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Twenty-three Years of Vegetation Change in a Fly-Ash Leachate Impacted Meadow



ON THE COVER

Clockwise from top left: Blag Sough in 1981 after draw down of water levels; Plot V31 in southwest corner of Blag Slough: site of extreme iron, aluminum, arsenic, and strontium soil concentrations; Common reed (*Phragmites australis*) in northwest corner of Blag Slough.

Twenty-three Years of Vegetation Change in a Fly-Ash Leachate Impacted Meadow

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Executive Summary

1. Blag Slough, located in Indiana Dunes National Lakeshore, has received leachates from nearby fly-ash ponds for 13 years (1967-1980). We have monitored vegetation and sediment of Blag Slough since 1982, two years after the sealing of the fly-ash ponds and one year after the substrate was first exposed. The pH of the soil has increased one order of magnitude from 3.0 to 4.0 over the 23 years (1982-2005). If the pH further increases the solubility of many heavy metals will decrease, except for arsenic. We provide evidence that boron and zinc were bioaccumulating in the leaves of woody plants in 1984. The ratio of leaf concentration and soil concentration of aluminum suggests this element was not bioaccumulating in woody plants in 1984.
2. Soil concentrations of iron, aluminum, arsenic, and strontium were higher nearest the fly-ash ponds in 2005. The southwest corner of Blag Slough and middle position of transect X had the highest elevated levels of these metals and correlated with the occurrence of mixed spikerush association (dominated by *Eleocharis olivacea*).
3. Only a few exotic species occurred in the Blag Slough. Common reed (*Phragmites australis*) was among such species that occurred in three large clones. Other exotic species included dandelion (*Taraxacum officinale*), mullein (*Verbascum thapsis*), Jerusalem oak goosefoot (*Chenopodium botrys*), and sheep sorrel (*Rumex acetosella*). Ruderal species have occurred including thistle (*Cirsium* spp.), fire weed (*Erechtites hieracifolium*), and horseweed (*Conyza canadensis*). While occasional cattail (*Typha*) have been sampled and mapped in Blag Slough they have never persisted for very long.
4. Species richness leveled off between 1991 and 2005, except for Transect X that had a peak in 1986-7. After an extreme rainfall event in August 18, 1990, Transect V had an average water depth of 0.70 cm, W had 7.1 cm, and X had 26.90 cm. Richness in Transect X declined to a low level in 1990 and 1991 after the extreme flooding event because this transect had the deepest surface water.
5. Typical late successional vegetation associations developed since 1991 include blue joint grass (*Calamagrostis canadensis*) and buttonbush (*Cephalanthus occidentalis*), but large areas consist of disturbance-dependent mosaics of rush (*Juncus effusus*) and other species. The large expanses of woolly sedge (*Scirpus cyperinus*) that dominated in the 1980's was replaced by rush.
6. Late-successional associations (*Glyceria canadensis* and *Calamagrostis canadensis*) were closer to the wetland edge compared to the other associations after the dewatering. This pattern occurred because wet meadow vegetation persisted at the wetland edge during the period of industrial flooding, but since then these associations expanded greatly into the north half of Blag Slough.
7. Richness, diversity, and floristic quality index (FQI) increased with time at the plot, association, association trajectories, and wetland levels; whereas mean conservatism scores (mean C), the basis of FQI calculation, decreased in time. The high C values, assigned to coastal plain disjunct species and shrubs by judgment of botanists based on their empirical

experience including regional or state level plant conservation designations are largely responsible for the contradicted trend between FQI and C. Such contradiction highlights a problem with the subjective assignment of C values, and thus the inadequacy of application of FQI in these wetland systems.

8. Occurrence of interveinal clearing in winged sumac (*Rhus copallina*), late boneset (*Eupatorium serotinum*), and black dewberry (*Rubus occidentalis*) suggest a potential phytotoxicity by heavy metals. However, cause-effect relationship between the metals and the plants are yet to be investigated. Nevertheless, boron and zinc accumulation ratios in leaves of woody plants (*Betula populifolia*, *Populus tremuloides*, *Rhus copallina*, and *Rubus* sp.) in 1984 suggest that boron and zinc were bioaccumulating in those species. Known toxicity effects of aluminum suggest that plants with vein clearing may be experiencing toxic effects of aluminum despite leaf concentrations 58 to 193 ppm.

9. In a greenhouse experiment, rye (*Secale cereale*) and radish (*Raphanus sativus*) germinated poorly in the sediments from Blag Slough having high concentrations of heavy metals (ZN, Mn, B, and NH_4^{+}) compared to potting soil. However, rye and radish plants grown in Blag Slough soil had shorter shoots and roots, lower root and shoot mass, and lower root to shoot mass ratios compared to plants grown in potting soil. These results suggest some effect of the soil constituents on rye and radish growth.

10. Positive signs in the recovery of Blag Slough include the increase in soil pH, the increasing dominance of late successional grasses, and the establishment of wetland zonation relative to seasonal water depth. Some areas of Blag Slough near the fly-ash ponds that continue to have high concentrations of heavy metals continue to be devoid of vegetation or are dominated by early successional species such as green spikerush. Localized heavy metal concentrations, evidence for zinc and boron bioaccumulation in 1984, vein clearing that persists today, effects of soil on rye and radish growth, and slow succession in the southern portion of Blag Slough suggest further toxicity study is necessary to better assess the impacts on this wetland ecosystem and identify restoration actions.

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Introduction

Hydric succession is largely driven by surface or ground water fluctuations that are often caused by variation in precipitation (van der Valk 1978, Keddy and Reznicek 1986). As a result of this periodic variation in flooding, wetlands are often devoid of trees and shrubs. For example natural wetlands such as palustrine emergent types (Cowardin 1982), often undergo cyclic successional sequences (Keough et al. 1999, Albert and Minc 2004, Wilcox 2004). In this sequence flooding prevents tree invasion and diminishes the dominance of the late successional perennials. Post-flooding drawdowns to the substrate then permit the germination of an early successional flora that is then replaced by various successional stages and species. Subsequently succession may then proceed back to the late successional dominant. While many studies have examined successional processes in natural and polluted wetlands, few have looked at succession from wetlands impacted by flooding and fly ash leachate.

The impacts of industrial pollution on vegetation has been of increasing importance since the start of the industrial revolution and the pioneering work of Bradshaw on zinc (Zn) mine tailings in England (Bradshaw 1952). The production of heavy metal laden fly-ash, also called pulverized fly-ash, from the burning of coal in power plants has been especially common in developed countries (Shaw 1992, Kaneko 1996, Choi et al. 2002, Hower et al. 2006). For instance, 120 million tons of fly-ash were produced annually in the U.S. in the early 21st century (Bienen 2003). Several studies have examined the development of vegetation on fly-ash in pits (Shaw 1992), but few have examined the impacts of leachate on vegetation development (Wilcox et al. 1985, Wilcox and Hardy 1988, Hilgenkamp 1990). Several authors have examined the natural revegetation through succession on polluted spoils at the same site through time (Densmore 1994, Jochimsen 1996, Smyth 1997, Jochimsen 2001, Hodacova and Prach 2003).

Many studies of revegetation of damaged lands have relied on the examination of multiple sites differing in age to construct successional sequences (Shaw 1992, Hodacova and Prach 2003, Pensa et al. 2004). Replication is the strength of this method, but it depends on the assumptions that the sites being examined have experienced similar history, comparable substrate or impact to accurately construct successional sequences, and that succession is predictable (Choi 2004). An alternative approach is to examine an impacted site over time. This is the approach taken here. While this approach may lack generality because of the lack of replication, its detail may allow greater understanding of processes and patterns. In addition, the palustrine emergent wetland systems, such the study wetland, harbor Atlantic coastal plain species of conservation concern that occur in a broad swath from Wisconsin across the southern Great Lakes to Nova Scotia and south along the Atlantic seaboard (Wisheu and Keddy 1989, Reznicek 1994).

Data over 23 years of sampling provide an opportunity to examine how vegetation composition has changed in time and to evaluate the effectiveness of the floristic quality assessment methods. Floristic quality assessment was developed by Gerould Wilhelm and has been used to assess the floristic quality of vegetation in natural areas (Wilhelm and Ladd 1988, Swink and Wilhelm 1994, Wilhelm and Masters 1995). It is based on the premise that species have tolerances to human disturbance and as a result of these tolerances, species can be ranked on the basis of their restriction or fidelity to high-quality natural area remnants. From the premise, knowledgeable

botanists can assign species coefficients of conservatism (C), ranging from 0 to 10, based on species fidelity to high-quality remnants. Species scored a 10 are only found in high quality natural areas whereas those with 0 are ubiquitous and found in the most disturbed sites.

Compiling a list of the plant species for an area is the first step in quantifying the mean C score of the documented species. The floristic quality index (FQI) is calculated by multiplying the mean C by the square root of the number of species. The square root is utilized to minimize the influence of increasing species richness with increasing area, but this still does not eliminate the problem of species-area dependence and has led to suggestions that sample size be controlled (Matthews et al. 2005). We used our temporal vegetation data to investigate the changes in mean C, weighted mean C and FQI through time.

This report focuses on the indirect effects of fly-ash ponds (i.e. the leachate) on the development of wetland vegetation through natural succession. We longitudinally examine vegetation recovery at the Blag Slough site that was impacted 27 years prior and that has been monitored for 23 years. We include data from preliminary tests on toxicity of the soil, soil chemistry data, and archival photographs and maps.

Study Site

Blag Slough is a wet meadow in the southwest corner of the Cowles Bog unit of Indiana Dunes National Lakeshore (INDU) in Porter County, northwest Indiana, USA (41° 38' 27"N, 87° 06' 49"W) (Figure 1). Blag Slough has been referred to as Pond B (Patterson and Fenn 1978) and Pond 2 (Meyer and Tucci 1979) in previous studies. Blag Slough was one of a series of interdunal meadows created after the formation of the 4000 year old Tolleston beach ridge. The oldest sediments at Blag Slough dated from 3505 ± 85 ybp (Futyma 1986). Fossil pollen indicated that Blag Slough was a pond early on, but that eventually a sedge-dominated community developed. Historic maps and photographs from the late 1800s and early 1900s indicated dramatic fluctuations in water level in these dunal depressions. There is no evidence that Blag Slough was ever ditched like Little Lake located beyond the dune ridge to the east (Wilcox 1995). Soils are Houghton muck (Eic mesic Typic Medisaprists) with occasional sandy dune ridges of Oakville (Mixed mesic Typic Udipasamments)(Furr 1981). Blag Slough is one of many intermittent wetlands in Northwest Indiana that is dominated by Atlantic coastal plain flora after drawdown events. This flora is dominated by seed bank annuals (Peattie 1922, Keddy 1985, Wisheu and Keddy 1989, Keddy and Sharp 1994, Reznicek 1994).

In 1962, the Northern Indiana Public Service Company (NIPSCO) commenced the construction of a coal-fired plant northwest of Cowles Bog to supply power to the integrated steel mill that was being constructed by Bethlehem Steel Corporation. The Bailly Generating Station went online in 1963 (Cook and Jackson 1978). Fly-ash is collected from the smoke stacks by electrostatic precipitation and delivered as slurry. To dewater the fly-ash slurry, a series of fly-ash settling ponds were constructed along the southwest edge of the Cowles Dunes unit of the Indiana Dunes National Lakeshore.

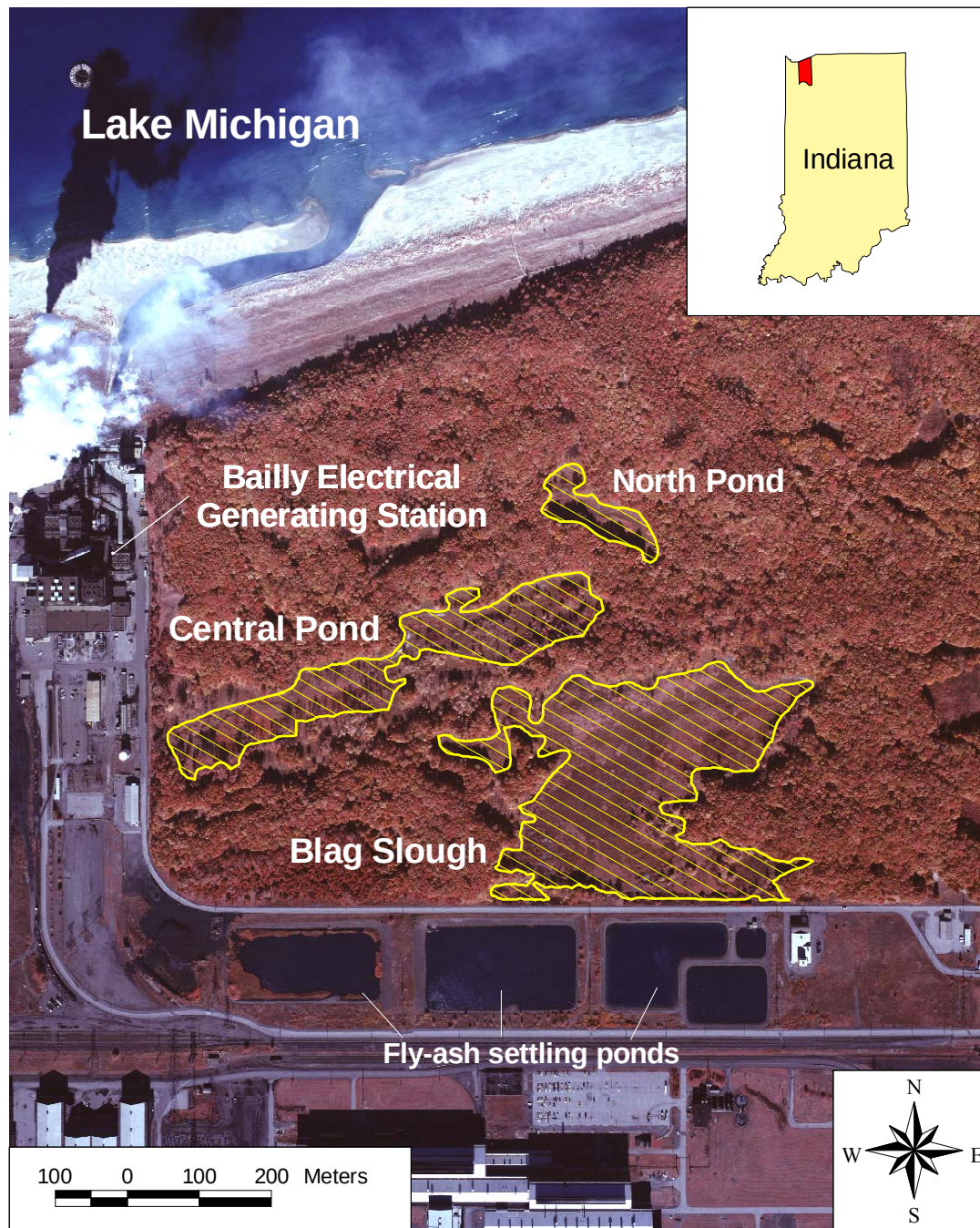


Figure 1. False color aerial photograph (autumn 2004) of Blag Slough, including the main pond (southernmost yellow hashed area), and the central and north ponds (shown northwest and north of the main pond, respectively).

These artificial ponds were to hold and dewater the fly-ash, prior to removal to landfills and to a site to the east at the corner of the dike (Cohen and Shedlock 1986). Seven and a half million liters of water per day flowed into the wetlands north of the fly-ash ponds, and into the Cowles Bog wetland complex that drains eastward into Dunes Creek (Meyer and Tucci 1979). Blag Slough and other wetlands were flooded by 1967 while the fly-ash ponds were unsealed (Wilcox

et al. 1985). The leachate waters contained heavy metals including arsenic (As), boron (B), molybdenum (Mo), and strontium (Sr) (Hardy 1981). After dewatering, the water table still contained higher concentrations of arsenic, boron, molybdenum, and zinc than background levels (Cohen and Shedlock 1986).

In 1967, the Indiana Dunes National Lakeshore (INDU) was authorized to be a new unit of the National Park Service (NPS) by the passage of HR51 by Congress and the subsequent signing of the bill by President Johnson (Cockrell 1988). The first lands were purchased and dedicated on September 8, 1972. The northern two-thirds of Blag Slough was incorporated into INDU. The southern third, part of the “Greenbelt” was retained by NIPSCO, but is now open for use by the National Park Service per a cooperative agreement with NIPSCO (Schumacher 1996).

In 1976 the National Park Service threatened litigation if NIPSCO failed to seal the fly-ash dewatering ponds (Cockrell 1988) because of the damage to the Cowles Bog wetland complex. NIPSCO agreed to seal the ponds in February 1978 and the ponds were sealed in 1979-80, stopping the water flow into the slough in 1980. Blag Slough and other wetlands subsequently experienced a water level drawdown and exposure of extensive mud flats in 1980 and 1981. Water level declines were 6 feet in Blag Slough and up to 14 feet in the west end of the central pond (Cohen and Shedlock 1986). This study was initiated in 1982 by Dr. Doug Wilcox and Dr. Ron Hiebert to document and understand the impacts of fly-ash leachate on wetland vegetation development and succession (Figure 2). Noel Pavlovic became involved in the project in 1983 as a biological technician and continued the project after the departures of Dr. Wilcox (1986) and Dr. Heibert (1988). In 1982, abundant standing and fallen trees in the wetland reflected the anthropogenic flooding of the wetland in the late 1960s and 1970s (Wilcox 1995). Appendix B contains historic and contemporary photographs of Blag Slough. The lands around Blag Slough were prescribed burned on April 26, 1997 and April 5, 2004 by the National Park Service. During the former, all of Blag Slough was lined with fire, but only the perimeter was burned. The latter burn did not include Blag Slough. Both prescribed burns spread across the central and north ponds.

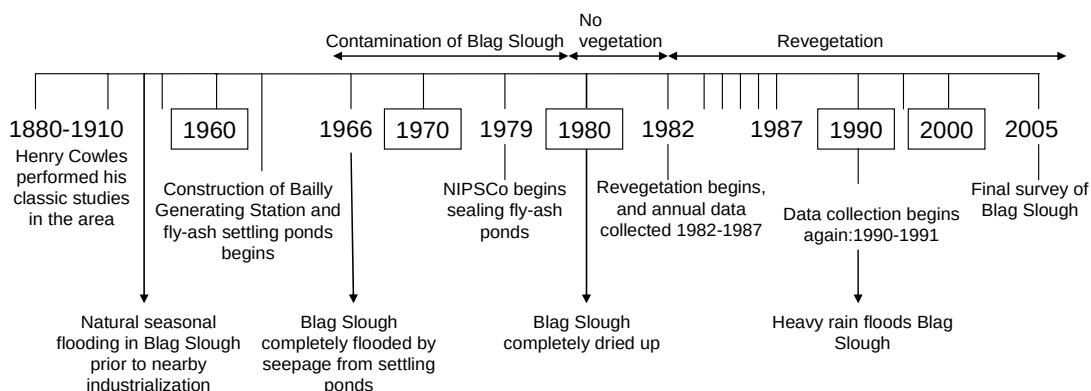


Figure 2. History of Blag Slough. Major events (environmental and anthropogenic) are included. Time line is not to scale. Modified from Hilgenkamp (1990).

Methods

In 1982 a grid of transects was laid out in the Blag Slough area of INDU, just north of the NIPSCO fly-ash settling ponds that had recently been dewatered (Wilcox et al. 1985b) (Figure 3). The transects traversed three former wetlands, Blag Slough, central pond just northwest of Blag Slough, and north pond northeast of central pond and north of Blag Slough. INDU topographic maps (1:2400) give the minimum elevations above sea level of the ponds respectively as 184.1 m (604.1'), 183.0 m (600.5'), and 182.1 m (597.4'); thus the ponds are respectively 7.7 m, 6.5 m, and 5.6 m above the average elevation of Lake Michigan (176.46 m). Transects A, B, C, and D extend north from the fly-ash settling ponds with A, B, and C

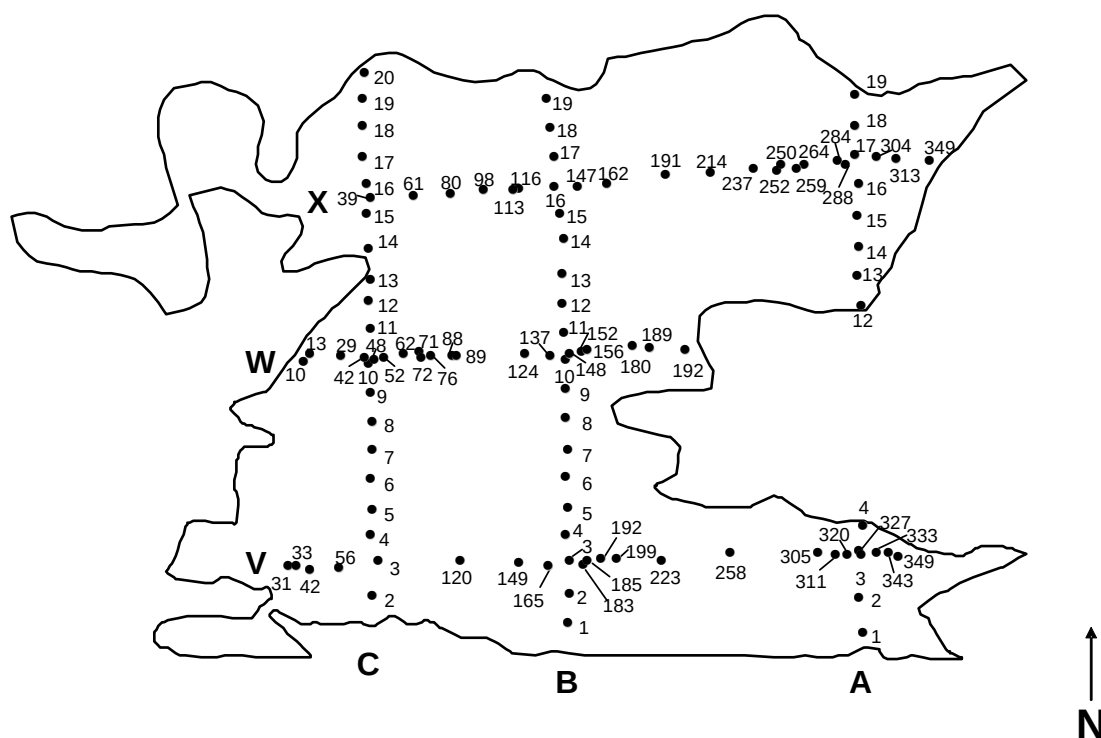


Figure 3. Map with survey plots of Blag Slough (main pond). Letters represent transects and numbers are the plot numbers. The numbers for plots in transects V, W, and X are the distances in meters along each transect.

traversing through the main pond, B and C through the north pond, and transects C and D traverse through the central pond (Portions of transects B and C that extend through the central and north ponds and transects D are not shown since we did not analyze the data from these ponds) (see Figure 2 in (Wilcox et al. 1985)). East-west transects V, W, and X extended across

the main pond (Figure 3) and Y and Z traversed, respectively, the central and north ponds (not shown). The transect ends were marked with metal rebar. The twelve transect intersections had groundwater wells for monitoring groundwater elevations. By 2005 many of the transect rebars were difficult to find especially in the central and north ponds, but in the north pond we were able to relocate transect Z and the approximate north ends of C and D. Vegetation plots along the north-south transects were 15 m apart (respectively 11, 21, 24, and 6 plots for transects A, B, C, and D), whereas the plot locations were random along the east-west transects (N = 20 plots per transect). Flags on wires marked the southeast corner of each plot. Plot distances along transect V, W, X, Y, and Z were recorded so that plots could be relocated by measurement and plot designations included the transect and distance (V31). Plots on transects A, B, C, and D were numbered sequentially starting with 1 (A1, A2, A3...). A metal detector was often used to relocate the wires at the plot corners. We sampled a total of 162 plots from 1982-1987, 110 plots from 1990-1991, and 136 in 2005 (excludes the central pond). Absolute percent total vegetation cover and percent cover by species were recorded for each plot.

Soil samples were collected from the 8 transect intersections and from additional locations (plots A16, B1, C2, V31, W180, X147, and X162) in 1982, 1983, and 2005. Soils were tested for organic matter (%), pH, potassium (K), phosphorus (P), nitrate-N (NO_3^-), and ammonium-N (NH_4^+) in 1983 and 1984. In 2005, we conducted soil tests for organic matter, potassium, phosphorus, pH, T (cation exchange capacity), base saturation of cations, tested for ammonium-N, nitrate-N, and for heavy metals (aluminum (Al), boron, nickel (Ni), zinc, arsenic, selenium (Se), iron (Fe), manganese (Mn), molybdenum, and strontium). Also in 2005, a single out-group 'control' soil sample was taken to the southeast of the site in the wetland at the west intersection of the elevated east-west dike with the Tolleston dunes at the southwest corner of the Cowles Bog Wetland Complex.

Vegetation was sampled in 1982-1987, 1990, 1991, and 2005; sampling occurred in June and early October in the first three years, and in early October thereafter. No results from the central pond are presented, because in 2005 we were unable to relocate transects D and Y. But we were able to relocate transects C, D, and Z in the north pond, so the data are presented in Appendix E3.

Vegetation of the three wetlands was hand mapped on a base map on site according to the composition and dominance from 1982 to 1986, 1991, and 2005. In 2005 the vegetation map was created as an overlay on a false color infrared photograph (background of Fig. 1). Many vegetation types were visible in the image so polygons could be directly drawn over the photograph. All vegetation maps were hand digitized in Arcview 3.3 for presentation.

Leaves from four woody plant species (*Betula populifolia*, *Populus tremuloides*, *Rhus copallinum*, and *Rubus* spp.) were collected in the fall of 1984 for chemical analysis of the following elements: percentage of nitrogen, phosphorus, potassium, calcium, and magnesium, and ppm aluminum, boron, copper (Cu), iron, manganese, sodium (Na), and zinc. These species were selected because they exhibited vein clearing in situ. Samples were collected from uplands, transect V, and transect X. Four replicates of each species were taken within each location.

In 1985 and 1987, we conducted a greenhouse study to compare growth of rye (*Secale cereale* M. Bieb.) and radish (*Raphanus sativus* L.) on Blag Slough soil (plot W1a), Blag Slough soil

with lime (CaCO_3) amendment, and commercial potting soil. In the first experiment, 50 seeds of each species were sown in the soils in a growth chamber. Germination and establishment were poor for both species, so additional experiments were conducted in 1987 in the NPS greenhouse. In subsequent experiments in 1987, seeds were germinated in Petri dishes in distilled water and seedlings were transplanted into the treatment soils. In the second experiment, seedlings were sown in flats on February 18 and plants were harvested in March 5. In the third experiment, seedlings were sown in flats on May 3 and plants were harvested on May 16. Plants were harvested, measured for shoot and root length, and dried at 105°C for 12 hours before measuring root and shoot biomass.

Analytical Methods

All data from all ponds were entered into an Access database in 2005. Data, across the years sampled, were analyzed for the main pond only, since the other ponds were infrequently or not sampled after 1987. The main pond dataset contained 97% empty values. For this reason nonmetric multidimensional scaling (NMS) was unable to produce an ordination solution. We used detrended correspondence analysis (DCA) ordination to examine habitat and species trends over time. We created an environmental dataset for indirect gradient analysis using soil type, 1990 surface water depth, distance from road north of fly-ash ponds, and distance from 608' contour that delineates the main pond perimeter and an island in the southwest corner of the main pond. Surface water depth was measured in 1990 because the highest recorded rain event since 1979, 19.7 centimeters, occurred on August 18, 1990 (the long-term average daily rainfall = 0.75 cm, median = 0.34, and the mode was 0.03) just a month and a half before the 1990 sampling. We had not seen Blag Slough with so much surface water. Distance from the 608' contour was deemed important because the periphery of the pond and any insular high spots were potential refugia for emergent wetland species during the flooding in the 1960's and 70's.

We also used Twinspan to classify the complete dataset into associations. This worked well because it created clusters that represented differences in joint occurrences of species compared to cluster analyses that produced single species dominance clusters. Plots that lacked vegetation were classified as bare ground. Two ordinations were performed, the first only with plots having vegetative cover and the second with all plots included. In the former ordination, the relationships among ordination scores and environmental variables were explored. In the latter, bare ground cover was included as a variable so that there would be a point in the ordination that represented no vegetation so we could track association trajectories over time. Temporal trajectories were generated by looking back in time, making the 2005 plant associations identified by Twinspan, as the groups for analysis. We generated mean composition of each cluster per year in ordination space and used these to graph the trajectories.

Diversity (S , E , H' , and D) and floristic quality indices (C , I , and I') were calculated at the whole pond, mean values per plots, mean values in time, mean values by association, and mean values by association over time to test the utility of applying floristic quality indices (FQI) to vegetation trends in space and time. The diversity indices are respectively species richness, evenness, Shannon, and Simpson's. We applied the original FQI metric (I). Modified metric I' (I -prime), which was proposed by Miller and Wardrop (2006), was also considered. However, I' differed little compared to Mean C , because there were so few exotic species. For this reason, I' results were excluded from this report. While comparing indices among associations, data for each association in the year it was most frequent (Table 5) were used rather than the complete plot by

association by year matrix to reduce the instances of autocorrelation when the same association occurred in the same plot across sampling years. We then analyzed the trends in species richness, mean C, frequency-weighted mean C (Cohen et al. 2004), and I over time within the plots comprising the vegetation associations classified in 2005. The Bonferroni adjustment was used ($\alpha = 0.05/7 = 0.007$) to determine the significance of the ANOVA. Since the spike rush/woolly sedge (EleoOliv) and Raspberry/steeplebush (RubuSpir) associations were represented by only one plot for each, these were not included in the graphs.

The impact of the 1990 surface water depth on vegetation cover was analyzed using simple linear regression. To measure impact, we subtracted the total covers between years to get a difference in total cover. We did this by subtracting 1987 from 1990 cover data, 1987 from 1991 cover data and 1990 from 1991 data. To determine if the slopes of the regression lines were different from each other, we used analysis of covariance (ANCOVA) (Quinn and Koehler 2002). Data were transformed to meet assumptions of normality. Untransformed data are displayed for ease of interpretation.

Plants were classified into life forms to determine if there were any trends in life history and cover in the main pond and transect V, W and X. The plants were classified into the following life forms: annual grasses, annual sedges, annual forbs, perennial grasses, perennial sedges, perennial forbs, woody plants, biennials and ferns. Across years, one-way ANOVA was used to determine differences in life form cover. If significant, we ran a Tukey's b test to examine which years were different.

We used repeated measures analysis of variance (Gurevitch and Chester 1986) over unequal time intervals (Systat 2004) to examine trends in S, E, H', D and total cover for transects V, W, and X. For each transect, values for the time series of the dependent variable were multiplied by polynomial coefficients to model trends of different orders (linear, quadratic, cubic, or higher order trend). The products were then summed across times, and the resulting sums were compared among treatments to determine differences in linear, quadratic or cubic trend. Total cover was square root transformed to meet assumptions of normality. We used a Bonferroni correction to adjust for multiple testing to control Type I error.

We categorized the Blag Slough plots into three zones, V, W, and X. Plots along transects A, B, and C were assigned to zones based on which transect V, W, or X they were closer to. We also classified plant communities in 1982 and 2005 into three successional classes, early, mid, and late (Figure 15). This created a table to examine successional trends at Blag Slough in relation to trajectory stages and compare successional trajectories among zones. We used chi-squared analysis to compare mid to late communities trajectories among zones.

In order to compare 1982 soil data to that from 2005 we conducted one-way ANOVA to see if the transects differed in pH, percent organic matter, ammonium-N, nitrate-N, potassium and phosphorous within a given year. Following this, we used t-test assuming unequal variances to compare 1982 and 2005 soil components overall.

To examine if different species of plants differentially took up select soil elements (phosphorous, potassium, calcium, magnesium, manganese, iron, boron, copper, zinc, aluminum, and sodium) we used one-way ANOVA, followed by Tukey test, within a given species (*Populus tremuloides*,

Rubus spp., *Betula populifolia*, and *Rhus copallinum*) to determine if the transect the plant grew on had an affect on mineral concentration. We also calculated the accumulation ratio (AR = leaf concentration/soil concentration) using the 1982 soil data with the 1984 leaf mass data. Values greater than 1 suggest the element is being accumulated. The same statistical approach was used to analyze rye and radish bioassays on root and shoot biomass, root and shoot lengths, and root shoot ratio. Soils data were transformed and standardized (divided by the mean) prior to analysis using principle components analysis. Some variables were removed because they had high correlations with others.

Results

Soil Characteristics

Raw soil data from 2005 are presented in Appendix E2. Principal components analysis identified five soil factors that explained 83% of the 2005 soil variation with the first three factors explaining 70% (Table 1, Figure 4). Factor 1 is an organic matter gradient with increasing quantities of iron, arsenic, molybdenum, strontium and other metals as pH decreases. Factor 2 is nitrogen, potassium, calcium, and magnesium gradient along which phosphorous declines. Factor 3 is boron, manganese, zinc, and pH gradient counter to the gradient of phosphorus, total cation exchange capacity, and potassium. Sampling point V31, that has had little vegetation cover over 23 years, had the lowest pH and highest metal concentrations along PCA axis 1; Otherwise transects V and W have intermediate chemical composition between transects Y and Z and V31.

Soils constituents varied significantly along the main gradient (V-W-X-Y-Z) (Table 2) with many declining in transect Y where soils were sandier and had lower organic matter. Only phosphorus and molybdenum decreased with increasing distance from the fly-ash ponds and iron peaked in transect W in the main pond. Transect Y was the most deviant in either having higher (base saturation of Ca and Mg) or lower concentrations of soil constituents (CEC, pH, base saturation of K and H) compared to the other transects. This may be attributed to the high content of sand.

ANOVA indicated that the three transects within a given year did not differ in their concentrations of soil elements and nutrients, pH or percent organic matter (Table 3). When comparing these concentrations between years, 1982 had a significantly lower pH ($t_{2,9.5} = 7.220$, $P < 0.001$), ammonium-N ($t_{2,9.1} = 3.853$, $P = 0.004$), nitrate-N ($t_{2,12.2} = 5.858$, $P < 0.001$) and potassium ($t_{2,8.6} = 3.859$, $P = 0.004$). Soil chemistry for plot V31, analyzed from a sample taken in 2005 showed the highest levels of iron, aluminum, arsenic, ammonium-N, and total cation exchange capacity, and the lowest pH. This site was essentially devoid of vegetation during the interval of this study; although individual plants occasionally established and then died. Maps of soil variables are presented in Appendix D.

Table 1. Principal components for NIPSCO ponds 2005 soils data. The absolute values of the loadings indicate the importance of each soil characteristic for each component. Parenthetic notes indicate transformation. Most important loadings are bolded for each component.

	Principal Component				
	1	2	3	4	5
Organic, % (log)	0.898	-0.2	-0.077	0.076	0.26
pH	-0.807	0.377	0.348	-0.028	-0.049
Tcec, meq/100g (sq)	0.657	-0.131	-0.358	0.287	0.115
NH4, ppm (log)	0.74	0.162	-0.372	-0.153	-0.121
NO3, ppm (log)	0.057	0.521	-0.591	0.013	0.344
Potassium, ppm (sq)	-0.126	0.708	-0.41	0.327	-0.32
Phosphorous, ppm (sq)	-0.181	-0.447	0.062	0.66	-0.015
Calcium, ppm (sq)	-0.239	0.856	-0.041	0.286	-0.012
Magnesium, ppm (sq)	-0.331	0.785	0.128	0.217	0.24
Aluminum, ppm (log)	0.725	-0.219	0.12	0.089	0.358
Arsenic, ppm (log)	0.838	0.059	-0.197	-0.137	-0.411
Boron, ppm (log)	0.338	-0.086	0.392	0.583	-0.271
Iron, ppm (sq)	0.904	0.151	0.106	-0.13	-0.091
Manganese, ppm (sq)	0.541	0.446	0.513	-0.226	-0.274
Molybdenum, ppm (log)	0.85	0.004	-0.195	0.057	-0.414
Nickel, ppm (sq)	0.793	0.106	0.421	0.068	0.204
Selenium, ppm (log)	0.778	-0.153	0.008	0.251	0.069
Strontium, ppm (log)	0.784	0.419	0.009	-0.068	0.299
Zinc, ppm	0.688	0.518	0.402	-0.024	0.093

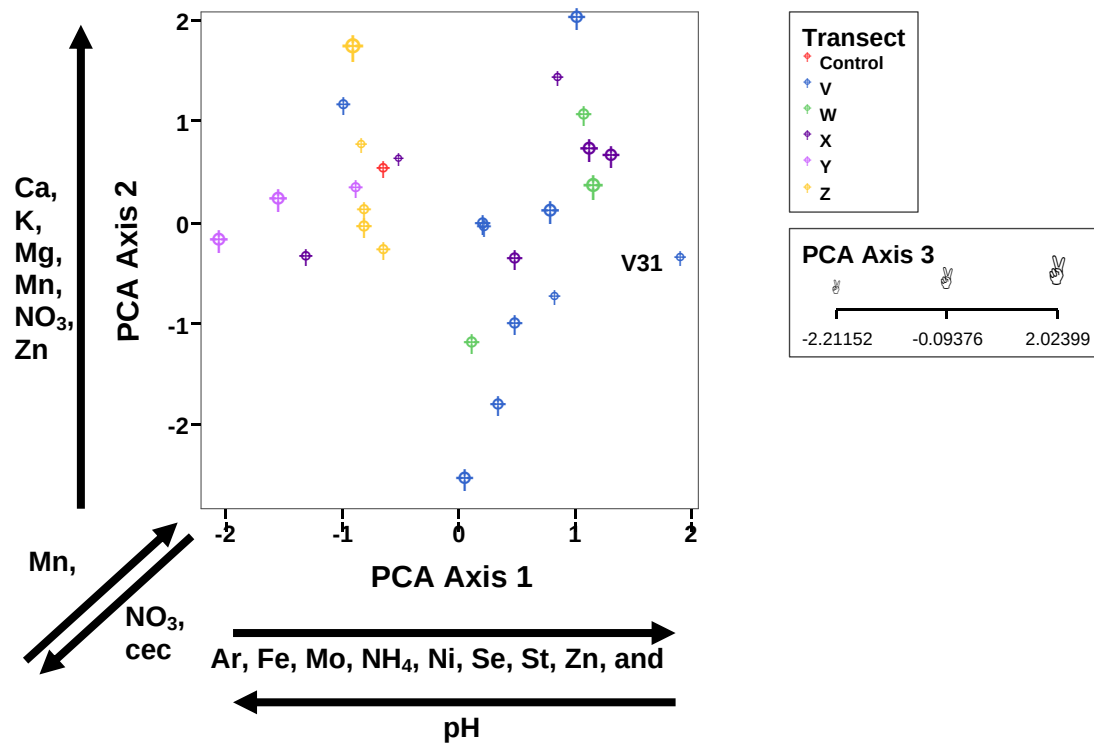


Figure 4. Principal components analysis of soil chemistry. Dot size is proportional to the position on the third axis. Control designates the sample taken from the extreme southwest corner of the Cowles Bog wetland complex located southeast of Blag Slough.

Table 2. Mean and standard errors of soil measurements from 2005. Different letters within a variable indicate significant differences at the $\alpha = 0.05$ level using Tukey's b test.

Variable	Transect					
	Mean	V	W	X	Y	Z
%Organic	3.5	25.8±3.5 ^a	27.7±5.9 ^a	25.6±5.5 ^a	3.5±1.9 ^b	5.8±0.9 ^b
P1 (ppm)	13.0	15.7±2.3 ^a	6.7±1.3 ^{bc}	4.7±0.4 ^c	14±1.5 ^{ab}	8.8±1.9 ^{abc}
P2 (ppm)	23	25.7±5 ^a	12±3.1 ^{ab}	7.2±0.3 ^b	17±1.2 ^a	14.4±2 ^{ab}
K (ppm)	62.0	24.8±3.3 ^a	24.3±6.6 ^a	26.8±3 ^a	26.3±3.9 ^a	25.8±3.3 ^a
Mg (ppm)	80.0	95±12 ^a	87±16 ^a	90±6 ^a	115±10 ^a	118±11 ^a
Ca (ppm)	1150	640±80 ^a	550±76 ^a	717±71 ^a	733±44 ^a	790±122 ^a
pH	5.5	4.7±0.2 ^a	4.6±0 ^a	4.8±0.1 ^a	6.2±0.5 ^b	5.5±0.3 ^{ab}
Tcec	10.2	12.9±1.5 ^a	9.1±0.9 ^{ab}	9.6±1 ^{ab}	5.9±1.5 ^b	8.1±0.4 ^{ab}
%bsK	1.60	0.59±0.1 ^a	0.67±0.12 ^a	0.75±0.11 ^{ab}	1.23±0.15 ^b	0.82±0.08 ^{ab}
%bsMg	6.60	7.14±1.19 ^a	7.8±0.76 ^a	8.13±0.85 ^a	17.47±2.42 ^b	12.06±0.8 ^a
%bsCa	56.5	28.4±4.6 ^a	29.8±1.3 ^a	37.9±2.1 ^a	67.7±11.2 ^b	48.5±6.7 ^{ab}
%bsH	35.4	63.8±5.9 ^a	61.7±2.1 ^a	53.3±3 ^a	13.6±13.6 ^b	38.6±7.5 ^{ab}
NH ₄ (ppm)	5.0	24.9±8.5 ^a	20.7±4.9 ^a	21.8±4.6 ^a	3.7±0.9 ^b	6.6±2.2 ^{ab}
NO ₃ (ppm)	3.0	3.2±0.4 ^a	4.3±1.9 ^a	6.5±1.9 ^a	3±1 ^a	5±0.9 ^a
Se (ppm)	1.88	2.59±0.28 ^{ab}	3.12±0.83 ^b	2.16±0.41 ^{ab}	0.92±0.39 ^a	2.11±1.29 ^{ab}
Zn (ppm)	24.4	48.2±9.2 ^a	80.9±23.8 ^a	64.1±14.7 ^a	21.1±5 ^a	37.7±13.8 ^a
B (ppm)	16.4	4.7±1.4 ^a	10.9±5.6 ^a	2.4±0.9 ^a	1.7±0.8 ^a	1.9±0.6 ^a
As (ppm)	14.5	13.9±5.8 ^{ab}	11.9±2.9 ^b	9.1±2.4 ^{ab}	1.7±0.5 ^a	2.8±0.7 ^{ab}
Ni (ppm)	4.1	8.5±0.9 ^a	12±2.9 ^a	9.9±3 ^a	2.5±0.3 ^a	4.6±1.4 ^a
Al (ppm)	1646	4.690±758 ^a	3.502±1225 ^a	3.898±759 ^a	1.678±128 ^a	1723±127 ^a
Fe (ppm)	2762	16,160±2723 ^a	19,876±4849 ^b	12,809±2942 ^{ab}	4.937±1243 ^{ab}	7684±1053 ^{ab}
Mn (ppm)	60	239±52 ^a	341±100 ^a	235±78 ^a	184±56 ^a	162±52 ^a
Mo (ppm)	97	247±171 ^{ab}	122±47 ^b	43±10 ^{abc}	8±4 ^c	14±5 ^{ac}
Sr (ppm)	5.6	11.4±1.7 ^{ab}	10.1±3 ^{ab}	16.1±3.5 ^b	4.7±0.3 ^a	7.9±0.8 ^{ab}

Table 3. Means and standard errors of soil measurements comparing transects V, W, and X in 1982 and 2005.

	1982			2005		
	V	W	X	V	W	X
%Organic	24.4±1.5	32.0±5.3	17.7±4.4	23.8±0.9	22.8±5.9	16.3±8.0
P (ppm)	8.8±6.1	2.8±2.3	11.2±2.6	16.7±6.7	8.0±0.0	4.7±0.9
K (ppm)	38.3±3.3	67.5±7.5	90±27.8	23.3±0.9	18.0±3.0	26.7±6.4
pH	3.8±0.1	3.5±0.2	3.7±0.03	4.6±0.3	4.6±0.0	5.0±0.3
NH ₄ (ppm)	122.2±23.6	741.4±600.4	105.8±50.4	20.3±3.5	19.0±8.0	15.7±6.9
NO ₃ (ppm)	118.5±77.4	41.4±1.2	28.5±10.8	3.7±1.2	2.5±0.5	6.3±3.4
Zn (ppm)	4.6	10.4	17.3	48.8±6.5	74.1±39.5	34.2±8.4
B (ppm)	1.3	1.9	2.6	4.2±2.1	11.4±9.6	1.7±0.9
As (ppm)	0.4	0.2	0.6	11.2±3.7	13.1±4.7	5.3±2.4
Ni (ppm)	0.0	0.0	1.0	9.0±0.5	10.7±4.6	3.8±2.6
Al (ppm)	180.0	120.0	190.0	4521.3±899.4	4268.0±1093.0	2293.7±547.4

Species Trends by Year

A total of 110 species (106 native species) were identified over 23 years (with sampling occurring during nine of these years). Only five exotic species were recorded 29 times in the plots over the nine years of sampling: one occurrence of Jerusalem oak goosefoot (*Chenopodium botrys*), 23 of common reed (*Phragmites australis*), one of sheep sorrel (*Rumex acetosella*), one of dandelion (*Taraxacum officinale*), and 3 of common mullein (*Verbascum thapsus*). Common reed has become dominant in three patches but has not expanded throughout the wetland complex. Four species were unidentified, rare, and/or low in cover and thus were excluded from the analyses. Six species that occurred in Blag Slough are listed for protection by State of Indiana. These species are black seeded spike-rush (*Eleocharis melanocarpa* Torr., threatened), umbrella sedge (*Fuirena pumila* Torr., endangered), spotted pondweed (*Potamogeton pulcher* Tuck., endangered), giant beakrush (*Rhynchospora macrostachya* Torr. ex Gray, rare), weak bulrush (*Schoenoplectus purshianus* (Fern.) M.T. Strong, endangered), and small bulrush (*Schoenoplectus smithii* (Gray) Soják, endangered). One species, Umbrella sedge (*Fuirena pumila*) has only been observed in 1991, 2007, and 2008, years following major precipitation years, suggesting that this annual species persists in the seed bank and responds to drawdowns after flooding. The total cover for the main pond has increased since the beginning of the survey (Table 4). In addition, there have been shifts in total cover in several of the key species which are classified into decreasing, peaking, and increasing. Bright green spikerush (*Eleocharis olivacea*) was an early colonizing species that has declined in subsequent years (Table 4). Five species peaked and then declined and eight species increased over the study duration. Woolly sedge (*Scirpus cyperinus*) and water pepper (*Polygonum hydropiper*) were more dominant in the middle years of the survey, while blue joint grass (*Calamagrostis canadensis*) and late boneset (*Eupatorium serotinum*) had higher mean cover more recently. Mean cover by species per year are presented in Appendix E1.

The highest recorded rain event since 1979, 19.7 centimeters, occurred on August 18, 1990 just a month and a half before the 1990 sampling (from 1951 to 2005, mean daily rainfall 0.75 cm, median 0.34 cm, and mode 0.03 cm). The precipitation was 5 cm greater than the next highest event (Figure 5, Table 5). Just two and a half months later, on November 28, 1990, the seventh largest rainfall of 9.83 cm occurred. Consequently, the main pond was flooded during the sampling in October 1990 (Figure 6). Mean water depth was 14 cm and the maximum depth that occurred was 70 cm in transect C, plot 18. Moving away from the fly-ash ponds, transect V had an average depth of 0.70 cm, W had 7.1 cm and X had 26.90 cm. Water caused a significant reduction in total vegetation cover. The cover in 1990 (Figure 7, $R^2 = 0.32$, $P < 0.001$) and 1991 (Figure 8, $R^2 = 0.18$, $P < 0.001$) was negatively impacted by the surface depth of the water in 1990. The change in vegetation between 1987 and 1990 and 1991 was not different from each other as indicated by ANCOVA interaction. The change in vegetation cover between 1990 and 1991 was not significantly impacted by water depth in 1990 (Figure 9).

Specific species (see Table 4), responded in different ways to this flooding event. Blue joint grass (*Calamagrostis canadensis*) was a species with low cover up until the flooding event of 1990, at which point this species began a sharp increase to be one of the most abundant species in 2005. Bright green spikerush (*Eleocharis olivacea*), on the other hand, was one of the most abundant species until the flood event, when its total cover in 1990 dropped to zero. *Eleocharis olivacea* persisted during this late season rain event, but murky water made assessing cover impossible in 1990. This species began to recover in 1991, presumably from seeds in the seed

bank, but as of 2005 had not recovered to its pre-flood levels. Woolly sedge (*Scirpus cyperinus*) was another species like *E. olivacea* that had high cover prior to the flood event and subsequently decreased in 1990.

The invasive grass, *P. australis*, was absent from sampled vegetation in the main Pond as of 1987, but as of 1990, this species became part of the flora and since then has increased greatly in cover. However the vegetation maps show that it appeared in the north pond and north half of Blag Slough in 1986 (see Figure 29). Winged sumac (*Rhus copallina*) invaded the pond in the early 1980's and disappeared completely by 1990. Five out of thirteen plots showed death of winged sumac before the flooding in 1990.

Vegetation Associations

TWINSPAN analysis of data from all years identified 20 vegetation types of which eleven persisted to 2005 (Table 6). These associations are determined by the cover of the dominants. Certain species such as woolly sedge (*S. cyperinus*) and late-flowering boneset (*E. serotinum*) appear throughout these associations besides defining specific associations when their cover is high. Below are descriptions of the eleven associations present in 2005 (See Appendix A1 for similarity in vegetation by type between successive years). The other nine associations were either rare associations (*e.g.* the blackfruit spike rush association) that only lasted for a short duration of time, or associations that persisted for longer periods of time, only to decline more recently (*e.g.* woolly sedge/rush association that decreased with the recent severe decline of *S. cyperinus*).

Bluejoint Meadow (Calacana)

Bluejoint meadows are the late successional stage of the palustrine wetlands. These are areas dominated by bluejoint grass (*Calamagrostis canadensis*), occasionally with buttonbush (*Cephalanthus occidentalis*) in the overstory. Other species such as late boneset (*E. serotinum*) and blackberry (*Rubus occidentalis/allegahaniensis*) are also present in this wet meadow association typical of the dunes.

Bluejoint/Steeplebush (CalaSpirRubu)

Similar to the bluejoint meadow, this association has bluejoint grass (*C. Canadensis*) with steeplebush (*Spiraea tomentosa*) forming an overstory. Additional species with significant cover are blackberry (*R. occidentalis/allegahaniensis*), dewberry (*R. hispidus/flagellaris*) and giant goldenrod (*Solidago gigantea*).

Table 4. Mean cover $\pm$ standard error for dominant species in select survey years at Blag Slough.

	1982	1983	1984	1987	1990	2005
Decreasers						
<i>Eleocharis olivacea</i>	10.55 $\pm$ 2.19	25.93 $\pm$ 3.56	14.44 $\pm$ 2.52	8.94 $\pm$ 2.18	-	3.38 $\pm$ 1.35
Peaking						
<i>Ludwigia</i> spp.	0.64 $\pm$ 0.26	1.15 $\pm$ 0.53	1.53 $\pm$ 0.84	0.39 $\pm$ 0.16	-	-
<i>Polygonum hydropiper/-oides</i>	3.48 $\pm$ 1.42	3.4 $\pm$ 1.27	1.31 $\pm$ 0.42	11.38 $\pm$ 1.99	11.06 $\pm$ 1.66	1.59 $\pm$ 0.68
<i>Rhus copallinum</i> var. <i>latifolia</i>	-	0.09 $\pm$ 0.09	0.89 $\pm$ 0.82	2.14 $\pm$ 0.99	0.01 $\pm$ 0.01	-
<i>Rubus occidentalis/alleghehiensis</i>	-	-	0.04 $\pm$ 0.04	1.52 $\pm$ 0.63	3.48 $\pm$ 1.03	0.6 $\pm$ 0.507
<i>Scirpus cyperinus</i>	2.84 $\pm$ 0.83	3.98 $\pm$ 1.13	7.76 $\pm$ 1.53	18.95 $\pm$ 2.67	13.84 $\pm$ 2.19	3.08 $\pm$ 0.94
Increasers						
<i>Calamagrostis canadensis</i>	0.59 $\pm$ 0.55	0.65 $\pm$ 0.35	1.24 $\pm$ 0.77	1.37 $\pm$ 0.84	3.41 $\pm$ 1.27	18.47 $\pm$ 3.34
<i>Cephalanthus occidentalis</i>	0.18 $\pm$ 0.18	0.27 $\pm$ 0.27	-	1.26 $\pm$ 0.66	1.7 $\pm$ 1.13	7.3 $\pm$ 2.198
<i>Eupatorium serotinum</i>	-	0.11 $\pm$ 0.06	0.23 $\pm$ 0.09	3.68 $\pm$ 0.96	7.08 $\pm$ 1.81	24.15 $\pm$ 3.11
<i>Glyceria canadensis</i>	-	-	-	-	0.64 $\pm$ 0.64	4.85 $\pm$ 1.94
<i>Juncus effusus</i>	0.74 $\pm$ 0.4	0.74 $\pm$ 0.38	0.51 $\pm$ 0.18	2.84 $\pm$ 0.84	4.95 $\pm$ 0.84	5.69 $\pm$ 1.11
<i>Phragmites australis</i>	-	-	-	-	0.73 $\pm$ 0.55	2.04 $\pm$ 0.96
<i>Rubus hispidus/flagellaris</i>	-	-	0.27 $\pm$ 0.27	2.33 $\pm$ 0.93	0.79 $\pm$ 0.49	6.39 $\pm$ 1.7
<i>Spiraea tomentosa</i> var. <i>rosea</i>	0.14 $\pm$ 0.06	0.37 $\pm$ 0.17	0.56 $\pm$ 0.21	4.83 $\pm$ 1.06	4.07 $\pm$ 1.16	8.809 $\pm$ 1.95
Total Cover	20.86 $\pm$ 3.02	39.68 $\pm$ 3.67	31.05 $\pm$ 2.90	61.93 $\pm$ 3.3	58.49 $\pm$ 2.78	83.97 $\pm$ 2.08

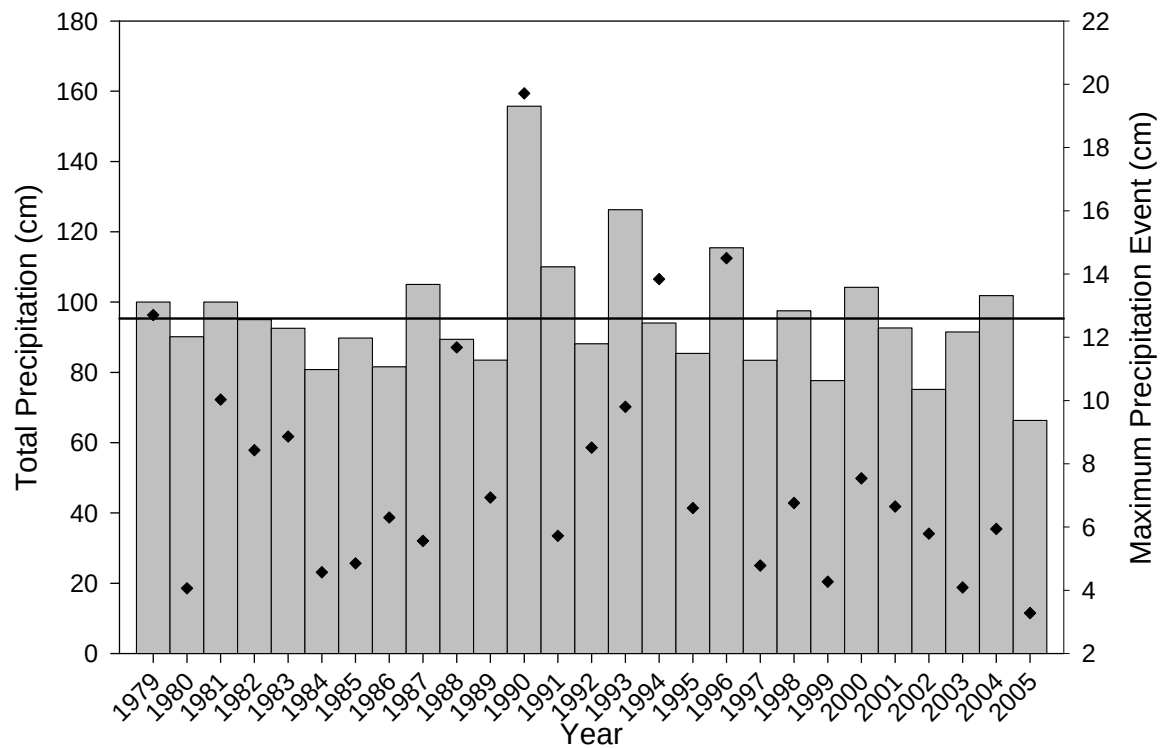


Figure 5. Total rainfall by year for Indiana Dunes: 1979-2005. Bars represent the total rainfall per year and black diamonds represent the maximum rainfall event of each year with its scale on the right axis. The reference line is for the average total rainfall across all the years.

Table 5. Top ten rainfall events from 1979-2005.

Rank	Date	Precipitation (cm)
1	18-Aug-1990	19.71
2	10-May-1996	14.50
3	14-Jun-1994	13.84
4	9-Aug-1988	11.68
5	18-Jul-1996	10.67
6	13-Jun-1981	10.03
7	28-Nov-1990	9.83
8	8-Jun-1993	9.80
9	18-Jun-1996	9.35
10	2-Jul-1983	8.86

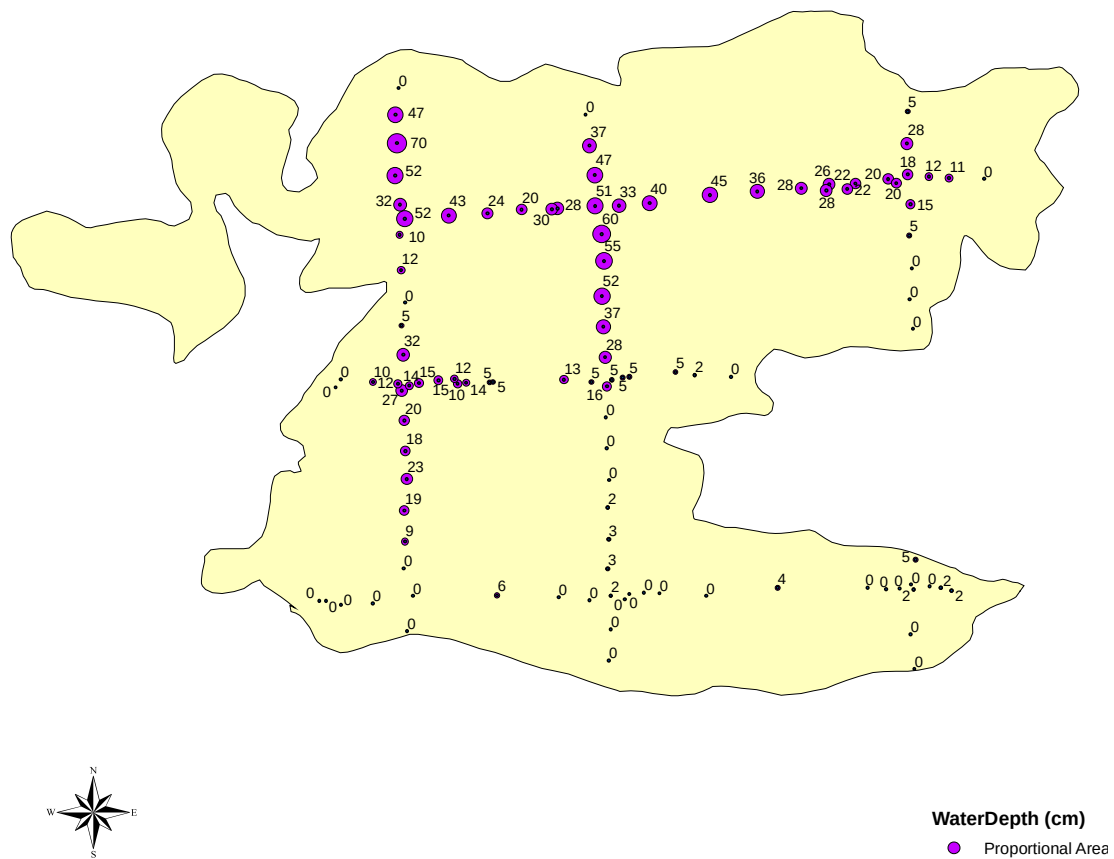


Figure 6. Map of Blag Slough showing depth of flooding in 1990.

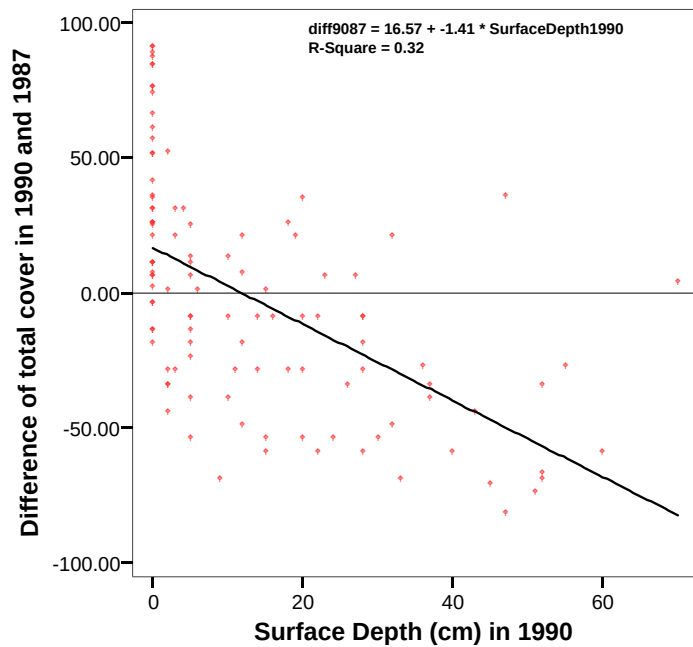


Figure 7. Simple linear regression of change in vegetation cover between 1987 and 1990 as a function of surface water depth in 1990.

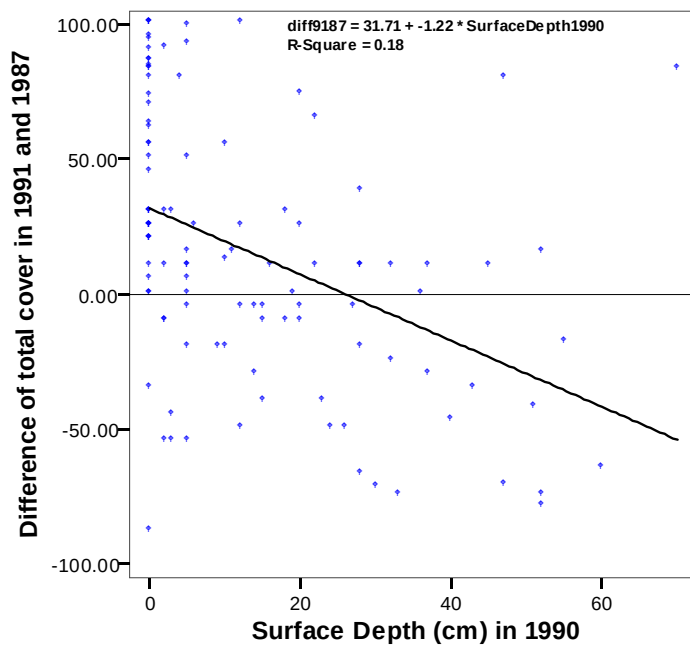


Figure 8. Simple linear regression of change in vegetation cover between 1987 and 1991 as a function of surface water depth in 1990.

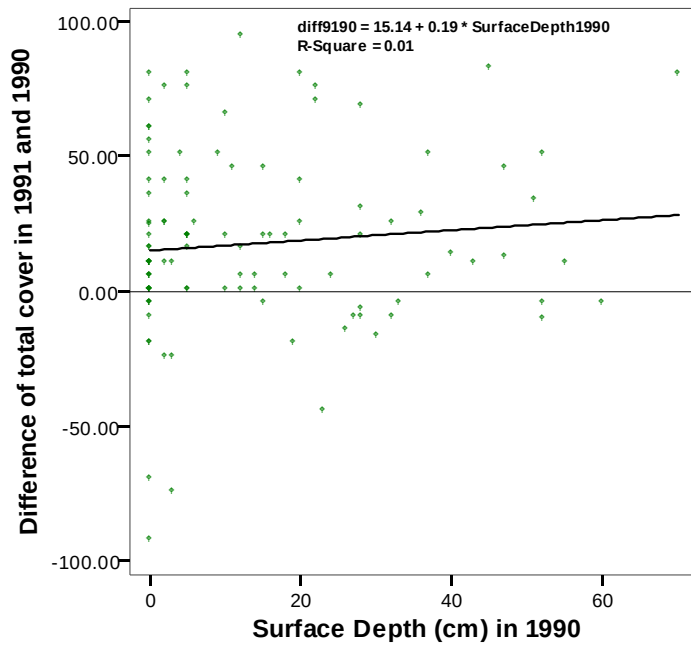


Figure 9. Simple linear regression of change in vegetation cover between 1990 and 1991 as a function of surface water depth in 1990.

Table 6. Frequency of plots by associations in each survey year with association codes for subsequent figures.

	1982	1983	1984	1985	1986	1987	1990	1991	2005
Spike rush/woolly sedge (Eleooliv)	27	17	23	13	13	6		2	1
Blackfruit spike rush (Eleomela)	3	9							
Spike rush/moss flats (EleoMossScir)	1	15	2	1	7	2		2	
Moss flats (MossEleo)	4	4	1	3	2	1	1		
Mixed spike rush meadows (EleoDiverse)	13	17	17	9	1	4	1	4	2
Spike rush/shrub (EleoShrub)		1	2	5	11	5	1	1	
Water smartweed (Polyamph)	3	4	5	2				1	
Woolly sedge/rush (ScirJucLow)	4	1	4	11	14	15	26	27	
Woolly sedge/rush with overstory (ScirJuncTall)		1	5	5	4	3	3	3	11
Woolly sedge/smartweed (ScirPolyDiverse)	7	12	18	34	31	36	41	40	6
Late flowering boneset/rush (EupaJunc)			1		1		9	6	29
Diverse rush meadow (JuncDiverse)						2	8	5	14
Rice cut grass (Leeroryz)	1							3	
Virginia creeper (Parth)	1	1	1						
Mannagrass/common reed (GlycPhrag)							1	4	9
Bluejoint meadow (Calacana)	1	1	2	1	1	2	3	4	15
Bluejoint/steplebush (CalaSpirRubu)			1	1	1	1	4	2	6
Steplebush shrubland (Shrubs)	1	4	3	5	10	15	3	2	16
Shining sumac (Rhuscopa)			2	4	4	5	2		
Raspberry/steplebush (RubuSpir)					2	4	7	4	1
N bareground	44	23	23	16	8	9	0	0	0

Mixed Spike Rush Meadows (EleoDiverse)

This early-mid successional association is predominantly comprised of bright green spikerush (*E. olivacea*). However, there are a variety of other species that are also present, such as Canadian rush (*Juncus canadensis*), moss, dwarf bulrush (*Schoenoplectis smithii* (*Scirpus purshianus*)) and the ubiquitous common rush (*J. effusus*).

Spike Rush/Woolly Sedge (Eleooliv)

These areas when mudflats, were dominated by bright green spikerush (*E. olivacea*). However, woolly sedge (*S. cyperinus*) came to dominate many of these associations with time. Both species were present early at the site and expanded greatly with time (Wilcox et al. 1985). In portions of the main pond, especially along transect W, woolly sedge dominated to the detriment of other vegetation by cover and thick litter. With the precipitous decline of both of these species by 2005, this association type is currently uncommon.

Late Flowering Boneset/Rush (EupaJunc)

Late boneset (*Eupatorium serotinum*) is the dominant in this association which has been increasing since its first appearance in 1987. Additional species include rush (*J. effusus*), leafy satin grass (*Muhlenbergia mexicana*), mild water pepper (*Polygonum hydropiper/oides*) and horseweed (*Conyza canadensis*). This is lumped with and mapped with diverse rush meadow (see below).

Mannagrass/Common Reed (GlycPhrag)

This late successional association is dominated by two large grasses, mannagrass (*Glyceria canadensis*) and the exotic common reed (*Phragmites australis*), with the latter being less common. This association is late successional and was not present at Blag Slough in the 1980's. These associations have formed on the peripheral area of the pond, mostly in transect X. Common reed is one of the few exotics in the pond, and may have been dispersed from plants in nearby areas.

Diverse Rush Meadow (JuncDiverse)

Common rush (*Juncus effusus*) dominates the understory of this very diverse association. Woody species such as gray birch (*Betula populifolia*), dewberry (*R. hispidus/flagellaris*), steplebush (*S. tomentosa*) and buttonbush (*C. occidentalis*) also have a significant presence. Forbs and grasses include *P. hydropiper/oides*, *E. serotinum*, *Boehmeria cylindrica* and *M. mexicana*.

Raspberry/Steeplebush (RubuSpir)

Although there are low numbers of other species present, this association is comprised of blackberry (*R. occidentalis/ alleghaniensis*) and steplebush (*S. tomentosa*).

Woolly Sedge/Rush with Overstory (ScirJuncTall)

Common rush (*Juncus effusus*) and woolly sedge (*S. cyperinus*) along with bright green spikerush (*E. olivacea*) form the lower layer of this association with late-flowering boneset (*E. serotinum*) forming the understory.

Woolly Sedge/Smartweed (ScirPolyDiverse)

This was the most common association type in the pond. Woolly sedge (*Scirpus cyperinus*) forms the overstory and mild water pepper (*P. hydropiper/oides*) forms the understory. The ubiquitous late-flowering boneset (*E. serotinum*) also occurred frequently in this common association.

Steeplebush Shrubland (Shrubs)

Steeplebush (*Spiraea tomentosa*) and blackberry (*R. hispidus/flagellaris*) dominate this association. However, there are additional forb species such as grass-leaved goldenrod (*Euthamia graminifolia*), *E. serotinum*, boneset (*E. perforatum*), *S. cyperinus* and rattlebox (*Ludwigia* spp).

DCA ordination showed compositional variation among positions of high cover of dominant species (Figure 10). Axes one to three explained respectively 27.9, 11.1, and 1.2 % of the variation in species composition. DCA ordination axes were weakly correlated with environmental variables listed here with decreasing magnitude by axis: axis 1 – distance from pond edge ($r^2 = 0.203$) and water depth in 1990 ($r^2 = 0.162$); axis 2 – elevation ($r^2 = 0.192$) and distance from fly-ash ponds ($r^2 = 0.118$) (Figure 11). Richness (and diversity) was negatively correlated with axes 2 and 3 ($r^2 = -0.373$ and -0.370 respectively).

Adding percent bare ground as a variable permitted the inclusion of all plots, even those without vegetation, in an ordination showing vegetation trajectories in the main pond. From this

ordination we could examine the trajectories of composition that led to the vegetation associations found in 2005 (Figure 12). Note that the ordination space is different from that shown in Figures 10 and 11. Most association trajectories commence in 1982 with low vegetation cover at about 175 and 200 on axes 1 and 2 in the ordination space, where bare ground is maximized. The mixed spike rush, boneset rush, woolly sedge smartweed, and woolly sedge rush association trajectories proceed towards the lower left showing dominance of *Eleocharis olivacea* first, and then turn about 90° towards dominance of woolly sedge. The spike rush woolly sedge association trajectory shows low vegetation cover early on and an increase in woolly sedge cover as the dominant species followed by a retrograde succession back to spikerush dominance with little cover of woolly sedge. This implies that woolly sedge cover declined either from loss of vigor or mortality. The bluejoint meadow, bluejoint steeplebush, mannagrass/common reed, diverse rush meadow, raspberry steeplebush, and steeplebush shrubland all change in composition towards the upper right quadrant. These are being dominated by steeplebush, bluejoint grass, or mannagrass.

Life Form Analyses

Some of the life forms show trends in time, while others exhibit a flat or random pattern in cover (Table 7). Perennial sedges (dominated by *S. cyperinus*) started out as the highest cover category for the main pond and reached a peak in 1991. However, by 2005, the cover for these species had decreased to that of the beginning of revegetation in 1982. Perennial grasses (dominated by *C. canadensis*), on the other hand, started out at low cover, and have now increased to be the most dominant life form across the entire main pond. Perennial forbs and woody plants have also shown a large increase in cover since 1982, becoming the next two highest cover categories behind perennial grasses.

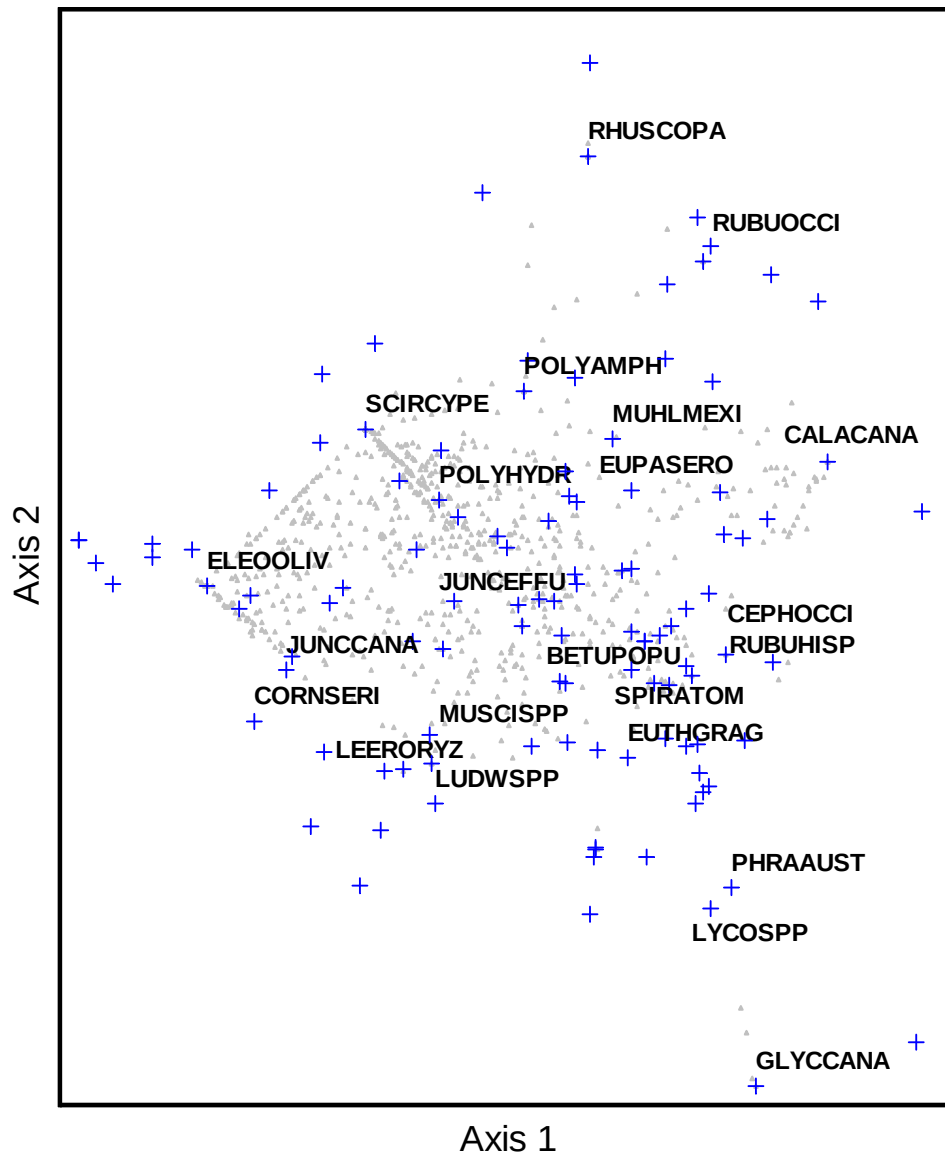


Figure 10. DCA ordination of Blag Slough vegetation from 1982-2005. Small gray dots represent the plots, and the blue crosses represent the species. Only dominant species have been labeled here.

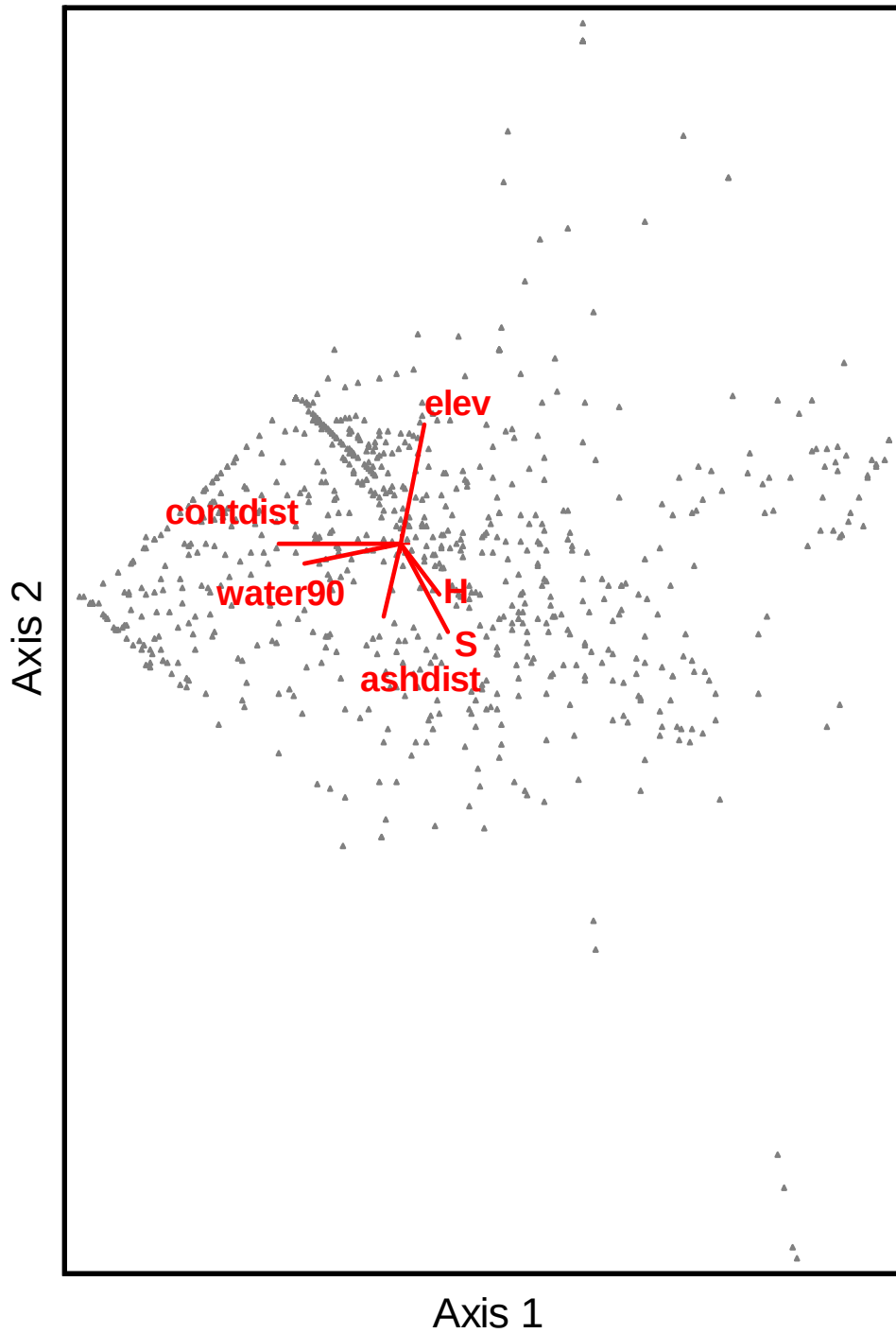


Figure 11. DCA ordination with biplot of environmental variables for Blag Slough vegetation from 1982-2005. “Elev” = relative elevation of the plot; “contdist” = distance from the edge of the pond; “water90” = water depth after flood event of 1990; “ashdist” = distance from fly-ash ponds; S = species richness; H = Shannon diversity.

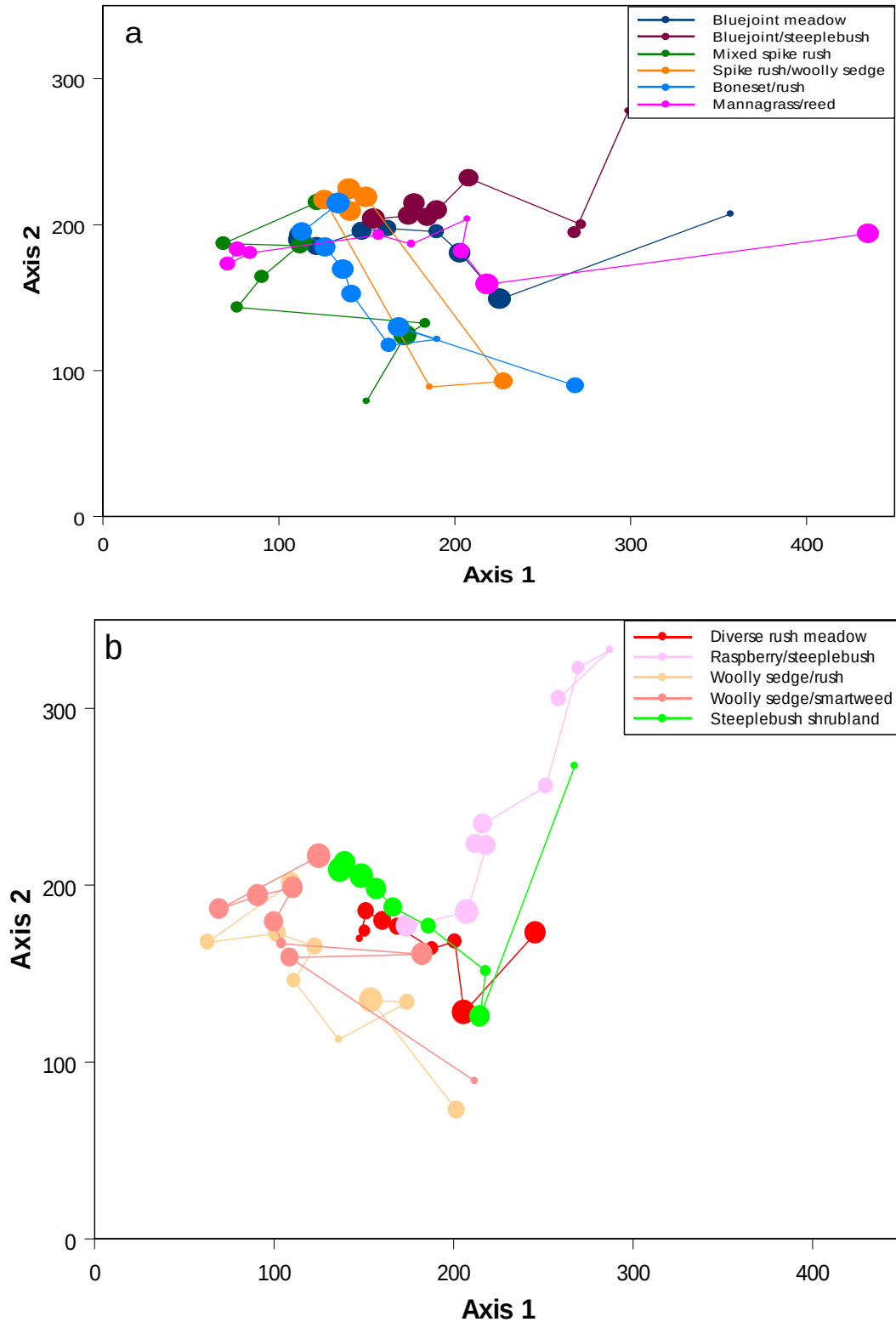


Figure 12a-b. Trajectories through time for the associations. Axis 1 and axis 2 are derived from PCA. a) Six association types, b) remaining five association types. Each dot represents a survey year, and the lines connect the dots in chronological order. The size of the dot is proportional to the size of the third axis.

Across transects, annual cover fluctuated greatly in space and time (Table 8). Cover of annual forbs was greatest in transect V except in 1985-1990 when it was highest in transect W. Perennial grasses were only present in transect V, but by 2005 had increased throughout the transects especially in transect X. Peaks in cover of perennial sedges occurred in 1983 in transect X and in 1991 in transects V and W (Table 8). Perennial forbs among transects had the greatest cover in 2005, but were consistently higher in cover in transect X in comparison to transects V and W until after 1987. Except for 1986 and 1987 cover of woody plants was greater in transect V, nearest to the fly-ash ponds. Ferns were only present in transect X and biennials were only present in transect W in 2005 (Table 8).

Richness, Diversity, Evenness, Cover, and Floristic Quality

In Blag Slough from 1982 to 2005, $S = 110$, $E = 0.6$, $H' = 0.9$, $D = 2.8$, mean $C = 5.4$, $FQI = 52.9$, and modified $FQI = 52.9$. In time within Blag Slough, the mean values of S , E , H' , D , and I increased, however, mean C and weighted mean C decreased (Fig. 13) from 1982 to 1990, increased in 1991, and then declined slightly by 2005, showing an overall decline in 23 years. Mean C did not differ among growth forms and lifecycles ($F_{5,85} = 0.43$, $P = 0.37$; $F_{4,90} = 1.87$, $P = 0.123$). However, if we simplify growth and life forms respectively into forbs and graminoids and annual/biennial and perennials, both differ significantly in mean C . Forbs have lower mean C (5.1 ± 0.5) than graminoids (6.2 ± 0.6): $F_{1,70} = 3.9$, $P = 0.51$. Annuals and biennials have lower mean C (4.1 ± 0.9) than perennials (5.9 ± 0.4): $F_{1,70} = 4.6$, $P = 0.036$.

Among plant associations, richness, diversity, mean C , and FQI showed considerable variation (Figure 14). Richness and diversity indices all show a similar pattern of early-successional habitats having the lowest values whereas mid- and late-successional habitats tending to have moderate to higher values (Figure 14A-D): S ; $F_{18,251} = 15.0$, $P < 0.001$; E ; $F_{18,251} = 4.5$, $P < 0.001$; H' ; $F_{18,251} = 9.7$, $P < 0.001$; D ; $F_{18,251} = 7.4$, $P < 0.001$.

Similarly mean C differed significantly among associations ($F_{18,251} = 35.0$, $P < 0.001$) but unlike richness and diversity measures, late and mid successional associations had low values compared to the earliest successional associations (Fig. 14E). For example, the four highest values were found in the following early successional associations: spike rush/woolly sedge (Eleooliv), blackfruit spike rush (Eleomela), spike rush/moss flats (EleoMossScir), and mixed spike rush meadows (EleoDiverse). Associations having shrubs or perennial graminoids included bluejoint/steeplesh (CalaSpirRubu), steeplesh shrubland (Shrubs), managrass/common reed (GlycPhrag), and rice cut grass (Leeroryz) were intermediate in Mean C values.

Table 7. Mean cover ($\pm$ SE) for different life forms by year. Means with different superscript letters are significantly different.

Life form	1982	1983	1984	1985	1986	1987	1990	1991	2005
annual grasses	0.07 $\pm$ 0.07 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a
annual sedges	0 ^a	0.57 $\pm$ 0.18 ^a	0.18 $\pm$ 0.07 ^a	0.05 $\pm$ 0.04 ^a	0.23 $\pm$ 0.13 ^a	0.18 $\pm$ 0.14 ^a	0.51 $\pm$ 0.26 ^a	1.02 $\pm$ 0.69 ^a	0.14 $\pm$ 0.05 ^a
annual forbs	3.52 $\pm$ 1.42 ^a	3.43 $\pm$ 1.27 ^a	1.31 $\pm$ 0.42 ^a	3.64 $\pm$ 1.13 ^a	6.67 $\pm$ 1.57 ^{ab}	12.28 $\pm$ 2.08 ^c	11.35 $\pm$ 1.65 ^{bc}	2.95 $\pm$ 0.84 ^a	2.25 $\pm$ 0.72 ^a
perennial grasses	0.66 $\pm$ 0.55 ^a	0.65 $\pm$ 0.35 ^a	1.44 $\pm$ 0.8 ^a	1.23 $\pm$ 0.82 ^a	1.56 $\pm$ 0.91 ^a	0.83 $\pm$ 0.49 ^a	7.36 $\pm$ 1.79 ^{ab}	11.65 $\pm$ 2.46 ^b	30.25 $\pm$ 3.85 ^c
perennial sedges	15.97 $\pm$ 2.62 ^a	32.19 $\pm$ 3.78 ^c	23.69 $\pm$ 2.8 ^{abc}	19.91 $\pm$ 2.2 ^{ab}	29.56 $\pm$ 3.06 ^{bc}	31.49 $\pm$ 3.28 ^c	19.27 $\pm$ 2.14 ^{ab}	51.21 $\pm$ 3.49 ^d	13.05 $\pm$ 1.94 ^a
perennial forbs	1.02 $\pm$ 0.37 ^a	2.29 $\pm$ 0.65 ^a	2.69 $\pm$ 0.98 ^a	3.64 $\pm$ 1.11 ^a	5.25 $\pm$ 1.08 ^{ab}	9.91 $\pm$ 1.43 ^b	7.5 $\pm$ 1.81 ^{ab}	4.47 $\pm$ 1.13 ^{ab}	29.38 $\pm$ 3.17 ^c
woody plants	0.6 $\pm$ 0.27 ^a	1 $\pm$ 0.37 ^a	2.19 $\pm$ 0.93 ^a	3.18 $\pm$ 1.02 ^{ab}	6.2 $\pm$ 1.44 ^{abc}	13.23 $\pm$ 2.48 ^{cd}	15.8 $\pm$ 2.69 ^d	10.31 $\pm$ 2.35 ^{bcd}	24.6 $\pm$ 3.51 ^e
ferns	0 ^a	0.01 $\pm$ 0.01 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0.02 $\pm$ 0.02 ^a	0.02 $\pm$ 0.02 ^a
biennials	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0.02 $\pm$ 0.02 ^a	0 ^a	0.02 $\pm$ 0.01 ^a

Table 8. Mean cover $\pm$ standard error for different life forms by year and transects with increasing distance from fly-ash ponds.

Life form	1982	1983	1984	1985	1986	1987	1990	1991	2005
<u>Annual grasses</u>									
V	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	0	0	0	0
X	0	0	0	0	0	0	0	0	0
<u>Annual sedges</u>									
V	0	0	0	0	0.6 $\pm$ 0.6	0	1.05 $\pm$ 0.69	5 $\pm$ 3.73	0.25 $\pm$ 0.12
W	0	2.4 $\pm$ 0.83	0.15 $\pm$ 0.11	0.05 $\pm$ 0.05	0.05 $\pm$ 0.05	0	0	0	0
X	0	0	0.15 $\pm$ 0.15	3.35 $\pm$ 1.9	9.05 $\pm$ 3.29	14.55 $\pm$ 5.82	8.75 $\pm$ 2.57	0.3 $\pm$ 0.15	0.1 $\pm$ 0.07
<u>Annual forbs</u>									
V	11.9 $\pm$ 6.04	11.35 $\pm$ 5.62	1.85 $\pm$ 0.89	1.75 $\pm$ 0.68	5.45 $\pm$ 2.69	10.15 $\pm$ 4.02	7.2 $\pm$ 2.49	9.35 $\pm$ 3.24	5.85 $\pm$ 3.08
W	0.6 $\pm$ 0.6	0.5 $\pm$ 0.5	0.5 $\pm$ 0.5	6.8 $\pm$ 4.17	13.3 $\pm$ 6.5	18.35 $\pm$ 6.57	18.6 $\pm$ 4.2	0.25 $\pm$ 0.25	1.5 $\pm$ 0.78
X	0	0	0.15 $\pm$ 0.15	3.35 $\pm$ 1.9	9.05 $\pm$ 3.29	14.55 $\pm$ 5.82	8.75 $\pm$ 2.57	0.3 $\pm$ 0.15	0.1 $\pm$ 0.07
<u>Perennial grasses</u>									
V	3 $\pm$ 3	1.75 $\pm$ 1.51	3 $\pm$ 3	2.5 $\pm$ 2.5	4 $\pm$ 4	2.65 $\pm$ 2.5	10.6 $\pm$ 4.65	4.9 $\pm$ 2.43	14.55 $\pm$ 4.52
W	0	0	0.05 $\pm$ 0.05	0	0	0.15 $\pm$ 0.15	7.05 $\pm$ 4.28	15.75 $\pm$ 7.18	15.25 $\pm$ 7.54
X	0	0.05 $\pm$ 0.05	0	0.15 $\pm$ 0.11	0.45 $\pm$ 0.28	0.4 $\pm$ 0.23	10.8 $\pm$ 5.35	18.5 $\pm$ 7.02	65.6 $\pm$ 10.69
<u>Perennial sedges</u>									
V	6.25 $\pm$ 3.17	7.2 $\pm$ 3.12	7.95 $\pm$ 3.49	10.4 $\pm$ 4.02	13 $\pm$ 3.53	18.2 $\pm$ 4.7	12.4 $\pm$ 4.98	55.35 $\pm$ 7.74	10.15 $\pm$ 3.19
W	9.15 $\pm$ 2.99	51.55 $\pm$ 10.15	26.55 $\pm$ 5.71	33.45 $\pm$ 6.26	43.05 $\pm$ 7.9	49.35 $\pm$ 8.68	32.65 $\pm$ 6.08	66.2 $\pm$ 7.5	16.35 $\pm$ 3.64
X	35.15 $\pm$ 7.54	62.4 $\pm$ 7.59	51.25 $\pm$ 7.5	30.7 $\pm$ 5.39	45.05 $\pm$ 7.38	34.95 $\pm$ 8.13	14.35 $\pm$ 2.53	37.3 $\pm$ 7.27	15.1 $\pm$ 6.6
<u>Perennial forbs</u>									
V	0.25 $\pm$ 0.25	0.95 $\pm$ 0.51	0.85 $\pm$ 0.47	0.6 $\pm$ 0.47	1.35 $\pm$ 0.75	8.45 $\pm$ 2.58	21.45 $\pm$ 7.79	2 $\pm$ 0.82	23.9 $\pm$ 6.28
W	0	0.5 $\pm$ 0.29	0.4 $\pm$ 0.31	0.65 $\pm$ 0.5	2.15 $\pm$ 1.15	8.25 $\pm$ 3.22	4.85 $\pm$ 2.53	0.65 $\pm$ 0.46	39.6 $\pm$ 7.44
X	1.15 $\pm$ 0.86	1.6 $\pm$ 1.21	5.4 $\pm$ 3.58	10.05 $\pm$ 4.3	14.45 $\pm$ 4.79	13.25 $\pm$ 2.78	0.75 $\pm$ 0.45	2.9 $\pm$ 1.11	24 $\pm$ 8.07
<u>Woody plants</u>									
V	1 $\pm$ 1	1.65 $\pm$ 1.5	1.65 $\pm$ 1.5	3.05 $\pm$ 2.53	4.35 $\pm$ 2.24	8.25 $\pm$ 2.94	21.2 $\pm$ 7.38	14.15 $\pm$ 5.81	32.15 $\pm$ 7.83
W	0.1 $\pm$ 0.1	0.05 $\pm$ 0.05	0.1 $\pm$ 0.1	2.3 $\pm$ 1.79	5.65 $\pm$ 4.14	8.9 $\pm$ 5.23	11.65 $\pm$ 4.9	3.35 $\pm$ 2.05	27.05 $\pm$ 8.53
X	0.2 $\pm$ 0.2	0.5 $\pm$ 0.5	0.7 $\pm$ 0.5	2.4 $\pm$ 1.05	4.65 $\pm$ 1.37	9.25 $\pm$ 2.89	4.1 $\pm$ 2.67	4.6 $\pm$ 4.39	4.85 $\pm$ 4.75

Table 8. Continud

Life form	1982	1983	1984	1985	1986	1987	1990	1991	2005
<u>Ferns</u>									
V	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	0	0	0	0
X	0	0.05±0.05	0	0	0	0	0	0.1±0.1	0.1±0.1
<u>Biennials</u>									
V	0	0	0	0	0	0	0	0	0.05±0.05
W	0	0	0	0	0	0	0	0	0
X	0	0	0	0	0	0	0	0	0

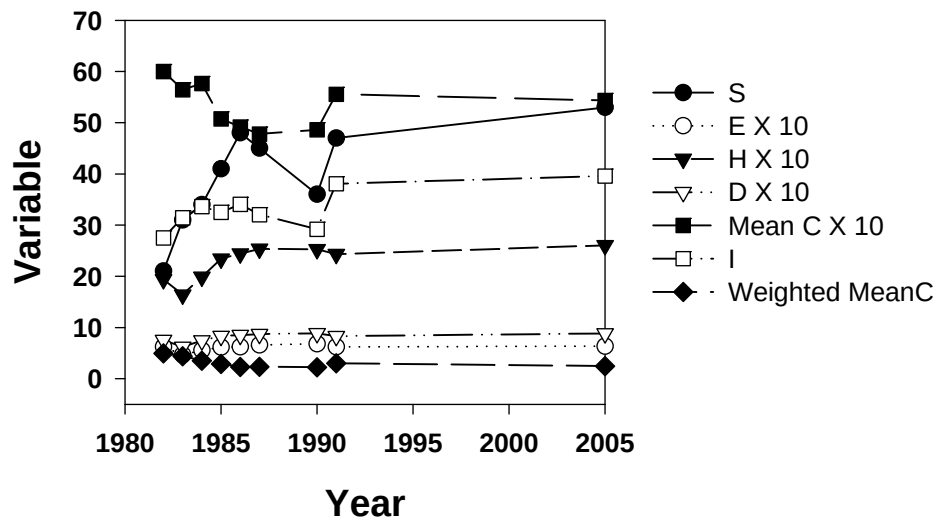


Figure 13. Temporal trends in species richness, diversity indices, mean conservatism scores (C) and floristic quality indices of Blag Slough. E, H', D, and Mean C were multiplied by ten to spread out the curves along the Y axis.

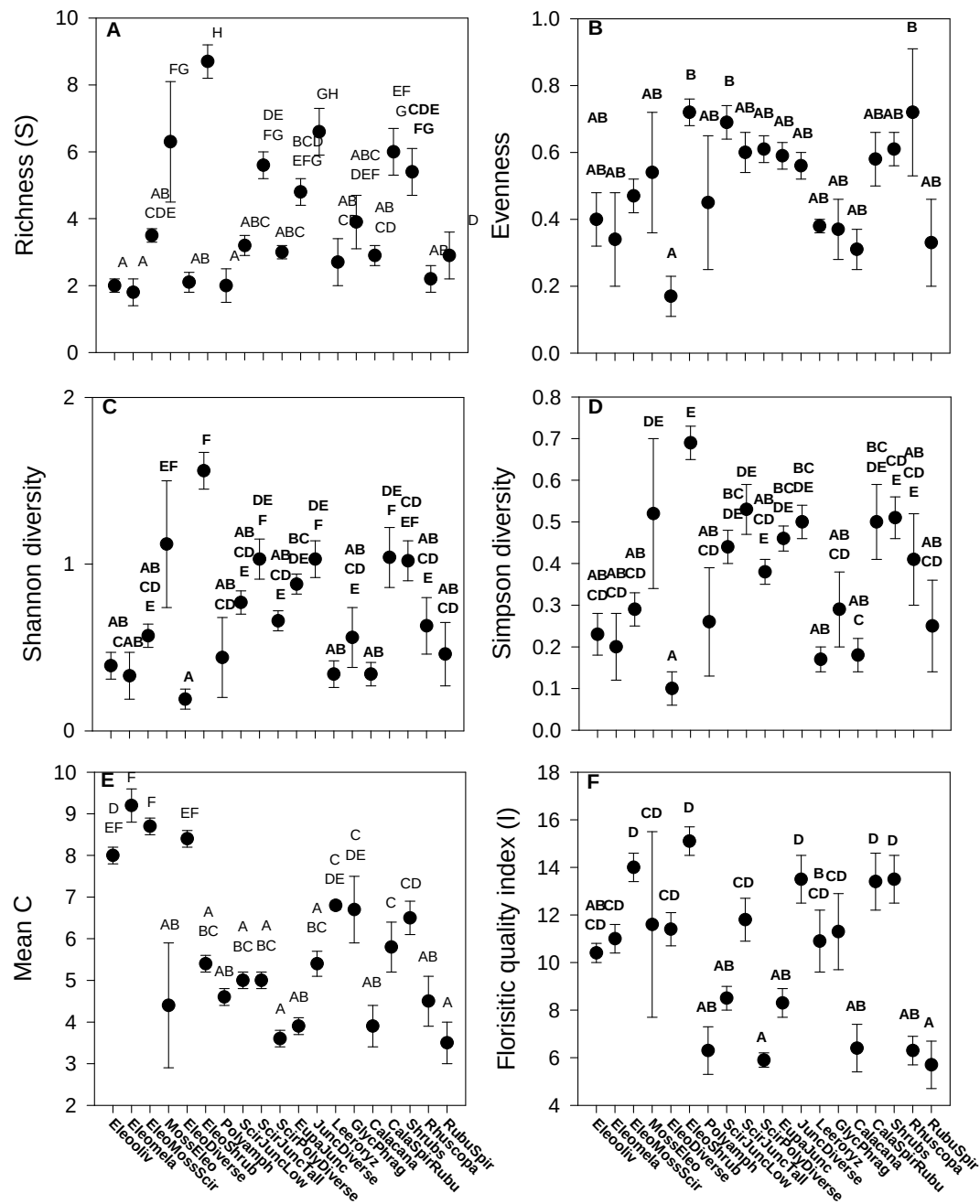


Figure 14. Variation in richness (A), diversity indices (B-D), mean C (E), and I (F) among association types at Blag Slough. Means with different letters are statistically different at $P = 0.05$.

Looking at trends among plant associations, more species had C values between 6 and 10 in early successional associations than did late successional associations (Figure 15). Species representing C values of 10 included:

Betula populifolia - tree
Cladium mariscoides – perennial graminoid
Eleocharis melanocarpa – seed bank annual
Glyceria canadensis – perennial graminoid
Hypericum kalmianum - shrub
Potamogeton pulcher – seed bank annual
Rhynchospora macrostachya – seed bank annual
Rhynchospora scirpoides – seed bank annual
Schoenoplectis smithii – seed bank annual
Spiranthes lacera – perennial forb
Triadenum virginicum – perennial forb

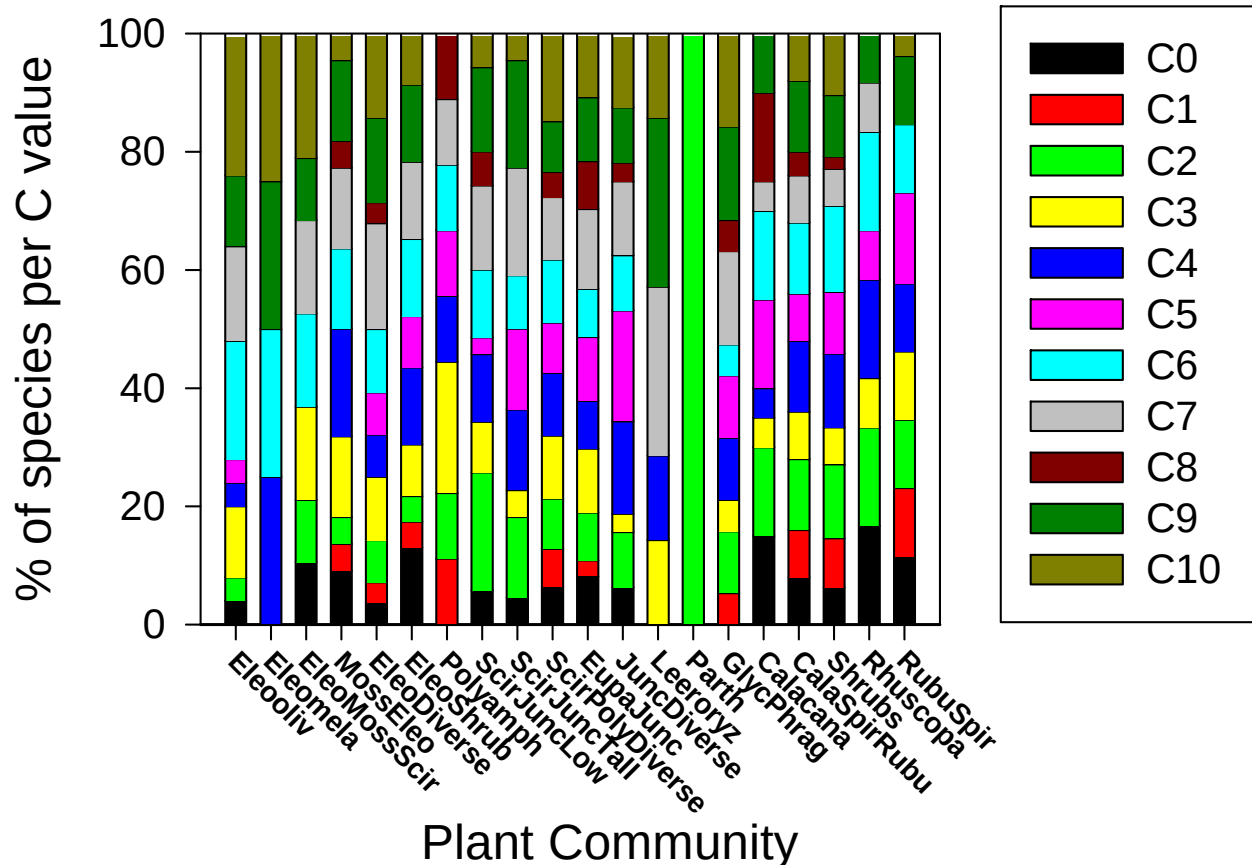


Figure 15. Proportion of species representing each conservatism score (C) by association in approximate successional order.

Of these 11 species, five (45%) are seed bank annuals. Species included in C values of 9 included:

Dulichium arundinaceum – perennial graminoid
Eleocharis olivacea – seed bank annual
Ilex verticillata - shrub
Rubus hispidus - shrub
Schoenoplectis purshianus – seed bank annual
Spireae tomentosa - shrub
Stachys hyssopifolia – seed bank annual

Of these seven species, three are seed bank annuals and three are shrubs. Combining these two C groups into one class of 18 species, eight (44%) were seed bank annuals, four (22%) were shrubs, three (17%) were perennial graminoids, two (11%) were shrubs, and one was a tree. Dominance of high C classes by seed bank annuals and shrubs explains respectively why early successional associations and shrub dominated associations have high mean C values (Fig. 14 E). Thus disturbance dependent early successional species and shrubs had higher C values.

Late-successional associations showed lower FQI values compared to early-successional associations (Fig. 14 F). Floristic quality was moderate to high in early successional associations. Associations with high floristic quality included spike rush/moss flats (EleoMossScir), spike rush/shrub (EleoShrub), diverse rush meadow (JuncDiverse), steplebush shrubland (Shrubs), and bluejoint/steplebush (CalaSpirRubu). Associations with low floristic quality included water smartweed (Polyamph), woolly sedge/smartweed (ScirPolyDiverse), bluejoint meadow (Calacana), shining sumac (Rhuscopa), raspberry/steplebush (RubuSpir).

Examining trends in species richness (S) by year for plots representing associations that were identified in 2005 demonstrates that there were no significant trends among years in the bluejoint meadow (Calacana), bluejoint/steplebush (CalaSpirRubu), mixed spike rush meadows (EleoDiverse), and steplebush shrubland (Shrubs) (Fig. 16A). Species richness increased in time in the late flowering boneset/rush (EupaJunc), diverse rush meadow (JuncDiverse), woolly sedge/rush with overstory (ScirJuncTall), and woolly sedge/smartweed (ScirPolyDiverse); however species richness peaked in the mannagrass/common reed (GlycPhrag) association in 1986 (Fig. 16 B). The latter decline was probably the result of the invasion of common reed (*Phragmites australis*) and growth of the dense cover of mannagrass in the understory.

Mean C in bluejoint/steplebush (CalaSpirRubu) and the diverse rush meadow (JuncDiverse) did not change with time (Fig. 17 A). Mean C declined in time in the bluejoint meadow (Calacana), mixed spike rush meadows (EleoDiverse), late flowering boneset/rush (EupaJunc), mannagrass/common reed (GlycPhrag), woolly sedge/rush with overstory (ScirJuncTall), woolly sedge/smartweed (ScirPolyDiverse), and steplebush shrubland (Shrubs) (Fig 17 B). Weighted mean C by associations showed greater rates of decline in time because the weight of high C valued seed bank species declined in cover while moderate to low C valued late successional species had greater weight as their cover increased in time (Fig. 18).

Floristic quality did not change in time in the bluejoint meadow (Calacana), bluejoint/steplebush (CalaSpirRubu), mixed spike rush meadows (EleoDiverse),

mannagrass/common reed (GlycPhrag), and woolly sedge/smartweed (ScirPolyDiverse) (Fig 19 A.). Floristic quality increased over time in the diverse rush meadow (JuncDiverse) whereas it declined and then increased in the late flowering boneset/rush (EupaJunc), woolly sedge/rush with overstory (ScirJuncTall), and steplebush shrubland (Shrubs) (Fig 19 B).

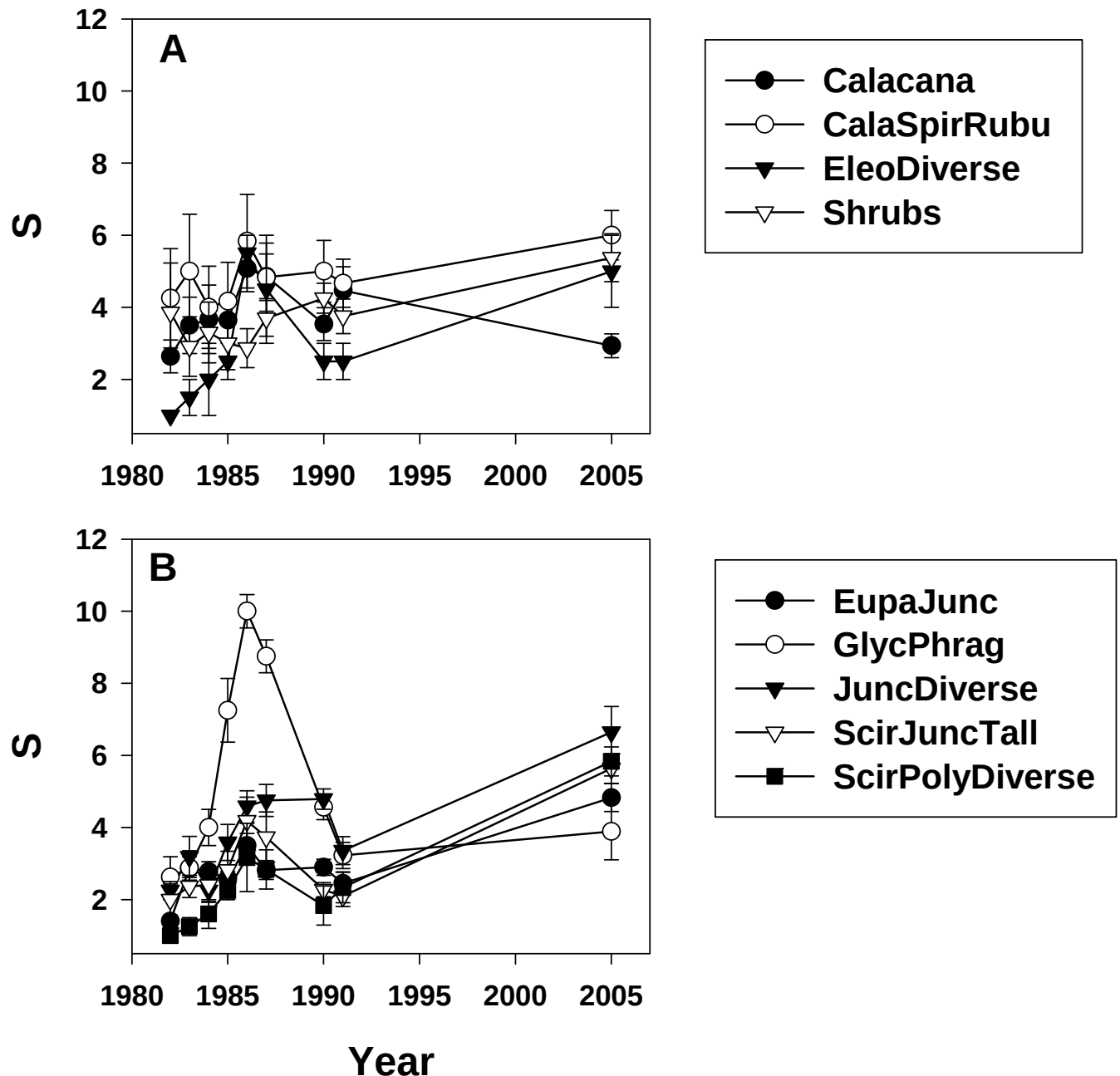


Figure 16. Trends in species richness in time among plots that comprised the plant associations in 2005. A and B are respectively associations without and with significant differences at $P < 0.007$.

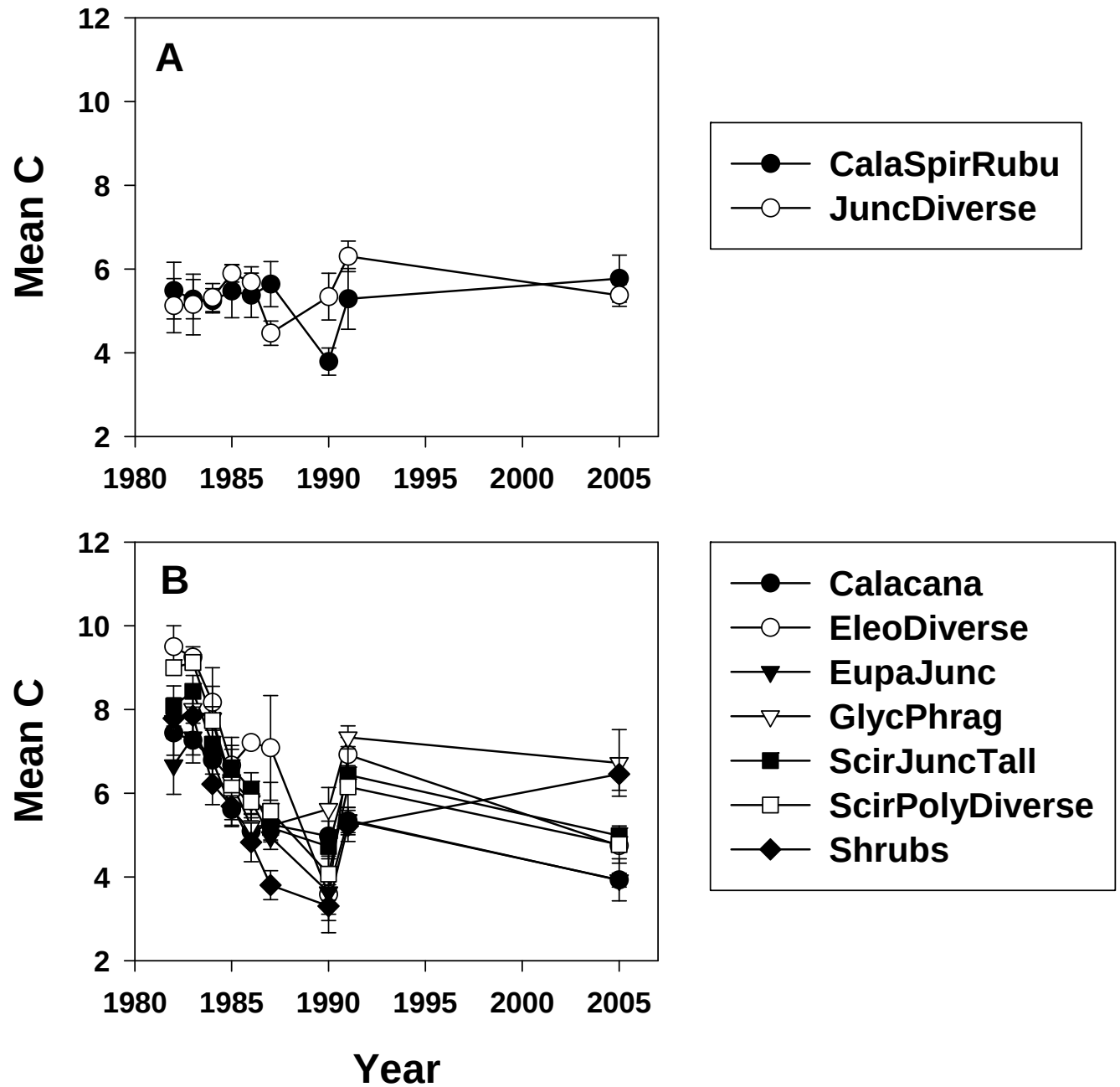


Figure 17. Trends in mean C in time among plots that comprised the plant associations in 2005. A and B are respectively associations without and with significant differences among years.

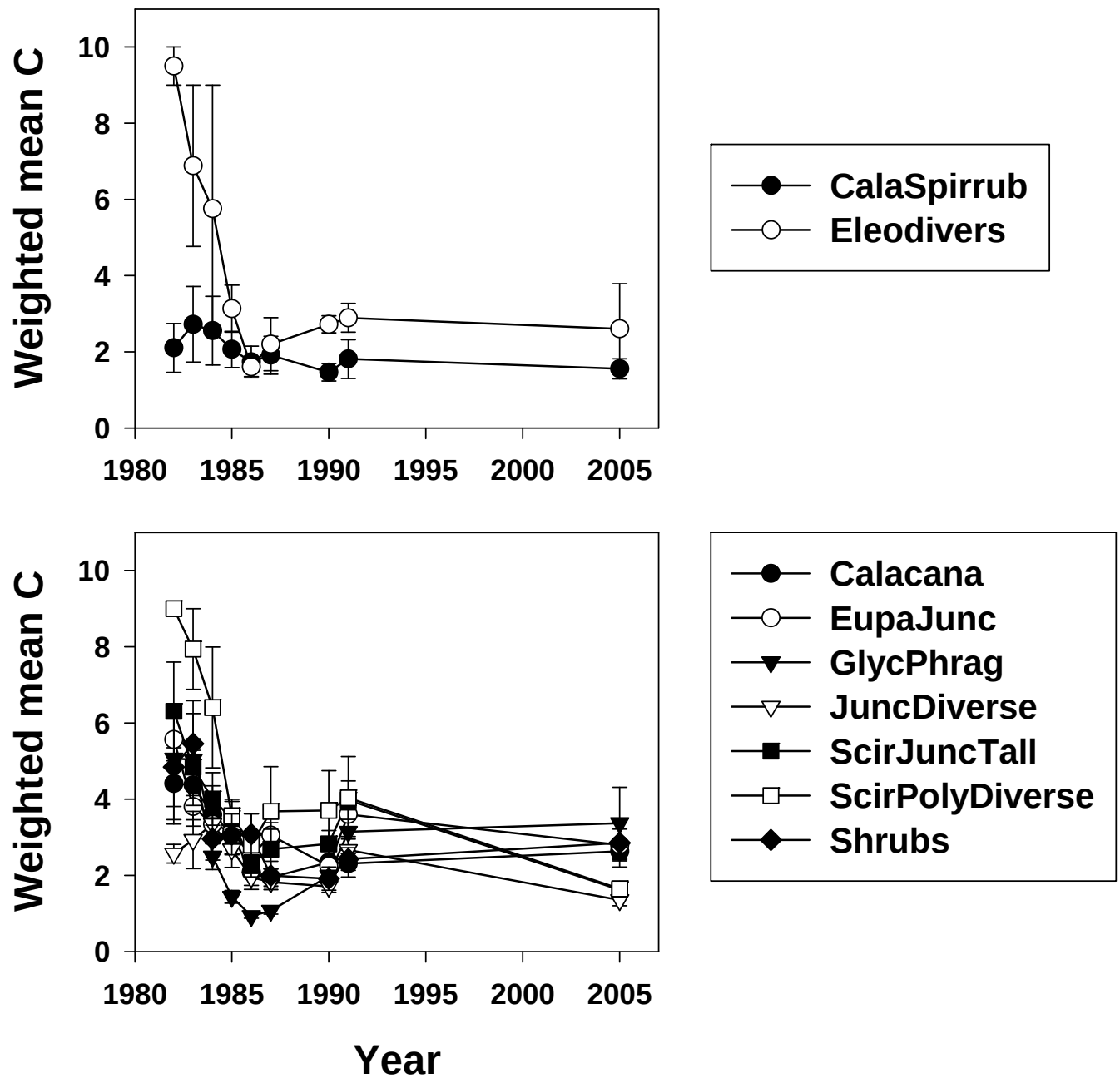


Figure 18. Trends in frequency weighted mean C in time among plots that comprised the plant associations in 2005. A and B are respectively associations without and with significant differences among years at $P < 0.007$.

Trends by Transects

Repeated measures ANOVA indicated that there was a significant difference in the linear and cubic trends between transects V and X and between the cubic trends of transects W and X for the measure of species richness (S) (Figure 20, Table 9). The large peak in species richness in the transect X in 1986 accounts for these differences in trends.

Evenness (E) however had a significant difference between V and X for the linear and quadratic trends and W and X for the quadratic trend (Figure 21 and Table 9). The quadratic trend of X is somewhat opposite that of V and W with a drop in evenness in 1986 while V and W show an increase in evenness in that same time period.

For Shannon diversity (H') there were significant differences in the linear trend between transects V and X and W and X (Figure 22 and Table 9). The shape of the diversity curves are somewhat similar, however the trajectory of transect X peaks and then drops, while V and W show a steady increase in H' .

Finally, for Simpson Diversity (D) there was a difference in the linear and quadratic trends for transects V and X (Figure 23 and Table 9). Transect V steadily increases, while transect X increases and then decreases in D.

Total cover was significantly different in the linear trends of W and X and highly significantly different in the quadratic trends for V and X and W and X and in the cubic trends for V and W and V and X (Figure 24 and Table 9). Many of the differences in total cover trends for the transects are a result of the cover of transect X decreasing sharply in 1990, while the other two transects do not have this drop. Although the trajectories for V and W are similar, there is a difference in the 1984 cover where transect W has a decrease in cover while V does not show as severe a drop.

In 1982 84% of the plots were early, 17 mid and 5 late-successional. By 2005, only 4% were early, 56% were mid and 40% were late-successional. Of the 20 and 26 plots in zones V and W, respectively, that started as early-successional communities, 65 and 60 percent ended being mid-successional communities (Table 10). In contrast, in zone X only 35% ended being mid-successional compared to 65% late successional communities ($\chi^2 = 7.16$, $P = 0.012$). Thus succession has progressed slower in the southern portion of Blag Slough. Maps of the plant communities in 2005 show that late successional bluejoint grass and fowl mannagrass are now invading into the area of north of transect W. We suspect that the failure of late successional grasses to invade in the south half of Blag Slough is related to heavy metals from the leachate and not from the higher topographic position of transects V and W because sources for bluejoint grass regeneration occur along the west end of transect V (east of V31).

Vegetation Maps

The vegetation maps (Figures 25-32) show that vegetative cover increased in time to a maximum cover in 1991 and thereafter. The wetland was dominated by spike rush (1982-3, Fig. 25 and 26), then woolly sedge (1984-7, Fig. 27 to 30), and finally by two associations: common rush and late boneset, and bluejoint grass and fowl mannagrass respectively in the central and north portions of Blag Slough (2005, Fig. 32). Refugia of blue joint grass (*Calamagrostis canadensis*)

and common rush (*Juncus effusus*) occurred peripherally and within high elevation positions in 1982 and 1983 (Fig. 25 and

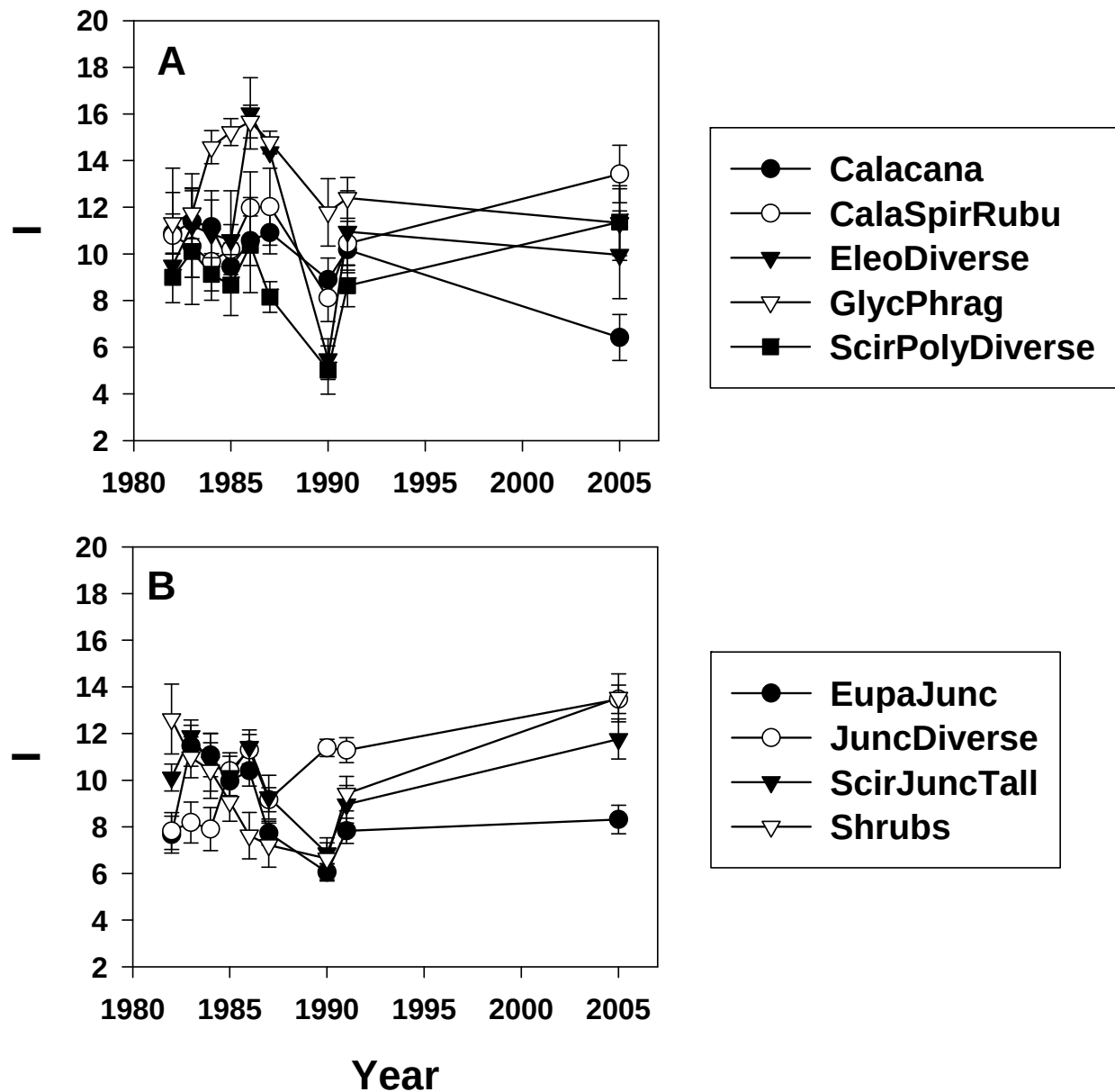


Figure 19. Trends in I in time among plots that comprised the plant associations in 2005. A and B are respectively associations without and with significant differences.

Table 9. Summary of trends repeated measures ANOVA. Significance was determined at the Bonferroni corrected $P = 0.016$ level. * = $P = 0.01 - 0.016$, ** = $P < 0.01$, *** = $P < 0.001$

Order	All transects	V and W	V and X	W and X
Species Richness (S)				
Linear	**	n.s.	**	n.s.
Quadratic	n.s.	n.s.	n.s.	n.s.
Cubic	**	n.s.	**	**
Species Evenness (E)				
Linear	n.s.	n.s.	*	n.s.
Quadratic	*	n.s.	**	**
Cubic	n.s.	n.s.	n.s.	n.s.
Shannon Diversity (H')				
Linear	**	n.s.	**	**
Quadratic	n.s.	n.s.	n.s.	n.s.
Cubic	n.s.	n.s.	n.s.	n.s.
Simpson's Diversity (D)				
Linear	**	n.s.	**	n.s.
Quadratic	n.s.	n.s.	*	n.s.
Cubic	n.s.	n.s.	n.s.	n.s.
Total Percent Cover				
Linear	*	n.s.	n.s.	**
Quadratic	***	n.s.	***	***
Cubic	***	**	***	n.s.

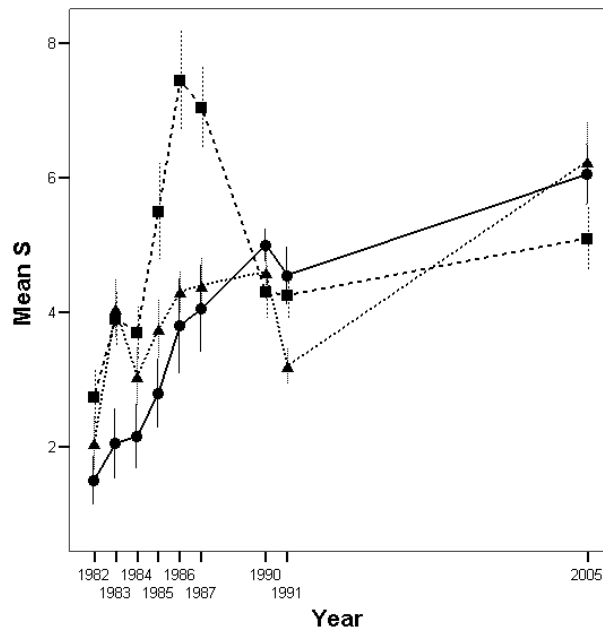


Figure 20. Mean species richness (S) by year for transects V (circles and solid lines), W (triangles and dotted lines), and X (squares and dashed lines). Error bars are standard error of the mean.

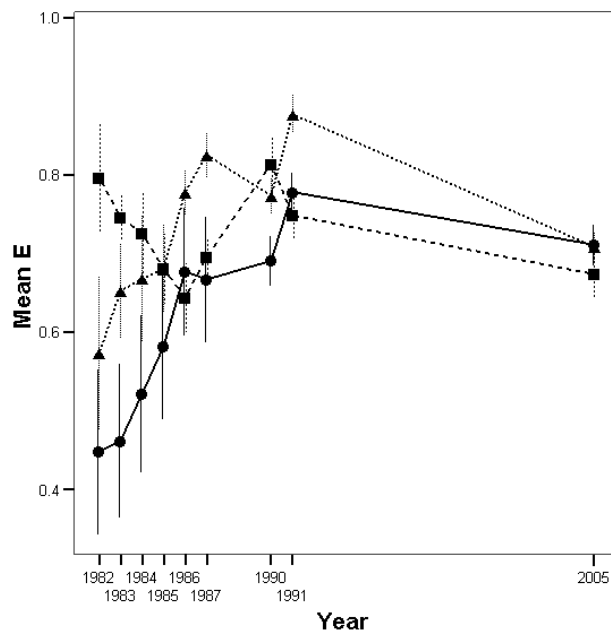


Figure 21. Mean species evenness (E) by year for transects V (circles and solid lines), W (triangles and dotted lines), and X (squares and dashed lines). Error bars are standard error of the mean.

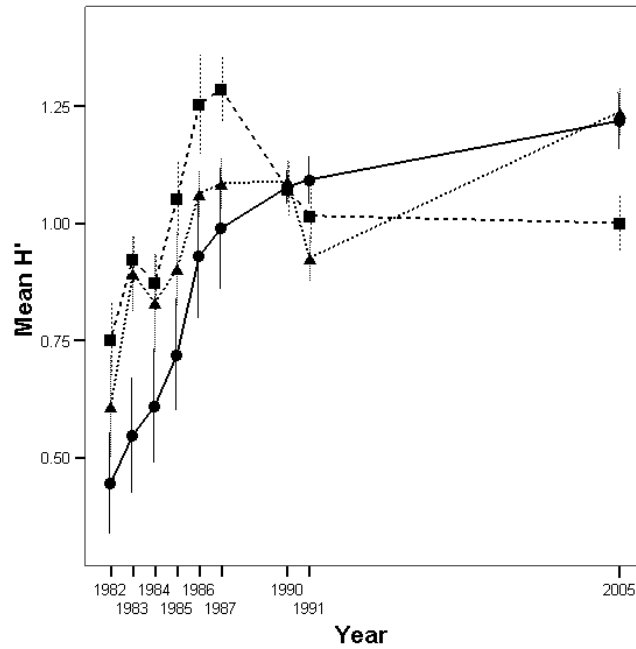


Figure 22. Mean Shannon diversity (H') by year for transects V (circles and solid lines), W (triangles and dotted lines), and X (squares and dashed lines). Error bars are standard error of the mean.

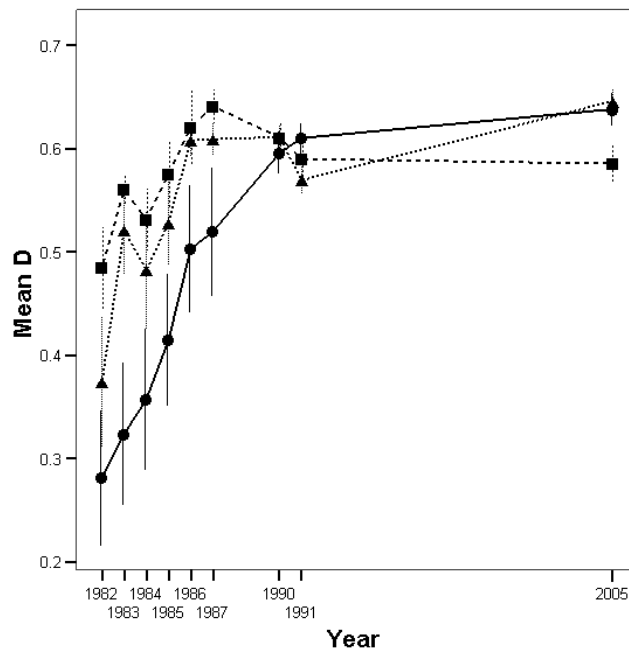


Figure 23. Mean Simpson's diversity (D) by year for transects V (circles and solid lines), W (triangles and dotted lines), and X (squares and dashed lines). Error bars are standard error of the mean.

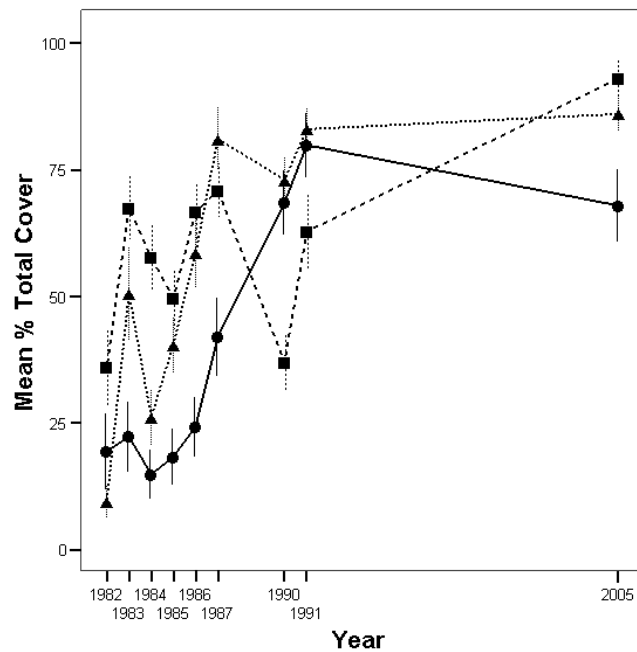


Figure 24. Mean percent total cover by year for transects V (circles and solid lines), W (triangles and dotted lines), and X (squares and dashed lines). Error bars are standard error of the mean.

Table 10. Frequency of plots and transition probabilities at Blag Slough by starting and ending successional stages and by wetland zone. Frequency data in highlighted cells was analyzed using chi-squared analysis.

		Final successional community		
		Early	Mid	Late
Starting successional community	Early V zone	2 (0.10)	13 (0.65)	5 (0.25)
	W zone	-	16 (0.59)	11 (0.41)
	X zone	1 (0.03)	13 (0.35)	23 (0.62)
	Mid V zone	-	11 (1.00)	-
	W zone	1 (0.14)	4 (0.57)	2 (0.29)
	X zone	-	-	1 (1.00)
	Late V zone	-	1 (0.33)	2 (0.67)
	W zone	-	2 (1.00)	-
	X zone	-	-	-

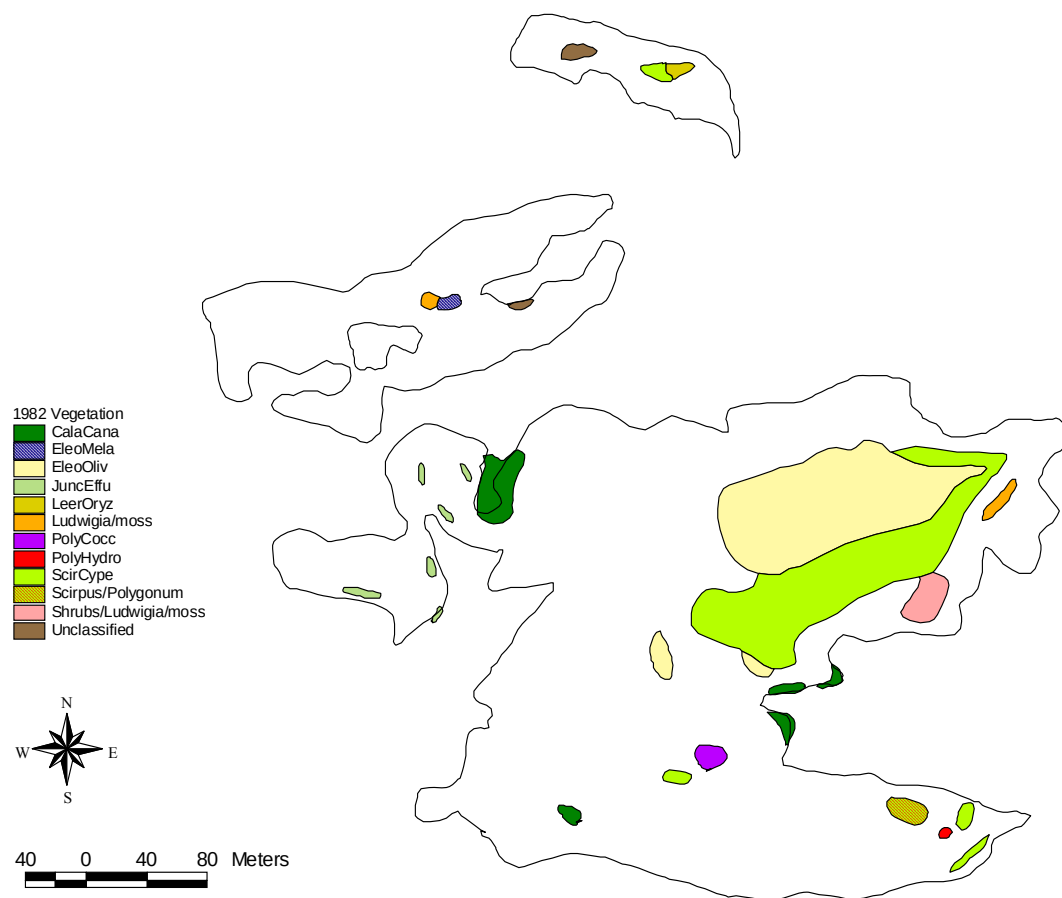


Figure 25. Vegetation map of Blag Slough, central, and north ponds in 1982.

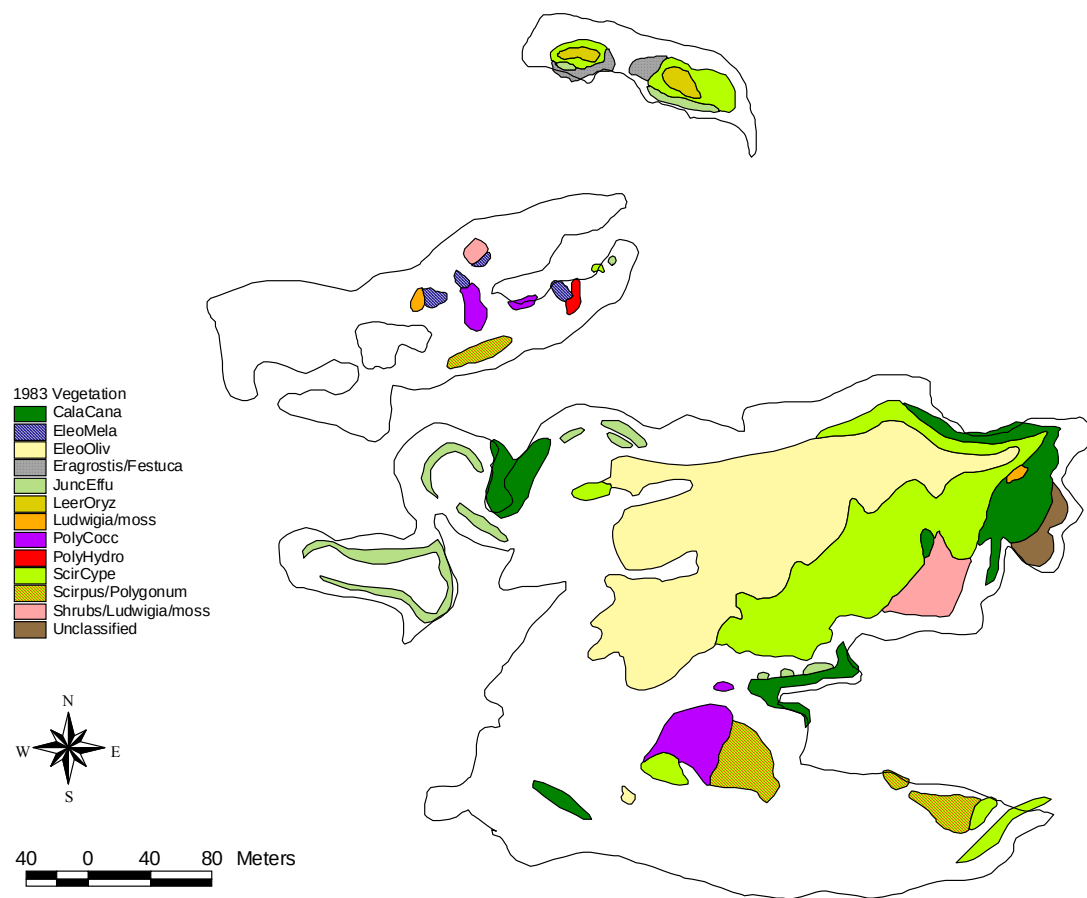


Figure 26. Vegetation map of Blag Slough, central, and north ponds in 1983.

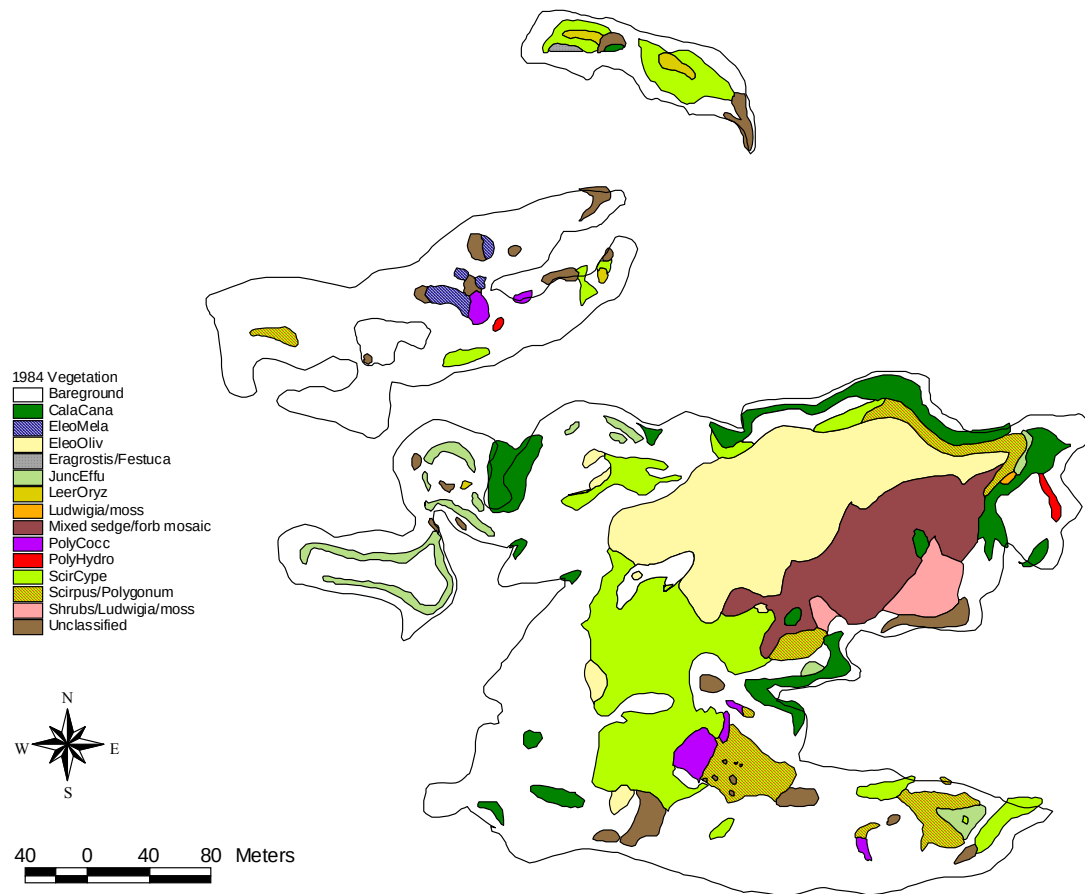


Figure 27. Vegetation map of Blag Slough, central, and north ponds in 1984.

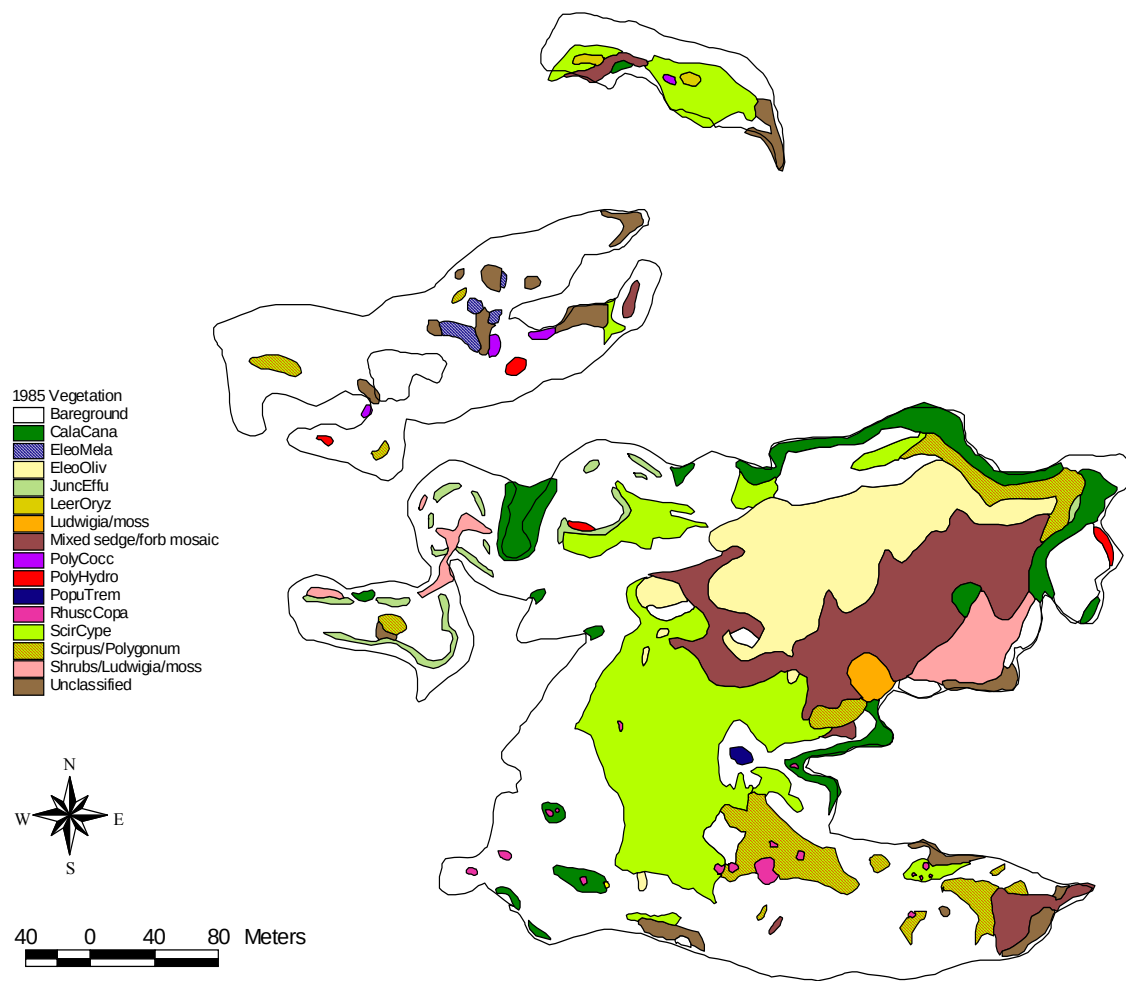


Figure 28. Vegetation map of Blag Slough, central, and north ponds in 1985.

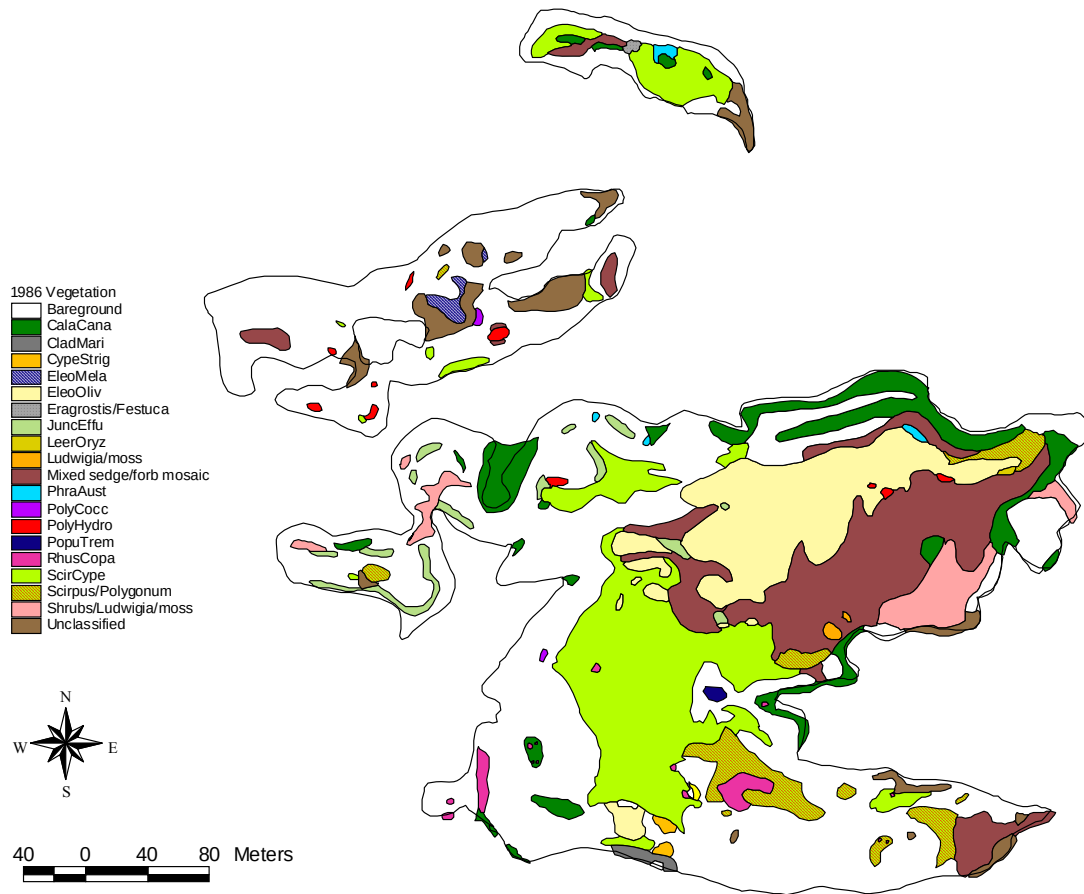


Figure 29. Vegetation map of Blag Slough, central, and north ponds in 1986.

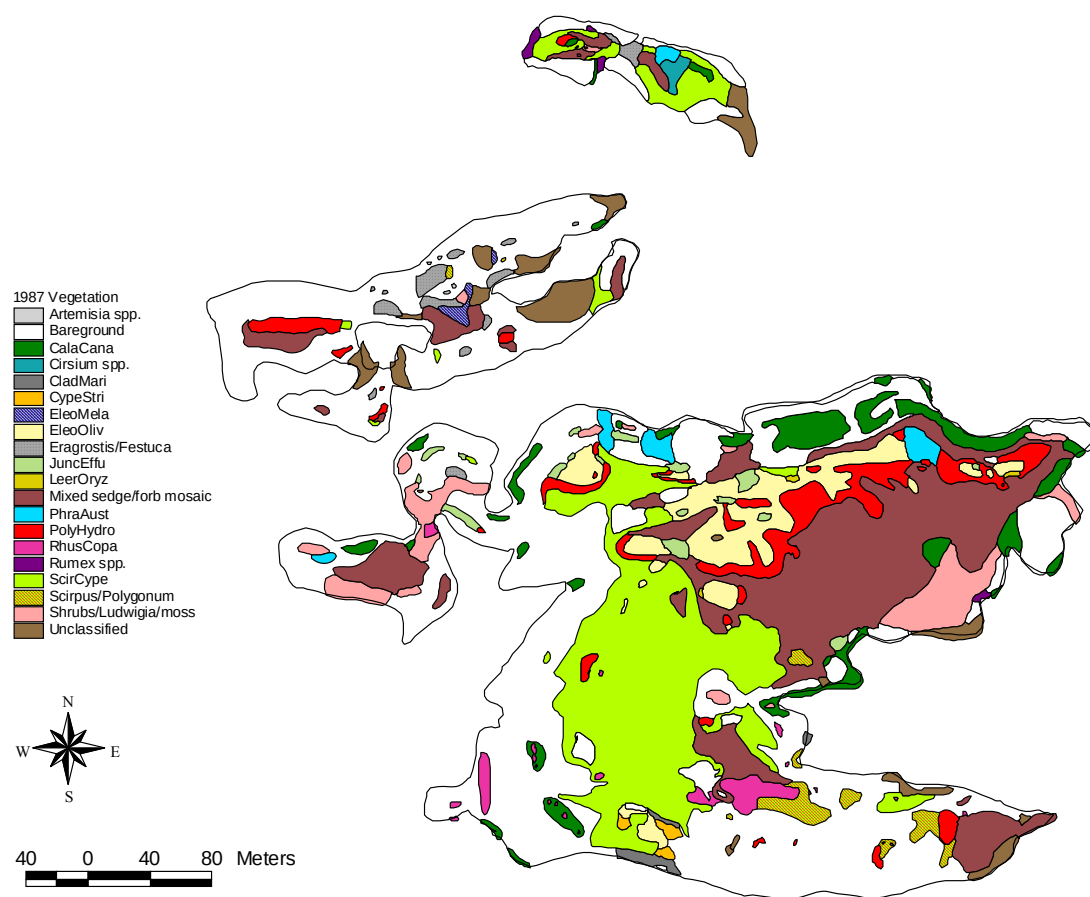


Figure 30. Vegetation map of Blag Slough, central, and north ponds in 1987

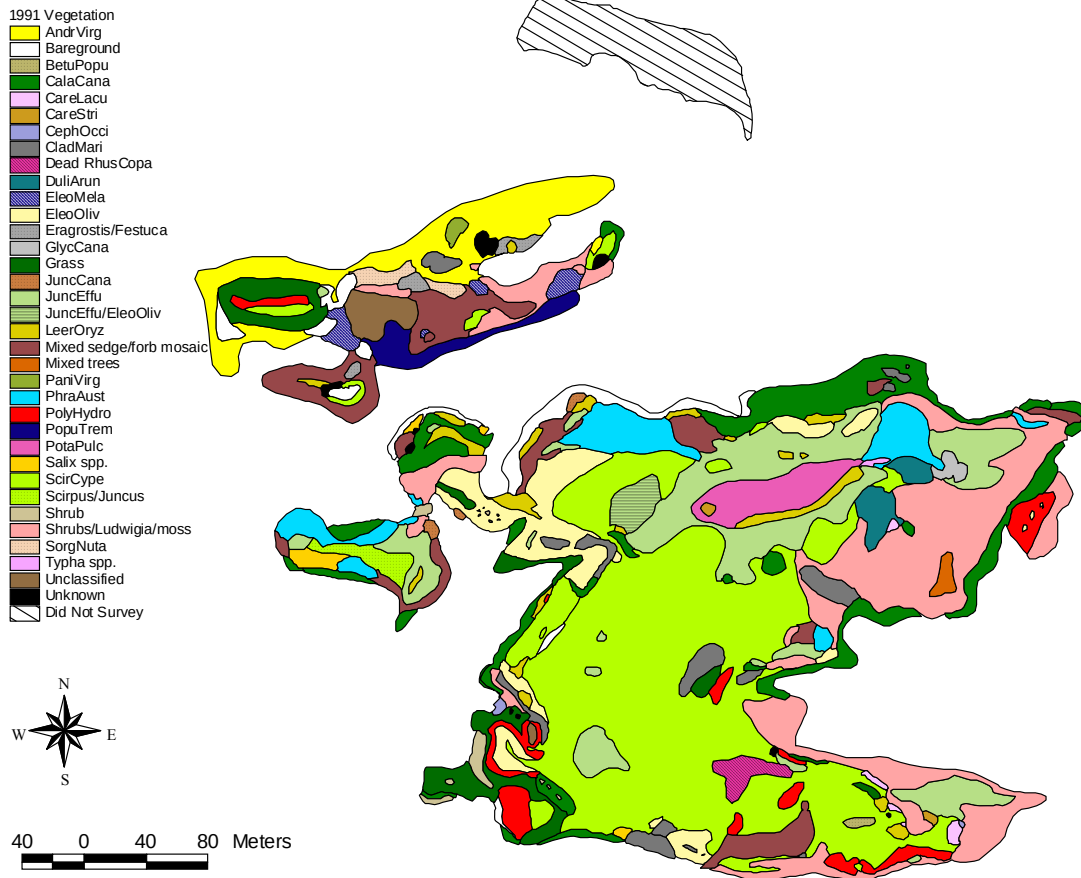


Figure 31. Vegetation map of Blag Slough, central, and north ponds in 1991

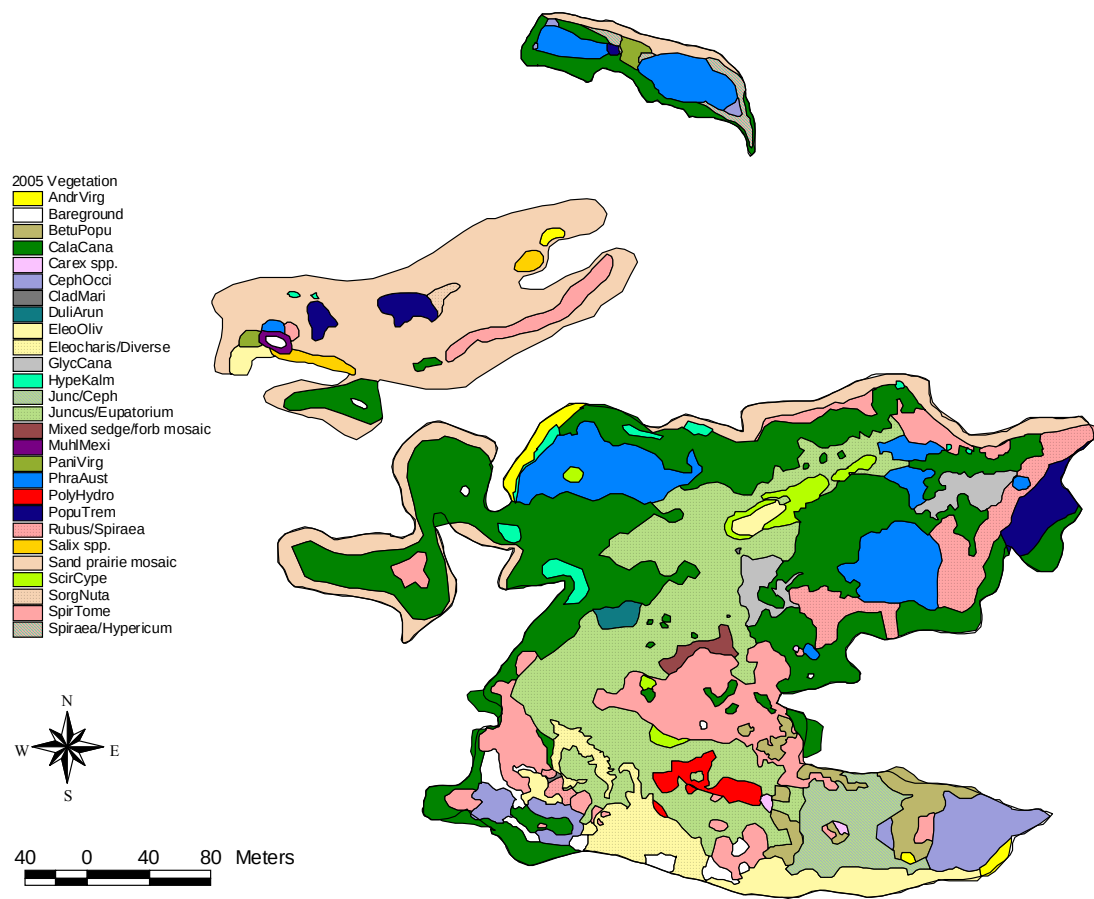


Figure 32. Vegetation map of Blag Slough, central, and north ponds in 2005

26). Common reed (*Phragmites australis*) arrived in the north pond and main pond in 1986 (Fig. 29). The north portion of Blag Slough was converted from dominance of spike rush in 1990 to concentric zones of pondweed surrounded by rush in 1991 because of the extreme rainfall event in 1990. This pattern persisted to 2005. Both rush and bluejoint grass illustrate invasion islands beyond the invasion front, respectively in 1991 (Fig. 31) and 2005 (Fig. 32) as the species migrate southward towards the fly-ash settling ponds. The early-successional spike rush and disturbance dependent woolly sedge both migrated and retreated southward over the 17 years. Buttonbush (*Cephalanthus occidentalis*) and *Spiraea* shrublands expanded in the southeast and southwest portions of Blag Slough. Unvegetated strips have persisted in Blag Slough up to 2005.

The invasion of sand prairie (*Andropogon virginicus/scoparius*) in upper elevations of the central pond (1991) has excluded wetland vegetation from the upper elevations and restricted it to depressions. The north pond shows the expansion of blue joint grass and common reed throughout.

Uptake of Soil Contaminants by Selected Plants

There was no consistent pattern to how minerals were taken up by various plants. In general, calcium content in plants was higher in the upland plots than it was in transects V or X (Table 10). However, for manganese and iron, plants in transects V or X had higher concentrations of these minerals than uplands. Iron decreased in concentration from transect V to X in *Populus tremuloides* and *Rubus* spp., but only sodium and zinc increased from V to X in *P. tremuloides*. In transect V nearest to the fly ash settling ponds, leaf iron concentration was highest in *Populus tremuloides* and manganese and iron were highest in *Rubus* and *Rhus copallinum*. *Rubus* had higher zinc concentrations in uplands compared to transect V. In *Betula populifolia* upland concentrations of aluminum, boron, iron, and sodium were higher compared to transect V. In *Rhus copallinum* copper concentration and % phosphorus, potassium and manganese were highest in transect V. Boron, iron, manganese, and zinc had high tissue concentrations overall. Accumulation ratios were high for boron and zinc, and low for aluminum for all the woody species and locations (Table 10). For example *Betula populifolia*, which was largely confined to the area of transect V nearest the fly-ash ponds, had leaf concentrations of zinc (500 ppm) two orders of magnitude greater than that in the soil (4.6 ppm) (Table 3 and Table 10)!

Impact on Contaminants of Rye and Radish: Biomass and Metals

The Blag Slough soil was collected in the plot W1a that had the highest concentration of heavy metals in 1983 (Zn 54 ppm, Mn 67 ppm, B 10.7 ppm, Al 290 ppm)(see data in Appendix E3). The pH value, ammonium-N, and nitrate-N concentration of this soil sample was 3.4, 487.93 ppm, and 238.95 ppm, respectively. In the initial experiment, germination was poor except for seeds in the potting soil: rye: in potting soil, 56%; Blag soil, 12%; and Blag soil with CaCO₃, 8%; radish: in potting soil, 42%; Blag soil, 2%; Blag soil with CaCO₃, 2%. Rye and radish showed significant differences in shoot and root sizes from growing in three different types of soil (Table 11). Overall, the plants of both rye and radish grown in potting soil were greater in shoot and root length, as well as shoot and root weight than soil that was limed and the soil from Blag Slough.

Table 11. Concentrations and accumulation ratios (AR) of minerals in leaves of four species in uplands and transects V and X. P, K, Ca, and Mg are in % by weight. Mn, Fe, B, Cu, Zn, Al, and Na are ppm. Mean $\pm$ standard error. n.a. indicates species was not present. Different letters indicate significant differences at the $\alpha = 0.05$ level within a given species using a Tukey test.

	Mineral	Upland	V	X	AR-V	AR-X
<i>Populus</i>	%P	0.10 $\pm$ 0.01 ^a	0.14 $\pm$ 0.02 ^a	0.12 $\pm$ 0.01 ^a	-	-
	%K	1.11 $\pm$ 0.10 ^a	0.81 $\pm$ 0.24 ^a	1.21 $\pm$ 0.23 ^a	-	-
	%Ca	2.89 $\pm$ 0.29 ^a	1.87 $\pm$ 0.21 ^b	1.75 $\pm$ 0.15 ^b	-	-
	%Mg	0.4 $\pm$ 0.04 ^a	0.45 $\pm$ 0.05 ^a	0.51 $\pm$ 0.05 ^a	-	-
	Mn	108.25 $\pm$ 17.47 ^a	265.88 $\pm$ 61.74 ^{ab}	301.13 $\pm$ 63.6 ^b	-	-
	Fe	67.63 $\pm$ 5.94 ^a	90.5 $\pm$ 4.34 ^b	71.38 $\pm$ 4.67 ^a	-	-
	B	100.38 $\pm$ 10.99 ^a	95.5 $\pm$ 15.10 ^a	93.25 $\pm$ 12.96 ^a	73.46	35.97
	Cu	4.88 $\pm$ 0.30 ^a	7.38 $\pm$ 1.27 ^a	8.0 $\pm$ 0.89 ^a	-	-
	Zn	507.13 $\pm$ 29.55 ^a	774 $\pm$ 67.15 ^a	1841.13 $\pm$ 193.07 ^b	110.24	106.42
	Al	90.75 $\pm$ 14.9 ^a	57.88 $\pm$ 12.59 ^a	98.13 $\pm$ 13.43 ^a	0.32	0.07
	Na	29.38 $\pm$ 3.5 ^a	21.88 $\pm$ 6.94 ^a	93.75 $\pm$ 25.78 ^b	-	-
<i>Rubus</i>	%P	0.11 $\pm$ 0.01 ^a	0.13 $\pm$ 0.02 ^a	0.09 $\pm$ 0.01 ^a	-	-
	%K	0.69 $\pm$ 0.12 ^a	0.75 $\pm$ 0.14 ^a	0.45 $\pm$ 0.02 ^a	-	-
	%Ca	1.2 $\pm$ 0.03 ^a	1.09 $\pm$ 0.10 ^a	0.93 $\pm$ 0.04 ^a	-	-
	%Mg	0.47 $\pm$ 0.02 ^a	0.4 $\pm$ 0.05 ^a	0.4 $\pm$ 0.02 ^a	-	-
	Mn	160.5 $\pm$ 19.31 ^a	401.38 $\pm$ 25.15 ^b	278.5 $\pm$ 28.5 ^b	-	-
	Fe	148.75 $\pm$ 6.52 ^a	202.75 $\pm$ 17.2 ^b	168 $\pm$ 5 ^a	-	-
	B	113.38 $\pm$ 10.51 ^a	79 $\pm$ 9.69 ^a	112 $\pm$ 1.0 ^a	60.77	43.08
	Cu	5.13 $\pm$ 0.23 ^a	5.5 $\pm$ 0.42 ^a	5.5 $\pm$ 0.5 ^a	-	-
	Zn	44.88 $\pm$ 2.2 ^a	30.75 $\pm$ 2.0 ^b	29 $\pm$ 1.0 ^b	6.68	1.68
	Al	192.63 $\pm$ 42.11 ^a	141.63 $\pm$ 14.89 ^a	160.5 $\pm$ 5.5 ^a	0.79	0.84
	Na	18 $\pm$ 0.76 ^a	22.5 $\pm$ 2.98 ^a	25.5 $\pm$ 3.5 ^a	-	-
<i>Betula</i>	%P	0.16 $\pm$ 0.01 ^a	0.17 $\pm$ 0.01 ^a	n.a.	-	-
	%K	0.56 $\pm$ 0.04 ^a	0.76 $\pm$ 0.07 ^b	n.a.	-	-
	%Ca	1.52 $\pm$ 0.06 ^a	0.73 $\pm$ 0.06 ^b	n.a.	-	-
	%Mg	0.35 $\pm$ 0.03 ^a	0.29 $\pm$ 0.06 ^a	n.a.	-	-
	Mn	368.13 $\pm$ 27.55 ^a	394.25 $\pm$ 21.71 ^a	n.a.	-	-
	Fe	265.13 $\pm$ 15.25 ^a	196 $\pm$ 30.37 ^b	n.a.	-	-
	B	89.38 $\pm$ 4.17 ^a	63.13 $\pm$ 3.72 ^b	n.a.	48.56	-
	Cu	4.63 $\pm$ 0.32 ^a	5.13 $\pm$ 0.30 ^a	n.a.	-	-
	Zn	499.75 $\pm$ 45.71 ^a	446.25 $\pm$ 82.09 ^a	n.a.	97.01	-
	Al	97.75 $\pm$ 4.82 ^a	69.13 $\pm$ 6.51 ^b	n.a.	0.38	-
	Na	24.63 $\pm$ 2.3 ^a	13.63 $\pm$ 0.89 ^b	n.a.	-	-
<i>Rhus</i>	%P	0.09 $\pm$ 0.01 ^a	0.13 $\pm$ 0.01 ^b	n.a.	-	-
	%K	0.51 $\pm$ 0.04 ^a	0.76 $\pm$ 0.05 ^b	n.a.	-	-
	%Ca	1.17 $\pm$ 0.12 ^a	1.5 $\pm$ 0.16 ^a	n.a.	-	-
	%Mg	0.18 $\pm$ 0.01 ^a	0.23 $\pm$ 0.01 ^b	n.a.	-	-
	Mn	54.75 $\pm$ 4.86 ^a	141.25 $\pm$ 13.71 ^b	n.a.	-	-
	Fe	108.25 $\pm$ 4.82 ^a	151.63 $\pm$ 13.11 ^b	n.a.	-	-
	B	62 $\pm$ 3.68 ^a	68.25 $\pm$ 6.87 ^a	n.a.	52.50	-
	Cu	2.88 $\pm$ 0.23 ^a	3.63 $\pm$ 0.26 ^b	n.a.	-	-
	Zn	26 $\pm$ 2.05 ^a	50.63 $\pm$ 7.39 ^b	n.a.	11.01	-
	Al	76.75 $\pm$ 3.86 ^a	69.75 $\pm$ 4.33 ^a	n.a.	0.39	-
	Na	18.25 $\pm$ 0.67 ^a	17 $\pm$ 1.38 ^a	n.a.	-	-

Table 12. Comparison of radish and rye plants grown in potting soil (control) limed soil from Blag Slough and untreated soil from Blag Slough. Values are the mean $\pm$ standard error. < 0.001 indicates that the standard error was lower than 0.001. Different letters within a year within a species indicate significant differences at the $\alpha = 0.05$ level using a Tukey's b test.

	Radish			Rye		
	Potting Soil	Limed Soil	Blag Slough Soil	Potting Soil	Limed Soil	Blag Slough Soil
May 1985						
Plant Height	8.667 $\pm$ 0.361a	4.898 $\pm$ 0.258b	6.265 $\pm$ 0.318c	20.684 $\pm$ 0.54a	4.91 $\pm$ 0.18b	6.704 $\pm$ 0.234c
Shoot Mass	0.015 $\pm$ 0.0010a	0.005 $\pm$ <0.001b	0.007 $\pm$ 0.001b	0.006 $\pm$ <0.001a	0.001 $\pm$ <0.001b	0.002 $\pm$ <0.001b
Root Mass	0.001 $\pm$ <0.001a	0 $\pm$ <0.001b	0.001 $\pm$ <0.001c	0.001 $\pm$ <0.001a	<0.0001 $\pm$ <0.001b	0.001 $\pm$ <0.001a
Root:Shoot	0.063 $\pm$ 0.004a	0.059 $\pm$ 0.005a	0.095 $\pm$ 0.007b	0.151 $\pm$ 0.009a	0.451 $\pm$ 0.035b	0.505 $\pm$ 0.043b
March 1987						
Shoot Length	7.76 $\pm$ 0.084a	4.799 $\pm$ 0.048b	3.696 $\pm$ 0.056c	9.419 $\pm$ 0.106a	6.079 $\pm$ 0.074b	5.928 $\pm$ 0.077b
Root Length	9.855 $\pm$ 0.181a	8.574 $\pm$ 0.194b	6.087 $\pm$ 0.149c	8.623 $\pm$ 0.233a	4.747 $\pm$ 0.1b	4.614 $\pm$ 0.161b
Shoot Mass	0.053 $\pm$ 0.002a	0.032 $\pm$ 0.001b	0.017 $\pm$ <0.001c	0.004 $\pm$ <0.001a	0.001 $\pm$ <0.001b	0.001 $\pm$ <0.001c
Root Mass	0.023 $\pm$ 0.001a	0.006 $\pm$ <0.001b	0.005 $\pm$ <0.001b	0.003 $\pm$ <0.001a	0.001 $\pm$ <0.001a	0.002 $\pm$ <0.001a
Root:Shoot	0.46 $\pm$ 0.024a	0.188 $\pm$ 0.006b	0.334 $\pm$ 0.023c	0.698 $\pm$ 0.016a	1.123 $\pm$ 0.076b	1.639 $\pm$ 0.054c
May 1987						
Shoot Length	6.618 $\pm$ 0.117a	6.296 $\pm$ 0.079b	4.484 $\pm$ 0.075c	11.022 $\pm$ 0.314a	7.971 $\pm$ 0.166b	6.867 $\pm$ 0.152c
Root Length	5.851 $\pm$ 0.218a	7.336 $\pm$ 0.263b	5.295 $\pm$ 0.196a	10.892 $\pm$ 0.509a	7.546 $\pm$ 0.45b	5.772 $\pm$ 0.385c
Shoot Mass	0.014 $\pm$ 0.001a	0.021 $\pm$ 0.001b	0.013 $\pm$ 0.001a	0.003 $\pm$ <0.001a	0.002 $\pm$ <0.001b	0.001 $\pm$ <0.001c
Root Mass	0.004 $\pm$ <0.001a	0.004 $\pm$ <0.001a	0.002 $\pm$ <0.001b	0.003 $\pm$ <0.001a	0.001 $\pm$ <0.001b	0.001 $\pm$ <0.001c
Root:Shoot	0.283 $\pm$ 0.033a	0.207 $\pm$ 0.016b	0.198 $\pm$ 0.017b	0.895 $\pm$ 0.063a	0.68 $\pm$ 0.031b	0.56 $\pm$ 0.034b

Discussion

Fly-ash, Leachate, and Metal Contaminants in Soil

Wilcox and Hardy (1988) reported high concentrations of sulfur, calcium (Ca) silica, sodium, aluminum and iron, exceeding 1,000 ppm for each, with lower levels of potassium, magnesium, boron, arsenic, zinc, fluoride, manganese, lead, strontium, molybdenum, and barium in fly-ash from the NIPSCO ponds. These are typically found in fly-ash and its leachate elsewhere (Patterson and Fenn 1978, Choi et al. 2002, Hower et al. 2006). Most studies of fly-ash pits are retrospective studies in situations where the fly-ash was alkaline (Shaw 1992 & 2009; Smyth 1977). Hardy (1981) found that groundwater downgradient of the fly-ash ponds was high in aluminum, arsenic, boron, iron, manganese, molybdenum, nickel, strontium and zinc. Water in down gradient areas of INDU were sometimes high in boron, molybdenum, cadmium and zinc (Hardy 1981).

Wilcox and Hardy (1988) also found that calcium sulfate decreased and calcium bicarbonate increased in the water with distance from the fly-ash ponds. They determined that water pH and alkalinity were depressed nearest to the dewatering ponds suggesting low water buffering capacity. In addition, Wilcox et al. (1985) noted that soil pH was between 3 and 4 in Blag Slough. They speculated that this low pH was probably because of the high sulfur content of the ash. Hardy (1984) found that low ratios of alkaline metals (primarily calcium) to sulfur were associated with low pH suggesting creation of iron sulfates that reduce pH.

In conditions of low pH, metals found in leachate become more soluble and are thus more likely to be available for uptake by plants (Brady 1974). Bohn et al. (1985) noted that anionic metals (nitrate-N, sulfate, chlorine, carbonate and the weak anions phosphate, carbonate, molybdenate, selenates, and arsenates) are more available at low pH compared to cationic metals (calcium, magnesium, sodium and potassium). Since the pH of the wetland has increased by one order of magnitude over the 23 year period, mobility of the anionic metals may become reduced. Metal concentrations in the soils varied regardless of the distance gradient from the fly-ash ponds. Concentrations of iron, arsenic, molybdenum, strontium, and ammonium-N were the highest in the southwest corner of the slough. This area had little or no vegetation. The concentrations also appeared to be elevated in the lowest portion of the transect X. This suggests that perhaps metals are migrating in solution during seasonally (late winter-spring) high water levels and become exposed at the lowest pond elevations.

Our data does not address how hydrological fluctuations of the slough (from wetland to dry land) influence the metal movement and availability; however, this is an intriguing dimension of this pollution problem. For example, Van Der Welle et al. (2007) found that plant growth (*Caltha palustris*, *Juncus effusus*, and *Rumex hydrolapathum*) in wet soils was mainly determined by nutrient availability whereas in dry soils, plant growth was determined by acidification and increased metal availability. They found that metal uptake under anaerobic conditions was predicted by acidification potential ($S/[Ca + Mg]$ ratio in sediment) (see also Samecka-Cymerman and Kempers 2001). The amount of $CaCl_2$ extractable metals in aerobic conditions best predicted metal uptake. Thus the total concentrations of metals in the soil are not good indicators of metal availability. Even so, it is difficult to say if soil concentrations of metals are high at Blag Slough. Using the Environmental Protection Agency's (EPA) ecological soil screening levels (Eco-SSL's) as guidelines, then aluminum and arsenic may be high enough to

suggest the need for additional impact studies (Environmental Protection Agency 2005). Below we review what is known about these elements.

Aluminum oxide constitutes 5 to 15% of typical soils. When present in low pH soils it can become soluble (Brady 1974). Aluminum toxicity is a leading limiter for crop production in soils with a pH less than 5 (Kochian et al. 2005). Symptoms include changes in root growth, and root morphology and at high concentrations aluminum interferes with Ca transport in plants (Delhaize and Ryan 1995, Kochian et al. 2005, Watanabe and Okada 2005). Aluminum is a likely candidate for toxicity at Blag Slough because of the low pH and the high concentrations in the soil and fly-ash leachate.

Arsenic is a poison that has been used as a pesticide and herbicide, (Blanck et al. 1989) and is present in trace quantities throughout the world (Page et al. 1982). It is prevalent in four valence forms that differ in the solubility, adsorption, and toxicity (Environmental Protection Agency 2005) and occur in inorganic and organic forms (Blanck et al. 1989). In addition, different plant species differ in rates of accumulation and response to arsenic in tissues. Arsenic is usually most available for plant uptake in soils of higher pH, high clay content, and reducing conditions (Cullen and Reimer 1989). Since high arsenic was associated with a pH of 4, it may not be bioaccumulating in the vegetation as much as if the pH were higher.

Metal Contaminants in Plants

Metal concentrations in plant tissues vary with species, plant tissue type, and hydrological regime. Demirezen and Aksoy (2004), Aksoy et al. (2005), and Peng et al. (2006) found that cattail (*Typha* spp.) and common reed (*Phragmites australis*) had higher capacity of metal uptake than *Potamogeton pectinatus* and *Ranunculus sphaerospermum*, respectively. Vandecasteele et al. (2005) noted that the uptake of cadmium and zinc in willows is greater in dry conditions compared to wetland conditions. In addition, numerous studies (Ellis et al. 1994, Samecka-Cymerman and Kempers 2001, Demirezen and Aksoy 2004, Deng et al. 2004, Weis and Weis 2004, Ding et al. 2007, Pankratz et al. 2007) have shown that concentrations of metal decrease from roots to stems to leaves. Are any of the dominant plant species associated with metal tolerance or often found in heavy metal contaminated sites?

At Blag Slough, birch (*Betula populifolia*) and aspen (*Populus tremuloides*) both showed the high concentrations of zinc in their leaf tissues consistent with recent studies showing these species tolerate and hyperaccumulate zinc (Marguí et al. 2007, Gallagher et al. 2008). Examining the accumulation ratios in Table 10 provides evidence that zinc and boron are being accumulated in all woody species measured. Most trace elements show an order of magnitude greater concentration in roots than shoots (Qian et al., 1999), except for boron, and element that moves with the transpiration stream or is metabolized or stored in aboveground tissues (Qian et al., 1999). Boron contamination is often associated with fly-ash leachates although is widely occurring from parent materials. Its significance relates to quantities in water that can affect plant growth (Bohn et al. 1985).

We were unable to find information about *Rhus copallina* uptake of heavy metals. Miles (Miles and Parker 1979) found about 60 ppm of zinc in poison ivy (*Rhus radicans*) plants grown in heavy metal contaminated soil and uncontaminated soil from Northwest Indiana. These

concentrations are comparable to leaf concentrations in transect V but higher than in upland plants.

Only three studies have been published discussing heavy metals in blackberry species (*Rubus* spp). Blag Slough blackberry leaves had comparable concentrations of copper, manganese, and zinc, higher concentrations of iron and lower concentrations of sodium compared to those in red raspberry (*R. idaeus*) growing in uranium mining tailings in Poland (Wislocka et al. 2006). They found that heavy metal concentrations were lower in *Rubus* compared to woody plants such as European white birch (*Betula pendula*) and goat willow (*Salix caprea*). Zinc concentrations in yankee blackberry (*Rubus frondosus*) in 1987 averaged 41.0 mg kg⁻¹ in fields that had received 10 years of sewage sludge (Levine et al. 1989). Shrubby blackberry (*Rubus fruticosus*) was found to accumulate heavy metals in England (Dorrington and Pyatt 1983).

Zinc is a micronutrient for plants, but in high levels can be toxic (Rout and Das 2003). Rush (*Juncus effusus*) is often associated with heavy metal contamination. In Spain, downstream from former lead, zinc and fluorite mines, zinc levels were 100 to 780 ppm in rush (*Juncus effusus*) (Sánchez et al. 1998). Collins et al (Collins et al. 2005) found that this species accumulated more Al and Fe in roots and more Mn and Zn in shoots. However, rush (*Juncus effusus*) did not show metal concentrations greater than those found in other natural wetlands. Rush (*Juncus effusus*) was found to tolerate high concentrations of zinc while jointleaf rush (*J. articulatus*) was intolerant based on plant growth and survival (Matthews et al. 2004).

Eleocharis olivacea has been an important colonizing species at Blag Slough and other studies have found different *Eleocharis* species to be important in damaged land revegetation. *Eleocharis quisetina* concentrated lead (Pb) and nickel (Ni) in plant tissues with root concentrations tending to be twice that of the shoots (Ding et al. 2007). Canada spikesedge (*Eleocharis geniculata*) was shown to hyperaccumulate copper (Cu) with dry weight concentrations from 1122 to 1493 mg kg⁻¹ (Das and Kumar Maiti 2008). Common spikerush (*E. acuta*) was an important colonizer in acid scald sites in Australia (Rosicky et al. 2006). The initial dominance by *Eleocharis olivacea* and other coastal plant species is consistent with the finding of early successional, stress tolerators, or disturbance dependent species on formerly contaminated industrial sites (Shaw 2009).

No information on the accumulation of metals in late-flowering boneset (*Eupatorium serotinum*) was found in the scientific literature. In China, while crofton weed (*E. adenophorum*) had a low enrichment coefficient of 0.45, it was suggested as a bioaccumulator of lead because its concentration in contaminated environments was 287 times greater than background environments (Yanqun et al. 2005). In Serbia, at one of the largest alkaline fly-ash sites (400 ha) in the world, hemp agrimony (*Eupatorium cannabinum*) had toxic levels of boron, above 50 ppm (Pavlović et al. 2004).

Even the restricted Pulcher's pondweed (*Potamogeton pulcher*) might be accumulating heavy metals at Blag Slough, since a related species crispy pondweed, (*Potamogeton crispus*) in Spain, downstream from former lead, zinc and fluorite mines, accumulated zinc to 1840 ppm (Sánchez et al. 1998)!

Woolly sedge (*Scirpus cyperinus*) is known to be favored in disturbed sites such as the salt impacted bog at Pinhook Bog (Wilcox et al. 1985), acid mine drainage treatment wetlands (Demchik and Garbutt 1999) and other wetland mitigations (Atkinson et al. 2005, Galbrand et al. 2008) and have wide tolerance to chemical conditions (Wilcox et al. 1985). Whether woolly sedge declined because of accumulation of heavy metals, especially aluminum (Wilcox et al. 1985) or successional replacement by rush (*Juncus effusus*) is unclear. Research shows that *J. effusus* extracts do not have an affect on the growth of *Scirpus cyperinus*, even though it does impact young *Juncus* plants (Ervin and Wetzel 2000). Thus allelopathy does not explain the replacement of woolly sedge by *Juncus effusus*.

The tolerance of common reed (*Phragmites australis*) to the accumulation of heavy metals primarily in the roots suggests that this species will continue to invade Blag Slough (Samecka-Cymerman and Kempers 2001, Weis and Weis 2004, Aksoy et al. 2005). *Phragmites* has been widely touted as a species for phytoremediation of heavy metals but studies have shown that metals are more concentrated in the roots (Bragato et al. 2006, Duman et al. 2007, Lesage et al. 2007, Vymazal et al. 2007, Ghassemzadeh et al. 2008, Sadecka 2008, Teuchies et al. 2008, Yang et al. 2008) and that concentrations vary with hydrology (Duman et al. 2007, Vymazal et al. 2007, Sadecka 2008, Teuchies et al. 2008). It appears that many of the plants in Blag Slough may be dominant because of their tolerance to heavy metals.

The cause for vein clearing in leaf tissue in Blag Slough is unclear, although leaf tissue analysis implicates aluminum, boron, or zinc. Vein clearing was evident in winged sumac (Appendix C 3-1). The local extirpations of winged sumac are either the result of the 1990 flooding, since upland species would be intolerant to this or metal toxicity. Nevertheless, interveinal clearing still persists in late boneset (*Eupatorium serotinum*), black dewberry (*Rubus occidentalis/allegahaniensis*) and other species (see photographs in Appendix C). The absence of vegetation or low vegetation cover dominated by *Eleocharis olivacea*, *Cyperus* spp., and moss occurs south of transect V and in the southwest portions of Blag Slough where heavy metal concentrations are high is suggestive of impacts.

Vegetation Dynamics

Wet meadow vegetation dynamics is driven by water level fluctuations as a result of rainfall variation and flooding (Keddy and Reznicek 1986, Wisheu and Keddy 1994, Wilcox 2004). The water levels have undergone a series of changes including anthropogenic drawdown from sealing of the fly-ash ponds and cutoff of contaminated water flow and climatic variation in the rainfall influencing water depth, and such changes have influenced the development of wetland community in the Blag Slough (Wilcox et al. 1985; Wilcox 1995). Futyma (1986) provided evidence that suggested flooding in the late 1960s and 1970s, as he found pollen grains of aquatic macrophytes, such as *Potamogeton*, *Nymphaea*, and *Brasenia*, in the sediment layers. When the fly-ash ponds were sealed, the water level dropped, allowing the initial establishment of the spikerush flats association, which includes bright green spikerush (*E. olivacea*), along with the mixed meadow association that includes woolly sedge (*S. cyperinus*) on the resulting mudflats (Wilcox et al. 1985, Wilcox et al. 1985b). Initially, bright green spikerush (*E. olivacea*) was more dominant, however, woolly sedge (*S. cyperinus*) soon became the major dominant, as a result of its taller perennial stature, copious seed production, and abundant leaf litter. This is reflected in the woolly sedge association increasing in the mid 1980s with the spike rush flats decreasing after 1984 (Table 6). The spikerush flat association declined to 0 plots in 1990,

coincident with the high water event of that year. Without mudflats available for establishment, *E. olivacea* drops out of the emergent community. Interestingly, when the water level dropped back down to more normal levels after 1990, the spikerush flat association did not recover in the entire area where it grew before, but instead was mostly replaced by blue joint grass (*Calamagrostis canadensis*). Yet it persists in the deepest part of Blag Slough along transect X where the wetland is seasonally flooded. These compositional changes are similar to the successional transition from monodominant, subdominant, to codominant species associations on copper tailings (Wang et al. 2004).

The observed successional changes in Blag Slough are comparable to the successional sequence in Little Lake, approximately 800 m east, except the early successional species at Little Lake was bald rush (*Psilocarya scirpoides*) rather than bright green spikerush (*Eleocharis olivacea*) (Wilcox 1995) and cattail (*Typha X glauca*) was absent from Blag Slough. The northern portion of the Blag Slough, and the central and northern ponds have reestablished a concentric pattern of vegetation with seasonal flooding that would be expected in natural systems.

Alpha diversity increased with time but has reached a plateau. Pyšek et al. (2003) found that species number did not increase with time on toxic landfills in the Czech Republic. At Blag Slough, species richness steadily increased from 1982, reaching a peak 1986, and sharply decreased from 1987-1991, likely a direct result of the flood event of 1990. With the 2005 survey, species richness had fully recovered, reaching a level higher than the peak of 1986. Soil nitrogen and potassium decreased significantly from 1983 to 2005. This reduction may be the result of nutrient uptake in wetland plants that have come to dominate the site. Kao et al. (2003) showed that woolly sedge (*Scirpus cyperinus*) and blue joint grass (*Calamagrostis canadensis*) had low concentrations of N and P in above ground biomass, but had high retention of nitrogen in their litter. When the former species was dominant in the mid-term, considerable litter was present on the site thus perhaps sequestering nitrogen from the soil plant system. In addition, the rise in dominance of *Juncus effusus* may have contributed to the decrease in N and P, because Kao et al. (2003) found that *Juncus effusus* had high accumulation rates of both nutrients, above- and below-ground, and had the highest retention of both in litter of the five species they studied. In addition, litter decomposition of *Scirpus cyperinus* and *Juncus effusus* is slower in acid conditions than at higher pH (Kittle et al. 1995).

Intriguing was the absence of hybrid cattail, *Typha x glauca* (Wilcox et al. 1984; Kuehn et al. 1999) from Blag Slough. With predominant wind directions being from the west, seed dispersal into Blag Slough may be limited, since to the west is the Burns Harbor-Ancelot/Mittal Steel (formerly Bethlehem Steel) industrial complex where seed sources might be absent. It is hard to believe that seed could not disperse from a half mile east of Blag Slough from the Cowles Bog Wetland Complex, but perhaps the high dune to the east of Blag Slough is enough of a barrier. It is possible substrate conditions are not favorable for *Typha* establishment, but this is difficult to believe. Dan Mason (unpublished data) found that the three most abundant seed bank species in the greatly altered Cowles Bog Wetland Complex to the east were *Typha x glauca*, *Scirpus cyperinus*, and *Juncus effusus*. The invasive grass, common reed (*Phragmites australis*) that did invade the wetland dispersed from the wetlands to the west, adjacent to the NIPSCO Bailly Generating Station access road.

Assessment of the Floristic Quality Index

Floristic quality assessment has been applied to wetlands especially among sites at a landscape scale (Bourdagh et al. 2006, Miller and Wardrop 2006, Nichols et al. 2006, Hargiss et al. 2008) and its application has generally demonstrated that FQI is negatively correlated with disturbance. We know of no studies that have examined FQI from a temporal dynamic aspect in wetland communities. While our study was limited to one wetland basin, the successional dynamics of these systems are well known (Keddy and Reznicek 1982, Wisheu and Keddy 1989, Hill and Keddy 1992, Wilcox and Whillans 1999) and the vegetation patterns seen at Blag Slough are typical of these wet meadows. Our data provided an opportunity to examine FQI in relation to wetland succession within a hydrologically dynamic dune meadow.

At the whole pond level, richness, diversity and FQI increased with time, but mean C declined over the 17 years. The 1990 flooding caused mean C to decline, because seed bank annuals with C scores of nine and 10, such as *Eleocharis olivacea* were under water. The 1991 drawdown caused mean C to increase because seed bank annuals re-emerged thus raising the mean C. High variability in mean C among successional seres (Figure 14) and shifting relative abundance of the seres (Table 6), explains why mean C will vary as succession proceeded in the slough.

Richness, diversity, mean C and FQI varied significantly among association types and along successional trajectories of plots defined by their composition in 2005. Richness showed a slight peak at intermediate seres in the successional gradient providing support for the intermediate disturbance hypothesis (Roxburgh et al. 2004, Shea et al. 2004). Cohen (2004) found that mean C declined consistently in time at the plot, association level and along the successional habitat gradient except where shrubs were prevalent. Should a late successional sere have a lower or greater mean conservatism score (or floristic quality) than an early successional patch?

It would make sense when evaluating a wetland, to enumerate the flora across all associations present in the wetland to avoid this problem of variation in floristic quality among and within seres (DeKeyser et al. 2003). Mean C has often been negatively correlated with human disturbance, but yet at Blag Slough it appears to be positively correlated with disturbance. At Blag Slough mean C was highest where heavy metal concentrations have been highest or where early successional vegetation is promoted by seasonal flooding. Sample size should be uniform within and among wetlands.

Moreover, C values are determined by personal judgment of investigator (or investigators), and thus likely to be biased and flawed (Mushet et al. 2002, Bowles and Jones 2006). There was considerable variation in expert botanist assigned C values (Cohen et al. 2004). For example seed bank annuals are often given 9 and 10 values because their appearance is often intermittent and infrequent, their aboveground appearance being timed with wetland drawdowns (van der Valk and Davis 1976, van der Valk 1978), and they seem to be restricted to wetlands with minimal human impact. Forty-four percent of species that have C values of 9 or 10 at Blag Slough were seed bank annuals. Yet their appearance is disturbance dependent, so should they rather be given low C values? Or do we give them high C values because they show fidelity to high quality wet meadows? For instance, such disturbance dependent species can become super abundant in anthropogenically created habitats (Pavlovic 1994), a point Wilhelm makes concerning the smallfruit spikerush (*Eleocharis microcarpa*) growing densely in a game pen at a site adjacent to the Indiana Dunes (Wilhelm 1990). In this context, do we give more weight to a

natural pond with seed bank annuals to one that is annually disked where it crosses a fire lane, a situation that occurs at Tefft Nature Preserve at Jasper Pulaski Fish and Wildlife Area in Jasper County, Indiana? The problem here is that disturbance dependent species are not limited to either high quality systems with natural disturbance or habitats that have anthropogenically disturbed systems.

Yet when seed bank species are absent from the above vegetation or water level vegetation, they are present as seeds often ubiquitously in the wetland soil (Keddy and Reznicek 1982, Wisheu and Keddy 1989). This is ironic because the seeds of these species are often the most prevalent in the seed bank while being cryptic from the perspective of a floristic survey. If we had sampled the viable seed bank at each plot in time, perhaps the trends in mean C would have increased in time or with successional stage. Seed bank sampling might be useful to capture drawdown dependent species that are present intermittently.

Like Rooney and Rogers (2002) we found that mean C and FQI varied with habitat type. Thus, when sampling wetland systems these indices would vary as the proportions of associations varied spatially in the wetland system. Again equal sampling among seres is one solution to this problem but may not work depending on the patch scale of different seres. If wetlands being sampled show the full compliment of vegetation types simultaneously due to heterogeneity in topography and hydrology, than FQI methods will capture many of the species present, but if the wetland is largely uniform in substrate or hydrology and largely alternates between vegetation seres, each being dominant in one year, then FQI will poorly reflect the floristic diversity of the system. Different seres that occur in patches might be sampled equally, i.e. the same number of plots to represent the whole wetlands system.

Another short coming of the FQI protocol is that sampling is based on the growing vegetation and thus only describes 'current' conditions. Seed bank potential is not included in the analysis unless the seed bank is sampled exclusively. For ecological systems where persistent seed banks play an important role in their dynamics the lack of characterizing the seed bank can represent a significant deficiency.

For these reasons, neither C nor FQI is an appropriate measure for determining the "quality" of vegetation in dynamic wet meadow systems such as these where the wetland alternates among successional seres and where seed banks are important in driving the dynamics. Managers should be cautious in interpreting mean C and floristic quality assessments for making management decisions. If floristic quality methods must be applied than they should be used at the whole wetland level to incorporate all species and communities present or over several years of sampling to capture species that may be intermittent in appearance or sample the seed bank along with the vegetation to maximize the species pool being sampled.

Further Research Needs

Phytotoxicity of Heavy Metals

Our data demonstrated highly elevated concentrations of heavy metals in the sediments of Blag Slough. Particularly, no or very little vegetation has established in the areas with highest metal concentrations. We also found vein-clearing and chlorosis in certain plants that grow in such areas. These findings are a circumstantial evidence of phytotoxicity. Coupled with the evidence

for bioaccumulation of boron and zinc in woody species, we can say that some plants may be showing the effects of heavy metals. A separate experiment is needed to investigate toxic effect of the metals on the plants. When flooded, analyses of metals in sediment, pore water, and plant tissue are required before identifying specific elemental causation (Rowe et al. 2002). When the system is terrestrial or semi-aquatic, because of climatic variation, analyses of metal in sediment, soil water and plant tissue would need to be conducted in comparing Blag Slough with a system such as Little Lake to the east which shows less impact from the fly-ash pond leachate (Wilcox 1995). A study of the bioaccumulation of these metals through the food chain (Rowe et al. 2002) of the Blag Slough ecosystem might be relevant as well. Isotopic signatures of boron have been used to identify fly-ash contaminated water (Davidson and Bassett 1993). Although evidence points to toxic effects in Blag Slough from metal contamination, further research needs to be conducted to establish causation. The soil analyses presented here are accurate but fail to indicate the relative proportions of the metal species (valence states), which is important in determining metal availability and assimilation into the vegetation.

Site Amendment and Phytoremediation

In the 25 years since the dewatering, Blag Slough has become vegetated and appears to be reestablishing natural vegetation and dynamics. Nevertheless the presence of heavy metals and vein clearing, and absence of vegetation in limited areas are of concern. The increase in pH by one order of magnitude in 23 years is significant and promising that pH will rise and further limit heavy metal solubility (except for boron). But we do not know the shape of the curve of pH response so it is questionable whether waiting for pH to rise is an option. If more focused research reveals the cause for the absence of vegetation in specific areas and identifies the contributing chemical element(s) of concern, then managers might consider the use of amendments to make the site more favorable for vegetation: (Madejon et al. 2006). A study of the feasibility of phytoremediation of heavy metals with such existing plants as common reed (*Phragmites australis*) might be useful (Ma et al. 2001, Weis and Weis 2004, LeDuc and Terry 2005, Meagher and Heaton 2005).

Vegetation Monitoring

The dynamics of wet prairies harboring coastal plain disjunct plants are known to be driven by hydrological fluctuations (Keddy and Reznicek 1982, Wisheu and Keddy 1989). The typical cycle is from grass/sedge dominance to submersed and floating aquatic plants to mud flat to annual flora to reassertion of grass/sedge dominance following the sequence of moderate water levels, flooding, drawdown, and a return to moderate water levels. Depending on the physiognomy of the wetland and its relation to ground water flow, all of these seres may coexist simultaneously. Many of the species exist as seed bank annuals that are intermittently present as plants above ground.

Monitoring of vegetation dynamics over time will be un-interpretable without water-level data, although composition may indicate what hydrologic conditions have produced what types of successional seres. If changes are unexpected, monitoring of water table is critically important for interpreting vegetation dynamics. Particularly, baseline water-level data will be important to distinguish between potential causes. The composition of Blag Slough vegetation has changed gradually, except periods after extreme flooding, for 23-year interval. The water table of Blag Slough is approximately 7 m above that of Lake Michigan and the surficial aquifer peaks in the dunes between the two (Shedlock et al. 1994), thus there is no direct hydrological connection

between them. Nevertheless, the extent that local water levels in Blag Slough are correlated with basin wide climate that controls the level of Lake Michigan, Blag Slough might be expected to generally follow the approximately annual, three decadal, and 160 year later level cycles of Lake Michigan (Thompson and Baedke 1997). Sampling every five years would give a good sense of vegetation change in this hydrological regime.

Conclusions

The vegetation of Blag Slough has redeveloped over the last 23 years since it was dewatered 24+ years ago. Growing conditions have improved as soil pH has increased; however, high levels of iron, aluminum, arsenic, and strontium remain in limited portions of the wetland where no vegetation has survived. High leaf concentrations of aluminum and elevated concentrations of boron and zinc relative to the soil suggest phytotoxicity especially with the presence of vein clearing and chlorosis in woody and herbaceous plants. The impact of such metals in higher trophic levels is also not known.

While the principal plant species overall have been wetland species, their abundance has changed with time. A major precipitation event in 1990 set the stage for a restoration of the vegetation zonation relative to water depth that is typical of these meadow systems. As a result, today an increasing herbaceous dominance of late successional wetland species occurs in the north of the main pond and is invading southward towards the former leachate source. In the north end of the main pond and in the central and north ponds, wetland zonation has developed relative to elevation and depth of inundation.

Floristic quality analysis of the Blag Slough vegetation data has revealed problems with this type of analysis. Early successional seres had higher mean coefficients of conservatism and higher floristic quality than late successional associations. This suggests that in this type of wet meadow system, disturbance dependent early and mid successional communities should be the goal rather than late successional communities. However, late successional seres would have higher floristic quality if the seed bank were sampled, as 44% of the species with C values greater than eight were seed bank species. In a wetland depression, which and how intensely seral communities are sampled, separately or collectively will determine the floristic quality of the wetland since the communities vary in mean C. Sampling equally among the major community types alleviates this heterogeneity problem.

From a manager's perspective, apart from the presence of clones of the invasive common reed (*Phragmites*), which might be removed, the north and central ponds, and north portions of Blag Slough appear to be recovering well on their own. Further investigation of soil and pore water chemistry in relation to presence of vein clearing and plant metal concentrations and bioaccumulation is warranted. This is particularly needed in the areas that are still unvegetated or dominated by bright green spikerush (*Eleocharis olivacea*) in close proximity to transect V and the fly-ash ponds. Although the pH of the soil has increased one order of magnitude over 23 years, whether further comparable or decelerating changes can be expected in the future are not known.

Recommendations

1 The vegetation of Blag Slough and Little Lake could be sampled and mapped every five years to document vegetation development and recovery in conjunction with water level measurements.

2. Further research might be conducted to identify the chemical elements and their valence states that may be contributing to impacts on plant growth (vein clearing) and to the absence of vegetation or dominance of bright green spikerush (*Eleocharis olivacea*) associations.

3. Since Blag Slough varies in surface water levels because of interannual precipitation variation, heavy metal research could focus on how alteration between dry (oxidated) and wet (reduced) environments changes soil and pore water chemistry, metal availability, and metal assimilation into plants.

4. Interpretation of mean conservatism scores (C) and floristic quality should be done with caution in these dynamic wet meadow systems. In these systems both shrubs and coastal plain disjunct annuals have been assigned high conservatism values that result in early successional and shrub dominated associations having higher mean C values than mid- and late-successional associations. As a result, there may be biases as to which successional seres should be given higher value even though they are all part of the same dynamic system. Values of the mean C and floristic quality index (I) vary among associations and temporally within some associations suggesting that FQI analysis should be done on a whole basin basis. If plot sampling is to be used, giving equal representation among associations would reduce the problem caused by the variation in proportional representation of the seres.

5. The Indiana Dunes National Lakeshore and Northern Indiana Public Service Company might consider chemical or biological methods of remediation of heavy metal contamination at Blag Slough.

6. The NPS portion of Blag Slough would be a good site to introduce other Atlantic coastal plain plants from other areas of the park to serve as a refugia for these species. Candidate species include meadow beauty (*Rhexia virginica* L.), longbeak beaksedge (*Rhynchospora scirpoides* (Torr.) A. Gray), *Brasenia schreberi*, *Chamaedaphne calyculata angustifolia*, smooth sawgrass (*Cladium mariscoides* (Muhl.) Torr.), *Cyperus engelmannii*, *Sagittaria rigida*, *Drosera intermedia*, Canada spikesedge (*Eleocharis geniculata* (L.) Roem. & Schult.), netted nutrush (*Scleria reticularis* Michx.), brownfruit rush (*Juncus pelocarpus* E. Mex.), *Sparganium americanum*, *Ludwigia sphaerocarpa deamii*, humped bladderwort (*Utricularia gibba* L.), warty panicgrass (*Panicum verrucosum* Muhl.), purple bladderwort (*Utricularia purpurea* Walter), slender yelloweyed grass (*Xyris torta* Sm.).

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Appendix A

Table A1. Mean Euclidean distances $\pm$ standard error for associations for each survey interval

Association	1983-1982	1984-1983	1985-1984	1986-1985	1987-1986	1990-1987	1991-1990	2005-1991
Bluejoint meadow	38.407 $\pm$ 8.345	28.852 $\pm$ 5.517	37.971 $\pm$ 7.177	42.733 $\pm$ 8.02	49.047 $\pm$ 8.762	86.949 $\pm$ 11.88	80.244 $\pm$ 14.354	215.809 $\pm$ 22.8
Bluejoint/steeplesbush	38.467 $\pm$ 16.29	40.971 $\pm$ 9.164	35.871 $\pm$ 10.615	36.414 $\pm$ 6.84	62.418 $\pm$ 9.256	111.447 $\pm$ 28.81	56.053 $\pm$ 10.307	148.61 $\pm$ 37.051
Mixed spike rush meadows	62.827 $\pm$ 39.011	59.868 $\pm$ 11.269	11.645 $\pm$ 1.115	44.31 $\pm$ 6.448	29.788 $\pm$ 10.718	124.125 $\pm$ 2.77	91.585 $\pm$ 43.965	119.659 $\pm$ 13.79
Spike rush/woolly sedge	0	0	0	15.546	14.445	151.879	77.569	167.056
Late flowering boneset/rush	39.524 $\pm$ 6.642	42.378 $\pm$ 6.281	27.099 $\pm$ 4.769	33.362 $\pm$ 3.651	64.905 $\pm$ 7.434	99.514 $\pm$ 8.774	78.612 $\pm$ 8.065	143.256 $\pm$ 9.503
Mannagrass/common reed	29.928 $\pm$ 7.999	24.18 $\pm$ 8.303	81.96 $\pm$ 16.076	33.903 $\pm$ 6.367	50.48 $\pm$ 9.846	80.028 $\pm$ 7.954	100.103 $\pm$ 14.5	239.199 $\pm$ 47.232
Diverse rush meadow	34.869 $\pm$ 8.17	52.177 $\pm$ 11.361	25.068 $\pm$ 5.039	24.807 $\pm$ 4.07	33.219 $\pm$ 6.944	93.586 $\pm$ 9.106	89.78 $\pm$ 11.842	121.772 $\pm$ 15.056
Raspberry/steeplesbush	41.815	58.466	9.89	13.783	50.914	70.46	35.445	60.794
Woolly sedge/rush with overstory	67.611 $\pm$ 12.055	49.559 $\pm$ 13.227	45.32 $\pm$ 7.674	40.392 $\pm$ 6.566	61.474 $\pm$ 7.135	90.008 $\pm$ 10.382	76.606 $\pm$ 11.288	114.794 $\pm$ 13.623
Woolly sedge/smartweed	65.83 $\pm$ 22.617	32.628 $\pm$ 11.247	36.009 $\pm$ 12.33	29.002 $\pm$ 12.882	41.909 $\pm$ 8.089	115.355 $\pm$ 24.955	107.458 $\pm$ 11.68	186.152 $\pm$ 25.794
Steeplesbush shrubland	23.975 $\pm$ 8.735	24.532 $\pm$ 7.026	27.01 $\pm$ 10.076	27.354 $\pm$ 6.116	50.314 $\pm$ 9.505	96.473 $\pm$ 15.123	83.504 $\pm$ 11.373	195.269 $\pm$ 22.64

Appendix B. Photographic Gallery



Photograph 1. Aerial view of the flooded Blag Slough (left) and Little Lake (right in dunes) in the background with the fly-ash ponds and dike in the front half of the photograph. A fly-ash fill area is visible in the lower right corner of the photograph. Taken on September 27, 1977.



Photograph 2. Aerial photograph of the flooded Blag Slough with fly-ash settling ponds 11 and 12 in the foreground. Taken September 27, 1977.



Photograph 3. East aerial view of the flooded Blag Slough with NIPSCO's Bailly Generating Plant in the foreground and the fly-ash ponds to the right. Photograph taken on October 10, 1977.



Photograph 4. Aerial view from south of Bethlehem Steel (foreground), fly-ash ponds (10, 11, 12, and 13), Blag Slough (mid right), and NIPSCO Bailly Generating Station (left). Photograph was taken on October 10, 1977.



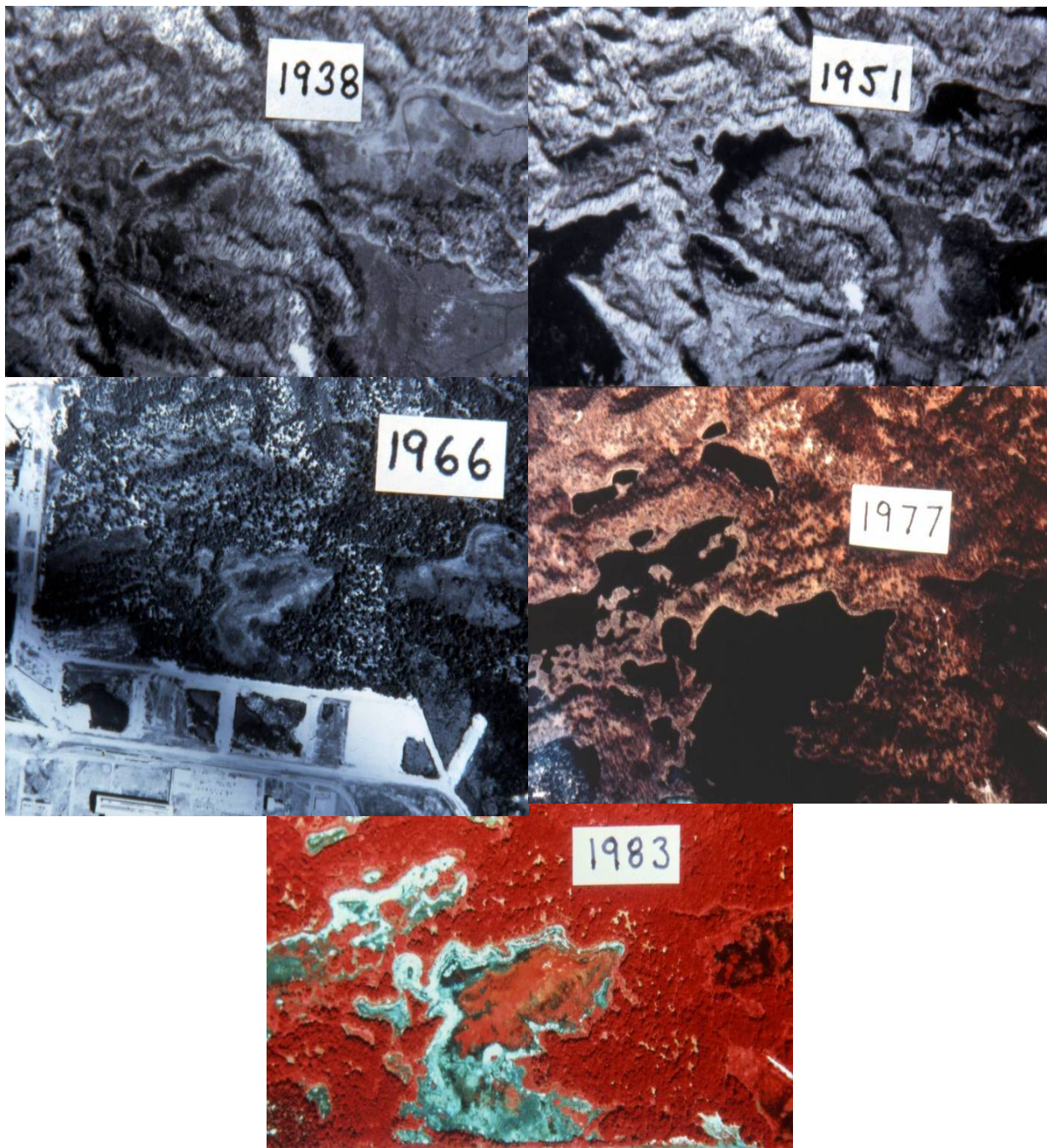
Photograph 5. Aerial view (November 3, 1977) of Blag Slough and associated wetlands including Little Lake in the upper right quadrant. Two fly-ash ponds are visible in the lower right. Note the standing dead trees in the central wetland at the left.



Photograph 6. The Bailly Generating Station behind the flooded Blag Slough (1970's).



Photograph 7. NIPSCO fly-ash settling pond in view to the southeast (DW).



Photograph 8. Historical series of aerial photographs of Blag Slough showing industrial development, post flooding vegetation development and water fluctuations in time. The 1951 photograph shows Walker or Goose Lake to the west of Blag Slough. Little Lake is visible to the northeast of Blag Slough in all of the photographs.



Photograph 9. Blag Sough in 1981 after draw down of water levels.



Photograph 10. Blag Slough in 1983 showing extensive area of bright green spike rush (*Eleocharis olivacea*) (tan) and invasion of woolly sedge (*Scirpus cyperinus*) (tall forbs). The view is looking north from near transect W towards transect X (NBP).



Photograph 11. South portion of Blag Slough as water level declines (DW).



Photograph 12. Dominance of *Eleocharis olivacea* in Blag Slough (north half) in 1983 (NBP).



Photograph 13. Umbrella sedge (*Fuirena pumila*) rediscovered in Blag Slough in 1991, 2007, and 2008, following years with major rainfall (NBP).



Photograph 14. Northwest corner of Blag Slough with flooding in 1990 (NBP).



Photograph 15. Common reed, (*Phragmites australis*) in northwest corner of Blag Slough.



Photograph 16. Flooding from extreme rainfall near intersection of transects B and X in October 1990 (NBP).



Photograph 17. North east section of Blag Slough showing dominance of blue joint grass (2005-NBP).



Photograph 18. View north across Blag Slough in October 1990 (NBP).



Photograph 19. View north from the beginning of transect B in fall 1996 (NBP). The foreground is *Eleocharis olivacea* and brown in middle ground is *Scirpus cyperinus*.



Photograph 20. Close-up of same common reed patch in Blag Slough (2005-NBP).



Photograph 21. Vein clearing in *Rubus allegheniensis* at CV intersection (2005-NBP).



Photograph 22. Three-way sedge (*Decodon verticillatus*) in Blag Slough.



Photograph 23. Plot V31 in southwest corner of Blag Slough. Site of extreme iron, aluminum, arsenic, and strontium soil concentrations (2005-NBP).



Photograph 24. East view from south end of transect B (south of transect V) showing short statured *Eleocharis olivacea* and *Cyperus* spp. (2005- NBP). Road to NIPSCO power plant and fly-ash ponds are to the right.



Photograph 25. Grass-leaved goldenrod (*Solidago* (*Euthamia*) *graminifolia*) patch in Blag Slough in 2005 (NBP).



Photograph 26. Bright green spike rush (*Eleocharis olivacea*) in Blag Slough.



Photograph 27. Black seeded spike rush (*Eleocharis melanocarpa*).

Appendix C

Herbarium Specimens Collected in 1982 Showing Vein Clearing or Chlorosis



Specimen 1. Vein clearing in fire cherry (*Prunus pennsylvanica*). Specimen #2002.



Specimen 2 (#1952). Vein clearing in white birch (*Populus alba*).



Specimen 3 (#1949). Vein clearing in gray birch (*Betula populifolia*).



Specimen 4 (#1959). Vein clearing in quaking aspen (*Populus tremuloides*).



Specimen 5 (#2001). Vein clearing in blackberry (*Rubus*).



Specimen 6 (#1945). Vein clearing in button bush (*Cephalanthus occidentalis*).



Specimen 7 (#1947). Vein clearing in black oak (*Quercus velutina*).



Specimen 8 (#1950). Vein clearing in cottonwood (*Populus deltoides*).



Specimen 9. Vein clearing in *Pyrus melanocarpa* (#1948).



Specimen 10. (#2012). Vein clearing in red maple (*Acer rubrum*) from Blag Slough.



Specimen 11 (#1946). Vein clearing in shining sumac (*Rhus copallina*). Clearing does not seem to be present, so perhaps it has faded with time.

Appendix D

Maps of Soil Chemistry Variables

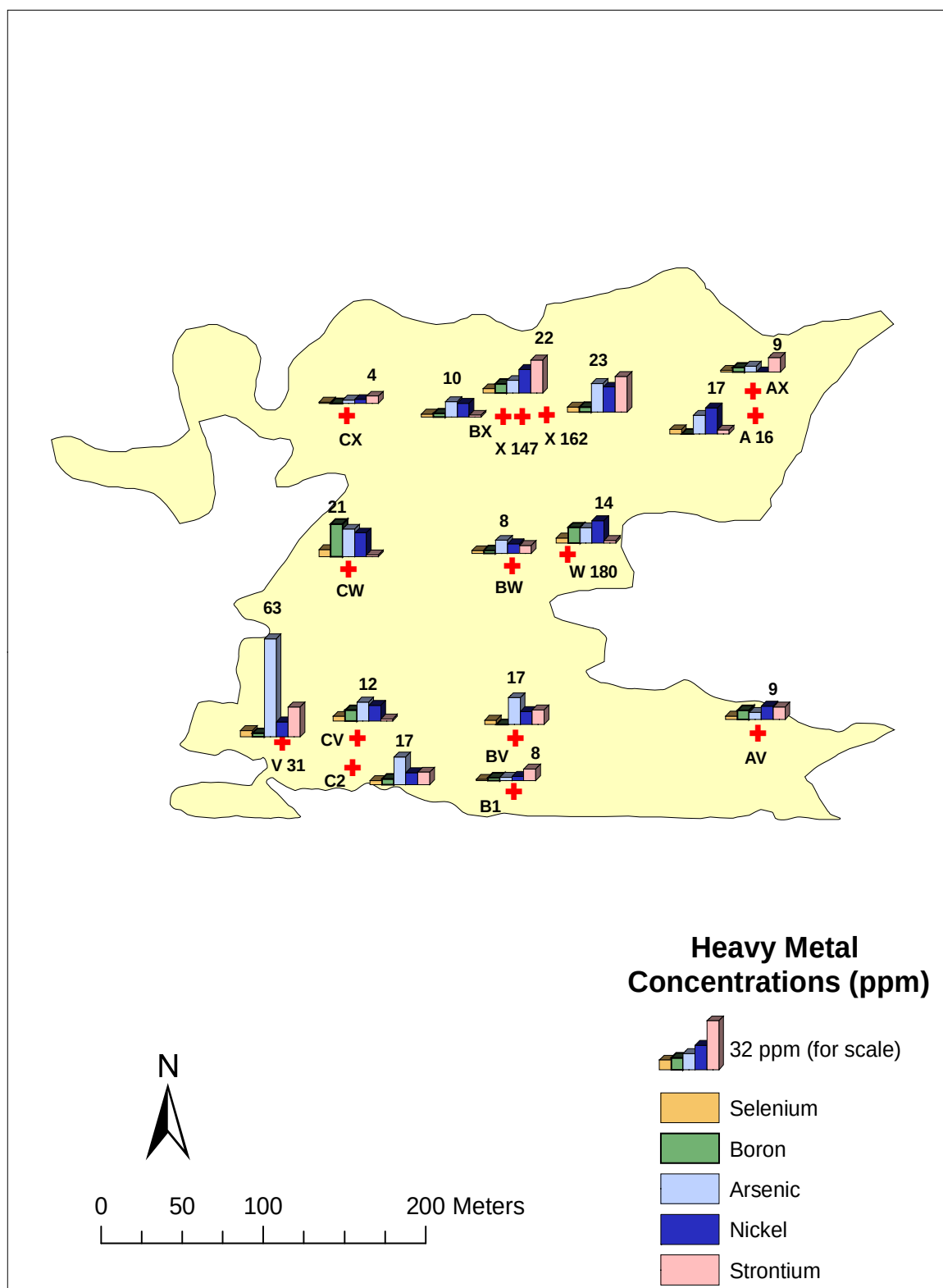


Figure D1. Heavy metal concentrations of Selenium, Boron, Arsenic, Nickel and Strontium for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

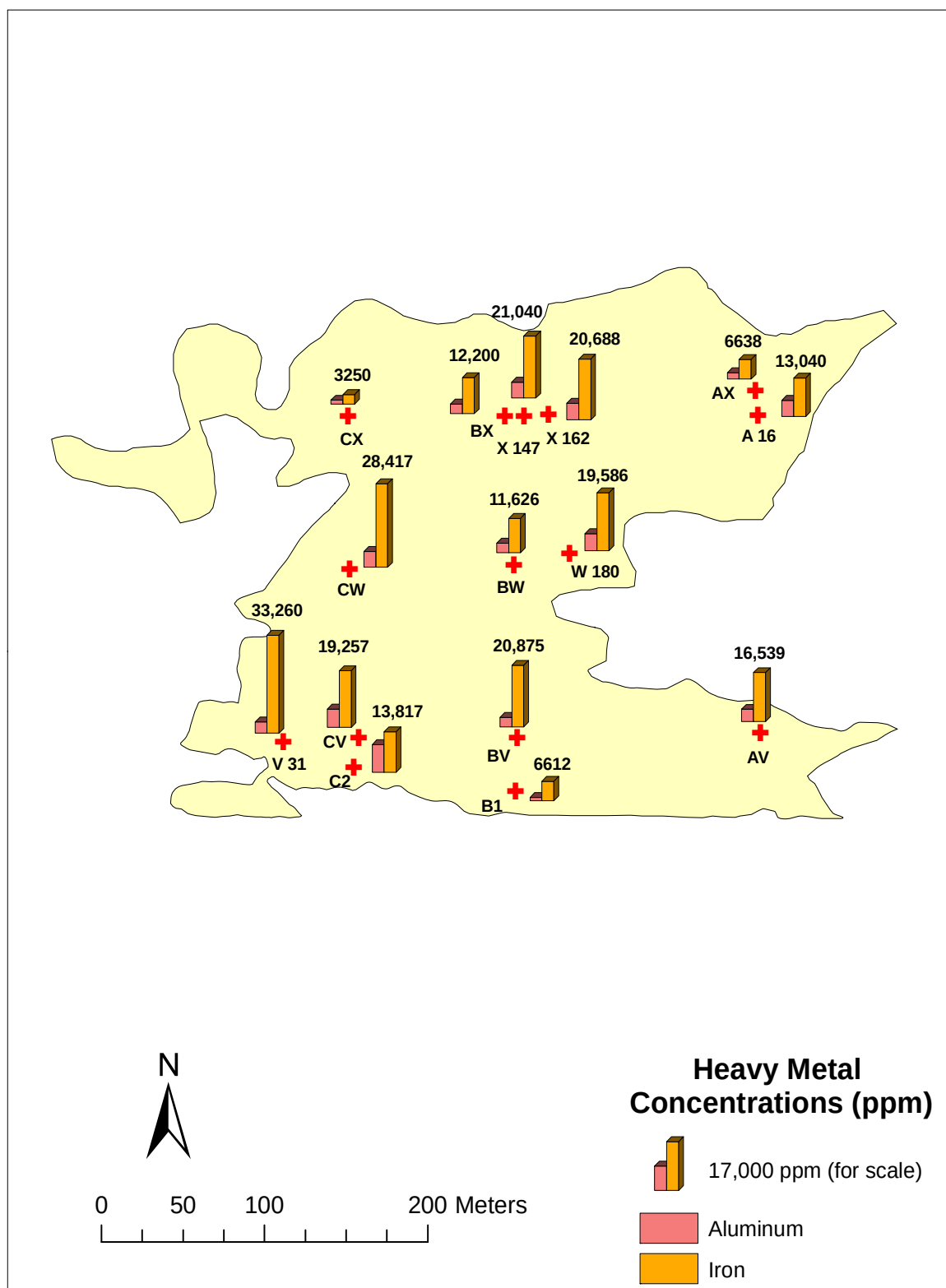


Figure D2. Heavy metal concentrations of Aluminum and Iron for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

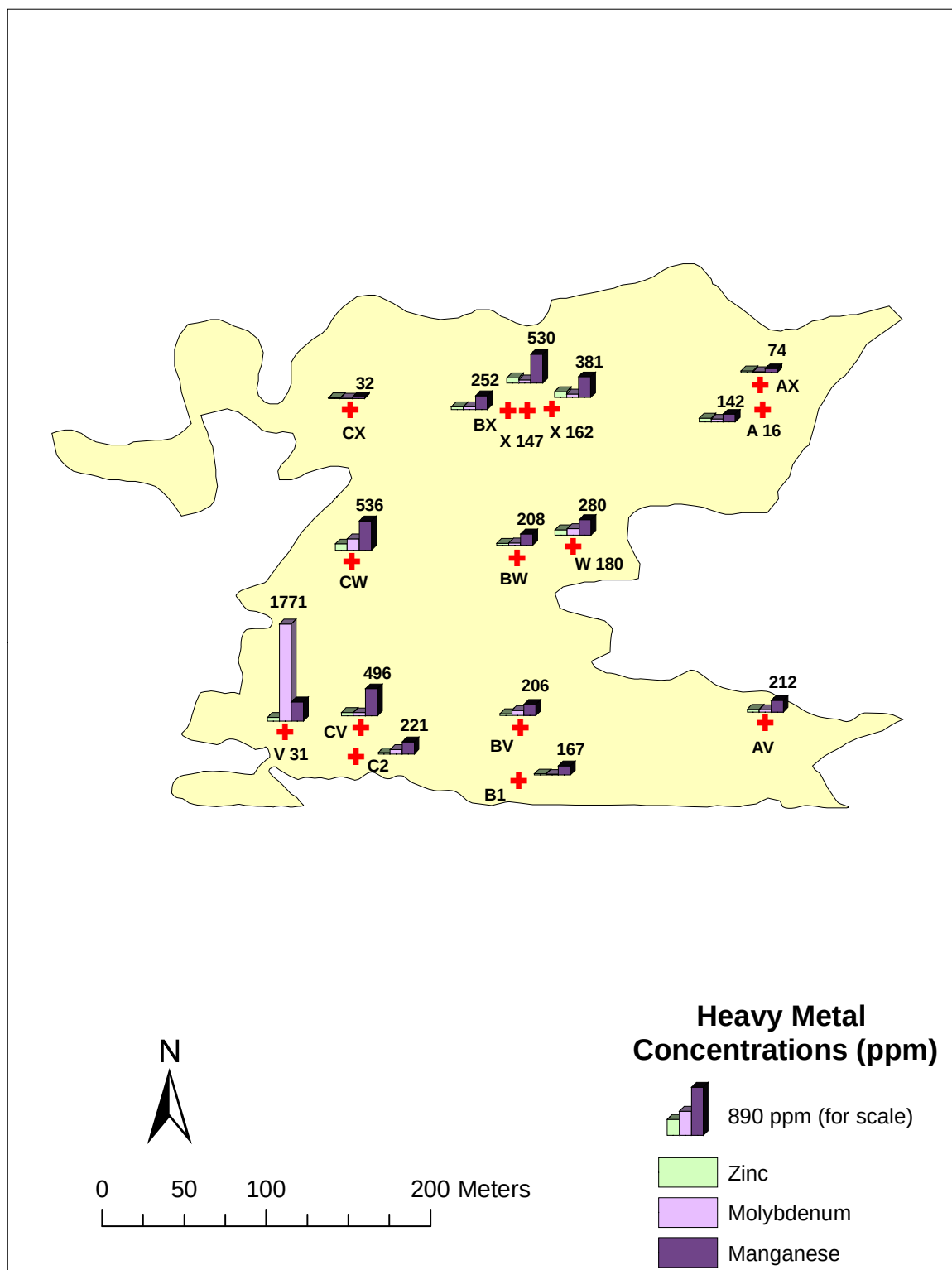


Figure D3. Heavy metal concentrations of Zinc, Molybdenum and Manganese for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

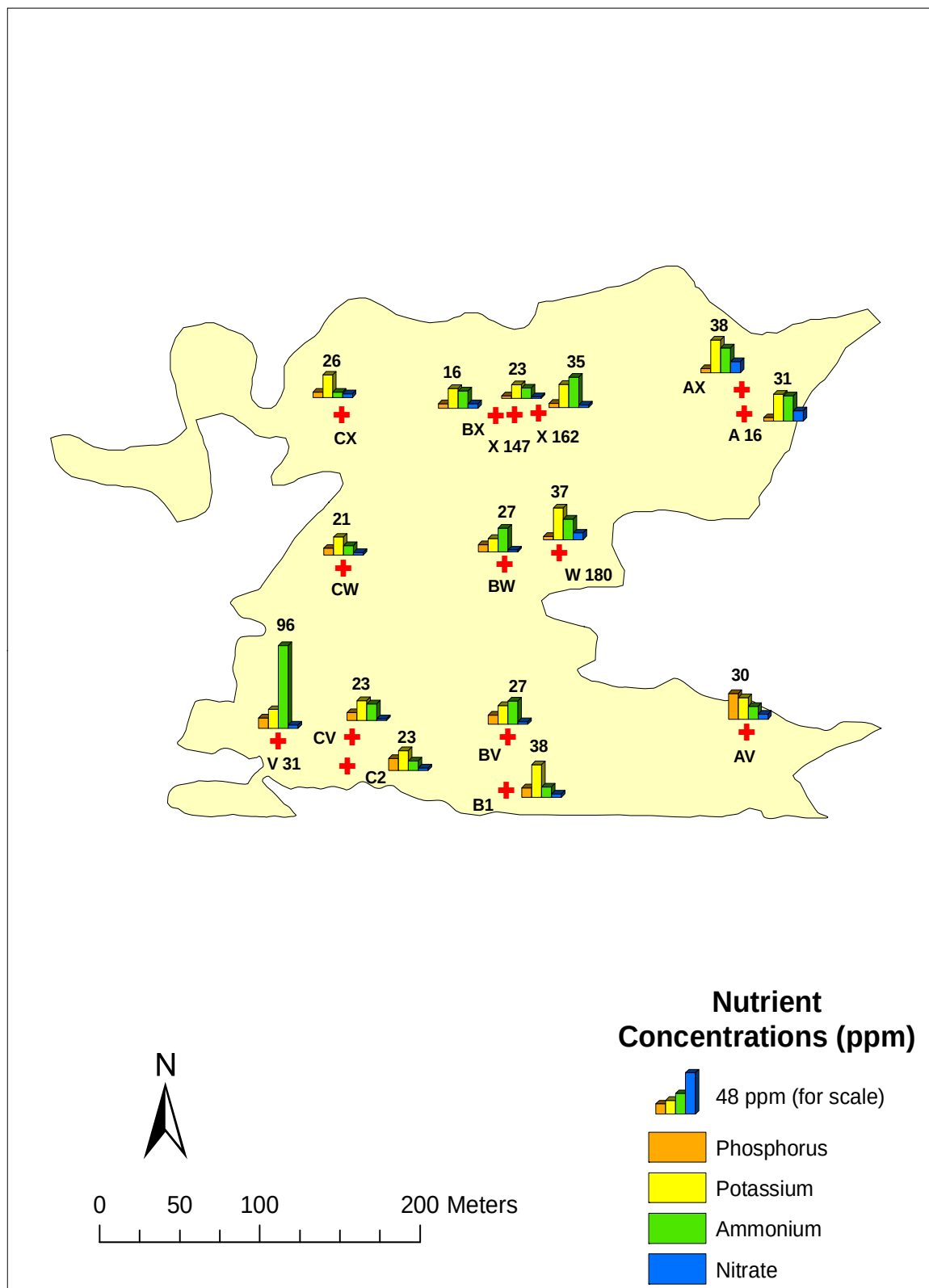


Figure D4. Nutrient concentrations of phosphorus, potassium, ammonium-N and nitrate for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

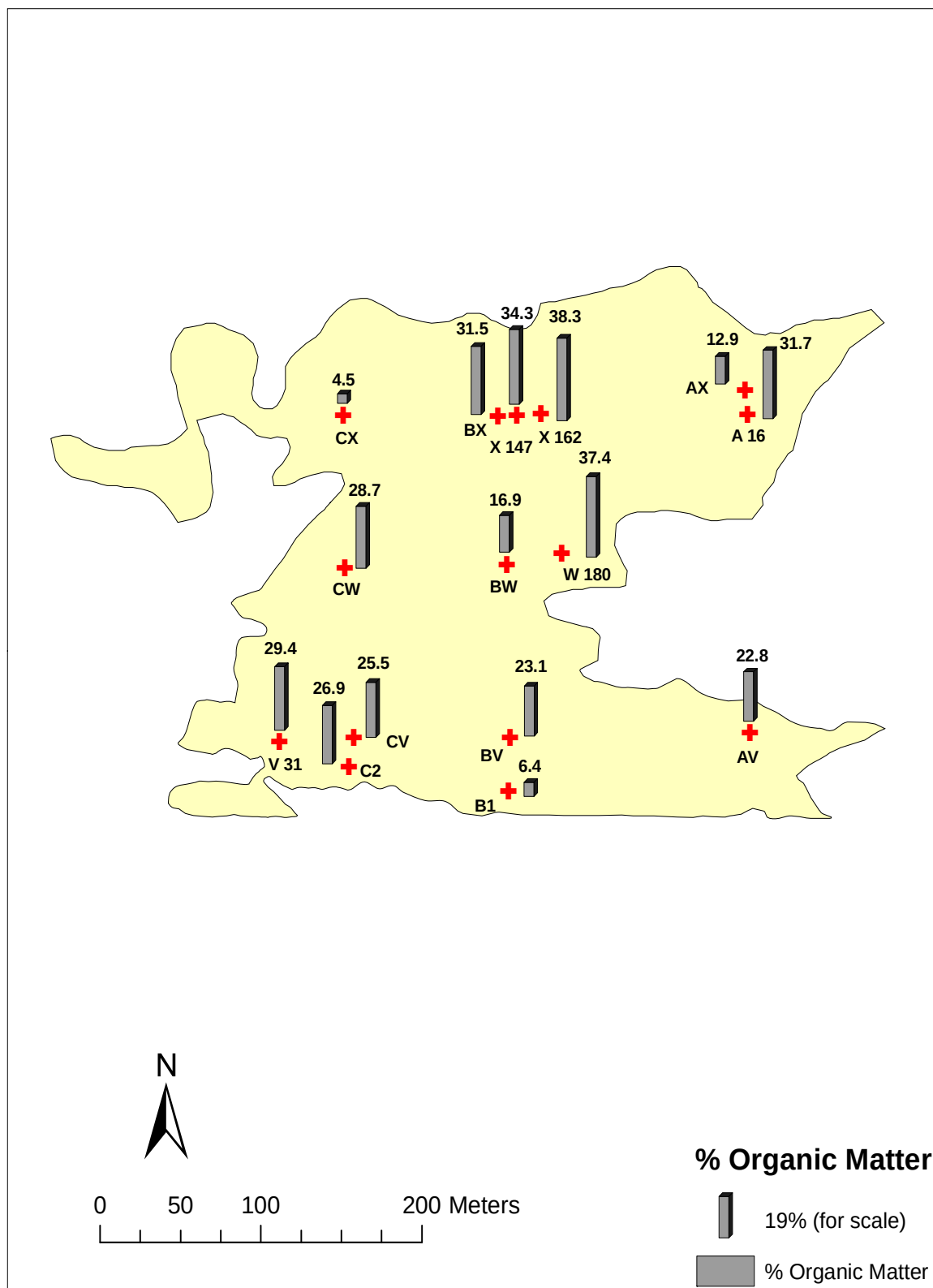


Figure D5. Percent organic matter for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

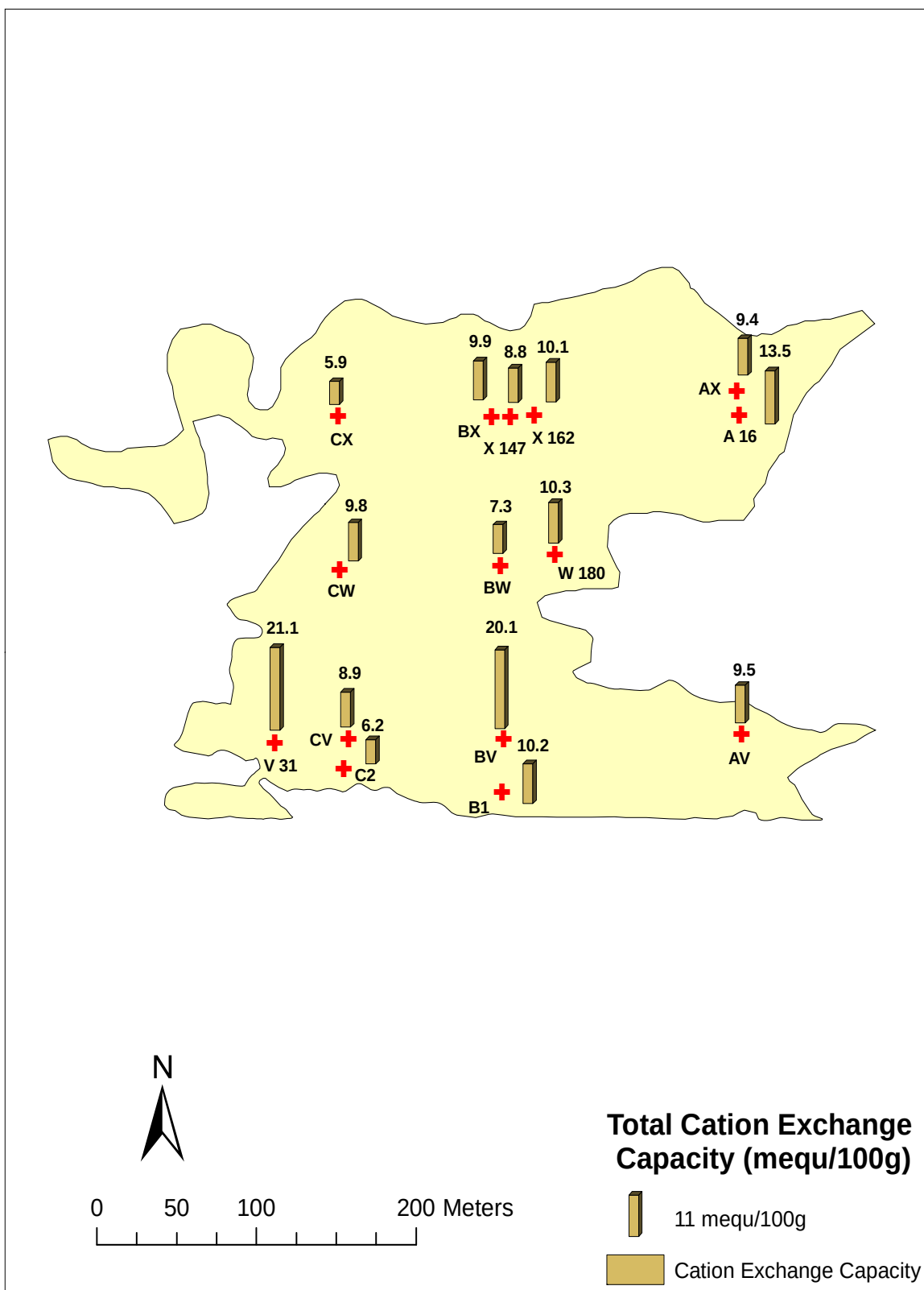


Figure D6. Total cation exchange capacity in milliequivalents per 100 g dry soil (mequ/100g) for Blag Slough in 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison.

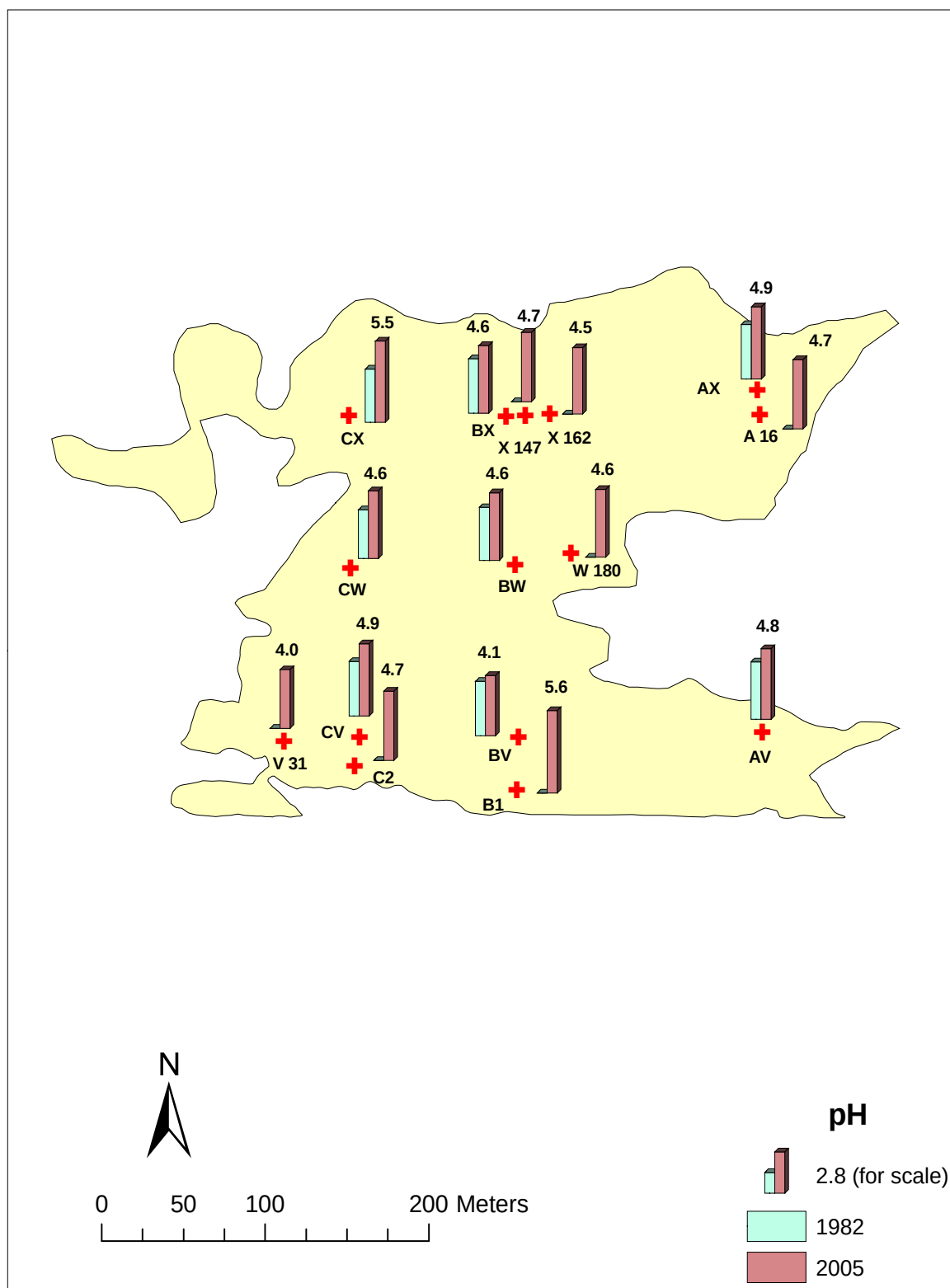


Figure D7. pH level for Blag Slough comparing 1982 to 2005. Letter/number combination represents the plot surveyed. Number over the bars represents the largest value of the elements for comparison. If the bar is absent, data were not taken in 1982.

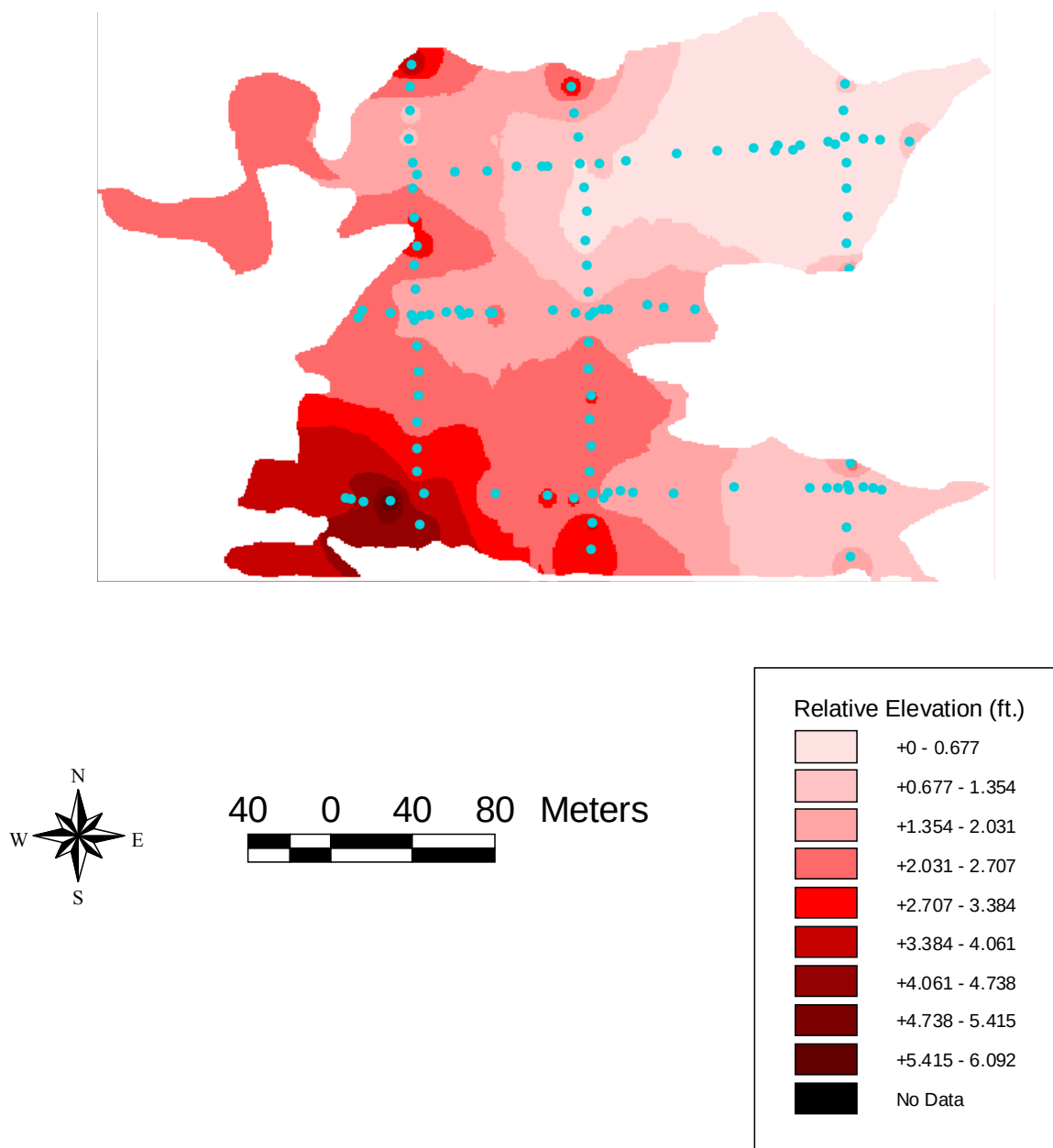


Figure D8. Relative elevations of Blag Slough. Elevations are in feet above the lowest point in the northeast corner of the Pond.

Appendix E

Data Tables

Appendix E1. Mean cover of species at Blag Slough (Main Pond) by year. The row with the scientific name contains mean cover $\pm$ standard error of the mean. Row with common name contains the frequency (number of plots) for the species.

	1982	1983	1984	1985	1986	1987	1990	1991	2005
<i>Ageratina altissima</i>	0.018 $\pm$ 0.018	-	-	-	-	-	-	-	-
White snakeroot	1	-	-	-	-	-	-	-	-
<i>Agrostis perennans</i>	-	-	-	-	-	-	0.073 $\pm$ 0.05	-	-
Upland bentgrass	-	-	-	-	-	-	3	-	-
<i>Amelanchier</i> spp.	-	-	-	-	-	-	-	-	0.009 $\pm$ 0.009
Serviceberry	-	-	-	-	-	-	-	-	1
<i>Andropogon virginicus</i>	-	-	-	-	-	-	-	-	0.036 $\pm$ 0.029
Broomsedge bluestem	-	-	-	-	-	-	-	-	2
<i>Betula populifolia</i>	-	-	0.082 $\pm$ 0.032	0.055 $\pm$ 0.025	0.127 $\pm$ 0.07	0.036 $\pm$ 0.036	2.691 $\pm$ 0.971	0.782 $\pm$ 0.396	0.727 $\pm$ 0.302
Gray birch	-	-	7	5	4	1	13	6	9
<i>Bidens cernua</i>	-	-	-	-	-	-	0.009 $\pm$ 0.009	-	-
Nodding beggartick	-	-	-	-	-	-	1	-	-
<i>Boehmeria cylindrica</i>	-	-	-	-	-	-	-	-	2.427 $\pm$ 1.077
Smallspike false nettle	-	-	-	-	-	-	-	-	17
<i>Bromus</i> spp.	0.073 $\pm$ 0.073	-	-	-	-	-	-	-	-
Brome grass	1	-	-	-	-	-	-	-	-
<i>Botrychium virginianum</i>	-	0.009 $\pm$ 0.009	-	-	-	-	-	-	-
Rattlesnake fern	-	1	-	-	-	-	-	-	-
<i>Calamagrostis canadensis</i>	0.591 $\pm$ 0.547	0.655 $\pm$ 0.354	1.245 $\pm$ 0.771	1.209 $\pm$ 0.816	1.409 $\pm$ 0.909	1.373 $\pm$ 0.835	3.409 $\pm$ 1.275	4.227 $\pm$ 1.649	18.473 $\pm$ 3.342
Bluejoint grass	2	6	6	5	4	4	11	10	35
<i>Campanula aparinoides</i>	-	-	-	-	-	-	-	-	0.009 $\pm$ 0.009
Marsh bellflower	-	-	-	-	-	-	-	-	1
<i>Carex</i> spp.	-	-	-	-	-	-	-	0.036 $\pm$ 0.036	0.127 $\pm$ 0.071
Sedge	-	-	-	-	-	-	-	1	4
<i>Carex lacustris</i>	0.136 $\pm$ 0.136	0.136 $\pm$ 0.081	0.145 $\pm$ 0.099	0.282 $\pm$ 0.203	0.073 $\pm$ 0.057	0.127 $\pm$ 0.09	0.018 $\pm$ 0.018	0.591 $\pm$ 0.591	0.027 $\pm$ 0.027
Common lake sedge	1	3	3	3	2	2	1	1	1
<i>Carex scoparia</i>	0.109 $\pm$ 0.066	-	-	0.027 $\pm$ 0.027	-	-	-	-	-
Lance-fruited oval sedge	3	-	-	1	-	-	-	-	-
<i>Carex stricta</i>	-	-	-	-	-	-	0.018 $\pm$ 0.018	0.073 $\pm$ 0.053	-
Common tussock sedge	-	-	-	-	-	-	1	2	-
<i>Carex tenera</i>	-	-	-	-	0.064 $\pm$ 0.049	0.018 $\pm$ 0.018	-	-	-
Narrow-leaved oval sedge	-	-	-	-	2	1	-	-	-
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Cephalanthus occidentalis</i>	0.182±0.182	0.273±0.273	-	0.027±0.027	0.1±0.066	1.264±0.659	1.7±1.132	2.245±1.258	7.3±2.188
Buttonbush	1	1	-	1	3	8	7	5	12
<i>Chenopodium botrys</i>	-	-	-	-	-	-	-	-	0.009±0.009
Jerusalem oak goosefoot	-	-	-	-	-	-	-	-	1
<i>Cirsium</i> spp.	-	0.036±0.036	0.091±0.056	0.309±0.273	0.282±0.123	1±0.425	-	-	0.127±0.059
Thistle	-	1	3	4	6	9	-	-	6
<i>Cladium mariscoides</i>	-	-	-	-	0.164±0.139	0.218±0.183	-	0.318±0.2	0.391±0.192
Twig rush	-	-	-	-	2	4	-	4	7
<i>Conyza canadensis</i>	-	-	-	0.118±0.072	0.336±0.123	0.345±0.162	0.082±0.043	0.073±0.05	0.427±0.158
Canada horseweed	-	-	-	4	11	7	4	3	14
<i>Cornus sericea</i>	-	-	-	0.027±0.02	0.091±0.091	0.273±0.273	-	-	-
Red-oiser dogwood	-	-	-	2	1	1	-	-	-
<i>Crataegus</i> spp.	-	0.018±0.013	-	0.009±0.009	0.055±0.028	-	-	-	-
Hawthorn	-	2	-	1	4	-	-	-	-
<i>Cyperus</i> spp.	-	-	0.018±0.013	0.018±0.013	0.073±0.053	0.182±0.143	0.509±0.258	1±0.691	0.036±0.018
Flatsedge	-	-	2	2	2	2	5	6	4
<i>Cyperus bipartitus</i>	-	-	0.018±0.013	-	0.073±0.053	-	-	-	0.009±0.009
Slender flatsedge	-	-	2	-	2	-	-	-	1
<i>Decodon verticillatus</i>	-	-	0.227±0.227	-	-	-	-	-	0.091±0.091
Swamp loosestrife	-	-	1	-	-	-	-	-	1
<i>Dichanthelium acuminatum</i>	-	-	-	-	-	-	-	0.218±0.145	-
Tapered rosette grass	-	-	-	-	-	-	-	4	-
<i>Dichanthelium sabulorum</i>	-	-	0.182±0.182	-	-	-	-	-	-
Hemlock rosette grass	-	-	1	-	-	-	-	-	-
<i>Dulichium arundinaceum</i>	0.055±0.046	0.173±0.101	0.2±0.096	0.409±0.285	0.273±0.157	0.182±0.082	0.518±0.375	2.482±1.279	0.045±0.037
Threeway sedge	2	5	6	4	6	6	5	8	2
<i>Eleocharis melanocarpa</i>	0.164±0.115	0.318±0.113	0.055±0.038	-	-	-	-	-	-
Blackfruit spikerush	3	15	3	-	-	-	-	-	-
<i>Eleocharis olivacea</i>	10.545±2.186	25.927±3.556	14.436±2.522	5.182±1.133	12.627±2.388	8.936±2.18	-	3.327±1.357	3.382±1.355
Bright green spikerush	42	54	48	39	43	27	-	16	18
<i>Erechtites hieracifolia</i>	-	-	-	0.009±0.009	-	0.4±0.283	-	0.018±0.018	0.127±0.08
American burnweed	-	-	-	1	-	5	-	1	3
<i>Erigeron annuus</i>	-	-	0.027±0.027	0.018±0.013	0.018±0.018	-	-	-	-
Annual fleabane	-	-	1	2	1	-	-	-	-
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Eupatorium maculatum</i>	-	-	-	-	-	-	-	-	0.091±0.074
Spotted joe pye weed	-	-	-	-	-	-	-	-	3
<i>Eupatorium perfoliatum</i>	-	0.109±0.077	0.155±0.08	0.282±0.087	0.736±0.219	2.518±0.655	-	0.036±0.026	-
Common boneset	-	3	5	13	16	22	-	2	-
<i>Eupatorium serotinum</i>	-	0.109±0.064	0.227±0.095	0.273±0.106	1.118±0.337	3.682±0.957	7.082±1.811	2.745±1.036	24.155±3.11
Late boneset	-	3	6	10	27	36	40	23	66
<i>Euthamia graminifolia</i>	-	0.118±0.085	0.227±0.109	0.845±0.522	0.936±0.275	1.482±0.418	0.155±0.067	0.136±0.136	0.827±0.59
Grass-leaved goldenrod	-	2	5	7	17	17	7	1	3
<i>Euthamia gymnospermoides</i>	-	-	-	-	-	0.164±0.082	-	-	-
Viscid grass-leaved goldenrod	-	-	-	-	-	4	-	-	-
<i>Fragaria virginiana</i>	-	-	0.009±0.009	0.009±0.009	0.036±0.036	0.045±0.045	-	-	-
Wild strawberry	-	-	1	1	1	1	-	-	-
<i>Galium</i> spp.	-	-	-	-	-	-	-	0.018±0.013	0.882±0.19
Bedstraw	-	-	-	-	-	-	-	2	38
<i>Glyceria canadensis</i>	-	-	-	-	-	-	0.636±0.636	1.182±0.857	4.855±1.942
Rattlesnake mannagrass	-	-	-	-	-	-	1	3	10
<i>Helianthemum canadense</i>	-	-	-	0.036±0.036	-	-	-	-	-
Common rockrose	-	-	-	1	-	-	-	-	-
<i>Hieracium</i> spp.	-	0.009±0.009	-	-	-	0.018±0.018	-	-	-
Hawkweed	-	1	-	-	-	1	-	-	-
<i>Hypericum kalmianum</i>	-	-	-	-	-	-	-	0.045±0.037	1.7±0.948
Kalm's St. Johnswort	-	-	-	-	-	-	-	2	7
<i>Hypericum majus</i>	0.036±0.029	-	-	-	-	0.018±0.018	0.009±0.009	0.009±0.009	-
Sand St. Johnswort	2	-	-	-	-	1	1	1	-
<i>Ilex verticillata</i>	-	-	-	-	-	-	-	0.027±0.027	-
Winterberry	-	-	-	-	-	-	-	1	-
<i>Juncus canadensis</i>	0.8±0.258	0.7±0.272	0.518±0.144	0.709±0.218	0.9±0.367	0.445±0.268	0.291±0.126	0.209±0.141	0.009±0.009
Canadian rush	14	13	18	16	17	5	6	5	1
<i>Juncus effusus</i>	0.745±0.4	0.736±0.38	0.509±0.181	1.436±0.478	2.445±0.699	2.845±0.842	4.955±0.843	15.273±2.36	5.691±1.106
Common rush	6	6	10	23	36	27	44	52	41
<i>Lactuca</i> spp.	-	0.018±0.018	-	-	0.018±0.018	-	-	-	0.009±0.009
Wild lettuce	-	1	-	-	1	-	-	-	1
<i>Lechea mucronata</i>	-	-	-	-	-	-	-	-	0.018±0.018
Hairy pinweed	-	-	-	-	-	-	-	-	1
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Leersia oryzoides</i>	0.073±0.073	-	0.045±0.045	0.018±0.018	0.082±0.052	0.055±0.041	0.127±0.075	2.609±1.179	0.164±0.067
Rice cut grass	1	-	1	1	3	2	4	12	7
<i>Lespedeza capitata</i>	-	-	-	-	0.027±0.027	0.045±0.045	0.027±0.027	-	-
Round-headed bush clover	-	-	-	-	1	1	1	-	-
<i>Ludwigia</i> spp.	0.636±0.262	1.155±0.535	1.527±0.837	1.618±0.721	1.5±0.601	0.391±0.157	-	0.891±0.307	-
Primrose-willow	10	10	13	12	21	12	-	17	-
<i>Lycopus</i> spp.	-	-	-	-	0.018±0.018	0.073±0.051	0.027±0.016	0.045±0.03	0.655±0.287
Water horehound	-	-	-	-	1	2	3	3	19
Moss spp.	1.764±0.959	3.155±0.913	1.282±0.757	2.318±0.932	2.527±0.974	2.782±1.186	2.491±1.354	0.909±0.909	0.018±0.018
	8	32	10	17	23	10	6	1	1
<i>Muhlenbergia mexicana</i>	-	-	-	-	0.027±0.02	0.055±0.034	0.982±0.718	0.691±0.477	1.818±0.482
Leafy satin grass	-	-	-	-	2	3	5	6	29
<i>Myriophyllum</i> spp.	-	-	-	0.018±0.018	-	-	-	0.027±0.027	-
Water milfoil	-	-	-	1	-	-	-	1	-
<i>Nuphar lutea</i>	-	-	-	-	-	-	-	0.009±0.009	-
Yellow pond lily	-	-	-	-	-	-	-	1	-
<i>Panicum</i> spp.	-	-	-	-	-	0.027±0.027	1.409±0.832	1.227±0.869	0.027±0.02
Panic grass	-	-	-	-	-	1	6	2	2
<i>Panicum capillare</i>	-	-	-	-	-	-	-	-	0.036±0.029
Witch grass	-	-	-	-	-	-	-	-	2
<i>Panicum dichotomiflorum</i>	-	-	-	-	-	-	-	0.045±0.045	-
Knee grass	-	-	-	-	-	-	-	1	-
<i>Parthenocissus quinquefolia</i>	0.027±0.027	0.091±0.091	0.045±0.045	0.009±0.009	0.009±0.009	-	-	-	-
Virginia creeper	1	1	1	1	1	-	-	-	-
<i>Phragmites australis</i>	-	-	-	-	-	-	0.727±0.554	1.445±0.835	2.045±0.963
Common reed	-	-	-	-	-	-	5	6	12
<i>Pilea pumila</i>	-	-	-	-	-	-	-	-	0.009±0.009
Clearweed	-	-	-	-	-	-	-	-	1
<i>Platanthera lacera</i>	-	0.018±0.018	-	-	-	-	-	-	-
Green fringed orchid	-	1	-	-	-	-	-	-	-
<i>Poa</i> spp.	-	-	-	-	0.045±0.03	-	-	-	2.755±1.241
Bluegrass	-	-	-	-	3	-	-	-	12
<i>Polygonum amphibium</i>	0.364±0.242	0.691±0.27	0.418±0.172	0.2±0.099	0.309±0.197	0.009±0.009	0.009±0.009	0.491±0.412	0.036±0.029
Water knotweed	4	8	7	5	6	1	1	4	2
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Polygonum hydropiper/-oides</i>	3.482±1.424	3.4±1.268	1.309±0.424	3.482±1.131	6.3±1.555	11.382±1.993	11.064±1.658	2.845±0.831	1.591±0.684
Water pepper	13	15	13	23	34	49	77	26	25
<i>Populus tremuloides</i>	-	-	-	-	0.027±0.016	0.027±0.027	0.455±0.326	0.218±0.114	0.345±0.277
Quaking aspen	-	-	-	-	3	1	2	4	4
<i>Potamogeton</i> spp.	-	-	-	-	-	-	-	0.073±0.073	-
Pondweed	-	-	-	-	-	-	-	1	-
<i>Potentilla simplex</i>	-	-	-	-	-	-	-	-	0.036±0.026
Common cinquefoil	-	-	-	-	-	-	-	-	2
<i>Proserpinaca palustris</i>	-	0.027±0.027	-	-	0.055±0.031	-	-	-	-
Mermaid weed	-	1	-	-	3	-	-	-	-
<i>Prunus serotina</i>	-	-	-	-	-	0.009±0.009	-	-	-
Black cherry	-	-	-	-	-	1	-	-	-
<i>Prunus</i> spp.	-	-	-	-	0.009±0.009	0.1±0.046	-	0.009±0.009	-
Cherry	-	-	-	-	1	5	-	1	-
<i>Quercus velutina</i>	-	-	-	-	-	0.045±0.045	-	-	-
Black oak	-	-	-	-	-	1	-	-	-
<i>Rhus copallinum</i> var. <i>latifolia</i>	-	0.091±0.091	0.891±0.819	1.045±0.823	1.545±0.91	2.145±0.987	0.009±0.009	0.091±0.091	-
Shining sumac	-	1	3	9	9	11	1	1	-
<i>Rhus typhina</i>	-	0.018±0.018	-	-	-	-	-	-	-
Staghorn sumac	-	1	-	-	-	-	-	-	-
<i>Rhynchospora macrostachya</i>	0.009±0.009	0.027±0.016	0.036±0.026	0.036±0.026	-	-	-	0.009±0.009	-
Horned beak rush	1	3	2	2	-	-	-	1	-
<i>Rhynchospora scirpoides</i>	-	-	0.009±0.009	0.036±0.036	0.082±0.05	-	-	-	-
Longbeak beak sedge	-	-	1	1	4	-	-	-	-
<i>Rubus hispidus/flagellaris</i>	-	-	0.273±0.273	0.882±0.555	1.482±0.809	2.327±0.933	0.791±0.492	0.273±0.273	6.391±1.7
Dewberry	-	-	1	5	5	10	9	1	29
<i>Rubus occidentalis/alleghehiensis</i>	-	-	0.045±0.037	0.109±0.093	0.527±0.23	1.518±0.63	3.482±1.025	2.118±0.777	0.6±0.507
Blackberry	-	-	2	2	7	10	24	10	3
<i>Rumex acetosella</i>	-	-	-	-	-	-	0.009±0.009	-	-
Field sorrel	-	-	-	-	-	-	1	-	-
<i>Salix</i> spp.	0.255±0.165	0.109±0.064	0.055±0.041	0.073±0.025	0.155±0.088	-	0.082±0.049	0.036±0.029	0.027±0.027
Willow	3	3	2	8	5	-	3	2	1
<i>Sassafras albidum</i>	-	0.027±0.027	-	0.027±0.02	0.064±0.041	0.036±0.029	-	-	0.009±0.009
Sassafras	-	1	-	2	3	2	-	-	1
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Schizachyrium scoparium</i>	-	-	-	-	-	-	-	-	0.045±0.037
Little bluestem	-	-	-	-	-	-	-	-	2
<i>Schoenoplectus smithii</i>	-	0.573±0.18	0.136±0.069	-	-	-	-	-	-
Smith's tufted bulrush	-	14	5	-	-	-	-	-	-
<i>Scirpus acutus</i>	0.564±0.288	0.191±0.087	0.127±0.068	0.027±0.027	0.009±0.009	-	-	0.5±0.372	0.291±0.273
Hard-stemmed bulrush	12	7	4	1	1	-	-	4	3
<i>Scirpus cyperinus</i>	2.845±0.829	3.982±1.127	7.764±1.526	11.764±1.874	12.927±1.79	18.945±2.669	13.836±2.192	29.118±3.368	3.082±0.943
Woolly sedge	27	35	53	68	75	65	57	67	21
<i>Scirpus purshianus</i>	-	-	-	-	-	-	-	0.018±0.018	0.091±0.044
Pursh's tufted bulrush	-	-	-	-	-	-	-	1	5
<i>Solidago</i> spp.	-	-	-	-	-	0.045±0.033	-	-	-
Goldenrod	-	-	-	-	-	2	-	-	-
<i>Solidago canadensis</i> var. <i>scabra</i>	-	-	-	0.018±0.018	0.145±0.068	0.318±0.152	0.036±0.029	-	-
Canada goldenrod	-	-	-	1	6	8	2	-	-
<i>Solidago gigantea</i>	-	-	0.045±0.045	0.018±0.018	0.036±0.036	0.091±0.091	0.091±0.091	-	-
Late goldenrod	-	-	1	1	1	1	1	-	-
<i>Solidago nemoralis</i>	-	-	-	0.009±0.009	-	0.009±0.009	0.036±0.036	-	0.018±0.018
Old-field goldenrod	-	-	-	1	-	1	1	-	1
<i>Solidago speciosa</i>	-	-	-	-	-	-	-	-	0.009±0.009
Showy goldenrod	-	-	-	-	-	-	-	-	1
<i>Spiraea alba</i>	-	-	-	-	-	-	0.155±0.137	0.018±0.018	0.027±0.016
Meadowsweet	-	-	-	-	-	-	3	1	3
<i>Spiraea tomentosa</i> var. <i>rosea</i>	0.136±0.065	0.373±0.172	0.564±0.214	0.9±0.281	1.982±0.558	4.836±1.063	4.073±1.164	3.791±1.425	8.809±1.95
Steeplebush	5	6	11	18	26	32	24	16	37
<i>Spiranthes lacera</i>	-	-	0.009±0.009	0.009±0.009	0.009±0.009	-	-	-	-
Slender ladies' tresses	-	-	1	1	1	-	-	-	-
<i>Stachys hyssopifolia</i>	-	-	-	-	-	0.136±0.136	0.182±0.182	-	0.073±0.073
Hyssop hedge nettle	-	-	-	-	-	1	1	-	1
<i>Stellaria</i> spp.	-	0.009±0.009	-	0.009±0.009	-	-	-	-	-
Chickweed	-	1	-	1	-	-	-	-	-
<i>Symphyotrichum pilosum</i> var. <i>pilosum</i>	-	-	-	-	0.027±0.02	0.018±0.018	0.027±0.02	-	-
Hairy aster	-	-	-	-	2	1	2	-	-
<i>Taraxacum officinale</i>	-	0.018±0.018	-	-	-	-	-	-	-
Common dandelion	-	1	-	-	-	-	-	-	-
Table E1. Contd.	1982	1983	1984	1985	1986	1987	1990	1991	2005

<i>Thelypteris palustris</i>	-	-	-	-	-	-	-	0.018±0.018	0.018±0.018
Marsh fern	-	-	-	-	-	-	-	1	1
<i>Triadenum virginicum</i>	-	-	-	-	0.018±0.013	-	-	-	0.082±0.053
Virginia marsh St. Johnswort	-	-	-	-	2	-	-	-	3
<i>Vaccinium</i> spp.	-	-	-	-	0.009±0.009	-	-	-	-
Blueberry	-	-	-	-	1	-	-	-	-
<i>Verbascum thapsus</i>	-	-	-	-	-	-	0.018±0.018	-	0.018±0.013
Common mullein	-	-	-	-	-	-	1	-	2
<i>Verbena hastata</i>	-	-	-	-	-	-	-	-	0.009±0.009
Blue vervain	-	-	-	-	-	-	-	-	1
<i>Vitis</i> spp.	-	-	-	0.009±0.009	0.009±0.009	-	-	0.018±0.018	0.018±0.018
Grape	-	-	-	1	1	-	-	1	1
Total Cover	20.864±3.018	39.682±3.675	31.055±2.905	31.555±2.634	43.8±3.108	61.927±3.3	58.491±2.784	76.318±2.571	83.973±2.085

Appendix E2. Soil data for 2005. “ppm” = parts per million, “mequ/100g” = milliequivalents per 100 grams of oven-dry soil, “%bs” = percent base saturation. Plots with letter combinations are the intersections of those respective transects. Plots with number and letter combinations are the specific plots.

	%Organic Matter	Bray P1 ppm	Bray P2 ppm	K ppm	Mg ppm	Ca ppm	pH	Cation Exchange Capacity mequ/100g	%bsK	%bsMg	%bsCa	%bsH	NH4 ppm	NO3 ppm
Pond 1														
AV	22.80	30	63	25	110	750	4.80	9.5	0.7	9.6	39.3	50.4	5.00	2.00
AX	12.90	5	7	38	95	750	4.90	9.4	1	8.4	39.7	50.9	5.00	3.00
BV	23.10	11	16	22	65	550	4.10	20.1	0.3	2.7	13.6	83.4	27.00	2.00
BW	16.90	8	14	15	60	400	4.60	7.3	0.5	6.8	27.3	65.4	38.00	2.00
BX	31.50	3	7	16	70	650	4.60	9.9	0.4	5.9	32.9	60.8	27.00	3.00
CV	25.50	9	11	23	95	650	4.90	8.9	0.7	8.9	36.5	53.9	19.00	2.00
CW	28.70	8	16	21	85	600	4.60	9.8	0.6	7.3	30.7	61.5	15.00	6.00
CX	4.50	6	8	26	85	550	5.50	5.9	1.1	12	46.4	40.5	11.00	8.00
A16	31.70	4	6	31	115	1050	4.70	13.5	0.6	7.1	38.9	53.4	12.00	2.00
B1	6.40	11	22	38	155	1050	5.60	10.2	1	12.6	51.3	35.2	2.00	5.00
5 m south of B1	11.50	15	27	33	95	700	4.70	10.4	0.8	7.6	33.7	57.8	6.00	4.00
C2	26.90	14	16	23	70	400	4.70	6.2	0.9	9.3	32	57.7	2.00	2.00
V31	29.40	12	40	22	60	500	4.00	21.1	0.3	2.4	11.9	85.5	3.00	3.00
10 m southwest of V 149 depth 0-5 cm	30.90	10	12	42	170	1050	5.00	12.8	0.8	11.1	41.1	47	29.00	12.00
10 m southwest of V 149 depth 5-10 cm	38.20	18	20	10	70	400	4.40	14.6	0.2	4	13.7	82.1	21.00	4.00
10 m southwest of V 149 depth 10-15 cm	43.70	27	30	10	60	350	4.30	15.5	0.2	3.2	11.3	85.3	5.00	2.00
W180	37.40	4	6	37	115	650	4.60	10.3	0.9	9.3	31.5	58.2	29.00	13.00
X147	34.70	5	8	23	85	650	4.70	8.8	0.7	8	36.9	54.4	12.00	4.00
X162	38.30	5	7	27	90	650	4.50	10.1	0.7	7.4	32.3	59.6	4.00	3.00
North of Pond 1														
10 m east of B34	6.00	13	14	24	90	700	5.40	6.7	0.9	11.2	52.1	35.8	24.00	8.00
BZ	5.70	8	13	22	120	750	5.30	8.4	0.7	11.9	44.6	42.8	13.00	6.00
CY	1.90	12	17	21	105	750	6.70	4.7	1.2	18.7	80.1		11.00	3.00
CYS	7.30	13	15	34	135	800	5.20	8.8	1	12.8	45.4	40.9	5.00	2.00
CZ	6.60	3	10	22	100	450	4.70	7.9	0.7	10.5	28.3	60.5	4.00	5.00
C35	2.60	7	13	22	155	1200	6.70	8.5	0.7	15.1	70.2	14	20.00	5.00
DY	1.20	17	19	24	105	650	6.70	4.2	1.5	20.9	77.6		11.00	3.00
2 m south of Z83	8.20	13	22	39	125	850	5.40	9	1.1	11.6	47.3	40	96.00	4.00
Outside of the area														
Control	3.50	13	23	62	80	1150	5.50	10.2	1.6	6.6	56.5	35.4	35.00	3.00

Appendix E2. Contd.	Sr ppm	Se ppm	Zn ppm	B ppm	As ppm	Ni ppm	Al ppm	Fe ppm	Mn ppm	Mo ppm
Pond 1										
AV	12.99	2.49	39.40	2.90	3.54	10.02	5594	10416	10	37.281
AX	5.559	1.88	24.41	16.39	14.50	4.11	1646	2762	60	96.899
BV	4.877	1.65	34.64	1.80	8.32	6.10	3175	11626	208	43.668
BW	8.55	1.90	39.21	2.81	9.31	5.03	2048	11923	210	261.126
BX	9.34	2.71	36.90	0.00	17.19	8.34	3226	20875	206	93.575
CV	13.02	3.00	59.43	6.98	12.15	10.08	6250	19257	496	55.798
CW	7.91	2.10	50.18	5.73	4.38	8.56	4088	16539	212	42.046
CX	7.46	0.94	30.15	0.00	3.06	2.72	1856	8266	68	14.162
A16	12.39	2.02	48.46	2.32	10.00	8.88	3280	12200	252	52.522
B1	5.47	0.76	19.81	3.05	5.63	2.88	1663	11192	131	34.718
5 m south of B1	4.65	0.78	19.23	0.00	2.10	2.52	1389	3250	32	9.254
C2	4.85	0.46	16.19	2.31	0.80	2.09	1628	2633	121	1.45
V31	10.23	0.72	92.32	2.95	1.61	10.02	1956	7759	357	7.15
10 m southwest of V 149 depth 0-5 cm	25.94	2.86	72.52	0.00	12.00	16.91	5480	13040	142	52.543
10 m southwest of V 149 depth 5-10 cm	21.91	2.86	119.40	4.47	7.86	13.70	4963	24188	480	95.991
10 m southwest of V 149 depth 10-15 cm	4.993	3.43	22.40	16.30	1.32	8.68	6306	4712	34	14.428
W180	9.42	1.17	34.86	2.85	3.84	0.00	2212	6638	74	15.093
X147	7.51	0.75	23.13	1.90	2.15	2.69	1088	6612	167	15.67
X162	7.25	7.25	21.92	1.07	1.62	3.66	1254	6255	82	6.394
North of Pond 1										
10 m east of B34	15.17	3.20	94.39	9.89	9.73	14.38	5769	19586	280	115.078
BZ	9.22	0.87	24.19	2.24	2.22	3.52	1884	4946	170	8.168
CY	8.026	2.63	25.65	3.59	17.77	7.73	9447	13817	221	79.154
CYS	4.06	0.61	31.01	0.00	1.97	2.46	1486	5281	295	8.313
CZ	5.1	1.68	15.98	2.64	2.36	2.98	1921	6898	136	15.173
C35	21.45	2.84	100.43	6.01	8.16	15.24	5403	21040	530	60.073
DY	10.32	4.52	113.54	21.01	17.79	15.39	5361	28417	536	206.651
2 m south of Z83	19.35	4.04	65.86	2.38	63.23	9.76	3889	33260	350	1771
Outside of the area										
Control	22.79	3.27	109.04	3.28	18.29	16.08	5624	20688	381	65.67

Appendix E3. Soil analysis of bioassay experiment soils. All values except for pH are in ppm.

	pH	Zn	Mn	B	Al	NH ₄ ⁺	NO ₃ ⁻
V1a	3.15	18	16	2	860	104.44	216.12
V3a	3.1	34	24	2.1	500	64.89	210.83
V4a	3.35	26	42	2.5	290	194.95	175.18
V5a	3.41	23	19	2	600	40.28	120.31
W1a	3.41	54	67	10.7	290	487.93	238.95
W2a	3.25	8.4	21	4.4	140	57.37	191.89
W3a	3.05	5.5	8	2.2	200	103.88	170.16
X1a	2.92	42	50	11.5	180	29.24	112.51
X2a	3.5	24	19	6.2	90	54.31	104.44
X3a	3.81	46	10	7.2	190	15.6	48.46
X4a	3.38	12.6	14	3.2	190	21.72	142.59
Y1a	3.4	8.2	12	2.1	130	177.13	215
Y2a	2.98	26	42	2	200	129.78	401.04
Z2a	3.9	75	29	6	220	76.64	14.2
2b1						133.96	19.5
3b1						2.79	4.46
4b1						51.52	37.6
5b1						1.11	1.11

Appendix E4. Species list for northern pond by year. The row with the scientific name contains mean cover $\pm$ standard error of the mean. Row with common name contains the frequency (number of plots) for the species.

	1982	1983	1984	1985	1986	1987	2005
<i>Acer rubrum</i>	0.1 $\pm$ 0.069	0.05 $\pm$ 0.05	-	-	-	-	0.1 $\pm$ 0.069
Red maple	2	1	-	-	-	-	2
<i>Agrostis perennans</i>	-	1.3 $\pm$ 1.248	5.158 $\pm$ 2.503	0.3 $\pm$ 0.179	6 $\pm$ 2.617	5 $\pm$ 1.405	-
Upland bentgrass	-	2	9	3	11	9	-
<i>Asclepias syriaca</i>	-	-	-	-	-	-	0.55 $\pm$ 0.32
Common milkweed	-	-	-	-	-	-	3
<i>Betula populifolia</i>	-	-	-	-	0.05 $\pm$ 0.05	-	-
Gray birch	-	-	-	-	1	-	-
<i>Bidens cernua</i>	-	0.95 $\pm$ 0.55	-	-	-	-	-
Nodding beggartick	-	4	-	-	-	-	-
<i>Calamagrostis canadensis</i>	-	-	-	-	-	-	21.65 $\pm$ 6.857
Bluejoint grass	-	-	-	-	-	-	10
<i>Carex rosea</i>	-	-	-	-	0.4 $\pm$ 0.4	-	-
Curly-styled wood sedge	-	-	-	-	1	-	-
<i>Carex scoparia</i>	0.7 $\pm$ 0.529	-	-	-	-	-	-
Lance-fruited oval sedge	2	-	-	-	-	-	-
<i>Carex stricta</i>	-	-	-	-	-	-	1.35 $\pm$ 0.595
Common tussock sedge	-	-	-	-	-	-	7
<i>Carex tenera</i>	-	-	-	-	-	0.85 $\pm$ 0.751	-
Narrow-leaved oval sedge	-	-	-	-	-	2	-
<i>Cirsium</i> spp.	0.1 $\pm$ 0.1	1.65 $\pm$ 0.582	0.105 $\pm$ 0.072	-	-	-	0.85 $\pm$ 0.455
Thistle	1	8	2	-	-	-	4
<i>Conyza canadensis</i>	-	-	-	-	0.05 $\pm$ 0.05	-	0.1 $\pm$ 0.1
Canada horseweed	-	-	-	-	1	-	1
<i>Cyperus bipartitus</i>	0.2 $\pm$ 0.2	0.15 $\pm$ 0.109	-	-	0.05 $\pm$ 0.05	-	-
Slender flatsedge	1	2	-	-	1	-	-
<i>Cyperus</i> spp.	0.2 $\pm$ 0.2	0.15 $\pm$ 0.109	-	-	0.05 $\pm$ 0.05	-	-
Flatsedge	1	2	-	-	1	-	-
<i>Dichanthelium acuminatum</i>	-	0.1 $\pm$ 0.1	-	-	-	-	-
Tapered panic grass	-	1	-	-	-	-	-
<i>Dichanthelium latifolium</i>	-	-	-	-	-	-	0.2 $\pm$ 0.2
Broad-leaved panic grass	-	-	-	-	-	-	1

Table E4. Contd.	1982	1983	1984	1985	1986	1987	2005
<i>Echinochloa crus-galli</i>	0.55±0.344	0.1±0.1	-	-	-	-	-
Barnyard grass	3	1	-	-	-	-	-
<i>Eleocharis melanocarpa</i>	-	0.1±0.1	-	-	-	-	-
Blackfruit spikerush	-	1	-	-	-	-	-
<i>Eleocharis olivacea</i>	-	0.05±0.05	-	-	-	-	-
Bright green spikerush	-	1	-	-	-	-	-
<i>Eragrostis spectabilis</i>	0.2±0.2	0.8±0.258	0.263±0.129	-	0.55±0.185	3±0.865	-
Purple love grass	1	8	4	-	8	10	-
<i>Erechtites hieracifolia</i>	-	-	-	-	-	0.85±0.638	-
American burnweed	-	-	-	-	-	2	-
<i>Eupatorium maculatum</i>	0.15±0.109	-	-	-	-	-	-
Spotted joe pye weed	2	-	-	-	-	-	-
<i>Eupatorium perfoliatum</i>	0.25±0.25	0.8±0.451	3.053±1.655	0.2±0.138	-	1.45±1.247	-
Common boneset	1	4	4	2	-	3	-
<i>Eupatorium serotinum</i>	-	-	-	-	0.1±0.1	1.35±0.509	1.35±0.437
Late boneset	-	-	-	-	1	7	9
<i>Euphorbia corollata</i>	-	-	-	-	0.05±0.05	-	-
Flowering spurge	-	-	-	-	1	-	-
<i>Euthamia graminifolia</i>	-	0.1±0.1	-	-	-	-	-
Grass-leaved goldenrod	-	1	-	-	-	-	-
<i>Festuca subverticillata</i>	-	1.85±0.621	-	-	-	-	-
Nodding fescue	-	11	-	-	-	-	-
<i>Galium</i> spp.	-	-	-	-	-	-	0.55±0.42
Bedstraw	-	-	-	-	-	-	2
<i>Hackelia virginiana</i>	-	-	-	-	-	-	0.15±0.109
Stickseed	-	-	-	-	-	-	2
<i>Hypericum kalmianum</i>	-	-	-	0.5±0.5	2.9±2.272	7.25±4.42	11.95±3.221
Kalm's St. Johnswort	-	-	-	1	4	4	14
<i>Hypericum majus</i>	-	0.15±0.109	0.263±0.185	-	-	-	-
Sand St. Johnswort	-	2	2	-	-	-	-
<i>Juncus canadensis</i>	0.1±0.1	-	0.211±0.145	-	0.05±0.05	-	-
Canadian rush	1	-	2	-	1	-	-
<i>Juncus effusus</i>	0.7±0.436	0.25±0.25	0.895±0.567	0.9±0.507	0.4±0.311	1.15±0.693	-
Common rush	3	1	3	3	2	3	-

Table E4. Contd.	1982	1983	1984	1985	1986	1987	2005
<i>Leersia oryzoides</i>	17.15±8.021	16±7.422	10.684±5.426	4.75±2.702	0.65±0.46	-	-
Rice cut grass	4	4	6	4	2	-	-
<i>Ludwigia</i> spp.	-	-	0.053±0.053	-	0.1±0.069	0.1±0.069	-
Primrose-willow	-	-	1	-	2	2	-
<i>Muhlenbergia mexicana</i>	-	-	-	-	-	-	1.65±1.292
Leafy satin grass	-	-	-	-	-	-	2
Moss spp.	-	-	-	-	0.2±0.156	0.5±0.5	-
	-	-	-	-	2	1	-
<i>Nepeta cataria</i>	-	-	-	-	-	-	0.15±0.15
Catnip	-	-	-	-	-	-	1
<i>Panicum capillare</i>	1.65±0.685	-	-	8.35±4.522	0.5±0.199	2.1±1.767	-
Witch grass	8	-	-	9	6	2	-
<i>Phragmites australis</i>	2.25±1.559	1.2±0.777	1.053±0.532	1.2±0.526	4.5±2.112	5.35±2.437	26.15±8.543
Common reed	2	4	4	5	5	5	11
<i>Polygonum amphibium</i>	0.15±0.15	0.75±0.75	0.263±0.263	0.4±0.285	-	0.75±0.547	-
Water knotweed	1	1	1	2	-	2	-
<i>Polygonum hydropiper/-oides</i>	0.1±0.1	0.8±0.414	-	0.1±0.1	2±1.316	-	-
Water pepper	1	4	-	1	4	-	-
<i>Populus tremuloides</i>	0.1±0.1	-	-	-	-	0.1±0.1	0.95±0.752
Quaking aspen	1	-	-	-	-	1	3
<i>Prunus serotina</i>	-	-	-	-	-	-	0.1±0.1
Black cherry	-	-	-	-	-	-	1
<i>Prunus</i> spp.	0.05±0.05	-	-	-	-	-	-
Cherry	1	-	-	-	-	-	-
<i>Quercus velutina</i>	-	-	-	-	-	-	0.1±0.1
Black oak	-	-	-	-	-	-	1
<i>Rubus hispidus/flagellaris</i>	-	-	-	-	-	0.2±0.138	0.3±0.206
Dewberry	-	-	-	-	-	2	2
<i>Rubus idaeus</i> var. <i>strigosus</i>	-	-	-	-	-	-	0.55±0.312
Red raspberry	-	-	-	-	-	-	3
<i>Rubus</i> spp.	-	0.3±0.219	0.526±0.428	2.6±1.563	2.85±1.795	6.75±3.25	-
Blackberry	-	2	2	4	4	4	-
<i>Rumex acetosella</i>	-	-	-	-	0.15±0.109	0.15±0.15	0.2±0.156
Field sorrel	-	-	-	-	2	1	2

Table E4. Contd.	1982	1983	1984	1985	1986	1987	2005
<i>Salix</i> spp.	0.3±0.252	0.15±0.109	0.263±0.263	0.1±0.1	-	1.75±1.75	-
Willow	2	2	1	1	-	1	-
<i>Sassafras albidum</i>	-	0.05±0.05	-	-	-	-	0.15±0.15
Sassafras	-	1	-	-	-	-	1
<i>Scirpus cyperinus</i>	4.3±1.761	3.1±1.351	8.526±3.515	8.1±3.456	8.25±2.871	6.35±1.906	-
Woolly sedge	8	9	9	9	11	10	-
<i>Solidago nemoralis</i>	-	-	-	-	-	0.3±0.252	-
Old-field goldenrod	-	-	-	-	-	2	-
<i>Sorghastrum nutans</i>	-	-	-	-	-	-	0.1±0.1
Indian grass	-	-	-	-	-	-	1
<i>Spiraea tomentosa</i> var. <i>rosea</i>	-	-	-	-	-	0.1±0.1	5.2±2.115
Steeplebush	-	-	-	-	-	1	7
<i>Symphyotrichum dumosum</i>	-	-	-	-	-	-	0.2±0.138
Rice-button aster	-	-	-	-	-	-	2
<i>Taraxacum officinale</i>	-	-	-	-	0.05±0.05	-	0.05±0.05
Common dandelion	-	-	-	-	1	-	1
<i>Triadenum virginicum</i>	-	-	-	-	0.05±0.05	-	-
Virginia marsh St. Johnswort	-	-	-	-	1	-	-
<i>Verbena hastata</i>	-	-	-	-	0.1±0.069	-	0.15±0.109
Blue vervain	-	-	-	-	2	-	2
<i>Verbascum thapsus</i>	-	-	-	-	0.15±0.109	-	0.15±0.109
Common mullein	-	-	-	-	2	-	2
Total Cover	23.85±8.744	28.8±8.047	29.158±7.164	27.6±6.73	27.4±4.934	41.55±5.031	71.25±4.275

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