Establishing vegetation in a created wetland in Lake County, Illinois

by

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GENERAL INTRODUCTION

Section 404 of the Clean Water Act of 1972 authorized the U. S. Army Corps of Engineers to oversee development projects that could impact the nation's wetlands. The primary duty of the Corps is to regulate the discharge of dredge and fill material into bodies of water (Office of Technology Assessment 1984). Under Section 404, the Corps approves or denies permits for filling wetlands. In cases where wetlands are destroyed in this manner, compensation for their loss is required. Such compensation, called mitigation, involves either restoring degraded wetlands or creating new wetlands to replace those lost.

The science of wetland restoration and creation is relatively new, and restoration and creation attempts have not always been successful (Race 1985). The establishment of vegetation is a crucial step in this process, yet techniques for doing this have not yet been perfected. There are several standard methods used to establish vegetation, including mulching with donor soil, seeding, and transplanting wetland plants (Broome *et al.* 1988). Natural colonization of the restored or created wetland is also possible, particularly if it is hydrologically connected to adjacent natural systems which will serve as a seed source (Cutlip 1984). I investigated two methods of establishing vegetation, donor seed banks and sowing seeds, in a created wetland.

Explanation of thesis format

My results are summarized in two papers, each in a format suitable for publication in a technical journal. The first paper deals with the composition of potential donor seed banks and the use of those seed banks. The second paper addresses the recruitment of sedge meadow and mesic prairie seedlings at various soil moistures.

PART I.

DONOR SEED BANKS AS A SOURCE OF SEED FOR A CREATED WETLAND

ABSTRACT

Donor soil from four wetlands scheduled for destruction on the site of a shopping mall near Gurnee, Illinois, was to be used as a seed source for establishing new wetlands on the site. The composition of the seed banks of these four wetlands was studied by sampling them at 0-10 cm and 25-30 cm. In all of the wetlands, seed densities were higher in surface soil. The seed banks of three of the wetlands contained high densities of seeds of undesirable species (*Lythrum salicaria, Phalaris arundinacea*, and *Typha* sp.), but one had a seed bank that contained primarily wet meadow species and other desirable species.

The actual effectiveness of using donor soil as a seed source on the Gurnee Mills site was also examined. A mean of only 13 seedlings m^{-2} were recruited in the field from donor soils, much less than the 75 seedlings m^{-2} predicted by the seed bank study. Poor germination in the field occurred, in part, because the donor soil was obtained from a thicker layer of soil than examined in the seed bank study, and therefore fewer seeds were present. Field recruitment was lower than expected primarily because of low soil moisture levels.

INTRODUCTION

The seed bank, a layer of soil that contains a reserve of ungerminated, viable seeds, has been studied in many habitats (Major and Pyott 1966; Thompson and Grime 1979; Roberts 1981, 1986; Leck *et al.* 1989), and its importance in determining the vegetation that develops after a disturbance has been noted (Roberts 1986). van der Valk and Davis (1976, 1978) demonstrated that seed bank composition and seed germination requirements of particular species in prairie wetlands largely determine floristic composition during vegetation cycles.

Restoration of freshwater wetlands has become increasingly necessary in recent years in order to comply with laws requiring the compensation for wetland loss due to development. Research, primarily in Florida, has established the feasibility of using donor seed banks as a seed source for newly created wetlands. More diverse plant communities developed in areas of a new wetland mulched with donor soil than in control areas lightly seeded with a cover crop of rice; however, the species composition of the resulting vegetation did not resemble that of the donor wetland (Ross *et al.* 1985). Initially, a random distribution of plant species was found in mulched areas on reclaimed phosphate strip mines during the first year, but normal patterns of zonation developed during the second year (Clewell 1981). Again, species richness and total cover were higher in areas with donor seed banks in reclaimed phosphate mines than in areas of overburden only (Erwin and Best 1985; Erwin *et al.* 1985). Similar results have been obtained in other mine reclamation studies (Beauchamp *et al.* 1975; Worthington and Helliwell 1987).

Germination requirements must be satisfied in order for recruitment from the seed bank to occur. Adequate soil moisture is critical for recruitment of species during drawdowns. In a study in the Delta Marsh, Manitoba, Canada, percent seed germination was a function of soil moisture (van der Valk and Pederson 1989), and most seedling mortality was a result of decreased soil moisture (van der Valk and Welling 1988). Litter and high seedling densities of

annual plants may also inhibit germination of perennial wetland species during drawdowns (van der Valk 1986).

Using seed banks for marsh restoration and creation in the Midwest has not been investigated. I studied the potential use of donor seed banks at a site where several wetlands were to be filled so that a shopping center could be built. New wetlands were to be created on the site in order to mitigate for the loss of the original wetlands. I examined the seed banks of the wetlands that were to be destroyed to determine their potential use as donor seed banks for the created wetlands. Since several undesirable species, particularly *Lythrum salicaria, Phalaris arundinacea,* and *Typha* sp., were known to be present, the occurrence of seeds of undesirable species as well as the general composition of the seed bank were of interest.

This study had the following objectives:

1. to determine the species composition of the seed bank of the topsoil from potential donor wetlands at the Gurnee Mills site, and specifically to identify locations where the seed bank contained undesirable species,

2. to provide an estimate of the relative abundance of seeds of each species in the seed bank, and

3. to determine the actual effectiveness of using donor seed banks for establishing vegetation in created wetlands.

SITE DESCRIPTION

The Gurnee Mills shopping mall site is located in Warren Township, Lake County, Illinois, immediately northwest of the village of Gurnee. The site is 142 hectares (ha) in size and is bordered by Interstate 94 on the east, Hunt Club Road on the west, Steam's School Road on the north, and Grand Avenue (Illinois Route 132) on the south.

Five wetlands (WL) were originally found on the property (Figure 1). WL1, WL4, WL5, and 2.4 ha on the western side of WL3 were all scheduled to be filled during construction of the mall, and these wetlands were included in the study. WL2 was preserved as part of the mitigation plan and was not sampled in the study. The eastern portion of WL3 consisted of a cattail marsh and was also preserved.

Vegetation

In 1988, a species inventory of the wetland vegetation was conducted between May and July (Kelsey *et al.* 1988). The species lists from that study are given in Appendix A. Approximately 60% to 80% of the total number of species present in these wetlands were found during the investigation (Kelsey *et al.* 1988).

WL1 was a degraded wetland. Woody vegetation was found on its north and south borders, and it was dominated by *Typha latifolia* and *Phragmites communis* in the center. A band of sedge meadow occurred around this central zone (Kelsey and Hootman 1990).

Most of WL3 was a cattail marsh characterized by open water areas and sedge meadow around the periphery. Variations in the soil chemistry of this wetland such as high sodium levels on the eastern edge of the property were due to the tollway and past cultivation (Kelsey and Hootman 1990).

WL4 was described as a "disturbed, low-grade natural area" (Kelsey *et al.* 1988). Patches of *Typha latifolia*, *Calamagrostis canadensis*, *Scirpus validus*, and *Carex stricta* were frequent.

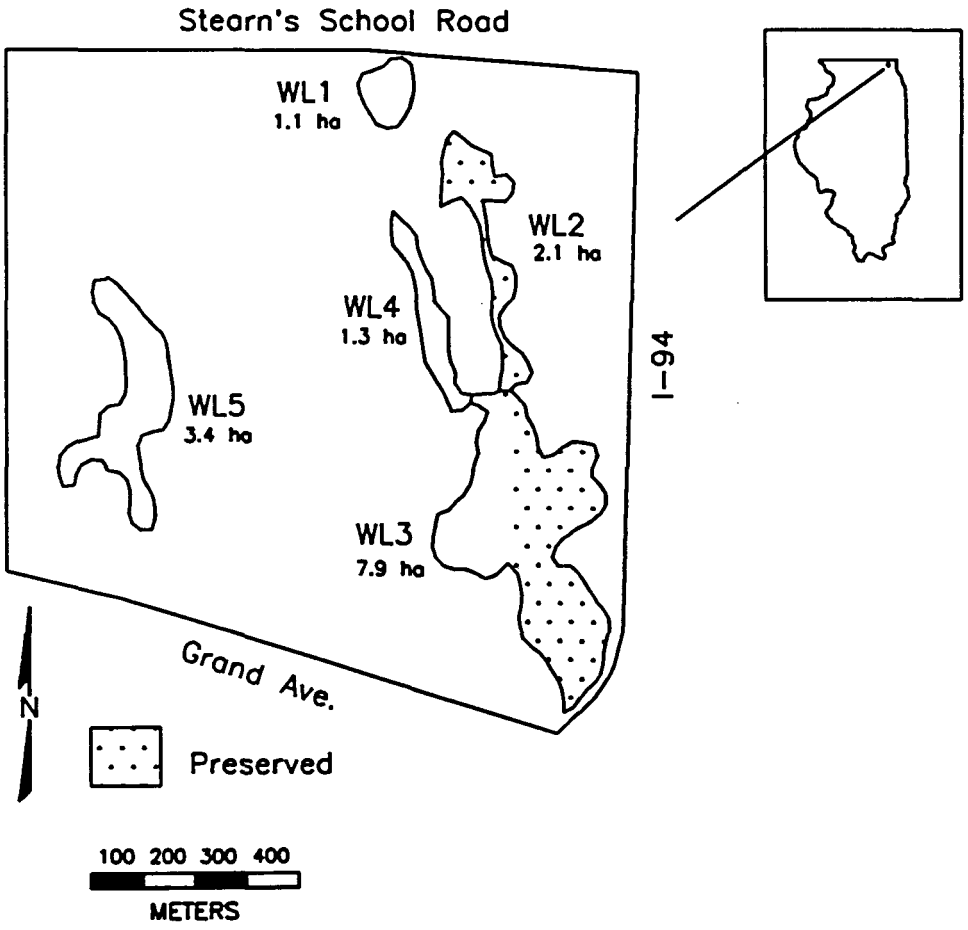

Figure 1. Location and size (ha) of wetlands (WL) on the Gurnee Mills site in Lake County, IL, prior to development

The largest wetland studied, WL5, was dominated by *Typha* sp., *Phalaris arundinacea, Phragmites communis, Lythrum salicaria*, and other disturbance species. Soils of this wetland were also affected by runoff from Grand Avenue and cultivation of nearby cropland (Kelsey and Hootman 1990).

Hydrology

The site is located in two subwatersheds of the Des Plaines River. Originally, about 52% (77 ha) of the site was in the Mill Creek subwatershed and drained to the north; the rest of the area drained to the south (National Survey and Engineering 1989). Most of the runoff from the mall parking lots will be diverted into retention or detention ponds before flowing into the created and preserved wetlands. The stormwater retention basins are designed to remove more than 75% of suspended solids and other pollutants in the runoff from the site (National Survey and Engineering 1989). Runoff from the roof of the shopping mall will be collected in a separate retention basin (Figure 2) and flow over a weir into the preserved wetland, WL2.

Water from WL2, WL3, and Created Wetland "A" will flow south to Detention Pond "A" and will be discharged under Grand Avenue (Figure 2). Runoff from offsite enters through structures under the I-94 tollway and will also be directed to the south through WL3 (National Survey and Engineering 1989).

Detention Pond "B" will hold drainage water from the north side of the site (Figure 2), and Created Wetland "B" will serve as its overflow basin. Discharge from this pond will occur through a structure under Steam's School Road (National Survey and Engineering 1989).

The construction of only a portion of the created wetland was completed by June 1989. This area (Created Wetland 1989) was 0.81 ha in size (Figure 2). Included in this part of the wetland were three areas (blocks) of sod transplanted from WL1 and WL4. A 20 cm thick layer of donor seed bank material excavated from 0.50 to 0.61 m below the surface of WL1 was spread over the remainder of the created wetland.

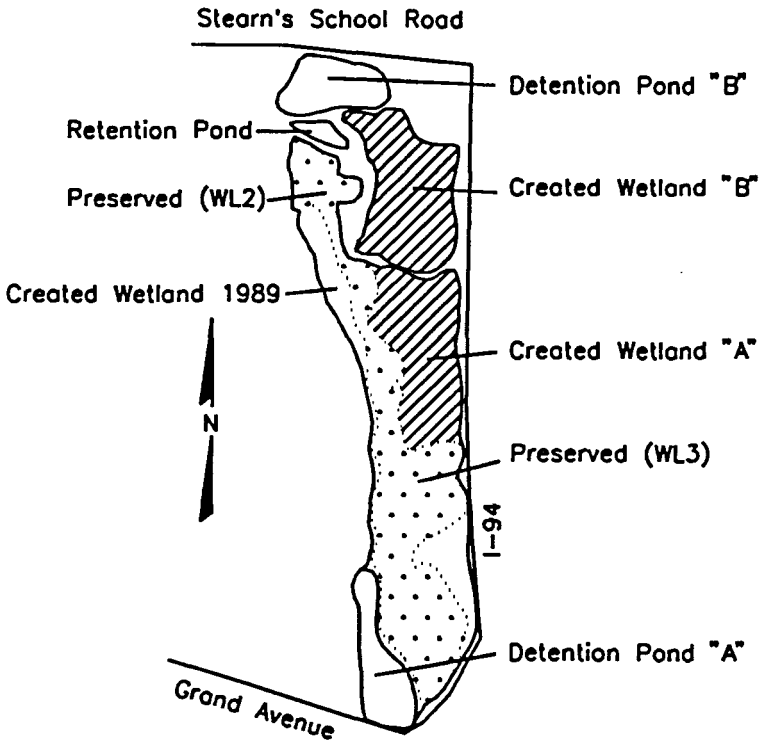

Figure 2. Design for wetland complex on the Gurnee Mills site, including preserved and created wetlands and retention and detention ponds

METHODS

Seed bank study of original wetlands

Soil from four wetlands on the Gurnee Mills site that were to be destroyed was collected in early December 1988. One hundred twenty samples were taken from fifty-seven locations using a stratified random sampling method (Figure 3). Each sample was a composite of two (in the case of WL3, WL4, and WL5) or three (in the case of WL1) 10x10x10 cm blocks of soil. When feasible, soil was collected at two depths: at the surface (excluding large roots and rhizomes) and 25 to 30 cm below the surface. Only one sample could be taken from five sites in WL3 because of the depth of standing water.

Samples were stored at 4^{o} C for two months. In early February 1989, each sample was sieved through 1 cm wire mesh to remove any remaining roots and rhizomes. Sieved soil from a sampling location was used to fill one 20 x 28 x 8 cm plastic tray to a depth of 7 cm. Trays were arranged randomly on a greenhouse bench. Seven additional trays filled with sterilized soil were also put out at random locations to test for seed contamination in the greenhouse. Temperature-controlled propagation mats and 400 watt high pressure sodium lamps were used to create a large (15^{o} to 20^{o} C) daily soil surface temperature fluctuation. Trays received approximately 14 hours of light daily. Photon flux density (400 to 700 nm) under the lamps at tray height and soil temperature in seven selected trays were measured throughout the study using a Li-cor 190SB quantum sensor and thermocouples, respectively. For each parameter, measurements were taken every minute, and hourly averages were recorded on a Campbell 21X data logger. Soil was kept moist by watering with tap water twice per day. After two months, plants were watered once with a 500 ppm solution of 15-15-10 (N-P-K) fertilizer.

Seedlings were assayed over a three month period. Dead seedlings were removed throughout the study. Plants that flowered during the study were also removed before seed set

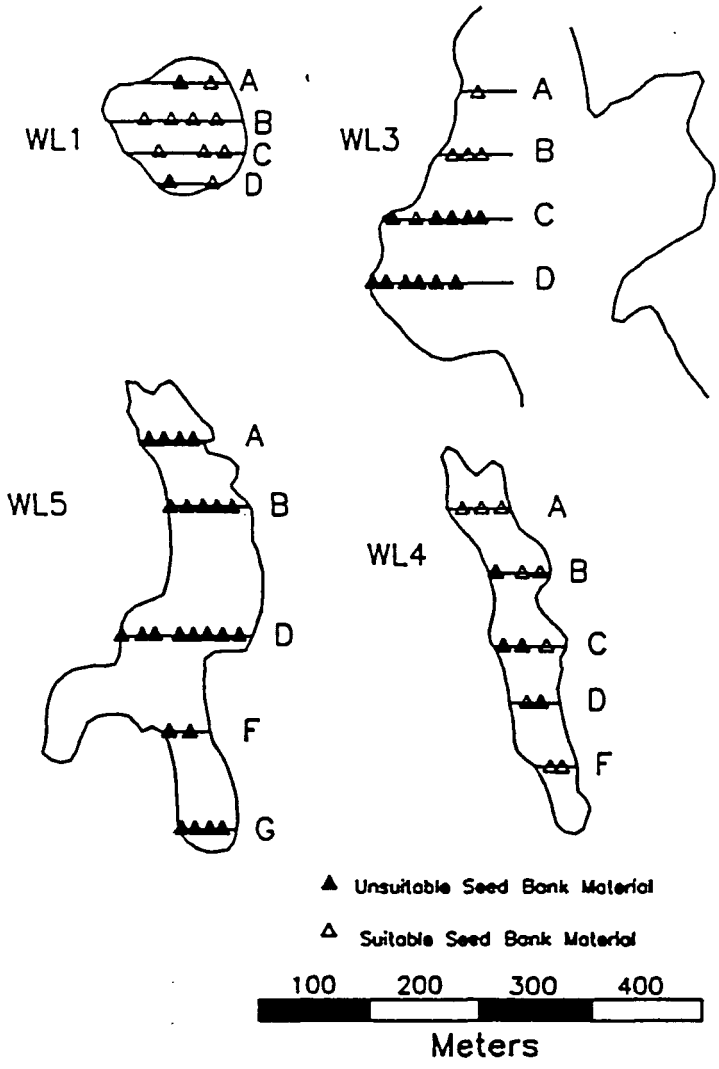

Figure 3. Seed bank sampling locations in wetlands at Gurnee Mills.

to prevent an additional input of seeds to the soil. After three months, representative seedlings of species that were still not identifiable were transplanted to pots and grown until they could be identified. Nomenclature in this study follows Pohl (1978) for grasses and Swink and Wilhelm (1979) for all other groups.

Field study of recruitment from donor soil

Seedling recruitment from donor seed banks was examined in the summer of 1989 at the Gurnee Mills site in a created wetland designed to have sedge meadow vegetation. This created wetland was west of preserved WL2 (Figure 2).

Two areas were covered by a layer of donor seed bank material approximately 20 cm thick and were separated by blocks of sod transplanted from two of the original wetlands (Figure 4). These two experimental areas are designated as "North" and "South" sections. Each section was divided into four plots approximately 5 m x 44 m. The donor seed banks in two of the four plots in each section were randomly chosen for monitoring. The other two plots were seeded with a commercial sedge meadow seed mix, and data from these seeded plots are not included in this paper.

Each plot was divided into three zones. Zone 1, located toward the west side of the area, was roughly 11 meters long and was highest in elevation; Zone 2, 18 m long, was characterized by slight depressions in each section, although most of the zone was at an intermediate level; and Zone 3, nearest the preserved wetland, was 15 m long and the lowest in elevation. Using stratified random sampling of the three zones, twelve 1 m x1 m permanent quadrats were set up in each plot (Figure 4).

Seedlings in the permanent quadrats were counted six times during July and August and once in September. Soil temperature (2 cm below the surface) at 16 locations in these plots was monitored as in the greenhouse study. The plots received only natural precipitation during

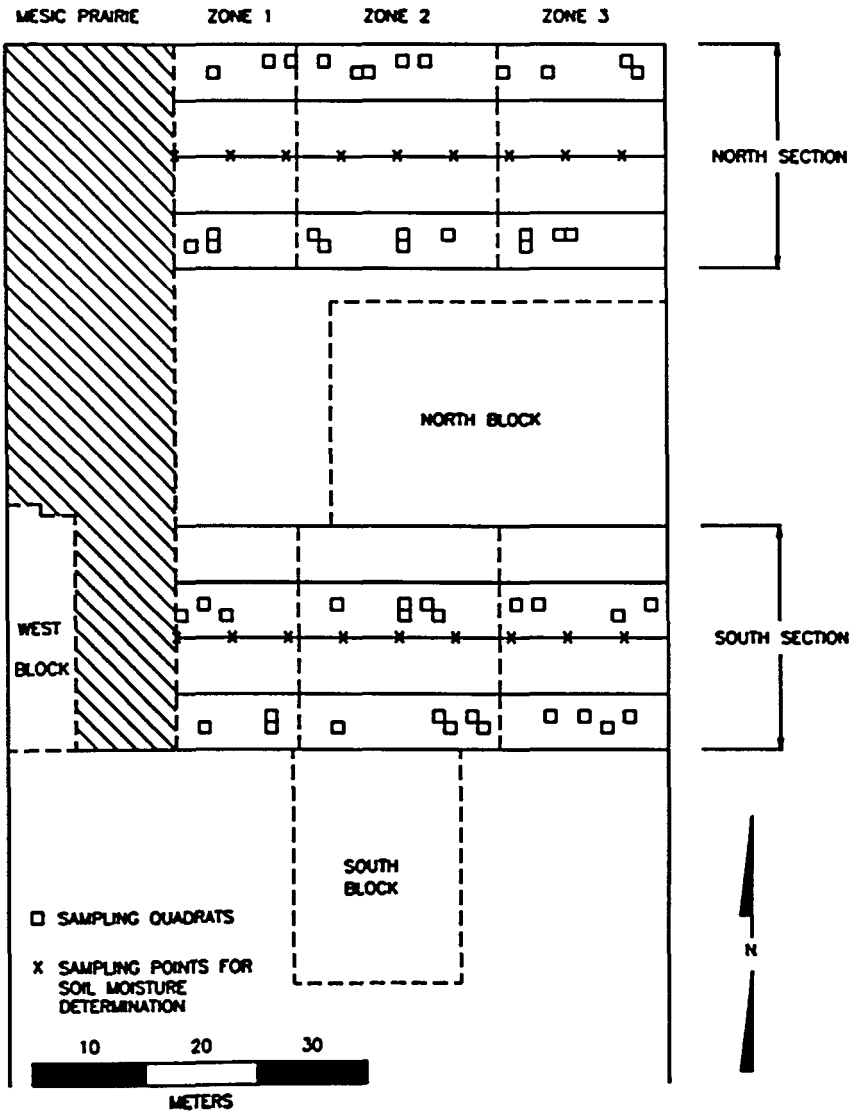

Figure 4. Locations of quadrats used for vegetation sampling and transects in center of each section used for soil moisture determinations of soil moisture in field seed bank study in 1989

June and July; beginning in mid-August the plots were spray-irrigated with water drained from the construction site.

Soil moisture in each section was determined throughout the study. Duplicate soil samples (0.24 l) were collected from the top 4 cm of soil at 5 m intervals along a transect through the center of each section (Figure 4). Each sample was weighed and oven-dried at 100^{o} to 105^{o} C to a constant weight. Moisture was calculated as a percentage of dry weight (Gardner 1986).

RESULTS

Seed bank study of original Gurnee Mills wetlands

In the greenhouse, day length and photon flux density (415 μmol m^{-2} s^{-1} on the average) were comparable to that in late spring and early summer. Daily soil temperatures fluctuated between 7^{o} and 20^{o} C; a weekly cycle is shown in Figure 5.

Appendix A includes a complete list of species present in the seed bank of the four original wetlands. A summary of the number of species and most abundant species in the seed bank samples from each location is given in Appendix B. High seed densities of the undesirable species, *Lythrum salicaria, Phalaris arundinacea,* and *Typha* sp., occurred in WL3, WL4, and WL5.

The seed bank of WL1 contained the fewest species of the five wetlands on the site (Table 1). Many of these species (75%) were emergent or wet meadow species (Table 2). One-third of the species in the seed bank samples of this wetland occurred in only one surface sample. Mean total seed density of both the surface and subsurface seed bank of WL1 was the lowest of all wetlands (Table 3). The most abundant species in surface samples was *Verbena hastata*, which had a mean density of 94 seedlings m^{-2} (Table 3). In subsurface samples, greatest densities were for *Glyceria striata* and *Solanum dulcamara* (Table 3). Its seed bank also contained two species that were considered undesirable, *Phalaris arundinacea* and *Typha* sp. Relatively high seed numbers of these species occurred in surface samples only. *Phalaris arundinacea* was found at only two of the 11 sample sites, and *Typha* sp. was found throughout the wetland.

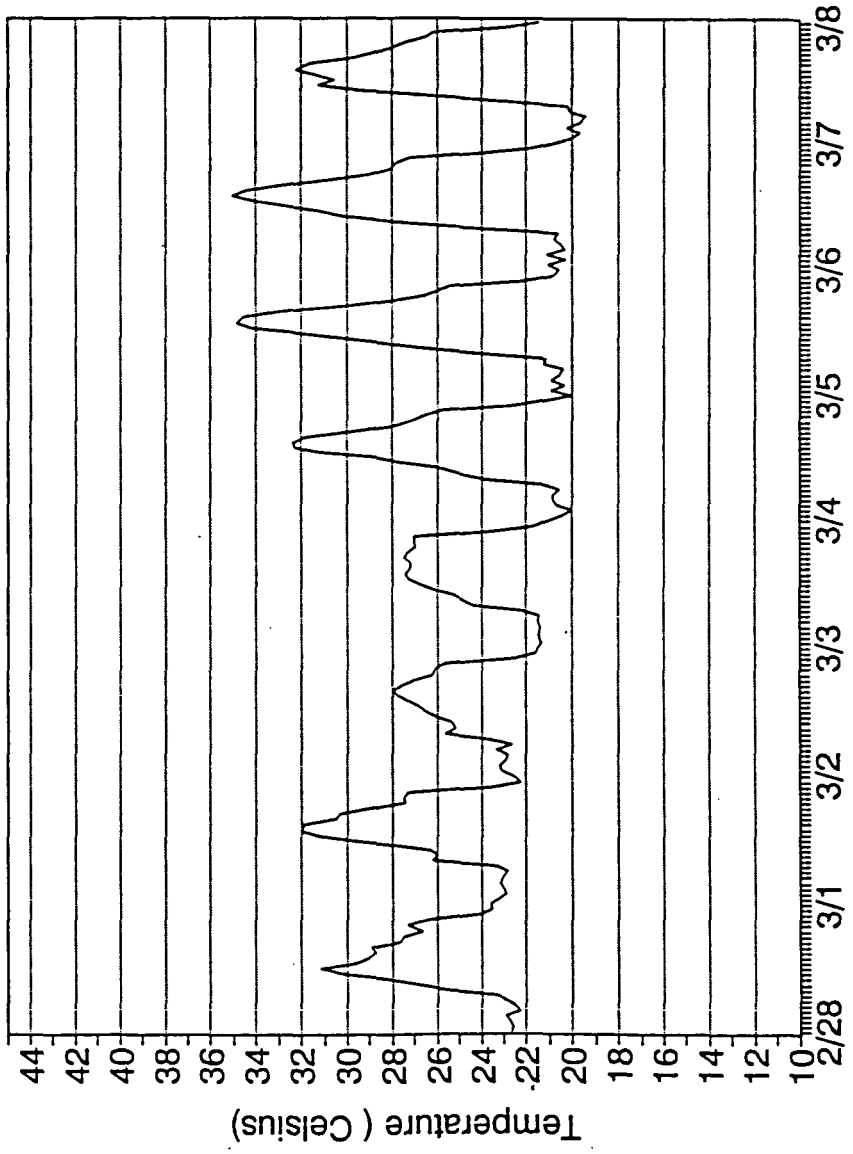

Figure 5. Mean soil surface temperatures in greenhouse trays from 28 February to 8 March 1989

Table 1. Overall species richness and species richness of emergent, wet meadow, and annual species in donor seed bank at each depth (cm) and combined total (T) from various wetlands and in donor soil in the field

	WL1			WL3			WL4			WL5			Field
	0-10	25-30	T	0-10	25-30	T	0-10	25-30	T	0-10	25-30	T	Study
Number of species	49	16	49	55	22	57	52	40	58	51	38	57	63
Emergent[a]	7	4	7	10	7	10	8	7	8	9	7	9	10
Meadow	30	7	30	26	5	26	27	18	28	17	9	19	25
Annual[b]	12	5	12	19	10	21	17	15	20	25	22	28	27

[a]Emergent species include the following genera: *Eleocharis*, *Juncus*, *Phalaris*, *Phragmites*, *Scirpus*, and *Typha*.

[b]Annual species include agricultural and European weeds and grasses.

Table 2. Mean relative density (%) of emergent, wet meadow, and annual species in donor seed banks at each depth (cm) from various wetlands and in donor soil in the field (S.D.=standard deviation)

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Emergent	24	26	61	61	17	24	19	17	15
S.D.	3.6	3.1	10.0	9.4	2.0	3.0	5.2	5.0	1.9
Meadow	52	41	33	19	76	60	58	31	52
S.D.	3.1	7.4	2.1	1.5	9.5	3.9	13.0	8.2	3.5
Annual	23	32	7	19	7	16	23	51	31
S.D.	3.4	8.6	0.37	3.8	0.61	0.95	1.9	5.5	1.5

Table 3. Mean density (seeds m^{-2}) of the most abundant species found in donor seed banks at each depth (cm) from various wetlands and in donor soil in the field (see Table 4 for complete species names). Total includes mean density of minor species

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
A.art.	1.6	0	4.5	1.6	2.7	1.4	186	68	0.13
A.alb.	0	0	1	0	1	0	1	1	0.85
C.lan.	0	0	123	6.5	22	12	5.4	0	0.25
*C.*spp.	0	0	38	8.1	111	5.5	12	10	0.33
C.str.	18	1.6	0	0	0	0	0	0	2.1
E.ell.	1.6	0	13	8.1	22	4.1	4.7	6.2	0.69
E.arv.	0	0	2.2	1.6	0	0	0	0	0.98
G.str.	55	16	23	3.3	8.2	17	0	0	0.13
J.dud.	50	0	79	39	76	15	12	3.1	0.02
J.nod.	0	0	0	1.6	11	15	7.9	3.1	0
L.sal.	0	0	0	0	15	6.9	2460	221	0
L.pal.	0	0	46	0	23	5.5	0	0	0
L.ala.	19	6.5	3.3	1.6	6	0	1.6	0.78	0.08
P.amp.	0	0	0	0	0	0	0	0	0.83
P.lap.	0	0	0	0	0	0	127	12	0
P.per.	0	0	0	0	1.4	4.1	64	43	0
P.aru.	49	4.9	212	11	130	2	721	116	0.04
P.cap.	15	1.6	19	18	28	9.6	364	208	0.04
P.pal.	0	0	7.8	0	1085	40	0	0	0
S.atr.	0	0	7.8	0	54	1.4	0.78	0	0
S.val.	8.1	6.5	17	0	60	19	55	10	0.21
S.dul.	67	16	4.5	0	45	4.1	0	0	0
*T.*sp.	36	6.5	374	31	12	0	38	5.4	0.60
V.has.	94	1.6	35	4.9	161	25	10	0	0.06
Total	623	75	1202	159	2150	254	4515	835	13

Fifty-seven species were found in the seed bank of WL3 (Table 1), including two undesirable species, *Phalaris arundinacea* and *Typha* sp. In both surface and subsurface samples, seedlings of seven species comprised three-fourths of the relative seedling density (Table 2). *Phalaris arundinacea* and *Typha* sp. were the most abundant emergents in the seed bank and had the highest surface densities (Table 3).

The seed bank of WL4 had 58 species (Table 1). Nearly two-thirds of those species were emergents or meadow species (Table 2). High densities of *Proserpinaca palustris* seeds (1100 seeds m^{-2} in surface samples) were found in this wetland (Table 3). Although seeds of

this species were present throughout the area, 96% were found at three sites located toward the center of the wetland. Seeds of several undesirable species, i.e., *Phalaris arundinacea*, *Typha* sp., and *Lythrum salicaria*, were also found; of these, *Phalaris arundinacea* had the highest seed density (Table 3). *Typha* sp. was distributed at low densities throughout the wetland. *Lythrum salicaria* was found at only one site.

Species richness of the seed bank of WL5 was comparable to that of WL4 (Table 1). However, there were more seeds of annuals and grasses in this seed bank, particularly in subsurface samples (Table 2). Seeds of both *Lythrum salicaria* and *Phalaris arundinacea* were found at high densities throughout the wetland, especially at the northern and southern ends of the area.

Recruitment from donor soils

Soil temperature fluctuations over a one-week period are shown in Figure 6. Soil moistures varied throughout the season (Figure 7). Rainfall throughout July and August totalled 17 cm.

Sixty-three species were present in the seed bank of the donor soil applied to the Created Wetland 1989 (Table 1), with seeds of wet meadow and annual species being the most common (Table 2). *Typha* sp. and *Phalaris arundinacea* seeds were present at low densities. Only 13 seeds m^{-2} germinated from the donor soil (Table 3).

Twenty-two of the species found in the permanent quadrats did not occur in any of the seed bank samples. Several of these species, primarily grasses, were recruited from the commercial seed mix planted in adjacent areas. These include *Agrostis alba*, *Avena sativa*, *Lolium perenne*, *Panicum virgatum*, and the composite, *Ratibida pinnata*.

A complete list of species occurring in the seed banks and in the donor soil is given in Table 4.

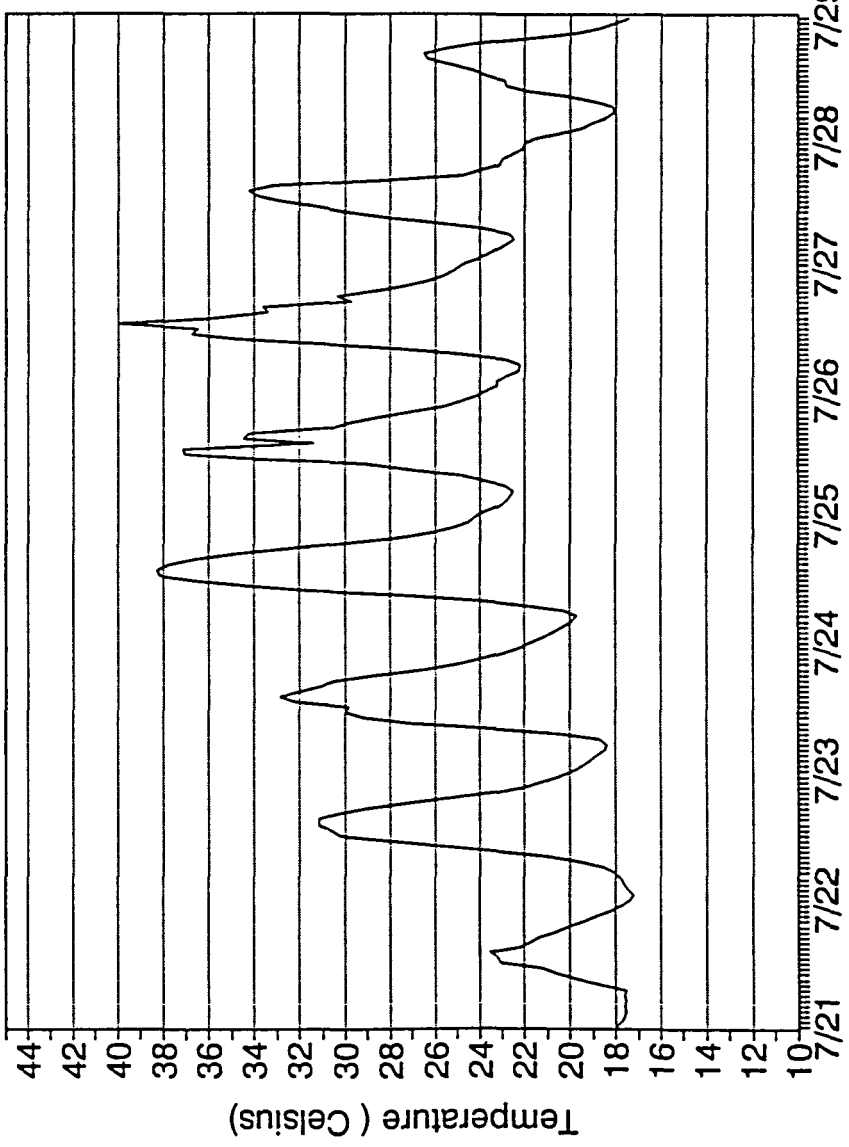

Figure 6. Mean soil temperatures in Created Wetland on Gurnee Mills site from 21 July to 29 July 1989

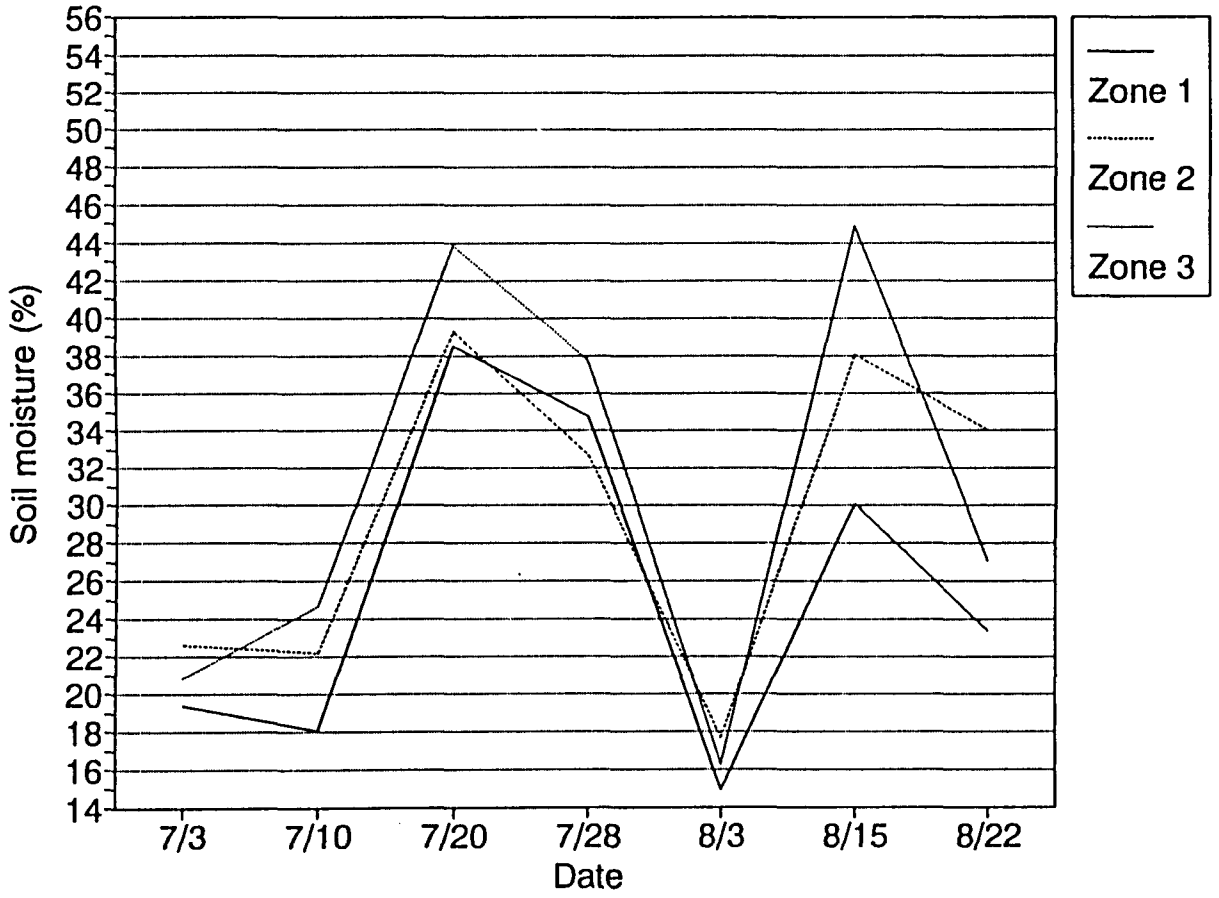

Figure 7. Mean soil moistures for all sample points in North and South sections in each zone in Created Wetland 1989 on Gurnee Mills site

Table 4. Total number of seedlings of each species recruited from donor seed bank material from various wetlands at each depth (cm) and from donor soil in the field

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Abutilon theophrasti Medic.	-	-	1	-	-	-	-	-	-
Acalypha rhomboidea Raf.	-	-	1	-	-	-	2	2	20
Agrostis alba L.	-	-	-	-	-	-	-	-	41
Amaranthus albus L.	1	-	1	1	1	-	104	29	2
Ambrosia artemisiifolia elatior (L.) Descourtils	1	-	4	1	2	1	240	88	6
Apocynum sibiricum Jacq.	-	-	1	-	-	-	-	-	-
Asclepias incarnata L.	14	1	-	-	1	-	-	-	1
Aster novae-angliae L.	1	-	-	-	-	-	-	-	-
Aster simplex Willd.	2	-	5	-	1	1	36	5	-
Avena sativa L.	-	-	-	-	-	-	-	-	11
Barbarea vulgaris R.Br.	-	-	-	-	-	-	-	-	10
Biden frondosa L.	8	-	-	-	28	1	1	-	-
Bidens vulgata Greene	1	-	-	-	-	-	1	1	-
Carex buxbaumii Wahlenb.	-	-	-	-	-	-	-	-	4
Carex granularis Muhl.	-	-	-	-	-	-	-	-	1
Carex lanuginosa Michx.	-	-	110	4	16	9	7	-	12
Carex sartwellii Dew. or *Carex stricta* Lam.	-	-	34	5	81	-	15	13	28
Carex stricta Lam.	11	1	-	-	-	-	-	-	100
Carex stricta Lam. or *Carex lanuginosa* Michx.	-	-	-	-	-	4	-	-	16
Chenopodium album L.	-	-	-	-	-	-	5	-	2
Chrysanthemum leucanthemum pinnatifidum Lecoq & Lamotte	-	-	1	-	-	-	-	-	-
Cirsium arvense L.	3	-	1	-	-	-	1	-	7
Convolvulus sepium (L.) Scop.	-	-	-	-	-	-	-	-	3
Cornus racemosa L.	3	-	1	-	4	1	-	-	10

Table 4. (Continued)

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Daucus carota Lam.	2	-	8	-	10	1	8	1	1
Dulichium arundinaceum (L.) Britt.	1	-	-	-	-	-	-	-	1
Echinacea sp.	-	-	-	-	-	-	-	-	1
Echinochloa crusgalli (L.) Beauv	-	-	-	-	-	-	14	2	15
Eleocharis calva Torr.	-	-	10	2	-	-	6	1	33
Eleocharis elliptica Kunth	1	-	12	5	16	3	6	8	-
Eleocharis sp.	-	-	-	-	-	-	-	-	5
Epilobium coloratum Biehler	1	-	-	-	-	-	-	-	-
Equisetum arvense L.	-	-	2	1	-	-	4	-	47
Eragrostis hypnoides (Lam.) B.S.P.	-	-	-	-	-	-	17	1	
Eragrostis pectinacea (Michx.) Nees	-	-	2	1	-	-	6	10	4
Erechtites hieracifolia (L.) Raf.	1	-	-	-	-	-	-	-	-
Erigeron annuus (L.) Pers.	-	-	1	-	1	-	-	-	-
Erysimum inconspicuum (S.Wats.) MacM.	-	-	-	-	-	-	-	2	-
Eupatorium perfoliatum L.	6	-	20	2	9	-	-	-	-
Eupatorium serotinum Michx.	1	-	8	1	-	-	-	-	-
Euphorbia maculatum L.	-	-	-	-	-	-	1	2	-
Fragaria virginiana Duchesne	3	1	1	-	3	-	4	-	-
Galium obtusum Bigel.	-	-	1	-	-	-	-	-	-
Geum sp.	-	-	-	-	1	-	-	-	1
Glyceria striata (Lam.) Hitchc.	34	10	21	2	6	12	-	-	6
Helenium autumnale L.	-	-	-	-	-	-	-	-	2
Helianthus grosseseratus Martens	11	-	-	-	8	-	1	1	3
Hibiscus trionum L.	-	-	-	-	-	-	4	-	2
Hypericum perforatum L.	-	-	-	-	3	2	-	-	-
Iris virginica shrevei (Small) E.Anders.	1	-	-	-	-	-	-	-	1
Juncus dudleyi Wieg.	31	-	71	24	55	11	15	4	1
Juncus nodosus L.	-	-	5	1	8	11	10	4	-
Juncus sp.	-	-	-	-	-	-	-	-	2

Table 4. (Continued)

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Juncus torreyi Coville	3	1	3	2	5	2	11	-	6
Lathyrus palustris L.	2	1	-	-	-	-	-	-	-
Leersia oryzoides (L.) Sw.	-	1	-	-	2	1	-	-	-
Lolium perenne L.	-	1	-	-	-	-	-	-	4
Ludwigia palustris americana (DC.) Fern. & Grisc.	-	1	41	-	17	4	-	-	2
Ludwigia polycarpa Short & Peter	2	-	8	-	13	7	-	-	-
Lycopus americanus Muhl.	2	-	4	-	7	-	1	-	2
Lycopus virginicus L.	-	-	4	-	-	2	-	-	-
Lythrum alatum Pursh	12	4	3	1	6	-	2	1	4
Lythrum salicaria L.	-	-	-	-	5	7	3169	285	-
Medicago lupulina L.	-	-	6	-	-	-	-	-	4
Melilotus alba Desr.	-	-	-	-	-	-	-	1	5
Mentha arvensis villosa (Benth.) S.R.Stewart	8	-	-	-	14	2	-	-	-
Mimulus ringens L.	-	-	9	-	3	3	-	2	-
Morus rubra L.	-	-	-	-	-	-	-	-	-
Muhlenbergia glomerata (Willd.) Trin.	4	-	1	-	8	1	-	-	2
Oenothera biennis L.	1	-	-	-	1	1	-	-	-
Oxalis stricta L.	-	-	-	-	17	4	1	-	-
Panicum capillare L.	9	1	17	11	20	7	469	268	2
Panicum dichotomiflorum Michx.	-	-	4	-	-	-	-	-	-
Panicum lanuginosum Ell.	-	-	3	-	-	1	-	-	2
Panicum virgatum L.	-	-	-	-	-	-	-	-	13
Penthorum sedoides L.	5	1	9	-	19	2	-	-	-
Phalaris arundinacea L.	30	1	190	7	95	2	928	149	2
Phleum pratense L.	-	-	-	-	-	-	-	-	5
Phragmites australis (Cav.) Trin.	-	-	-	-	-	-	-	-	5
Physalis heterophylla Nees	-	-	-	-	-	-	-	1	-

Table 4. (Continued)

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Plantago major L.	5	2	7	1	9	-	26	17	-
Platanus occidentalis L.	-	-	1	-	-	-	-	-	-
Poa compressa L.	-	-	-	-	-	-	-	-	4
Polygonum amphibium stipulaceum (Coleman) Fern.	-	-	-	-	-	-	-	-	40
Polygonum lapathifolium L.	-	-	-	-	-	-	164	15	-
Polygonum pensylvanicum laevigatum Fern.	-	-	-	-	-	-	57	21	-
Polygonum persicaria L.	-	-	-	-	1	3	82	55	-
Portulaca oleracea L.	-	-	-	-	-	-	-	1	-
Proserpinaca palustris crebra Fern. & Grisc.	-	-	7	-	790	29	-	-	-
Ranunculus flabellaris Raf.	-	-	-	-	11	6	1	-	-
Ratibida pinnata (Vent) Barnh.	-	-	-	-	-	-	-	-	5
Rhamnus cathartica L.	-	-	-	-	-	-	1	-	-
Rhamnus frangula L.	-	-	-	-	-	-	-	-	1
Rhamnus cathartica L.	-	-	-	-	-	-	1	-	-
Rhamnus frangula L.	-	-	-	-	-	-	-	-	1
Rorippa islandica fernaldiana Butt. & Abbe	-	-	1	-	-	-	22	-	-
Rumex crispus L.	-	-	-	-	-	-	1	-	-
Scirpus atrovirens Willd.	-	-	7	-	39	1	1	-	-
Scirpus lineatus Michx.	1	-	4	-	-	-	-	-	-
Scirpus sp. or *Carex atherodes* Spreng.	-	-	-	-	-	-	-	-	1
Scirpus validus creber Fern.	5	4	-	-	44	14	71	13	10
Scutellaria epilobiifolia A. Hamilton	7	-	-	-	-	-	-	-	2
Senecio paupercaulus balsamitae (Muhl.) Fern.	-	-	1	-	-	-	1	-	-
Setaria faberi Herrm.	7	-	-	2	1	-	108	30	28
Setaria lutescens (Weigel) Hubb.	-	-	-	-	-	-	15	4	-

Table 4. (Continued)

	WL1		WL3		WL4		WL5		Field
	0-10	25-30	0-10	25-30	0-10	25-30	0-10	25-30	Study
Solanum americanum Mill.	10	1	1	-	-	1	2	-	1
Solanum dulcamara L.	47	1	4	-	33	3	-	-	-
Solidago gigantea Ait.	1	-	15	-	14	-	97	17	2
Solidago graminifolia nuttallii (Greene) Fern.	1	-	-	-	-	-	-	-	-
Solidago riddellii Frank	2	-	16	-	1	-	-	-	-
Sonchus uliginosus Bieb.	-	-	-	-	-	1	-	-	7
Sonchus asper (L.) Hill	1	1	6	-	2	3	7	1	-
Spartina pectinata Link	-	-	-	-	1	-	-	-	9
Taraxacum officinale Weber	1	-	-	-	-	-	-	-	5
Trifolium agrarium L.	-	-	1	-	3	-	5	2	-
Trifolium repens L.	-	-	-	-	-	1	-	-	-
Trifolium sp.	-	-	-	2	-	-	-	1	-
Typha sp.	22	4	335	19	9	-	49	7	29
Ulmus sp.	-	-	-	-	-	-	-	-	1
Verbascum thapsus L.	-	-	-	-	-	1	-	-	-
Verbena hastata L.	58	1	31	3	117	18	13	-	3
Vitis riparia Michx.	4	-	-	-	2	1	1	11	-
Unknown #1	-	-	-	-	1	-	1	-	-
Unknown #2	-	-	-	-	-	-	-	-	-

DISCUSSION

The initial seed bank study provided information on locations from which to obtain suitable donor soil for the created wetlands on the Gurnee Mills site (see Appendix B). Sites where the seed bank contained large numbers of *Lythrum salicaria*, *Phalaris arundinacea*, and *Typha* sp. were avoided because these species can rapidly colonize disturbed areas and form monotypic stands. High seed densities of annual plants may also inhibit germination of perennial wetland species during drawdowns (van der Valk 1986). Large numbers of these undesirable species and of annual plants occurred in three of the wetlands. Based on the rarity of these species in the seed bank of WL1, this wetland was the best source for donor soil.

Overall, the composition of the seed banks of the original wetlands generally reflected the composition of their vegetation. For example, WL1 had the greatest number of meadow species and the fewest annuals, and WL5 was characterized by agricultural weeds and grasses (Table 2).

Numbers of seeds and numbers of species were higher in surface samples than in subsurface samples of all wetland seed banks. This trend has been shown in other studies as well. About half the number of seeds was found at 1 m and 2 m depths in piles of soil from opencast coal mining compared to surface densities (Dickie *et al.* 1988). In a Missouri study, the number of seeds in a wetland seed bank was found to increase to a depth of 4 cm and then rapidly decrease with increasing depth (Naim 1987), and seeds were found as deep as 20 to 25 cm in some wetlands in Iowa and Manitoba (Pederson and Smith 1988). A decline of seed density with depth is common in many habitats (Moore and Wein 1977).

Germination of seeds from donor soil in the field was extremely poor. Although, on the average, 75 seeds m^{-2} germinated in the initial seed bank study, an average of only 13 seeds m^{-2} germinated from the donor soil in the field (Table 3). Poor field germination could be due to several factors. Donor soil from WL1 was excavated from deeper in the soil profile than was sampled in the initial study. Since the number of seeds in the seed bank has been

shown to decrease with increasing depth, fewer viable seeds may have been present. In addition, incidental observations of the donor soil suggest that it had a higher clay content than the soil sampled for the seed bank study. In similar research in a reclaimed phosphate strip mine in Florida, establishment of wetland plants was inhibited by clayey soil (Clewell 1981).

Timing of the application of the donor soil also is a factor. Seeds often have seasonal requirements for germination (Pederson 1983; Fenner 1985; Roberts 1986). Some seeds may not have germinated until they experienced cooler temperatures in late autumn or winter. In a study of the establishment of vegetation of wetlands restored on CRP land in Wisconsin, there were increases in the number of native species and in the number of wetland plants from one- to two-year-old wetlands (Reinartz and Warne 1990).

Finally, environmental conditions in the field were not ideal for seed germination. Although the donor soil was in place by late May, it was harrowed in early July, prior to the planting of seeded plots. This disturbance may have killed any seedlings that had already emerged. In addition, soil was not always moist throughout the growing season as it was under greenhouse conditions. Lower densities of seedlings in the field study may simply be the result of the much lower soil moisture levels in the field than in the greenhouse (see Part II). In another study, recruitment of species from a seed bank in the Delta Marsh, Manitoba, Canada, was found to be inhibited by low soil moisture (van der Valk and Pederson 1989). Elsewhere, research in a tidal wetland found that fewer seedlings occurred in the field than were suggested by the seed bank, due to differences in physical and biotic stress (Parker and Leck 1985).

On the basis of these results it is difficult to assess the advantages and disadvantages of using donor seed banks to establish vegetation in a created wetland. The seed bank study clearly indicated that seeds of sedge meadow species were present in the seed bank. However, environmental conditions in the field reduced seed germination to such an extent that the seed

bank, at least during the first year, was not very effective. During the second year of the wetland creation project, when more rain fell and some spray-irrigation took place, vegetation in these plots appeared to be more abundant.

Engineers and construction contractors must be made more aware of the ecological realities and environmental conditions needed for the successful establishment of vegetation using donor soil; e.g., the depth from which donor soil is obtained, the season in which the seeds are planted, and the soil moisture levels required for seed germination. These factors must be considered during the design and construction of new wetlands. Unless the proper conditions are created, the vegetation that develops in the new wetlands will not be what was planned.

Further research is needed on the optimal soil moisture requirements for seeds of wetland species. If a suitable donor seed bank is available and favorable environmental conditions occur so that germination requirements can be satisfied, the use of donor seed banks could be an efficient method of creating or restoring wetlands.

LITERATURE CITED

Beauchamp., H., R. Lang, and M. May. 1975. Topsoil as a seed source for reseeding strip mine spoils. Research Journal of the Wyoming Agricultural Experiment Station 90. 8 pp.

Clewell, A. F. 1981. Vegetational restoration techniques on reclaimed phosphate strip mines in Florida. Wetlands 1:158-170.

Dickie, J. B., K. H. Gajjar, P. Birch, and J. A. Harris. 1988. The survival of viable seeds in stored topsoil from opencast coal workings and its implications for site restoration. Biological Conservation 43: 257-265.

Erwin, K. L. and G. R. Best. 1985. Marsh community development in a central Florida phosphate surface-mined reclaimed wetland. Wetlands 5:155-166.

Erwin, K. L., G. R. Best, W. J. Dunn, and P. M. Wallace. 1985. Marsh and forested wetland reclamation of a central Florida phosphate mine. Wetlands 4:87-104.

Fenner, M. 1985. Seed ecology. Chapman and Hall, New York, New York. 151 pp.

Gardner, W. H. 1986. Water content. Pages 493-544 *in* A. Klute, editor. Methods of soil analysis, Part 1: Physical and mineralogical methods, Second edition. American Society of Agronomists, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin.

Kelsey, P. and R. Hootman. 1990. Soil investigation of five wetland areas on the Gurnee Mills Shopping Mall site, Gurnee, Illinois. Kelsey and Associates, Aurora, Illinois. 34 pp.

Kelsey, P., R. Hootman, and J. Mengler. 1988. Environmental assessment of the Gurnee Mills project site. Kelsey and Associates, Aurora, Illinois. 29 pp.

Leck, M. A., V. T. Parker and R. L. Simpson. 1989. Ecology of soil seed banks. Academic Press, San Diego, California. 462 pp.

Major, J. and W. J. Pyott. 1966. Buried, viable seeds in two California bunchgrass sites and their bearing on the definition of a flora. Vegetatio 13:253-282.

Moore, J. M. and R. W. Wein. 1977. Viable seed populations by soil depth and potential site recolonization after disturbance. Canadian Journal of Botany 55:2408-2412.

Naim, P. A. 1987. Wetland seed banks: Implications in vegetation management. Ph. D. dissertation. Iowa State University, Ames, Iowa. 93 pp.

National Survey and Engineering. 1989. Stormwater management report for Gurnee Mills, Village of Gurnee, Illinois. National Survey and Engineering, Brookfield, Wisconsin. [unpaged mimeograph].

Parker, V. T. and M. A. Leck. 1985. Relationships of seed banks to plant distribution patterns in a freshwater tidal wetland. American Journal of Botany 72:161-174.

Pederson, R. L. 1983. Abundance, distribution, and diversity of buried seed populations in the Delta Marsh, Manitoba, Canada. Ph. D. dissertation. Iowa State University, Ames, Iowa. 97 pp.

Pederson, R. L. and L. M. Smith. 1988. Implications of wetland seed bank research: A review of Great Basin and prairie marsh studies. Pages 81-95 in D. A. Wilcox, editor. Interdisciplinary approaches to freshwater wetlands research. Michigan State University Press, East Lansing, Michigan.

Pohl, R. W. 1978. How to know the grasses. Third edition. Wm. C. Brown Company Publishers, Dubuque, Iowa. 200 pp.

Roberts, H. A. 1981. Seed banks in soils. Advances in Applied Biology 6:1-55.

Roberts, H. A. 1986. Seed persistence in soil and seasonal emergence in plant species from different habitats. Journal of Applied Ecology 23:639-654.

Reinartz, J. A. and E. Warne. 1990. Development of vegetation in wetlands restored on Ozaukee County Conservation Reserve Program lands. Field Station Bulletin, University of Wisconsin-Milwaukee 23:18-24.

Ross, D., C. Kocur, and W. Jurgens. 1985. Wetlands creation techniques for heavy construction equipment. Pages 210-220 *in* F. G. Webb, editor. Proceedings of the 12th annual conference on wetlands restoration and creation. Hillsborough Community College, Tampa, Florida.

Swink, F. and G. Wilhelm. 1979. Plants of the Chicago region. The Morton Arboretum, Lisle, Illinois. 922 pp.

Thompson, K. and J. P. Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. Journal of Ecology 67:893-921.

van der Valk, A. G. 1986. The impact of litter and annual plants in recruitment from the seed bank of a lacustrine wetland. Aquatic Botany 24:13-26.

van der Valk, A. G. and C. B. Davis. 1976. The seed banks of prairie glacial marshes. Canadian Journal of Botany 54:1832-1838.

van der Valk, A. G. and C. B. Davis. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. Ecology 59:322-335.

van der Valk, A. G and C. H. Welling. 1988. The development of zonation in freshwater wetlands: An experimental approach. Pages 145-158 *in* H. J. During, M. J. A. Werger, and J. H. Williams, editors. Diversity and pattern in plant communities. SPB Academic Publishing, the Hague, the Netherlands.

van der Valk, A. G. and R. L. Pederson. 1989. Seed banks and the management and restoration of natural vegetation. Pages 329-346 *in* M. A. Leck, V. T. Parker, and R. L. Simpson, editors. Ecology of soil seed banks. Academic Press, San Diego, California.

Worthington, T. R. and D. R. Helliwell. 1987. Transference of semi-natural grassland and marshland onto newly created landfill. Biological Conservation 41:301-307.

PART II.

RECRUITMENT OF SPECIES FROM SEED ALONG A SOIL MOISTURE GRADIENT UNDER GREENHOUSE AND FIELD CONDITIONS

ABSTRACT

Greenhouse and field studies were conducted on recruitment from a commercial seed mix added to a donor seed bank at various soil moisture levels. In the greenhouse, mean seedling densities were significantly different among all soil moisture treatments except the two driest. Mean species richness (16 species per tray) and mean maximum seedling densities (78 seedlings per tray) occurred when trays were kept moist, i.e., watered daily. Sedges and many wet meadow species, primarily from the seed mix, germinated best in this treatment, while annuals and grasses from the seed bank were recruited in the driest treatments.

In the field, soil moisture was lower than in the greenhouse studies, and many meadow species did not germinate. Seedling densities in the two driest soil moisture treatments were significantly different from those in the wettest. Mean species richness (27 species m^{-2}) and mean maximum seedling densities (1249 seedlings m^{-2}) occurred in the wettest treatment. As in the greenhouse, most of the species recruited in the wettest treatments were from the seed mix, and the annuals and grasses that became established in the drier treatments came primarily from the seed bank.

These results show that soil moisture conditions can significantly affect the composition of thevegetation in newly established wetlands. The seed bank was not as important as the commercial seed mix for establishing vegetation in both the greenhouse and the field.

INTRODUCTION

Establishing sedge meadow species from seed in wetland restoration and creation projects has only recently been attempted in the Midwest. As a result, little is known about how this can best be accomplished. Some studies suggest that germination requirements for wetland plants are very specific (Galinato and van der Valk 1986; Apfelbaum *et al.* 1989). This implies that the season of the year when seeds are sown is important (Thompson and Grime 1979; Leck and Simpson 1987; Baskin and Baskin 1988), because environmental factors such as soil temperature and light quantity and quality can significantly affect seed germination (Grime *et al.* 1981; Galinato and van der Valk 1986; Baskin *et al.* 1989; Kerans 1990).

Little attention has been given to the effects of soil moisture on seed germination. Seeds of species commonly found in wetland seed banks often have different moisture requirements for germination (van der Valk and Davis 1978; van der Valk 1981), and recruitment of some wetland species can be restricted to certain areas along a moisture or water depth gradient (Keddy and Ellis 1985; Welling *et al.* 1988). Nevertheless, seeds of many wetland species germinate over a broad range of soil moisture conditions (Keddy and Ellis 1985).

In wetland creation, commercial seed mixes are customarily used to establish vegetation. These seed mixes are designed for a range of soil moisture conditions with the expectation that different species will germinate along different positions of the moisture gradient (Paul Sherbeyn, Lafayette Home Nursery, Lafayette, IL, personal communication). Specific soil moisture requirements for germination of seeds of different species in these commercial mixes, however, has not been investigated.

In some situations, commercial seed mixes are used in conjunction with a donor seed bank, a layer of soil collected from an area with desired vegetation that contains a reserve of ungerminated, viable seeds. When this approach is taken, the composition of the mix may be

altered to provide seeds of species not found in the donor seed bank (Brown *et al.* 1985; van der Valk and Verhoeven 1988). This method of supplementing a donor seed bank with a commercial seed mix was used to establish vegetation in created wetlands at a site near Gurnee, Illinois. Wetlands were created at this site to mitigate for the loss of several wetlands due to construction of a shopping mall. Soil from the destroyed wetlands was used to establish a seed bank in portions of the created wetlands (see Part I).

The primary purpose of this study was to document recruitment of species in a commercial seed mix at different soil moistures under greenhouse and field conditions to determine the optimal soil moisture conditions for establishing different species. In both greenhouse and field studies, the seed mix was sown in donor soil from a natural wetland. Therefore, I was also investigating the effectiveness of using a seed mix to supplement donor seed banks for establishing vegetation. In addition, two seed germinability tests were performed to estimate the potential seed germination percentages of seeds of species in the seed mix.

METHODS

Seed germinability tests

Seed germinability was tested in the greenhouse by placing 50 seeds each of 20 species on Whatman #1 filter paper in a 15 x 100 mm plastic Petri dish. There were two replicates for each species. The Petri dishes were placed at random on a greenhouse bench, and tap water was added as needed to keep the seeds moist. Seeds were regarded as germinated when they had roots longer than 0.5 cm. Seed germination was monitored over a 6-week period. These studies were done at the same time as the greenhouse seed germination studies described in the next section.

A second standard seed germinability test was performed in the ISU Seed Science Laboratory. One hundred seeds of each species were placed in plastic crispers (15 x 23 x 5 cm) on moist blotters. Crispers were placed in a growth chamber which provided 8 hours of light at 30^{o} C and 16 hours of darkness at 20^{o} C. *Solidago rigida* seeds were pre-chilled at 10^{o} C for two weeks prior to this treatment. A second lot of 100 seeds of *Gentiana andrewsii* was similarly pre-chilled before testing.

Greenhouse study

Soil used for this experiment was collected from a subsurface layer (25 to 30 cm deep) from two wetlands that were to be destroyed on the site of a proposed shopping mall near Gurnee, Illinois. Because it contained a seed bank of desirable wetland plants, this soil also served as a donor seed source for a wetland created on the site. Some of the soil was collected in December 1988 and stored at 4^{o} C for 13 months. Additional subsurface soil from one of the wetlands was collected in September 1989. This soil had been stockpiled for three months during construction for later use in the created wetland (see Part I) and was kept in cold storage for four months. In late January 1990, soil from both collection dates was sieved through 1 cm wire mesh to remove large roots and rhizomes. Soil from both collections was then thoroughly mixed using a rotary cement mixer.

Seeds of the 20 sedge meadow and mesic prairie species selected for the study were obtained from Lafayette Home Nursery, Lafayette, Illinois (Table 1). This nursery supplied seed for the created wetland and surrounding sedge meadow areas on the Gurnee Mills site. In early February 1990, 20 seeds of each species were planted in each of 24 trays (20 cm x 28 cm x 8 cm) filled with the mixed soil to within 1 cm of the top of the tray. Exceptions to this were *Aster praeltus*, *Aster puniceus*, and *Iris virginiana* for which 7, 7, and 3 seeds per tray were planted, respectively. Soil in the trays was wetted with about 500 ml of tap water one day prior to planting. Seeds were scattered over the soil surface in each tray and then covered with 1 cm of sieved wetland soil. All trays were arranged randomly on a greenhouse bench. Steam-sterilized greenhouse soil was put in 12 additional trays placed at random on the greenhouse bench to test for any seed contamination in the greenhouse.

Soil temperatures were controlled using 400 watt high pressure sodium lamps and electric propagation mats. Trays received 14 hours of light daily, and photon flux density (453 $\mu mol\ m^{-2}\ s^{-1}$ on the average) was comparable to normal daylight in late spring and early summer. Throughout the experiment soil surface temperatures in 13 selected trays were measured with thermocouples every minute and recorded as an hourly average on a Campbell 21X data logger.

Soil temperatures for a representative one-week period are shown in Figure 1. Differences in the four soil moisture treatments were maintained by adding 250 ml of tap water (approximately the amount required to saturate the soil after drying for one day) to each tray at four intervals: 1) twice daily, 2) once daily, 3) every other day, and 4) every third day. Soil in the wettest treatment became saturated early in the study, and the addition of 250 ml could sometimes cause the tray to overflow. When this occurred, only as much water was added as the tray would hold without overflowing. Each tray was weighed immediately after seeds were planted and periodically throughout the study. Soil (0.24 l) was collected from each tray at the

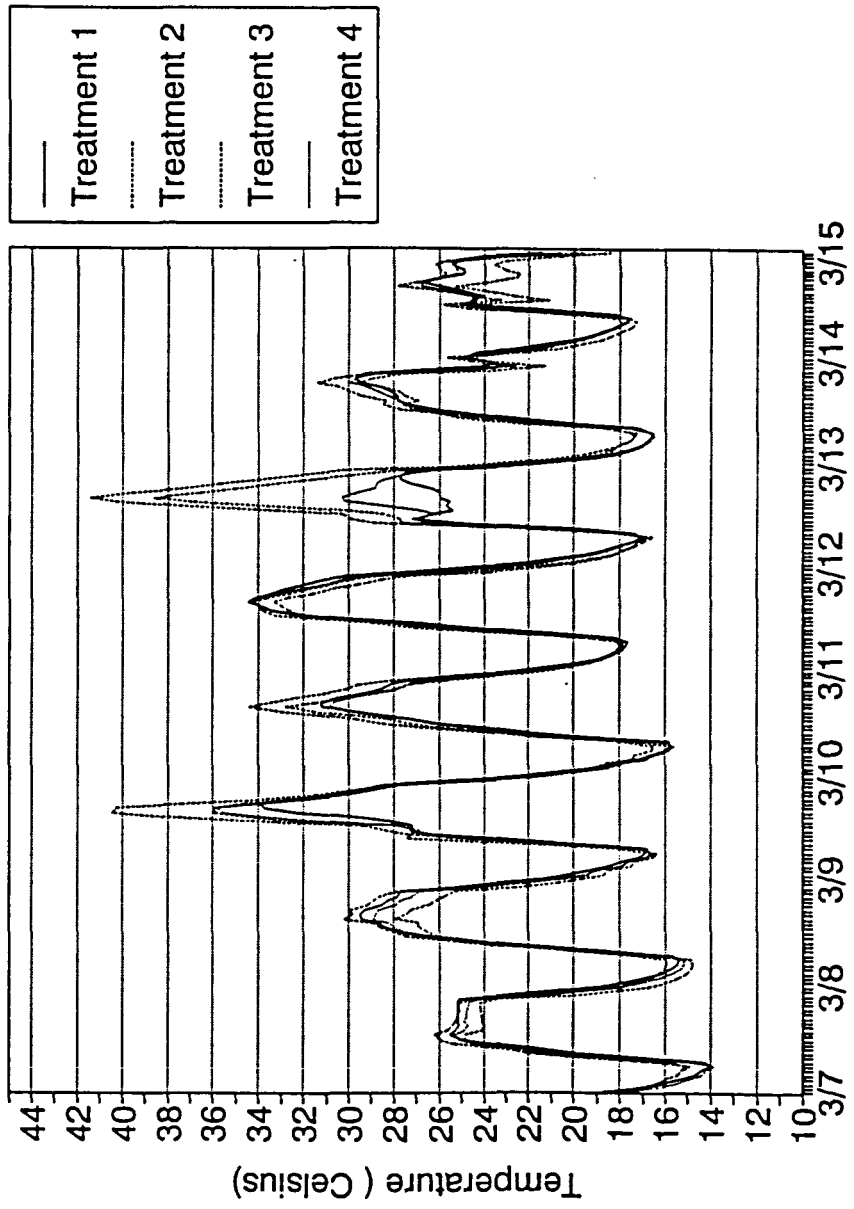

Figure 1. Mean soil surface temperatures in greenhouse trays from 7 March to 15 March 1990

conclusion of the 11-week study, weighed, and dried at 100^{o} to 105^{o} C to a constant weight. Percent soil moisture was then calculated (Gardner 1986). This value was used to estimate mean percent soil moisture throughout the study (Table 2). Seedlings were counted twice weekly and identified as this became possible. Nomenclature follows Pohl (1978) for grasses and Swink and Wilhelm (1979) for all other species.

Field study

In 1990, a second soil moisture study was performed in a newly created wetland at the Gurnee Mills shopping mall site, Gurnee, Illinois. The 142 hectare site includes a wetland complex approximately 22 ha in size that consists of both natural wetlands and adjacent areas of newly created wetland (Figure 2). A layer of donor soil approximately 20 cm thick from a wetland that was destroyed due to mall construction had been spread over the newly created wetland areas to provide a donor seed bank. Previous studies indicated that the seed bank of the original wetland contained a diversity of wetland species (see Part I).

The experimental area used for this study was located along the North edge of an open water area of Created Wetland "B", directly south of Detention Pond "B" (Figure 2). This site was selected for its close proximity to a water source and low probability of flooding. Thirty-one 1 m x 1 m permanent quadrats were arranged randomly at the site, with quadrats at least one meter apart. Permanent quadrats were delimited with 10 cm wide plastic lawn edging pressed into the soil in order to reduce the amount of water leaving the quadrat. The soil had been prepared for planting with a harrow and was also smoothed with a metal-tined rake immediately prior to planting.

Approximately 43 g of a commercial seed mix from Lafayette Home Nursery, Lafayette, Illinois, was planted by hand in each of the plots in early June. The seed mix contained seeds of wetland, wet prairie, and mesic prairie species. See Appendix C for a complete species list.

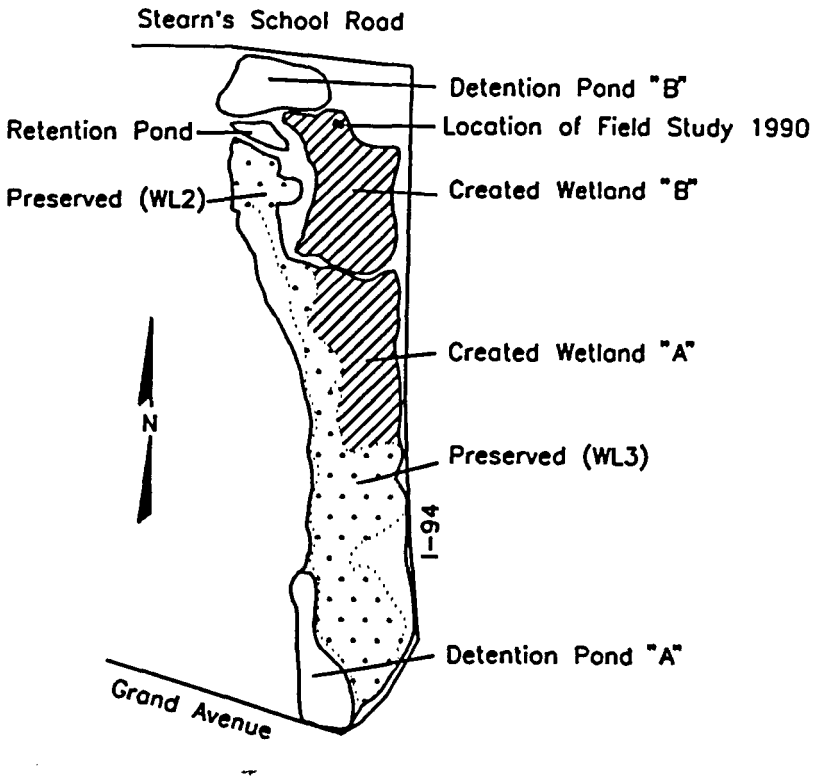

Figure 2. Design for wetland complex on the Gurnee Mills site, including preserved and created wetlands and retention and detention ponds

Soil moisture differences were maintained with four watering frequencies: 1) alternating watering once one day with watering twice the following day, 2) once a day, 3) every other day, and 4) not watered. Seven liters of water, obtained from Detention Pond "B," were used per quadrat when watered. Quadrats were not watered on days when it rained. Gravimetric analysis of soil moisture from quadrats of each treatment was determined weekly as described previously. Soil temperatures (2 to 4 cm deep) of 15 selected quadrats were monitored with thermocouples from 8 June to 8 August; temperatures were measured every minute and were stored as an hourly average on a Campbell 21X data logger (Figure 3).

Seedlings were counted bi-weekly and identified as it became possible. Seven subplots (15 cm x 15 cm) per quadrat were counted when seedlings became too numerous to count in the entire quadrat.

Data were analyzed with a one-way analysis of variance using SAS (SAS Institute 1985). If treatment effects were significant, pairwise comparisons of means were made using Fisher's protected least significant difference (LSD). In the greenhouse study, *Carex* species were not distinguishable from each other and were grouped as one taxon in the analysis. A similar procedure was followed for the seedlings that died before they could be identified. Species were divided into two categories in the ANOVA's for each study: (a) in the greenhouse study, sedges and grasses (which included *Acorus calamus*, *Carex* spp., *Scirpus* spp., and all grasses) were combined into one group while the second group, forbs, contained all other species; and (b) in the field, grasses were combined into one group and all other species were combined into a group called forbs.

Species similarity for treatments (j, k) using presence-absence data was calculated using the following equation:

$$PS_{jk} = [2W/(A+B)](100)$$

where $W = \Sigma [\min(X_{ij}, X_{ik})]$, $A = \Sigma X_{ij}$, $B = \Sigma X_{ik}$ (Ludwig and Reynolds 1988).

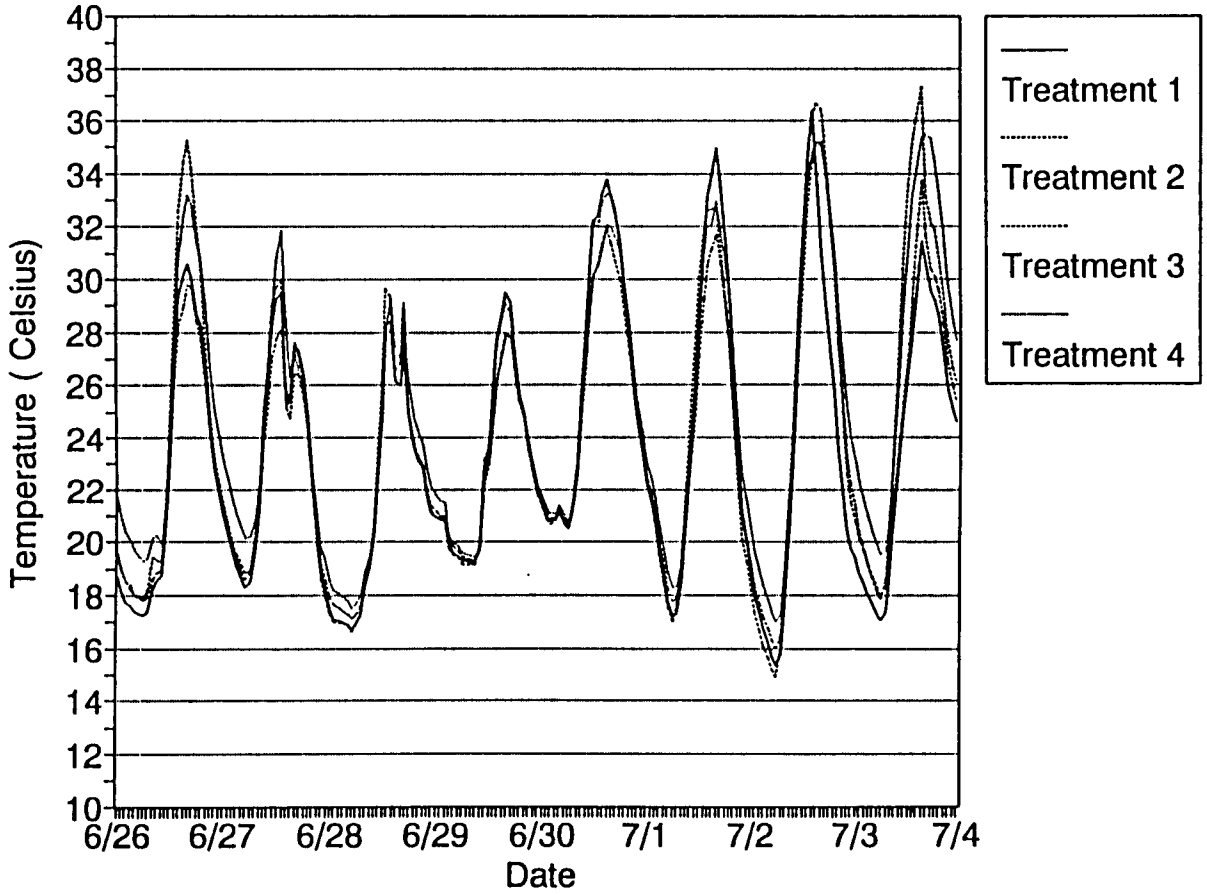

Figure 3. Mean soil temperatures in quadrats in Created Wetland "B" on Gurnee Mills site from 26 June and 4 July 1990

RESULTS

Seed germinability tests

Seeds of most species had low germinability, but more seeds germinated under greenhouse conditions (Table 1). *Acorus calamus*, *Carex annectens*, and *Helenium autumnale* had the highest percent seed germination under greenhouse conditions. Maximum germination percentages of seeds planted in soil in the trays in the greenhouse are also shown; overall, the

Table 1. Percent germination of seeds in germinability tests under standard seed laboratory (STD) and greenhouse (GH) conditions and maximum percent germination of seeds emerging in any one treatment in greenhouse trays (SOIL)

Species	STD	GH	SOIL
Acorus calamus	7	77	55
Andropogon gerardi	0	0	0
Aster praeltus	15	5	0
Aster puniceus	0	0	0
Carex annectens	57	55	-[a]
Carex aquatilis	12	21	-[a]
Carex lacustris	0	0	-[a]
Carex vulpinoidea	0	0	-[a]
Echinacea pallida	2	6	3
Eupatorium maculatum	3	15	23
Gentiana andrewsii	1	20	0
Glyceria striata	0	0	15
Helenium autumnale	4	90	24
Iris virginiana	-	-	1
Monarda fistulosa	46	44	23
Pycnanthemum virginicum	8	2	1
Scirpus acutus	0	0	1[b]
Scirpus lineatus	0	0	1[b]
Solidago riddellii	0	0	-[c]
Solidago rigida	36	5	12[c]
Overall mean	9.6	17.0	9.9

[a]Germinability of indistinguishable *Carex* spp. combined was 17%.
[b]Germinability of indistinguishable *Scirpus* spp. combined was 1%.
[c]Germinability of indistinguishable *Solidago* spp. combined was 20%.

same number of seeds germinated in the soil as under standard seed laboratory conditions (Table 1). Except for *Acorus calamus* and the two *Scirpus* species, which germinated best in the wettest treatments, seed germination was highest in the daily watering treatment.

Greenhouse study

Mean soil moistures, except for those in the two driest treatments, were significantly different from each other (Table 2). These differences affected both species composition and density. Twelve taxa that were identifiable to species germinated from the seed mix in the greenhouse study. Seeds of 16 species, ten of which had been sown, germinated in the daily watering treatment which had a mean soil moisture of around 50% (Table 3). Only three species, all from the seed bank, germinated in the driest treatment that had a mean soil moisture of 22%. Percent species similarity among the three wettest treatments was around 50%, but was only 14% to 21% between the two wettest and the two driest treatments (Table 4).

Table 2. Mean percent soil moisture by treatment[a] (TRT) ($P<0.0001$). Standard errors are given in parentheses

	TRT 1	TRT 2	TRT 3	TRT 4	5% LSD
Greenhouse	60.3 (0.37)	49.4 (0.54)	25.6 (0.53)	21.6 (0.62)	6.4
Field	33.6 (0.88)	30.2 (1.33)	23.7 (1.30)	19.3 (1.62)	4.1

[a]Treatments in this and subsequent tables were the following watering frequencies: 1) twice daily (greenhouse) or alternately watering once one day with watering twice the following day (field), 2) once a day, 3) every other day, and 4) every third day (greenhouse) or not watered (field).

Table 3. Mean number of species germinating from the seed mix and the seed bank (TOT) and from the seed mix only (SM). Standard errors are given in parentheses (P<0.0001)

	TRT 1		TRT 2		TRT 3		TRT 4		5% LSD	
	TOT	SM	TOT	SM	TOT	SM	TOT	SM	TOT	SM
Greenhouse (N=24)	8.3 (0.49)	5.8 (0.31)	16.3 (1.15)	10.2 (0.31)	5.0 (0.68)	2.8 (0.40)	2.7 (0.76)	0.3 (0.33)	2.4	1.0
Field (N=31)	27.1 (1.33)	12.0 (0.60)	25.9 (1.14)	10.6 (0.43)	21.4 (0.80)	9.9 (0.40)	20.8 (1.03)	9.5 (0.85)	3.1	0.8

Table 4. Percent species similarity between treatments for all species germinating in each treatment in greenhouse study

Treatment	1	2	3	4
1	100	49	50	21
2		100	49	14
3			100	14
4				100

Mean seedling densities are summarized in Tables 5 and 6 and ANOVA's are given in Tables 7 and 8. Seedling densities were highest in trays watered daily. For total density, means were significantly different among all treatments except for the two driest. Ninety-one percent of all seeds that germinated in the daily watering treatment were recruited from the seed mix, but the seed bank became more important in drier treatments, where only 8% of the seeds that germinated were from the seed mix. *Carex* spp. and *Glyceria striata* germinated best when soil was watered daily, as did the wet meadow species *Eupatorium maculatum, Ludwigia polycarpa, Lythrum alatum, Helenium autumnale, Monarda fistulosa,* and *Verbena hastata. Convolvulus sepium, Helianthus grosseserratus, Polygonum persicaria, Setaria faberi,* and*Vitis riparia* germinated best under drier conditions. *Ambrosia artemisiifolia* seeds germinated equally well in treatments watered daily and every other day, but this species made up over one-fourth of the total density of seedlings recruited in the drier treatments.

Table 5. Mean density (seedlings tray^{-1}) of species recruited from the seed mix and the seed bank during greenhouse study (N=24). Standard errors are given in parentheses

	TRT 1	TRT 2	TRT 3	TRT 4	5% LSD
Forb	15.8	52.3	6.5	2.3	6.5
	(1.4)	(14.0)	(1.6)	(1.0)	
Sedge	26.5	25.7	2.7	1.3	20.9
	(2.6)	(3.2)	(1.4)	(0.5)	
Total	42.3	78.0	9.2	3.7	24.3
	(3.5)	(16.0)	(1.9)	(1.3)	

Table 6. Mean density (seedlings tray^{-1}) of species recruited from the seed mix during greenhouse study (N=24). Standard errors are shown in parentheses

	TRT 1	TRT 2	TRT 3	TRT 4	5% LSD
Forb	15.0	31.2	4.0	0.3	4.9
	(1.4)	(2.8)	(1.3)	(0.3)	
Sedge	23.7	23.0	2.5	0.0	5.9
	(2.4)	(2.9)	(1.4)	(0.0)	
Total	38.7	54.2	6.5	0.3	9.1
	(3.5)	(4.9)	(1.6)	(0.3)	

Table 7. ANOVA for seedling density in greenhouse study

Source	DF	Mean Square	F Value	Pr>F
Forb				
Treatment	3	3109.83	10.36	0.0001
Error	20	300.05		
Sedge				
Treatment	3	1162.49	39.57	0.0003
Error	20	29.38		
Total				
Treatment	3	7080.49	17.38	0.0001
Error	20	407.48		

Echinochloa crusgalli also germinated best at very high and very low soil moistures.

Essentially only annuals and grasses from the seed bank were recruited in the driest treatment.

The most abundant species are shown in Table 9. Two of the species that were in the

seed mix, *Acorus calamus* and *Carex* spp., were the most abundant species in the wettest treatments. The seed-bank annual *Ambrosia artemisiifolia* was most abundant in the trays watered every third day.

Table 8. ANOVA for seedling density of species recruited from the seed mix in greenhouse study

Source	DF	Mean Square	F Value	Pr>F
Forb				
Treatment	3	1149.82	68.41	0.0001
Error	20	16.81		
Sedge				
Treatment	3	982.04	1.02	0.0001
Error	20	23.94		
Total				
Treatment	3	3976.28	69.21	0.0001
Error	20	57.45		

Table 9. Total number of seedlings of selected species germinating in greenhouse study. Relative abundance within each treatment is given in parentheses

Species	TRT 1	TRT 2	TRT 3	TRT 4
Acorus calamus	66 (26%)	34 (9%)	3 (5%)	0 (0%)
Ambrosia artemisiifolia	1 (<1%)	5 (1%)	3 (5%)	6 (27%)
Carex spp.	72 (28%)	83 (22%)	11 (19%)	0 (0%)
Echinochloa crusgalli	4 (2%)	1 (<1%)	0 (0%)	4 (10%)
Monarda fistulosa	7 (3%)	27 (7%)	13 (22%)	0 (0%)
unidentified forbs	53 (21%)	49 (13%)	9 (15%)	1 (5%)

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Field study

Overall, soil moistures in the field study were lower than in the greenhouse study (Table 2). Mean number of species did not vary as much among treatments as in the greenhouse study (Table 3), and percent species similarity among soil moisture treatments ranged from 71% to 90% (Table 10).

Twenty-four identifiable species, including the matrix grasses, *Avena sativa* and *Lolium perenne*, were recruited from the commercial mix. These species accounted for a higher percentage of forbs than of grasses. Forty-seven species, mostly annuals, were recruited from the seed bank. Of these species, 40% in the wettest treatment were annuals and grasses; these species increased to 46%, 54%, and 51% for the drier treatments. Relative densities of these annual species also changed considerably, from 4.7% in the wettest quadrats to 10% in the three drier treatments. Species that germinated best in the wettest treatment were *Andropogon gerardi, Asclepias incarnata, Echinacea purpurea, Liatris* sp., *Ratibida pinnata,* and *Panicum virgatum. Agrostis alba, Polygonum pensylvanicum* , and *Rudbeckia hirta* germinated similarly in the wettest and driest treatments. *Ambrosia artemisiifolia, Hibiscus trionum, Coreopsis lanceolata,* and *Setaria faberi* germinated best under drier conditions.

Only in the two driest treatments were seedling densities significantly different from those in the wettest (Tables 11 and 12). Seedling densities of species recruited from the

Table 10. Percent species similarity for all species in each treatment in field study

Treatment	1	2	3	4
1	100	79	84	76
2		100	74	71
3			100	90
4				100

Table 11. ANOVA for seedling density of species recruited from the seed mix and the seed bank in field study

Source	DF	Mean Square	F Value	Pr>F
Forb				
Treatment	3	60283.37	2.72	0.0642
Error	27	22170.63		
Grass				
Treatment	3	418658.66	3.27	0.0365
Error	27	128114.32		
Total				
Treatment	3	729275.20	3.37	0.0328
Error	27	216134.75		

Table 12. Mean density (seedlings m^{-2}) of species recruited from the seed mix and the seed bank in quadrats during field study (N=31). Standard errors are given in parentheses

	TRT 1	TRT 2	TRT 3	TRT 4	5% LSD
Forb	357.32	236.06	151.58	208.05	152.77
	(68.22)	(58.13)	(24.07)	(54.06)	
Grass	891.70	612.73	550.69	335.64	367.24
	(207.22)	(115.85)	(80.92)	(47.07)	
Total	1249.03	848.79	702.27	544.69	476.99
	(257.26)	(163.30)	(92.06)	(97.71)	

commercial mix alone were significantly higher in the two wettest treatments (Tables 13 and 14). These species made up about 80% of the total density in all treatments.

Species with the highest total density are shown in Table 15. All of these species except *Setaria faberi* were in the seed mix. Of the two most abundant species germinating from the seed mix (excluding matrix grasses), *Panicum virgatum* and *Rudbeckia hirta*, only mean densities of *Panicum virgatum* varied significantly among the moisture treatments, and this difference occurred only between the wettest and the driest treaments.

Table 13. ANOVA for seedling density of species recruited from the seed mix in field study

Source	DF	Mean Square	F Value	Pr>F
Forb				
Treatment	3	53928.15	2.40	0.0902
Error	27	22506.55		
Grass				
Treatment	3	260188.58	2.56	0.0759
Error	27	101642.30		
Total				
Treatment	3	494324.24	2.71	0.0649
Error	27	182495.66		

Table 14. Mean density (seedlings m^{-2}) of species recruited from the seed mix during field study (N=31). Standard errors are given in parentheses

	TRT 1	TRT 2	TRT 3	TRT 4	5% LSD
Forb	325.9	212.0	129.6	190.0	153.9
	(71.0)	(80.1)	(45.8)	(67.2)	
Grass	693.7	449.8	427.8	255.4	327.1
	(179.1)	(100.8)	(85.8)	(44.2)	
Total	1019.6	661.9	557.4	445.4	438.3
	(231.0)	(144.0)	(101.5)	(93.7)	

Table 15. Total number of seedlings, by treatment, for selected species in field study. Relative abundance within each treatment is given in parentheses

Species	TRT 1	TRT 2	TRT 3	TRT 4
Andropogon gerardi	767 (7%)	740 (12%)	507 (9%)	359 (8%)
Avena sativa	1292 (13%)	684 (12%)	552 (10%)	434 (10%)
Coreopsis palmata	153 (2%)	220 (4%)	142 (3%)	186 (4%)
Panicum virgatum	4756 (48%)	2400 (40%)	2903 (52%)	1679 (39%)
Ratibida pinnata	342 (3%)	171 (3%)	76 (1%)	32 (1%)
Rudbeckia hirta	1672 (17%)	825 (14%)	676 (12%)	1199 (28%)
Setaria faberi	229 (2%)	429 (7%)	403 (7%)	138 (3%)

DISCUSSION

The germinability tests provided an estimate of the potential germination of species in the seed mix. Generally, more seeds germinated under greenhouse conditions than in the ISU Seed Lab. The species tested in this study responded more favorably to the greater day-night temperature fluctuations in the greenhouse (as much as 20° C, see Figure 1). These results are consistent with many others that have shown that alternating temperatures promote the highest germination for emergents, e.g., germination of seeds of *Hordeum jubatum*, *Phragmites australis*, *Scolochloa festucacea*, and *Typha glauca* was much higher in alternating temperatures than in constant temperatures (Galinato and van der Valk 1986). Sedges especially germinate in a narrow range of relatively high temperature, and some are very sensitive to diurnal fluctuations in temperature and alternating periods of light and shade (Grime *et al.* 1981). Mean germination percentage in soil in the greenhouse, however, was similar to those in the laboratory.

Watering treatments affected species composition and density of seedlings recruited from the commercial seed mix under both greenhouse and field conditions. Treatment effects were more pronounced, however, under the controlled conditions in the greenhouse, where soil moistures covered a broader range (Table 3). Under greenhouse conditions, the number of species and seedling densities were highest in trays watered daily; in the field, greatest germination response occurred in the wettest treatments in which quadrats were watered once or twice daily. Moist soil clearly is conducive for the germination of seeds of wetland species. Some species, however, especially weedy annuals, germinated better at lower soil moistures. *Echinochloa crusgalli* behaved as in a previous study (Naim 1987), germinating at very high and very low soil moistures; in the field, similar numbers of this species germinated in the three driest treatments. Other species that Naim (1987) studied also showed a differential response to soil matric potential: *Eleocharis obtusa* germinated best at high soil moisture in the greenhouse but responded to a wider range in the field, *Polygonum hydropiperoides*

germinated best at high soil moisture, and *Xanthium pensylvanicum* had the greatest germination at low soil moisture.

Previous investigations have shown that, from seed banks, more species germinated under moist soil conditions than when soils were flooded (Pederson 1983; Smith and Kadlec 1983; Siegley *et al.* 1988). Millar (1973) reported that deep marsh emergents such as *Typha latifolia* and *Scirpus validus* germinated on soils that were very wet or shallowly flooded; this germination response for emergents was also observed during the first few months after a drawdown (Welling 1987). In a study of deep marsh and sedge meadow seed banks in Okefenokee Swamp, sedge meadow seeds did not germinate in standing water (Gerritsen and Greening 1989). Other research has shown that germination, and, especially, the health of seedlings, were negatively affected when the length of time between wet periods was longer than 12 hours (Berrie and Drennan 1971). Similar results were obtained with annual plants (Pickett and Bazzaz 1978) and in a restored marsh (Worthington and Helliwell 1987).

Even though the preliminary studies indicated that the seed bank contained desirable wetland species (see Part I), it did not prove to be an important source for recruiting species in either the greenhouse or in the field. The seed bank's major contribution to recruitment was in the drier treatments, although some meadow species were recruited from the seed bank in the wettest treatments. In the greenhouse, species from the seed bank comprised only 9% of the total density in trays watered twice daily, but 92% in the driest treatment. In the field, the percent of the total number of seedlings recruited from the seed bank was around 20% in all treatments, and this component of the vegetation was primarily species of annual weeds and grasses.

Some consideration must be taken when interpreting these results. In the analysis, seedlings of any species in the seed mix were regarded as having been recruited from the mix rather than from the seed bank. However, several species in the mix were also present in the

seed bank. It is likely that recruitment from the seed mix has been overestimated, especially in the wetter treatments. This problem was particularly acute in the greenhouse study, where many of the sedges and grasses could not be identified to species and were all assumed to have been recruited from the mix.

Several other complications may have influenced the results, including high seedling mortality in the wettest treatments in the greenhouse study. This made it difficult to accurately identify and quantify all the species that had germinated. It is not clear why so many of the seedlings died, but saturated soils may have killed small seedlings of terrestrial species.

In the field, soil moistures were not sufficiently high to allow germination of most of the wetland species, and consequently, similar composition and seedling densities were found in all four treatments. In addition, it was impossible to maintain consistent differences in soil moisture. Rainfall events and flooding occurred several times during the study. Several quadrats were flooded for as long as a few days and remained wet for almost one week in some instances. These incidents certainly influenced germination and seedling survival. Additionally, many seeds did not germinate until later in the season (late July) after there had been some heavy rainfall.

Poor recruitment from the seed bank in both studies may be related to length of storage of the donor topsoil. The topsoil used in both studies had been stored or stockpiled for nearly one year. In other studies, storing donor topsoil or seeds longer than a few months resulted in the recruitment of fewer seeds (Dickie *et al.* 1988; Apfelbaum *et al.* 1989). Also, the area from which the donor topsoil was collected was small compared to the area over which it was spread. Consequently, only a thin layer of donor seed bank soil was present to serve as a seed source in the field.

These studies emphasize the need for adequate moisture for establishing wetland vegetation. During the first growing season, if soil moistures are low, the vegetation that

becomes established may lack many wetland species whose seeds were in the seed bank or sown. Regardless of whether wetland seeds are found in the donor seed bank or have been sown, they will not germinate in dry soil. Establishing wetland vegetation is best done on saturated soils. As a wetland develops, soil moistures should increase and become favorable for the germination of seeds of wetland species.

LITERATURE CITED

Apfelbaum, S. I., M. Leach, and R. Baller. 1989. Report propagation results for *Carex* spp., other wetland species. Restoration and Management Notes 7:38-39.

Baskin, C. C. and J. M. Baskin. 1988. Germination ecophysiology of herbaceous plant species in a temperate region. American Journal of Botany 75:286-305.

Baskin, J. M., C. C. Baskin, and D. M. Spooner. 1989. Role of temperature, light and date: Seeds were exhumed from soil on germination of four wetland perennials. Aquatic Botany 35:387-394.

Berrie, A. M. M. and D. S. H. Drennan. 1971. The effect of hydration dehydration on seed germination. New Phytologist 70:135-142.

Brown, M. T., F. Gross, and J. Higman. 1985. Studies of a method of wetland reconstruction following phosphate mining. Pages 24-45 *in* F. J. Webb, editor. Proceedings of the 11th annual conference on wetlands restoration and creation. Hillsborough Community College, Tampa, Florida, USA.

Dickie, J. B., H. H. Gajjar, P. Birch, and J. A. Harris. 1988. The survival of viable seeds in stored topsoil from opencast coal workings and its implications for site restoration. Biological Conservation 43:257-265.

Galinato, M. I. and A. G. van der Valk. 1986. Seed germination traits of annuals and emergents recruited during drawdowns in the Delta Marsh, Manitoba, Canada. Aquatic Botany 26:89-102.

Gardner, W. H. 1986. Water content. Pages 493-544 *in* A. Klute, editor. Methods of soil analysis, Part 1: Physical and mineralogical methods, Second edition. American Society of Agronomists, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin.

Gerritsen, J. and H. S. Greening. 1989. Marsh seed banks of the Okefenokee Swamp: Effects of hydrologic regime and nutrients. Ecology 70:750-763.

Grime, J. P., G. Mason, A. V. Curtis, J. Rodman, S. R. Band, M. A. G. Mowforth, A. M. Neal, and S. Shaw. 1981. A comparative study of germination characteristics in a local flora. Journal of Ecology 69:1017-1059.

Keddy, P. A. and T. H. Ellis. 1985. Seedling recruitment of eleven wetland species along a water level gradient: Shared or distinct responses? Canadian Journal of Botany 63:1876-1879.

Kerans, K. 1990. The restoration business. Restoration and Management Notes 8:29-31.

Leck, M. A. and R. L. Simpson. 1987. Seed bank of a freshwater tidal wetland: Turnover and relationship to vegetation change. American Journal of Botany 74:360-370.

Ludwig, J. A. and J. F. Reynolds. 1988. Statistical ecology. John Wiley and Sons, Inc., New York. 337 pp.

Millar, J. B. 1973. Vegetation changes in shallow marsh wetlands under improving moisture regime. Canadian Journal of Botany 51:1443-1457.

Naim, P. A. 1987. Wetland seed banks: Implications in vegetation management. Ph. D. dissertation. Iowa State University, Ames, Iowa.

Pederson, R. L. 1983. Abundance, distribution, and diversity of buried seed populations in the Delta Marsh, Manitoba, Canada. Ph. D dissertation, Iowa State University, Ames, Iowa. 97 pp.

Pickett, S. T. A. and F. A. Bazzaz. 1978. Germination of co-occurring annual species on a soil moisture gradient. Bulletin of the Torrey Botanical Club 105(4):312-316.

Pohl, R. W. 1978. How to know the grasses. Third edition. Wm. C. Brown Company Publishers, Dubuque, Iowa. 200 pp.

SAS Institute. 1985. SAS User's Guide: Basics manual. Version 6. SAS Institute, Cary, North Carolina. 1390 pp.

Siegley, C. E., R. E. J. Boerner, and J. M. Reutter. 1988. Role of the seed bank in the development of vegetation on a freshwater marsh created from dredge spoil. Journal of Great Lakes Research 14:267-276.

Smith, L. M. and J. A. Kadlec. 1983. Seed banks and their role during drawdown of a North American marsh. Journal of Applied Ecology 20:673-684.

Swink, F. and G. Wilhelm. 1979. Plants of the Chicago region. The Morton Arboretum, Lisle, Illinois. 922 pp.

Thompson, K. and J. P. Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. Journal of Ecology 67:893-921.

van der Valk, A. G. 1981. Succession in wetlands: A Gleasonian approach. Ecology 62:688-696.

van der Valk, A. G. and C. B. Davis. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. Ecology 59:322-335.

van der Valk, A. G. and J. T. A. Verhoeven. 1988. Potential role of seed banks and understory species in restoring quaking fens from floating forests. Vegetatio 76:3-13.

Welling, C. H. 1987. Reestablishment of perennial emergent macrophytes during a drawdown in a lacustrine marsh. M.S. thesis. Iowa State University, Ames, Iowa.

Welling, C. H., R. L. Pederson, and A. G. van der Valk. 1988. Recruitment from the seed bank and the development of zonation of emergent vegetation during a drawdown in a prairie wetland. Journal of Ecology 76:483-496.

Worthington, T. R. and D. R. Helliwell. 1987. Transference of semi-natural grassland and marshland onto newly created landfill. Biological Conservation 41:301-307.

SUMMARY

Vegetation in wetlands created for mitigation purposes can be established from seed. Seed may be obtained from various sources, including donor seed banks and commercial seed mixes. Both the seed bank and a seed mix can supply a diversity of plant species, but only those whose germination requirements are met will emerge. My investigations of seedling recruitment from each of these sources affirm findings of previous studies that demonstrated that adequate soil moisture is essential for the germination of wetland species. In this respect, techniques of wetland creation and restoration can be improved. Reliable methods of supplying water to the seeds in the created marsh need to be developed so that the vegetation in a created marsh will closely resemble that of a natural wetland.

The success and feasibility of planting wetland species cannot accurately be assessed in a two-year study. The results of my studies raise the question of whether seeds of wetland species will be recruited under favorable conditions in following years. Therefore, long-term monitoring of created and restored wetlands needs to occur. Furthermore, since natural wetlands are systems which include all types of wildlife, they evolve over many years and continue to change with seasonal cycles. All of these parameters should be addressed in wetland creation.

LITERATURE CITED

Broome, S. W., E. D. Seneca, and W. W. Woodhouse, Jr. 1988. Tidal salt marsh restoration. Aquatic Botany 32:1-22.

Cutlip, C. G. Jr. 1984. An evaluation of reclaimed wetlands on five phosphate mined sites in central Florida. Pages 62-72 *in* F. J. Webb, editor. Proceedings of the 11th Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc., New York. 547 pp.

Office of Technology Assessment. 1984. Wetlands: Their use and regulation. U.S. Congress, Washington, D.C. OTA-0-206.

Race, M. S. 1985. Critique of present wetlands mitigation policies in the United States based on an analysis of past restoration projects in San Francisco Bay. Environmental Management 9:71-82.

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APPENDIX A: SPECIES LISTS

Included in the following tables are species identified by Kelsey *et al.* (1988) in the initial environmental assessment of each original wetland area and the species identified in the seed bank study.

Table 1. Flora of WL1 as identified in environmental resource inventory (from Kelsey *et al.* 1988)

Acer negundo	*Poa pratensis*
Acer saccharinum	*Polygonum amphibium stipulaceum*
Apocynum cannabinum	*Polygonum coccineum*
Asclepias incarnata	*Populus deltoides*
Asclepias syriaca	*Populus tremuloides*
Aster puniceus	*Prunus serotina*
Bromus inermis	*Prunus virginiana*
Carex atherodes	*Pycnanthemum virginianum*
Carex buxbaumii	*Rhamnus cathartica*
Carex lacustris	*Rhamnus frangula*
Carex sartwellii	*Rosa multiflora*
Carex scoparia	*Rubus occidentalis*
Carex stricta	*Salix bebbiana*
Carex vulpinoidea	*Salix discolor*
Cornus racemosa	*Salix interior*
Equisetum arvense	*Salix nigra*
Erigeron annuus	*Scirpus atrovirens*
Fragaria virginiana	*Scirpus fluviatilis*
Galium obtusum	*Scirpus lineatus*
Geum canadense	*Scirpus validus creber*
Glyceria striata	*Senecio pauperculus balsamitae*
Helianthus grosseserratus	*Smilax lasioneura*
Hierochloe odorata	*Solanum dulcamara*
Impatiens capensis	*Solidago graminifolia nuttallii*
Iris virginica shrevei	*Sparganium eurycarpum*
Juncus tenuis	*Spartina pectinata*
Juniperus virginiana crebra	*Taraxacum officinale*
Leersia oryzoides	*Thalictrum dasycarpum*
Lindernia dubia	*Typha angustifolia*
Lycopus americanus	*Typha latifolia*
Lythrum alatum	*Verbena hastata*
Parthenocissus quinquefolia	*Veronicastrum virginicum*
Phalaris arundinacea	*Viburnum lentago*
Phragmites communis berlandieri	*Viola papilionacea*

Table 2. Flora of WL2 as identified in environmental resource inventory (from Kelsey *et al.* 1988)

Acer negundo	*Lycopus virginicus*
Achillea millefolium	*Lythrum salicaria*
Agrostis alba	*Mentha arvensis villosa*
Ambrosia trifida	*Mimulus ringens*
Apocynum sibiricum	*Monarda fistulosa*
Asclepias incarnata	*Oenothera biennis*
Aster novae-angliae	*Penthorum sedoides*
Aster puniceus	*Phalaris arundinacea*
Aster simplex	*Poa pratensis*
Barbarea vulgaris	*Polygonum amphibium stipulaceum*
Bidens frondosa	*Polyganum coccineum*
Boltonia latisquama recognita	*Populus deltoides*
Calamagrostis canadensis	*Proserpinaca palustris*
Carex atherodes	*Pycnanthemum virginianum*
Carex bebbii	*Ranunculus flabellaris*
Carex brevior	*Rhamnus cathartica*
Carex lacustris	*Rorippa islandica fernaldiana*
Carex lanuginosa	*Rumex crispus*
Carex sartwellii	*Sagittaria latifolia*
Carex stricta	*Salix fragilis*
Carex tetanica	*Salix interior*
Carex vulpinoidea	*Salix nigra*
Cirsium vulgare	*Sambucus canadensis*
Convolvulus sepium	*Scirpus atrovirens*
Cornus racemosa	*Scirpus fluviatilis*
Eleocharis calva	*Scirpus validus creber*
Equisetum arvense	*Senecio pauperculus balsamitae*
Erechtites hieracifolia	*Smilacina stellata*
Erigeron annuus	*Solanum dulcamara*
Erigeron philadelphicus	*Solidago altissima*
Eupatorium maculatum	*Solidago gigantea*
Eupatorium perfoliatum	*Solidago graminifolia nuttallii*
Galium triflorum	*Sparganium eurycarpum*
Geum laciniatum trichocarpum	*Spartina pectinata*
Helianthus grosseserratus	*Stachys palustris homotricha*
Hierochloe odorata	*Thalictrum revolutum*
Hypoxis hirsuta	*Typha latifolia*
Iris virginica shrevei	*Ulmus pumila*
Juncus dudleyi	*Verbena hastata*
Ludwigia polycarpa	*Viola papilionacea*
Lycopus americanum	*Xanthium strumarium*

Table 3. Flora of WL3 as identified in environmental resource inventory (from Kelsey *et al.* 1988)

Achillea millefolium	*Ludwigia palustris americana*
Apocynum sibiricum	*Lycopus americanus*
Asclepias syriaca	*Lycopus virginicus*
Aster puniceus	*Lysimachia thyrsiflora*
Aster sagittifolius drummondii	*Mentha arvensis villosa*
Calamagrostis canadensis	*Mimulus ringens*
Caltha palustris	*Onoclea sensibilis*
Carex buxbaumii	*Parthenocissus quinquefolia*
Carex lacustris	*Phalaris arundinacea*
Carex lanuginosa	*Poa pratensis*
Carex sartwellii	*Polygonum amphibium stipulaceum*
Carex scoparia	*Polygonum coccineum*
Carex stipata	*Polygonum lapathifolium*
Carex stricta	*Potentilla recta*
Carex tenera	*Proserpinaca palustris crebra*
Carex tetanica	*Prunus virginiana*
Carex vulpinoidea	*Pycnantheumu virginianum*
Chrysanthemum leucanthemum pinnatifidum	*Ranunculus flabellaris*
	Rhamnus cathartica
Cirsium arvense	*Rosa multiflora*
Cornus racemosa	*Salix discolor*
Daucua carota	*Salix interior*
Eleocharis calva	*Scirpus atrovirens*
Epilobium coloratum	*Scirpus fluviatilis*
Equisetum arvense	*Scirpus validus creber*
Erigeron annuus	*Senecio pauperculus balsamitae*
Erigeron philadelphicus	*Solanum dulcamara*
Eriophorum angustifolium	*Solidago altissima*
Eupatorium perfoliatum	*Solidago gigantea*
Eupatorium pupureum	*Solidago graminifolia nuttallii*
Fragaria virginiana	*Sonchus uliginosus*
Galium obtusum	*Spartina pectinata*
Geum laciniatum trichocarpum	*Thalictrum dasycarpum hypoglaucum*
Helianthus grosseserratus	*Typha angustifolia*
Hypoxis hirsuta	*Ttypha latifolia*
Iris virginica shrei	*Verbena hastata*
Juniperus virginiana crebra	*Veronicastrum virginicum*
Lathyrus palustris	*Viburnum lentago*
Lemna minor	*Viola papilionacea*
Lindernia dubia	*Vitis riparia*

Table 4. Flora of WL4 as identified in environmental resource inventory (from Kelsey *et al.* 1988)

Ambrosia artemisiifolia elatior	*Phalaris arundinacea*
Asclepias incarnata	*Polygonum amphibium stipulaceum*
Aster puniceus	*Polygonum coccineum*
Barbarea vulgaris	*Populus deltoides*
Bidens frondosa	*Proserpinaca palustris crebra*
Calamagrostis canadensis	*Prunus serotina*
Carex lacustris	*Ranunculus flabellaris*
Carex lanuginosa	*Sagittaria latifolia*
Carex sartwellii	*Salix discolor*
Carex stricta	*Salix nigra*
Carex vulpinoidea	*Scirpus atrovirens*
Cirsium arvense	*Scirpus fluviatilis*
Cornus racemosa	*Scirpus lineatus*
Equisetum arvense	*Scirpus validus creber*
Eupatorium perfoliatum	*Senecio pauperculus balsamitae*
Helianthus grosseserratus	*Smilacina stellata*
Juncus dudleyi	*Solanum dulcamara*
Lathyrus palustris	*Solidago altissima*
Lemna minor	*Solidago gigantea*
Lycopus americanus	*Sparganium eurycarpum*
Lythrum salicaria	*Stachys palustris homotricha*
Mentha arvensis villosa	*Tradescantia ohioensis*
Mimuls ringens	*Typha latifolia*
Penthorum sedoides	*Verbena hastata*

Table 5. Flora of WL5 as identified in environmental resource inventory (from Kelsey *et al.* 1988)

Abutilon theophrasti	*Phragmites communis berlandieri*
Acer negundo	*Poa compressa*
Acer saccharum	*Poa pratensis*
Agropyron repens	*Polygonum amphibium stipulaceum*
Ambrosia artemisiifolia elatior	*Polygonum coccineum*
Apocynum sibiricum	*Polygonum lapathifolium*
Asclepias syriaca	*Populus deltoides*
Asparagus officinalis	*Rhamnus cathartica*
Aster novae-angliae	*Rhus typina*
Bromus inermis	*Rorippa islandica fernaldiana*
Calamagrostis canadensis	*Rosa multiflora*
Carex lanuginosa	*Rumex crispus*
Carex stipata	*Salix discolor*
Cirsium arvense	*Salix interior*
Convolvulus sepium	*Scirpus atrovirens*
Cornus racemosa	*Scirpus validus creber*
Cornus stolonifera	*Solanum americanum*
Daucus carota	*Solanum dulcamara*
Epilobium coloratum	*Solidago altissima*
Equisetum arbense	*Solidago gigantea*
Erigeron annuus	*Solidago graminifolia nuttallii*
Geum laciniatum trichocarpum	*Sparganium eurycarpum*
Helianthus grosseserratus	*Spartina pectinata*
Juncus dudleyi	*Stachys palustris homotricha*
Juncus torreyi	*Typha angustifolia*
Juniperus virginiana crebra	*Typha latifolia*
Lycopus americanus	*Ulmus americana*
Lythrum salicaria	*Ulmus rubra*
Melilotus alba	*Vitis riparia*
Phalaris arundinacea	*Xanthium strumarium*
Phleum pratense	

Table 6. Species germinating from the seed bank of WL1, WL3, WL4, and WL5. Plants for which the specific epithet is tentative are denoted by "*"; 3 species were unidentifiable

Abutilon theophrasti Medic.
Acalypha rhomboidea Raf.
Amaranthus albus L.
Ambrosia artemisiifolia L.
Apocynum sibiricum Jacq.
Asclepias incarnata L.
Aster novae-angliae L.
Aster simplex Willd.
Bidens frondosa L.
Bidens vulgata Greene
**Carex lanuginosa* Michx.
**Carex sartwellii* Dew.
Carex stricta Lam.
Chenopodium album L.
Chrysanthemum leucanthemum L.
Cirsium arvense (L.) Scop.
Cornus racemosa Lam.
Daucus carota L.
Dulichium arundinaceum (L.) Britton
Echinochloa crusgalli (L.) Beauv.
**Eleocharis calva* Torr.)
**Eleocharis elliptica* Kunth
Epilobium coloratum Biehler
Equisetum arvensis L.
Eragrostis hypnoides (Lam.) BSP
Eragrostis pectinacea (Michx.) Nees
Erechtites hieracifolia (L.) Raff.
Erigeron annuus (L.) Pers.
Erysimum inconspicuum (Wats) MacMill.
Eupatorium perfoliatum L.
Eupatorium serotinum Michx.
Fragaria virginiana Duchesne
Galium obtusum Bigel.
Glyceria striata (Lam.) Hitchc.
Helianthus grosseseratus L.
Hibiscus trionum L.
Hypericum majus (Gray) Britt.
Iris virginica L.
Juncus dudleyi Weig.
Juncus nodosus L.
Juncus torreyi Coville
Lathyrus sp.
Leersia orzoides (L.) Sw.
Ludwigia palustris (L.) Ell.
Ludwigia polycarpa Short & Peter
Lycopus americanus Muhl.
Lycopus virginicus L.
Lythrum alatum Pursh.
Lythrum salicaria L.
Medicago lupulina L.
Mentha arvensis L.
Morus rubra L.
Mimulus ringens L.
Muhlenbergia glomerata (Willd.) Trin.
Oenothera biennis L.
Oxalis stricta L.
Panicum capillare L.
Panicum dichotomiflorum Michx.
Panicum lanuginosum Ell.
Penthorum sedoides L.
Phalaris arundinacea L.
Physalis heterophylla Nees
Plantago major L.
Platanus occidentalis L.
Polyganum lapathifolium L.
Polyganum pennsylvanicum Fern.
Polyganum persicaria L.
Portulaca oleracea L.
Proserpinaca palustris L.
Ranunculus flabellaris Raf.
Rhamnus cathartica L.
Rorippa islandica fernaldiana Butt.&Abbe.
Scirpus lineatus Michx.
Scirpus validus Vahl.
Scutellaria epilobiifolia Hamilton
Setaria faberi Herrm.
Setaria lutescens (Weigel.) Hubb.
Solanum dulcamara L.
Solanum nigrum L.
Solidago gigantea Ait.
Solidago graminifolia (L.) Salisb.
Solidago riddellii Frank
Sonchus asper (L.) Hill
Spartina pectinata Link
Taraxacum officinale Weber
Trifolium repens L.
Typha sp.
Verbascum thapsus L.
Verbena hastata L.
Vitis riparia Michx.

APPENDIX B: PRELIMINARY REPORT

The following information was included in a preliminary report on the composition of the seed banks in the original wetlands on the Gurnee Mills site. The purpose of this report was to identify areas in each wetland where the seed bank contained high densities of *Lythrum salicaria*, *Phalaris arundinacea*, and *Typha* sp.

Key to abbreviations used in tables:

Site -- Wetland number (1,3,4,5); transect letter (A-G); sample number along East-West transect (1-8); surface sample (S) (just below the rhizome layer) or subsurface sample (G) (20 to 25 cm below the surface)

* -- Sample contains significant number of seeds of unwanted species

Den -- Seedling density in 20x28x8 cm trays:
S -- Sparse (1-10 seedlings)
L -- Low (11-30 seedlings)
M -- Moderate (31-80 seedlings)
H -- High (>80 seedlings)

No. -- Number of species

Indicator species: Ty.--*Typha* sp.; Ph.--*Phalaris arundinacea*; Ly.--*Lythrum salicaria*; Ca.--*Carex* spp.; Sc.-- *Scirpus* spp.; W.M.--wet meadow species

Abundance rankings:
P -- Present (1-5 seedlings)
F -- Few (6-10 seedlings)
C -- Common (11-30 seedlings)
A -- Abundant (>30 seedlings)

Table 1. Abundance of indicator species of the seed bank of WL1

Site	Den.	No.	Ty.	Ph.	Ly.	Ca.	Sc.	W.M.
1A1S*	L	13	-	C	-	P	-	F
1A1G	S	2	-	P	-	-	-	-
1A2S	M	13	P	-	-	P	-	F
1A2G	S	1	-	-	-	-	-	
1B1S	M	8	P	-	-	-	-	P
1B1G	L	4	P	-	-	-	-	P
1B2S	L	9	P	-	-	P	P	P
1B2G	S	5	P	-	-	-	P	P
1B3S	L	11	P	-	-	P	P	F
1B3G	S	1	P	-	-	-	-	-
1B4S	M	6	-	-	-	P	-	P
1B4G	S	2	-	-	-	-	-	P
1C1S	S	4	P	-	-	-	P	P
1C1G	S	2	-	-	-	-	-	P
1C2S	M	3	-	-	-	-	-	A
1C2G	S	1	-	-	-	-	-	P
1C3S	S	8	-	-	-	P	-	P
1C3G	0	0	-	-	-	-	-	-
1D1S*	M	16	-	C	-	P	-	F
1D1G	L	5	-	P	-	-	-	-
1D2S	M	10	-	-	-	-	P	C
1D2G	S	2	-	-	-	P	-	P

Table 2. Abundance of indicator species in the seed bank of WL3

Site	Den.	No.	Ty.	Ph.	Ly.	Ca.	Sc.	WM
3A1S	L	8	-	-	-	-	-	P
3A1G	S	2	-	-	-	-	-	P
3B1S	M	14	P	-	-	C	P	P
3B1G	S	2	-	-	-	-	-	-
3B2G	S	2	P	-	-	-	-	P
3B3S	L	10	P	-	-	-	-	F
3B3G	S	4	-	-	-	-	-	-
3C1S*	M	12	F	-	-	C	-	F
3C1G	S	5	P	-	-	P	-	P
3C2S	S	5	P	-	-	P	-	P
3C2G	S	2	P	-	-	-	-	-
3C3S*	M	10	C	-	-	F	-	C
3C3G*	L	9	C	-	-	P	-	F
3C4*	M	4	A	-	-	F	-	F
3C5*	H	5	A	-	-	A	-	F
3C6*	H	6	A	-	-	P	C	F
3D1S*	H	10	P	A	-	P	-	C
3D1G*	S	2	-	A	-	-	-	P
3D2S	M	13	P	P	-	C	-	A
3D2G	L	7	-	-	-	P		C
3D3S*	M	11	F	-	-	P	-	F
3D3G	S	4	-	-	-	-	-	P
3D4S*	M	9	F	-	-	-	-	C
3D4G	0	0	-	-	-	-	-	-
3D5*	H	13	A	-	-	P	P	A
3D6*	M	8	C	-	-	F	-	C

Table 3. Abundance of indicator species of the seed bank of WL4

Site	Den.	No.	Ty.	Ph.	Ly.	Ca.	Sc.	W.M.
4A1S	H	10	-	-	-	C	-	A
4A1G	L	9	-	-	-	P	-	C
4A2S	L	10	P	P	-	P	-	F
4A2G	S	8	-	P	-	-	-	-
4A3S	L	6	-	-	-	-	-	P
4A3G	S	1	-	-	-	-	-	-
4B1S	M	11	-	-	F	P	P	A
4B1G	L	9	-	-	F	P	P	C
4B2S	M	10	-	-	-	C	-	C
4B2G	L	6	-	-	-	-	P	P
4B3S	L	6	-	-	F	-	-	P
4B3G	S	1	-	-	-	P	-	-
4C1S*	H	17	P	C	-	C	P	C
4C1G	S	7	-	-	-	-	P	F
4C2S*	H	11	-	A	-	F	F	A
4C2G	S	5	-	-	-	-	-	F
4C3S	M	10	-	P	-	-	F	A
4C3G	L	5	-	-	-	-	P	P
4D1S	M	10	-	-	-	P	-	C
4D1G	L	8	-	-	-	-	-	P
4D2S*	H	6	-	F	-	-	C	A
4D2G	L	4	-	-	P	P	P	C
4E1S	M	7	P	-	-	C	P	C
4E1G	L	4	-	-	-	P	P	F
4E2S	L	11	P	P	-	C	-	C
4E2G	S	10	-	-	-	-	-	F

Table 4. Abundance of indicator species in the seed bank of WL5

Site	Den.	No.	Ty.	Ph.	Ly.	Ca.	Sc.	W.M.
5A1S*	H	15	-	A	A	-	-	F
5A1G*	M	6	-	C	C	-	-	F
5A2S*	H	16	-	A	A	P	C	F
5A2G	M	9	-	P	F	-	F	C
5A3S*	H	10	-	A	A	P	-	C
5A3G	M	7	-	P	A	-	-	P
5A4S*	H	5	-	A	A	-	-	-
5A4G*	H	6	-	C	A	-	-	P
5B1S*	H	7	-	A	P	-	-	P
5B1G	L	6	-	P	-	-	-	P
5B2S	M	7	-	P	-	-	-	C
5B2G	M	8	-	P	-	-	-	F
5B3S	H	12	-	-	C	-	-	C
5B3G	H	10	-	-	P	-	-	F
5B4S*	H	6	-	A	P	-	-	C
5B4G*	M	7	-	F	P	-	-	F
5B5S	H	5	-	C	A	-	-	-
5B5G	M	7	-	-	P	P	-	P
5D1S	L	7	-	P	-	F	-	P
5D1G	L	8	P	-	P	-	-	P
5D2S*	L	8	-	F	P	-	-	P
5D2G*	L	6	-	P	P	-	-	C
5D3S*	M	6	-	A	-	-	-	-
5D3G*	L	5	-	C	-	-	-	P
5D4S*	M	10	F	F	F	-	-	P
5D4G*	M	5	-	F	-	-	-	P
5D5S*	H	11	-	C	A	-	-	C
5D5G	L	6	-	P	P	-	-	P
5D6S*	H	7	P	C	A	-	P	-
5D6G	M	5	-	P	C	-	-	-
5D7S*	H	9	-	F	A	-	-	-
5D7G	M	6	-	P	F	-	-	-
5D8S*	H	7	-	A	A	-	-	-
5D8G*	H	3	-	F	A	-	-	-
5F1S	H	15	-	P	A	-	-	C
5F1G	M	7	-	-	A	-	-	P
5F3S*	M	15	C	-	C	-	P	C
5F3G	L	6	-	-	F	P	P	P
5G1S*	H	12	-	A	C	P	C	P
5G1G	L	6	-	P	P	-	F	-
5G2S	H	12	P	-	F	P	-	A
5G2G	M	10	P	-	-	-	P	F
5G3S*	H	18	C	-	A	C	-	C
5G3G*	M	9	-	C	-	-	-	C
5G4S*	H	19	P	C	A	-	C	A
5G4G*	H	15	P	A	F	C	P	A

APPENDIX C: SEED MIX SPECIES

Table 1. Species list for the seed mix for the Gurnee Mills site provided by LaFayette Home Nursery, Inc., LaFayette, Illinois, and used in the greenhouse and field studies

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Acorus calamus
Agrostis alba
Alisma subcordatum
Amorpha canescens
Amorpha fruiticosa
Andropogon gerardi
Angelica sp.
Asclepias incarnata
Asclepias sullivantia
Aster laevis
Aster novae-angliae
Aster praeltus
Aster puniceus
Avena sativa
Baptisia leucantha
Bidens sp.
Boltonia latisquama recognita
Bromus kalmii
Cacalia suaveolens
Calamagrostis canadensis
Camassia scilloides
Carex annectens
Carex buxbaumii
Carex cristatella
Carex hystricina
Carex lacustris
Carex shortiana
Carex sp.
Carex stipata
Carex stricta
Carex trichocarpa
Carex vulpinoidea
Cassia marilandica
Ceanothus americanus
Cephalanthus occidentalis
Coreopsis sp.
Dodecatheon meadia
Echinacea pupurea
Elymus canadensis
Eryngium yuccifolium
Eupatorium maculatum
Eupatorium perfoliatum
Gentiana andrewsii
Gentiana flavida
Gentiana puberula
Glyceria striata
Helenium autumnale
Hordeum jubatum
Hypericum pyramidatum
Iris sp.
Juncus balticus
Juncus torreyi
Leersia oryzoides
Liatris pycnostachya
Liatris spicata
Lobelia cardinalis
Lobelia siphilitica
Lobelia sp.
Lolium perenne
Lupinus spp.
Monarda fistulosa
Panicum virgatum
Parthenium integrifolium
Pedicularis canadensis
Pedicularis lanceolata
Penstemon grandiflorus
Petalostemum candidum
Petalostemum purpureum
Phleum pratense
Physostegia virginiana
Prenanthes racemosa
Pycnanthemum tenuifolium
Pycnanthemum virginianum
Ratibida pinnata
Rosa setigera
Rudbeckia hirta
Rudbeckia subtomentosa
Sagittaria latifolia
Scirpus acutus
Scirpus americanus
Scirpus lineatus
Scirpus torreyi
Scirpus validus
Silene regia
Silphium integrifolium
Silphium laciniatum

Table 1. (Continued)

Silphium perfoliatum	*Thalictrum dasycarpum*
Silphium terebinthinaceum	*Tripsacum dactyloides*
Sisyrinchium albidum	*Verbena hastata*
Sisyrinchium muscronatum	*Vernonia fasciculata*
Solidago riddellii	*Veronicastrum virginicum*
Solidago rigida	*Zizania aquatica*
Sparganium eurycarpum	*Zizea aurea*
Spartina pectinata	

APPENDIX D: RELEVE DATA

In April 1989 sections of sod approximately 1 m x 1 m x 0.3 m were transplanted from WL1 and WL4 (see Figure 1, Part I) into three areas or blocks in the newly created wetland (Figure 4, Part I). Dimensions of the blocks are as follows: the North block, 17 m x 29 m; the South block, 15 m x 21 m; and the West block, 6 m x 22 m. To describe the plant communities found in this transplanted material, the releve method of community sampling was used (Mueller-Dombois and Ellenberg 1974). Five 1 m x 1 m permanent quadrats were set up randomly within each block. Vegetation was assessed seven times in both 1989 and 1990 in two of the blocks; all but one quadrat in the West block were destroyed by construction activities in September 1990, and consequently vegetation in this block was sampled only six times that year.

The following cover-abundance scale was used:

5 Any number, with cover more than 3/4 of the reference area (>75%)
4 Any number, with 1/2-3/4 cover (50-75%)
3 Any number, with 1/4-1/2 cover (25-50%)
2 Any number, with 1/20-1/4 cover (5-25%)
1 Numerous, but less than 1/20 cover, or scattered, with cover up to 1/20 (5%)
+ Few, with small cover
r Solitary, with small cover

North Block--Q1 1989	12-Jun	26-Jun	8-Jul	26-Jul	8-Aug	22-Aug	22-Sep
Agrostis alba							
Ambrosia artemisiifolia							
Asclepias incarnata	+	+	1	2	2	2	1
Aster pilosus							
Aster simplex	1	1	1	1	1	2	1
Bidens frondosa							
Carex buxbaumii							
Carex lanuginosa							
Carex stricta	4	3	3	3	2	3	1
Carex vulpinoidea							
Cirsium arvense							
Cornus racemosa							
Eleocharis elliptica					r		
Equisetum arvense	r	r					
Erechtites hieracifolia						r	+
Erigeron sp.		+					
Fragaria virginiana	+						
Geum aleppicum							
Glyceria striata		1	1	1	+	+	1
Helianthus grosseserratus	2	2	2	3	3	2	2
Lycopus americanus	+	+				1	
Lycopus virginicus	+	+	1	1	1	1	1
Lythrum alatum					r	+	
Medicago lupulina							
Mentha arvensis					+	+	+
Muhlenbergia glomerata							
Polygonum amphibium	+	1	1	1	1	1	1
Populus deltoides							
Potentilla norvegica							
Setaria faberi							
Solidago gigantea							
Sonchus uliginosus					r		
Taraxacum officinale	r	r					
Teucrium canadense							
Typha latifolia					r	r	r
Verbena hastata		1	1	1	1	1	1

North Block--Q1 1990	30-May	11-Jun	25-Jun	11-Jul	29-Jul	15-Aug	22-Sep
Agrostis alba		1	1	1	1	1	1
Ambrosia artemisiifolia	+	+	+	+	+	+	
Asclepias incarnata	1	1	1	1	1	1	1
Aster pilosus		+	+	+	+	+	1
Aster simplex	1	1	1	1	1	1	1
Bidens frondosa	+	+	+	+	+	+	+
Carex buxbaumii	1	1	1	1	1		
Carex lanuginosa	1	1	2	2	2	2	2
Carex stricta	1	1	1	1	1	1	1
Carex vulpinoidea	1	1	1	1	1	1	1
Cirsium arvense		r	r	r	r		
Cornus racemosa	+	+	+	+	+	+	+
Eleocharis elliptica	1	+	+	+	+	+	
Equisetum arvense		+	+				
Erechtites hieracifolia		+	+	+	+	1	+
Erigeron sp.							
Fragaria virginiana							
Geum aleppicum	r	r	+	+	+	+	+
Glyceria striata	1	1	1	1	1	1	+
Helianthus grosseserratus	1	2	2	2	2	3	2
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	1	1	1	1	1	1	1
Lythrum alatum	+	+	+	+	1	1	+
Medicago lupulina	+						
Mentha arvensis		1	1	1	1	1	+
Muhlenbergia glomerata					+	+	+
Polygonum amphibium	1	1	1	1	1	1	1
Populus deltoides				+	r	r	
Potentilla norvegica			r	r	r	r	r
Setaria faberi						+	+
Solidago gigantea			+	+	+	+	+
Sonchus uliginosus						r	
Taraxacum officinale		+	+	+	+		
Teucrium canadense						1	r
Typha latifolia	1	1	1	1	1	1	1
Verbena hastata	1	1	1	1	1	1	1

North Block--Q2 1989	JUN12	JUN27	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea							
Agrostis alba							
Ambrosia artemisiifolia						r	
Aster simplex	1	1	1	1	1	1	1
Calamagrostis canadensis				1	1	1	+
Carex buxbaumii							
Carex lanuginosa							
Carex stricta	2	1	2	2	1	1	1
Carex vulpinoidea							
Cerastium vulgatum						r	r
Cornus racemosa	r	r		1	+	1	1
Daucus carota	+	+	+	+	+	+	+
Eleocharis elliptica	1	1	+			+	+
Equisetum arvense				r			
Galium obtusum				+			
Glyceria striata	1	1		1	1	+	1
Helianthus grosseserratus	r	r	+	1	1	1	1
Juncus dudleyi	1	+	+	1		+	r
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus			1	1	1	1	
Lythrum alatum	1	1	1	1	1	1	1
Medicago lupulina	r						
Muhlenbergia glomerata	+	+	+	1	1	1	1
Oenothera biennis				+	+	+	1
Oxypolis rigidior			r		r	r	r
Panicum lanuginosum			r	+	+	+	+
Polygonum pensylvanicum							
Populus deltoides				r	r	r	r
Pycnanthemum virginianum						r	+
Rosa arkansana?							
Rosa multiflora	1	1	1	1	1	2	1
Salix interior				+			
Solidago gigantea	1	1	2	2	1	2	1
Solidago graminifolia	1	1	2	1	1	1	1
Solidago riddellii		1	1		+	1	+
Spartina pectinata	1	1	1	1			
Taraxacum officinale					r	r	+

North Block--Q2 1990	MAY30	JUN11	JUN25	JUL11	JUL29	AUG15	SEP22
Acalypha rhomboidea	1	+	+	+	+	+	+
Agrostis alba			+	+	+	1	1
Ambrosia artemisiifolia	1	1	1	1	1	+	+
Aster simplex	1	1	1	1	1	1	1
Calamagrostis canadensis	1	1	1	1	1	1	1
Carex buxbaumii	1	1	1	1	+	1	1
Carex lanuginosa	+	+	1	1	1	1	1
Carex stricta							
Carex vulpinoidea						2	2
Cerastium vulgatum	1	1	1	1	1	1	1
Cornus racemosa							
Daucus carota						r	r
Eleocharis elliptica	1	1	1	1	+	+	
Equisetum arvense	r	r			+	+	
Galium obtusum							
Glyceria striata	1	1	1	1	1	1	+
Helianthus grosseserratus	1	1	1	1	1	2	1
Juncus dudleyi				+	+	+	+
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	1	1	1	1	1	1	1
Lythrum alatum	1	1	1	2	2	2	+
Medicago lupulina							
Muhlenbergia glomerata	1	1	1	1	1	1	1
Oenothera biennis	r						
Oxypolis rigidior				r	r	r	r
Panicum lanuginosum	+	+	+	+	+	1	1
Polygonum pensylvanicum		r	r	r	r	r	1
Populus deltoides							
Pycnanthemum virginiani	r	+	+	+	+	+	1
Rosa arkansana?	1	2	2	2	3	3	2
Rosa multiflora							
Salix interior							
Solidago gigantea	1	2	2	3	3	3	2
Solidago graminifolia	1	1	1	1	1	1	2
Solidago riddellii	+	1	1	1	1	1	1
Spartina pectinata							
Taraxacum officinale	1	1	1	1	1	1	1

North Block--Q3 1989	JUN12	JUN26	JUL8	JUL25	AUG8	AUG22	SEP22
Agrostis alba						r	+
Ambrosia artemisiifolia			r	1	+	+	1
Aster novae-angliae				r	r		
Aster pilosus							
Aster puniceus				+	1	+	+
Bidens frondosa							
Calamagrostis canadensis							
Carex buxbaumii							
Carex granularis							
Carex interior							
Carex sartwellii							
Carex stricta	2	1	1	1	1	1	1
Carex lanuginosa							
Cirsium arvense			r		r	r	r
Daucus carota		r	r		+	+	+
Eleocharis calva	r			+	+		
Eragrostis pectinacea				r	r	r	r
Fragaria virginiana					+	+	r
Galium obtusum	1	1	1	+	+	+	+
Geum canadense							
Glyceria striata	1	1	1	1	+	+	+
Helianthus grosseserratus	1	1	1	1	1	r	r
Iris virginiana	+	+	+	1	+	+	+
Juncus dudleyi	1	+	+		r	r	+
Lathyrus palustris	r	+	+	+	+	+	
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	+	+	+	1	+	1	+
Lythrum alatum	r	r	r			r	
Medicago lupulina	r	r	+				
Melilotus alba				+	+	+	+
Muhlenbergia glomerata	r	r	r		r		+
Oenothera biennis							
Oxalis stricta							
Oxypolis rigidior							
Panicum capillare				r	r	r	r
Panicum lanuginosum							
Plantago major				r	r	1	+
Poa compressa							
Poa pratensis		r	r	r			
Polygonum amphibium							
Populus deltoides							
Potentilla norvegica							
Pycnanthemum virginiani	r	r	r		+	r	r
Rhamnus cathartica			r	+	r	+	r
Salix alba				1	1	1	1
Salix rigida	1	1	1	1	1	1	1

Scirpus atrovirens					+	r	r
Scirpus lineatus			1	+			
Setaria faberi					r	+	r
Solanum carolinense			r	r	1	1	1
Solanum dulcamara				r	r	1	r
Solidago altissima	r	r	1				r
Solidago gigantea	1	1	1	1	1	1	1
Solidago graminifolia	1	+	1	1	+	1	+
Solidago riddellii		1	1	1	1	1	1
Taraxacum officinale							
Verbena hastata			+		+	+	+
Viola papilionacea							

North Block--Q3 1990	MAY30	JUN11	JUN25	JUL11	JUL29	AUG15	SEP22
Agrostis alba							
Ambrosia artemisiifolia				r	r	r	+
Aster novae-angliae		r	r	r	r	r	r
Aster pilosus	r	1	1	1	r	r	+
Aster puniceus							
Bidens frondosa			r	r	r	r	
Calamagrostis canadensis		+	+	+	+	+	+
Carex buxbaumii	+	1	1	1	1	+	1
Carex granularis	1	+	+	+	+	+	+
Carex interior		+	+	1	1	+	+
Carex sartwellii		+	1	1	1	+	+
Carex stricta		1	1	1	1	+	+
Carex lanuginosa						1	1
Cirsium arvense					r	r	r
Daucus carota		r	r	+	+	+	+
Eleocharis calva	r	r	r				
Eragrostis pectinacea			r	r	r	+	
Fragaria virginiana							
Galium obtusum	1	1	1	1	1	1	1
Geum canadense			r	r	r	r	r
Glyceria striata	1	1	1	1	1	1	+
Helianthus grosseserratus	+	1	1	1	1	1	1
Iris virginiana	1	1	1	1	1	1	1
Juncus dudleyi	1	1	1	1	1	1	1
Lathyrus palustris	+	+	+	+	1	1	1
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	+	1	1	1	1	1	1
Lythrum alatum		+	1	1	1	1	1
Medicago lupulina							
Melilotus alba	1	1	1	1	1	r	+
Muhlenbergia glomerata	+	+	+	+	1	1	1
Oenothera biennis				+	+	+	+
Oxalis stricta							r
Oxypolis rigidior					r	r	r
Panicum capillare			r	r	r	+	r
Panicum lanuginosum	r	r	r	r	+	+	+
Plantago major							
Poa compressa		+	+	+	+	+	+
Poa pratensis	r	+	+	+	+	+	+
Polygonum amphibium							
Populus deltoides							r
Potentilla norvegica	r	r	r	r	r	+	+
Pycnanthemum virginiani	1			r	+	+	+
Rhamnus cathartica							
Salix alba	1	1	1	1	1	1	1
Salix rigida	1	1	1	2	2	2	2

Scirpus atrovirens	r	r	r	r	r	r	r
Scirpus lineatus							
Setaria faberi						r	
Solanum carolinense		+	+	+	1	1	1
Solanum dulcamara							
Solidago altissima	r	1	1	1	r	r	
Solidago gigantea	1	1	1	1	1	1	1
Solidago graminifolia	1	1	1	1	1	1	1
Solidago riddellii	1	1	1	1	1	1	1
Taraxacum officinale				r	r		
Verbena hastata			1	1	1	1	1
Viola papilionacea				r	r	r	

North Block--Q4 1989	JUN20	JUN26	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea				r	r	r	r
Agrostis alba					+	+	+
Asclepias incarnata							
Aster pilosus							
Aster puniceus	r	r	r	+	+	+	1
Aster simplex	r	+	r	+		+	
Bidens frondosa							
Calamagrostis canadensis							
Carex buxbaumii							
Carex interior							
Carex lanuginosa							
Carex stricta	1	1	1	1	1	1	1
Chrysanthemum leucanthemum							r
Cirsium arvense							
Eleocharis elliptica				+	+	+	+
Equisetum arvense						+	+
Eriophorum angustifolium							
Eupatorium perfoliatum							
Glyceria striata	1	1	1	1	1	+	+
Helianthus grosseserratus	+	+	1	1	1	1	1
Iris virginiana	+	+	+	+	1	+	+
Juncus dudleyi					+	+	
Lathyrus palustris							
Ludwigia polycarpa						+	+
Lycopus americanus	1	1	1	1	1	2	1
Lycopus virginicus	+	+		+			
Lysimachia quadriflora							
Lythrum alatum	1	1	+		1	1	+
Muhlenbergia glomerata	+	+	+	1	+	1	1
Oxypolis rigidior							
Panicum capillare							
Panicum lanuginosum	1	1	1	1	1	1	1
Plantago sp.						r	r
Populus deltoides							
Pycnanthemum virginianum							
Salix rigida			r		1	+	r
Scirpus atrovirens					r	1	r
Scirpus lineatus							
Senecio paupercaulus							
Solidago gigantea	1	1	1	1	1	1	1
Solidago graminifolia	+	+	+	1	1	1	1
Solidago riddellii	r	r	+	+	+	+	+
Trifolium sp.						r	r
Verbena hastata				+	+	1	+
Viola papilionacea							
Vitis riparia							

North Block--Q4 1990	MAY30	JUN11	JUN25	JUL11	JUL29	AUG15	SEP22
Acalypha rhomboidea							
Agrostis alba							
Asclepias incarnata	+						
Aster pilosus		r	+	+	+	+	+
Aster puniceus	r	+	+	1	1	1	1
Aster simplex	1	1	1	1	1	1	1
Bidens frondosa		r	+	+	r	r	r
Calamagrostis canadensis	+	+	+	+	1	1	1
Carex buxbaumii	1	1	1	1	1	1	1
Carex interior	+	+	+	+	+	+	+
Carex lanuginosa	+	+	1	1	1	1	1
Carex stricta	1	1	1	1			
Chrysanthemum leucanthemum							
Cirsium arvense						+	
Eleocharis elliptica	+	+	+	+	1	1	1
Equisetum arvense	+	1	1	1	1	1	+
Eriophorum angustifoliur	1	1	1	1	1	1	1
Eupatorium perfoliatum			r	r	r	r	+
Glyceria striata	+	1	1	1	1	1	1
Helianthus grosseserratus	1	1	1	1	1	1	1
Iris virginiana	+	+	+	+	+	+	
Juncus dudleyi		+	+	1	1	1	1
Lathyrus palustris		r	r				
Ludwigia polycarpa							
Lycopus americanus	1	1	1	1	1	2	2
Lycopus virginicus	+	+	+	+	1	1	1
Lysimachia quadriflora						+	+
Lythrum alatum	+	1	1	1	1	1	+
Muhlenbergia glomerata	+	+	+	1	1	1	1
Oxypolis rigidior	r	r	r	+	+	+	+
Panicum capillare						r	r
Panicum lanuginosum	+	1	1	1	1	1	1
Plantago sp.							
Populus deltoides						r	1
Pycnanthemum virginianum			+				
Salix rigida	r	r	r	r	+	+	+
Scirpus atrovirens							
Scirpus lineatus	1	1	+	1	1	1	1
Senecio paupercaulus		r	r	r	r	r	r
Solidago gigantea	+	+	1	1	1	1	1
Solidago graminifolia	1	1	1	1	1	1	1
Solidago riddellii	+	+	+	+	+	1	1
Trifolium sp.							
Verbena hastata	+		+	+	+	+	+
Viola papilionacea		r	r	r	r	r	r
Vitis riparia						r	

North Block Species--Q5	JUN12	JUN26	JUL8	JUL26	AUG8	AUG22	SEP22
Agrostis alba							+
Ambrosia artemisiifolia							
Asclepias incarnata		r	+	1	r		
Aster novae-angliae							
Aster pilosus							
Aster simplex	1	1	1	1	1	1	1
Bidens frondosa							
Carex atherodes							
Carex buxbaumii							
Carex granularis							
Carex lanuginosa							1
Carex stricta	2	2	1	1	1	1	1
Cornus racemosa							
Eleocharis calva	2	1	1	1	1	1	1
Eleocharis elliptica							
Erechtites hieracifolia							
Eriophorum angustifolium							
Eupatorium perfoliatum					+		
Galium obtusum		r	r		+		
Glyceria striata	2	1	+	1	1	1	1
Helianthus grosseratus	1	+	+	+	+	1	1
Juncus dudleyi						+	r
Leersia oryzoides			+				
Lycopus americanus	1	1	1	1	1	1	+
Lycopus virginicus		1	1	1	1	1	+
Lythrum alatum	1	1	1	1	1	1	+
Melilotus alba							
Oxalis stricta							
Polygonum amphibium	r	1	1	1	1	1	r
Scirpus lineatus	r	r	+	+			
Senecio pauperculus							
Solidago gigantea	1	1	1	+	1	1	+
Solidago graminifolia	1	1	1	1		1	+
Solidago riddellii		r	1	1	1	1	1
Sonchus uligonosus							
Spartina pectinata	1	1	+	r			r
Taraxacum officinale						r	+
Teucrium canadense				r			+
Typha latifolia						r	r
Verbena hastata			+	+	+	+	+

North Block--Q5 1990	MAY31	JUN11	JUN25	JUL11	JUL29	AUG15	SEP22
Agrostis alba	+	+	+	+	+	+	+
Ambrosia artemisiifolia	r	r	+	+	+		
Asclepias incarnata	r	r	r	r	+	+	+
Aster novae-angliae				r	r	r	
Aster pilosus		+	+	+	+	+	+
Aster simplex	+	+	1	1	1	1	1
Bidens frondosa	r	r	+	+	+	+	
Carex atherodes	+	+	+	1	1	1	1
Carex buxbaumii	1	1	1	1	+	+	+
Carex granularis		+	+	+	r	r	+
Carex lanuginosa	1	1	1	1	1	1	1
Carex stricta	1	1	1	1	1	1	1
Cornus racemosa		r	r	r	r		
Eleocharis calva	1	1	1	1	1	+	+
Eleocharis elliptica	1	1	1	1	1	1	1
Erechtites hieracifolia				+	+	+	+
Eriophorum angustifoliur	+	+	+	+	+	+	1
Eupatorium perfoliatum	+	+	+	+	+	1	+
Galium obtusum	+	+	+	+	+	+	+
Glyceria striata	1	1	1	1	1	1	1
Helianthus grosseratus	+	1	1	1	1	1	1
Juncus dudleyi		r	+	+			
Leersia oryzoides							
Lycopus americanus	+	1	1	1	1	1	1
Lycopus virginicus	+	1	1	1	1	1	1
Lythrum alatum	1	1	1	1	1	1	+
Melilotus alba		+	+	r	+		
Oxalis stricta		r					
Polygonum amphibium	+	+	1	1	1	1	
Scirpus lineatus							
Senecio pauperculus				r	r	r	
Solidago gigantea	1	1	1	1	1	1	1
Solidago graminifolia	1	1	1	1	1	1	1
Solidago riddellii			1	1	1	1	1
Sonchus uligonosus			r	r	+	+	+
Spartina pectinata							
Taraxacum officinale			r		r	r	r
Teucrium canadense							
Typha latifolia	r	r	r	r	r	r	r
Verbena hastata		+	+	+	+	+	+

South Block--Q1 1989	JUN13	JUN27	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea							
Agrostis alba					+	1	1
Allium cernuum				1			
Ambrosia artemisiifolia						r	r
Aster puniceus	1	1	1	1	1	1	1
Bidens vulgata	1	1	1	3	2	2	2
Calamagrostis canadensis			+				
Carex buxbaumii							
Carex lanuginosa							
Carex sartwellii							
Carex stricta	2	2	2	1	2	1	1
Chenopodium album				r	r	r	
Cirsium arvense						r	1
Cornus racemosa				r	r	r	
Equisetum arvense							
Fragaria virginiana				r			
Galium obtusum	+	+	+	+	+	+	+
Glyceria striata		r					
Lathyrus palustris	+	+	+	+	+	+	+
Lycopus americanus				r			
Lycopus virginicus	1	1	1	2	2	2	2
Oxalis stricta					+		r
Panicum capillare		r	r				
Phalaris arundinacea							
Phleum pratense					+	+	+
Polygonum amphibium	+	1	1	1	1	+	
Proserpinaca palustris				r	r	r	+
Rhamnus cathartica		r	r	r	r	r	r
Rosa sp.	r						
Scirpus acutus	r	r	+	+	r	+	r
Scuttellaria epilobiifolia	+	+	+	+	1	+	1
Solidago altissima						r	r
Solidago gigantea	1	1	1	1	1	1	1
Solidago graminifolia							
Sonchus uliginosus			r		r	r	
Taraxacum officinale					r	r	r
Typha angustifolia							
Typha latifolia	2	1	1	1	1	1	1
Verbascum thapsus				r		r	r
Verbena hastata			+	1	1		1

South Block--Q1 1990	JUN1	JUN12	JUN25	JUL11	JUL30	AUG16	SEP22
Acalypha rhomboidea		+	r	+	+	+	
Agrostis alba	+	+	+	1	1	1	1
Allium cernuum							
Ambrosia artemisiifolia	+		r	r			
Aster puniceus	1	1	1	1	2	2	1
Bidens vulgata	1	1	1	1	1	1	+
Calamagrostis canadensis	1	1	1	1	1	1	1
Carex buxbaumii			+	1	1	+	+
Carex lanuginosum		+	1	1	1	1	1
Carex sartwellii	1	1	1	1	1	1	1
Carex stricta	1	1	1	1	1	1	1
Chenopodium album							
Cirsium arvense						r	r
Cornus racemosa							
Equisetum arvense	r	r	+	+	+		
Fragaria virginiana							
Galium obtusum	+	+	+	+	+	+	+
Glyceria striata							+
Lathyrus palustris	+	+	+	+	+	+	
Lycopus americanus							
Lycopus virginicus	1	1	1	1	1	1	1
Oxalis stricta				r	+	+	
Panicum capillare							
Phalaris arundinacea	1	1	1	1	1	1	1
Phleum pratense			1	1	1	+	+
Polyganum amphibium	+	1	1	1	1	1	1
Proserpinaca palustris			r		r	+	+
Rhamnus cathartica							
Rosa sp.							
Scirpus acutus	+	+	+	+	+	+	1
Scuttellaria epilobiifolia	1	1	1	1	1	2	1
Solidago altissima							
Solidago gigantea	+	1	1	1	1	1	1
Solidago graminifolia		r					
Sonchus uliginosus							
Taraxacum officinale	r	r	r	r	r	r	r
Typha angustifolia					r	r	r
Typha latifolia	+	+	+	+	+	1	1
Verbascum thapsus							
Verbena hastata	1	1	1	1	1	1	+

South Block--Q2 1989	JUN13	JUN26	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea							
Agropyron trachycaulum						r	+
Agrostis alba						+	+
Allium cernuum	+	+	+	+	+	+	+
Amaranthus albus		r					
Aster novae-angliae							
Aster puniceus	1	1	1	1	1	1	1
Aster simplex				1			
Bidens frondosa							
Calamagrostis canadensis				+			
Carex buxbaumii							
Carex granularis							
Carex interior							
Carex sartwellii							
Carex stricta	2	1	1	1	1	1	1
Cirsium arvense		+	r	+	+	r	r
Cornus racemosa	+	r	+	+	1	1	1
Eleocharis calva	+	+	+	+	+	+	+
Equisetum arvense	r	r	+	+	+	+	+
Equisetum fluviatile	r	+	r		+	r	
Eriophorum angustifolium							
Eupatorium perfoliatum			+	+	+	+	
Fragaria virginiana	r	r	r		r	r	r
Galium obtusum	+	+	+	+	+	+	+
Geum canadense	r	r	r	r	r	r	+
Glyceria striata			+		+		
Helianthus grosseserratus	r	1	1	1	1	1	+
Juncus dudleyi					+	+	+
Juncus torreyi							
Lathyrus palustris	+	1	+	+	+	+	+
Lycopus americanus	+	+	+	+	+	+	+
Lycopus virginicus		+	+	+	+	+	+
Lysimachia quadriflora							
Lythrum alatum				r		r	r
Muhlenbergia glomerata			r		+	+	+
Oenothera biennis	r			r	r	r	r
Oxalis stricta					+	+	+
Panicum capillare				+	r	r	r
Panicum lanuginosum		r			r		
Poa pratensis						r	+
Polygonum amphibium	r	+	+	r	r	+	+
Populus deltoides			r			+	r
Potentilla simplex			r	r	r	r	r
Prunus virginiana							
Pycnanthemum virginiani	+	+			+	+	r
Rhamnus cathartica			+	r		+	+

Rosa multiflora		+	+	+	+	+	1
Rudbeckia hirta			r		r	+	+
Scirpus atrovirens							
Senecio pauperculus	r	r				r	+
Smilicina stellata	+	+	+	+	+	+	r
Solanum dulcamara				r			
Solidago gigantea						r	+
Solidago graminifolia	1	1	1	1			1
Solidago riddellii	+	+	+	+		1	+
Sonchus uliginosus				r	+	+	r
Taraxacum officinale		r				+	r
Verbena hastata				1	+	+	+
Vitis riparia		+	+	+	+	r	+

South Block--Q2 1990	JUN2	JUN12	JUN25	JUL11	JUL30	AUG16	SEP22
Acalypha rhomboidea		r					
Agropyron trachycaulum							
Agrostis alba		r	r	+	+	+	+
Allium cernuum		+	+	+	+	+	+
Amaranthus albus							
Aster novae-angliae						+	
Aster puniceus	1	1	1	1	1	1	1
Aster simplex							
Bidens frondosa	1	1	1	1	1	1	1
Calamagrostis canadensis							
Carex buxbaumii	1	1	1	1	1	1	1
Carex granularis		1	+	+	+	+	+
Carex interior	r	+	+	+	+	1	+
Carex sartwellii	+	+	+	1	+	+	+
Carex stricta	1	1	1	1	1	1	1
Cirsium arvense					r	r	
Cornus racemosa	+	+	+	1	1	1	+
Eleocharis calva	+	1	1	1	1	1	1
Equisetum arvense	+	+	+	+	+	+	+
Equisetum fluviatile	r						
Eriophorum angustifoliur	r	+	+	+	+	+	+
Eupatorium perfoliatum			+	+	+	+	+
Fragaria virginiana	r	r	r	r	+	+	+
Galium obtusum	+	+	+	+	+	+	1
Geum canadense	r	r	r	+	r	r	1
Glyceria striata	+	+	+	+	+	+	+
Helianthus grosseserratus	+	1	1	1	1	1	1
Juncus dudleyi	1	1	1	1	1	1	1
Juncus torreyi				+	+	+	+
Lathyrus palustris	+	+	+	+	+	+	+
Lycopus americanus	+	+	+	1	1	1	1
Lycopus virginicus	+	1	1	1	1	1	1
Lysimachia quadriflora				+	+	+	+
Lythrum alatum	+	1	1	1	1	1	+
Muhlenbergia glomerata	r	r					
Oenothera biennis							
Oxalis stricta	r	r	r				
Panicum capillare							
Panicum lanuginosum							
Poa pratensis						r	+
Polygonum amphibium						+	1
Populus deltoides				r	r	+	+
Potentilla simplex							
Prunus virginiana	r	r	r	r	r	r	r
Pycnanthemum virginianum							
Rhamnus cathartica	r	+	+	+	+	+	+

Rosa multiflora	r	+	+	1	1	1	1
Rudbeckia hirta					r	r	
Scirpus atrovirens						r	+
Senecio pauperculus	r	r	r	r	r	r	r
Smilicina stellata	+	+	+	+	+	+	+
Solanum dulcamara							
Solidago gigantea							
Solidago graminifolia	1	1	1	1	1	1	1
Solidago riddellii	+	+			+	1	1
Sonchus uliginosus			r	r	r	r	
Taraxacum officinale			+		r	+	
Verbena hastata	+	+	+	+	+	+	+
Vitis riparia	+	+	+	+	+	+	+

South Block--Q3 1989	JUN13	JUN27	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea							
Agrostis alba					+	+	+
Aster novae-angliae	r	r	+	r	+	+	+
Aster puniceus					+	1	1
Aster simplex	+	+	+	1	1	1	1
Bidens frondosa							
Calamagrostis canadensis	+	+	+	r	+	+	+
Carex buxbaumii							
Carex lanuginosa							
Carex stricta	2	2	1	1	1	1	1
Cirsium arvense					r	r	r
Cornus racemosa	r	+	+	+	1	+	+
Eleocharis elliptica	1	1	+	1	1	1	1
Equisetum arvense	+	+	+	+	+	+	+
Eriophorum angustifolium							
Eupatorium perfoliatum			+	+	1	1	1
Fragaria virginiana							r
Glyceria striata				+			+
Helianthus grosseserratus							
Lathyrus palustris			+	+	+	+	+
Lycopus americanus				1	+	+	1
Lycopus virginicus	1	+	1	1	1	1	1
Lysimachia quadrifolia			r	r	r	r	
Lythrum alatum					+	+	+
Melilotus alba							
Muhlenbergia glomerata				r	+	+	+
Panicum capillare				r		r	r
Polyganum amphibium	+	+	1	1	+	+	+
Populus deltoides						r	r
Pycnanthemum virginicum						+	
Rhamnus cathartica					r	r	+
Scirpus atrovirens					r	r	r
Scirpus lineatus							
Smilicina stellata							
Solidago altissima	r						
Solidago gigantea				1	+	+	+
Solidago riddellii	1	1	+	+	1	1	1
Sonchus uliginosus					+	r	
Spartina pectinata	r	r	+	+			
Taraxacum officinale	r	r		+	r	+	+
Unknown							
Verbena hastata	r	+	1	1		1	1

South Block--Q3 1990	JUN2	JUN12	JUN25	JUL11	JUL31	AUG16	SEP22
Acalypha rhomboidea			+	+	+	+	
Agrostis alba							
Aster novae-angliae	1	1	1	1	1	1	1
Aster puniceus	1	1	1	1	1	2	1
Aster simplex	1	1	1	1	1	1	1
Bidens frondosa	+	+	+	+	1	1	1
Calamagrostis canadensis	1	1	1	1	1	1	+
Carex buxbaumii			+	+	+	+	+
Carex lanuginosa			+	+	+	+	1
Carex stricta	1	1	1	1	1	2	1
Cirsium arvense							
Cornus racemosa	1	1	1	1	1	1	1
Eleocharis elliptica	1	1	1	1	1	1	1
Equisetum arvense	1	1	1	1	1	1	+
Eriophorum angustifoliur	+	+	+	+	+	+	1
Eupatorium perfoliatum	1	1	1	1	1	1	1
Fragaria virginiana							
Glyceria striata							
Helianthus grosseserratus	+	+	+	+	1	+	+
Lathyrus palustris	+	1	1	1	1	1	+
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	1	1	1	1	1	1	1
Lysimachia quadrifolia						+	+
Lythrum alatum	+	+	+	"+	+	1	1
Melilotus alba	+		r	+	+	+	+
Muhlenbergia glomerata	+	+	+	"+	+	+	+
Panicum capillare							
Polyganum amphibium	+	+	1	1	1	1	1
Populus deltoides				r	r	r	r
Pycnanthemum virginicum							
Rhamnus cathartica	r	r	r	+	+	+	+
Scirpus atrovirens							
Scirpus lineatus							
Smilicina stellata				r			
Solidago altissima		+	+	+	+	+	+
Solidago gigantea					+	+	+
Solidago riddellii	1	1	1	1	1	1	1
Sonchus uliginosus	+	+	+	+	1	1	+
Spartina pectinata							
Taraxacum officinale	+	+	+	+	+	+	+
Unknown		r	r	r	r	r	r
Verbena hastata	1	1	1	1	1	1	+

South Block--Q4 1989	JUN13	JUN27	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea							
Allium cernuum				r		+	
Ambrosia artemisiifolia				r	+	r	
Asclepias incarnata	r						
Aster novae-angliae	r	1	1	+		r	r
Aster puniceus				1	1	1	1
Bidens vulgata							
Calamagrostis canadensis					+	+	+
Carex buxbaumii							
Carex granularis							
Carex interior							
Carex lanuginosa							
Carex stricta	1	1	1	1	1	1	1
Cirsium arvense							r
Cornus racemosa				+		+	+
Daucus carota			r				r
Eleocharis elliptica	+	1	+	+	+	+	+
Equisetum arvense	+	+	+	+	+	+	+
Eriophorum angustifolium							
Eupatorium perfoliatum	+	+	r	1	+	1	1
Galium obtusum	+	1	+	1	+	+	+
Glyceria striata					+	+	
Helianthus grosseserratus							
Juncus dudleyi					+	+	+
Lathyrus palustris	+	+	+	+	+	+	+
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus		+		+	1	1	1
Lythrum alatum					+	+	+
Muhlenbergia glomerata	+	+	+	+	+	1	+
Panicum capillare						r	r
Polygonum amphibium					+		+
Pycnanthemum virginiani	1	1	+	1	1	1	1
Scirpus atrovirens							
Senecio pauperculus	+	+	+	+	+	+	+
Smilicina stellata	r	r					
Solidago altissima	r						
Solidago gigantea	+	+	1	1	+	1	1
Solidago riddellii	+	+	1	1	1	1	1
Verbena hastata	r			+	+	+	+
Verbascum thapsus							

South Block--Q4 1990	JUN2	JUN12	JUN25	JUL11	JUL31	AUG16	SEP22
Acalypha rhomboidea			+				
Allium cernuum							
Ambrosia artemisiifolia	+			r	r	r	
Asclepias incarnata		r					
Aster novae-angliae							
Aster puniceus	1	1	1	1	1	1	1
Bidens vulgata	1	1	1	1	1	1	1
Calamagrostis canadensis	+	+	+	+	1	1	1
Carex buxbaumii	1	1	1	1	1	1	+
Carex granularis			+	+	r	r	r
Carex interior	1	1	1	1	1	1	1
Carex lanuginosa	1	1	1	1	1	1	1
Carex stricta	1	1	1	1	1	1	1
Cirsium arvense							
Cornus racemosa							
Daucus carota					r	r	
Eleocharis elliptica	1	1	1	1	1	1	1
Equisetum arvense	1	1	1	1	1	1	1
Eriophorum angustifolium			+	+	+	+	+
Eupatorium perfoliatum	1	1	1	1	1	1	
Galium obtusum	+	+	1	1	1	1	1
Glyceria striata	+	+	+	+	+	+	+
Helianthus grosseserratus	+	+	+	+	+	+	r
Juncus dudleyi	1	1	+	1	+	+	+
Lathyrus palustris	+	+	+	+	+	+	+
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	1	+	1	1	1	1	1
Lythrum alatum		+	+	+	+	+	+
Muhlenbergia glomerata	1	1	1	1	1	1	1
Panicum capillare					+		
Polygonum amphibium	r	+	+	1	1	1	1
Pycnanthemum virginiani	1	1	1	1	1	1	
Scirpus atrovirens			+	+	+	+	+
Senecio pauperculus	+	+	+	+	1	1	1
Smilicina stellata	+	+	+	+	+	+	1
Solidago altissima							
Solidago gigantea	+	+	+	+	+	+	+
Solidago riddellii	1	1	1	1	1	1	+
Verbena hastata	+	1	1	1	+	+	
Verbascum thapsus	r	r					

South Block--Q5 1989	JUN13	JUN27	JUL8	JUL26	AUG8	AUG22	SEP22
Acalypha rhomboidea		r	+	+	+	+	+
Asclepias incarnata							
Aster novae-angliae							
Aster puniceus	1	1	1	1	2	1	1
Calamagrostis canadensis							
Carex sartwellii							
Carex stricta	2	2	1	1	2	1	1
Cirsium arvense						+	r
Cornus racemosa	r	r					r
Equisetum arvense	+	+	+	1	1	1	1
Eragrostis pectinacea				+			
Fragaria virginiana				+	+	+	+
Galium obtusum	r	+	+		+	r	r
Glyceria striata			+	r	+	+	+
Helianthus grosseserratus	r	r	+	+	+		
Juncus dudleyi			r	+	+	+	1
Juncus torreyi							
Lathyrus palustris	r				+		
Lycopus americanus	+	+	+	1	1	1	1
Lycopus virginicus				+			r
Lythrum alatum			r	+	+	+	+
Muhlenbergia glomerata					+	+	+
Oenothera biennis					r		
Panicum capillare		+	+	+	+	+	+
Polygonum amphibium		+	+	+	1	1	1
Populus deltoides					r	r	r
Pycnanthemum virginiani	r	+	+		+	r	
Rudbeckia hirta						r	r
Sonchus uliginosus				r	r		
Taraxacum officinale			+	r	+	+	+
Verbena hastata		+	1	r	1	1	+
Viola papilionacea							

South Block--Q5 1990	JUN2	JUN12	JUN26	JUL11	JUL31	AUG16	SEP22
Acalypha rhomboidea			+	+	+	+	
Asclepias incarnata							
Aster novae-angliae					r	r	+
Aster puniceus	2	1	2	2	2	2	1
Calamagrostis canadensis						+	+
Carex sartwellii				+	+	+	+
Carex stricta	1	2	2	2	2	2	1
Cirsium arvense	r	r	r	r	r	r	
Cornus racemosa							
Equisetum arvense	1	1	1	1	1	2	1
Eragrostis pectinacea							
Fragaria virginiana		r	+	+	+	+	
Galium obtusum	+	+	+	+	+	+	+
Glyceria striata	1	1	1	1	1	1	1
Helianthus grosseserratus							
Juncus dudleyi	1	1	1	1	1	1	1
Juncus torreyi				1	1	1	1
Lathyrus palustris							
Lycopus americanus	1	1	1	1	1	1	1
Lycopus virginicus	1				+		
Lythrum alatum	1	1	1	1	1	1	1
Muhlenbergia glomerata							
Oenothera biennis							
Panicum capillare					+	+	+
Polygonum amphibium	1	1	1	1	1	1	1
Populus deltoides				+	+	+	
Pycnanthemum virginiani	+	+	+	+	+	+	
Rudbeckia hirta							
Sonchus uliginosus	r	r	r	+	+	+	+
Taraxacum officinale							
Verbena hastata	+	+	1	1	1	1	+
Viola papilionacea			+	+	+	+	1

West Block--Q1 1989	JUN14	JUN27	JUL10	JUL26	AUG8	AUG24	SEP22
Abutilon theophrasti	r		r	1	1	1	
Acalypha rhomboidea						r	
Achillea millefolium			r		r		r
Allium cernuum	1	1	1	1	1	1	+
Ambrosia artemisiifolia	r	r	r		1	1	r
Asclepias syriaca	1	1	1	1	1	1	1
Bidens frondosa							
Bromus inermis	r	r	r	r			
Carex buxbaumii							
Carex granularis							
Carex lanuginosa							
Carex stricta	1	1	1	1	1	1	+
Carex vulpinoidea							
Cerastium vulgatum							
Cirsium vulgare							
Convolvulus sepium							
Cornus racemosa	1	1	1	1	1	1	1
Daucus carota			r	+	1	+	+
Galium obtusum	r	r	r		r		
Glyceria striata				+	+	+	+
Lathyrus palustris	+	+	+	+	r	+	+
Medicago lupulina							
Muhlenbergia glomerata	r	+			+		+
Oxalis stricta			+		r	+	+
Panicum capillare				r	r	r	
Poa compressa							+
Poa pratensis					+	+	1
Polygonum pensylvanicu:	r	r	1	1	1	1	1
Prunella vlugaris							
Prunus virginiana		r	r				
Pycnanthemum virginian	r	r	+	r	+		r
Rhamnus cathartica	+	+	+	1	1	1	1
Rhamnus frangula				r	r	r	
Rosa arkansana			+				
Rosa multiflora	+	+	1	1	1	r	1
Setaria faberi	2	1	+		1		
Smilicina stellata	1	1	1	1	1	1	r
Solidago altissima	1	+	1	1	1	1	1
Solidago graminifolia	1	+	+	1	1	1	1
Sorghastrum nutans	2	1	1	1	1	2	1
Taraxacum officinale							
Unknown	r	r	r		r	r	+
Verbascum thapsus						+	1
Verbena hastata						r	+
Viola papilionacea	r	+	+	+	+		
Vitis riparia	+	+	+	+	+	+	+

West Block--Q1 1990	MAY31	JUN11	JUN25	JUL12	JUL31	AUG16
Abutilon theophrasti						
Acalypha rhomboidea						
Achillea millefolium	1	+	1	1	+	+
Allium cernuum	1	1	1	1	1	1
Ambrosia artemisiifolia	1	1	1	1	1	1
Asclepias syriaca	1	1	1	1	1	1
Bidens frondosa			+	r	r	r
Bromus inermis	1	1	1	1	1	1
Carex buxbaumii				+	+	+
Carex granularis				+	+	
Carex lanuginosa	1	1	1	1	1	1
Carex stricta	1	1	1	1	1	1
Carex vulpinoidea				+	+	1
Cerastium vulgatum						r
Cirsium vulgare	r	r	r	r	r	r
Convolvulus sepium					r	r
Cornus racemosa	1	1	1	1	2	2
Daucus carota	+	1	1	1	1	1
Galium obtusum						
Glyceria striata	+	+	+	+	1	+
Lathyrus palustris	+	+	+	r	r	r
Medicago lupulina						r
Muhlenbergia glomerata						
Oxalis stricta	1	1	1	1	1	1
Panicum capillare						
Poa compressa						
Poa pratensis	1	1	1	1	1	+
Polygonum pensylvanicum			+	+	+	+
Prunella vlugaris						+
Prunus virginiana	r	r	r	r	r	r
Pycnanthemum virginiani	r	r	+	+	+	+
Rhamnus cathartica	1	1	1	1	1	1
Rhamnus frangula						
Rosa arkansana	1	1	1	1	1	1
Rosa multiflora						
Setaria faberi					1	1
Smilicina stellata	2	1	1	2	2	1
Solidago altissima	2	2	1	2	2	1
Solidago graminifolia	1	1	1	2	2	2
Sorghastrum nutans	1	1	1	1	1	1
Taraxacum officinale				r	r	r
Unknown						
Verbascum thapsus	r	r	r	r	r	r
Verbena hastata						
Viola papilionacea		+	+	+	+	
Vitis riparia	+	+	+	+	+	+

West Block--Q2 1989	14-Jun	27-Jun	10-Jul	26-Jul	8-Aug	24-Aug	23-Sep
Abutilon theophrasti							
Acalypha rhomboidea				r	r	+	+
Achillea millefolium	+	+	+	+	+	+	+
Agrostis alba							
Allium cernuum	1	1	+	1	+	+	+
Ambrosia artemisiifolia							
Apocynum cannabinum	+			r	1	r	r
Asclepias syriaca	1	1	1				
Aster pilosus							
Bidens frondosa							
Bromus inermis							
Calamagrostis canadensis					+	+	+
Carex buxbaumii							
Carex granularis							
Carex lanuginosa							
Carex stricta	2	1	1	1	1	+	+
Carex vulpinoidea							
Cerastium vulgatum	r			r			
Cirsium arvense			r	r			
Cornus racemosa	1	2	3	3	2	2	2
Daucus carota	r	1	+	1	+	+	1
Galium obtusum	r	1	+	+	+	+	+
Geum laciniatum			r	r			
Glyceria striata					+	1	+
Helianthus grosseserratus	1	1	2	2	3	1	2
Juniperus virginiana	+		r	r			
Lathyrus palustris	+	1 +	+	+	+	+	
Lysimachia quadriflora							
Morus sp.							
Muhlenbergia glomerata	1	1	1	+	1	1	1
Oenothera biennis						r	
Oxalis stricta			+	+	+	+	+
Panicum capillare						r	r
Panicum lanuginosum	r						
Poa compressa						+	+
Poa pratensis						+	
Polygonum convolvulus							
Polygonum pensylvanicum							
Pycnanthemum virginiani	+	+	1	+	+	+	+
Rhamnus cathartica	r	+	+	r	r	r	+
Rosa multiflora	2	1	1	1	1	1	+
Rubus sp.					r	r	r
Scirpus lineatus	1	1	+	+	+	+	r
Setaria faberi							
Smilicina stellata	2	+	1	+	1	1	r
Solidago altissima	+	+	2	2	1	1	1
Solidago graminifolia	1	+	1	1	1	1	+
Sorghastrum nutans							
Taraxacum officinale				r			
Verbena hastata					r		
Vitis riparia	r	r	r	+	+	r	+
Unknown					r	r	

West Block--Q2 1990	31-May	11-Jun	25-Jun	12-Jul	31-Jul	16-Aug
Abutilon theophrasti						
Acalypha rhomboidea				r	r	+
Achillea millefolium	+	+	+	1	+	r
Agrostis alba				1	1	+
Allium cernuum	+	+	+	+	+	+
Ambrosia artemisiifolia						+
Apocynum cannabinum						
Asclepias syriaca						
Aster pilosus					r	r
Bidens frondosa	+	+	+	+	+	+
Bromus inermis	+	1	1	1	1	1
Calamagrostis canadensis						
Carex buxbaumii	+	1	1	1	1	1
Carex granularis				+	+	+
Carex lanuginosa	+	1	1	1	1	1
Carex stricta						
Carex vulpinoidea				1	1	1
Cerastium vulgatum	+	+	+	+	+	+
Cirsium arvense						
Cornus racemosa	2	2	3	3	3	3
Daucus carota	1	1	1	1	1	1
Galium obtusum	+	+	1	1	1	1
Geum laciniatum		r	+	+	+	+
Glyceria striata	1	+	+	+	+	+
Helianthus grosseserratus	1	1	2	2	2	3
Juniperus virginiana	r	r	r	r	r	r
Lathyrus palustris	+	+	+	+	+	+
Lysimachia quadriflora					+	+
Morus sp.	r	r	r	r	r	r
Muhlenbergia glomerata	1	1	1	+	+	+
Oenothera biennis						
Oxalis stricta	+	+	+	+	+	+
Panicum capillare						
Panicum lanuginosum						
Poa compressa						
Poa pratensis	1	1	1	1	1	+
Polygonum convolvulus						+
Polygonum pensylvanicum					+	+
Pycnanthemum virginiani	+	+	1	1	1	1
Rhamnus cathartica	+	1	1	1	1	1
Rosa multiflora	1	1	1	1	1	1
Rubus sp.						
Scirpus lineatus						
Setaria faberi						+
Smilicina stellata	1	1	1	2	1	1
Solidago altissima	2	2	2	2	2	3
Solidago graminifolia	1	1	1	1	1	1
Sorghastrum nutans			2	2	2	3
Taraxacum officinale			1	1	1	2
Verbena hastata					+	
Vitis riparia	+	+	+	r	r	r
Unknown						

West Block--Q3 1989	JUN14	JUN27	JUL10	JUL26	AUG8	AUG23	SEP23
Acalypha rhomboidea			r	+	+	+	+
Achillea millefolium	+	+	+	+	+	+	1
Agrostis alba							
Allium cernuum	+	1	1	1	1	1	+
Ambrosia trifida							
Aster novae-angliae							
Aster pilosus							
Carex buxbaumii							
Carex granularis							
Carex lanuginosa							
Carex stricta	1	1	1	1	1	1	+
Cerastium vulgatum	r	r	r	r	+	+	r
Cornus racemosa	+	1	1	1	1	1	1
Daucus carota	r	r	r			+	+
Equisetum fluviatile	+	r		+			
Galium obtusum	1	+	+	+	+	+	+
Geum laciniatum	r	r	r		r	r	r
Glyceria striata		+			+	+	+
Helianthus grosseserratus	+	+	1	1	1	1	1
Hypoxis hirsuta							
Juniperus virginiana		+	r	r	r	r	r
Lathyrus palustris	+	r					+
Lycopus americanus		r	r		r	r	r
Lythrum alatum							
Melilotus alba							
Muhlenbergia			+	+	+	+	1
Oxalis stricta						+	
Phalaris arundinacea				+			
Poa pratensis							
Polygonum amphibium			r	r	r	r	
Prunella vulgaris							
Prunus virginiana	r	r	r	r	r	r	
Pycnanthemum virginiani	1	+	+	1	1	1	
Rhamnus cathartica						r	+
Rosa multiflora	1	1	1	1	1	1	1
Setaria faberi							
Smilicina stellata	1	1	1	1	1	1	1
Solidago altissima	1	+	1	1	1	1	1
Solidago graminifolia	r		r	r		+	+
Sonchus uliginosus						r	
Sorghastrum nutans	1	+	1	+	1	1	+
Taraxacum officinale							
Vitis riparia			+			1	+

West Block--Q3 1990	MAY31	JUN11	JUN25	JUL12	JUL31	AUG16	SEP22
Acalypha rhomboidea							
Achillea millefolium	+	1	1	1	1	+	
Agrostis alba						+	+
Allium cernuum	1	1	1	1	1	+	+
Ambrosia trifida	r	r					
Aster novae-angliae					r	r	r
Aster pilosus				r	r	+	+
Carex buxbaumii	1	1	1	1	1	1	1
Carex granularis					1	1	+
Carex lanuginosa	+	+	1	1	1	1	1
Carex stricta	+	+	+	+	+	+	+
Cerastium vulgatum	+	+	+	+	+	+	+
Cornus racemosa	1	1	2	2	2	2	2
Daucus carota	+	+	1	1	1	1	1
Equisetum fluviatile							
Galium obtusum	+	1	1	1	1	1	1
Geum laciniatum	1	1	1	1	1	1	1
Glyceria striata	1	+	+	1	1	1	1
Helianthus grosseserratus		1	1	1	1	1	1
Hypoxis hirsuta	+	+	+				
Juniperus virginiana		r	r	r	r	r	r
Lathyrus palustris	+	+	+	+	+	+	+
Lycopus americanus							
Lythrum alatum							r
Melilotus alba	r	r	r	r	r		r
Muhlenbergia	+	+	1	1	1	1	1
Oxalis stricta		+	+		r	+	1
Phalaris arundinacea							
Poa pratensis	1	1	1	1	1	+	+
Polygonum amphibium							
Prunella vulgaris			+	+	+	+	+
Prunus virginiana	r	r	r	r	r	r	r
Pycnanthemum virginiani	1	1	1	1	1	1	1
Rhamnus cathartica							
Rosa multiflora	1	1	2	2	2	1	1
Setaria faberi		r	r	r	+	+	+
Smilicina stellata	1	1	2	2	2	2	2
Solidago altissima	1	1	1	2	2	2	1
Solidago graminifolia	+	+	1	1	1	1	1
Sonchus uliginosus				r	r	r	r
Sorghastrum nutans	+	+	+	+	+	1	1
Taraxacum officinale		r	r	r	r	+	+
Vitis riparia	r	1	1	1	r	r	r

West Block--Q4 1989	14-Jun	27-Jun	10-Jul	26-Jul	8-Aug	24-Aug	23-Sep
Acalypha rhomboidea							
Agrostis alba							
Allium cernuum		r	+	+	+	+	r
Ambrosia artemisiifolia	r	+	1	1	1	1	1
Aster puniceus	1	+	1	1	1	1	1
Aster simplex	1	1			+	1	1
Bidens frondosa					r	r	r
Calamagrostis canadensis			+	+	+	+	+
Carex lanuginosa							
Carex stricta	2	1	1	1	1	1	1
Carex vulpinoidea							
Cirsium arvense					r	r	r
Cornus racemosa	1	2	3	3	3	2	2
Daucus carota			r		+	+	+
Fragaria virginiana							
Galium obtusum	1	1	+	1	+	+	+
Geum aleppicum					r	r	r
Glyceria striata					r	1	1
Helianthus grosseseratus	1	1	2	1	2	2	2
Lathyrus palustris	+	+	+	+	+	+	+
Medicago lupulina		r			+	r	
Morus sp.			r	+	r	+	+
Muhlenbergia glomerata	+	1	+	+	1	1	1
Oxalis stricta	+	+	1	1	1	1	+
Panicum capillare		+	+			+	+
Poa pratensis		+			r		
Polygonum amphibium	r	r	r	r			
Prunella vulgaris							
Pycnanthemum virginianum						+	+
Rhamnus cathartica					r		
Setaria faberi							
Smilicina stellata			1	1	1	1	
Solidago altissima	1	1	1	2	2	1	1
Solidago graminifolia	1	1	1	1	1	1	1
Sonchus uliginosus							
Taraxacum officinale							
Verbena hastata				+	+	+	+
Viola papilionacea						r	+
Vitis riparia							

West Block--Q4 1990	31-May	12-Jun	25-Jun	12-Jul	31-Jul	16-Aug
Acalypha rhomboidea	r	r	+	+	+	+
Agrostis alba		+	+	+	+	+
Allium cernuum	+	+	+	1	1	+
Ambrosia artemisiifolia	1	1	1	+	1	1
Aster puniceus	1	1	1	1	1	2
Aster simplex	1	1	1			
Bidens frondosa		+	+	r	r	r
Calamagrostis canadensis						
Carex lanuginosa	1	1	1	1	1	1
Carex stricta	1	1	1	1	1	1
Carex vulpinoidea				1	1	1
Cirsium arvense						
Cornus racemosa	2	2	2	3	3	3
Daucus carota	+	1	1	1	1	1
Fragaria virginiana					r	r
Galium obtusum	1	1	1	1	1	1
Geum aleppicum		+	+	+	r	r
Glyceria striata			1	1	1	1
Helianthus grosseseratus	1	1	1	1	1	1
Lathyrus palustris	+	+	2	+	+	+
Medicago lupulina						
Morus sp.						+
Muhlenbergia glomerata	+	+	+	+	+	+
Oxalis stricta	+	1	1	1	1	1
Panicum capillare						
Poa pratensis	1	+	+	+	+	+
Polygonum amphibium						
Prunella vulgaris			+	+		
Pycnanthemum virginianum		r	r	+	+	+
Rhamnus cathartica					r	
Setaria faberi					+	+
Smilicina stellata	1	1	1	1	1	1
Solidago altissima	1	1	2	2	2	2
Solidago graminifolia	1	1	1	1	1	1
Sonchus uliginosus		r	r	r	r	
Taraxacum officinale	r					
Verbena hastata					+	r
Viola papilionacea	+	+	+	+	+	1
Vitis riparia	+	+	+	+	+	

West Block--Q5 1989	14-Jun	27-Jun	10-Jul	26-Jul	8-Aug	23-Aug	23-Sep
Acalypha rhomboidea		+			+	1	+
Achillea millefolium	1	1	1	1	1	1	1
Agrostis alba					+	+	+
Ambrosia artemisiifolia	+	+	+	1	1	1	1
Asclepias incarnata							
Aster novae-angliae							+
Aster simplex	+	1					
Calamagrostis canadensis				+			
Carex lanuginosa							
Carex stricta	2	1	1	1	1	1	+
Chenopodium album					r		
Cirsium arvense				+		+	+
Cornus racemosa	+	1	1	1	1	1	1
Daucus carota	+	+	+	+	+	1	+
Eleocharis sp.							
Equisetum arvense	r	+	+	+	+	+	+
Galium obtusum	+	+	+	+	+	+	+
Geum aleppicum	+	+	+	+	+	+	+
Glyceria striata				+	+	+	+
Lathyrus palustris					+	+	+
Lycopus americanus	r	+	1	1	1	1	1
Lythrum alatum							+
Melilotus alba					r	r	r
Muhlenbergia glomerata	1	1	1	1	1	1	1
Poa pratensis							
Polygonum amphibium			r			r	r
Prunella vulgaris				r	r	r	+
Pycnanthemum virginiani	1	1	1	1	1	1	+
Rosa arkansana	r	+	1	1	1	1	1
Rosa multiflora					+		
Rudbeckia hirta							
Senecio paupercaulus	r	r	r	r	+	+	+
Setaria faberi							
Smilicina stellata	2	2	1	1	1	1	
Solidago altissima	r					r	
Solidago graminifolia	1	1	1	1	1	1	2
Solidago riddellii	+	+	1	1	1	1	1
Trifolium repens					+	r	r
Verbena hastata						+	
Viola papilionacea		r	r	r	+		

West Block--Q5 1990	1-Jun	12-Jun	25-Jun	12-Jul	31-Jul	16-Aug
Acalypha rhomboidea	r	+	+	+	+	+
Achillea millefolium	1	1	1	1	1	1
Agrostis alba		+	+	+	+	1
Ambrosia artemisiifolia	1	1	1	1	1	1
Asclepias incarnata					r	+
Aster novae-angliae				+	+	+
Aster simplex						
Calamagrostis canadensis	1	1			1	1
Carex lanuginosa		+	1	1	1	1
Carex stricta	1	1	1	1	1	1
Chenopodium album						
Cirsium arvense	+					
Cornus racemosa	1	1	1	1	1	1
Daucus carota	+	1	1	1	1	1
Eleocharis sp.	r					
Equisetum arvense	1	1	1	+		
Galium obtusum	1	1	1	1	1	1
Geum aleppicum	2	+	+	+	+	+
Glyceria striata	1	1	1	1	1	1
Lathyrus palustris	+	+	+	+	+	+
Lycopus americanus	1	1	1	1	1	1
Lythrum alatum						
Melilotus alba	+	+	+	+	+	
Muhlenbergia glomerata	1	1	1	1	1	1
Poa pratensis	1	+	+	+	+	+
Polygonum amphibium					1	
Prunella vulgaris	+	1	1	1	1	1
Pycnanthemum virginiani	1	1	2	2	1	1
Rosa arkansana	1	1	1	1	1	1
Rosa multiflora						1
Rudbeckia hirta						1
Senecio paupercaulus						
Setaria faberi					r	r
Smilicina stellata	2	2	2	2	2	2
Solidago altissima	1	1	1	1	1	1
Solidago graminifolia	1	1	1	2	2	3
Solidago riddellii	1	1	1	1	1	1
Trifolium repens						
Verbena hastata						
Viola papilionacea						