2013

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Recommended Citation
Roubik, J., J. Reinartz, and G. Meyer. 2013. Use of small-scale disturbances to establish native plants in an abandoned agricultural field. Field Station Bulletin 33: 18-40

Use of Small-scale Disturbances to Establish Native Plants in an Abandoned Agricultural Field

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Abstract: Small-scale disturbances in plant communities create open patches that may allow new species to invade or suppressed species to become more abundant. We evaluated whether small-scale disturbances in an abandoned agricultural field dominated by exotic grasses could be used to increase abundance and diversity of native plants. Coverboards made of plywood (2 X 122 X 81cm) were laid out on a 15 meter by 15 meter grid in the South Hayfield at the Field Station in 2008 for a study of the Butler's garter snake. The boards were kept in place until March 2010, creating many small-scale disturbances after removal of the boards. One of four treatments was applied to each of these experimental plots: 1) no seeding, or seeded with a mix of, 2) native forbs, 3) native grasses,or 4) both forbs and grasses.

The plots were seeded in July 2010, and vegetation was sampled August - September 2011. Percent cover of each plant species was estimated in each disturbance plot. A paired undisturbed plot was sampled to describe the background vegetation of the field. Species richness and diversity were higher in disturbed plots than in the undisturbed community for both seeded and unseeded plots. Seeded plots had much greater abundance and diversity of native species than unseeded disturbances, particularly for plots seeded with forbs. The forb-only seed mix provided the highest establishment of seeded species after one full growing season, and suppressed exotic species more than the grass-only seed mix. However, only Black-eyed Susan (*Rudbeckia hirta*), Wild bergamot (*Monarda fistulosa*), and Whorled milkweed (*Asclepias verticillata*) established in more than half the plots in which they were seeded. Grasses established poorly compared to the most successful forb species. However, the grasses were very small plants after a single growing season; their frequency may have been underestimated and their cover may increase in subsequent seasons.

INTRODUCTION

It is notoriously difficult to establish native species in abandoned agricultural oldfields because of the aggressive growth of the exotic, perennial grasses (such as Bluegrass, *Poa* spp., and Smooth brome) that can dominate them. Many oldfields have eroded soils that often exhibit low organic matter and nutrient availability. Non-native grasses established in oldfields crowd out and compete with native forbs and grasses (Barnes 2004, Foster *et al*. 2007, Grygiel *et al*. 2009). Exotic perennial grasses have been cited as one of the top reasons that revegetation efforts fail because they compete aggressively with desired native species via their rapid rhizomatous spread (Bakker and Wilson 2001, Barnes 2004, Foster *et al*. 2007, Grygiel *et al.* 2009).

Use of fertilizers, herbicides and pesticides associated with agriculture have wreaked havoc on the Midwestern prairie, and restoring oldfields back to prairie habitats has garnered much attention (Barnes 2004, Lawson *et al.* 2004, Foster *et al*. 2007). The benefits of prairie restoration are many, including restoring beautiful native species and floristic diversity, providing valuable wildlife habitat, improving water quality, conserving soil, and acting as a possible sink for atmospheric carbon (Berg 1992, Foster *et al.* 2007). However, most prairie restorations never attain the same diversity as remnant patches (Foster *et al*. 2007, Dickson and Busby 2009, Grygiel *et al*. 2009).

While there are myriad different methods and schools of thought about prairie restoration, many of them seem to center around the idea that establishment in grasslands is disturbance dependent (Hayes and Holl 2003). Colonization of new plants into established vegetation is very rare; it is difficult for a seed to find a habitable "safe spot" in which to germinate because a large majority of perennial plants spread vegetatively and rely little on seed (Harper 1977, Benson and Hartnett 2006). When a disturbance occurs, thatch is cleared away from the soil, shading is eliminated, and the soil is warmed, providing a new site for seed establishment (Lawson *et al.* 2004, Rosburg and Owens 2004, Benson and Hartnett 2006). In a native prairie, disturbances not related to fire are typically made by wildlife and are usually quite small (Johnson and Anderson 1986, Kotanen 1997, Grygiel *et al.* 2009).

A disturbance may be revegetated by clonal growth of plants or by establishment from seed that may be newly migrated or viable in the soil seed bank (Harper 1977, Rogers and Hartnett 2001). Small disturbances may be useful to provide safe sites for establishment of native species. We studied whether small-scale disturbances in an oldfield dominated by exotic grasses could be used to increase abundance and diversity of native plants.

We studied these disturbance plots to ask four questions:

1) Does disturbance alone alter the plant community, and how does the community change?
2) Does seeding disturbances increase the abundance and diversity of native plants?
3) Do more native species establish if disturbances are seeded with native forbs, native grasses, or a mixture of forbs and grasses?
4) Which species are most likely to successfully establish?

METHODS

Study Site. This study took place at the UWM Field Station (Saukville Township, Ozaukee Co. WI). The study site is a former agricultural field, called the South Hayfield (43.390295° N, 88.024406° W for center of field). Although the presettlement habitat of this field would have been deciduous forest, one of the goals of the UWM Field Station is to maintain a diversity of plant communities for research purposes, including open fields with an abundance of native species. Prairies were once widespread in southern Wisconsin, and although the Field Station lies outside the historical geographical region for prairie habitats, prairie species do grow well here. The study area soil is Sisson fine sandy loam which was deposited as various glaciolacustrine deposits (USDA 2011). The documented agricultural history of the South hayfield began in 1977 and, with few exceptions, it was cropped for hay two or three times a season until 2000. After 2000, the field was no longer used for agriculture and there was no further planting or mowing. The only management was some control of invasive shrubs. The South hayfield is dominated by the exotic grasses Kentucky bluegrass (*Poa pratensis*), Smooth brome (*Bromus inermis*), and Quack grass (*Elymus repens*).

Experimental Design. In the spring of 2008, a total of 83 coverboards made of 2 x 122 x 81cm plywood were laid down in a 15 meter by 15 meter grid for a study of the Butler's garter snake (Hileman 2010). When the boards were placed in the field, the above-ground plant material was removed using a weed-whacker, rake, and pruning shears. The boards were removed in March of 2010, and the vegetation underneath them had died back, leaving mostly bare ground. The coverboards had created many small-scale disturbances ideal for our study.

Each of the resulting 83 disturbances in the South Hayfield was randomly assigned to one of three differing experimental seeding treatments: a mix of native prairie forbs (henceforth called FORB), a mix of native prairie grasses (GRASS), a mix of both forbs and grasses (BOTH), plus a control treatment with no seeding (NONE). Each of the disturbance plots was paired with a BACKGROUND plot located 2 meters away in order to assess the background vegetation of the field and estimate the composition of the plots prior to disturbance. The species used in the seeding treatments are shown in Table 1.

The seeds were collected from prairie plantings at the Field Station in 2009 and dry stratified outside over winter. A trial germination of each species was performed in a greenhouse to determine the viability of seeds after stratification. The planting rate was 3 grams per disturbance plot (0.99 m^2) for all 3 seeding treatments. There were 18 species in the FORB treatment and each contributed an equal weight of seeds to each plot (5.8% of the total), except for Round-headed bush clover and Cream wild indigo which had less because of limited seed collection (5.3% and 1.7%, respectively). Big blue-stem and Indian grass each contributed 40% of the GRASS mix and Little blue-stem made up the remaining 20%. The BOTH mix consisted of 1.5 g of the FORB mix and 1.5 g of the GRASS mix. The seed was thoroughly and frequently mixed (to avoid over-representation of any seeds) and portioned into 3 gram packets by weight. In July 2010, the assigned treatment was seeded onto the treatment plots while a cover crop of oats was raked into the plot simultaneously to provide shade and improve seed germination. The NONE control plots received no seeding, raking, or cover crop.

The vegetation was sampled in both the disturbance and the background plots in August through September of 2011. For sampling purposes, a quarter-meter square quadrat was placed in the center of the former coverboard site. Plants were identified to the species level except for *Poa, Desmodium,* and *Melilotus* which were identified to genus (Appendix A). Percent cover was visually estimated using a Braun-Blanquet-style cover scale. Up to 5% coverage was represented as "1", 5 to 25% coverage was represented as "2", 26 to 50% coverage was designated as "3", 51 to75 % coverage was "4" and 76 to 100% coverage was marked as "5". Cover values were only recorded for plants that were rooted in the quadrat. The percentage cover of bare ground and thatch were also estimated using the same cover classes. Bare ground specified the amount of open, bare soil visible in each plot while thatch

Table 1. Native species used in the seed mixes. All species are perennial. Type: F - Forb, G -Grass. C.C: Coefficient of Conservatism code (see Methods for explanation). Bloom Time: Months that species is in flower, from WISFLORA (2011). Trial Germ: Germination success in the greenhouse. Prairie Type: D = Dry, DM = Dry-Mesic, M = Mesic, WM = Wet-Mesic, W = Wet (Curtis 1959). %Frq where seeded: Percent of seeded plots where the species was observed.

Scientific Name	Common Name	Type	C.C.	Bloom Time	Trial Germ.	Prairie Type	%Frq where seeded
Allium cernuum	Nodding wild onion	F	7	Jul-Aug	None	M	0
Amorpha canescens	Lead-plant	F	7	Jun-Jul	Yes	D, DM, M, WM	17
Andropogon gerardii	Big blue-stem, Turkeyfoot	G	4	Aug-Oct	Yes	D, DM, M, WM, W	17
Asclepias verticillata	Whorled milkweed	F	2	Jul-Sep	Yes	DM	71
Baptisia bracteata	Cream wild indigo	F	7	May-Jun	Yes	WM	0
Dalea purpurea	Purple prairie clover	F	7	Jun-Aug	Yes	D, DM, M	5
Desmodium spp.	Tick-trefoil	F	7 or 4	Jul-Aug	Yes	M, WM, W	2
Echinacea pallida	Pale purple coneflower	F	7	Jun-Aug	Yes	M	0
Eryngium yuccifolium	Rattlesnake master	F	8	Jul-Aug	Limited	M	0
Heliopsis helianthoides	False sunflower	F	5	Jul-Sep	Yes	M	43
Lespedeza capitata	Round-headed bush clover	F	5	Jul-Sep	Yes	DM, M, WM	0
Monarda fistulosa	Wild bergamot	F	3	Jul-Sep	Yes	D, DM, M, WM, W	88
Penstemon digitalis	Foxglove beard-tongue	F	-	May-Jul	Yes	M	2
Ratibida pinnata	Yellow coneflower	F	4	Jun-Aug	Yes	DM, M, WM, W	10
Rudbeckia hirta	Black-eyed Susan	F	4	Jun-Oct	Yes	DM, M, WM, W	90
Schizachyrium scoparium	Little blue-stem	G	4	Aug-Oct	Yes	D, DM, M, WM	22
Silphium integrifolium	Prairie rosinweed	F	6	Jul-Sep	Yes	M, WM	0
Silphium terebinthinaceum	Prairie dock	F	7	Jul-Sep	Limited	WM	0
Solidago rigida	Rigid goldenrod	F	5	Jul-Oct	Yes	DM, M, WM, W	2
Sorghastrum nutans	Indian grass	G	5	Aug-Sep	Yes	DM, M, WM	22
Veronicastrum virginicum	Culver's root	F	6	Jul-Aug	Yes	WM, W	2

was the cover of dead, dried plant material (primarily grass). Identical methods were used for the background plots, which were located 2 meters north of the corresponding disturbance plot. Seeded species that were rooted in the disturbance plot, but outside of the sampling quadrat, were recorded to track germination success of the seeded species.

Data Analysis. Percent cover was estimated using the midpoint of each cover class (i.e. 2.5, 15, 38, 66, and 88%) and relative percent cover was calculated as a percent of total cover. We calculated species richness and diversity of each plot. We used the Shannon Diversity Index which incorporates both the number of species and their relative abundance (Brower *et al*. 1977). We also determined the Coefficient of Conservatism (CC) score for each species and calculated both the mean CC and the Floristic Quality Index (FQI) for each plot. The CC score ranges from 0-10, with 0 indicating that the species will grow just about anywhere and is very common, while a 10 indicates that the species is rare and will only thrive in very particular habitats (WISFLORA 2011). The FQI uses the CC codes of native species in conjunction with the total species richness of a site to rate the quality of the site sampled. A higher FQI would represent a site with lower disturbance and degradation and more native plant species (WISFLORA 2011). For some analyses, species were grouped as native or exotic, annual/biennial or perennial, and forb or grass (Appendix A). Data on each species followed information on the Wisconsin State Herbarium's Vascular Plant Species website (WISFLORA 2011), with some exceptions. *Poa* was not identified to species and was treated as exotic and perennial. Three species of *Poa* are known to occur at the Field Station: Canada bluegrass (*P. compressa*), Kentucky bluegrass (*P. pratensis*), and Marsh bluegrass (*P. palustris*). The exotic perennials Canada and Kentucky bluegrass were dominant in the abandoned agricultural field sampled for this experiment. Black-eyed Susan (*Rudbeckia hirta*) was listed as biennial/perennial by WISFLORA, but we treated this species as perennial as it generally grows as a short-lived perennial in our area. We treated Leadplant (*Amorpha canescens*) as a forb, rather than a shrub since, although it is woody, it has a low stature that makes it part of the herbaceous stratum. Although both technically vines, Field bindweed (*Convolvulus arvensis*) and Poison ivy (*Toxicodendron radicans*) were treated as forbs for our study rather than vines since Bindweed is herbaceous and Poison ivy behaves more as a forb in the field that we sampled

Total sample size for this study was 166 plots: 20 disturbance plots with the NONE treatment, 22 seeded with FORB mix, 21 GRASS mix, 20 BOTH mix, and 83 BACKGROUND plots. A one-way ANOVA followed by the Tukey HSD test was used to assess differences among treatments. Statistical analyses were run in R.

RESULTS

Disturbance alone altered the composition of the plots and increased the abundance of native species. The unseeded experimental disturbances (NONE) had dramatically increased bare ground and decreased thatch as compared to the BACKGROUND plots (Figure 1). The BACKGROUND plots had very little bare ground (< 5%) and extensive thatch (nearly 90%), while the disturbances (NONE plots) had

26% bare ground and 50% thatch. Disturbance alone also caused dramatic increases in the mean species richness and Shannon Diversity Index (SDI, Figure 2). Both the species richness and SDI almost doubled from the BACKGROUND plots to the NONE plots. A total of 21 species that were not present in the background and were not seeded were recorded in at least one of the disturbance plots (both NONE and the seeded plots, Table 2). The relative cover of annual/biennial species and the cover of native species were very low in the BACKGROUND plots (Figure 3), but increased substantially in the NONE plots with no manipulation other than the disturbance. The cover of forb species increased by almost five-fold in the NONE plots compared to the BACKGROUND plots (Figure 4). The cover of exotic species was lower by over 15% in the NONE plots, compared to the BACKGROUND

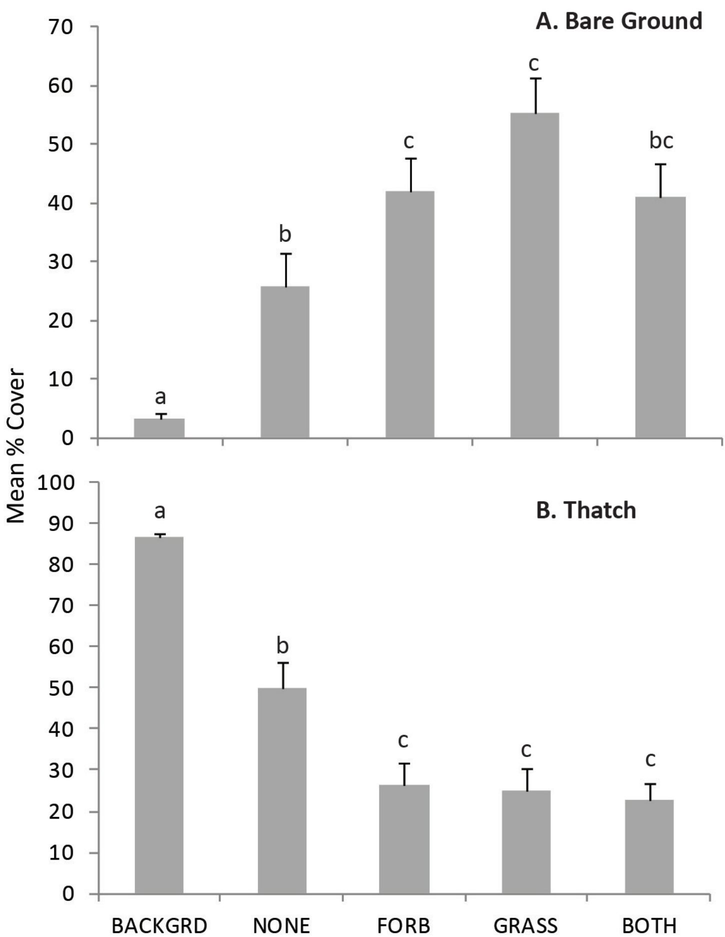

Figure 1. Mean percent cover of bare ground (A) and thatch (B) for the background and all four types of treatment plots. Error bars represent one standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

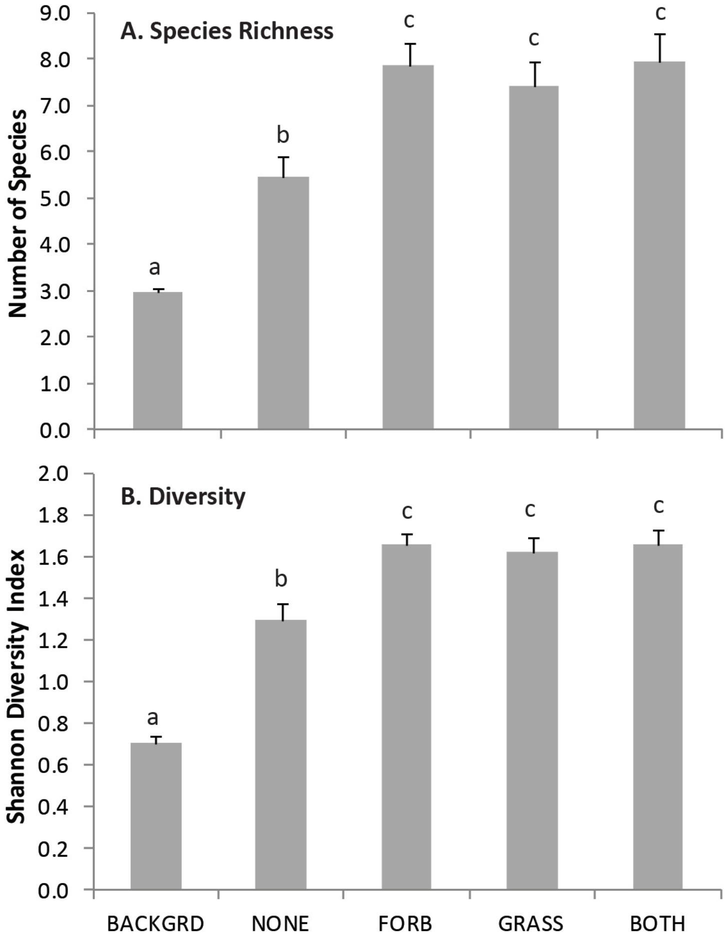

Figure 2. Mean Species Richness (A) and Shannon Diversity Index (B) for the background and all four treatment plots. Error bars represent standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

plots (Figure 5).

Seeding the plots caused further changes in the plant community and enhanced the abundance and diversity of native plants. Seeded plots had more bare ground and less thatch than the unseeded NONE plots. The three seeding treatments were generally similar in percent bare ground and percent thatch (Fig. 1). The seeded plots also had significantly higher species richness and SDI compared to both the NONE and BACKGROUND plots, with all three seeding treatments showing similar increases (Fig. 2). The three seeding treatments did not differ significantly from the NONE plots in the percent relative cover of annual and biennial species (Fig. 3A). However, all three seeding treatments had higher relative percent cover of native species than the NONE plots, although these differences were only signifi-

Table 2. **A**. Cover and frequency of all sampled species. Mean percent cover (% Cvr) and frequency of occurrence as a percentage (% Frq) of all species sampled for the background plots, each treatment plot and overall (All Plots). Seeded species are in bold. Non-seeded species that appeared in the disturbance plots but not in the background indicated by *. Dashes represent a zero.
B. Summary of diagnostic categories. Mean percent cover for total cover, bare ground and thatch, as well as mean Species Richness, Coefficient of Conservatism (CC), Floristic Quality Index (FQI), and Shannon Diversity Index (Shannon).
C. Summary of species by category. Mean percent relative cover (as a percent of total cover) and frequency of occurrence as a percentage (% Frq) of important species categories such as exotic or annual.

A. Cover and frequency	**BACKGRD**		**NONE**		**FORB**		**GRASS**		**BOTH**		**ALL PLOTS**	
of all species	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq
Poa spp.	57.4	100.0	36.7	95.0	22.8	100.0	29.3	100.0	27.0	100.0	43.1	99.4
Bromus inermis	27.0	96.4	21.5	95.0	11.9	68.2	17.5	95.2	15.2	80.0	21.7	90.4
Rudbeckia hirta	-	-	-	-	31.4	86.4	0.1	4.8	19.0	85.0	6.5	22.3
Elytrigia repens	3.3	48.2	10.5	55.0	5.5	59.1	11.2	76.2	6.3	55.0	5.8	54.8
Silene latifolia	0.2	1.2	10.2	40.0	7.0	36.4	11.2	57.1	12.5	65.0	5.2	25.3
Asclepias verticillata	3.2	21.7	2.4	25.0	8.5	72.7	7.1	52.4	5.2	60.0	4.5	37.3
Asclepias syriaca	0.5	6.0	6.2	25.0	0.8	9.1	8.0	38.1	4.8	15.0	2.7	13.9
Monarda fistulosa	0.2	1.2	-	-	12.0	95.5	0.7	4.8	6.6	65.0	2.6	21.7
*Erigeron annuus**	-	-	6.3	30.0	3.4	27.3	1.8	23.8	3.4	15.0	1.9	12.0
Physalis heterophylla	0.6	2.4	-	-	2.5	13.6	1.8	4.8	3.3	5.0	1.3	4.2
*Conyza canadensis**	-	-	2.4	20.0	1.7	22.7	3.3	38.1	2.7	10.0	1.3	11.4
Solidago canadensis	1.8	3.6	1.5	10.0	-	-	0.7	4.8	0.8	5.0	1.2	4.2

Table 2 - continued.	**BACKGRD**		**NONE**		**FORB**		**GRASS**		**BOTH**		**ALL PLOTS**	
	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq
*Panicum capillare**	-	-	1.0	15.0	1.6	18.2	3.7	28.6	1.8	20.0	1.0	10.2
*Ambrosia artemisiifolia**	-	-	3.7	25.0	0.7	4.5	1.7	19.0	1.1	20.0	0.9	8.4
Heliopsis helianthoides	-	-	-	-	3.3	40.9	-	-	2.6	30.0	0.8	9.0
Schizachyrium scoparium	-	-	-	-	-	-	4.7	23.8	1.0	15.0	0.7	4.8
*Oxalis stricta**	-	-	2.6	30.0	0.7	27.3	0.1	4.8	1.0	15.0	0.5	9.6
Convolvulus arvensis	0.0	1.2	0.9	10.0	1.1	22.7	1.5	38.1	0.5	20.0	0.5	12.0
Andropogon gerardii	-	-	-	-	-	-	3.7	28.6	0.1	5.0	0.5	4.2
Toxicodendron radicans	0.5	3.6	-	-	0.7	4.5	0.7	4.8	0.1	5.0	0.5	3.6
Sorghastrum nutans	-	-	-	-	-	-	3.1	28.6	0.3	10.0	0.4	4.8
Medicago sativa	0.4	2.4	0.8	5.0	0.1	4.5	0.2	9.5	0.1	5.0	0.3	4.2
*Polygonum aviculare**	-	-	0.1	5.0	0.3	13.6	1.9	9.5	0.1	5.0	0.3	4.2
Fraxinus americana	0.4	2.4	0.8	5.0	-	-	-	-	-	-	0.3	1.8
*Glechoma hederacea**	-	-	1.9	5.0	-	-	-	-	-	-	0.2	0.6
*Potentilla simplex**	-	-	-	-	0.8	9.1	0.7	4.8	0.3	10.0	0.2	3.0
*Aster pilosus**	-	-	0.8	5.0	-	-	0.7	4.8	0.1	5.0	0.2	1.8
*Daucus carota**	-	-	0.8	5.0	-	-	-	-	0.9	10.0	0.2	1.8
*Verbascum densiflorum**	-	-	0.9	10.0	0.7	4.5	-	-	-	-	0.2	1.8
Lactuca canadensis	0.2	1.2	-	-	-	-	0.7	4.8	-	-	0.2	1.2
Amorpha canescens	-	-	0.3	10.0	0.2	9.1	-	-	0.5	20.0	0.1	4.8

Table 2 - continued.	BACKGRD		NONE		FORB		GRASS		BOTH		ALL PLOTS	
	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq	% Cvr	% Frq
*Medicago lupulina**	-	-	-	-	0.2	9.1	0.7	4.8	-	-	0.1	1.8
*Achillea millefolium**	-	-	-	-	0.7	4.5	0.1	4.8	-	-	0.1	1.2
Equisetum arvense	0.0	1.2	-	-	-	-	-	-	0.8	5.0	0.1	1.2
*Setaria pumila**	-	-	0.1	5.0	-	-	-	-	0.8	5.0	0.1	1.2
*Carex granularis**	-	-	0.8	5.0	-	-	-	-	-	-	0.1	0.6
*Lactuca serriola**	-	-	-	-	-	-	0.7	4.8	-	-	0.1	0.6
Tragopogon dubius	0.2	1.2	-	-	-	-	-	-	-	-	0.1	0.6
Melilotus spp.*	-	-	0.3	10.0	0.1	4.5	-	-	0.1	5.0	0.1	2.4
Ratibida pinnata	-	-	-	-	0.2	9.1	-	-	0.1	5.0	0.0	1.8
*Amaranthus retroflexus**	-	-	-	-	-	-	0.2	9.5	-	-	0.0	1.2
Dalea purpurea	-	-	-	-	0.1	4.5	-	-	0.1	5.0	0.0	1.2
*Taraxacum officinale**	-	-	-	-	-	-	0.2	9.5	-	-	0.0	1.2
*Acer negundo**	-	-	-	-	-	-	-	-	0.1	5.0	0.0	0.6
Lotus corniculatus	0.0	1.2	-	-	-	-	-	-	-	-	0.0	0.6
Penstemon digitalis	-	-	-	-	0.1	4.5	-	-	-	-	0.0	0.6
Rhamnus frangula	0.0	1.2	-	-	-	-	-	-	-	-	0.0	0.6
*Trifolium pratense**	-	-	-	-	-	-	-	-	0.1	5.0	0.0	0.6
Veronicastrum virginicum	-	-	-	-	-	-	-	-	0.1	5.0	0.0	0.6

Table 2 - continued

	BACKGRD		NONE		FORB		GRASS		BOTH		ALL PLOTS	
B. Diagnostic categories	% Cvr		% Cvr		% Cvr		% Cvr		% Cvr		% Cvr	
Mean Total Cover	95.8	-	113.1	-	119.1	-	118.4	-	119.4	-	106.7	-
Mean Bare Ground	3.3	-	25.8	-	42.0	-	55.3	-	41.1	-	22.3	-
Mean Thatch	86.9	-	50.0	-	26.3	-	25.0	-	22.8	-	58.9	-
Mean Spp Richness	-	3.0	-	5.5	-	7.9	-	7.4	-	8.0	-	5.1
Mean CC	-	0.2	-	0.3	-	1.5	-	0.8	-	1.5	-	0.6
Mean FQI	-	0.1	-	0.1	-	0.6	-	0.3	-	0.5	-	0.2
Mean Shannon	-	0.7	-	1.3	-	1.7	-	1.6	-	1.7	-	1.1
C. Summary by category	% Cvr	%Frq	% Cvr	%Frq	% Cvr	%Frq	% Cvr	%Frq	% Cvr	%Frq	% Cvr	%Frq
Exotic	93.3	100	76.2	100	42.6	100	65.0	100	55.0	100	76.3	100
Exotic Grass	92.5	100	64.0	100	34.1	100	51.4	100	43.0	100	70.1	100
Annual/Biennial	0.5	4	20.7	80	13.2	82	20.6	86	19.4	90	9.5	44
All Forb	7.1	30	33.9	90	64.6	100	35.7	95	53.8	100	27.2	63
Seeded Species	3.0	22	1.6	30	45.1	100	15.9	71	29.9	100	13.3	49
Seeded Grass	-	-	-	-	-	-	9.9	43	1.1	25	1.4	8
Native	6.7	29	23.8	75	57.4	100	35.0	86	45.0	100	23.7	60
Non-sown Native	3.7	18	22.2	70	12.3	77	19.1	81	15.1	70	10.4	46

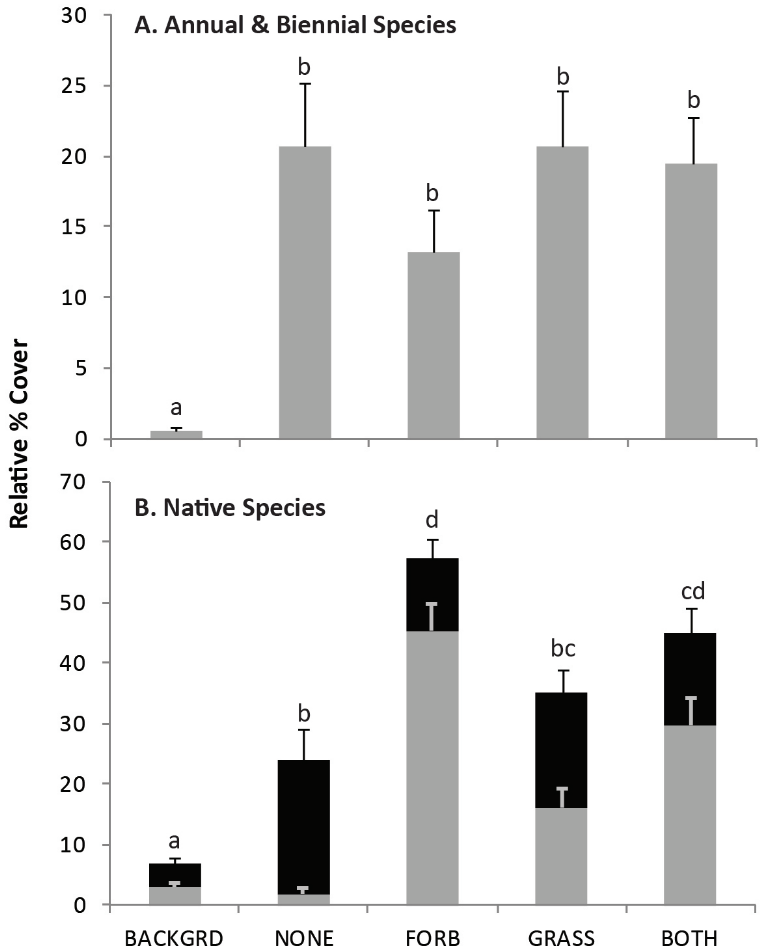

Figure 3. Relative percent cover of annual and biennial species (A) and native species (B) for the background and all four types of treatment plots. Within the native species, seeded species are represented by the light grey while black represents unseeded native species. Error bars represent standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

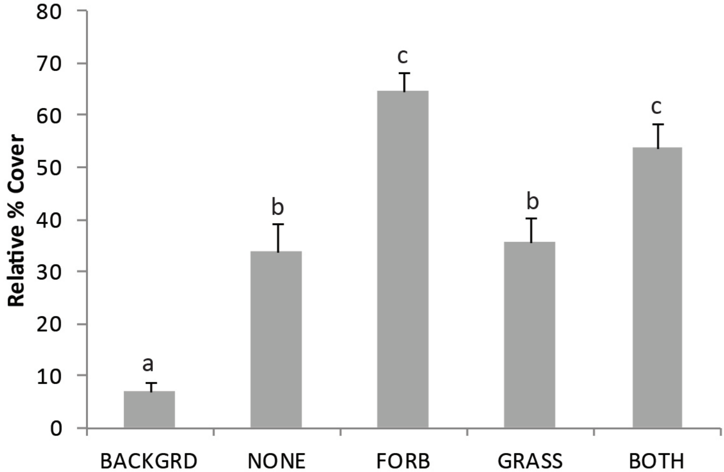

Figure 4. Relative percent cover of forb species for the background and all four types of treatment plots. Error bars represent standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

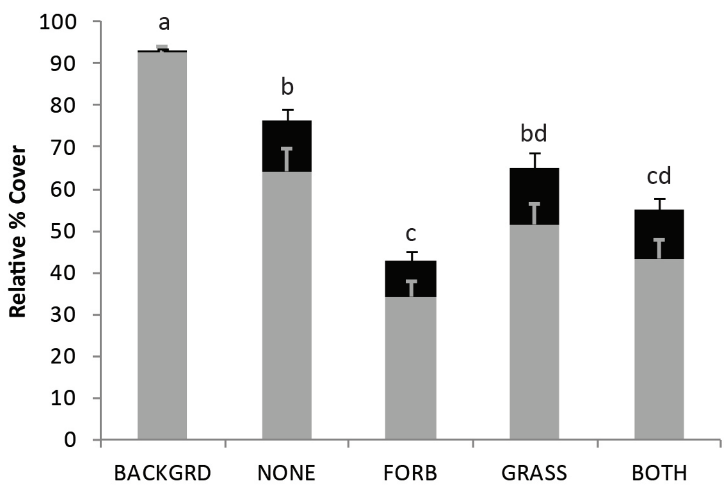

Figure 5. Relative percent cover of exotic species for the background and all four types of treatment plots. Within each bar, the light grey represents exotic grasses while the black represents exotic forbs. Error bars represent standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

cant for the FORB treatment and the BOTH treatment (Fig 3B). All seeded plots had much greater cover of forb species than the BACKGROUND (Fig. 4), but only the FORB and BOTH treatments gained significantly more forbs than the NONE plots. Relative percent cover of forbs in the GRASS plots was equivalent to that in the NONE plots. The cover of non-native species was lower in the two treatments seeded with forbs than it was in the NONE plots (Fig. 5).

Seeding the plots with native species allowed them to establish in the disturbances (Figure 6). The mixes that contained forb species had much greater relative cover of seeded species than the mix that contained only grasses. A few seeded species were extant in the field at the onset of this study, and they comprise a small fraction of the cover in the BACKGROUND and NONE plots (primarily Whorled milkweed and Wild bergamot, Table 3). Seeded forbs were also present in the GRASS treatment, where they were not seeded (primarily Whorled milkweed, Fig. 6, Table 3, but Black-eyed Susan and Wild bergamot were also present, Table 2). Most of the plots were dominated by *Poa* and smooth brome (Table 3). The FORB treatment was the only one to elevate the cover of a native species (Black-eyed Susan, *Rudbeckia hirta*) over *Poa* (Table 3). In the BOTH plots, Black-eyed Susan was the second most abundant species (Table 3).

There were clear differences in the establishment success of the seeded species. Black-eyed Susan, Wild bergamot, and Whorled milkweed all established in over 70% of the plots where they were seeded (Table 1). Five other species had more moderate rates of establishment in the seeded plots: these included False sunflower (43%), the three grass species (17-22%) and Lead-plant (17%). Six species were found established but appeared in 10% or fewer of the plots where they were seeded (Table 1). The remaining seven seeded species were not found at all in the study (Table 1). Three of these species either failed to germinate (Nodding wild onion) or

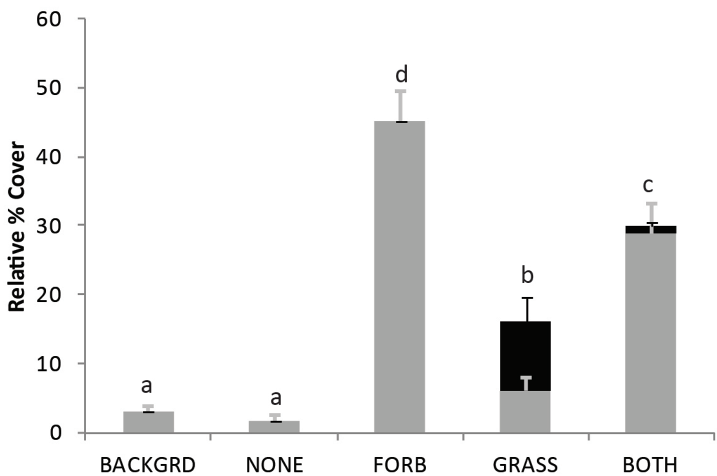

Figure 6. Relative percent cover of seeded species for the background and all four types of treatment plots. Within each bar, the light grey represents seeded forbs while the black represents seeded grasses. Error bars represent standard error. Treatments labeled with the same lower-case letter do not differ significantly at the 0.05 level.

Table 3. Top 15 species per plot. Ranked by mean percent cover (% Cvr) and presented with frequency of occurrence (Frq). See Appendix A for species codes. Seeded species in bold.

BACKGRD			NONE			FORB			GRASS			BOTH			ALL		
Species	%Cvr	Frq	Species	%Cvr	Frq	Species	%Cvr	Frq	Species	%Cvr	Frq	Species	%Cvr	Frq	Species	%Cvr	Frq
Poa	57.37	1.00	Poa	36.73	0.95	**RUDHIR**	31.41	0.86	Poa	29.31	1.00	Poa	27.00	1.00	Poa	43.09	0.99
BROINE	26.95	0.96	BROINE	21.45	0.95	Poa	22.80	1.00	BROINE	17.52	0.95	**RUDHIR**	19.03	0.85	BROINE	21.68	0.90
ELYREP	3.31	0.48	ELYREP	10.45	0.55	**MONFIS**	11.95	0.95	ELYREP	11.24	0.76	BROINE	15.15	0.80	**RUDHIR**	6.47	0.22
ASCVER	3.18	0.22	Silene	10.23	0.40	BROINE	11.93	0.68	Silene	11.17	0.57	Silene	12.48	0.65	ELYREP	5.82	0.55
SOLCAN	1.77	0.04	ERIANN	6.33	0.30	**ASCVER**	8.45	0.73	ASCSYR	8.05	0.38	**MONFIS**	6.63	0.65	Silene	5.16	0.25
PHYHET	0.64	0.02	ASCSYR	6.20	0.25	Silene	6.98	0.36	**ASCVER**	7.07	0.52	ELYREP	6.28	0.55	**ASCVER**	4.52	0.37
TOXRAD	0.54	0.04	AMBART	3.65	0.25	ELYREP	5.45	0.59	**SCHSCO**	4.67	0.24	**ASCVER**	5.15	0.60	ASCSYR	2.67	0.14
ASCSYR	0.45	0.06	OXASTR	2.63	0.30	ERIANN	3.43	0.27	**ANDGER**	3.69	0.29	ASCSYR	4.80	0.15	**MONFIS**	2.56	0.22
FRAAME	0.36	0.02	**ASCVER**	2.40	0.25	**HELHEL**	3.30	0.41	PANCAP	3.69	0.29	ERIANN	3.40	0.15	ERIANN	1.85	0.12
MEDSAT	0.36	0.02	CONCAN	2.38	0.20	PHYHET	2.52	0.14	CONCAN	3.33	0.38	PHYHET	3.30	0.05	PHYHET	1.28	0.04
LACCAN	0.18	0.01	GLEHED	1.90	0.05	CONCAN	1.70	0.23	**SORNUT**	3.10	0.29	CONCAN	2.65	0.10	CONCAN	1.25	0.11
MONFIS	0.18	0.01	SOLCAN	1.50	0.10	PANCAP	1.59	0.18	POLAVI	1.93	0.10	**HELHEL**	2.63	0.30	SOLCAN	1.25	0.04
Silene	0.18	0.01	PANCAP	1.00	0.15	CONARV	1.14	0.23	PHYHET	1.81	0.05	PANCAP	1.75	0.20	PANCAP	1.01	0.10
TRADUB	0.18	0.01	CONARV	0.88	0.10	ASCSYR	0.80	0.09	ERIANN	1.79	0.24	AMBART	1.13	0.20	AMBART	0.88	0.08
CONARV	0.03	0.01	VERDEN	0.88	0.10	POTSIM	0.80	0.09	AMBART	1.67	0.19	OXASTR	1.00	0.15	**HELHEL**	0.75	0.09

showed limited germination (Rattlesnake master and Prairie dock) in the greenhouse test, and so we did not expect to see them in the field.

DISCUSSION

Disturbance can alter a plant community by creating safe sites for species to germinate and establish. Increased resources (light, space, water, etc.) following a disturbance may allow for higher seed recruitment as well as activation of dormant seeds (Harper 1977, Johnson and Anderson 1986). In our study the disturbance alone reduced thatch and increased bare ground in all disturbance plots without actively adding any new propagules. A thatch layer can reduce soil temperatures by up to ten degrees, favoring earlier emerging cool-season species, such as *Poa*, Smooth brome or Quackgrass. (Benson and Hartnett 2006, Grygiel *et al*. 2009). *Poa* was reduced from background levels more in the seeded plots than in the NONE plots (Table 3).

Even in the absence of seeding, the disturbed plots gained species compared to the background, indicating that the disturbance alone allowed new species to establish in the plots. Following a disturbance, there is often high recruitment of disturbance-dependent annual/biennial species which can come from the seedbank (Johnson and Anderson 1986, Schramm 1992, Kirt 2001, Lawson *et al*. 2004, Rosburg and Owens 2004). Germination from the seed bank may explain the increase of species diversity and annual/biennial species in all of the disturbance plots, and account for the appearance of species that were not found in any of the background plots. We did not measure the seed bank in this study, but the seed banks of eleven oldfields on the Field Station property that surround the South hayfield were previously analyzed (Krause 1995). Eight of the twenty-one species observed in our disturbance plots that were not sampled in the background plots were recorded in the seed bank (Appendix B); other species may also have dispersed in from surrounding areas.

While the unseeded disturbed plots showed increases in species richness and cover of native species over background levels, the disturbance alone did not lead to establishment of many native perennial species. Only 6 of the 21 unseeded species that appeared in the plots were native perennials; the majority were annual or biennial (12/20) and the remaining 3 were exotic perennials. Seeding the plots with native perennial species led to a greater abundance and diversity of native plants compared to the unseeded plots. Seeding native species increased species richness, mean Shannon diversity, mean CC, and mean FQI in all seeded treatments compared to the unseeded plots, supporting the idea that seeding does change the successional direction of an area (Lawson *et al*. 2004, Foster *et al*. 2007).

In this study, which only described the disturbances after their first growing season, the FORB seed mix had the best establishment of seeded species, with significantly higher cover of seeded species than the GRASS or the BOTH treatment, and was better than the GRASS treatment at suppressing exotic species. It was also the only treatment to have a native perennial ranked first in mean percent cover. The FORB treatment included more species than the GRASS treatment (18 vs. 3) and showed a greater range in establishment success of the seeded species (percent frequency of seeded species in seeded plots ranged from 0-90% for FORB vs. 17-22% for GRASS). The greater success of the FORB mix was due to the presence of a few strongly competitive species, such as Black eyed Susan and Wild bergamot. Strongly competitive pioneer species grow quickly and can out-compete other plants. They have substantial growth in one season and are recommended by some who advocate planting species in stages (Berg 1992, Schramm 1992, Betz *et al*. 1998, Kirt 2001). Black-eyed Susan was the dominant seeded species in FORB and BOTH, and was the third-ranked species (in terms of percent cover) across all of the plots, after *Poa* and smooth brome, making it the seeded species with the greatest establishment in the first growing season.

The GRASS mix did not contain any high-performing species, at least during the first growing season. All three of the seeded grass species had mean percent covers under 5%, and the seeded species ranked 7th, 8th and 11th (in terms of percent cover) in the GRASS plots. Since all 3 of the seeded grass species were able to establish in the plots, it is possible that their cover may increase over time. A two-inch tall grass seedling may have roots that can be up to two feet below the soil surface at the end of the first growing season (Schramm 1992). This is thought to make the young grass plant highly competitive, which may explain the high amounts of bare ground in the GRASS plots (Cornelius 1946, Schramm 1992). The BOTH seed mix generally performed very similarly to the forb-only mix, except in a few key areas: it was intermediate between FORB and GRASS in terms of suppressing exotics and in the relative cover of seeded species. Because the total amount of seed used per plot was held constant across all three seeding treatments, the BOTH mix had only half the quantity of forb seed as the FORB mix. Since it was the forbs that were most successful at achieving high cover during the first year of establishment, it is not surprising that the BOTH mix gave results intermediate between the FORB and GRASS treatments.

The species we seeded that performed poorly all tended to be those primarily of mesic, wet-mesic or wet prairies (Table 1, Curtis 1959, Cochrane and Iltis 2000). Conversely, the best performing species all tended towards dry, dry-mesic, and mesic prairies. The top-performing species, Black-eyed Susan, was not present in the field before seeding, but the second and third most successful seeded species were found in the background plots (Whorled milkweed and Wild bergamot). These 3 top species had an average CC of 3, while the seven species that were not sampled at all had an average CC of 6.7. Conservative species - those with a higher Coefficient of Conservatism - can be sensitive to soil type (Weber 1999). In addition, competition may affect conservative species more profoundly that those with lower CC (Weber 1999).

The seeded plots will be monitored for the next few years to track changes in community composition and succession between and within the treatments. Some missing seeded species may appear in the next sampling. As noted earlier, many restorationists advocate planting prairie species in stages, starting with aggressive pioneer species and slowly moving toward more sensitive obligate species (Berg 1992, Schramm 1992, Betz *et al*. 1998, Kirt 2001). But some suggest that planting too many pioneer species may slow or completely prevent the emergence of more sensitive plants due to severe competitive effects (Weber 1999). It will be important to track these changes in the coming years especially as the Black-eyed Susan (a short-lived perennial) will begin to die back, which will change the make-up of the FORB and BOTH plots. It will also be important to see whether the native grass species do, in fact, begin to become more aggressive the second year, which would change the composition of the plots.

CONCLUSIONS

At the onset of this study we asked four questions: 1) Does disturbance alone alter the plant community? 2) Can seeding experimental disturbances with native species increase the abundance and diversity of native plants? 3) Do more native species establish if disturbances are seeded with native forbs, native grasses, or a mixture of forbs and grasses?, and 4) Which species are most likely to successfully establish? We found that disturbance alters a community by providing new safe sites for propagules and creating opportunities for both non-sown species as well as seeded species to take root. We saw that seeding with native prairie species after a disturbance will increase abundance and diversity of those native plants and reduce the abundance of weedy species. Lastly, seeding with a mix of prairie forbs that includes strongly competitive species, like Black-eyed Susan, will give the biggest initial effect in terms of exotic species reduction, and seeded species establishment and growth. It is too early to tell how forb-grass and native-exotic species competition will affect the different seed mixes and their outcomes in the long run.

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Appendix A. All recorded species for South Hayfield. Scientific name, status, type, and CC from WisFlora (2011). Status: N - Native, INV - Invasive, introduced, Int/Nat - Introduced; naturalized. LH: Life History, A - annual, A/Bi - either annual or biennial, Bi - biennial and P -perennial. C.C.: Coefficient of Conservatism, see Methods. *Desmodium* spp. lists both CC codes for the species found at the Field Station, as the species was not determined.

Code	Scientific Name	Common Name	Status	Type	LH	C.C.
ACENEG	*Acer negundo*	Box elder	N	Tree	P	0
ACHMIL	*Achillea millefolium*	Common Yarrow	N	Forb	P	1
AMARET	*Amaranthus retroflexus*	Pigweed	N	Forb	A	0
AMBART	*Ambrosia artemisiifolia*	Common ragweed	N	Forb	A	0
AMOCAN	*Amorpha canescens*	Lead plant	N	Forb	P	7
ANDGER	*Andropogon gerardii*	Big blue-stem	N	Grass	P	4
ASCSYR	*Asclepias syriaca*	Common milkweed	N	Forb	P	1
ASCVER	*Asclepias verticillata*	Whorled milkweed	N	Forb	P	2
ASTPIL	*Aster pilosus*	Frost aster	N	Forb	P	1
BROINE	*Bromus inermis*	Smooth brome	INV	Grass	P	0
CARGRA	*Carex granularis*	Limestone meadow sedge	N	Sedge	P	3
CONARV	*Convolvulus arvensis*	Field bindweed	INV	Forb	P	0
CONCAN	*Conyza canadensis*	Horseweed	N	Forb	A	0
DALPUR	*Dalea purpurea*	Purple prairie clover	N	Forb	P	7
DAUCAR	*Daucus carota*	Queen Anne's-lace	INV	Forb	Bi	0

Appendix A, continued.

Code	Scientific Name	Common Name	Status	Type	LH	C.C.
Desmod.	*Desmodium* spp.	Tick trefoil	N	Forb	P	4 or 7
ELYREP	*Elytrigia repens*	Quackgrass	INV	Grass	P	0
EQUARV	*Equisetum arvense*	Field horsetail	N	Fern Ally	P	1
ERIANN	*Erigeron annuus*	Annual fleabane	N	Forb	A	0
FRAAME	*Fraxinus americana*	White ash	N	Tree	P	5
GLEHED	*Glechoma hederacea*	Creeping Charlie	INV	Forb	P	0
HELHEL	*Heliopsis helianthoides*	False sunflower	N	Forb	P	5
HYPPER	*Hypericum perforatum*	St. John's-wort	INV	Forb	P	0
LACCAN	*Lactuca canadensis*	Wild lettuce	N	Forb	A/Bi	2
LACSER	*Lactuca serriola*	Prickly lettuce	Int/Nat	Forb	A/Bi	0
LOTCOR	*Lotus corniculatus*	Bird's-foot trefoil	INV	Forb	P	0
MEDLUP	*Medicago lupulina*	Black medick	Int/Nat	Forb	A/Bi	0
MEDSAT	*Medicago sativa*	Alfalfa	Int/Nat	Forb	P	0
Melilotus	*Melilotus* spp.	Sweet clover	INV	Forb	A/Bi	0
MONFIS	*Monarda fistulosa*	Bee balm, Wild bergamot	N	Forb	P	3
OXASTR	*Oxalis stricta*	Common yellow oxalis	N	Forb	P	0
PANCAP	*Panicum capillare*	Witch grass	N	Grass	A	1
PENDIG	*Penstemon digitalis*	Foxglove beard-tongue	N	Forb	P	-
PHYHET	*Physalis heterophylla*	Clammy ground-cherry	N	Forb	P	3

Appendix A, continued..

Code	**Scientific Name**	**Common Name**	**Status**	**Type**	**LH**	**C.C.**
Poa	*Poa* spp.	Bluegrass/Turf grass	INV	Grass	P	0
POLAVI	*Polygonum aviculare*	Knotweed	Int/Nat	Forb	A	0
POTSIM	*Potentilla simplex*	Common cinquefoil	N	Forb	P	2
RATPIN	*Ratibida pinnata*	Yellow coneflower	N	Forb	P	4
RHAFRA	*Rhamnus frangula*	Glossy buckthorn	INV	Shrub	P	0
RUDHIR	*Rudbeckia hirta*	Black-eyed Susan	N	Forb	P	4
SCHSCO	*Schizachyrium scoparium*	Little blue-stem	N	Grass	P	4
SETPUM	*Setaria pumila*	Yellow foxtail grass	Int/Nat	Grass	A	0
Silene	*Silene latifolia*	White campion	Int/Nat	Forb	Bi/P	0
SOLCAN	*Solidago canadensis*	Canadian goldenrod	N	Forb	P	1
SOLRIG	*Solidago rigida*	Stiff goldenrod	N	Forb	P	5
SORNUT	*Sorghastrum nutans*	Indian grass	N	Grass	P	5
TAROFF	*Taraxacum officinale*	Common dandelion	Int/Nat	Forb	P	0
TOXRAD	*Toxicodendron radicans*	Eastern poison-ivy	N	Forb	P	4
TRADUB	*Tragopogon dubius*	Goat's-beard, Yellow salsify	Int/Nat	Forb	Bi	0
TRIPRA	*Trifolium pratense*	Red clover	INV	Forb	P	0
VERDEN	*Verbascum densiflorum*	Dense-flower mullein	Int/Nat	Forb	Bi	0
VERVIR	*Veronicastrum virginicum*	Culver's-root	N	Forb	P	6

Appendix B. Species found only in the disturbance plots that were also detected in the seed bank in a previous study. That study sampled the seedbanks of eleven oldfields on Field Station property in the vicinity of the South Hayfield (Krause 1995). Status: N - Native, INV - Invasive. Int/Nat - Introduced; naturalized. LH: Life history, A - annual, A/Bi - either annual or biennial, Bi - biennial and P -perennial. Sites sampled: the number of sites out of the eleven total sites studied by Krause in which the species was found.

Scientific Name	Status	Type	LH	Sites Sampled
Ambrosia artemisiifolia	N	Forb	A	4
Aster pilosus	N	Forb	P	4
Daucus carota	INV	Forb	Bi	7
Melilotus spp.	INV	Forb	A/Bi	6
Oxalis stricta	N	Forb	P	4
Panicum capillare	N	Grass	A	5
Trifolium pratense	INV	Forb	P	1
Verbascum spp.	Int/Nat	Forb	Bi	9