TWENTY-YEAR CHANGES IN FIRE-MANAGED AND UNMANAGED SAND PRAIRIE VEGETATION IN NORTHWESTERN ILLINOIS

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SUMMARY

We resampled eight high quality sand prairie remnants identified by the Illinois Natural Areas Inventory in 1976, comparing their floristic changes over time in relation to fire-management. Three of the sites were grade B dry sand prairies, two of which are fire-managed. The remaining five were either grade A (four sites) or grade B (one site) dry-mesic sand prairie, one of which is fire-managed. We found that the unmanaged dry-mesic sites underwent a loss of late-successional plant species and invasion by alien grasses. In relation, two of the fire-managed sites had increased native species richness measured at the plot level, while the unmanaged sites either lost native species richness or had no change. These results underscore the need to use fire as the principal management tool for prairie vegetation, and indicate that unmanaged prairies have deteriorated over time.

INTRODUCTION

Protection and management of sand prairies

Since completion of the Illinois Natural Areas Inventory (INAI), most of the ~1000 high quality natural areas that were identified have been protected and managed. However, small isolated natural areas such as prairie remnants in railroad right-of-ways often have not been protected or managed. These small areas also have a high edge:interior ratio, and are highly vulnerable to adjacent land use and woody or alien plant invasion, and may show more rapid degradation than larger sites.

Fire is the primary management need for prairie vegetation because it increases cover and biomass of graminoid plants, reduces woody plant cover, and maintains species richness (Collins

& Glenn 1988, Collins & Gibson 1990). As a result, fire protection of unmanaged native prairies is thought to contribute to their degradation and loss of species richness (Robertson *et al.* 1994). However few studies have compared data over long time periods. In a study of Wisconsin prairies originally sampled by Curtis (1959), Leach & Givnish (1996) attributed absence of fire as causing loss of species richness and decline of small-structured plant species, especially Legumes. They also found that the larger more diverse prairies had lost fewer species, and annual species loss rates ranging from 0.45% in dry prairies to over 1% in wet prairies. Sand prairies are often subject to dynamic erosion processes (Gleason 1910) that help maintain species diveristy (Loucks *et al.* 1985, Plumb-Mentjes 1990); however, this process makes them vulnerable to alien species invasion (Denslow 1985, Bowles 1993).

Study objective

This study examines the fate and condition of eight small sand prairie remnants identified by the INAI in northwestern Illinois (White 1978). We determine twenty-year changes in their floristic composition by comparing data collected by the INAI in 1976 with data obtained by resampling mapped transects areas. In doing so, we compare protected fire-managed sites with unprotected sites, and determine whether the unprotected sites have degraded over time.

METHODS

Study areas and data collection

Study areas were divided into three dry-mesic and five dry sand prairie community groups, which were located in Carroll, Henderson, Henry, and Whiteside counties (Table 1). All but one of the dry-mesic sites were classified by the INAI as grade A (essentially undisturbed), and were characterized by grasses such as *Andropogon gerardii, Stipa spartea, & Sporobolus heterolepis* and included forbs such as *Echinacea pallida & Lithospermum canescens*. The dry sites were classified as grade B (lightly disturbed) and had grasses such as *Andropogon scoparius, Koeleria micrantha, & Carex muhlenbergii*, and the forbs *Ambrosia psilostachya & Opuntia humifusa*. Each site was sampled by the INAI in 1976 with 20-30 1/4 meter square circular plots along transects that were marked on aerial photo overlays. These transects areas were relocated and resampled with one or more transects, resulting in sampling of 371 plots, as opposed to 180 plots sampled in 1976 (Table 1).

Two sites in the dry sand prairie group have been protected and consistently fire-managed over the last 20 years: Ayers Sand Prairie (Carroll No. 402), and Big River State Forest (Henderson 572). One dry-mesic site, Sandytown Cemetery (Whiteside No. 880) is protected and managed. Although we cannot prove that the unprotected sites have not burned periodically, burning frequency over time will be higher and more consistent at the managed sites (R.W. Nyboer & J. Hiem, pers. comm.).

Table 1. Experimental design for Illinois Natural Areas Inventory study sites.

INAI County/ Site Number	Acreage by Natural Quality A	B	C	No. of plots sampled in 1976/1996	Moisture Gradient Position	Type of area and management
Carroll/402	0	29.0	19.0	B (30/42)	Dry	Fire-managed Natural area
Henderson/572	0	2.8	0	B (20/40)	Dry	Fire-managed Railroad ROW
Henderson/357	0	133.9	5.0	B (30/55)	Dry	Unmanaged Natural area
Carroll/415	0	1.5	0	B (20/22)	Dry-mesic	Graded Railroad ROW
Henry/575	0.9	0.4	0	A (20/70)	Dry-mesic	Unmanaged Railroad ROW
Henry/574	0.8	1.0	0	A (20/25)	Dry-mesic	Unmanaged Railroad ROW
Whiteside/880	1.0	0.5	0	A (20/31)	Dry-mesic	Fire-managed Cemetery Prairie
Whiteside/1076	10.0	4.1	19.0	A (20/86)	Dry-mesic	Unmanaged Railroad ROW

Hypotheses testing and data analysis

We test the general hypothesis that lack of fire will lead to degradation of sand prairie vegetation by comparing the abundances of native species and species groups over time in burned and unburned sites. More specifically, we expected that late-successional plant species will have declined in unburned sites and alien species have invaded these areas, while burned sites have remained stable. We also expected that prairies that have not been fire-managed will have declined in native species richness, while fire-managed sites will have remained stable.

To assess these changes, we compared dry and dry-mesic sites in separate groups. We used Detreneded correspondence analysis (DECORANA) on the PCORD software program (McCune 1994) to compare the 1976 and 1996 data sets using the frequency of occurrence of each plant in plots sampled at each site. DECORANA aligns community data along strong floristic gradients (Hill & Gauch 1980), and distances between temporally paired transects can indicate trajectories of vegetation change (Dunn & Sharitz 1987, Bowles *et al.* 1996). In our analysis, dry-mesic sites, but not dry sites, demonstrated a strong temporal floristic gradient. This allowed correlation of species frequencies along the first ordination axis to identify how species composition had changed over time. Once species with high positive or negative correlations were identified, we compared their frequencies in 2 x 2 contingency tables using Chi Square analysis of the proportional differences in number of plots occupied vs those not occupied between 1976 and 1996. We also directly tested for differences in native species richness at the plot level (*i.e.*, the average number of native species sampled per plot) in an analysis of variance (ANOVA) comparing these differences in fire-managed and unmanaged sites between 1976 and 1996.

RESULTS

Dry sand prairie sites

All species sampling data is compiled in Appendix I, which compares species frequencies in 1976 vs 1996. Dry sand prairie sites did not shift over time along the first ordination axis (figure not shown), and consequently, no significant changes in alien or late successional species were identified. There was also no significant difference in mean plot richness of native species among the three study sites; however, there was a significant change in mean plot species richness over time (Table 2). This change resulted from a significant increase in native plot species richness at the fire-managed Ayers Sand Prairie, while the other sites did not change (Figure 1).

Table 2. Analysis of variance of changes in native mean plot species richness in dry sand prairies. See Figure 1 for site differences.

Source	DF	Sum-squares	Mean square	F-Ratio	Probability
Site	2	2.112	1.056	0.31	0.736
Year	1	12.661	12.661	3.68	0.055
Interaction	2	9.614	4.807	1.40	0.250

Dry-mesic sites

All species sampling data is compiled in Appendix II, which compares species frequencies in 1976 vs 1996. Site numbers 0176, 415, 574, and 575 are combined because their compositions were similar. Site 880 (Sandytown Cemetery) is compiled separately.

Unmanaged dry-mesic sites had a strong temporal gradient along the first ordination axis, while the fire managed Sandytown Cemetery Prairie did not shift (Figure 2). The temporal gradient was due to significant shifts in alien and native species (Table 3). For example, species with high positive correlations with the first axis included late-successional species such as the grass *Stipa spartea* and the forbs *Echinacea pallida,* and *Lithospermum* species, which declined over time in the unburned sites. In contrast, species with negative correlations included the alien grasses *Agropyron repens, Bromus inermis*, and *Poa pratensis,* which increased over time in the unburned sites. The native grasses *Sorghastrum nutans* and *Leptoloma cognatum* also had higher frequencies in 1996.

Table 3. Species with high correlations with the first ordination axis (see Figure 2) and significant Chi-square probabilities for temporal changes in frequencies between 1976 and 1996 unburned dry-mesic sand prairies. Alien species are indicated by an asterisk (*).

		Species Frequencies		
Species	Correlation	1976	1996	Probability
**Agropyron repens*	-.459	0	11	0.004
**Bromus inermis*	-.673	0	35	<.0001
Danthonia spicata	+.546	21	0	<.0001
**Poa pratensis*	-.834	4	57	<.0001
Sorghastrum nutans	-.612	9	20	0.032
Stipa spartea	+.787	64	32	<.0001
Leptoloma cognatum	-.519	0	9	0.012
Artemsia campestris	+.638	16	0	<.0001
Asclepias verticillata	+.670	18	1	<.0001
Echinacea pallida	+.640	16	1	<.0001
Heterotheca camporum	+.718	12.5	0.5	<.0001
Lithospermum canescens	+.302	4	0	0.037
Lithospermum caroliniense	+.436	9	2	0.024
Rosa carolina	+.522	16	0.5	<.0001
Solidago nemoralis	+.617	7	0	0.001

Unlike the dry sand prairie sites, there were significant differences in mean plot richness of native species among the five dry-mesic study sites, a significant change in mean plot species richness over time, and an interaction between sites and time (Table 4). These changes resulted from a significant increase in native plot species richness at the fire-managed Sandytown Cemetery Prairie, while unmanaged sites either declined in native richness or did not change (Figure 3).

Table 4. Analysis of variance of changes in native mean plot species richness in dry-mesic sand prairies. See Figure 3 for site differences.

Source	DF	Sum-squares	Mean square	F-Ratio	Probability
Site	2	63.167	15.792	4.5	0.0015
Year	1	13.088	13.088	3.73	0.0535
Interaction	1	118.109	29.527	8.41	<.00001

DISCUSSION

Our study suggests that fire protection of sand prairies leads to a general degradation of these prairies through two pathways. First, a shift in relative abundance between alien and native species results in an increase of alien grasses while late-successional species decline in unburned dry-mesic sites. Second, mean plot richness of native species usually declines in unburned sites. In relation, fire management also appears to contribute to a positive change in native species, as mean plot species richness of native species increased in burned sites.

Once established, the sod-forming nature of alien grasses apparently contributes to decline of native praiirie by filling in the interstitial niche habitat present between native bunchgrasses. This increases competition against forbs that normally occupy this habitat. Ecological differences between dry and dry-mesic sand prairies probably contribute to differences in these results. The lower availability of water and more open dynamic wind-blown habitat of dry sand prairies (Gleason 1910, Loucks *et al.* 1985) probably creates a habitat more resistant to invasion by alien grasses that are primarily adapted to more mesic silt loam soils (*e.g.* Blankespoor & May 1996). However, with disturbance by grazing, annual and biennial alien species can invade these sites (Bowles 1993). The late successional prairie grasses and forbs that declined are most typical of silt-loam soils and were less abundant or absent from dry sites. However, some of these species also may have been absent due to past grazing disturbance of the dry sites, as they were classified as grade B.

The small size and location of these sites among unnatural habitats also may have contributed to alien invasions. For example, *Bromus inermis* typically invades prairie by an advancing front from the site boundary rather than by seed (Blankespoor & May 1996). As a result, it is possible that the late-successional species would have declined at lower frequencies in larger less isolated habitats (*e.g.* Leach & Givnish 1996).

The finding of greater mean plot species richness of native species in most managed dry and dry-mesic sites in comparison to unmanaged sites, and the temporal increase in richness in both habitats with fire-management, underscore the importance of prescribed burning for managing sand prairie remnants and indicate that unmanaged sites are deteriorating. Although such sites may undergo less woody plant invasion than mesic sites due to more frequent drought episodes (Bowles 1993), they clearly respond positively to fire-management.

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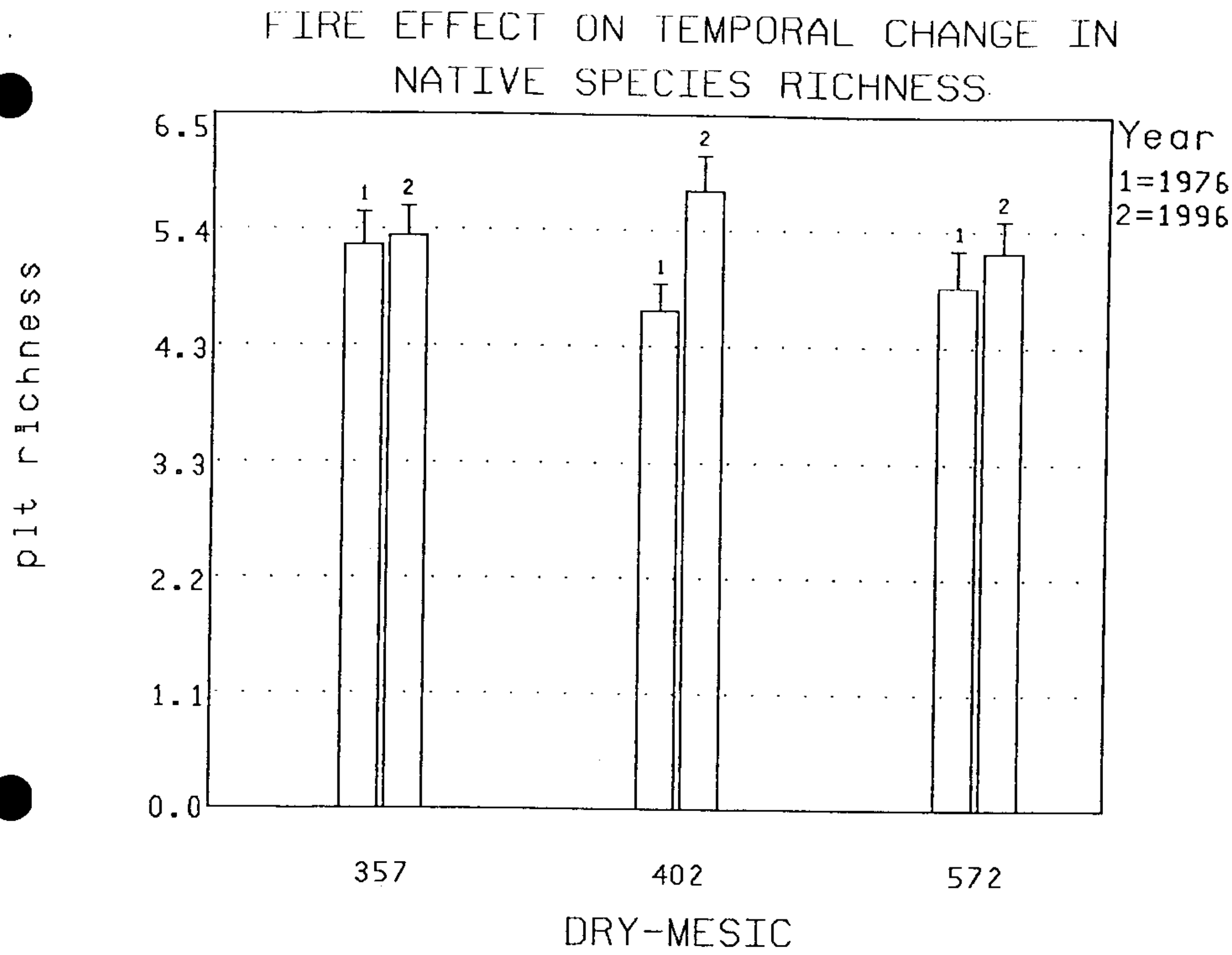

Figure 1. Effects of management on mean plot richness of native species in dry-mesic sand prairies.

County & site No.	Management	Probability of significant difference
Carroll 402	Fire-managed	P = 0.0144
Henderson 357	Unmanaged	P = 0.846
Henderson 572	Unmanaged	P = 0.506

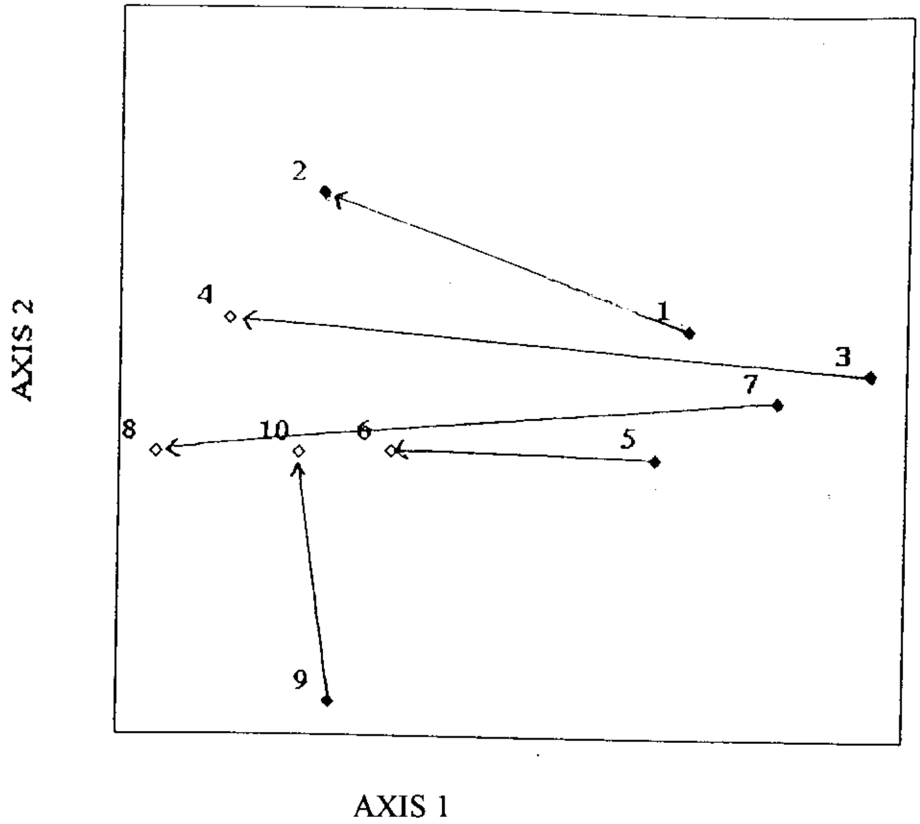

Figure 2. Temporal change in plot species richness in managed and unmanaged dry-mesic sand prairies. Axis 1 is increasing frequencies of late-successional species and decreasing frequencies of alien grasses (see Table 3). Site postions and temporal shifts are shown below

County & Site No.		1976	1996
Whiteside 1076	(unmanaged)	1	2
Carroll 415	(unmanaged)	3	4
Henry 575	(unmanaged)	7	8
Henry 574	(unmanaged)	5	6
Whiteside 880	(fire-managed)	9	10

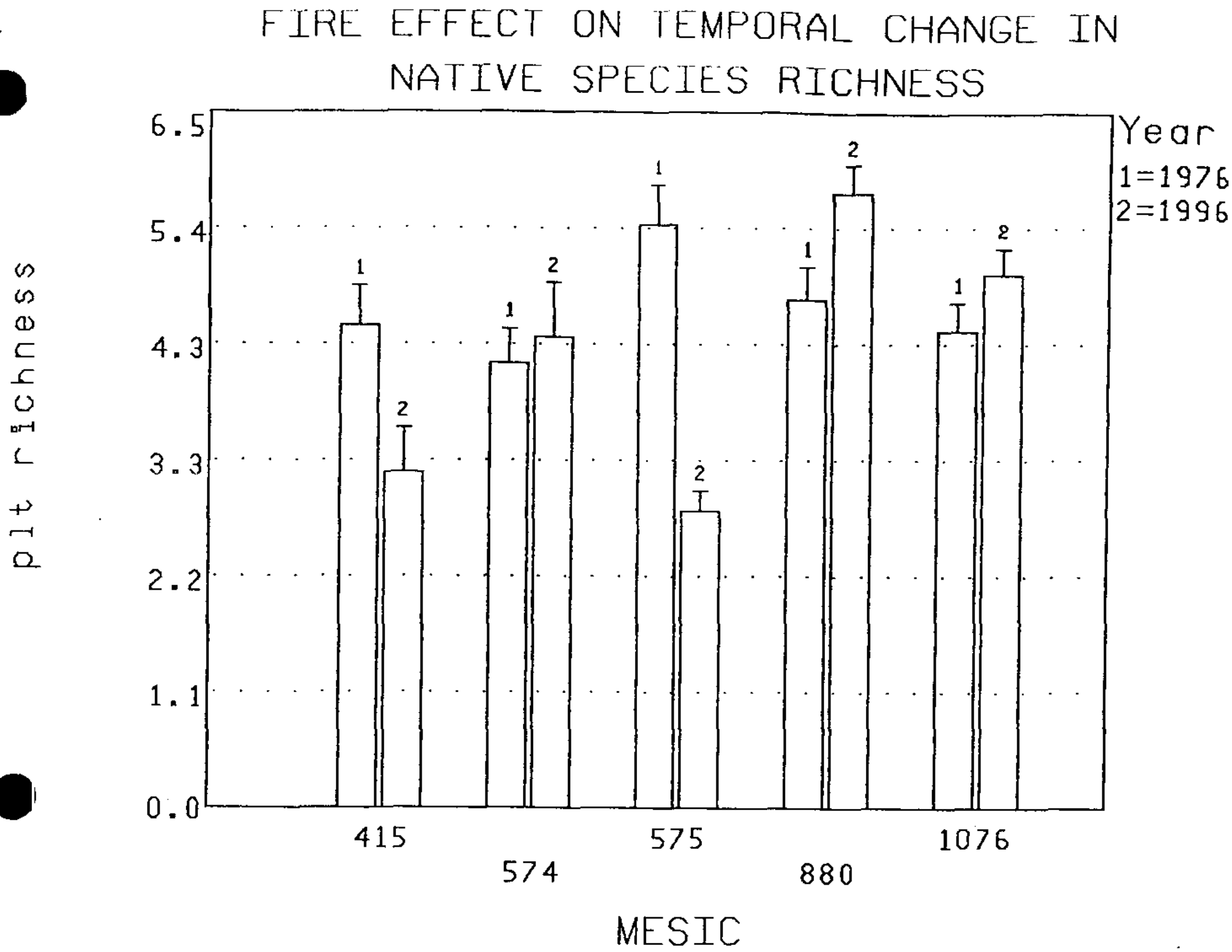

Figure 3. Effects of management on mean plot richness of native species in mesic sand prairies.

County & site No.	Management	Probability of significant difference
Whiteside 1076	Unmanaged	P = 0.333
Carroll 415	Unmanaged	P = 0.0187
Henry 575	Unmanaged	P = <.0001
Henry 574	Unmanaged	P = 0.6957
Whiteside 880	Fire-managed	P = 0.0202

Appendix I. Comparison of species frequencies in 1976 and 1996 in dry sand prairies

Henderson/357	N=30 Freq. 1976	N=55 Freq. 1996
Increasing species		
FORBS		
Ambrosia psilostachya	70%	78%
Aristida tuberculosa	0	2
Gnaphlium obtusum	0	14
Hedeoma hispida	0	2
Helianthus rigidus	0	7
Lepidium virginicum	0	7
Mollugo verticillata	0	4
Oenothera rhombipetala	3	4
Opuntia humifusa	43	64
Solidago nemoralis	0	13
Specularia perfoliata	0	5
Tephrosia virginiana	7	24
Teucrium canadense	0	2
Tradescantia ohiensis	0	42
Viola pedata	0	2
GRAMINOID		
Calamovilfa longifolia	0	2
Carex muhlenbergii	0	11
Cyperus filiculmis	0	14
Dichanthelium oligosanthes	0	4
Dichanthelium villosissimum	0	24
Eragrostis spectabilis	0	4
Koeleria macrantha	0	7
Leptoloma cognatum	0	5
Paspalum bushii	0	5
Paspalum ciliatum	0	4
Poa compressa	0	2
Triplasis purpurea	0	5

	Freq. 1976	Freq. 1996
WOODY		
Rhus glabra	0	4
Decreasing species		
FORBS		
Amorpha canescens	7	0
Commelina erecta	33	7
Erigeron canadensis	47	5
Euphorbia corollata	30	14
Helianthus occidentalis	23	13
Lithospermum carolinense	7	2
Monarda punctata	13	2
Polygala polygama	3	0
Silene antirrhina	3	0
Talinum rugospermum	7	0
GRAMINOID		
Andropogon gerardii	17	7
Andropogon scoparius	93	91
Dichanthelium sp.	43	0
Panicum capillare	3	0
Stipa spartea	7	2
No Change		
FORBS		
Lespedeza capitata	7	7
WOODY		
Rhus aromatica	20	20

Carroll/ 402

Increasing species	N=30 Frequency 1976	N=42 Frequency 1996
FORBS		
Achillea millefolium	10	24
Apocynum sibiricum	0	2
Aristida tuberculosa	17	21
Aster ericoides	0	7
Croton glandulosus	0	5
Erigeron canadensis	0	19
Euphorbia geyeri	0	7
Lepidium virginicum	0	9
Lespedeza capitata	0	7
Lithospermum carolinense	0	2
Mollugo verticillata	0	9
Oenothera rhombipetala	10	40
Plantago patagonica	0	7
Polygonella articulata	0	5
Polygala polygama	3	36
Specularia perfoliata	0	38
Tephrosia virginiana	3	7
Tradescantia ohiensis	0	7
Viola pedata	0	7
GRAMINOID		
Bromus inermis	0	2
Carex muhlenbergii	0	19
Carex tonsa	0	24
Dichanthelium depauperatum	0	5
Dichanthelium villosissimum	0	48
Koeleria macrantha	20	45
Panicum virgatum	10	14
Paspalum bushii	0	9

	Freq. 1976	Freq. 1996
WOODY		
Rhus aromatica	0	2

Decreasing species

	Freq. 1976	Freq. 1996
FORBS		
Ambrosia psilostachya	67	29
Amorpha canescens	3	0
Asclepias verticillata	20	17
Callirhoe triangulata	33	12
Coreopsis palmata	3	2
Helianthus occidentalis	7	2
Heterotheca camporum	13	2
Hieracium longipilum	3	0
Hudsonia tomentosa	7	0
Liatris aspera	17	9
Monarda punctata	3	2
Physalis virginiana	3	0
Selaginella rupestris	23	9
Solidago nemoralis	7	2
Talinum rugospermum	3	0
GRAMINOID		
Andropogon scoparius	70	64
Bouteloua hirsuta	10	2
Cyperus filiculmis	20	7
Cyperus schweinitzii	37	5
Dichanthelium oligosanthes	30	7
Panicum capillare	3	0
Paspalum ciliatifolium	3	2
Poa pratensis	23	17
Stipa spartea	3	2

Henderson/572

Increasing species	N=20 Freq. 1976	N=40 Freq. 1996
FORBS		
Chenopodium sp.	0	17
Lepidium virginicum	0	7
Monarda punctata	20	29
Oenothera rhombipetala	0	5
Opuntia humifusa	5	10
Physalis sp.	0	7
Polygala polygama	0	2
Solidago nemoralis	0	2
Specularia perfoliata	0	7
Tradescantia ohiensis	0	27
Tragopogon dubius	0	5
GRAMINOID		
Andropogon scoparius	75	78
Bouteloua hirsuta	0	5
Carex festucacea	0	2
Cyperus filiculmis	0	15
Dichanthelium villosissimum	15	29
Eragrostis spectabilis	10	24
Gnaphlium obtusifolium	0	2
Helianthus occidentalis	5	7
Koeleria macrantha	40	44
Leptoloma cognatum	0	22
Sporobolus cryptandrus	0	2
Stipa spartea	0	20
WOODY		
Rhus aromatica	10	27

Decreasing species	Freq. 1976	Freq. 1996
FORBS		
Ambrosia psilostachya	60	32
Asclepias syriaca	5	0
Commelina erecta	30	12
Echinacea pallida	5	2
Erigeron canadensis	20	0
Euphorbia corollata	30	12
Helianthus rigidus	30	17
Lespedeza capitata	15	5
Stylisma pickeringii	15	10
GRAMINOID		
Andropogon gerardii	20	10
Calamovilfa longifolia	5	0
Danthonia spicata	20	0
Dichanthelium oligosanthes	40	24
Paspalum ciliatifolium	25	7

Appendix II. Comparison of species frequencies in 1976 and 1996 in dry-mesic sand prairies

Whiteside/1076, Carroll/415, Henry/574 and Henry/575

Increasing species

FORBS

	N=80 Frequency 1976	N=197 Frequency 1996
Achillea millefolium	0%	8%
Ambrosia artemisiifolia	0	0.5
Anemone virginiana	0	0.5
Arabis glabra	0	0.5
Artemesia ludoviciana	0	1
Asclepias syriaca	1	8
Cassia fasiculata	0	4
Chenopodium sp.	0	1
Cirsium discolor	0	4
Convolvulus arvensis	0	2
Equisetum laevigatum	0	1
Hedeoma hispida	0	1
Kuhnia eupatorioides	0	2
Lactuca candensis	0	2
Lespedeza virginica	0	1
Melilotus sp.	0	3
Monarda fistulosa	0	2
Monarda punctata	0	2
Oenothera biennis	0	0.5
Oxalis stricta	0	0.5
Physalis subglabrata	0	0.5
Plantago lanceolata	0	0.5
Plantago patagonica	0	0.5
Poinsettia dentata	0	1
Polygala polygama	0	0.5
Potentilla arguta	0	0.5
Saponaria officinalis	0	6
Scutellaria parvula	0	0.5
Solanum carolinense	0	2
Solidago canadensis	0	7
Solidago gigantea	0	0.5
Solidago riddellii	0	0.5

	Freq. 1976	Freq. 1996
Tradescantia ohiensis	19	27
Tragopogon dubius	0	0.5
Verbascum thapsus	0	1
Verbena stricta	0	3
GRAMINOID		
Agropyron repens	0	12
Andropogon gerardii	5	20
Bouteloua hirsuta	0	1
Bromus inermis	0	38
Carex festucacea	0	1
Carex sp.	2	10
Cyperus filiculmis	0	0.5
Dichanthelium depauperatum	0	0.5
Dichanthelium oligosanthes	6	24
Dichanthelium villosissimum	0	2
Elymus canadensis	1	2
Eragrostis spectabilis	0	0.5
Leptoloma cognatum	0	9
Poa compressa	0	0.5
Poa pratensis	4	46
Setaria glauca	0	0.5
Sorghastrum nutans	9	15
Sporobolus asper	1	5
Sporobolus cryptandrus	0	1
Sporobolus heterolepis	14	22
WOODY		
Cornus drummondii	0	2
Prunus angustifolia	0	1
Rosa blanda	0	4
Rosa suffulta	0	6
Salix humilis	2	4

Decreasing Species	Freq. 1976	Freq. 1996
FORBS		
Amorpha canescens	11	8
Artemesia campestris	7	0
Asclepias verticillata	17	0
Aster ericoides	10	6
Aster sericeus	2	0
Aster sp.	4	0
Callirhoe triangulata	6	1
Ceanothus americanus	1	0
Comandra umbellata	4	0.5
Coreopsis palmata	17	11
Crotalaria sagittalis	1	0
Dalea purpurea	4	0
Echinacea pallida	16	1
Equisetum hyemale	19	10
Euphorbia corollata	34	31
Gentiana puberulenta	1	0.5
Helianthus occidentalis	6	2
Helianthus rigidus	12	5
Heterotheca camporum	12	1
Lespedeza capitata	1	0.5
Liatris aspera	2	0.5
Lithospermum canescens	4	0
Lithospermuim carolinense	9	2
Phlox pilosa	1	0
Potentilla argentea	1	0
Silene stellata	2	0.5
Solidago juncea	1	0
Solidago nemoralis	7	1
Tephrosia virginiana	1	0
GRAMINOID		
Andropogon scoparius	60	26
Danthonia spicata	25	0
Koeleria macrantha	5	4
Panicum virgatum	1	0.5
Stipa spartea	64	28
WOODY		
Rosa carolina	16	0

No Change	Freq. 1976	Freq. 1996
FORBS		
Aster pilosus	1	1
Oenothera rhombipetala	1	1
Opuntia humifusa	1	1

Whiteside/880

Increasing species	N=20 Freq. 1976	N=31 Freq. 1996
FORBS		
Ambrosia psilostachya	0	16
Amorpha canescens	15	26
Cirsium discolor	0	6
Erigeron canadensis	0	6
Equisetum hyemale	0	6
Euphorbia cyparissias	5	6
Kuhnia eupatorioides	0	26
Oxalis stricta	0	6
Phlox pilosa	15	26
Potentilla arguta	0	6
Senecio sp.	0	3
Verbena stricta	0	10
GRAMINOID		
Andropogon gerardii	5	10
Andropogon scoparius	55	71
Bromus inermis	0	3
Dichanthelium oligosanthes	0	35
Leptoloma cognatum	0	23
Sorghastrum nutans	25	32
Sporobolus heterolepis	20	55
Stipa spartea	20	39
WOODY		
Rosa suffulta	0	29
Rubus allegheniensis	0	3
Rubus occidentalis	0	3

Decreasing species	Freq. 1976	Freq. 1996
FORBS		
Achillea millefolium	20	0
Anemone cylindrica	5	0
Callirhoe triangulata	70	64
Equisetum sp.	10	0
Euphorbia corollata	75	64
Lespedeza capitata	5	0
Lithospermum caroliniense	10	0
Rumex sp.	5	0
Tradescantia ohiensis	45	0
Viola pedata	10	6
GRAMINOID		
Carex sp.	15	0
Dichanthelium villosissimum	50	0
Poa pratensis	90	55
WOODY		
Rosa carolina	15	0