Trends of Change in Composition and Structure of Chicago Region Wetland Vegetation

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Marlin Bowles and Michael Jones examine 26-year changes in Chicago region wetlands to assess the state of our wetlands.

Summary
To understand long-term changes in Chicago region wetlands, in 2002 we investigated the status of 31 high quality grass- or sedge-dominated wetland plant communities that were originally sampled in 1976. Our objectives were to quantify vegetation changes over time by resampling transects and then correlating changes with site fire histories, as well as other factors linked with compositional and structural change. Three of the sites sampled in 1976 were destroyed. The 28 remaining sites included ten graminoid fens, ten sedge meadows, four calcareous floating mats, two marshes, a single calcareous seep and one graminoid bog. Analysis showed that 20 % or more fire frequency maintained species richness, but that most sites had less frequent burning, and the majority of these sites declined in species richness. Almost all communities underwent significant increases in alien and woody vegetation as well as invasion by narrow-leaved cattail, which also had a negative relationship with native species richness. Marshes and fens underwent the most significant declines. There was a 50% loss of species richness in marshes that was largely replaced by an increase in narrow-leaved cattail. In fens, woody vegetation increased in abundance while grasses and sedges declined, and compositional changes included replacement of characteristic species by more generalist wetland and alien species. Infrequent fire and altered environmental factors appear to be driving these changes. Applied research is needed to determine how combinations of fire management and control of other environmental factors can maintain high quality wetland vegetation.

Introduction
When natural processes that maintain plant communities are altered, their vegetation becomes vulnerable to loss of plant species, change in structure, or invasion of alien plants (Pickett & White 1985, Hobbs & Hunneke 1992). Chicago region wetlands may be particularly vulnerable, as they represent one extreme of a landscape moisture gradient in which vegetation is maintained by fire and is also dependent upon hydrology (Bowles & Jones 2004, Bowles & Jones 2006a). For example, midwestern fens and

Community	Grade (N)	xRn		Sn		NRI	
		Mean	Std. err.	Mean	Std. err.	Mean	Std. err.
Calcareous floating mat	A (4)	10.16	(+2.24)	30.75	(+6.35)	35.30	(+9.08)
Calcareous seep	A (1)	7.13	(+0)	41.00	(+0)	26.49	(+0)
Graminoid bog	A (1)	7.55	(+0)	26.00	(+0)	24.60	(+0)
Graminoid fen	A (8)	11.19	(+0.58)	40.88	(+2.19)	41.56	(+2.68)
	B (3)	10.52	(+1.91)	38.00	(+4.62)	38.57	(+8.18)
Marsh	A (2)	7.05	(+0.1)	29.00	(+9.00)	23.42	(+2.60)
	B (1)	6.13	(+0)	27.00	(+0)	20.21	(+0)
Sedge meadow	A (6)	6.67	(+0.51)	23.50	(+2.14)	21.13	(+2.07)
	B (5)	6.44	(+0.75)	26.80	(+2.37)	21.25	(+2.80)

Table 1: Mean (+ standard error) species richness indices for Grade A and B high quality wetland plant communities sampled by the Illinois Natural Areas Inventory in 1976. Sample sizes (N) are in parentheses. Grade B vegetation was not sampled for calcareous floating mat or calcareous seep.

sedge meadows appear to be fire-dependent, yet patterned by hydrology and chemical gradients, all of which can be modified by human impacts (Curtis 1959, Zimmerman 1983, Bowles et al. 1996, Bridgham et al. 1996, Bowles et al. 2005, Kost & De Steven 2000). As a result, understanding changes in wetland vegetation is critical for its conservation and management. In this paper we examine 26-year changes in Chicago region wetlands originally sampled by the Illinois Natural Areas Inventory (INAI) in 1976 (White 1978). The INAI data are valuable because they were collected from vegetation thought to be relatively undisturbed by human impacts. Our objectives were to resample original INAI transects in order to 1) determine the present condition of vegetation, 2) quantify vegetational changes by comparing the 1976 and current data sets, 3) correlate these changes with fire management histories and other factors, and 4) project vegetation trends and suggest management and research needs.

Methods

The INAI originally sampled 31 Chicago region wetland stands representing marsh, graminoid bog, graminoid fen, calcareous floating mat, sedge meadow and calcareous seep natural community types (Table 1). Community classification follows White & Madany (1978). Twenty-two of these sites were Grade A (essentially undisturbed) and the remainder Grade B (lightly disturbed). The INAI usually sampled Grade B vegetation when Grade A examples were not present within a natural area, resulting in fewer Grade B data sets. The data also represent samples of a larger number of INAI natural areas, not all of which were sampled. We relocated the study sites in 2002 using original INAI community and transect maps, and re-sampled those that remained extant (Bowles & Jones 2003). Following INAI methods, all sites were sampled for species presence in 20 or 30 circular 1/4m2 plots placed randomly along transect lines (White 1978). Almost all of these sites were officially protected and managed, and fire-management histories were obtained from land managers.

We used species richness as a primary metric of vegetation change, as it is sensitive to effects of management and restoration (e.g., Korb et al. 2003, Bowles & Jones 2004, Bowles & Jones 2006b,). For each transect data set, we calculated the total number of native species sampled (Sn), the average number of native species sampled per plot (xRn), the Native Richness Index (NRI = Ln(Sn)*xRn), and an Alien Index (AI) of the proportion of alien species present. We used t-tests to determine whether xRn changed over time in each site. We used linear regression to determine the relationship between changes in species richness over time and how often sites had been burned, expressed as fire frequency. We calculated changes in relative abundance of invasive or alien species, primarily purple loosestrife (*Lythrum salicaria*) and buckthorns (*Rhamnus frangula* and *R. cathartica*), as well as the broadleaf cattail (*Typha latifolia*) and narrowleaf cattail (*T. angustifolia*), which may include their hybrid blue cattail (*T. x glauca*). Regression analysis was used to determine how species richness responded to change in Typha abundance. Nomenclature for scientific names follows Swink & Wilhelm (1994).

As a measure of vegetation structure we calculated a ratio of the relative abundance of woody to graminoid vegetation (Bowles & Jones 2004). Repeated analysis of variance was used to determine whether this variable changed over time. PC-ORD software (McCune and Mefford 1999) was used to conduct three multivariate tests. To assess compositional changes at the community level, we calculated the average proportional similarity across all sites within calcareous floating mat, graminoid fen and sedge meadow community types using the method of Bray and Curtis (1957) and compared the average values over time. Multi-response permutation procedures (MRPP) was used to test significance of this change (e.g. Zimmerman et al. 1985). Indicator species analysis (Dufrene & Legendre 1997) was used to determine whether different indicator species were associated with graminoid fen in 1976 and in 2002, as this community changed significantly in composition over time.

Results and Discussion

In 1976, species richness varied across communities, with greater values in graminoid fens and calcareous floating mats (Table 1). The most abundant species occurred across multiple vegetation types, tending to be dominant in single communities and less frequent elsewhere. Few characteristic or indicator species were encountered, possibly because they were too infrequent to be sampled with consistency (Bowles and Jones 2006a). The most frequent graminoid species in each wetland community were distributed as follows. Calcareous seep: hair beak rush (*Rhynchospora capillacea*) and wicket spike rush (*Eleocharis rostellata*); graminoid fen: marsh wild timothy (*Muhlenbergia glomerata*), big blue stem (*Andropogon gerardii*), dioeciuos sedge (*Carex sterilis*); sedge meadow: common tussock sedge (*Carex stricta*); calcareous floating mat: blue joint grass (*Calamagrostis canadensis*), narrow-leaved wooly sedge (*Carex lasiocarpa*); marsh: common lake sedge (*Carex lacustris*), broadleaf cattail; graminoid bog: narrow-leaved cottongrass (*Eriophorum angustifolium*).

Table 2: Indicator species (P < 0.10) in 1976 and 2002 for graminoid fen vegetation. Probabilities are based on 1000 permutations of the original data set in a Monte Carlo test (Dufrene & Legendre 1997). Asterisk (*) = alien species.

Species	Common name	Year	
Carex sterilis	dioecious sedge	1976	
Glyceria striata	fowl manna grass		2002
Dryopteris thelypteris	marsh fern		2002
Muhlenbergia glomerata	marsh wild timothy	1976	
Scirpus acutus	hard-stemed bulrush		2002
Panicum implicatum	old field panic grass		2002
**Rhamnus frangula*	glossy buckthorn		2002
Solidago ohioensis	Ohio goldenrod	1976	
Solidago riddellii	Riddell's goldenrod	1976	
Carex stricta	common tussock sedge		2002
Calamagrostis canadensis	blue joint grass		2002
Impatiens capensis	spotted touch-me-not		2002
**Rhamus catharitca*	common buckthorn		2002

"Chicago region wetlands are undergoing widespread undesirable changes in plant species composition and vegetation structure."

In 2002, we located and resampled 90% of the original INAI wetland sites. Only single graminoid fen, marsh, and sedge meadow stands were destroyed. Significant positive or negative changes in plot species richness between 1976 and 2001 occurred in 54% of all sites, with about 29% increasing in species richness and 25% decreasing in richness (Bowles & Jones 2003). Half of the sedge meadows increased in species richness, while only one decreased. Three graminoid fens increased in richness, while four decreased. One calcareous floating mat increased in richness while one declined. Both marshes and the graminoid bog declined in richness, while the calcareous seep remained stable.

Change in species richness appears to be regulated in part by the frequency at which wetland sites are burned (Figure 1). Our analysis suggests that a 20% fire frequency (four burns over a 20-year period) is needed to maintain species richness in Grade A wetlands. Regression also suggests that more frequent burning increases species richness in Grade B wetlands, which would indicate that management can improve their quality. However, the slope was not significant, possibly because too few sites were available for resampling. Fire management records indicated that only one-third of the Grade A sites had 20% or greater fire frequency. As a result, more Grade A sites decreased than increased in richness. Mesic and wet mesic prairies also appear to require 20% fire frequency for maintenance of species richness (Bowles & Jones 2004). Similar responses in wetlands and prairies suggest that fire has an equally important role in maintaining species richness in both habitats.

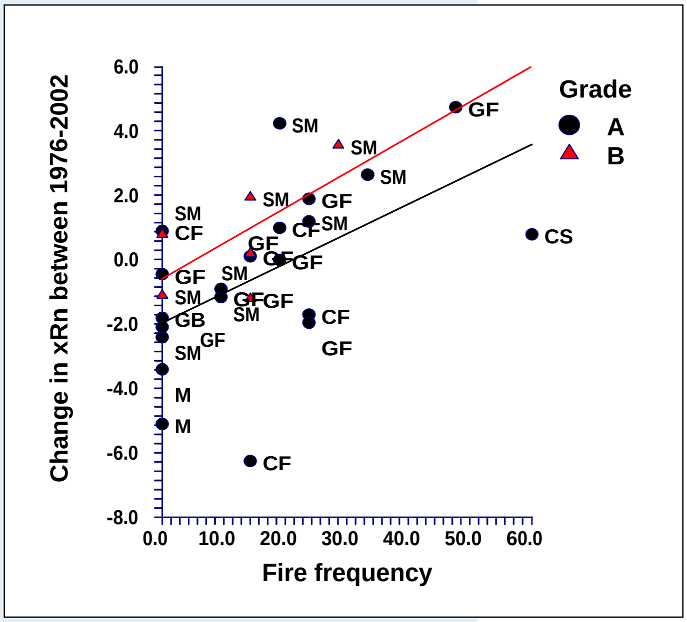
In 1976, alien species were rarely encountered in transects; however, by 2002, alien species were rarely absent from transects, and their proportional abundance increased significantly over time in calcareous floating mat, graminoid fen and sedge meadow (Repeated ANOVA: Year $F = 20.25$, $P < 0.001$). This primarily was due to increases of purple loosestrife and buckthorns. This increase appeared to have no relationship with change in native species richness. This may be due in part to introduction of leaf eating beetles that can effectively reduce purple loosestrife flowering, leaf area and stem height, so that native species co-exist with it, a process we observed at several sites. The broadleaf and narrowleaf cattails also increased significantly (Figure 2). Moreover, there was also a significant negative relationship between increasing abundance of narrowleaf cattails and plot richness of native species across all communities (Figure 3). This process appears to be most advanced in marshes, which lost more that 50 % of their species richness between 1976 and 2002 (Bowles & Jones 2003).

The ratio of woody to graminoid vegetation increased significantly over time, with a comparatively large increase within graminoid fens and a lesser increase within sedge meadows (Figure 4). This difference occurred because graminoid fens underwent an increase in woody vegetation abundance as well as a decline in graminoid abundance, while sedge meadows only increased in woody abundance. The single graminoid bog also underwent an increase in woody vegetation. There was a significant temporal shift in composition of graminoid fen vegetation shown by a low mean proportional similarity between 1976 and 2002 (mean = 40 %, MRPP: $t = -4.0342$, $P < 0.0001$). In association with this shift, there were different indicator species in 1976 and 2002 (Table 2). These changes in indicator species indicate lower importance of formerly dominant or characteristic species, such as dioeciuos sedge (*Carex sterilis*) and Ohio goldenrod (Solidago ohioensis), and greater importance of aliens and generalist species that occupy a wide range of community types. The decline of dioeciuos sedge could be directly related to the lack of fire, as this small stature sedge is easily covered by unburned litter from the previous growing season. However, individual species responses may differ, as Ohio goldenrod also declined under high fire frequencies used to restore graminoid vegetation at Bluff Springs Fen (Bowles et al. 1996).

Conclusions

Chicago region wetlands are undergoing widespread undesirable changes in plant species composition and vegetation structure. Calcareous floating mats have increased in alien species and cattails, but have not changed significantly in species composition. While only two marshes were re-sampled, both have undergone large-scale invasion by cattail and almost a complete collapse of species composition. The authors observed a single graminoid bog habitat that underwent an increase in woody vegetation and is threatened by cattail invasion from adjacent wetlands. Graminoid fens and sedge meadows have increased in alien species, cattails, and woody vegetation, and fens have undergone shifts in composition and indicator species. If these trends continue, there will be increasingly less resemblance between the high quality examples of wetlands found in 1976 and those that survive in the future.

The causes of these changes may be complex and interrelated, involving both environmental factors as well as successional change. Few long-term studies have projected fire frequencies needed to maintain wetlands. However, these results are similar to changes occurring in prairie communities that receive low fire frequencies (Bowles and Jones 2004). Continued monitoring and experimental management will be needed to test our projection that a 20% fire frequency is needed to maintain plot-scale species richness across all wetland vegetation types. This relationship could differ among community types, and may be stronger in graminoid fen and sedge meadow because they have a greater component of species that also occur in prairie (Moran 1981, Bowles et al. 1996, Bowles et al. 2005). The increase in woody vegetation



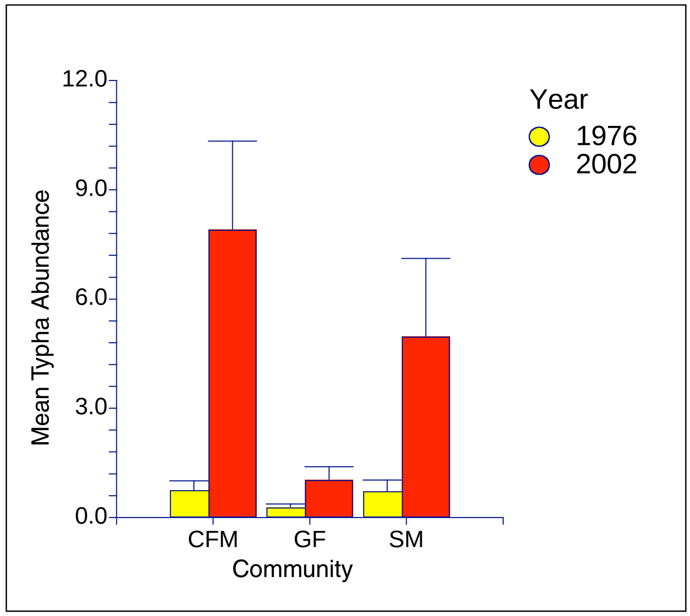
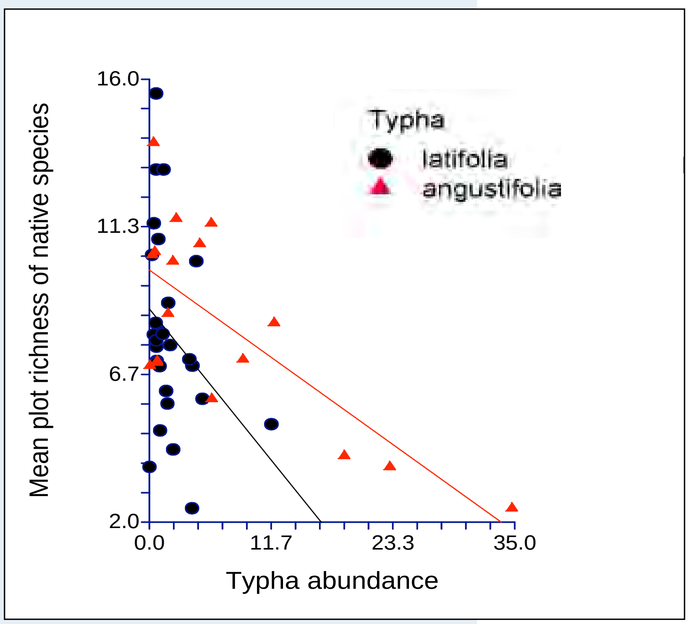


Figure 1: Positive relationships between percent fire frequency and temporal change in plot richness of native species for Grade A (r2 = 0.3076, P = 0.009) and Grade B (r2 = 0.4707, P = 0.089) wetland vegetation. CF = calcareous floating mat, CS = calcareous seep, GB = graminoid bog, GF = graminoid fen, M = marsh, SM = sedge meadow.

Figure 2: Temporal increase in abundance of Typha latifolia and T. angustifolia in calcareous floating mat (CFM), graminoid fen (GF) and sedge meadow (SM). Repeated ANOVA with pooled species: Year F = 15.57, P < 0.001).



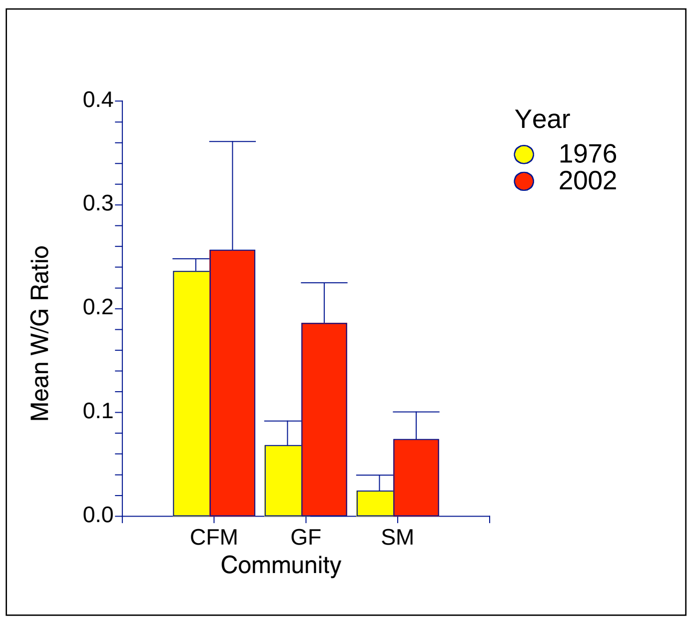


Figure 3: Negative effect of the relative abundance of T. latifolia (r2 = 0.106, P = 0.091) and T. angusitfolia (r2 = 0.540, P = < 0.001) on plot richness of native species (xRn).

Figure 4: Temporal increase in the mean ratio (W/G) of woody to graminoid species in calcareous floating mat (CFM), graminoid fen (GF) and sedge meadow (SM). Repeated ANOVA: Year F = 9.64, P = 0.001.

relative to graminoid vegetation in these habitats indicates a reduction of the fine fuel matrix, which will reduce the effectiveness of fire in structuring vegetation a critical process in fire-dependent graminoid fens (Bowles et al. 1996). For example, Bowles et al. (1996) found that a 70% burn frequency recovered fen vegetation by increasing graminoid importance relative to woody and forb vegetation. In Wisconsin sedge meadows, Kost & De Steven (2000) found that fire increased living biomass and maximized diversity among species with different life-histories, but recommended fire rotations to allow replenishment of seed banks. Increasing invasive species can have a great degree of impact because they can alter vegetation structure by increasing vegetative biomass, thereby altering species composition and reducing species richness. Once established, many of these species also appear to be insensitive to fire, and may reduce the effectiveness of fire in structuring vegetation and maintaining species richness. They also may have the capacity to alter soil nutrient cycling processes, possibly in a feedback process (Ehrenfeld 2003, Heneghan et al. 2004).

Altered hydrology and increasing pollution and eutrophication are linked with wetland vegetation deterioration and increasing invasive species, including both, narrowleaf cattails and blue cattail (e.g. Wilcox et al. 1985, Galatowitsch et al. 1999, Panno et al. 1999, Keddy 2000, Woo & Zedler 2002, Werner & Zedler 2002, Rickey & Anderson 2004, Miklovic & Galatowitsch 2005). All of these factors appear to be so widespread in the Chicago region that few wetlands have escaped their impacts (J. Miner, Illinois State Geological Survey, pers. comm.). Particularly disruptive effects result from destabilized surface water and groundwater extraction, sodium and chlorine release from septic fields and road salt, excessive herbicide use, and fertilizer runoff. Increasing regional nitrogen (Hey 2002) and phosphorus levels also may be critical, as they limit native plant growth in wetlands (Verhoeven et al. 1996). For example, increased nitrogen and phosphorus levels stimulate growth of broadleaf cattail (Svengsouk and Mitsch 2001), and narrowleaf cattail becomes a superior competitor to broadleaf cattail under eutrophic conditions (Weisner 1993). Unless environmental factors contributing to the increase of alien and invasive plant species in wetlands can be understood and controlled, fire management may be ineffective in maintaining species composition and structure in graminoid wetland vegetation. One approach used to avoid eutrophication in European wetlands is the annual summer harvest of nitrogen- and phosphorus-rich hay (Verhoeven et al. 1996). This harvest technique was formerly used in Wisconsin fens (Curtis 1959) and might be applied experimentally to appropriate Chicago region wetlands.

Acknowledgments
For support, we thank the Illinois Department of Natural Resources Wildlife Preservation and Conservation-2000 funding programs, the Chicago District of the U.S. Army Corps of Engineers and CorLands, and the Chicago Wilderness and Illinois Conservation Foundation for administering USDA Forest Service and US Fish & Wildlife Service funds. Essential assistance, management data and permits were provided by the Illinois Nature Preserves Commission, Illinois DNR, the Forest Preserve or Conservation Districts of DuPage, Cook, Kane, Lake, McHenry and Will counties, and many private landowners and stewards. We also thank the Illinois DNR, as well as the original INAI staff, for providing the original INAI data, and Tim Bell, Christopher Dunn, Andrew Hipp, Jenny McBride, Jeff Mengler, Jim Miner and John White for review, discussion or technical assistance.

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Appendix I. Average frequencies of leading dominant graminoid, forb, and woody vegetation comprising a wetland vegetation gradient in the Chicago region of Northeast Illinois. Calcareous seep and graminoid bog data represent single data sets, other data are pooled from Grade A and B INAI data (Bowles & Jones 2006a).

Graminoid	Habit	CS	GF	SM	CFM	M	GB
Rhynchospora capillacea	G	56.67	0.45	----	----	----	----
Eleocharis rostellata	G	46.67	----	----	2.50	----	----
Carex haydenii	G	30.00	26.36	1.82	----	15.00	----
Carex sterilis	G	20.00	50.00	0.91	----	----	----
Muhlenbergia glomerata	G	16.67	45.61	0.91	42.50	----	15.00
Andropogon gerardii	G	----	59.55	----	2.50	----	----
Carex stricta	G	----	23.18	95.00	----	----	----
Calamagrostis canadensis	G	----	10.91	47.12	70.00	25.00	5.00
Carex buxbaumii	G	----	19.09	----	40.00	1.67	----
Carex lasiocarpa v. americana	G	----	----	----	73.33	21.67	----
Carex aquatilis v. altior	G	----	----	----	50.00	6.67	----
Carex lacustris	G	----	----	11.36	1.67	51.11	----
Typha latifolia	G	----	2.27	5.15	6.67	36.11	5.00
Eriophorum angustifolium	G	----	----	----	----	----	100.00
Lobelia kalmii	F	50.00	10.00	----	1.25	----	----
Solidago uliginosa	F	46.67	19.24	11.06	28.75	----	15.00
Senecio aureus	F	30.00	1.36	----	----	----	----
Silphium terebinthinaceum	F	26.67	----	0.45	----	----	----
Lysimachia quadriflora	F	10.00	31.36	1.67	18.75	13.33	----
Solidago ohioensis	F	----	61.06	0.45	----	----	----
Rudbeckia hirta	F	6.67	30.91	0.45	----	----	----
Pycnanthemum virginianum	F	3.33	43.48	46.97	----	----	----
Solidago riddellii	F	----	26.67	----	5.00	----	----
Eupatorium maculatum	F	----	14.39	37.88	12.50	13.33	15.00
Lycopus virginicus	F	----	24.09	23.64	54.58	20.00	55.00
Dryopteris thelypteris v. pub.	F	----	5.15	22.73	42.50	18.33	90.00
Aster borealis	F	----	16.06	10.00	43.75	5.00	5.00
Lysimachia thyrsiflora	F	----	0.45	12.27	38.75	23.33	30.00
Campanula uliginosa	F	----	3.18	6.36	33.33	----	----
Hypericum virginicum v. fraseri	F	----	1.36	1.82	30.42	----	5.00
Scutellaria epilobiifolia	F	----	----	7.88	35.00	38.89	15.00
Potentilla palustris	F	----	----	0.91	25.83	3.33	45.00
Sarracenia purpurea	F	----	0.61	----	----	----	55.00
Viola pallens	F	----	----	----	----	10.00	30.00
Drosera rotundifolia	F	----	----	----	----	----	50.00
Potentilla fruticosa	W	66.67	8.94	----	----	----	----
Salix candida	W	----	0.91	0.91	20.00	1.67	10.00
Spiraea alba	W	----	----	----	21.67	----	----
Cornus stolonifera	W	----	2.27	0.45	1.25	11.67	----
Betula pumila	W	----	0.76	----	8.75	1.67	45.00
Salix pedicellaris v. hypoglauca	W	----		0.45	31.25	1.67	50.00
Decodon verticillatus	W	----	----	----	----	----	10.00