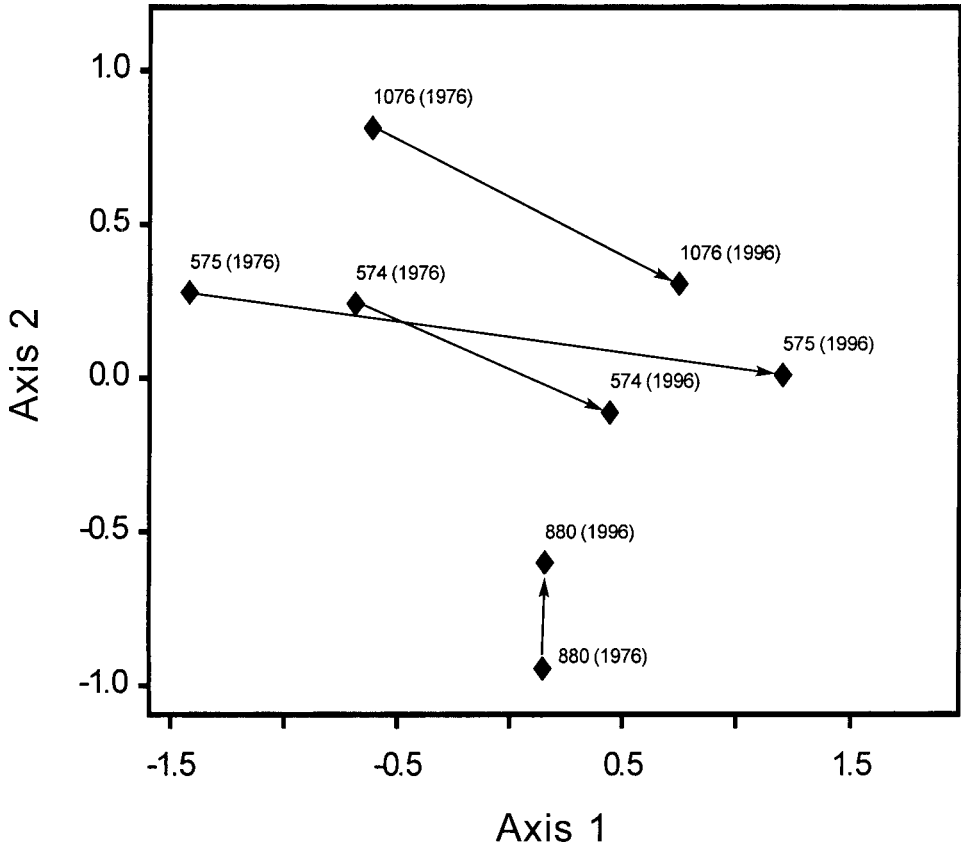


FIG. 2.—Nonmetric Multidimensional Scaling ordination of temporal change in biennially burned (No. 880) and unburned dry-mesic sand prairies sampled in 1976 and in 1996. Axes 1 and 2 contain >90% of variance in main matrix (cumulative $r^2 = 0.906$) with $\leq 5\%$ ($P = 0.0476$) of randomized runs with stress \leq observed stress. Axis 1 is the primary axis for temporal change as shown by vectors. MRPP probability of no significant difference among the unburned sand prairies between 1976 and 1996: $t = -2.902$, $P = 0.022$

and M. Jones, pers. obs.) and Henderson (1992) found that species richness declined after 1988 in both burned and unburned plots on a dry prairie in Wisconsin.

The changes in alien species richness, which involved primarily *Bromus inermis* and *Poa pratensis* in dry-mesic habitat, support findings that alien richness increases with fire exclusion and decreases with burning (e.g., Gibson and Hulbert, 1987). The decline of *P. pratensis* in the biennially burned dry-mesic site also agrees with other findings that annual or biennial spring burns cause greatest reduction of this species (Towne and Owensby, 1984; Henderson, 1992; Svedarsky *et al.*, 1986; Abrams and Hulbert, 1987). Although we cannot confirm it statistically, our observations suggest that alien invasion is facilitated by site shape and landscape location. Railroad ROW prairies are linear with high edge : interior ratios and are highly vulnerable to adjacent land use and alien plant invasion (Harrington and Leach, 1989; Christiansen, 1990). *Bromus inermis* typically invades by an advancing front

TABLE 3.—Nonmetric Multidimensional Scaling ordination Axis I correlations (see Fig. 2), % frequencies and chi-square probabilities for species with significant temporal change in abundance in unburned dry-mesic sand prairies. Alien species are indicated by an asterisk (*)

	Axis I Correlation	Species % frequencies		Probability
		1976	1996	
Increasing				
<i>*Bromus inermis</i>	+ .802	0	29.1	<0.001
<i>Andropogon gerardii</i>	+ .639	6.7	19.6	0.025
<i>*Poa pratensis</i>	+ .568	5.0	45.8	<0.001
<i>Tradescantia ohiensis</i>	+ .561	6.7	25.2	0.002
<i>Dicanthelium oligosanthes</i>	+ .406	8.3	25.2	0.014
<i>Ambrosia psilostachya</i>	+ .381	0	25.2	<0.001
<i>Leptoloma cognatum</i>	+ .301	0	9.35	0.010
Decreasing				
<i>Echinacea pallida</i>	− .866	21.7	1.9	<0.001
<i>Rosa carolina</i>	− .835	21.7	3.7	0.001
<i>Schizachyrium scoparium</i>	− .818	73.3	28.0	<0.001
<i>Helianthus rigidus</i>	− .608	16.7	4.7	0.021
<i>Danthonia spicata</i>	− .585	23.3	0	<0.001
<i>Stipa spartea</i>	− .581	53.3	31.8	0.010
<i>Coreopsis palmata</i>	− .260	21.7	8.4	<0.029

from a site boundary rather than by seed (Blankenspoor and May, 1996), and this appears to have been the process for invasion of sand prairies by this species (M. Jones pers. obs.).

Fire effects on species composition.—Temporal changes in individual species in burned and unburned eastern tallgrass prairie remnants are not well documented, and species responses can be variable and individualistic (e.g., Gibson and Hulbert, 1987; Biondini *et al.*, 1989). However, some of the species changes in this study have been found in other burn studies. *Helianthus rigidus* also declined in unburned northern mixed prairie (Biondini *et al.*, 1989). In Kansas, *Ambrosia psilostachya* increased in unburned prairie (Towne and Owensby, 1984; Gibson and Hulbert, 1987; Gibson and Towne, 1995) and *Sporobolus heterolepis* was more abundant in burned prairie (Gibson and Towne, 1995). Other species that increased without burning also respond to grazing and patch disturbance. The alien grasses *Bromus inermis* and *Poa pratensis*, as well as the native grass *Leptoloma cognatum* and forb *Ambrosia psilostachya*, increase with grazing (Gleason, 1910; Willson, 1992; Blankenspoor and May, 1996; Bowles, 1993). *Ambrosia psilostachya* and *Tradescantia ohiensis* are also more frequent on badger and pocket gopher mounds than in undisturbed habitat in dry sand prairie (Fulk and Ebinger, 1999). The native grass *Andropogon gerardii* may become dominant in burned or unburned prairie (Weaver and Rowland, 1952; Gibson and Towne, 1995). This species spreads by tillering (Brejda *et al.*, 1989) and could have expanded in unburned habitat by this process, especially if facilitated by soil disturbance (Collins, 1989).

Many of the species that declined in unburned dry-mesic prairie or increased in the burned dry-mesic prairie have been considered modal or mid- to late-successional in silt-loam prairie and have low rates of colonization after disturbance (Curtis, 1959; Haverkamp and Whitney, 1983; Swink and Wilhelm, 1994). For example, *Schizachyrium scoparium*, *Sporobolus heterolepis*, *Echinacea pallida*, *Helianthus rigidus* and *Coreopsis palmata* often establish in late stages of prairie restoration (Sperry, 1983; Betz, 1986; Schramm, 1992; Betz *et al.*, 2000). One declining species (*Danthonia spicata*) is an exception, as it often colonizes

disturbed or eroded soils (Swink and Wilhelm, 1994). This species may have declined due to increased competition from grasses in former disturbance patches.

Management and restoration implications.—The decline in native species and increase in alien species in unburned sand prairies underscore the importance of prescribed burning for managing prairie remnants. As in Missouri prairie (Kucera and Koelling, 1964), our data indicate that biennial burning of dry-mesic prairie allows maintenance of native species richness while reducing richness of alien species. Evidence from western tallgrass prairie, as well as restorations in the Midwest, indicates that more frequent (*e.g.*, annual) burning may eventually reduce forb richness by increasing cover and competition from native grasses unless coupled with grazing, mowing or summer fire (Collins, 1987; Collins and Glenn, 1988; Collins and Gibson, 1990; Howe, 1994a, b; Collins *et al.*, 1995; Collins *et al.*, 1998; Howe, 1999; Knapp *et al.*, 1999; Davidson and Kindscher, 1999). However, similar effects may not occur in all prairie types (Collins and Gibson, 1990) and such applications to ungrazed eastern tallgrass prairie remnants are untested and controversial (Henderson, 1992, 1999; Leach *et al.*, 1999). Timing of burns is critical for maintaining species richness as annual late spring burns negatively impact spring flowering forbs (Towne and Owensby, 1984). Tallgrass prairie can also maintain high species richness among forbs that complete their growth and flowering before warm season grass cover is developed (Curtis, 1959; Kindscher and Wells, 1995). For example, the biennially burned dry-mesic site contains one of the largest concentrations in Illinois, and greatest flowering percentage, of the state threatened prairie trout lily *Erythronium mesochoreum*, an ephemeral interstitial species (McClain *et al.*, 1999).

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