VEGETATION CHANGE AFTER THIRTEEN YEARS OF FIRE MANAGEMENT OF A NORTHEASTERN ILLINOIS OAK WOODLAND

2000

Steve Apfelbaum[1], Marlin Bowles[2], Mark O'Leary[1], & Bill Stoll[1]
[1]Applied Ecological Services & [2] The Morton Arboretum, Lisle, IL

INTRODUCTION AND PROBLEM

Landscape fire processes patterned midwestern vegetation at the time of European settlement, producing mosaics of oak-dominated savannas and woodlands throughout the prairie / forest border of northeastern Illinois and southern Wisconsin (Anderson 1991, Leitner et al. 1991, Bowles et al. 1994). Because of the importance of fire in maintaining oak forests (Abrams 1992), fire-protection since European settlement is thought to have been a critical factor leading to successional changes and loss of floristic biodiversity caused by a decline in understory plants (McIntosh 1957, Curtis 1959, Wilhelm 1991, Bowles & McBride 1996, Anderson & Bowles 1999). Prescribed fire is used as a management tool to restore Midwest oak savannas and woodlands by counteracting this tendency (Apfelbaum & Haney 1991). However, very little information is available on the long-term effects of fire, especially on how repeated burning will effect ground-layer composition. As a consequence, prescribed fire management is subject to continuous debate (*e. g.* Mendelson 1998).

Prescribed burning increased richness of prairie species in a Minnesota sand savanna (White 1983, Tester 1989), and ground-layer species richness in a southern Wisconsin oak forest (Kline & McClintock 1994). Schwartz and Heim (1996) found that a single March fire in a degraded oak forest reduced woody stems, but did not affect herbaceous species. However, a May fire in the same woods reduced herb density over three years. Luken & Shea (2000) found five years of repeated burning of an upland maple-ash forest caused a reduction of small woody stems, but little change in ground-layer richness.

Results such as these have not clarified assumptions that prescribed fire can restore or increase species richness and diversity in midwestern forests or woodlands, nor has it illustrated causal factors. Further, a lack of solid baseline data on species composition and the structure of the original oak woodlands makes it difficult to set quantitative restoration or management goals. To help address these issues, we established permanent sampling transects in 1986 in pre-designated "burn" and "unburn" (control) management units of oak woodland at Reed-Turner Woodland Nature Preserve, Lake County, Illinois. We sought to determine whether richness, composition, and structure of ground-layer vegetation were enhanced by repeated, long-term, prescribed burning in comparison to areas that were not been burned since burning was implemented in 1987.

STUDY AREA MANAGEMENT

This research was conducted at Reed-Turner Woodland Nature Preserve in Lake County, Illinois. This preserve is located in the Morainal Natural Division of Illinois, where rugged Pleistocene stratigraphy has allowed for the development of mosaics of prairie, savanna, woodland, and forest (Swink & Wilhelm 1994). Reed Turner Woodland is a remnant of the original Long Grove, a former prairie grove that developed on fire-protected morainal topography along Indian Creek in Section 24 of Ela Township (T43N, R10E). In 1848, the Public Land Survey recorded primarily bur and white oak as scattering timber and timber, with oak and hazel (*Corylus americana*) undergrowth in Long Grove (Apfelbaum et al. 1987, Simpson et al. 1999). This remnant now contains upland and streamside vegetation dominated by white oak (*Quercus alba*), bur oak (*Q. macrocarpa*), and red oak (*Q. rubra*), with a diverse ground-layer of forest and woodland species, including Penn sedge (*Carex pensylvanica*), shooting star (*Dodecatheon meadia*), Culver's root (*Veronicastrum virginicum*), and wild hyacinth (*Camassia scilloides*). This area was recognized as having potential for restoration of former oak woodland, and was partitioned into four management units. Three units were located within the woodland natural area, and were designated as the “East Woods”, the “Center Woods”, and the “West Woods”. These areas were divided into burn treatment areas and control areas. A fourth management unit was a species rich area of “Yard” vegetation that was formerly maintained as a mowed lawn.

The management units were fire-managed until 1993. At that time, no differences in plot species richness were found between treatment and control areas, and resprouting had increased shrub-layer stem densities (Apfelbaum 1993). As a result, supplemental cutting and herbicide application was used to remove shrub-layer species in sections of burn treatment and control units of the West and Center Woods. However, alien shrub-layer species were also removed from other transect areas as part of routine management. Here, we report on the long-term effects of this shrub-layer management and continued burning on ground-layer vegetation. We expected fire and cutting to significantly reduce shrub-layer densities and to select for greater diversity of fire-adapted herbaceous species.

METHODS

Data collection and management

In 1986, permanent transects were established at Reed-Turner Woodland to allow monitoring of vegetation change in response to fire-management and controls. Four transects were located in the East and Center Woods units, and two transects each in the West Woods and Yard units (Figure 1). Tree species stems that were > 1 m high and > 2.5 cm dbh were sampled by 5-cm size classes in 2-meter wide line intercepts along these transects, shrub stems >1 meter high and < 2.5 cm dbh were sampled in 1-meter wide line intercepts, and cover of ground layer species was recorded from 1-meter square plots at 10-meter intervals along transects. Over 1000 meters of transect length were sampled (Table 1). About 40% of the transect lengths were fire-managed, with complete shrub-layer clearing on about 15% of these burned transects, and about 23% of the unburned transects.

Vegetation data analysis

Plot density of shrub-layer species was calculated based on numbers of stems in each 1-meter wide by 50-meter long transect section, resulting in estimates of mean density/50m^2. Ground-layer species were analyzed for percent plot frequencies within treatment areas, and for mean native and alien plot species richness within treatment areas. Relative frequencies were calculated for alien, forb, graminoid, and woody species functional groups within treatment areas. A two-factoral Analysis of Variance (ANOVA) was used to test for differences in mean plot richness of native and alien species between burn and unburn treatments of the East, Center, and West Woods units in 1999. Temporal change in species richness between 1986 and 1999, and interactions with burn/nonburn treatments, was then tested with a two-factorial ANOVA for the east and center woods and yard transects. This constitutes a before/after control-impact (BACI) analysis, where a significant interaction indicates a significant temporal effect of fire or fire protection (Green 1979). However, other factors might also have temporal effects (Stewart-Oaten et al 1986, Underwood 1994). A two-factor ANOVA was also used to test for interactions between shrub-layer clearing and fire treatments in forested tracts in 1999

RESULTS

Shrub-layer changes

In 1986, the shrub-layer had between 17-18,000 stems/ha in the pre-burn and unburn treatment areas of the forested management units, with greater proportions of shrubs and vines, tree saplings, and alien species functional groups, and fewer stems of small tree species (Table 2). The shrub *Cornus racemosa* was the dominant species, with *Prunus virginiana* an important secondary shrub. *Prunus serotina, Fraxinus americana*, and *Tilia americana* were the most abundant saplings, and *Rhamnus* *cathartica* and *R. frangula* the most abundant aliens. *Ostrya virginiana* was the most important small tree. In 1999, stem densities in burned portions of the shrub-layer transects had been reduced by about 98%, with about 94% reduction in unburned areas (Table 2).

Changing temporal patterns of ground-layer species

In 1999, forbs were the dominant species group in the Center and East Woods plots, and their relative frequency increased over time (Figure 2). Dominant woodland species in 1986 and 1999 were *Erythronhium albidum, Circaea lutetiana, Smilacina racemosa*, and *Arisaema triphyllum,* while *Viola sororia* and *Aster sagittfolius* were additional dominant species in the Yard plots. All species frequencies by treatment are provided in Appendix 1. Few forb species appear to have had large increases or decreases in frequency, although *Smilacina racemosa* decreased across all treatments. *Geum canadense* and *Hackelia virginiana* had the most substantial increases in the East or Center Woods, while *Solidago ulmifolia* and *Amphicarpa bracteata* appeared with high frequencies in the Yard transects. Woody species were the second most important species group, but shifted toward lower relative abundance in 1999, especially in wooded transects (Figure 2). However, *Prunus serotinna*, *Rubus occidentalis*, and *Fraxinus* species had slight increases, probably due to resprouting from shrub-layer stems after fire. Graminoid species were the least abundant species group, but increased in relative abundance in the Center Woods. This was due primarily to a substantial increase in *Carex pensylvanica*. Alien species declined in the Yard transects but increased in the wooded tracts. This was due to the region wide invasion of *Alliaria petiolata* that intensified after initial sampling in 1986. This alien species had equal abundance in the burned and unburned Center Woods transects, but was more abundant in the burned East Woods transect.

Changes in plot richness in relation to time and management treatments

In 1999, native plot species richness was significantly higher in burned than in unburned transects in the Center and West Woods, but not the East Woods, exceeding a mean of 9 species/plot in the burned Center and West Woods (Figure 3). Similarly, alien richness was significantly higher in the Center and West Woods burned transects, but not the East Woods (Figure 3). This pattern was also apparent over time, as mean native richness increased in the burned and unburned East and Center Woods transects and in the Yard transects, exceeding 12 species/plot in the burned and unburned Yard vegetation (Figure 4). These increases appear to be fire-stimulated in the Yard areas, as increases occurred only in burn transects, yielding significant interactions between time and management treatments. However, native richness increased significantly in the East Woods and Center Woods and in both burned and in unburned transects. Alien richness showed a somewhat similar pattern by increasing in burned and unburned transects of the East and Center Woods, but it decreased in the Yard transects.

Shrub-layer clearing appears to have had no significant impact on changes in native or alien richness in wooded transects (Figure 5). In both cases, there was no significant interaction between fire and shrub-layer treatments, with greater richness in response only to fire.

DISCUSSION

Compositional changes and increasing species richness

Our results suggest that long-term (13 years) fire-management can change ground-layer composition and structure and can result in increased goundlayer species richness in oak woodland. This increase did not reflect dramatic increases in most species, but rather small increases in many species. However, these cumulative changes lead to important shifts in ground-layer structure, with increased graminoid and forb abundance, and decreased woody abundance. Our results support conceptual and empirical work on savanna, where repeated long-term burning reduces woody vegetation and increases graminoid fuel species and overall species richness (White 1983, Tester 1989). This process may be slow, as no changes were found after 6 years at Reed Turner (Apfelbaum 1993), nor after single fires (Schwartz & Heim 1996) or after 5 years of repeated fire (Luken & Shea 2000).

Despite the increases in species richness at Reed Turner, setting of limits or expectations for management goals for restored oak woodland remains difficult. The highest mean native plot richness at Reed Turner was over 12 species/plot in the burned and unburned Yard vegetation. But it is unknown if this represents a realistic natural community. In comparison, maximum plot species richness measured in old-growth forest stands exceeded 10 species/plot in Raccoon Grove, a red oak stand in Will Co., and was over 9 species/plot in at the Elburn Forest Preserve, a white oak stand in Kane Co. (Bowles et al. 2000). Higher values may be obtained in savanna. For example, plot species richness measured in ½ meter square plots exceeded 12 species/plot in canopy openings in savanna at Wolf Road Prairie, in Cook Co. (Bowles & McBride 1998).

Causal factors

Causes of increased species richness with fire in forest systems are thought to be related to increased light made available to the forest floor by reduction of woody canopy species, removal of leaf litter, and increased nutrient levels. For example, increased canopy light levels are positively correlated with increased species richness and species change across the light gradient in savanna (Bowles & McBride 1996), and in forest systems (Bowles et al. 2000). Although our data does not yet suggest that removal of shrub-layer cover contributes to compositional changes, it should be recalled that this treatment was implemented half way through the study and, as such, significant correlations may emerge with time and the collection of additional data. Repeated removal of ground-layer leaf litter and release of nutrients may be an important factor in situations where dramatic increases in canopy light levels does not occur, and may be an important factor at Reed Turner Woodland.

Management tradeoffs

Monotonic management treatments such as repeated burning can be expected to have important effects on vegetation, but will also have tradeoffs for desired results (Luken & Shea 2000). In the case of forest and woodland, an important result is the almost complete removal of shrub-layer vegetation. Despite the increase in ground-layer richness, loss of shrub-layer vegetation represents a reduction of structural diversity that may have negative effects on other species groups, such as forest interior birds (Whelan & Dilger1992.), that use this layer of forest vegetation. More work is needed to determine which species groups decline with this treatment, and if other groups, such as different bird assemblages, replace forest interior birds. Shrub-layers also may have been important components of natural woodlands and savannas, with dominance by *Corylus americana* (Bowles et al. 1994, Anderson & Bowles 1999).

Another tradeoff of repeated fire appears to be persistence of fire-adapted or fire-resistant alien species. For example, the invasive biennial weed *Alliaria petiolata* now persists at Reed Turner even though it is routinely removed by pulling. Assumptions have been that late spring fire will control this species by destroying overwintering rosettes (e.g. Nuzzo 1991, Schwartz & Heim 1996). However this species persists with repeated fire (Luken & Shea 2000) and is more abundant in fire-managed Chicago region forests (Bowles et al. 2000). Garlic mustard is disturbance-adapted and has a density-dependent survivorship (Anderson et al. 1996). It colonizes after removal of leaf litter, and then persists because large populations can develop from only a few overwintering rosettes. A secondary tradeoff in using late spring fires to more effectively control this species is decline of native herblayer vegetation (Schwartz & Heim 1996).

SUMMARY AND RECOMMENDATIONS

Long term monitoring of fire-managed oak woodland vegetation at Reed Turner Woodland revealed compositional changes in ground-layer vegetation were accompanied by an increase in plot richness of native ground-layer species. This increase was not detectable after 6 years, after which removal of shrub-layer vegetation was initiated in treatment plots. Although an effect of shrub-layer removal could not be detected statistically, it may have contributed to the increase in plot richness, especially if supplemented by wide scale removal of alien shrubs. Several tradeoffs occurred with this management. Removal of shrub-layer species caused the loss of a potentially important structural component of woodland diversity, and repeated burning has probably enhanced the persistence of the alien garlic mustard.

These results suggest that fire-management to restore richness of oak woodland ground-layer vegetation may require long term efforts. Supplementary removal of shrub-layer species may enhance this process, but should focus on alien species and tree saplings that have the capability of directly altering canopy structure. However, realistic goals for species composition and structure are not yet clear.

REFERENCES

Abrams, M.D. 1992. Fire and the development of oak forests. BioScience 42:346-353.

Anderson, R.C. 1991. Presettlement forests of Illinois. Pages 9-19 in G.V. Burger, E.E. Ebinger, G.S. Wilhelm, editors. Proceedings of the Oak Woods Management Workshop. Eastern Illinois University, Charleston.

Anderson, R.C., S.S. Dhillon, & Timothy M. Kelley. 1996. Aspects of the ecology of an invasive plant, garlic mustard (*Alliaria petiolata*), in central Illinois. Restoration Ecology 4:181-191.

Apfelbaum, S.I., M.L. Bowles, G.W. Wilhelm, & S. Packard. 1987. Baseline analysis of vascular vegetation and preliminary management recommendations for historic oak savanna remnants of northern Illinois. Applied Ecological Services.

Apfelbaum, S.I. & A.W. Haney. 1991. Management of degraded oak savanna remnants in the upper Midwest: preliminary results from three years of study. Pages 81-90 in: Proceedings of the Oak Woods Management Workshop. G.V. Burger, J.E. Ebinger, & G.S. Wilhelm, eds. Eastern Illinois University, Charleston.

Apfelbaum, S.I. 1993. Assessment of vegetation response to understory thinning at Reed-Turner Woodland Nature Preserve, Lake County, Long Grove Illinois. Applied Ecological Services.

Bowles, M.L. & J.L. McBride. 1998. Vegetation composition, structure, and chronological change in a decadent midwestern North American savanna remnant. Natural Areas Journal *in press*.

Bowles, M.L., M.D. Hutchison, & J.L. McBride. 1994. Landscape pattern and structure of oak savanna, woodland, and barrens in northeastern Illinois at the time of European settlement. Pages 65-73 *in*, J.S. Fralish, R.C. Anderson, J.E. Ebinger, & R. Szafoni, *editors*, Proceedings of the North American Conference on Savannas and Barrens.Environmental Protection Agency, Great Lakes National Program Office, Chicago.

Bowles, M.L., C. Dunn, M. Jones, T. Bell, & J. McBride. 2000. Baseline structure, composition, and species richness indices for dry-mesic and mesic forests of the Illinois Chicago region. Erigenia 18 (*in press*).

Curtis, J.T. 1959. Vegetation of Wisconsin. University of Wisconsin Press, Madison.

Green, R.H. 1979. Sampling designs and statistical methods for environmental biologists. Wiley Interscience. Chichester, England.

Kline, V.M. and T. McClintock. 1994. Effect of burning on a dry oak forest infested with woody exotics. Pages 207-213 in R.G. Wickett, P.D. Lewis, A. Woodliffe, & P. Pratt, editors.
Proceedings of the Thirteenth North American Prairie Conference. Windsor, Ontario.

Leitner, L.A., C.P. Dunn, G.R. Guntenspergen, F. Stearns, & D.M. Sharpe. 1991. Effects of site, landscape features, and fire regime on vegetation patterns in presettlement southern Wisconsin. Landscape Ecology 5:203-217.

Luken, J.O., & M. Shea. 2000 . Repeated prescribed burning at Dinsmore Woods State Nature Preserve

(Kentucky, USA): responses of the understory community. Natural Areas Journal 20:150-158.

McIntosh, R.P. 1957. The York Woods: a case history of forest succession in southern Wisconsin. Ecology 38:29-37.

Mendelson, J. 1998. Restoration from the perspective of recent forest history. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters. 86:137-147.

Nuzzo, V.A. 1991. Experimental control of garlinc mustard [*Alliearia petiolota* 9Bieb.) Cavara & Grande] in northern Illinosi using fire, herbicide, and cutting. Natural Areas Journal 11:158-167.

Schwartz, M.W. & J.R. Heim. 1996. Effects of a prescribed burn on degraded forest vegetation. Jatural Areas Journal 16:184-191.

Simpson, T. et al. 1999. Ecological restoration management at Reed-Turner Woodland, Village of Long Grove, Lake County, Illinois. Northeastern Illinois University, Chicago.

Stewart-Oaten, A., W.M. Murdoch, & K.R. Parker. 1986. Environmental impact assessment: “pseudoreplication” in time? Ecology 67:929-940.

Swink, F. & G. Wilhelm. 1994. Plants of the Chicago Region. The Morton Arboretum, Lisle, Ill.

Tester, J.R. 1989. Effects of fire frequency on oak savanna in east-central Minnesota. Bulletin of the Torrey Botanical Club 116:134-144.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4:3-15.

White, A.S. 1983. The effects of thirteen years of annual prescribed burning on a *Quercus ellipsoidalis* community in Minnesota. Ecology 64:1081-1085.

Whelan, C.J. & M.L. Dilger. 1992. Invasive, exotic shrubs: a paradox for natural area managers? Natural Areas Journal 12:109-110.

Wilhelm, G. 1991. Implications of changes in floristic composition of the Morton Arboretum's East Woods. Pages 31-54 in: Proceedings of the Oak Woods Management Workshop. G.V. Burger, J.E. Ebinger, & G.S. Wilhelm, eds. Eastern Illinois University, Charleston.

Table 1. Experimental design for shrub-layer and ground layer sampling. Values are % proportions of transects re-sampled in different management units in 1999. Burn treatments were initiated in 1987 and shrub-layer clearing treatments in 1993. Total transect length in meters is given in parentheses. Sampling plots were established at 10-meter intervals.

Area	Transect	Burned %Cleared	Burned %Uncleared	Unburned %Cleared	Unburned %Uncleared
Yard	E. 1 & 2 (80m)				100
	W. 1 & 2 (80m)		100		
East Woods	1 (60m)				100
	2 (50m)				100
	3 (50m)		100		
	4 (50m)		100		
Center Woods	1 (150m)	20	20		60
	2 (120m)		33.3		66.7
	3 (130m)	7.7	15.4	15.4	61.5
	4 (90m)		22.2	33.3	44.4
West Woods	1 (90)m)	22.2		77.8	
	2 (120m)		50	25	25
Total	1070m	14.6	85.4	22.7	77.3

Table 2. Temporal change in shrub layer species densities (mean + s.e. density/50 meter square transect) in burned and unburned transect areas. Asterisk (*) indicates alien species.

		1986	**Burn**	**1986**	**Unburn**	**1999**	**Burn**	**1989**	**Unburn**
Habit	**Name**	**Mean**	**+s.e.**	**Mean**	**+s.e.**	**Mean**	**+s.e.**	**Mean**	**+s.e.**
Shrub	*Cornus racemosa*	21.30	13.06	20.10	13.63				
Shrub	*Viburnum acerifolium*	1.10	0.54	2.90	2.34				
Shrub	*Ribes sp.*	2.00	0.63	1.90	1.55				
Shrub	*Viburnum prunifolium*	0.71	0.70						
Shrub	*Viburnum dentata*	0.14	1.68	0.43	0.52				
Shrub	*Ribes missouriensis*							0.20	0.20
Vine	*Rhus radicans*			0.79	0.60				
Vine	*Vitis riparia*	0.64	0.35						
Small tree	*Prunus virginiana*	9.60	2.28	5.50	1.74			0.06	0.06
Small tree	*Ostrya virginiana*	2.10	1.49	4.60	2.06	0.10	0.10	0.92	0.37
Small tree	*Crataegus sp*	1.70	1.04	1.80	0.76			0.79	0.64
Small tree	*Carpinus caroliniana*	0.79	0.63	0.29	0.35				
Small tree	*Malus sp.*			0.71	0.66				
Small tree	*Crateagus mollis*			0.19	0.60				
Tree	*Prunus serotina*	6.70	3.45	10.90	6.93			1.32	0.52
Tree	*Fraxinus americana*	9.10	3.60	3.60	1.71				
Tree	*Tilia americana*	6.60	3.86	3.60	1.33	0.10	0.10	0.40	0.22
Tree	*Ulmus americana*	1.70	1.20	5.40	1.36	0.70	0.52	0.54	0.30
Tree	*Quercus rubra*			5.50	2.28				
Tree	*Carya ovata*	2.10	0.66	2.10	0.82			0.08	0.08
Tree	*Fraxinus americana*			3.60	1.71			0.06	0.06
Tree	*Ulmus rubra*			1.90	0.32			0.10	0.10
Tree	*Acer saccharum*	1.00	0.47	0.83	0.63	0.10	0.10	0.15	0.15
Tree	*Juglans nigra*	0.29	0.35						
Tree	*Quercus coccinea*			0.14	0.17				
Tree	*Quercus velutina*			0.14	0.17				
Tree	*Carya cordiformis*					0.25	0.25	0.19	0.13
Tree	*Fraxinus pennsylvanicus*							0.13	0.13
*Shrub	*Philadelphica coronarium*			0.43	0.51				
*Shrub	*Lonicera tatarica*	1.00	0.63	0.29	0.23				
*Shrub	*Ligustrum sp.*	0.70	0.85						
*Shrub	*Berberis thunbergii*			0.14	0.17				
*Shrub	*Euonymus alatus*							0.50	0.50
*Shrub	*Virburnum opululus*							0.25	0.25
*Vine	*Celastrus orbiculatus*	1.94	3.23	0.14	0.17				
*Small Tree	*Rhamnus cathartica*	12.00	8.06	7.80	5.85				
*Small Tree	*Rhamnus frangula*	7.70	5.19	1.20	0.79				
*Small Tree	*Rhamnus sp.*			0.14	0.17				
*Tree	*Gleditsia triacanthus*	1.40	1.61						

	1986	**1986**	**1999**	**1999**
	Burn	**Unburn**	**Burn**	**Unburn**
Total native stems/50m2	67.57	76.92	1.25	4.93
Total alien stems/50m2	24.74	10.14	0.00	0.75
Native stems/ha	13514.00	15384.00	250.00	986.10
Alien stems/ha	4948.00	2028.00	0.00	150.00

Figure 1. Transect and treatment locations at Reed-Turner Woodland Nature Preserve.

Figure 2. Temporal change in vegetation structure between 1986 and 1999 in burned (B) and unburned (UB) Yard, Center Woods, and East Woods transects. Values are relative frequencies summed for alien, graminoid, forb, and woody vegetation sampled from 1-meter square transects. See Appendix I for species frequencies.

Figure 3. Native (upper graph) and alien (lower graph) plot species richness in relation to fire treatment and location in the Center, East, or West management units.

ANOVA report:

Native Richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Location	0.63	0.5357	0.1484
Treatment	17.00	0.00009	0.9786
Location x Treatment	2.22	0.11488	0.4286

Alien richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Location	1.91	0.1540	0.3756
Treatment	3.69	0.05794	0.4595
Location x Treatment	0.67	0.51353	0.1557

Figure 4. Native and alien plot species richness in relation to year and fire treatment in the East Woods, Center Woods, and Yard Management units.

ANOVA report:

East Woods Native Richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Year	16.09	0.00024	0.9696
Treatment	0.35	0557869	0.8731
Year x Treatment	0.70	0.40697	0.12617

East Woods Alien richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Year	21.68	0.00003	0.9936
Treatment	0.12	0.73434	0.06232
Year x Treatment	0.78	0.38328	0.13449

CenterWoods Native Richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Year	30.07	<.00000	0.9997
Treatment	6.63	0.01139	0.7162
Year x Treatment	10.96	0.00125	0.9022

CenterWoods Alien richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)

Year	7.56	0.00693	0.77143
Treatment	1.44	0.23256	0.2185
Year x Treatment	1.55	0.21509	0.23206

Yard Native Richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Year	1.97	0.1714	0.2592
Treatment	9.66	0.00429	0.8275
Year x Treatment	4.43	0.04447	0.5033

Yard Alien richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Year	11.37	0.00219	0.88316
Treatment	2.35	0.13659	0.29954
Year x Treatment	0.38	0.54479	0.08446

Figure 5. Native (upper graph) and alien (lower graph) plot species richness in relation to fire and shrublayer clearing treatments, combined for the Center, East, and West management units.

ANOVA report:

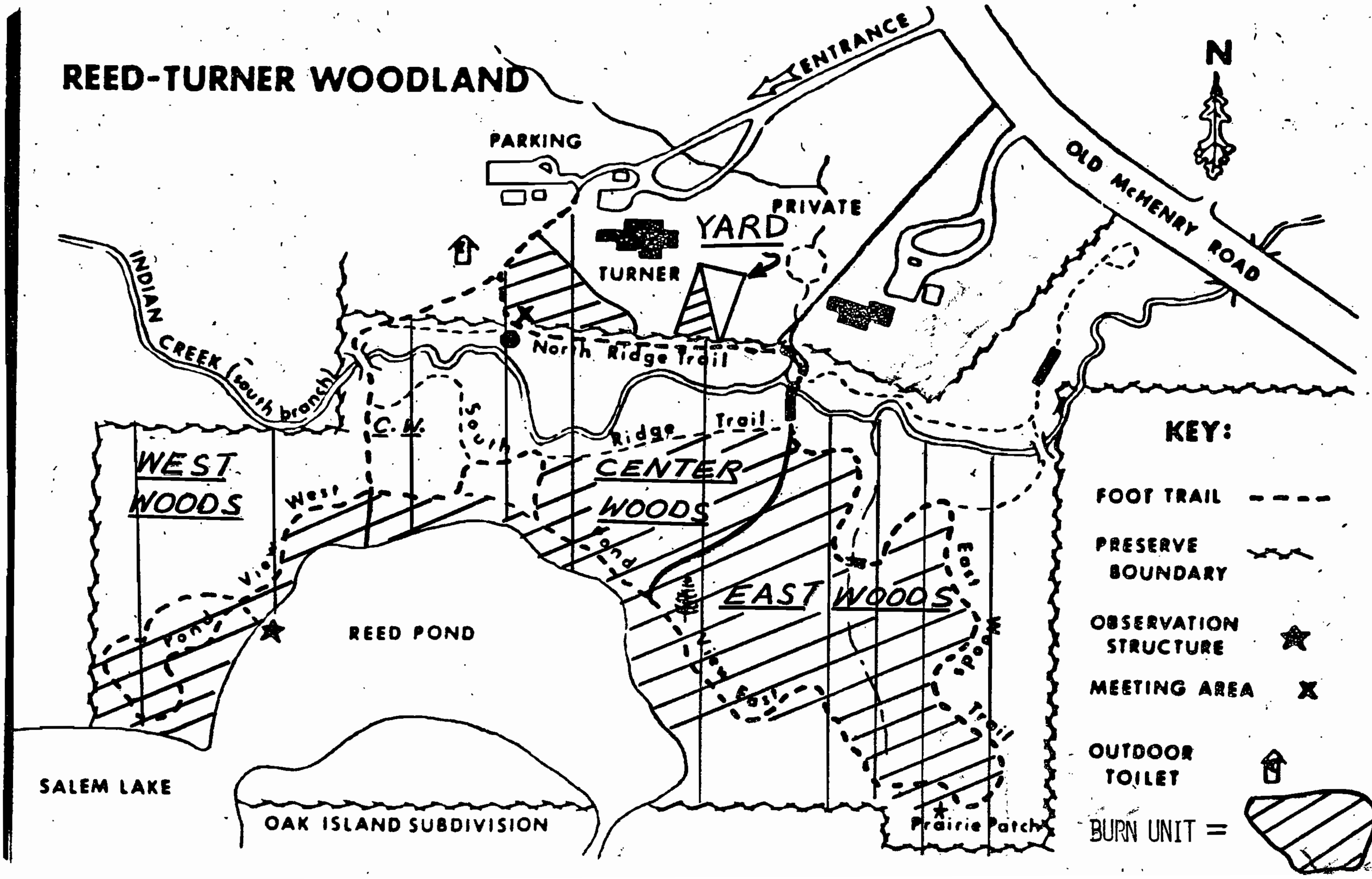
Native Richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Fire	18.3	0.00005	0.98692
Clearing	1.77	0.18729	0.25517
Fire x Clearing	0.55	0.45950	0.11234

Alien richness

Source	F-Ratio	Probability	Power (Alpha = 0.05)
Fire	4.98	0.02816	0.58837
Clearing	0.36	0.55090	0.09012
Fire x Clearing	0.27	0.60621	0.0798

Figure 3. LOCATION OF STUDY AREAS AND BURN TREATMENT UNITS AT REED-TURNER NATURE PRESERVE, LAKE CO., IL



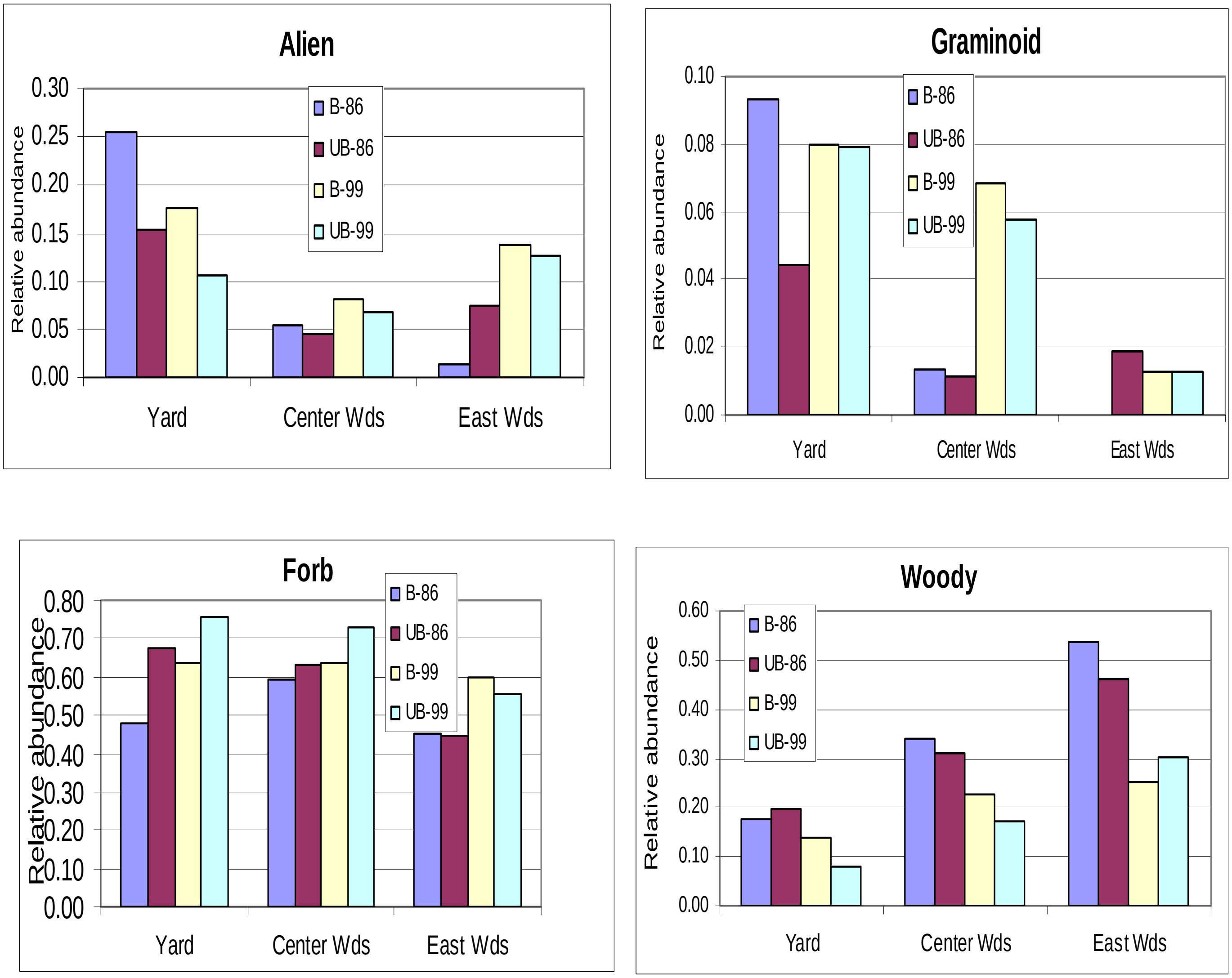
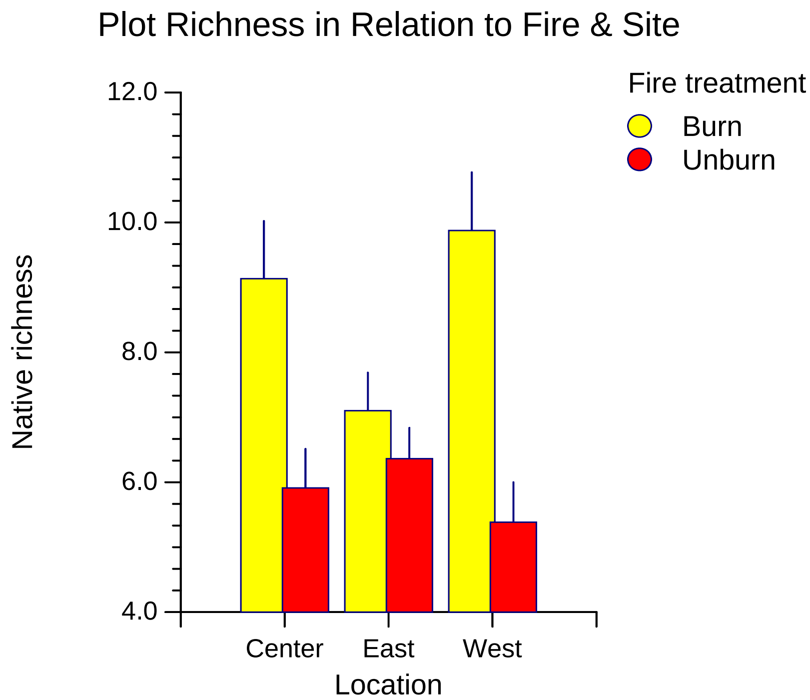


Figure 2. Temporal change in vegetation structure between 1986 and 1999 in burned (B) and unburned (UB) Yard, Center Woods, and East Woods transects. Values are relative frequencies of alien, graminoid, forb, and woody vegetation sampled from 1-meter square plots.



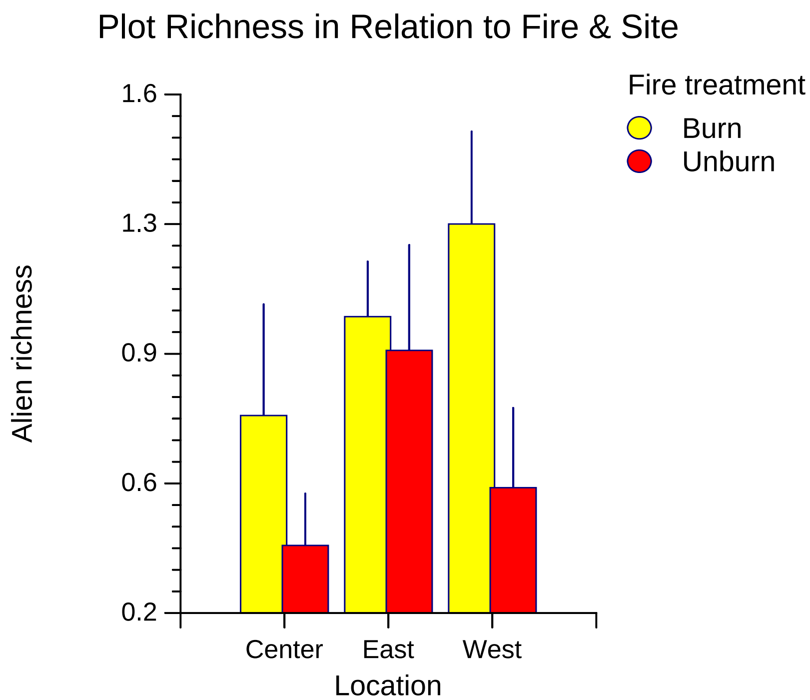
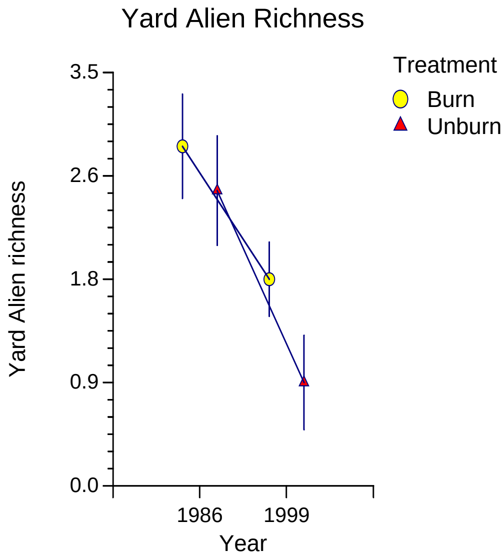
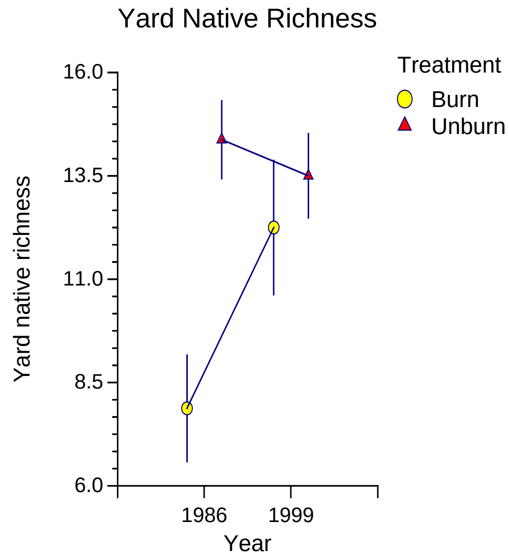
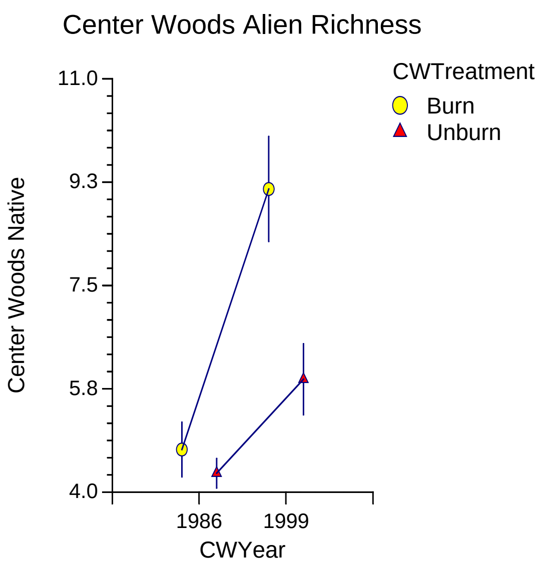


Figure 3. Plot species richness in 1999 by site and treatment.


Yard Alien Richness
Treatment
Burn
Unburn
3.5
2.6
1.8
0.9
0.0
Yard Alien richness
1986
1999
Year


Yard Native Richness
Treatment
Burn
Unburn
16.0
13.5
11.0
8.5
6.0
Yard native richness
1986
1999
Year


Center Woods Alien Richness
CWTreatment
Burn
Unburn
11.0
9.3
7.5
5.8
4.0
Center Woods Native
1986
1999
CWYear

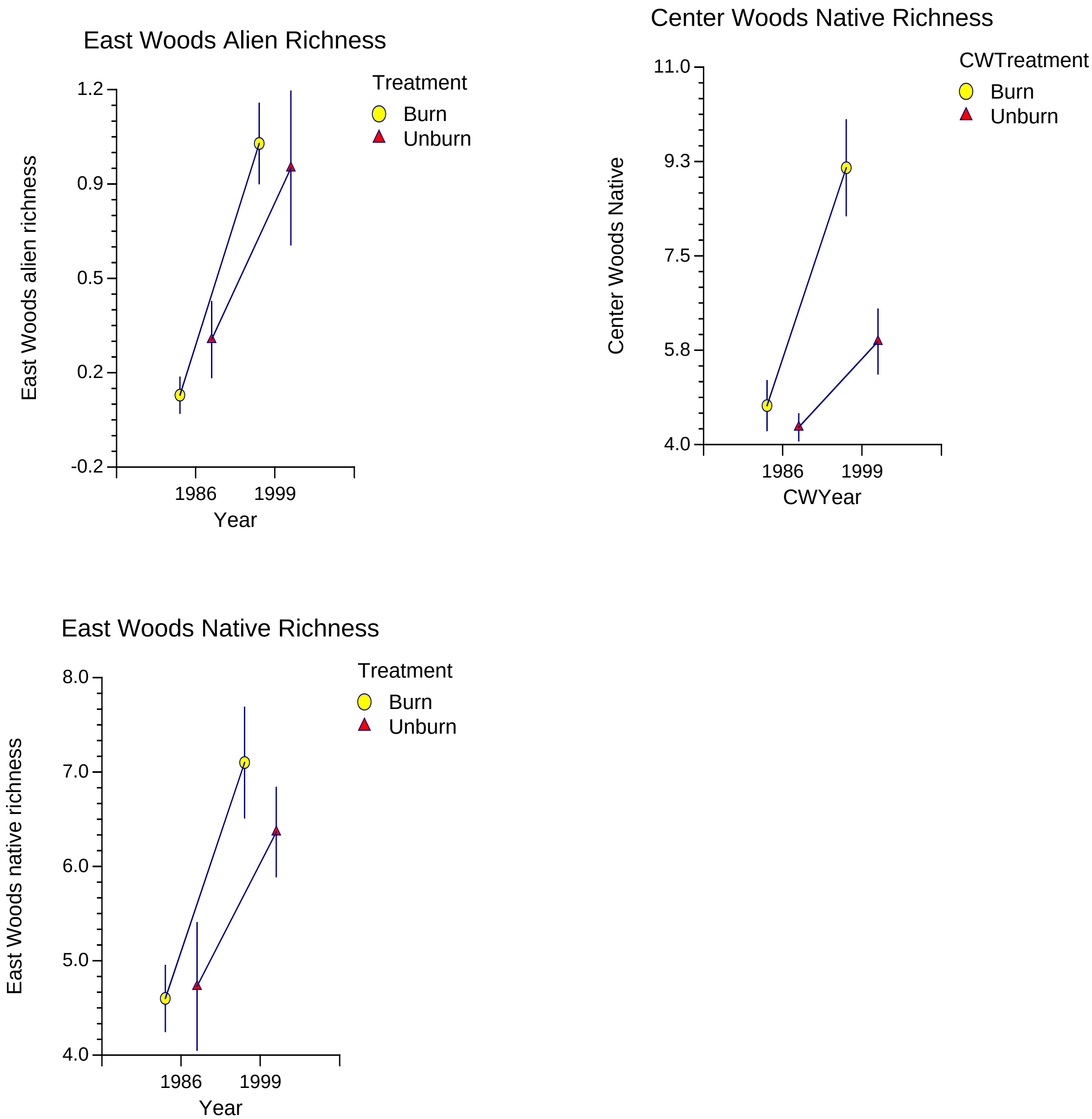


Figure 4. Temporal change in species richness by burn treatment.

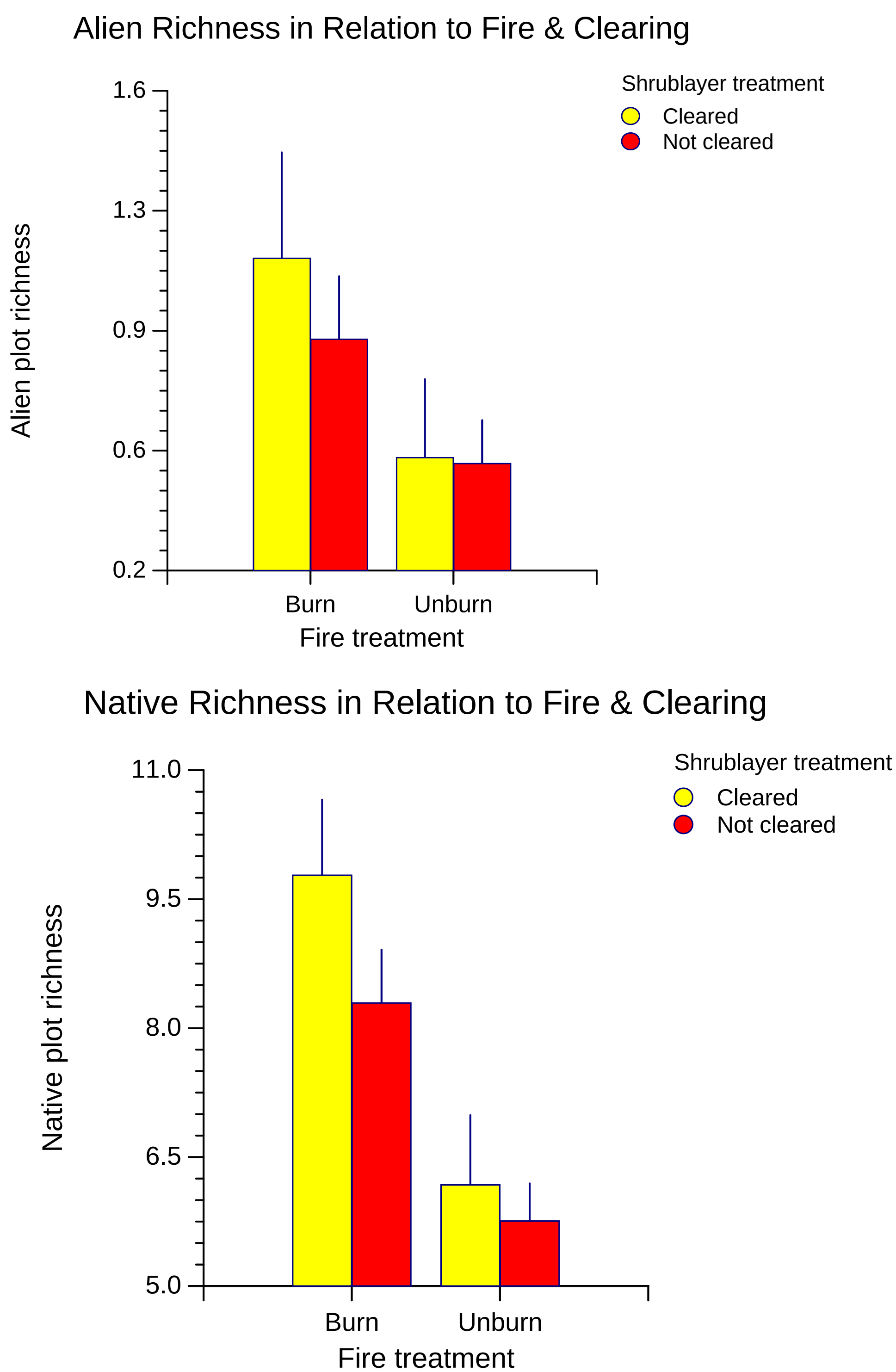


Figure 5. Species richness in response to fire and shrub-layer clearing.

Appendix I.Temporal shange in species frequencies between 1986 and 1999 in burned (B) and unburned (UB)Yard plots.

	Yard	**B-86 (n=8)**	**UB-86 (N=8)**	**B-99 (N=8)**	**UB-99 (N=8)**
A	*Taraxacum officinale*	75.00	87.50	37.50	37.50
A	*Poa pratensis*	62.50	50.00	37.50	25.00
A	*Rhamnus cathartica*	25.00	25.00	25.00	12.50
A	*Poa compressa*	12.50		50.00	12.50
A	*Dactylis glomerata*		12.50		37.50
A	*Gelchoma hederacea*	12.50	37.50		
A	*Trilium erectum*			37.50	12.50
A	*Achillea millefolium*	25.00		12.50	
A	*Rosa multiflora*	12.50	12.50	12.50	
A	*Rhamnus frangula*		12.50	12.50	
A	*Berberis thunbergii*		12.50		
A	*Cerastium vulgatum*			12.50	
A	*Dainthus armeria*	12.50			
A	*Lonicera tatarica*	12.50			
A	*Ornithogalum umbellatum*	12.50			
A	*Scilla sibirica*				12.50
A	*Trifolium repens*			12.50	
A	*Viburnum opulus*	12.50	12.50		
F	*Viola sororia*	50.00	100.00	100.00	50.00
F	*Smilacina racemosa*	12.50	100.00	37.50	75.00
F	*Aster sagittfolius*	50.00	62.50	62.50	37.50
F	*Erythronium albidum*	75.00	62.50	37.50	37.50
F	*Anemone quinquefolia*	12.50	75.00		87.50
F	*Solidago ulmifolia*			87.50	87.50
F	*Oxalis stricta*	25.00	37.50	62.50	37.50
F	*Potentilla simplex*	62.50	25.00	50.00	12.50
F	*Hieracium sp.*	50.00	50.00	25.00	12.50
F	*Dentaria laciniata*	12.50	25.00	25.00	62.50
F	*Anemonella thalictroides*		25.00	25.00	50.00
F	*Circaea lutetiana can.*		12.50	50.00	37.50
F	*Arenaria lateriflora*		50.00	12.50	25.00
F	*Geranium maculatum*		37.50		50.00
F	*Hydrophyllum virginianum*		25.00	25.00	37.50
F	*Unknown grass*	25.00	50.00		
F	*Amphicarpaea bracteata*				62.50
F	*Sanicula gregaria*		25.00	25.00	12.50
F	*Solidago sp.*	25.00	37.50		
F	*Agrimonia gryposepala*			37.50	12.50
F	*Allium tricoccum*		25.00		25.00
F	*Antennaria plantaginifolia*	12.50	37.50		
F	*Aster sp.*			37.50	12.50
F	*Fragaria virginiana*	25.00		25.00	
F	*Ranunculus arbortivus*	25.00	25.00		

F	*Claytonia virginica*		25.00		12.50
F	*Prunella vulgaris*			37.50	
F	*Viola pubescens*				37.50
F	*Allium canadense*		12.50	12.50	
F	*Anemone virginica*		25.00		
F	*Antennaria neglecta*	12.50			12.50
F	*Erigeron annuus*			12.50	12.50
F	*Eupatorium purpureum*			12.50	12.50
F	*Eupatorium sp.*	12.50	12.50		
F	*Galium sp.*		12.50		12.50
F	*Geum candensis*		25.00		
F	*Hepatica acuitloba*		12.50		12.50
F	*Phlox divaricata*			12.50	12.50
F	*Prenanthes alba*		12.50		12.50
F	*Smilax ecirrhata*	12.50	12.50		
F	*Solidago flexicaulis*			12.50	12.50
F	*Unknown #1*		25.00		
F	*Unknown #2*		25.00		
F	*Viola sp.*				25.00
F	*Dryopteris sp.*				12.50
F	*Erigeron philadelphicus*			12.50	
F	*Erigeron strigosus*	12.50			
F	*Krigia biflora*		12.50		
F	*Lathyrus ochroleucus*				12.50
F	*Lespedeza violacea*			12.50	
F	*Maianthemum canadense int.*				12.50
F	*Phlox glaberrima*		12.50		
F	*Ranunculus fascularis*		12.50		
F	*Smilacina stellata*			12.50	
F	*Smilax lasioneura*			12.50	
F	*Smilax sp.*			12.50	
F	*Solidago canadensis*				12.50
F	*Solidago graminifolia*			12.50	
F	*Trillium recurvatum*		12.50		
F	*Unidentified fern*				12.50
F	*Veronicastrum virginicum*				12.50
F	*Viola pensylvanica*		12.50		
F	*Unknown grass*				
G	*Carex rosea*		25.00	75.00	62.50
G	*Carex pensylvanica*	37.50	25.00	12.50	37.50
G	*Carex sp.*	25.00	25.00		
G	*Carex blanda*			25.00	
G	*Danthonia spicata*	25.00			
G	*Elymus virginicus*				12.50
G	*Festuca sp.*	12.50			
W	*Fraxinus americana*	50.00	50.00		

W	*Ostrya virginiana*	12.50	25.00		50.00
W	*Rhus radicans*		25.00	37.50	12.50
W	*Cornus racemosa*	25.00	12.50	25.00	
W	*Prunus serotina*	12.50	25.00	25.00	
W	*Quercus alba*	25.00	25.00		
W	*Quercus rubra*		12.50		25.00
W	*Rubus occidentalis*	12.50		25.00	
W	*Acer negundo*	12.50			
W	*Acer saccharum*		12.50		
W	*Carya cordiformis*			12.50	
W	*Carya ovata*		12.50		
W	*Corylus americana*			12.50	
W	*Fraxinus pennsylvanica sub.*			12.50	
W	*Juglans nigra*	12.50			
W	*Prunus virginiana*	12.50			
W	*Vibubrnum dentatum*	12.50			
W	*Vitis riparia*		12.50		
W	*Rubus occidentalis*				

Appendix I- Temporal shange in species frequencies between 1986 and 1999 in burned (B) and unburned (UB) Center Woods plots.

	Center Woods	**UB-86 (n=49)**	**B-86 (n=18)**	**B-99 (n=15)**	**UB-99 (n=34)**
A	*Alliaria petiolata*			13.33	14.29
A	*Taraxacum officinale*	4.08		6.67	14.29
A	*Rhamnus frangula*	4.08		20.00	
A	*Rhamnus cathartica*	6.12	5.56	6.67	
A	*Poa compressa*		11.11	6.67	
A	*Poa pratensis*			13.33	
A	*Cirsium vulgare*			6.67	
A	*Phalaris arundinacea*			6.67	
A	*Viburnum opulus*	6.12			
A	*Trillium erectum*				5.71
A	*Lonicera proliferum*		5.56		
A	*Rhamnus sp.*	2.04			2.86
A	*Hesperis matronalis*				2.86
A	*Celastrus orbiculatus*	2.04			
F	*Erythornium albidum*	61.22	77.78	80.00	48.57
F	*Circaea lutetiana canadensis*	48.98	22.22	86.67	68.57
F	*Smilacina racemosa*	63.27	55.56	26.67	22.86
F	*Arisaema triphyllum*	26.53	38.89	26.67	51.43
F	*Anemonella thalictroides*	10.20	22.22	53.33	22.86
F	*Allium canadense*	4.08	11.11	26.67	40.00
F	*Potentilla simplex*	2.04	11.11	53.33	8.57
F	*Geum canadense*		5.56	40.00	20.00
F	*Dentaria laciniata*	22.45		6.67	11.43
F	*Geranium maculatum*	2.04		26.67	8.57

F	*Camassia scilloides*	4.08	11.11	13.33	8.57
F	*Smilacina stellata*	2.04		20.00	11.43
F	*Aster sp.*	2.04		20.00	5.71
F	*Oxalis stricta*			20.00	5.71
F	*Claytonia virginica*	2.04		6.67	11.43
F	*Aster sagittifolius*	2.04		13.33	2.86
F	*Anemone quinquefolia*		11.11	6.67	
F	*Sanguinaria canadensis*			6.67	8.57
F	*Gallium triflorum*			13.33	
F	*Solidago canadensis*			13.33	
F	*Solidago flexicaulis*			6.67	5.71
F	*Viola sororia*		5.56	6.67	
F	*Geums sp.*		11.11		
F	*Actaea pachypoda*	2.04	5.56		2.86
F	*Allium tricoccum*	4.08			5.71
F	*Agrimonia sp.*			6.67	2.86
F	*Prenanthes alba*			6.67	2.86
F	*Ranunculus abortivus*	2.04		6.67	
F	*Amphicarpaea bracteata*			6.67	
F	*Apocynum sp.*			6.67	
F	*Galium sp.*			6.67	
F	*Maianthemum canadense interius*			6.67	
F	*Dodecatheon meadia*				5.71
F	*Hackelia virginiana*				5.71
F	*Impatiens capensis*				5.71
F	*Unidentified species*				5.71
F	*Polygonatum biflorum*		5.56		
F	*Unknown dicot*		5.56		
F	*Veronicastrum virginicum*		5.56		
F	*Aster laevis*				2.86
F	*Bidens frondosa*				2.86
F	*Cirsium sp.*				2.86
F	*Dioscorea villosa*				2.86
F	*Geum aleppicum strictum*				2.86
F	*Hieracium sp.*				2.86
F	*Hydrophyllum virginianum*				2.86
F	*Lilium michiganense*				2.86
F	*Oxalis sp.*				2.86
F	*Solidago ulmifolia*				2.86
F	*Unknown forb*				2.86
F	*Uvularia sessilifolia*				2.86
F	*Agrimonia gryposepala*	2.04			
F	*Smilax ecirrhata*	2.04			
F	*Solidago caesia*	2.04			
F	*Trillium recurvatum*	2.04			
G	*Carex pensylvanica*	2.04		40.00	11.43

G	*Carex blanda*			6.67	5.71
G	*Agrostis perennans*			6.67	2.86
G	*Unidentified grass*			6.67	2.86
G	*Panicum sp.*			6.67	
G	*Unknown grass*		5.56		
G	*Carex cephalophora*				2.86
G	*Carex rosea*				2.86
G	*Cinna arundinacea*				2.86
G	*Dactylis glomerata*				2.86
G	*Carex gracillima*	2.04			
G	*Poa sp.*	2.04			
		6.12	5.56	66.67	34.29
		0.01	0.01	0.07	0.06

W	*Fraxinus americana*	51.02	38.89	13.33	8.57
W	*Prunus serotina*	8.16	5.56	26.67	11.43
W	*Cornus racemosa*	16.33	11.11	20.00	
W	*Prunus virginiana*	20.41	11.11	6.67	8.57
W	*Rubus occidentalis*	8.16		26.67	2.86
W	*Rhus radicans*		5.56	13.33	14.29
W	*Quercus rubra*	2.04	11.11	13.33	2.86
W	*Parthenocissus quinquefolia*		11.11	6.67	11.43
W	*Ostrya virginiana*	2.04		20.00	2.86
W	*Ribes missouriense*	10.20		13.33	
W	*Rubus allegheniensis*			13.33	8.57
W	*Tilia americana*	10.20	5.56		5.71
W	*Carya ovata*			13.33	5.71
W	*Vitis riparia*	4.08	5.56		8.57
W	*Ulmus americana*	4.08	11.11		2.86
W	*Quercus alba*		11.11	6.67	
W	*Parthenocissus insertus*	14.29			
W	*Acer saccharum*		11.11		2.86
W	*Rubus idaeus*			13.33	
W	*Crataegus sp.*			6.67	
W	*Quercus coccinea*			6.67	
W	*Crataegus mollis*		5.56		
W	*Ribes sp.*		5.56		
W	*Celastrus scandens*				2.86
W	*Sambucus canadensis*				2.86
W	*Rubus sp.*	2.04			

Appendix I. Temporal shange in species frequencies between 1986 and 1999 in burned (B) and unburned (UB) East Woods plots.

	East Woods	**B-86 (N=15)**	**UB-86 (N=11)**	**B-99 (N=10)**	**UB-99 (N=11)**
A	*Alliaria petiolata*			80.00	36.36
A	*Taraxacum officinale*			10.00	18.18
A	*Rhamnus cathartica*		27.27		
A	*Viburnum trilobum*			10.00	9.09

A	*Rosa multiflora*		9.09		9.09
A	*Trilium erectum*			10.00	
A	*Lonicera tatarica*				9.09
A	*Solanum dulcamara*				9.09
A	*Rhamnus frangula*	6.67			
F	*Erythronium albidum*	60.00	63.64	70.00	81.82
F	*Circaea lutetiana can.*	53.33	36.36	90.00	81.82
F	*Arisaema triphyllum*	6.67	27.27	80.00	72.73
F	*Smilacina racemosa*	60.00	45.45		18.18
F	*Geum canadense*			90.00	18.18
F	*Hackelia virginiana*			20.00	45.45
F	*Dentaria laciniata*	6.67		40.00	
F	*Oxalis sp.*		9.09	20.00	
F	*Sanguinaria canadensis*			20.00	9.09
F	*Anemonella thalictroides*		9.09		18.18
F	*Viola sororia*			10.00	9.09
F	*Aster sp.*	6.67	9.09		
F	*Allium canadense*			10.00	
F	*Aster lateriflorus*			10.00	
F	*Impatiens capensis*			10.00	
F	*Ranunculus recurvatus*			10.00	
F	*Allium tricoccum*				9.09
F	*Arisaema dracontium*		9.09		
F	*Claytonia virginica*				9.09
F	*Floerkea proserpinacoides*				9.09
F	*Podophyllum peltatum*				9.09
F	*Ranunculus arboritivus*		9.09		
F	*Smilacina stellata*				9.09
F	*Fragaria virginiana*	6.67			
F	*Viola papilionacea*	6.67			
G	*Carex rosea*			10.00	
G	*Carex hirsutella*				9.09
G	*Panicum sp.*		9.09		
W	*Fraxinus americana*	66.67	81.82	60.00	
W	*Fraxinus pennsylvanica sub.*			20.00	90.91
W	*Ribes missouriense*	53.33	9.09		27.27
W	*Tilia americana*	6.67	9.09	10.00	27.27
W	*Rhus radicans*	13.33	18.18	10.00	9.09
W	*Cornus racemosa*	26.67	9.09	10.00	
W	*Rubus sp.*		45.45		
W	*Prunus serotina*	26.67		10.00	
W	*Ulmus americana*	6.67		20.00	9.09
W	*Carya ovata*	6.67	27.27		
W	*Crataegus sp.*			30.00	
W	*Rubus occidentalis*			20.00	9.09

W	*Parthenocissus*		9.09		18.18
W	*Prunus virginiana*		9.09		9.09
W	*Quercus rubra*		9.09		9.09
W	*Acer saccharum*	13.33			
W	*Vitis riparia*			10.00	
W	*Ostrya virginiana*				9.09
W	*Crataegus crusgali*	6.67			
W	*Ribes americana*	6.67			
W	*Rosa setigera*	6.67			
W	*Viburnum dentata*	6.67			