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EFFECTS OF SALINITY ON THE BIOTA OF NATURAL AND CREATED WETLAND COMMUNITIES

By

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ABSTRACT

EFFECTS OF SALINITY ON THE BIOTA OF NATURAL AND CREATED WETLAND COMMUNITIES

By

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Natural saline wetlands are rare in the temperate regions of the United States. In Michigan, only two high quality saline wetlands are known to exist. One of the remaining wetlands located near the Maple River in Clinton County, Michigan was surveyed in this study. This unique habitat supported two species of native halophytic plant species, *Schoenoplectus americanus* and *Eleocharis parvula*, which are considered extremely threatened in Michigan. *E. parvula* was present at the seep only in the second year, but *S. americanus* occupied an area of 3200 m^2 and was positively correlated to conductivity, Na, Cl and depth to water table, but negatively associated with reactive phosphorus, nitrate and spring water depth.

The created saline wetland had three connected ponds with increasing salinity in each pond. The pond with the greatest diversity of invertebrates and algae had the least salinity. *Phragmites australis* was the most common emergent plant around the created wetland and birds were the most common vertebrates present.

To increase the diversity at the created wetland, four emergent salt tolerant plants, *S. americanus, S. pungens, P. australis* and *Typha angustifolia* were transplanted to the created saline wetland and a control fresh water wetland (except for *P. australis*). All species grew well at the control wetland, but only *S. americanus* increased in number of stems at the created saline wetland.

Dedicated to my husband, Charles

For all his love and encouragement

And to Peter Alexander, your short

Time on earth changed our lives!

We love you, your Mom and Dad

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CHAPTER 4

Chapter 1: Introduction

A History of Salt

Salt, specifically sodium chloride (NaCl), also known as table salt, or rock salt is an integrated part of most cultures, societies and habitats on earth. Salt and its ionic form of Na^+ and Cl^- are important physiologically, economically, environmentally and historically.

Physiology: Na^+ and Cl^- both play vital roles in the human body and are two of the major mineral elements that compose the majority of the human body (Vander et al. 1998). Sodium helps maintain water balance and is important in the normal functioning of cell and cell membrane transport, nerve function, kidney function and digestion (Vander et al. 1998). Chloride is important for cell homeostasis, cell transport and neural functioning (Vander et al. 1998).

Excess sodium in the diet, which is very prevalent in the United States (MacGregor and Wardener 1998), may partly be responsible for hypertension, which can damage the heart, kidneys and brain (Vander et al. 1998). In addition, high sodium may leach calcium from the bones to be used in the kidneys for balancing ions and may increase risk of osteoporosis and kidney stones (MacGregor and Wardener 1998). Sodium causes the bronchioles to be more reactive which may increase asthma (MacGregor and Wardener 1998).

Economics: Salt is an important natural resource used for many purposes. Michigan is one of the leading suppliers in the United States (Dorr and Eschman 1988, Heinrich 1976) and is estimated to have 6,000 cubic miles of rock salt (Heinrich 1976). Formerly over 100 brine evaporation plants, where saline ground water was evaporated to obtain salt, existed in Michigan, but only a dozen are still in operation today, the largest occurring in Midland, Michigan. In addition, Michigan has one underground salt mine in Wayne County, Michigan (Heinrich 1976).

Besides table salt, salt is used for chemical manufacturing, meat packing, deicing streets, in water softeners, animal feed (Dorr and Eschman 1988) and to improve the soil for agriculture (Winchell 1860). In addition to salt, brine waters that contain other trace minerals are evaporated to harvest some of the less abundant chemicals such as bromine, calcium chloride, iodine, magnesium compounds and potash (Dorr and Eschman 1988).

History: Throughout history, salt has played a role in establishing cities, causing wars, preserving food, and was surrounded by religion and myths. Salt was believed to empower fertility and protection. Salt packets were carried by brides and groom in Europe to prevent impotence. Babies were rubbed with salt for protection (Kurlansky 2002).

Ancient Egyptians were the first to preserve food with salt by 2000 B.C, and salt was the major way of preserving food until the 1800s when canning using heat was developed followed by the development of quick freezing in the 1900s. The ancient Chinese were reported to have the first salt works. The Roman Empire built most of their cities near salt works, and one of the first Roman road was built to transport salt. The Romans are the source of some common English words, such as salary, which originated from Roman soldiers sometimes being paid in salt. Also, Romans would put salt on their greens giving rise to the term "salad" (Kurlansky 2002).

In the Middle Ages, salt was used to preserve food, cure leather, clean chimneys, solder pipes, glaze pottery and as medicine. Trade of salt was a major industry, and salt taxes in France played a major role in the French Revolution that overthrew Louis XVI and his wife Marie Antoinette (Kurlansky 2002). In more recent times, salt was an extremely precious commodity, especially in poorer areas like the interior of Africa where salt was a luxury of the rich and at times could only be obtained from sources 90 miles away (Winchell 1860). In India, Ghandi lead a march to the sea at Dandi to harvest salt as part of a rebellion against British salt laws (Kurlansky 2002).

In the Americas, most Native American cultures had a salt god among their deities. Cortez with his Spanish army took over the salt works of the Aztec Empire to take over power. The first patent issued in America was made in the early colony of Jamestown for a special process to make salt (Kurlansky 2002).

In Michigan, Native Americans used salt seeps before white men came (Cook 1914). Soon after white men settled, attempts were made to manufacture salt on the Salt River and Macomb County and at Saline in Washtenaw County (Cook 1914). In the 1835 convention to form a state constitution, the development of the Michigan salt industry was begun (Cook 1914). When Michigan became a state in 1836, it was given the power to reserve 72 sections as state salt lands (Cook 1914). In the following year, Douglas Houghton was assigned as the first state geologist, and the major part of his first report discussed the salt springs found in the state (Houghton 1838). Houghton reported five areas of salt springs in Michigan, and, soon after, the state attempted to develop salt works. However, the state salt works were a failure, and the state salt lands were sold. The first private salt well was established in 1840 in Grand Rapids, but no others were attempted until 20 years later (Cook 1914). The salt industry in Michigan peaked in

1905, with the state producing the most and best quality salt in the United States (Cook 1914).

Unlike the brine salts manufactured today, sodium chloride was the main product. In the early days of the salt industry, the other constituents such as bromine, calcium chloride, magnesium chloride, etc., were waste product called bittern and usually thrown away (Winchell 1860). Later, bromine and calcium chloride were also manufactured from the bittern (Cook 1914). Salt was so valuable that some early manufacturers before 1860 would use 220 or more gallons of water to produce one bushel of salt, meaning the brine was about 2.9% salt (Winchell 1860). Later, manufacturers had wells that produced brine with 17% to 25% salt, which only required 33 to 22 gallons of water, respectively to produce one bushel of salt (Cook 1914, calculations from Winchell 1860).

Environment: Natural saline aquatic areas occur in oceans, coastal wetlands, inland lakes and wetlands in arid regions, and saline wetlands in some temperate regions (Waisel 1972), however, many of these areas are being degraded or destroyed by humans (Ungar 1991, Hinrichsen 1998). Worldwide, coastal saline wetlands may have already been reduced by 50%. In the United States, 50% of coastal wetlands were lost between 1970 and 1990 (Hirichsen 1998). Inland wetlands of all types have not fared much better, many of them being destroyed for agriculture and development (Mitsch and Gosselink 2000). In temperate regions, rare saline wetlands (Waisel 1972) have become rarer and are extremely threatened globally (MNFI).

Although many natural saline areas are being degraded, many formerly non-saline areas are becoming impacted by salts due to agricultural irrigation in arid regions, road salt run-off, urbanization, sewage output and waste products from chemical manufacturing (Waisel 1972, Ungar 1974).

In arid regions, salts are left in the soil after irrigation. In some locations, they exist as natural deposits in fossil beds. Eventually, when enough salts build up, the land can not produce crops. In the United States about 8 million acres are affected by salt (Carter 1975). Due to the leaching of salt from soils, streams that drain irrigated fields usually increase in salinity as they move down stream and some streams have salt marshes adjacent to them due to the salt run-off (Carter 1975).

Salt run-off from icy roads has been studied by several authors for impacts on various environmental aspects (Hutchinson 1970, Hughes et al. 1975, Wilcox 1986, Demers and Sage 1989, Richburg et al. 2001, Pitelka and Kellogg 1979) and the invasion of salt tolerant plants beyond their normal range (Rezinek 1980, Scott and Davison 1985). Sodium chloride, the main road salt used, can be especially problematic in clay soils. Na+ ions bond with clay soils making it impermeable and reducing drainage (Hutchinson 1970, Semoradova 1984). Also sodium salts seem to replace other soil nutrients such as potassium, calcium, magnesium and phosphorus (Semoradova 1984).

Road salts have significantly increased the salt concentration of streams in the Adirondack Mountains of New York that pass under or adjacent to salted highways, and salinity levels remain high for six months after road salting ceases (Demers and Sage 1990). Thus, these streams could have permanently raised salt levels if salting continues year after year. Also, road salts have contaminated drinking wells near roads so that they have exceeded recommended limits for salt (Hutchinson 1970).

Deicing salt modified the plant community in a *Sphagnum* bog in Indiana by allowing non-bog species to invade and reducing or destroying the salt intolerant species (Wilcox 1986). In a calcareous fen community, species richness, evenness and plant cover were reduced in areas of high road salt run-off (Richburg et al. 2001). In the New England area, roadside maple trees have been killed by the salts (Hutchinson 1970), and, in some areas, road salts have killed the vegetation resulting in soil erosion (Hughes et al. 1975).

On British roadways, coastal salt tolerant plants are usually found where the glycophytic plants (plants that do not tolerate salt) have been damaged allowing halophytes to invade (Scott and Davison 1985). Coastal species have also been found on roadsides in many European countries and the United States (Scott and Davison 1985) In Michigan, a halophyte assemblage found in a saline roadside median contained 12 non-native species, 6 of these new to the state, and 12 salt tolerant species often found in weedy non-saline areas (Reznicek 1980).

The effects of industry were seen in the early 1900s where brine wells were creating a salty enough environment for several halophytic plants to occur (Brown 1917). Brine salt spills often occur with oil well drilling (Baveye et al. 1985). Industrial processes to harvest trace minerals from brines and remediation of underground brine storage wells, such as at the Dow plant in Midland, Michigan have produced ponds containing highly saline water with low biotic diversity.

Purpose of the Study

The main question addressed in my study was an assessment of how salt affects wetland communities. This assessment includes wetland communities in both a natural salt wetland and a created salt pond in Michigan.

Natural saline wetlands are extremely rare in Michigan as well as globally (MNFI). I surveyed the plant community in relation to water chemistry characteristics of one of the few remaining natural salt seep wetlands in the state of Michigan (Chapter 2).

Secondly, I surveyed the biota and water chemistry of a created salt pond (Chapter 3). At the Dow Chemical Company in Midland, MI, spent brine resulting from chemical processes had been released over several decades into a created storage pond complex. This brine pond complex consisted of four interconnected ponds with three of them being chemically distinct; salinity was lowest in the north-south (N-S) pond, intermediate in the east-west (E-W) pond, and highest in the hydrologically interconnected main and outlet ponds. These differences in salinity have resulted in unique plant and animal communities living in each section of the pond complex. This pond provided a unique gradient of increasing salinity, which allowed me to compare effects of increasing salinity on the biota.

Thirdly, to increase the biotic diversity of the created salt pond, I studied survival and growth (Chapter 4) of four species of salt tolerant plants transplanted to the brine pond in Midland. Since this transplanting experiment occurred late in the growing season, three of these four species were transplanted to a freshwater storm water retention pond on the campus of Michigan State University to determine if plants transplanted so late in the season would survive and grow. Since one species, *Phragmites australis*, is extremely invasive (Hammer 1992) and already occurred on site around the edge of the Dow pond in Midland, it was not transplanted to the storm water retention pond.

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Chapter 2: Survey of a Natural Salt Seep Wetland in Relation to Water Chemistry

Introduction

In the United States, saline aquatic habitats are common along ocean shores and inlets and in wetlands in arid regions of the western United States. In the more humid, inland areas of the Midwestern United States, saline aquatic habitats are rare and usually only occur over fossil salt beds or by salt springs (Waisel 1972). According to the Michigan Natural Features Inventory (MNFI), inland salt seeps are extremely threatened habitats on a global basis.

Saline seeps and wetlands in the Midwest are a result of prehistoric seas that once covered the area. Seas during the Paleozoic era formed in the Michigan Basin, which was a large depressional area covering most of the current state of Michigan (Dorr and Eschman 1970). These seas were relatively isolated and became highly saturated with salts that precipitated to the sea floor. During the Pleistocene Ice Age, a thick layer of glacial sediments covered and isolated the salty sea sediments. Salt seeps form when these glacial sediments are eroded away so that ground water seeping up to the surface passes the saline sediments and carries some of the dissolved ions to the land surface (Dorr and Eschman 1970).

In 1838, Douglas Hougthton, Michigan's first state geologist reported over 20 natural salt seeps or springs in nine counties in the central lower peninsula of Michigan (Houghton 1838). However, most of these natural seeps have been destroyed due to human interference, and natural saline marshes are now critically imperiled with fewer than 5 inland seeps left in the state of Michigan (MNFI).

Plants that can live some part of their life cycle in 0.5 ppt salinity are considered halophytes (Chapman 1974). Based on early records of plants and natural saline areas, only three halophytic plants appear to be native to Michigan, *Schoenoplectus americanus* (formerly *Scirpus olneyi*), *Eleocharis parvula*, and *Chara* spp. (Catling and McKay 1981). *S. americanus* (Olney's three-square bulrush) is an emergent species of bulrush that is considered threatened in the state of Michigan (MNFI). It is reportedly found in four Michigan counties (Voss 1972), and can tolerate salinity up to 20 ppt (Broome et al. 1995). This species is ideal for revegetating salt impacted wetland areas because it is a tall native halophyte that is used for food and habitat by birds and mammals (Weller 1994). *E. parvula*, known as dwarf spike rush, is a short emergent and extremely rare halophyte found in only two saline wetlands in Michigan (Voss 1973). The third halophytic species, *Chara* spp. (musk grass), is actually an unidentified species of macroalgae.

Although only three halophytes are native to Michigan, several non-native halophytes from the East and West Coasts and Europe have been identified along a roadside median in Michigan (Reznicek 1980, see Appendix A). In addition, several species native to Michigan appear to tolerate elevated saline levels in other populations and areas of their range (see App. A).

The Michigan Natural Features Inventory (MNFI) surveyed the wetlands in Michigan and found nearly 40 saline wetlands, but only two were good quality (Chapman et al. 1985). Chapman et al. (1985) described the plant community of one of these salt marshes along the Maple River in Clinton County. The other good quality saline seep is located on the south side of the Maple River, also in Clinton County, and was the focus of this study (Figure 1).

Hypotheses

I addressed the following questions for the Maple River salt seep: 1) What environmental factors influence the distribution and abundance of plant species at the Maple River salt seep?; 2) Did detectable differences occur in plant community composition between 2001 and 2002; and 3) had the plant community changed since its composition was documented by Shaddellee (1983)?

In the central areas of the seep, *S. americanus* is dominant, but the edges, which are affected by fluctuating water levels, are dominated by *Typha angustifolia* and *T. latifolia* (narrow and broad leafed cattails) and more diverse forested areas. The edge areas receive run-off from an upland forest on the south end, and overflowing river water on the north, east, and west edges. Therefore, I hypothesized that high halophyte abundance would correlate with high salt concentration and stable water levels and that *S. americanus* abundance would decrease due to less saline conditions as distance increased from the seepage area. Second, I hypothesized that there would be no detectable differences in plant community composition between 2000 and 2001. Third, I hypothesized that the composition of the plant community in 2000 and 2001 would be similar to the community composition described in 1983 by Shaddellee (1983).

Site Description

The Maple River natural salt seep is located in the flood zone on the south side of the Maple River in northwest Clinton County, Michigan (T8N, R4W, sec. 15)(Figure 1a and 1b). The wetland around the seep has a very distinctive plant assemblage dominated by *S. americanus*, *Aster lanceolatus*, and *T. angustifolia* (App. B). The *S. americanus* patch stretches for approximately 90 m in a northeast direction and is approximately 40 m wide (Figure 1b). At the southwest end of the *S. americanus* patch, there is an open muddy area, believed to be the main seepage area for the saline water, approximately 10 m^2 in size. On the east and west edges of the patch, forested wetland replaces *S. americanus*, and a steep sloping hill with upland vegetation replaces *S. americanus* on the southern edge of the patch. At the northern edges of the patch, *S. americanus* is replaced by nearly monodominant stands of *T. angustifolia* (Figure 1b). Two other patches of Typha (a mixture of *T. angustifolia* and *T. latifolia*) occur on the south west corner just past the open muddy area, and near the middle of the *S. americanus* at the base of the upland hill (Figure 1b).

Methods

Adjacent circular plots with a 10 m radius (315 m^2) for transect A and a 5 m radius (79 m^2) for transect B were established along two perpendicular transects (A and B) that crossed at the center of the saline water seepage area. Transect A was longer than transect B since the *S. americanus* dominated area was not as wide as it was long (Figure 1b). Thus, a smaller plot size was used along transect B. This design resulted in 8-11 individual plots per transect (n=10 for 2000, 11 for 2001 for transect A; n=8 in both years for transect B). A smaller plot size was used for transect B to more precisely document the change in plant communities expected along this axis based on the shape of the *S. americanus* dominated patch (Figure 1b). Plant stems were counted and identified within 0.25 m^2 quadrats at three random locations within each plot. All stems were counted at the base of the plant. The plant community was sampled in early August 2000 and late

July of 2001 to determine changes from year to year. In addition, field notes from 1983 (Shaddalee 1983) from the Michigan Natural Features Inventory were used for comparison to the current plant assemblage.

Water samples were collected on May 24, 2001 from the center of every plot. Conductivity, temperature, and water depth were recorded on site, and water samples were taken to the laboratory to test for pH and alkalinity. Samples were analyzed by the Michigan State University Soil Testing Laboratory for NO_3-N, NH_4-N, K, Ca, ortho-P, Mn, Na, and Cl concentrations. NO_3-N was analyzed using a colorimetric method on a Lachat (Balson 1988). NH_4-N was determined using the salicylate colorimetric method (Nelson 1983). K, Ca, Mn, and Na were analyzed using flame emissions (Warncke and Brown 1998). Cl was determined by the chloride electrode method (Gelderman 1998). Finally, ortho-P was analyzed using the ascorbic acid method (Frank et al 1998).

Water depth and/or depth to the water table was measured in the fall of 2001. Where there was no standing water, a pit up to 76 cm deep was dug every 10 m along transect A and every 5 m along transect B. Water was allowed to fill the pit, and the distance of the water surface to the soil surface was used as depth to water table. Conductivity and water temperature were also taken at this time and compared to results of the spring samples.

Statistical analyses – The stem counts were averaged for the three 0.25m^2 quadrats per plot and multiplied by four to obtain stem counts/m^2 per plot. Relative abundances were determined by dividing the number of stems for each species within a plot by the total number of stems in that plot. The dominant and common plant species (dominant meaning those plants with >50% frequency of occurrence and relative abundance and common plants meaning those with >50% frequency of occurrence but <50% relative abundance) were analyzed individually, and all other plants were grouped into an "other species" category. Averages and standard deviations for environmental variables were determined and differences in these variables based on the presence or absence of *S. americanus* were determined using a t-test in Systat 8.0. Abundances of each plant species were correlated to the environmental variables and to abundances for each year using a Spearman's rank correlation in Systat 8.0, since the data were not normally distributed (Wheater and Cook 2000). To determine environmental variables that could be used in a regression analysis, a principal components factor analysis was run using Systat 8.0 to remove the collinear data in the set of environmental variables (Kachigan 1986). Environmental factors that were chosen based on factor analysis were standardized and used in forward stepwise multiple regression analyses for dominant, common and other plant species for each year using Systat 8.0, although the environmental factors were only recorded in 2001. To determine changes in plant community over time, a Wilcoxon signed rank test of the differences between years was used to compare the stem counts/m^2 and relative abundances of species per plot for 2000 and 2001. The Wilcoxon signed rank test was used because of expected non-normal distribution of the data (Schabenberger 1999). Significant differences were determined at $p<0.05$.

Results

The species found at the Maple River salt seep are listed in Appendix B. The dominant species were *Schoenoplectus americanus* and *Aster lanceolatus* in the saline area and *Typha* spp. around the edges and to the north of the saline area (Figure 1a).

Mentha arvensis was also considered common; however, its relative abundance was low (Figures 2 and 3, Table 1) in most plots. Two species of endangered, native Michigan halophytes were found at this seep (MNFI, Catling and McCay 1981): *S. americanus* was abundant both in 2000 and 2001, while *Eleocharis parvula* was found only around the seep area in 2001. In 2000, a few dead *Chara* spp. plants, the third native Michigan halophyte, were found at the seep area, but none were found in 2001.

A total of 41 species were found in the plant sampling. Fifteen species were found in the *S. americanus* patch, but six of these species were found only on the edges of the patch. Fifteen species were also exclusively found in the upland forest, six species were exclusively found in the forested wetland and one species was exclusively found in the *Typha* patch (see App. B).

The means for all plots of the stem counts/m^2 and relative abundances for the dominant and common plant species were the same for all species except *S. americanus* and *T. latifolia* (Table 1). Both species of *Typha* were grouped together in 2000, but were separated into two species in 2001. *T. angustifolia* was significantly correlated with the grouped *Typha* spp. for both years since it was found more often than *T. latifolia* in 2001. Correlations comparing 2000 to 2001 showed positive r, meaning similar patterns of association for all species except *T. latifolia* in 2001 to *Typha* spp. in 2000 (Table 1).

Relative abundance per plot (Figures 2 and 3) were significantly correlated to average stem counts per m^2 for each dominant plant species within the same year (Table 2). Correlations for stem counts (Figures 4-8, Table 2) and relative abundance (Figures 2 and 3) comparing 2000 to 2001 were also significant for all the dominant species except

T. latifolia. The number of species per plot (Figure 9) positively correlated with stem counts of other species (Table 2).

Conductivity data (Figure 10), chemical data for Cl, Ca, and Na (Figures 11 and 12) and depth to water table measures (Figure 15) confirm that the open muddy area assumed to be the primary salt seep (0 point in the graphs) is the source of most salinity in this wetland, although there seems to be a secondary seepage area at a distance of about 50-55 m from point 0 along transect A (Figures 11, 12 and 15). There also is a peak in nearly all water chemistry measurements (except NO_3-N, Figure 13) at –40m on transect A (Figures 11-14), however, this peak is not seen in the conductivities (Figure 10) that were performed in the field.

The peak stem counts and relative abundances for *S. americanus* were near the open muddy seep area, and 60 to 80m from the muddy area on transect A (Figures 2-4). These high counts of *S. americanus* corresponded to the peak conductivities, Cl, Ca, and Na concentrations (Figures 10-12).

The depth of the water table, conductivity, alkalinity, Ca, Na, and Cl were significantly higher in plots where *S. americanus* was present (Table 3). However, temperature and NO_3 were significantly higher in plots where *S. americanus* was absent (Table 3). Spring water depth, pH, NH_4, ortho-P, K, and Mn were similar whether *S. americanus* was present or absent (Table 3).

Conductivity was measured in both spring and summer of 2001. The trends in conductivity for spring and summer 2001 were similar for both transects (Figure 10). Conductivities were generally lower in the spring than in the summer, perhaps due to a higher water table and/or the influence of spring flooding. In particular, the northern section of transect B was strongly influenced by the flooded Maple River in the spring, and conductivities for this part of the transect were much lower than those recorded in the fall (Figure 10).

Environmental factors indicated strong positive correlations between Na, Cl, Ca and alkalinity (Table 4, Figure 17). Spring water depth, NO_3, and ortho-P (Figures 13, 14) were also positively correlated to each other, but negatively correlated to Na, Cl, Ca and alkalinity (Table 4, Figure 17). Spring water depth was also negatively correlated to conductivity and depth to water table, but conductivity and depth to water table were positively correlated to each other (Table 4, Figure 17). Temperature was negatively correlated to conductivity, and ortho-P was positively correlated to NH_4. K, Mn, and pH had no significant correlations (Table 4, Figure 17).

Table 5 shows the correlations of the plant data to the environmental data. *S. americanus* was positively correlated with depth to water table, conductivity and Na, but negatively correlated with spring water depth, NO_3, and ortho-P in both years for stem counts/m^2 and relative abundance per plot (Table 5). *M. arvensis* stem counts/m^2 were positively correlated with alkalinity (Table 5). Other species were negatively correlated with depth to water table for stem counts/m^2 and for 2000 relative abundance per plot (Table 5).

Based on the principal components factor analysis, four environmental factors were determined to account for the majority of variation. These factors were depth to water table, conductivity, pH, and alkalinity. However, since I was interested in effects of salinity, I also included Cl in the analysis. Also, nutrients are important factors in plant communities, so NO_3 and ortho-P were also included. Thus, a total of seven environmental factors were used in the regression analysis (Table 6).

Stem counts and relative abundance of *S. americanus* were positively related to conductivity and negatively related to ortho-P for both years. *S. americanus* was also negatively related to Cl, NO_3, and alkalinity in 2000, but not 2001. In 2000, *S. americanus* stem counts were negatively related to depth of the water table, but in 2001, stem counts and relative abundance were positively correlated to depth of water table (Table 6). *M. arvensis* was negatively related to alkalinity for all but 2001 relative abundance, and positively related to Cl in 2000, but not in 2001 (Table 6). *A. lanceolatus* relative abundance was positively correlated to ortho-P for both years (Table 6). In 2001, *T. latifolia* was positively correlated to ortho-P for stem counts and relative abundance. *T. angustifolia* was negatively correlated to conductivity in 2001 (Table 6). Other species were negatively related to alkalinity in all but relative abundance for 2000. Other species were also negatively related to conductivity in 2000, but not 2001, and negatively related to depth to water table in 2001, but not 2000 (Table 6).

Discussion

The water levels at the muddy open area were never deeper than a few centimeters. Even when the area was not flooded, the water table was always within a few cms of the surface, and the soil remained saturated for the whole growing season. Chemical and environmental data confirmed that this muddy area was the primary source of saline water into the wetland, although a secondary seepage area appeared to be likely about 50 to 60 m to the southeast along transect A (Figure 1b) based on chemical data (Figures 10-12 and 15). The wetland around the primary seep maintained a fairly stable water level throughout the year ranging from 5 cm above to 17 cm below the soil surface. The areas down slope to the north, east, and west, where the plant community visibly changed from a *S. americanus* dominated community to a *Typha* dominated or forested wetland community, had much greater fluctuations in water depth, ranging from nearly one m deep in the spring to 30 cm below the soil surface in late summer. The areas down slope of the *S. americanus* patch were mainly flood plain wetlands, and, not surprisingly, water level appeared to be controlled by the flood regime of the Maple River. The seep was more dependent on ground water, as was indicated by its more consistent water levels. This seepage area is near the base of a steep hill or small escarpment that separates the adjacent upland from the floodplain. The upland area south of the seep never had water near the soil surface.

Of the 41 species found in the seep plant sampling, only 15 were found in the *S. americanus* patch (App. B). Of these 15 species, 6 were at the edges of the patch and 9 were found within the patch. Nine species found were salt tolerant, and eight of the salt tolerant species were found in the *S. americanus* patch (*Peltandra virginica*, an introduced species in Michigan, was only found in the forested wetland, App A and B). Two of the species found in the patch are rare and endangered native halophytes of Michigan (*S. americanus* and *E. parvula*, Catling and McKay 1981, MNFI). *Atriplex patula*, an introduced, non-native salt tolerant species in Michigan (Voss 1985), was frequently encountered within the *S. americanus* patch, and *T. angustifolia*, another introduced halophyte (Chapman et al 2001), was abundant on the edges and formed monodominant stands on the north end of the *S. americanus* patch (App B). The four remaining salt tolerant species (*Aster lanceolatus*, *T. latifolia*, *Mentha arvensis*, and

Acorus calamus) are common throughout the state of Michigan (Voss 1972, 1996). Although the remaining seven species are not identified as salt tolerant, four of these species (*Eupatorium perfoliatum*, *E. maculatum*, *Onoclea sensitiva*, and *Equisetum* spp.) were found in another salt seep in Michigan (Chapman et al 1985) and are often found along roadsides (Voss 1996, Billington 1952) indicating possible salt tolerance. These remaining seven species (*Scuttelaria galericulata*, *Phalaris arundinacea* and *Pilea* spp. in addition to the four mentioned above) found in the *S. americanus* patch (App. B) are widespread and common throughout the state of Michigan with the exception of *Pilea* spp. which is found mostly in southern Michigan.

In most cases, the plants that were found at the seep are common species found throughout Michigan, but were found in low numbers in the seep (except for the endangered halophyte *E. parvula*). The four dominant and common species at the seep were all salt tolerant, and with the exception of *S. americanus* are also very common in the state of Michigan.

Based on my literature search, 88 native plant species in Michigan and numerous introduced species have salt tolerant populations at some point in their habitat range (Chapman et al 2001, Winchell 1860, Voss 1972, 1985, and 1996, Reznicek 1980, App. A). However, only nine salt tolerant species were found at the seep, two introduced and the other seven native Michigan species (App A and B). Furthermore, two endangered Michigan halophytes (MNFI) were found, one of them dominating a large portion of the seep. Wheeler (1891) reported these two species at this seep (a "deer lick" near Hubbardston) in the late 1800s. Thus, this seep appears to be a well-suited habitat for these two rare species in Michigan.

Abundance of *S. americanus* was related to conductivity. *S. americanus* is a halophytic plant, and as expected was associated with high ion concentrations. *E. parvula*, another native Michigan halophyte, was very rare and found only in the open, non-vegetated seep area in 2001. *E. parvula* seedlings emerge in greater densities from non-vegetated areas (Baldwin et al. 1996) as was supported by this study. Although this species is capable of germinating at high salinities (up to 16 ppt in flooded conditions), salinities of only 2 ppt can greatly reduce germination (Baldwin et al. 1996). Although this wetland is predominately ground water fed, rain can reduce the salinity of surface layers by 1% salinity (Chapman 1974). The annual precipitation (based on monthly precipitation data) from Grand Rapids, MI (July 1997-current) for both years of this study were nearly the same, but a few years before 2000, the precipitation was much lower. Perhaps, salinity in this low precipitation period rose to levels high enough to eliminate *E. parvula* from the seepage area. If so, it is possible that *E. parvula* seeds may have required an extended period of two or more years of average or higher than average rainfall to lower salinities in the seep area to levels low enough for germination. This is a possible explanation of why germination was only detected in 2001 and not in 2000 despite similar level of rainfall in both years. Since I did not collect chemical data in 2000, my data were not sufficient to document that salinities were indeed lower in 2001 than in 2000. Since *E. parvula* is such a rare plant in Michigan (MNFI, Voss 1972), and the seep I studied is only one of two areas in Michigan where both threatened species (*S. americanus* and *E. parvula*) of native halophytes grow, further studies should be conducted on its life cycle and habitat needs in order to develop a management plan to preserve the species in Michigan.

S. americanus abundance was also negatively correlated with ortho-P. This species is a sub-climax species (Broome et al. 1995), meaning it is easily out-competed by other species. In 2001, *T. latifolia* abundance was correlated to ortho-P; however, *Typha* spp. grouped together in 2000 and *T. angustifolia* in 2001 did not have significant correlations with ortho-P. Since the species of *Typha* were not distinguished in 2000, correlations to environmental factors may have been hindered. *Typha* spp. (especially *T. latifolia)* are known to be highly competitive, and will take over areas that are enriched with nutrients (Svengsouk and Mitsch 2001, Hutchinson 1975). *T. latifolia* was not found in this wetland in a 1983 survey (Shaddalee 1983), and the *Typha* dominated stand where this species is predominately found was also not indicated in the 1983 study (Shaddalee 1983). *T. latifolia* is a very competitive species that often displaces *T. angustifolia* to less desirable deep water (Grace and Wetzel 1981) and high salinity habitats (McMillan 1959). Maintaining this *S. americanus* population may depend on maintaining low P levels in and down slope of the saline water seepage area.

The composition of the plant community did not appear to change from 2000 to 2001 except that *E. parvula* was present in 2001 but not in 2000. In comparing field notes of this wetland from 1983 (Shaddellee 1983) with my study, the plant community structure appears to be similar, especially in terms of the distribution of the dominant species present. *S. americanus* was the dominant plant in 1983, with *T. angustifolia* being locally dominant on the north, east and the eastern portion of the south edges. However, I found a mixed patch of both *T. angustifolia* and *T. latifolia* on the south west edge of the *S. americanus* dominated patch that was not indicated in Shaddellee's notes (1983). In both studies, *Aster lanceolatus* (called *A. simplex*, see Voss 1996) was abundant to the point of being considered co-dominant. In both surveys *Eupatorium maculatum*, *E. perfoliatum*, *M. arvensis*, *Onoclea sensibilis*, *Atriplex hastata*, *Thelypteris palustris* and *Pilea* spp. were present in lower abundances. A few of the rarer species in both surveys did not correspond (Shaddellee 1983). However, being rare, those species could have escaped notice or recently immigrated into or emigrated out of the wetland. Also, rare species are likely to differ between any two studies of the same area when random quadrat placement within plots is part of the experimental design especially when limited numbers of quadrats are sampled per plot (e.g. 3 in this study).

The greatest difference between the two surveys was that Shaddellee (1983) found *Eleocharis rostellata* to be co-dominant with *S. americanus* in this wetland, and that species was not found in my study 17 years later. Wheeler (1891) also found this species at the seep over 100 years ago. *E. rostellata* is an early colonizer of marl beds and seems to grow best on marl soil that receives runoff from glacial till (Seischab et al. 1985). Since this wetland is groundwater fed, *E. rostellata* may have been less hearty and unable to compete with the abundant and dense population of *S. americanus*. However, since *E. rostellata* was likely present in this seep from Wheeler's (1891) observations to Shaddellee (1983) study, its absence would indicate a recent disappearance. Since Shaddellee (1983) reported *E. rostellata* as a codominant species with *S. americanus* it is unlikely that my survey would have missed this species even though I did not sample the entire wetland. This species absence may be an early indicator of a changing environment at the seep, and the seep should be continually monitored for changes in the plant assemblage.

Cl, Ca, Na, and K were the four highest concentrated ions, respectively, at this seep. Cl, Na, and K ion concentrations were similar to those found in seawater (Fortescue 1980). Unfortunately, Mg another common salt of seawater was not tested in this study. Based on the geology of Michigan, this wetland is very likely obtaining water from the saline aquifers that are remnants of the Paleozoic seas that covered Michigan (Dorr and Eschman 1970). Ca, which tends to be in low concentrations in sea water (Fortescue 1980) and in the brine waters of Michigan (Cook 1914, Dorr and Eschman 1970, Winchell 1860), likely derives from the glacial till deposits in the lower peninsula which tend to have high concentrations of calcium carbonates (Chapman et al. 1985).

Compared to the water chemistry of bogs, swamps and fens in Northern Michigan studied by Schwintzer and Tomberlin (1982), Cl, Ca, Na, K, conductivity, and pH were all higher at the Maple River salt seep. The alkalinity and ortho-P (reactive-P) at the Maple River salt seep wetland were comparable to those found by Schwintzer and Tomberlin (1982) for northern Michigan wetlands. However, the NO3 and NH4 concentrations at the salt seep were more similar to river water (Allen 1995) than to Northern Michigan wetlands (Schwintzer and Tomberlin 1982), since the NO3 concentration were much higher than the NH4 concentrations at the Maple River salt seep.

The Michigan Department of Environmental Quality (MDEQ 2003) studied the river water of the Maple River watershed. They found that the river water had ammonia values ranging from 0.012 to 9.71 mgN/L and NO3 levels ranged from 0.09 to 14.1 mgN/L (MDEQ 2003). The NH4 and NO3 concentrations at the salt seep were within the range of concentrations found in the river water. Since three edges of the salt seep were flooded by river water, the river water likely contributes its nutrient concentrations to the salt seep wetland.

Compared to the salt marsh studied by Chapman et al., (1985), my seep had weaker brine, however, I determined ion concentrations from the water, whereas Chapman et al. (1985) used dry soil samples. Calcium, magnesium and chloride were the most abundant ions, respectively, at the Chapman et al. (1985) marsh, where as chloride, calcium, and sodium had the highest concentrations, respectively, at my seep. Also pH had a greater range in their study (Chapman et al. 1985), than in my salt seep.

This unique and rare salt seep wetland appears to support a healthy population of rare and endangered halophytes in Michigan (MNFI). However, compared to a survey from 17 years ago (Shaddellee 1983), some changes in plant assemblages have occurred. This seep should continue to be monitored and protected to maintain its integrity and to preserve the diversity of the unique plants it contains.

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Table 1. The dominant and common species found at the Maple River salt seep showing the sample means, standard deviations (SD), and relative frequencies (Rel Freq) for both 2000 (n=17) and 2001 (n-18) for average stem counts/m^2 and relative abundance per plot. Also shown are the p-values for the sign test to determine differences in means between years and the r^2 from the Spearman rank correlations. The * indicate a significance at the 0.05 level and ** indicate significance at the 0.01 level. The "- " indicates data not recorded for that parameter.

		Year						Year Comparisons	
		2000			2001			Sign test	Spearman correlation
	Species	Mean	SD	Rel Freq	Mean	SD	Rel Freq	p-value	r^2
Average stem count per m2	*S.americanus*	108.3	134.0	0.588	230.5	236.8	0.722	0.039*	0.817**
	M. arvesis	4.5	9.8	0.588	8.7	11.7	0.667	0.109	0.404**
	A. lanceolatus	58.8	68.6	0.824	90.6	100.3	0.722	0.607	0.584**
	T. latifolia	-	-	-	1.3	3.0	0.167	0.002**	0.080
	T.angustifolia	-	-	-	12.0	14.1	0.667	0.388	0.643**
	Typha spp.	8.4	10.1	0.697	13.3	14.3	0.667	0.092	0.755**
	Other spp.	26.1	35.7	0.765	33.1	43.3	0.833	0.936	0.398**
	# spp.	6.3	3.5	-	6.4	3.0	-	0.424	0.676**
Relative abundance per plot	*S.americanus*	0.3	0.4	-	0.4	0.4	-	0.030*	0.870**
	M. arvesis	0.02	0.03	-	0.03	0.04	-	0.388	0.362*
	A. lanceolatus	0.2	0.3	-	0.2	0.2	-	0.302	0.584**
	T. latifolia	-	-	-	0.004	0.01	-	0.001**	0.088
	T.angustifolia	-	-	-	0.07	0.1	-	0.581	0.669**
	Typha spp.	0.2	0.3	-	0.08	0.1	-	0.581	0.706**
	Other spp.	0.2	0.3	-	0.2	0.2	-	1.000	0.531**

Table 2. Spearman rank correlations for average stem counts/m^2 and relative abundance per plot for dominant, common and other plant species for 2000 and 2001. * indicates $p < 0.05$ and ** indicates $p < 0.01$.

	2000 average stem count per m2						2000 relative abundance per plot				
	S. americanus	*M. arvensis*	*A. lanceolatus*	*Typha* spp.	Other spp.	# spp.	*S. americanus*	*M. arvensis*	*A. lanceolatus*	*Typha* spp.	Other spp.
2000 average stem count per m2											
S. americanus	1										
M. arvensis	0.421	1									
A. lanceolatus	0.527*	0.604*	1								
Typha spp.	-0.27	-0.166	-0.244	1							
Other spp.	-0.243	0.144	-0.16	-0.548*	1						
# spp.	-0.073	0.357	0.029	-0.610*	0.759**	1					
2000 Relaitve abundance per plot											
S. americanus	0.969**	0.41	0.412	-0.26	-0.206	-0.074	1				
M. arvensis	0.3	0.958**	0.560*	-0.134	0.121	0.372	0.311	1			
A. lanceolatus	0.245	0.502*	0.919**	-0.143	-0.062	0.077	0.15	0.542*	1		
Typha spp.	-0.36	-0.223	-0.309	0.974**	-0.510*	-0.626**	-0.353	-0.177	-0.197	1	
Other spp.	-0.505*	-0.113	-0.422	-0.38	0.906**	0.666**	-0.461	-0.102	-0.284	-0.311	1
2001 average stem count per m2											
S. americanus	0.904**	0.514*	0.711**	-0.265	-0.282	-0.158	0.892**	0.422	0.478	-0.334	-0.558*
M. arvensis	0.456	0.636**	0.21	0.162	0.035	0.207	0.527*	0.582*	0.123	0.036	-0.122
A. lanceolatus	0.298	0.372	0.764**	0.131	-0.237	-0.195	0.19	0.386	0.784**	0.112	-0.358
T. latifolia	-0.069	0.344	0.159	0.283	-0.107	0.009	0.017	0.515*	0.32	0.292	-0.134
T. angustifolia	-0.4	-0.259	-0.353	0.802**	-0.426	-0.634**	-0.337	-0.193	-0.199	0.785**	-0.27
Typha spp.	-0.387	-0.217	-0.326	0.869**	-0.471	-0.647**	-0.314	-0.118	-0.149	0.854**	-0.321
Other spp.	-0.441	-0.349	-0.644**	-0.319	0.631**	0.515*	-0.426	-0.352	-0.598*	-0.251	0.740**
# spp.	-0.152	0.178	-0.154	-0.557*	0.822**	0.822**	-0.08	0.19	-0.099	-0.550*	0.753**
2001 relative abundance per plot											
S. americanus	0.908**	0.530*	0.595*	-0.24	-0.244	-0.073	0.933**	0.46	0.386	-0.326	-0.518*
M. arvensis	0.422	0.633**	0.393	0.071	-0.131	0.107	0.473	0.602*	0.331	-0.038	-0.271
A. lanceolatus	0.139	0.377	0.619**	0.109	-0.037	-0.029	0.059	0.46	0.746**	0.105	-0.151
T. latifolia	-0.092	0.359	0.151	0.283	-0.071	0.041	-0.006	0.527*	0.323	0.296	-0.099
T. angustifolia	-0.454	-0.248	-0.405	0.817**	-0.366	-0.595*	-0.383	-0.167	-0.226	0.818**	-0.185
Typha spp.	-0.446	-0.196	-0.378	0.841**	-0.38	-0.580*	-0.37	-0.108	-0.189	0.840**	-0.207
Other spp.	-0.562*	-0.448	-0.776**	-0.211	0.563*	0.407	-0.530*	-0.453	-0.719**	-0.143	0.731**

Table 2 (continued).

	2001 average stem count per m2								2001 relative abundance per plot					
	S. americanus	*M. arvensis*	*A. lanceolatus*	*T. latifolia*	*T. angustifolia*	*Typha* spp.	Other spp.	# spp.	*S. americanus*	*M. arvensis*	*A. lanceolatus*	*T. latifolia*	*T. angustifolia*	*Typha* spp.
2001 average stem count per m2														
S. americanus	1													
M. arvensis	0.262	1												
A. lanceolatus	0.366	0.235	1											
T. latifolia	0.079	0.221	0.201	1										
T. angustifolia	-0.422	0.116	0.086	0.118	1									
Typha spp.	-0.394	0.148	0.092	0.299	0.974	1								
Other spp.	-0.642**	-0.134	-0.539*	-0.435	-0.084	-0.179	1							
# spp.	-0.291	0.344	-0.131	-0.034	-0.276	-0.322	0.668**	1						
2001 relative abundance per plot														
S. americanus	0.970**	0.357	0.237	0.152	-0.412	-0.365	-0.596*	-0.24	1					
M. arvensis	0.3	0.730**	0.478*	0.215	0.217	0.187	-0.355	0.184	0.324	1				
A. lanceolatus	0.205	0.276	0.928**	0.255	0.131	0.148	-0.376	0.013	0.13	0.435	1			
T. latifolia	0.059	0.224	0.197	0.995**	0.115	0.293	-0.429	-0.026	0.14	0.235	0.265	1		
T. angustifolia	-0.464	0.119	0.044	0.176	0.985**	0.976**	-0.063	-0.262	-0.438	0.173	0.122	0.18	1	
Typha spp.	-0.447	0.133	0.044	0.26	0.968**	0.979**	-0.129	-0.294	-0.408	0.201	0.124	0.27	0.991**	1

Table 3. The means (± SD) for environmental factors for all plots combined, plots containing *S. americanus* and plots where *S. americanus* was absent. The t-statistics and p-values comparing plots with and without *S. americanus*. Number of samples (n) in parenthesis. A * indicates significance below .05 and ** indicates significance at or below .001.

Environmental factors	Means for all plots (n=18)	*S. americanus* absent (n=5)	*S. americanus* present (n=13)	T, p values
Depth to water table (cm)	-11 ± 8	-29 ± 1	-8 ± 3	-14.47, >0.001**
Spring water depth (cm)	24 ± 37	64 ± 52	9 ± 9	2.35, 0.077
Conductivity (uS)	1560 ± 1060	534 ± 3	1790 ± 1040	-4.35, 0.001**
pH	7.45 ± 0.22	7.39 ± 0.04	7.47 ± 0.24	-1.19, 0.253
Alkalinity (mg $CaCO_3$/L)	248 ± 82	160 ± 1	268 ± 77	-5.00, >0.001**
Temperature (°C)	14.1 ± 0.9	14.9 ± 0.3	13.9 ± 1.0	2.91, 0.014*
NO_3 (mg N/L)	3.0 ± 3.6	7.51 ± 0.18	1.96 ± 3.13	6.35, >0.001**
NH_4 (mg N/L)	0.10 ± 0.07	0.13 ± 0.02	0.09 ± 0.07	1.73, 0.105
Ortho-P (mg/L)	0.04 ± 0.05	0.06 ± 0.01	0.04 ± 0.06	1.28, 0.221
K (mg/L)	5.4 ± 5.1	3.3 ± 4.5	5.8 ± 5.3	-0.85, 0.453
Ca (mg/L)	391 ± 298	102 ± 2.9	458 ± 292	-4.39, 0.001**
Mn (mg/L)	0.18 ± 0.29	0.05 ± 0.04	0.21 ± 0.31	-1.74, 0.104
Na (mg/L)	203 ± 191	12 ± 1	247 ± 185	-4.58, 0.001**
Cl (mg/L)	661 ± 580	74 ± 4	797 ± 561	-4.64, 0.001**

Table 4. Spearman rank correlations comparing environmental factors. * indicates $p < 0.05$ and ** indicates $p < 0.01$.

	Depth to water table (cm)	Conductivity (uS)	pH	Alkalinity (mg CaCO3/l)	Temper-ature (oC)	Spring depth (cm)	NO3-N (mg/l)	NH4-N (mg/l)	K (mg/l)	Ca (mg/l)	Ortho-P (mg/l)	Mn (mg/l)	Na (mg/l)
Depth to water table	1												
Conductivity	0.627*	1											
pH	0.291	-0.171	1										
Alkalinity	0.284	0.432	0.022	1									
Temperature	-0.389	-0.533*	-0.039	-0.425	1								
Spring depth	-0.711**	-0.679**	-0.108	-0.789**	0.614	1							
NO3-N	-0.137	-0.345	0.033	-0.848**	0.211	0.690**	1						
NH4-N	-0.481	-0.212	0.135	0.086	-0.044	0.272	0.019	1					
K	-0.108	0.359	-0.333	0.075	-0.046	-0.248	-0.292	-0.148	1				
Ca	0.235	0.367	-0.149	0.698**	-0.185	-0.652**	-0.804**	-0.217	0.298	1			
Ortho-P	-0.436	-0.148	-0.137	-0.402	0.043	0.566*	0.526*	0.570*	-0.29	-0.550*	1		
Mn	0.441	0.468	-0.13	0.39	-0.186	-0.293	-0.201	-0.096	0.023	0.194	0.067	1	
Na	0.276	0.439	-0.059	0.689**	-0.237	-0.716**	-0.863**	-0.234	0.41	0.951**	-0.573*	0.118	1
Cl	0.265	0.431	-0.15	0.677**	-0.22	-0.639**	-0.837**	-0.229	0.323	0.957**	-0.544*	0.217	0.963**

Table 5. Spearman rank correlations for average stem counts/m^2 and relative abundance per plot for dominant, common and other plant species for 2000 and 2001 compared to environmental data. * indicates $p < 0.05$ and ** indicates $p < 0.01$.

	Depth to water table (cm)	Conductivity (uS)	pH	Alkalinity (mg CaCO3 /l)	Temper-ature (oC)	Spring depth (cm)	NO3-N (mg/l)	NH4-N (mg/l)	K (mg/l)	Ca (mg/l)	Ortho-P (mg/l)	Mn (mg/l)	Na (mg/l)	Cl (mg/l)
2000 average stem count per m2														
S. americanus	0.563*	0.614*	0.026	0.508*	-0.304	-0.532*	-0.575*	-0.435	0.35	0.477	-0.785**	0.157	0.545*	0.511*
M. arvensis	0.158	0.383	-0.026	0.506*	-0.595*	-0.423	-0.454	-0.037	0.139	0.399	-0.095	0.262	0.399	0.396
A. lanceolatus	0.469	0.459	0.36	0.595*	-0.281	-0.646**	-0.509*	-0.058	0.022	0.339	-0.219	0.304	0.442	0.343
Typha spp.	0.018	-0.2	0.007	0.082	-0.014	0.371	0.258	0.297	-0.05	-0.147	0.089	0.105	-0.223	-0.131
Other spp.	-0.652*	-0.195	-0.233	-0.291	-0.024	-0.104	-0.035	0.123	0.304	-0.078	0.379	-0.182	0.014	-0.014
# spp.	-0.515	0.009	-0.478	0.082	-0.204	-0.379	-0.18	-0.085	0.163	0.34	0.211	0.006	0.242	0.216
2000 Relaitve abundance per plot														
S. americanus	0.597*	0.579*	0.046	0.462	-0.368	-0.513*	-0.533*	-0.428	0.354	0.408	-0.789**	0.085	0.497	0.451
M. arvensis	0.164	0.422	-0.137	0.433	-0.629	-0.402	-0.327	-0.048	0.092	0.336	0.065	0.179	0.341	0.324
A. lanceolatus	0.35	0.38	0.249	0.555*	-0.287	-0.604*	-0.417	0.007	-0.06	0.262	0.032	0.254	0.39	0.293
Typha spp.	-0.052	-0.162	-0.026	-0.018	0.016	0.469	0.332	0.382	-0.04	-0.219	0.238	0.127	-0.284	-0.182
Other spp.	-0.774**	-0.457	-0.282	-0.552*	0.203	0.167	0.291	0.274	0.13	-0.27	0.573*	-0.247	-0.271	-0.247

Table 5 (continued).

	Depth to water table (cm)	Conductivity (uS)	pH	Alkalinity (mg CaCO3 /l)	Temperature (oC)	Spring depth (cm)	NO3-N (mg/l)	NH4-N (mg/l)	K (mg/l)	Ca (mg/l)	Ortho-P (mg/l)	Mn (mg/l)	Na (mg/l)	Cl (mg/l)
2001 average stem count per m2														
S. americanus	0.820**	0.673**	0.421	0.502	-0.359	-0.563*	-0.503*	-0.386	0.23	0.439	-0.628**	0.326	0.539*	0.475
M. arvensis	-0.151	0.025	-0.041	0.552*	-0.44	-0.228	-0.358	0.117	0.134	0.137	-0.263	-0.032	0.127	0.099
A. lanceolatus	0.056	0.258	0.137	0.277	-0.259	-0.263	-0.165	-0.01	0.076	-0.022	0.036	0.173	0.103	0.024
T. latifolia	0.295	0.436	-0.218	0.173	-0.592	-0.245	0.137	0.229	0.096	-0.082	0.355	0.213	-0.059	-0.082
T. angustifolia	-0.164	-0.506*	-0.018	-0.227	0.22	0.575*	0.397	0.081	-0.27	-0.509*	0.158	-0.151	-0.501	-0.442
Typha spp.	-0.086	-0.364	-0.052	-0.14	0.079	0.503*	0.379	0.19	-0.23	-0.464	0.209	-0.148	-0.453	-0.4
Other spp.	-0.708**	-0.425	-0.44	-0.548*	0.467	0.408	0.301	-0.006	0.183	-0.27	0.258	-0.309	-0.335	-0.311
# spp.	-0.726**	-0.246	-0.297	-0.201	-0.018	-0.132	0.089	0.102	0.236	-0.258	0.288	-0.249	-0.24	-0.329
2001 relative abundance per plot														
S. americanus	0.804**	0.688**	0.268	0.576*	-0.39	-0.579*	-0.562*	-0.399	0.281	0.535*	-0.665**	0.305	0.612*	0.560*
M. arvensis	0.12	-0.001	-0.053	0.466	-0.532*	-0.289	-0.3	-0.227	-0.11	0.122	-0.33	0.179	0.119	0.114
A. lanceolatus	-0.184	0.215	-0.098	0.227	-0.204	-0.18	-0.179	0.013	0.131	0.018	0.194	0.015	0.156	0.083
T. latifolia	0.265	0.427	-0.257	0.212	-0.599	-0.245	0.082	0.248	0.104	-0.028	0.367	0.253	-0.009	-0.022
T. angustifolia	-0.215	-0.468	-0.094	-0.22	0.197	0.597	0.389	0.172	-0.25	-0.489	0.252	-0.132	-0.487	-0.409
Typha spp.	-0.158	-0.408	-0.133	-0.13	0.106	0.542	0.322	0.209	-0.24	-0.407	0.251	-0.076	-0.412	-0.325
Other spp.	-0.716	-0.539	-0.368	-0.624	0.449	0.504	0.409	0.104	0.049	-0.356	0.319	-0.352	-0.44	-0.383

Table 6. Regression equations and variance (R^2) explained by the environmental factors (independent variables) for the dependent (plant) variables of abundance and relative abundance for both summers. A dash (--) means there were no significant explanatory variables.

Dependent Variable	Independent Variables	R^2
2000 average stem counts/m^2		
S. americanus	-118(Cl) –46(ortho-P) –264(NO3-N) –31(water table) +78(conductivity) –105 (alkalinity)	0.940
M. arvensis	9.9(Cl) –5.8(alkalinity)	0.349
A. lanceolatus	33.0(alkalinity)	0.229
Typha spp.	--	--
Other species	-11.5(conductivity)-15.2(alkalinity)	0.452
2000 relative abundance per plot		
S. americanus	-0.2(Cl) –0.1(ortho-P) –0.5(NO3-N) +.2(conductivity) -.3(alkalinity)	0.908
M. arvensis	0.02(Alkalinity)+0.03(Cl)	0.389
A. lanceolatus	0.1(water table) +0.1(ortho-P)	0.388
Typha spp.	-0.1(water table)	0.369
Other species	-0.1(conductivity)-0.2(NO3-N)	0.585
2001 average stem counts/m^2		
S. americanus	54.4(water table) + 84.8(pH)-99.4(ortho-P) +120.3(conductivity)	0.895
M. arvensis	+6.1(alkalinity)	0.248
A. lanceolatus	--	--
T. latifolia	1.2(conductivity) + 1.6(ortho-P)	0.494
T. angustifolia	-5.4(conductivity)	0.292
Typha spp.	--	--
Other species	-28.4(water table)-13.6(alkalinity)	0.677
2001 relative abundance per plot		
S. americanus	0.1(water table) –0.2(ortho-P)+0.2(conductivity)	0.854
M. arvensis	--	--
A. lanceolatus	0.1(ortho-P)	0.268
T. latifolia	0.004(water table) +0.009(ortho-P)	0.733
T. angustifolia	-0.02(conductivity)	0.311
Typha spp.	0.02(ortho-P)+0.01(water table) -0.02(conductivity)	0.497
Other species	-0.2(water table) –0.06(alkalinity)	0.827

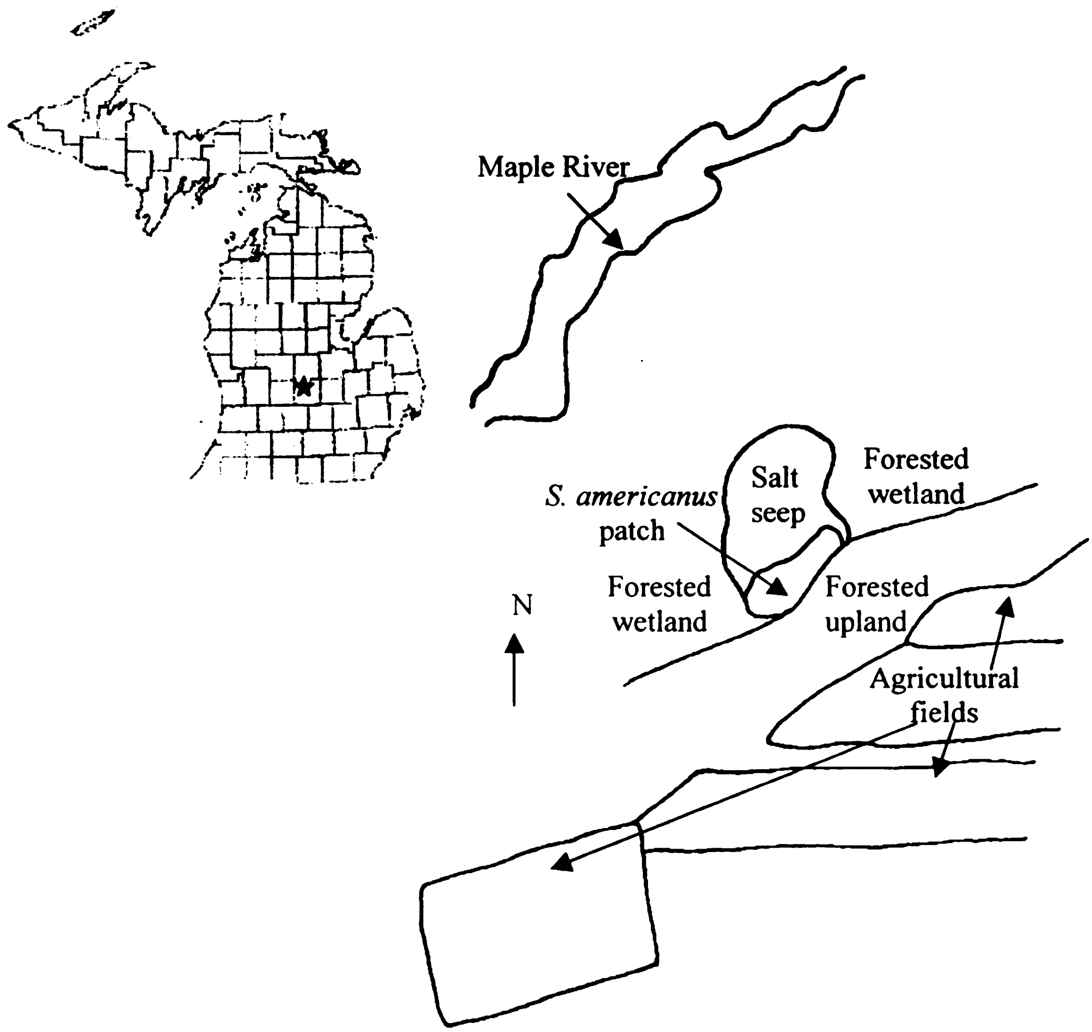

Figure 1a. Location of the Maple River salt seep. The insert shows a map of Michigan with the ✱ indicating the location of the Maple River salt seep in Clinton County, Michigan. The larger map is a landscape overview of the Maple River salt seep.

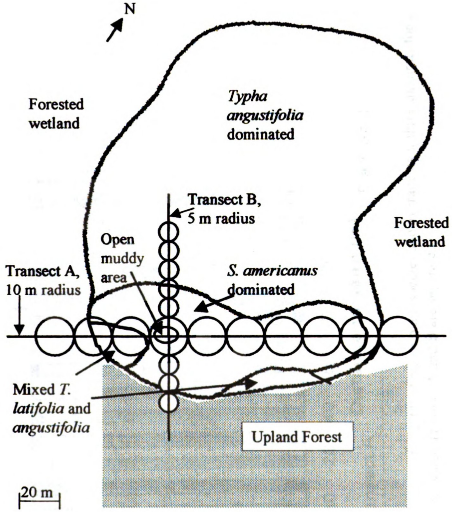

Figure 1b. The Maple River salt seep wetland indicating dominant plant characteristics and location of transects.

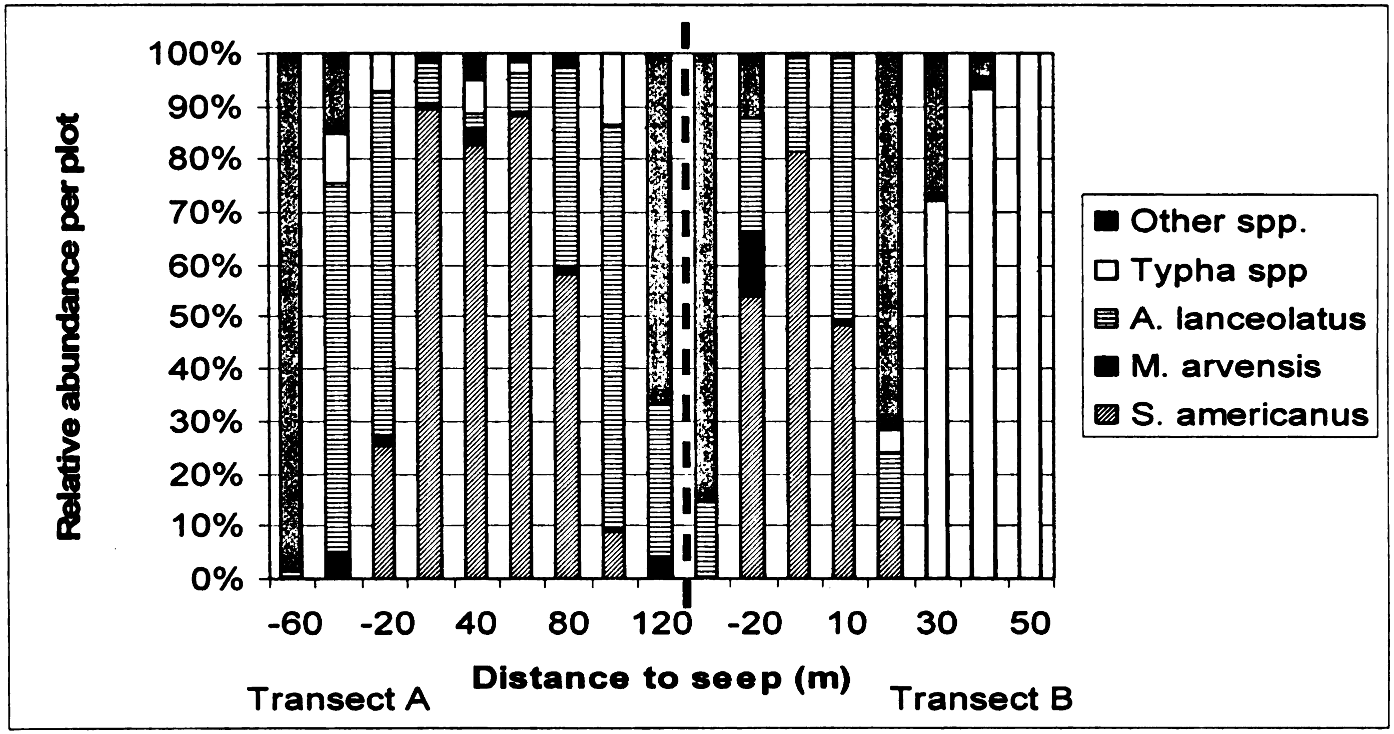

Figure 2. Relative abundances for 2000 of major plant species and average over three quadrats for each plot. The thick dashed lines indicate where Transect A and B are separated.

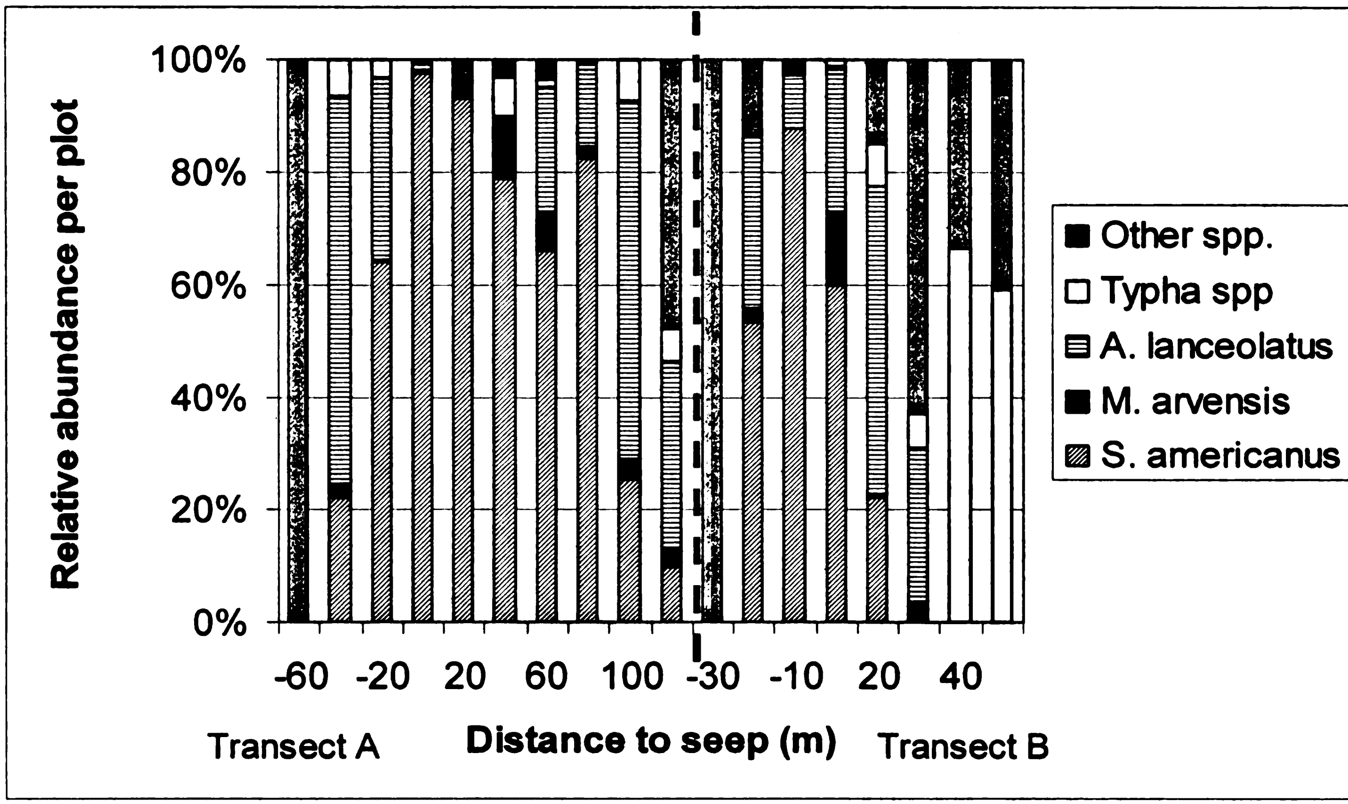

Figure 3. Relative abundances for 2001 of major plant species and averaged for three quadrats for each plot. The thick dashed lines indicate where a Transect A and B are separated.

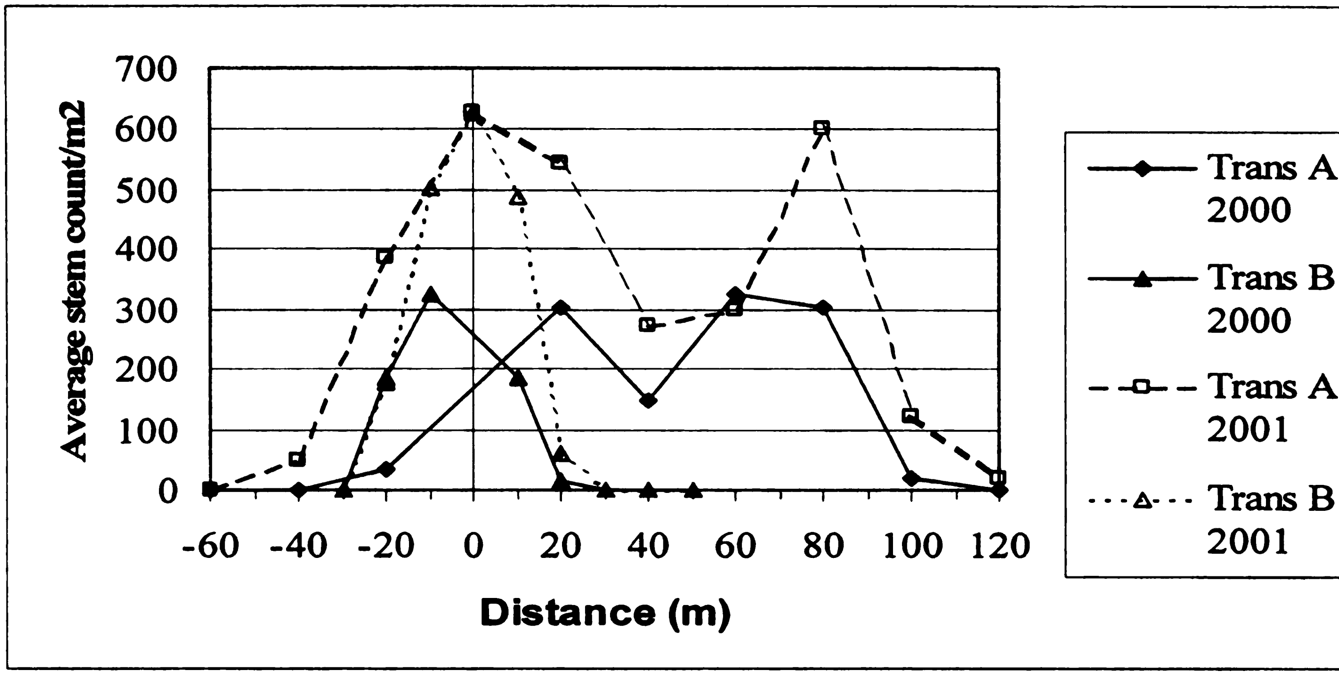

Figure 4. Average stem count per m^2 for *S. americanus* for 2000 and 2001. Summer 2001 data had significantly higher mean stem counts ($p=0.039$ based on sign test for non-parametric means), but similar patterns of association ($r^2=0.817$, $p<0.01$) to 2000 data. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

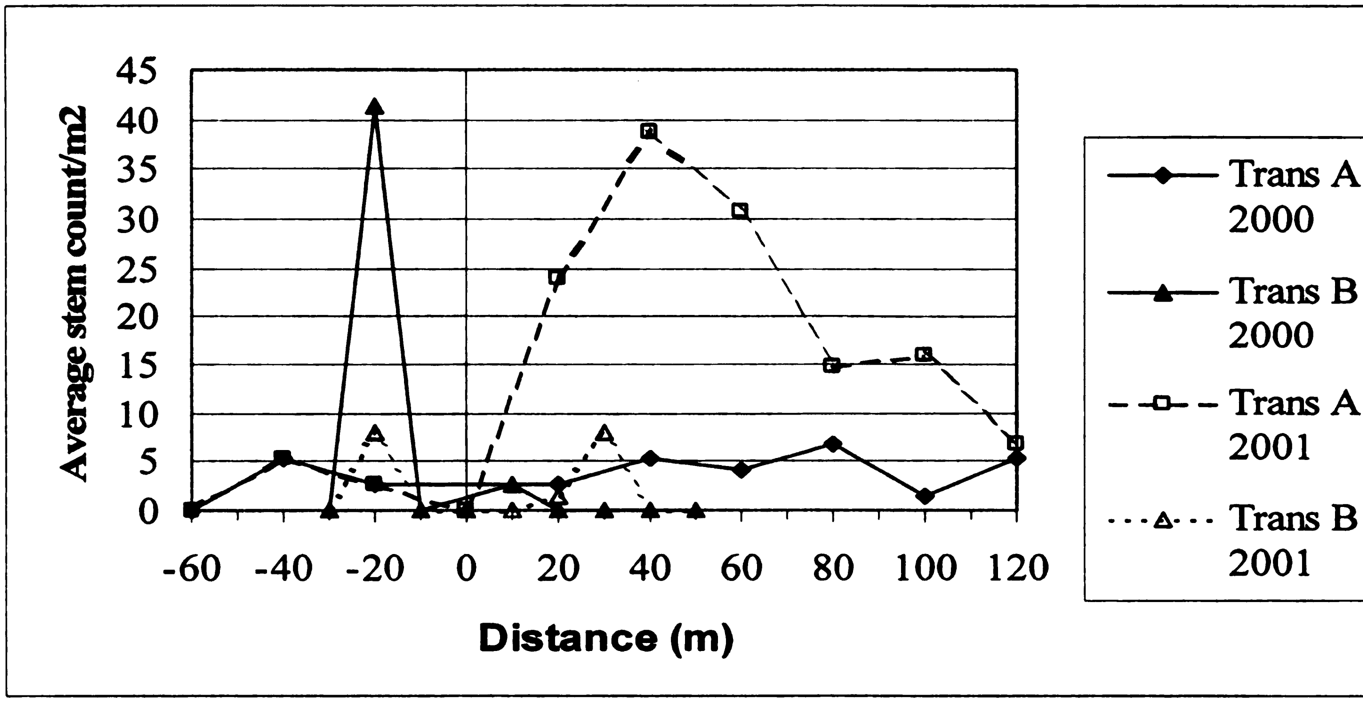

Figure 5. Average stem count per m^2 for *M. arvensis* for 2000 and 2001. Mean stem counts ($p=0.109$ based on sign test for non-parametric means) were were similar and patterns of association were similar ($r^2=0.404$, $p>0.01$) between years. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

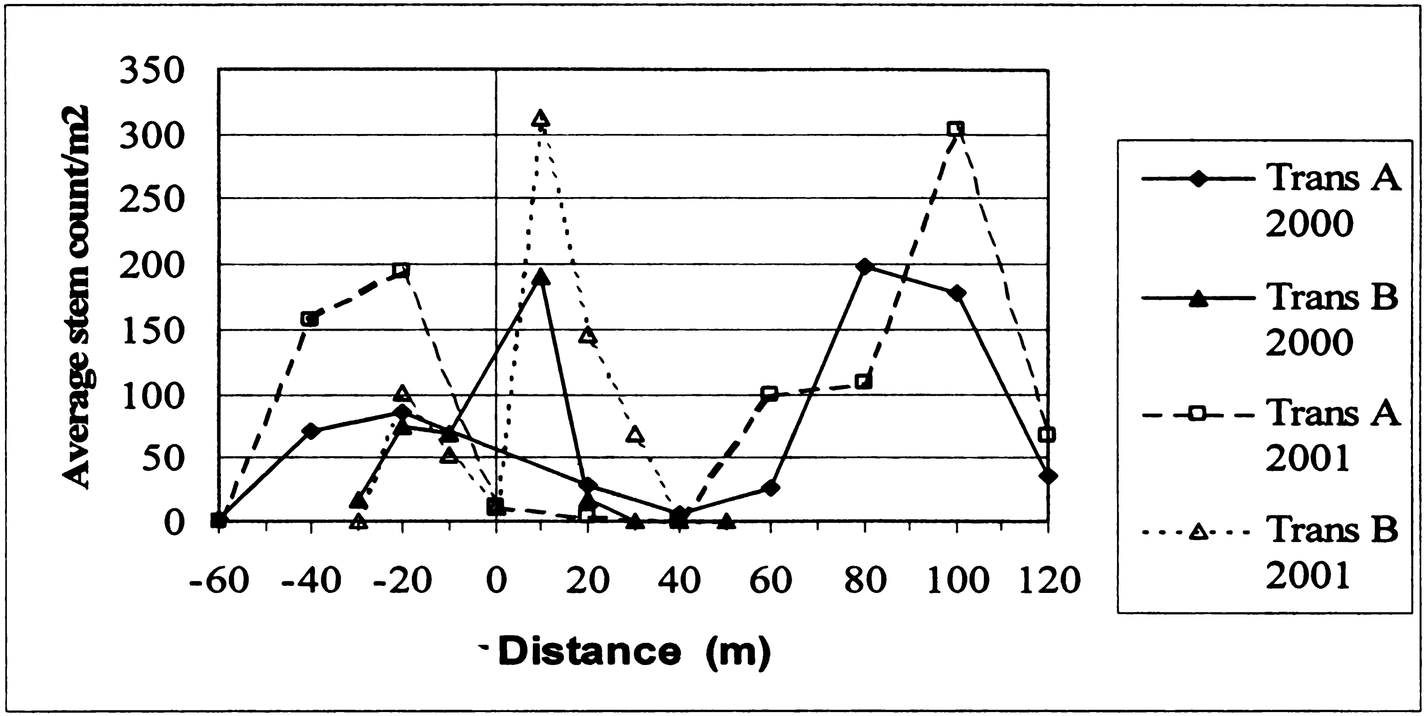

Figure 6. Average stem count per m^2 for *A. lanceolatus* for 2000 and 2001. Similar mean stem counts ($p=0.607$ based on sign test for non-parametric means) and similar patterns of association ($r^2=0.584, p<0.01$) were seen for both years. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

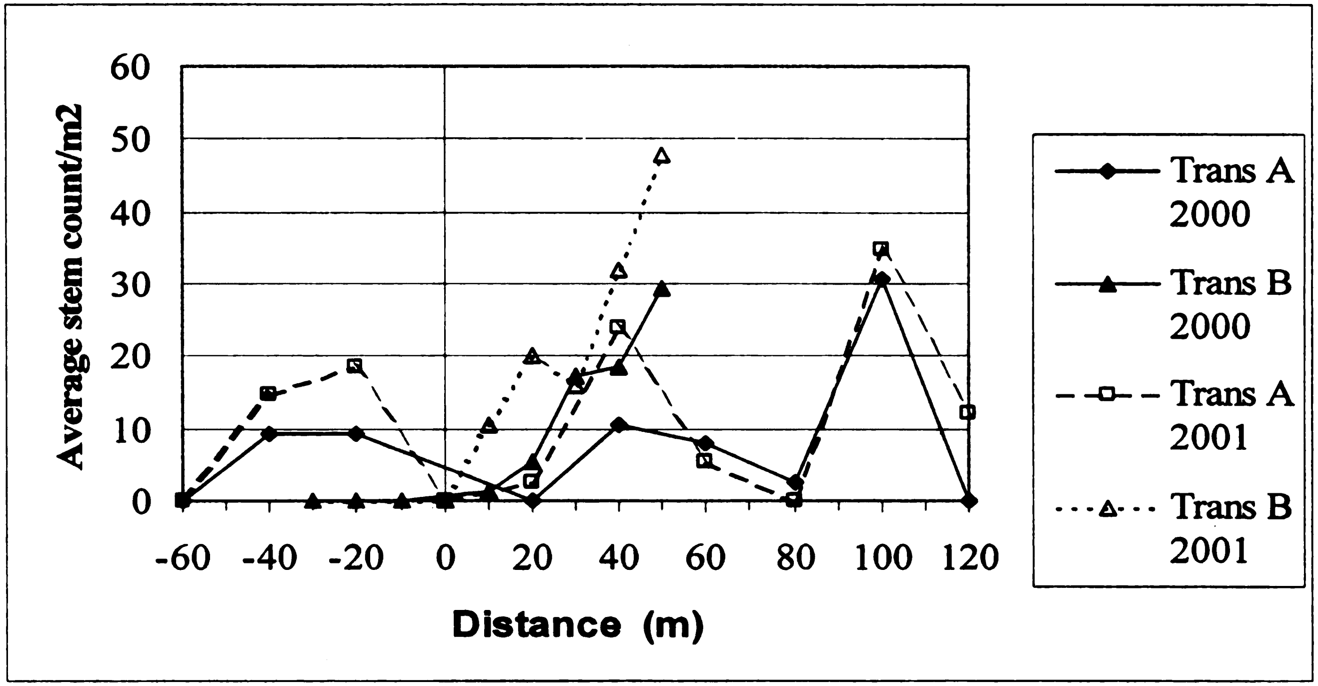

Figure 7. Average stem count per m^2 for *Typha* spp. for 2000 and 2001. Similar mean stem counts ($p=0.092$ based on sign test for non-parametric means) and similar patterns of association ($r^2=0.755$, $p<0.01$) are seen for both years. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

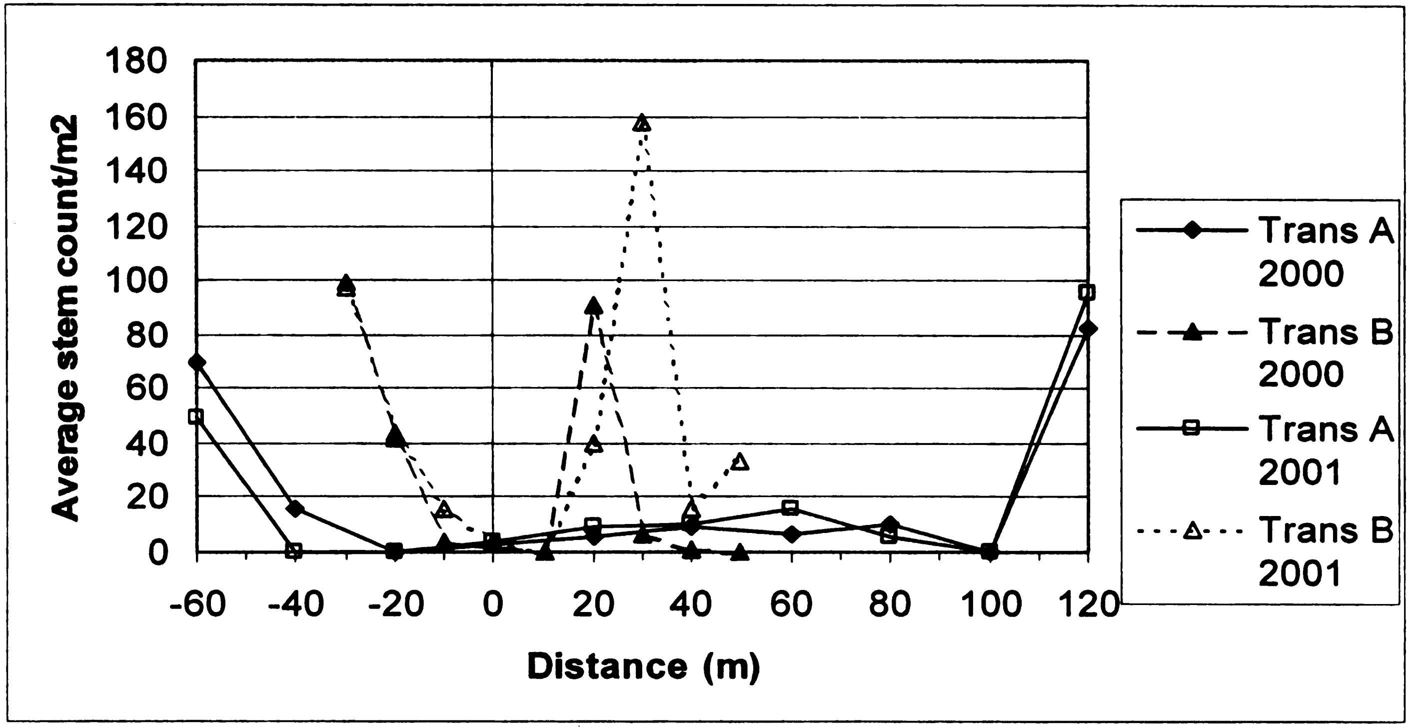

Figure 8. Average stem count per m^2 for other species (not including dominant or common species) for 2000 and 2001. Similar mean stem counts ($p=0.424$ based on sign test for non-parametric means) and similar patterns of association ($r^2=0.398$, $p<0.01$) are seen for both years. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

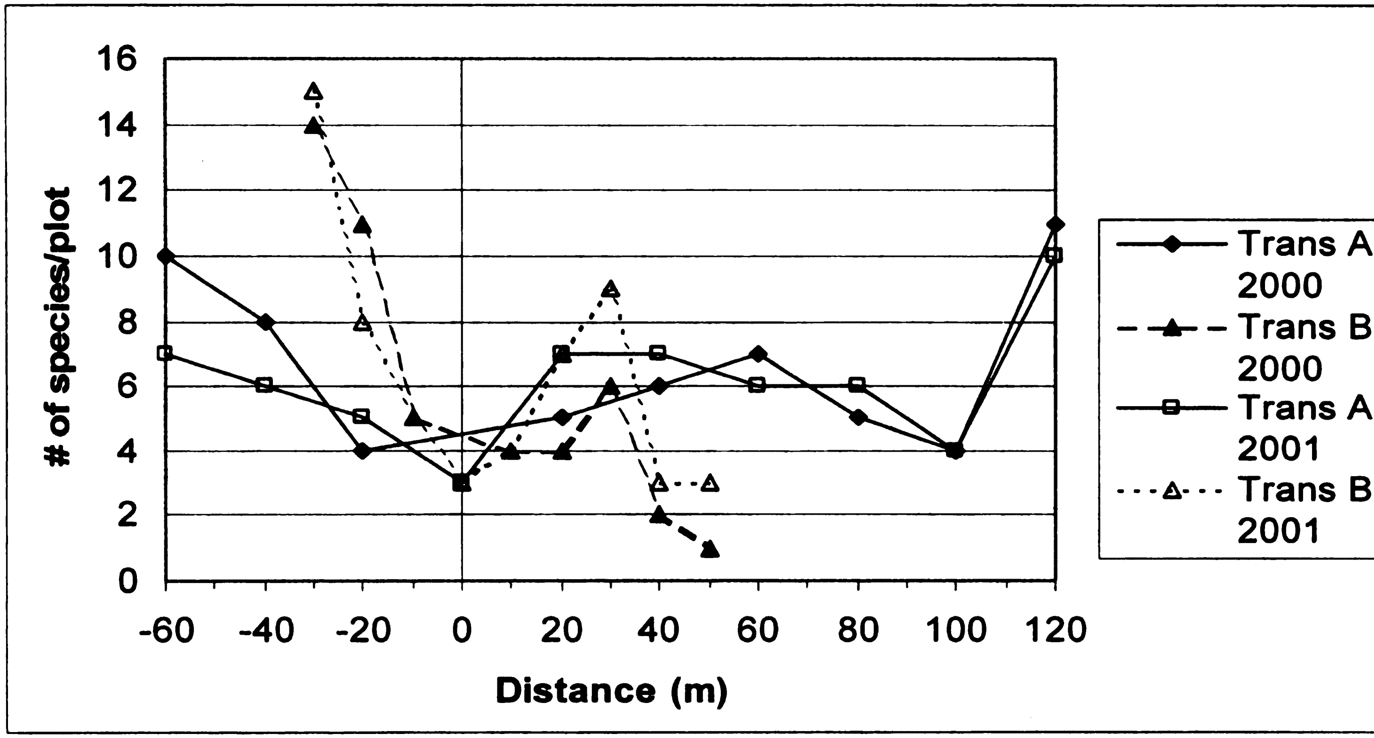

Figure 9. The total number of species found in in all three quadrats per plot for 2000 and 2001. Similar mean number of species (p=0.424 based on sign test for non-parametric means) and similar patterns of association (r^2=0.676, p<0.01) are seen for both years. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

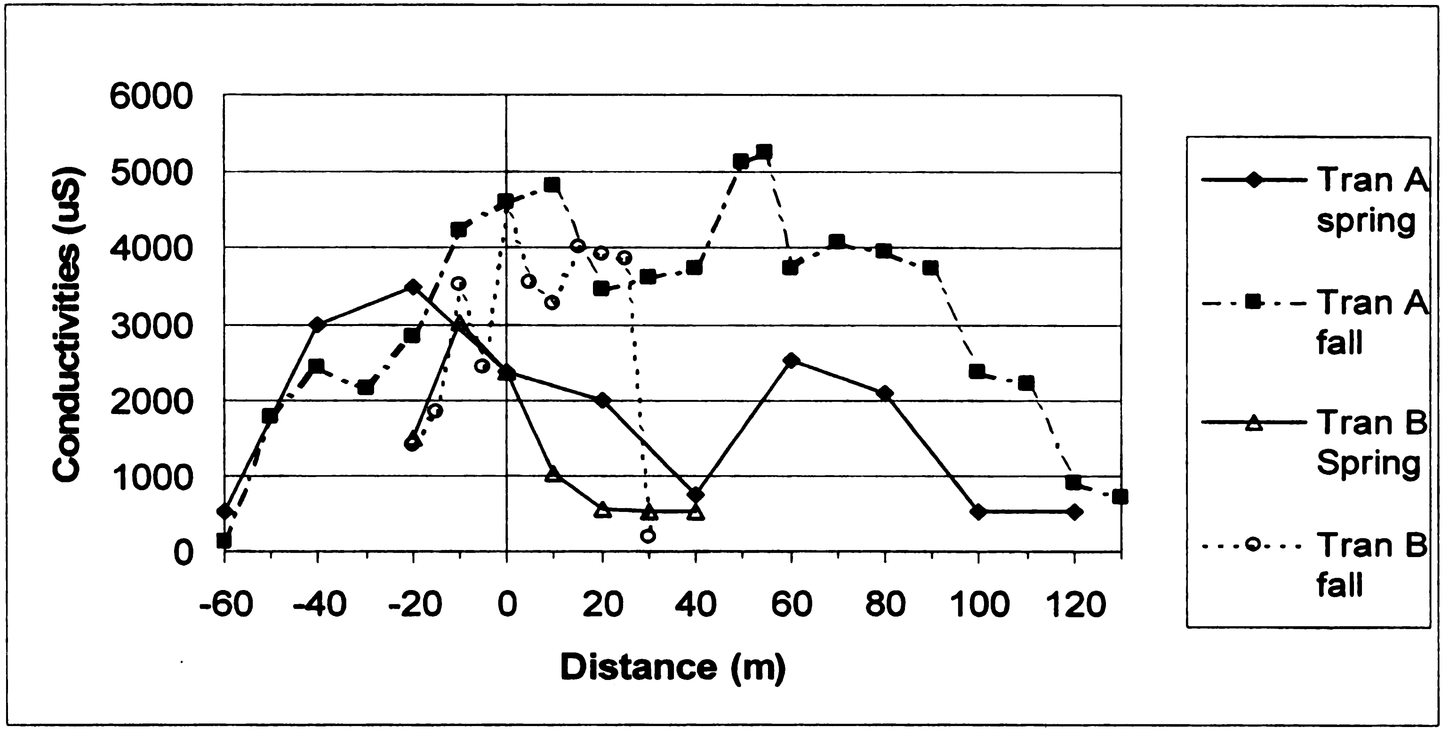

Figure 10. The spring and summer conductivities of the salt seep from summer of 2001 for both transects. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

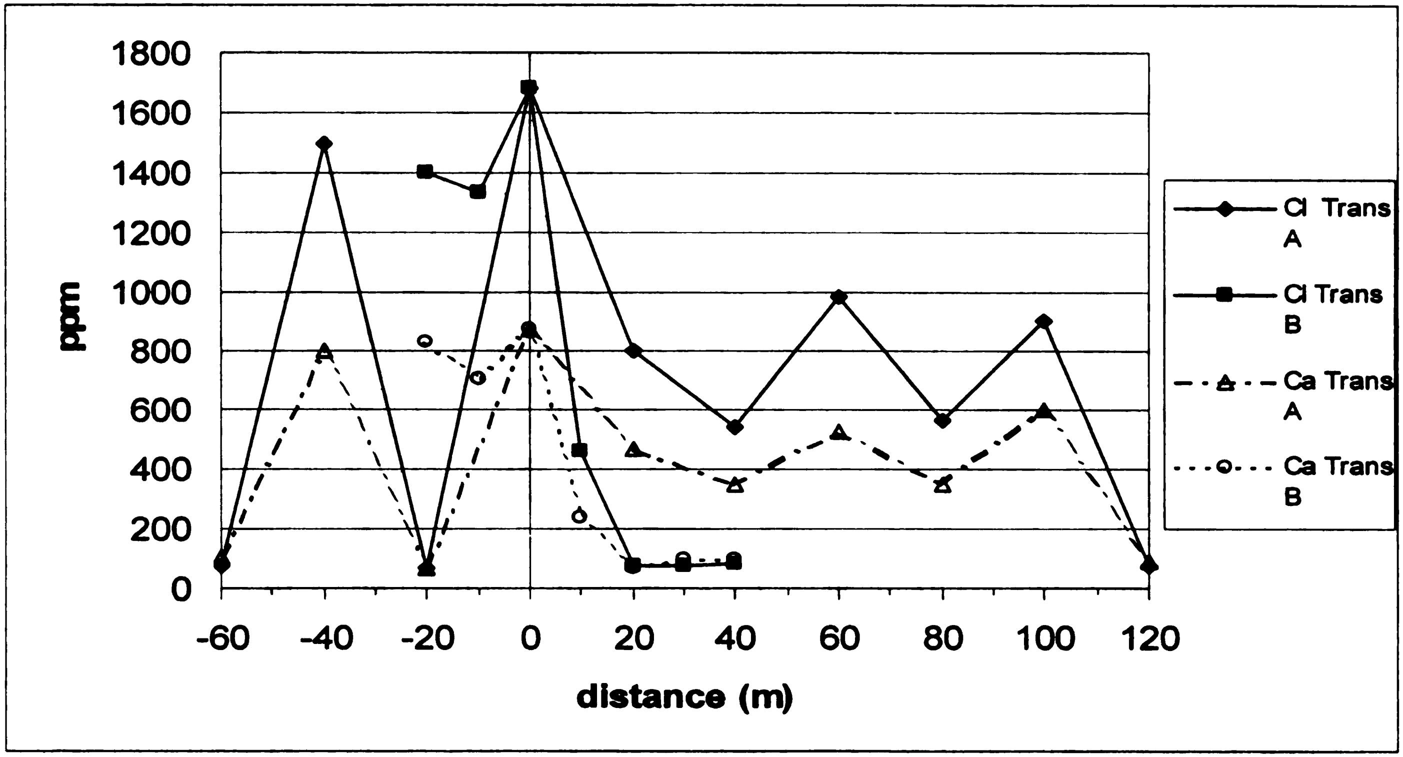

Figure 11. The Cl and Ca concentrations for each transect taken from water samples in the spring of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

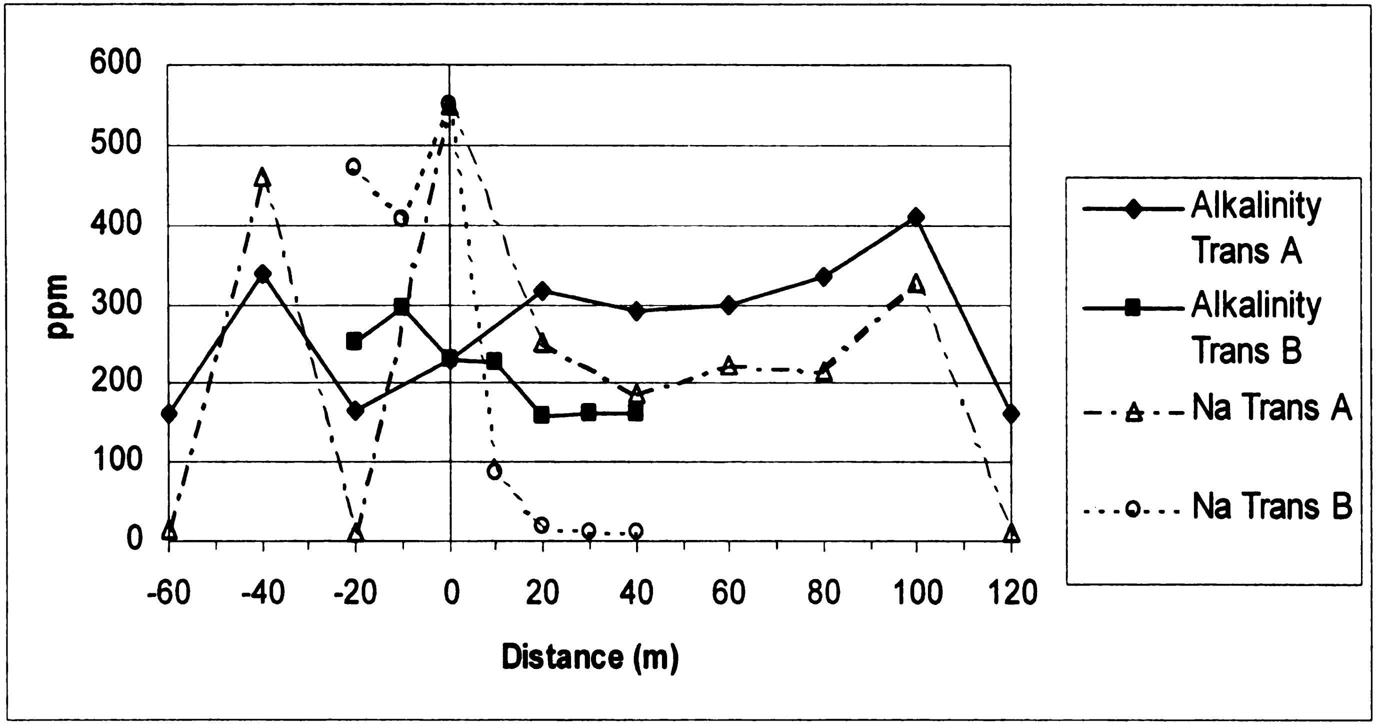

Figure 12. The alkalinity and Na concentrations for each transect taken from water samples in the spring of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

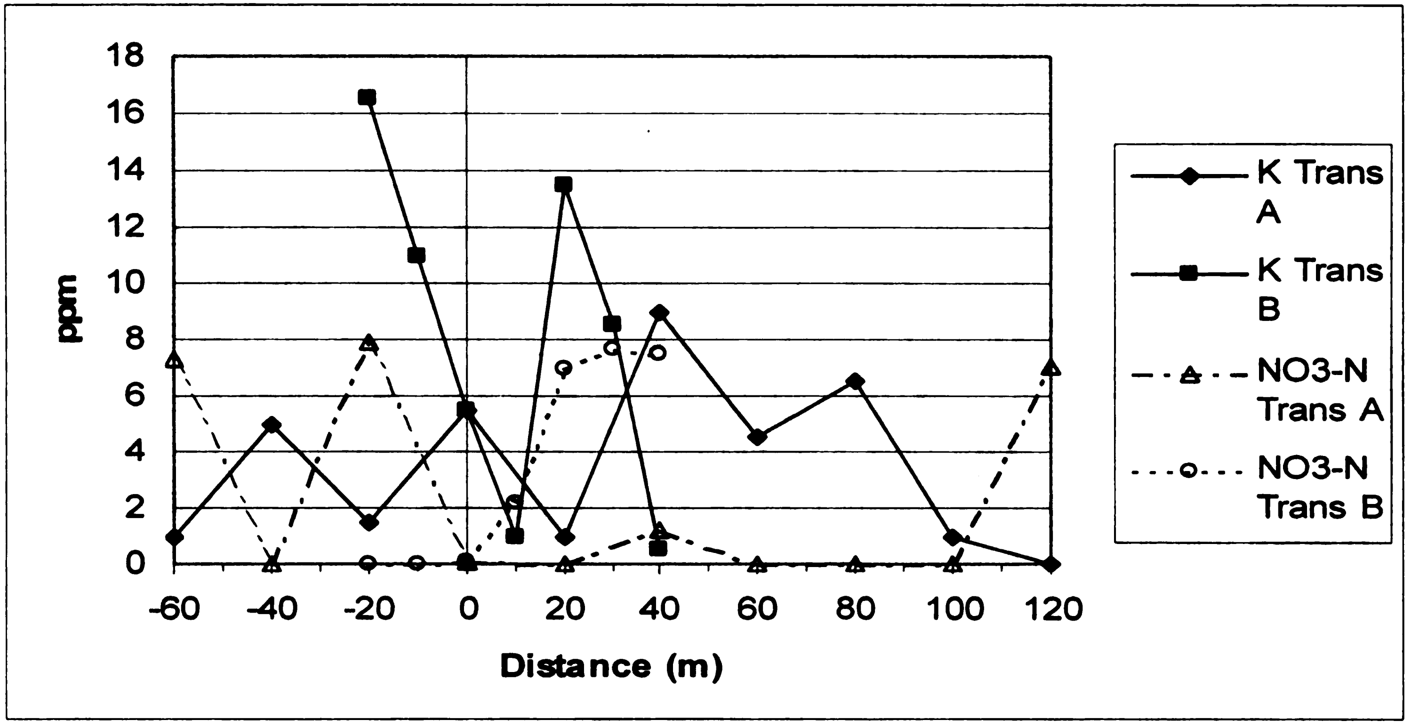

Figure 13. The K and NO_3-N concentrations for each transect taken from water samples in the spring of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

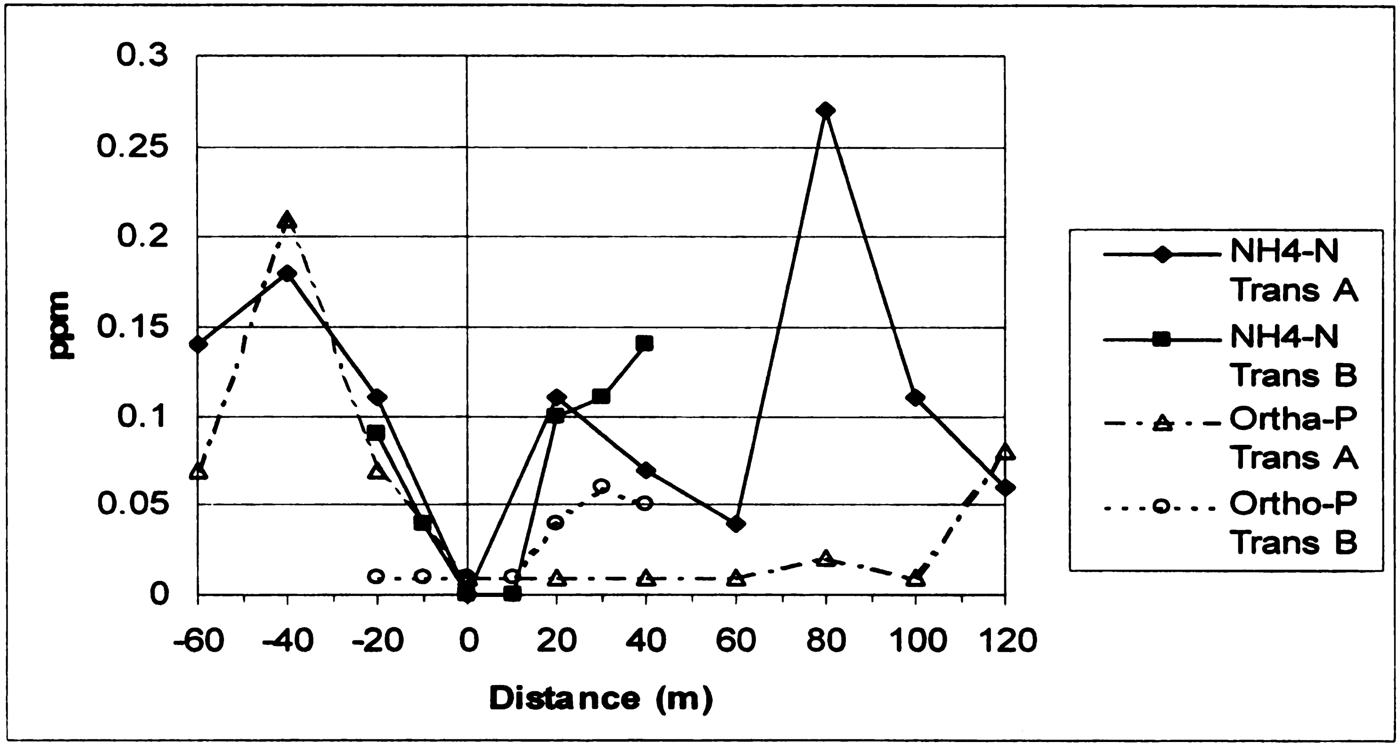

Figure 14. The NH_4-N and Ortho-P concentrations for each transect taken from water samples in the spring of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

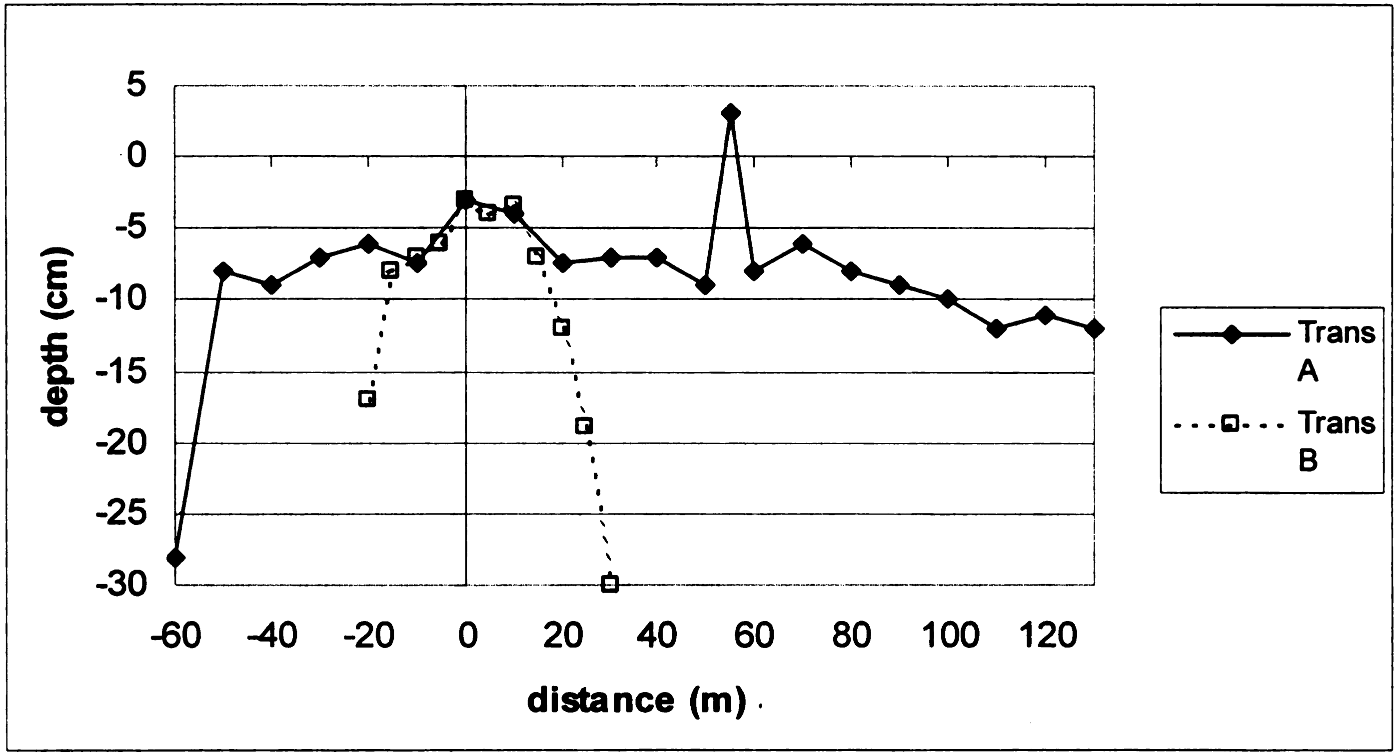

Figure 15. The depth of the water table for each transect measured in the fall of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

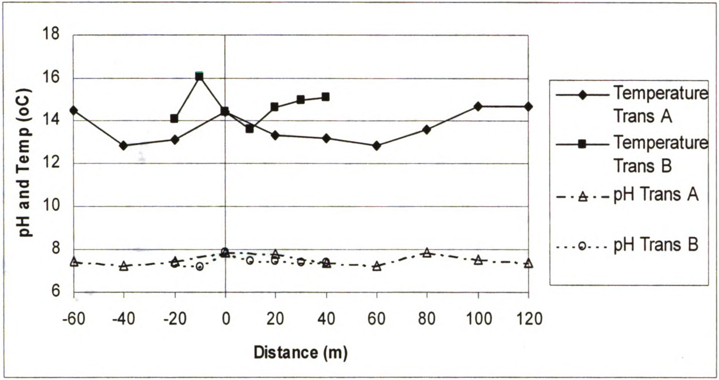

Figure 16. The temperature and pH for each transect taken from water samples in the spring of 2001. The distance at 0m indicates the location of the open muddy area where transect A and B intersected.

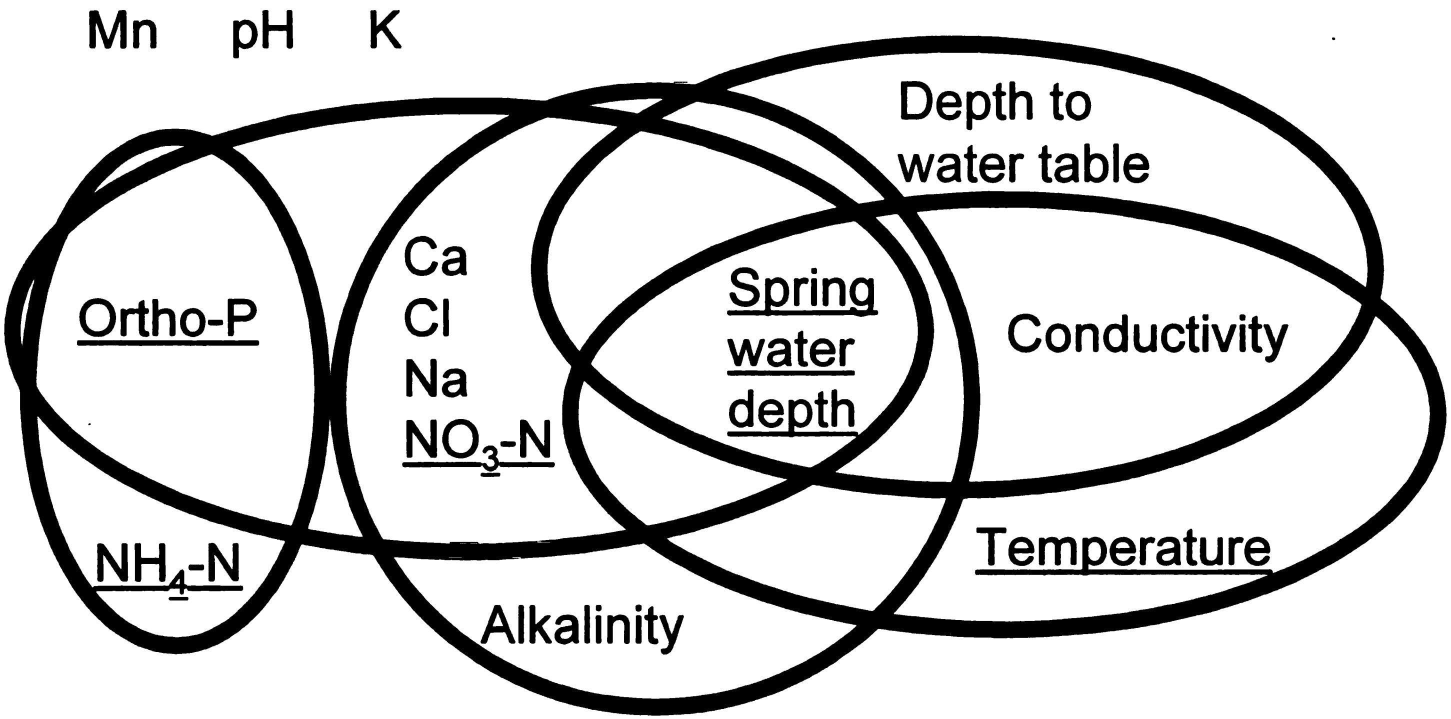

Figure 17. Environmental factors that are correlated are contained within the same circle. Factors in which the words are both underlined or both not underlined are positively correlated, but factors in which one word is underlined and the other is not are negatively correlated to each other. Factors that are not within circles are not correlated to any other factors.

Chapter 3: Water Chemistry and Biota of a Brine Pond Complex in Midland, Michigan

Introduction

Human impacts have increased saline areas in the Midwest by urbanization, road salt runoff, agricultural runoff, municipal and industrial waste discharge, and salt mining (Waisel 1972, Ungar 1974). For example, salting of roads in Wayne County, Michigan, has created saline wetlands with a unique community of non-native salt tolerant species (Reznicek 1980). Commercial salt mining in Michigan began in the mid 1800s (Catling and McKay 1981, Cook 1914, Allen 1918). As a result of mining activities, saline environments with a variety of non-native salt tolerant plants developed (Farwell 1916, Brown 1917).

Another example of a created saline habitat due to industrial use of brine wells is at the Dow Chemical Company in Midland, MI. Spent brine resulting from Dow operations has been released since the 1930s into a constructed pond complex (Figure 1). This 130-acre pond complex consists of four interconnected ponds that are chemically distinct; salinity is lowest in the north-south (N-S) pond and increases in salt levels to the east-west (E-W) and main ponds. The main and outlet ponds are chemically identical and will not be considered as separate ponds in this paper.

The main pond has a layer of inorganic salt sediments ranging from 0 to 15 feet thick (Hydrogeologcial study 1990) covering naturally occurring soils. These sediments precipitated from spent brine and contain NaCl, $CaCl_2$, MgCl, $FeCl_2$, FeOHCl, $CaCO_3$, MgOHCl, $CaSO_3$, and $Mg(OH)_2$ (Physical description 1991). Three colors of sediments are present and all contain large amounts of NaCl, and $CaCl_2$, but vary in concentration of the other salts. $FeCl_2$ is a major component in the dark red-brown sediments, $CaCO_3$ and $CaSO_3$ are highly concentrated in the tan sediments and $Mg(OH)_2$ is a main component of the white sediments (Physical description 1991). A composite sample of sediments was also tested for metals, total organic carbon (TOC), and volatile organic compounds. The Resources Conservation and Recovery Act (RCRA) metals were all below background levels for Michigan, the volatile organics were all below recommended levels for cleanup, and TOC was less than 0.03% (Saxena 1990).

The spent brine water pumped into the ponds during active extraction of salts from brine wells was composed mainly of water and $CaCl_2$ (17.6%), NaCl (6.5%), $Fe(OH)_3$ (4.6%), $MgCl_2$ (3.2%), and $Fe(OH)_2$ (1.6%) (Oct 29, 1971 analysis in Delaney 1989). In January 1989, the average chloride concentration was 35,933 mg/L, sodium was 6,143 mg/L, magnesium was 1,767 mg/L, calcium was 14,567 mg/L, total dissolved solids (TDS) was 62,321 mg/L, total suspended solids (TSS) was 27.7 mg/L, and TOC was 6.3 mg/L (Physical description 1991). No volatile or extractable organic compounds were found in the water (Physical description 1991). Thus, the main chemical components of brines that would have affected the biota in the Dow pond complex during active extraction of brines were water and salt. At the time of this study in 2001, brine extraction had ceased and the brine wells were undergoing remediation by dilution with freshwater resulting in a freshening of the water in the ponds as remediation continued.

Because of differences in salinity in the three ponds in the complex, this brine pond complex represents a unique, highly salinated pond environment found nowhere else in Michigan. Since highly salinated aquatic systems other than those associated with brines resulting from industrial activities, salt mining or oil well drilling are rare in

Michigan, the brine pond provides the opportunity to determine what types of organisms will tolerate and inhabit such environments.

To investigate the organisms present in this saline environment, I surveyed the biota present in and around the brine pond complex. I identified algae, plants, invertebrates, and vertebrates in the N-S, E-W, and main ponds. Also, I compared the water chemistry of each pond.

Objectives and Hypotheses

The first objective of my study was to inventory the biota existing in and around Dow pond complex to determine the nutrient and food web basis. Since the ponds were chemically distinct, I hypothesized that the biota would be different in each pond. I hypothesized that the pond with the freshest water (N-S pond) would have a greater biotic diversity than the more saline ponds (main pond), since few saline environments occur in Michigan that could provide a source of salt tolerant organisms (MNFI). I surveyed rooted wetland plants along pond margins, algal communities in the pond water column and on the sediments, and the animals (vertebrates and invertebrates) living in and around the pond.

Methods and Materials

Site Description

Dow pond: A detailed description of the history and chemistry of the Dow brine pond complex is given above. *Phragmites australis* dominated several areas around the edges of the pond, and *Chara* sp. dominated the N-S and grew in small patches in the E-W ponds.

Survey of Biota - The Dow pond complex was surveyed for benthic (bottom-dwelling) and planktonic (water column dwelling) algae, vascular plants, invertebrates, and vertebrates by sampling along the shores of the four ponds and from a pontoon boat in the main pond. Water samples were taken once in early spring to determine nutrient and salt concentrations in the Dow pond complex. The surface of the sediments in the main pond was covered with a felt-like mat of organic material with algae growing on or in it. Benthic algae were sampled by taking approximately 30 cm^2 sections of this surface mat back to the laboratory for microscopic identification. Planktonic algae were sampled using a standard plankton tow net (64 um mesh size). Samples were preserved in 6:3:1 (60% water, 30% ethanol and 10% formalin) for laboratory identification. Algae were identified by Ms. Kalina Manoylova at Michigan State University.

Invertebrates were sampled using a 500 um mesh, standard D-frame aquatic dip net. Captured invertebrates were preserved in ethanol and taken to the laboratory for identification. Since the main pond is significantly larger than the N-S and E-W ponds, the majority of sampling occurred in the main pond. To standardize for sampling effort, the average number of species per sample was calculated by dividing the total number of species found in each pond by the number of invertebrate or algae samples taken per pond.

Wetland plants were surveyed by recording the plant species present around the pond and mapping the general distribution of these plants around the pond (Figure 1). Visual observations from the shore or evidence of animal use or presence (e.g., deer tracks, toad carcasses) were used to identify vertebrates at the pond.

Results

Water Chemistry - The N-S pond was the freshest of the three ponds in the Dow pond complex (the main pond and outlet pond were grouped as one since they were chemically similar), having the lowest conductivities and TDS concentrations (Table 1). However, specific ions and nutrients were not tested on this pond. The main pond had higher conductivities, TDS, K^+, Ca^{++}, Na^+, and Cl^- concentrations, and the lower nitrate and ammonia concentrations compared to the E-W pond (Table 1). Dissolved oxygen concentrations during the day were often greater than 100 % throughout the pond complex, indicating supersaturation in each of the ponds. Compared to 12 years ago (Table 1), the water in the main pond was fresher in 2001.

Algae - The sediments in the main pond were covered with a thick organic mat of unknown origin. Although the origin of the mat was not specifically determined, it is probable that benthic algae and bacteria accumulating over time formed the organic mat (biofilm) on the pond bottom. The matrix was often more than 15 mm thick and cohesive enough to be pulled up in large pieces. On the west half of the main pond, the mat was textured and colored brown and black. On the east half of the main pond, the mat was slightly thinner, less textured and tan colored. The underside of the mat had a black, felt-like appearance, indicating anaerobic conditions.

The thick organic mat covering the sediments was primarily found in the main pond. The N-S pond was deeper than the main pond and completely covered with *Chara* sp., so no sediments were visible. The E-W pond was deeper than the main pond, however, in shallow areas, thin patches of organic matrix spotted the sediments.

Sixteen species of microscopic algae and one macroscopic alga (*Chara* sp.) were identified in samples from the Dow pond complex (Table 2). Almost all 17 algal species identified were benthic species associated with the organic mat covering the bottom. Very few algae were collected in plankton tows. The main pond contained seven species of diatoms (Bacillariophyta), five species of blue-green algae (Cyanophyta), and one species of green algae (Chlorophyta) (Table 2). The main pond contained the highest number of species, but the N-S pond contained the highest number of species per sample.

Macrophytes - Several dense stands of the common reed (*Phragmites australis*) grew along the edges of the ponds in the Dow pond complex. Most of these stands grew in soil in the corners of the ponds except for one medium sized stand on the western end of the main pond. The largest stand of common reeds grew in the southwest corner of the main pond by Overlook Park (Figure 1) in an area where soil had been pushed into the edge of the pond during construction of the park. In the large stand of common reed in this area, many long rhizomes extended along the soil surface and into the pond water. The rhizomes appeared not to grow in areas where the gel-like substrates that formed the bottom of the ponds in most places were not covered with at least some soil. In other areas, the common reed grew along the apparent high water mark established in prior years with few, if any, stems growing in or near the water. As a result, most of the stands were well away from the water in 2001, since water in the Dow pond was lower than former high water levels during the growing season.

On the west end of the main pond above the water line, a few stems of *Schoenoplectus pungens* (three-square bulrush) were present in one small area of the pond, however, they were not very well established or vigorous. A small patch of *Typha* *angustifolia* (narrow-leafed cattail) was also found above the water line on the west end of the main pond. In the E-W pond, a stand of *T. angustifolia* and *Juncus* sp. (rush) was also found. *T. angustifolia* was very common along the edges of the adjacent waste treatment pond just south of E-W pond.

In the N-S pond, *Chara* sp. (a macro-alga) was very abundant throughout the water column. By late summer, it had moved into the E-W pond. Several ducks were observed feeding in these beds of *Chara*. Invertebrates were also relatively abundant in these *Chara* beds.

Macroinvertebrates - Two families of true flies (Diptera), the biting midges (no-see-ums, Ceratopogonidae) and shore or brine flies (Ephydridae), were widely distributed throughout the pond complex (Table 3). These two families of flies were found as larvae and pupae in all ponds, and were the only invertebrates found in the middle of the main pond. Adult brine flies were also seen in large swarms around the edges of the pond during much of the summer. The biting midge larvae were very abundant in the main pond, but were much rarer in the E-W and N-S ponds, whereas the brine fly larvae were lower in abundances but were more evenly distributed throughout all ponds. Two other families of dipterans, the long-legged flies (Dolichopodidae) and midges (Chironomidae) were found in low numbers from the main pond. Three beetle families (Coleoptera) and one family of true bugs (the water boatmen (Corixidae, Hemiptera)) were found in the main pond. Many of the same species were found in the N-S pond, but macroinvertebrates in this pond also included additional families of true bugs (back-swimmers, Notonectidae), damselflies and dragonflies (Odonata), mayflies (Ephemeroptera), and seed shrimp (Ostracoda). The E-W pond contained the largest number of species including a combination of species collected from the other ponds as well as some additional groups of dragonflies, beetles and water mites (Hydracarina, Arachnida) (Table 3). However, the N-S pond had the greatest number of species per sample, followed closely by the E-W pond.

Vertebrates Observed - No plans were made to quantify use of the ponds by vertebrates during 2001; however, we recorded species observed (Table 4). The most commonly observed vertebrates at the Dow pond were birds. We observed at least 14 species using the ponds or pond berms. These included geese (Canadian and Domestic), swans, mallard ducks, double-crested cormorants, Great blue herons, gulls (probably Herring and Ring-Bill), terns (Least and Common), shore birds (killdeer, dunlin, and unidentified sandpipers), and bank swallows. Several species of waterfowl and shore birds were present throughout the summer. Mixed flocks of birds, especially gulls and terns, were often concentrated on the small island in the middle of the main pond. Mallard ducks with ducklings were seen in the N-S and E-W pond, indicating that this species uses the pond for rearing young.

Mammal use of the Dow pond was either directly observed (woodchucks) or physical signs (e.g. tracks, fecal deposits, decaying carcasses) of them indicated their presence. Deer tracks were commonly seen around Dow pond and a decaying deer carcass was observed along the southeastern shore of the main pond. In the spring, several bloated, toad (*Bufo americanus)* carcasses were seen in the water by Overlook Park. No amphibians were seen in or around the pond any other time

Discussion

Water Chemistry - The major ions in the Dow pond were Cl^- and Ca^{2+}. Ca^{2+} ion concentrations were approximately three times higher than sodium, and more than 10 times higher than potassium. Wetlands with high calcium ions are not uncommon in Michigan, however, the high concentration found in the main pond of the Dow Brine Pond Complex (about 100 times higher concentration) is unique (Schwintzer and Tomberlain 1982). The Main pond had TDS concentrations (17-25 g/L) 3 times as high as the E-W pond, and 4 times higher than the freshest N-S pond. The conductivity in the main pond (24-38.5 mS) was twice as high as the E-W pond and four times higher than the N-S pond.

Compared to concentrations of natural saline areas in Michigan such as the Maple River salt seep (see Chapter 2), the conductivities in the N-S pond (2-9.5mS) were comparable to the *Schoenoplectus* dominated areas at the seep (1.8-5mS). Ocean water has a TDS around 35g/L, about 1/3 to ½ times more concentration than the Dow main pond. Similar to the Dow pond, the main anion is Cl^-, but the main cation in ocean water is Na^+ not Ca^{2+} (Fortescue 1980).

The chloride concentration in the E-W pond is higher than the TDS values. The ion concentrations were measured only one time, whereas several TDS samples were taken throughout the summer, so the individual chloride ion concentrations are unconfirmed. Additional testing should be done to resolve this discrepancy.

Algae - Only 17 algal species were found in the Dow pond complex. This is relatively low species richness compared to most freshwater systems (Stewart et al. 1999). Many freshwater systems support from 100-300 species of algae (Stewart et al. 1999), however, the diatom community in various saline habitats can range from 10 species to 100 species (Blinn 1993, Sullivan 1975, Cumming and Smol 1993). Thus my findings of 10 diatom species is on the low end compared with other studies.

Despite the low species richness of algae, they appear to be abundant enough to supersaturate the water with oxygen (% oxygen saturation of the pond water exceeded 100% during the day). Such supersaturated conditions indicate high rates of primary production. Oxygen produced by photosynthesis has to exceed loss of oxygen to the atmosphere and respiration of all organisms in the pond for supersaturation to occur.

Most of the diatom species identified are wide spread and inhabit a wide variety of habitats, including saline habitats (Cumming and Smol 1993, Sullivan 1975, Patrick and Reimer 1966). However, one species *Eunotia incisa* is often found in cool, clear water with low dissolved mineral contents, especially low contents of calcium (Patrick and Reimer 1966). Thus, this pond with high mineral contents is an atypical habitat for this diatom species. The diatom, *Cymbella sp.*, was found in all ponds. This unidentified species of *Cymbella* (Fig. 2) was an unusual species rarely found in the Midwestern lakes or ponds. Ms. Kalina Manoylova, a Ph.D. student at Michigan State University who is doing her dissertation on evolution of this genus, identified the algae for me. She has never seen this species before despite having identified algae from around the world.

The blue-green algae found in this pond have salt tolerant species (*Lyngbya* spp. and *Spirulina* spp., Prescott 1968) or survive in habitats such as stagnant pools or polluted waters (*Oscillatoria* spp., Smith 1933, Prescott 1968). However, *Chroococus turgidus* is normally found in acidic, soft water with a low Ca:K ratio such as *Sphagnum* bogs (Prescott 1968, 1978). This pond is an atypical habitat for this species of algae due to the high Ca and mineral content and slightly basic pH.

Two species of green algae were found. *Chara* spp. are widely distributed and found both in fresh and brackish waters (Prescott 1978). *Cosmarium* is the largest genus of green algae and contains thousand of species (Prescott 1978).

Macrophytes - The species richness of macrophytes in the Dow brine pond complex was extremely low (four species). All the species found are considered salt tolerant (see App. A). Even though saline habitats generally have low species richness of vascular plants (Ungar 1991), four species is still lower than the species richness reported for many saline habitats (Mitsch and Gosselink 2000, Shupe et al., 1986). *Phragmites australis* was the dominant plant around the edges of the Dow pond complex. This species tends to be an aggressive weed that is commonly found along roadsides throughout Michigan. It can dominate an entire wetland (Hammer 1992). It is also known to tolerate salinity levels as high as 27.5 ppt salinity (Chapman 1974). Therefore, the dominance of this species in the plant community around the brine pond complex is not surprising.

The brine pond complex was not completely surrounded by vegetation (Figure 1), and only *Chara* sp. (a macroalgae) was found in the N-S and part of the E-W ponds. No plants, submersed or emergent, were found in the main pond even though the main pond was 1-2 feet deep, suitable for some wetland plants. The gel-like sediments may have inhibited plant establishment, and a top layer of topsoil may be needed for plants to inhabit the pond.

The high salt content of this pond limits the growth of most native Michigan wetland plants (App. I). In addition, non-native plants from coastal areas may not adjust to the differing salt content of this pond (high Cl and Ca) compared to ocean water (high Cl and Na, Fortescue 1980). In addition, germination of seeds, which is likely the main mechanism by which plants have come into this area, is strongly inhibited by high salinity such as in the Dow pond (Ungar 1991)

Invertebrates - The greatest species richness of invertebrates (12 species) was found in the E-W pond, and lowest richness (8 species) was found in the main pond. If these data are corrected for sampling effort (number of species per sample), the N-S pond had the highest number of species per sample (4.5 species/sample) closely followed by the E-W pond (4 species/sample). The biting midges, Ceratopogonidae, were most abundant taxon in the main pond, but their numbers decreased as the ponds became fresher, being nearly replaced by midges, Chironomidae in the N-S pond. In the fresher waters of the N-S pond, Ephemeroptera (mayflies) started to appear. The Odonata (dragonflies and damselflies) were found in the N-S pond and the moderately salty E-W pond.

Dipterans, and some members of nearly every family of aquatic beetle, Coleoptera are tolerant of salty water (Ward 1992). In contrast to my data, Ward (1992) found that Chironomidae tended to be more salt tolerant than Ceratopogonidae. Odonates, especially the dragonflies (damselflies are more rare) and the true bug (Hemiptera) families of Corixidae and Notonectidae, are moderately tolerant of brackish water (Ward 1992). Tricopterans and the Ephemereoptera family of Baetidae have a lower tolerance of brackish water (Ward 1992). These salinity tolerances of invertebrate groups fit well with my results.

The mean tolerance values for families indicated for North Carolina stream biotic index indicated Odonates to be the most tolerant species of environmental stress, followed by miscellaneous Dipterans, Coleoptera, Chironomidae and Ephemeroptera (Lenat 1993). Hemipterans were not included in this study (Lenat 1993). Hilsenhoff's tolerance classes developed for Wisconsin streams suggested that Chironomidae are the most tolerant, followed by Odonata, Coleoptera, and miscellaneous Diptera, with Ephemeroptera being the least tolerant (Hilsenhoff 1987). Not surprisingly given the close proximity of Michigan and Wisconsin, Hilsenhoff's (1987) tolerance classes for Wisconsin fits my data better than do the Lenat's (1993) tolerance classes for North Carolina. Since the tolerance classes of Hilsenhoff and Lenat were primarily for stream habitats, they may not apply to ponds and wetlands, which may have different biotic indices than do stream habitats. Despite the fact that neither Hilsenhoff nor Lenat worked specifically with salinity as a stress, the species that occurred in the Dow Brine Pond complex included species listed by these authors as tolerant of stress.

The N-S pond was covered by the macroalga, *Chara* sp., which increases habitable areas for invertebrates (Krecker 1939, Rosine 1955). This increased habitat complexity and the fresher water in this pond may explain why it supported the greatest number of invertebrate species per sample of any pond in the brine pond complex. Inundated areas of the E-W pond had patches of bare sediment without *Chara* interspersed with areas with *Chara* present, whereas the main pond had no *Chara* present throughout. Similarly, species of invertebrates present were greatest in the N-S pond, intermediate in the E-W pond and lowest in the main pond. In the main pond, Ephydridae and Ceratopogonidae were found throughout the pond, while all other invertebrate families were found by the *P. australis* stand on the west end of the main pond. This again suggests that invertebrate species richness was affected both by salinity and habitat complexity associated with growth of macrophytes in or near the margin of the pond.

Vertebrates - In the spring, several bloated toad (*Bufo americanus)* carcasses were found in the water in main pond by Overlook Park. They may have entered the water to breed and not been able to leave because of rapid, osmoregulatory driven changes in body fluids due to the salt concentrations in the pond. No live amphibians were seen in the ponds. Thus, this habitat is probably not suitable for amphibians.

Birds and deer (deer prints were frequently seen) use the Dow pond. Birds were seen most often on or near the island and the berms in the main pond. Terns were seen diving, indicating feeding most likely on the invertebrates in the pond (Robbins et al. 1983). Ducks and geese were most often seen in the E-W and N-S ponds. These ponds had macrophytic algae, *Chara* sp., and a larger variety of invertebrates on which to feed.

In general, the biotic diversity of algae, plant and animals increased as the pond water freshened with the N-S pond having the greatest diversity in the pond complex. If the pond complex water continues to freshen as it has since the last survey done in 1989 (Table 1), it is possible that the main pond could support a greater amount of diversity as seen in the N-S and E-W ponds, especially if the main pond becomes fresh enough to become suitable habitat for Chara or other species of macrophytes.

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Table 1. Water chemistry of the individual ponds in the Dow brine pond complex in 2001 compared to data from January 1989 (Physical description 1991). The main pond and outlet ponds were combined since they were chemically similar. "n.d." indicates non-detectible, and "—" indicates parameters not sampled.

Parameters	N-S pond	E-W pond	Main Pond	Jan 1989 data
TDS (g/L)	2-6	3.5-8	17-25	61.8-62.7
Conductivity (mS)	2-9.5	5.5-16.5	24-38.5	—
NO_3 –N (mg N/L)	—	0.33	0.13-0.24	—
NH_4 –N (mg N/L)	—	2.94	0.69-0.77	—
Potassium (K, mg/L)	—	329	414-441	—
Calcium (Ca, mg/L)	—	4408	5400-5795	13,600-16,300
Ortho-Phosphorus (mg/L)	—	n.d.	n.d.	—
Manganese (Mn, mg/L)	—	0.2	0.2	—
Sodium (Na, mg/L)	—	1377	1728-1874	5240-7860
Chloride (Cl, mg/L)	—	10,600	12,315-14,065	34,700-36,800
Dissolved oxygen (mg/L)	—	—	7.77-8.74	—
% oxygen saturation	—	—	92.9-103	—
Alkalinity (mg $CaCO_3$/L)	—	—	67-75	—
pH	—	—	8	—

Table 2. Algal species collected from at the Dow pond complex, including the number of samples (in parentheses), location (Main, E-W, and N-S), total number of species and average number of species per sample in which each species was found. The "X" indicate a species was present and "—" indicates the species was absent from a location

Division	Species	Frequency (14 samples)	Location		
			Main(11)	E-W(2)	N-S(1)
Cyanophyta (blue-green)	*Chroococcus turgidus*	2	X	—	—
	Lyngbya lagerheimia	1	X	—	—
	Oscillatoria minnesotense	5	X	—	—
	Oscillatoria tenuis	1	X	—	—
	Spirulina major	5	X	—	—
Bacillariophyta (diatoms)	*Achnanthes minutissima*	2	—	X	X
	Amphora libyca	1	X	—	—
	Amphora sp.	1	X	—	—
	Anomoeoneis vitrea	2	—	X	X
	Cymbella microcephala	1	X	—	—
	Cymbella sp.	10	X	X	X
	Denticula cf. kuetzingii	2	—	X	X
	Eunotia incisa	1	X	—	—
	Navicula sp.	5	X	X	—
	Navicula tripunctata	1	X	—	—
Chlorophyta (green)	*Chara* sp. (macroalgae)	1	—	X	X
	Cosmarium cf. minor	2	X	—	X
Total # species			13	6	6
Avg # spp/sample			1.2	3	6

Table 3. The orders and families of macroinvertebrates found in the Dow pond complex showing the number of samples (in parentheses), locations (Main, E-W and N-S), total number of species found and number of species/per sample in which each family was found. An "X" indicates presence and "—" indicates absence in a location.

Order	Family	Frequency (13 samples)	Location Main(8)	E-W(3)	N-S(2)
Diptera (true flies)	Ceratopogonidae	12	X	X	X
	Ephrydridae	12	X	X	X
	Chironomidae	8	X	X	X
	Dolichopodidae	1	X	—	—
Coleoptera (beetles)	Dytiscidae	4	X	X	X
	Elmidae	1	X	—	—
	Hydrophilidae	1	X	—	—
	Haliplidae	1	—	X	—
Hemiptera (true bugs)	Corixidae	3	X	X	—
	Notonectidae	2	—	X	X
Odonata (dragonflies and damselflies)	Coenagrionidae	5	—	X	X
	Corduliidae	2	—	X	X
	Aeshnidae	1	—	X	—
Ephemeroptera (mayflies)	Baetidae	1	—	—	X
Ostracoda (seed shrimp)		3	—	X	X
Arachnid (water mites)	Hydracarina	1	—	X	—
Total # of species			8	12	9
Avg # spp/sample			1	4	4.5

Table 4. Vertebrates found at the Dow pond.

Birds	
Bank swallow	Gulls
Canada geese	Killdeer
Common tern	Least tern
Domestic geese	Mallards (with ducklings)
Dunlin	Sandpipers
Double-crested cormorant	Swan
Mammals	
Woodchuck	Deer (tracks)
Others	
Toads (deceased)	

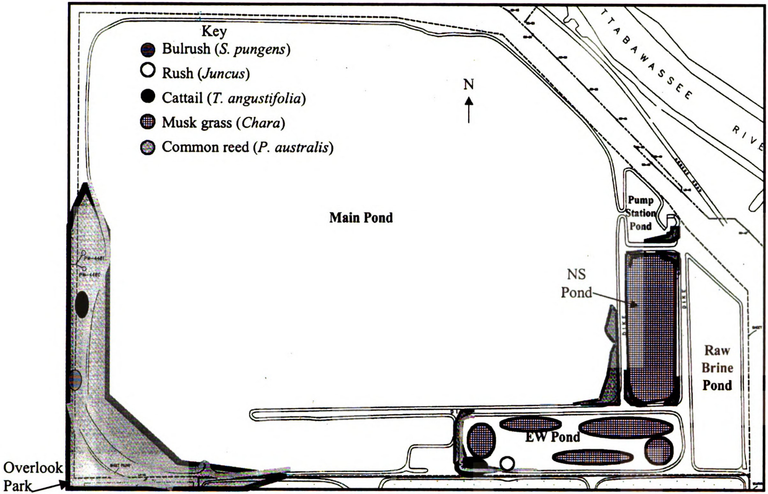

Figure 1. Layout of the Dow pond complex showing the location of plant species.

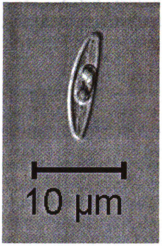

Figure 2. Unknown *Cymbella* spp. of benthic diatom algae that was common found in the Dow pond.

Chapter 4: Growth of Salt Tolerant Plants in a Brine and Storm Water Pond in Michigan

Introduction

Environmental conditions strongly influence the composition and structure of a plant community. In ponds and wetlands, plants must deal with the stresses of saturated or inundated soils in which oxygen levels in the root zone are low (Sculthorpe 1967). In salty environments such as along ocean coastlines, plants must deal with high osmotic pressures in the external environment caused by high salt concentrations, in addition to dealing with low oxygen levels in the root zone (Waisel 1972, Queen 1974). Plants have developed several mechanisms to deal with high salt including: succulence (Ungar 1991), accumulation of ions or organic compounds (Broome et al. 1995, Ewing et al. 1989), secretion of salts by salt glands or salt hairs (Waisel 1972), and selective or restrictive ion absorption (Queen 1974, Ungar 1991).

In the wetter regions of the midwestern United States, saline wetlands and ponds are historically rare, usually only occurring over fossil salt beds or in the vicinity of salt springs (Waisel 1972). Thus, few native halophytes occur in these areas (Catling and McKay 1981). However, human impacts have increased saline areas in the Midwest by urbanization, road salt runoff, agricultural runoff, and municipal and industrial waste discharge (Waisel 1972, Ungar 1974, Williams et al. 1997).

The brine pond at the Dow Chemical Company in Midland, Michigan, has been strongly impacted by salinity. Since highly salt impacted areas are relatively rare in Michigan, this pond provided an opportunity to investigate types of plants that could tolerate this habitat after being transplanted into it.

The objective of this study was to identify salt tolerant, native Michigan vascular plants that could be used to create wetlands along the margins of the Dow brine pond complex. I assumed that diversifying the plant community would enhance wildlife habitat and encourage use of the pond by a greater diversity of organisms. I hypothesized that native Michigan wetland plants with a high salt tolerance could be used to establish and expand wetland habitat in and around the Dow pond. Four species of emergent wetland plants: common reed (*Phragmites australis*), narrow leaf cattail (*Typha angustifolia*), three square bulrush (*Schoenoplectus pungens*), and Olney's three square bulrush (*S. americanus*) were used in the transplant study.

Methods and Materials

Site Description

Dow pond - The structure, water chemistry and biota of the Dow brine pond complex are discussed in detail in Chapter 3. An open sandy bank of the main pond was selected for the transplanting experiment (Figure 1). This area had been submerged by pond water in 2000 and prior years according to Dow employees, but water levels had not reached this area in 2001 by the time the rhizome/stem sections of the four selected plant species were transplanted into plots for the experiment. Based on conversations with DOW employees, I assumed that this area would be inundated during the growing season. Unfortunately, this proved to be an incorrect assumption. All growth experiments occurred in the main pond of the Dow brine pond complex (Figure 1). The main pond will be referred to as the "Dow pond" in this chapter.

MSU pond - A storm retention pond, called the "MSU pond," was constructed on the campus of Michigan State University (MSU) to treat runoff from a newly constructed parking lot. The parking lot was constructed across Farm Lane road from the MSU Pavilion south of the Turf Grass Research Facility south of Mt. Hope Road. Runoff from the newly constructed parking lot was routed via a grassy swale into the pond, which was constructed east of the parking lot. In addition, an agricultural tile was intercepted and water from it was routed through the swale and pond to insure that the pond had sufficient water in it to support wetland vegetation. Since the edges of this newly constructed pond consisted of bare sediment, I was able to use the MSU pond as a non-saline reference for the transplanting of three of the emergents planted at the Dow pond (Figure 2). The purpose of this reference was to demonstrate whether these species could successfully be transplanted from the source populations into a freshwater environment following the same time schedule and procedures used for transplanting these species into the Dow pond. I elected not to transplant the fourth species, *Phragmites australis,* into this pond given its invasive nature and the desire of project planners to have a more diverse population of native plant species around the MSU pond.

Prior to the transplanting experiment, the MSU pond had a heavy bloom of green algae and some small patches of sedges and smartweed growing around the pond edges. Twenty feet or more of bare soil surrounded the pond. Later, grass seed and fertilizer were spread on the bare soil; however, very little grass had grown by the end of the first season.

Selection of Salt Tolerant Plants - A literature search revealed salt tolerant wetland plants that grow in Michigan (App. A). In addition, surveys of a natural salt seep community growing along the Maple River in Clinton County, Michigan (see Chapter 2), and the existing plant community at the Dow pond were used to select four species of emergent wetland plants to test in the transplant experiment at the Dow pond. The emergent plants were chosen based on four main criteria: 1) high salt tolerance, 2) availability of source populations, 3) native to Michigan, and 4) usefulness of plant structure to provide wildlife food and habitat.

Growth Studies - Two growth experiments were conducted in the Dow main pond using plots constructed of topsoil and potted emergent plants placed in shallow water (Figure 1). The four plant species chosen for the emergent plant experiments were *S. pungens* (three-square bulrush), *S. americanus* (Olney's bulrush), *Typha angustifolia* (narrow leaved cattail), and *Phragmites australis* (common reed). All of these except *S. americanus* were already growing in or near the water at the Dow pond.

Plugs of *S. pungens* and *T. angustifolia* were obtained from wetlands along Saginaw Bay. *S. americanus* plugs were obtained from a natural salt seep on the Maple River in Clinton County, Michigan. *P. australis* plugs were transplanted from one of several dense stands growing around the perimeter of the Dow pond.

Transplanting the plugs of the four emergent species at the Dow pond did not occur until mid-summer (June 26, 2001 for *T. angustifolia*, *S. pungens*, and *P. australis*, and June 27, 2001 for *S. americanus*). Transplanting stems that late in the season (beyond mid-summer) can prevent successful transplanting (Hammer 1992). To determine whether transplanting could be successfully done this late in the season, plugs of the two bulrushes (June 18 for *S. americanus*, and June 26 for *S. pungens*) and *T. angustifolia* (June 21, 2001) were transplanted to plots set up at the MSU pond (Figure 2). The two species of bulrush came from the same source populations as the plants at the Dow pond; however, the *T. angustifolia* came from a marsh on the MSU campus.

The common reed was not transplanted into the MSU pond, since it is a highly invasive species that spreads easily and is difficult to control (Sculthorpe 1985, Hammer 1992).

At the Dow pond, each of the emergent species was transplanted into three replicated experimental plots constructed on shallow areas of the main pond that were exposed during low water conditions (Figures 1, 3 and 4). Topsoil was obtained locally and hauled to the site by Dow contractors. Six inches (15 cm) of topsoil were spread out along the shore in two areas that were expected to be inundated by rising water as the pond was filled during the summer. The nine plots were constructed in a 3 x 27 yd area away from the dense stands of common reed that grew along the shore (Figure 2). Each of the nine plots (three plots allocated to *T. angustifolia*, three allocated to *S. americanus*, and three allocated to *S. pungens*) measured 3 x 3 yd. The treatments (species transplanted) were randomly assigned to each of the nine plots. The three plots for the *P. australis* were constructed in a 3 x 9 yd area with the same plot dimensions used for the other three species (9 yd^2, 6 inches topsoil depth) but were placed adjacent to an existing reed stand (Figure 1). Each plot contained 15 plugs for a total of 45 plugs for each species. These plugs contained one or more rhizomes and stems of the species being transplanted.

The individual plots at the MSU pond were similarly designed to those at the Dow pond (Figure 2 and 3). However, each species was not randomly assigned to plots, but grouped in one area with an empty plot between each planted plot (Figure 2). Since the pond was already covered with topsoil, the plots could be more widely spaced. The plugs were planted at the edge of the pond under the water, and were covered by about 5 cm of water for most of the summer.

Based on my understanding of water depths in the Dow pond in previous summers, I assumed that the plots would be inundated within a few weeks of transplanting the plant plugs. However, flooding of the plots did not occur during the 2001 growing season. Since the plots at the Dow pond were not in the pond water, the plots were watered starting July 16 with fresh water at the rate of 0.25-0.5 inches of water/day, 5 days/wk so that the transplants could become established before being exposed to brine from the pond. Then starting in mid-August, the plants were watered 5 days/wk with 0.25-0.5 inches of saline water pumped from the Dow Pond until November 1, 2001.

The numbers of surviving and new stems, based on being green in color and/or having new shoots or leaves, were recorded for each plug. Maximum stem lengths were measured periodically from time of transplanting until October 10 at the Dow pond. The number of live plugs was based on the presence of live stems. Stem heights were measured only if they were whole, upright stems (not bent or cut). The stem lengths were not measured on the day they were transplanted, but were measured up to one week later.

The number of surviving stems and stem lengths were also recorded periodically at the MSU pond until August 8. Counting of stems was stopped at the MSU pond because the stems became so numerous and spread out that they were difficult to count and made the individual plugs indistinguishable. Toward the end of the summer, a random sample of over 50 plant heights for all three species was taken at the MSU pond to compare to the Dow pond populations. Random samples were taken by tossing a stick into the plot and measuring heights of the nearest three stems. Also, measurements of stem height from the *S. americanus* population at the salt seep on the Maple River were randomly sampled to compare to the MSU and Dow pond populations.

Pot experiment - Since pond water depth never increased enough to inundate the plots during the summer, a second experiment was initiated in late July with three of the emergent plants (excluding *P. australis*). Six pots per species with one plant plug per pot were placed in the edge of the main pond so that the base of the plant was inundated but the stem extended above the water line. An additional six pots were placed in a wetland pond on the MSU campus as a control. The condition of the transplanted stems (live and growing, dead, senescent) or growth of new stems in each pot was recorded periodically until October 10, 2001.

Statistical analyses - Statistical analyses on species specific data were performed using Systat 8.0. Paired Student's t-tests were used to determine differences between number of live stems per plug and stem lengths per plug for all plots combined on each sampling day within the same population (Dow or MSU). Differences between the Dow and MSU pond populations for the average number of live stems per plug and average stem lengths per plug were determined using a two-group independent t-test. Differences among the three plots within the same population on the same sampling date were determined using ANOVA. Finally, the different stem lengths between *S. americanus* populations (Dow, MSU, and Maple River salt seep) were determined using a two-group independent t-test. Significant differences were determined at $p<0.05$.

Results:

Water Chemistry – The results of the water chemistry are shown in Table 1. The MSU pond had higher dissolved oxygen and % saturation than the Dow pond, although both were supersaturated. Conductivities were the highest at the Dow pond, followed by the Maple River salt seep, from where the *S. americanus* plant plugs were taken. The MSU pond had the lowest conductivity of all three areas. The Dow pond had very low alkalinity indicating low buffering capacity, but the MSU pond and Maple River seep were comparable. The pH and chloride ion concentration was also highest in the Dow pond, whereas the other two sites were lower. Nitrate concentrations were much higher at the MSU pond, than at the other sites, but ammonium was higher at the Dow pond. Several ion concentrations were not measured at the MSU pond; however, the Dow pond had much higher ion concentrations than the Maple River salt seep (Table 1).

Plot experiment - The results of the plot growth experiments are presented in Figures 5-19 and Tables 2-4. The results for *T. angustifolia* are shown in Figure 5-6. At the Dow pond, this species did send up new shoots while the plots were being watered with freshwater (57% increase), even though 8 of the 45 plugs appeared dead (Table 2). However, the total number of stems declined after the plots were watered with saline water from the main pond and an additional 6 plugs appeared dead (see Table 2, Figure 5). Average maximum stem length decreased while being watered with fresh water but increased after being watered with pond water (Figure 5).

Typha angustifolia at the MSU pond significantly increased the total number of living stems by 284% over the summer and only one plug appeared dead (Figure 5, Table 2). Stem lengths decreased over the summer (Figure 6). In comparing the two populations on similar sampling dates, the population at MSU had higher average numbers of living stems initially and at the end of the summer. Initial stem lengths were significantly longer at the MSU pond. Stem lengths were significantly shorter at the Dow pond both after fresh watering and salt watering (Table 3 and 4).

Results for *S. americanus* are shown in Figures 7-9. Live stems at the Dow pond increased 16% over the entire summer, even though the number of live plugs decreased by 7 (Table 2). The total number of live stems continued to increase although live plugs decreased by 3 even after the first sampling with pond salt water. Only in the final sampling did total number of live stems decrease and two more plugs appeared dead giving a total of 38 live plugs at the end of the summer (Table 2, Figure 7). Stem lengths also increased over most of the summer after an initial decrease. (Figure 8).

At the MSU pond, *S. americanus* live stems and stem lengths increased over the summer (Figures 7 and 8). This species had the highest growth rate of all the species with an increase of 1444% in total number of live stems over the summer and only one plug appeared dead (Table 2). Initially, the average number of live stems and stem heights were similar for the populations at both ponds (Table 3). Later in the summer, the MSU pond had significantly more live stems and taller stem lengths than at the Dow pond both before and after watering with salt water (Table 4). Comparing the stem lengths to the source population by the Maple River, the MSU pond had similar stem lengths, but the Dow pond had significantly shorter stem lengths both before and after salt watering. Stem lengths were significantly longer at the Dow pond after watering with salt water than before salt watering. (Figure 9).

S. pungens responded poorly to transplanting at the Dow pond plots. The total number of live stems decreased after the first two samplings, but remained stable the rest of the summer, until it decreased again in the final sampling (Figure 10, Table 2). The number of live plugs decreased greatly with this species, from an initial transplanting of 45 plugs to 7 plugs by the end of the summer (Table 2). Stem lengths decreased significantly after the first sampling; but began to lengthen after being watered with pond water (Figure 11).

The number of stems increased by 477% over the summer for *S. pungens* at the MSU pond (Figure 10, Table 4). Average stem lengths maintained the same length except for a small dip in the third sampling (Figure 11). The number of live plugs decreased by four (to 41 live plugs) over the summer (Table 2). The initial average number of live stems was higher at the MSU pond than at the Dow pond, but stem lengths were similar when comparing both populations (Table 3). The number of live stems and the stem lengths were much greater at the MSU pond than at the Dow pond later in the summer (Table 4).

Despite being well established in many stands around the Dow pond complex, *P. australis* responded poorly to transplanting. The total number of live stems decreased greatly after transplanting and decreased by 85% over the summer (Figure 12). The number of live plugs also had a large decrease of 41, only 4 live plugs remained at the end of the summer (Table 2). The average number of live stems decreased even more after being watered with saline pond water (Table 2, Figure 12). The average stem lengths were not significantly different throughout the summer (Figure 13).

The average number of live stems per plug in each of the three plots per plant species were not significantly different for most sampling dates. However differences were seen on a few sampling dates for *T. angustifolia* at both the Dow and MSU ponds (Fig. 14 and 15, respectively), for *S. americanus* at the Dow pond (Fig. 16), and for *S.*

pungens at the MSU pond (Fig. 17). The only significant differences in average stem lengths per plug for the three plots per plant species was seen in the *T. angustifolia* plots at the Dow pond (Fig. 18) and in *S. americanus* at the MSU pond (Fig. 19).

Pot experiment - Because of problems with the transplanting experiment (i.e., pond water not reaching the plots at the Dow pond), a pot growth experiment was set up. This experiment was conducted very late in the growing season (late July). After the first weeks at the Dow pond, above ground stems of all three species appeared dead. However, a week later *S. americanus* had a new shoot appear. After four weeks, *S. americanus* had two new shoots per pot (12 shoots total) and *T. angustifolia* had one new shoot for all six pots. *S. pungens* had no shoots and appeared to be dead.

Six pots of all three species were also set up at the MSU pond to see if the transplants would grow so late in the summer. However, animals ate the rhizomes on all the *S. pungens* and on three of the *T. angustifolia*. The pot experiment was run with the remaining three *T. angustifolia* and six *S. americanus* pots. Nearly all the original stems appeared dead, but *T. angustifolia* had one new shoot per pot (three total) and *S. americanus* had an average of four new shoots per pot (24 total).

Discussion

Plot experiments – The plants at the Dow pond grew worse overall than the plants transplanted to the MSU pond in every experiment. The MSU pond is much fresher than the main pond at Dow (see Table 1). *T. angustifolia* and *S. americanus* were transplanted 5 days and 9 days earlier, respectively, at the MSU pond than at the Dow pond. Although this may have had some impact on establishment and growth, other factors likely contributed as well to their lower growth such as water levels, salinity and grazing. At the MSU pond, a few centimeters of water covered the plots for nearly the entire summer, whereas water never reached the Dow pond plots without manually watering by a hose.

All the species at the Dow pond and *T. angustifolia* and *S. americanus* at the MSU pond showed none or very few reproductive seed heads. However, *S. pungens* produced many seed heads in the MSU pond. *T. angustifolia* and *P. australis* were already starting to flower at the time of transplanting. Due to transplanting shock, above ground shoots often die and new growth from shoots occurs, (Hammer 1992) thus the transplants may have put more effort into establishing themselves and vegetatively growing instead of sexually reproducing.

The plants at the MSU pond were successful at establishing and greatly proliferated. Although they continued to grow after the early August sampling, they became so numerous it was difficult to count. At the Dow pond, however, few new shoots were added after watering with salt water, but stem length did increase. *S. americanus* continued growing the first sampling after watering with pond water because the number of live stems increased, but the number of stems decreased in the final sampling at the Dow pond. For both *S. pungens* and *T. angustifolia*, the number of live stems decreased after watering with salt water.

The average maximum stem lengths were significantly taller at the MSU pond than at the Dow pond. In poor environmental conditions, such as at the Dow pond, plants do not grow as well as was seen in this experiment (Begon et al. 1990). At the Dow pond, stem lengths continued to increase after being watered with salt water, although in most cases no new stems were added.

The most salt tolerant species was *P. australis* (Hellings and Gallagher 1992), which was found growing in several areas around the Dow pond perimeter. This species had the worst transplanting record of all four species. As with all the species, they were transplanted late in the season. In temperate regions, the best time to plant is early spring, although planting can occur up until mid-summer (Hammer 1992). Some species, such as cattails and bulrush can be planted later than mid-summer (Hammer 1992), but *P. australis* does not appear to be as tolerant.

S. pungens has the second highest salinity tolerance (App. I), however this species had the second worst growth record at the Dow pond. Although this species is reported to tolerate high salinity, different populations have varying tolerance levels (Ungar 1991). Therefore, the source population of *S. pungens* may have not had a high salt tolerance. This species' low salt tolerance is also seen in the pot experiment, in which all pots of *S. pungens* had no new growth, while the other two species produced new shoots. In addition, this species suffered the greatest amount of grazing at the Dow pond. On several occasions, the entire stem and rhizome appeared to be removed.

Of all the species, *S. americanus* grew best at both ponds. *S. americanus* had the second lowest salinity tolerance of all the plants tested (App I). This species may have been more successful partly because the plugs had more soil than the other species. The source populations of *T. angustifolia*, *S. pungens* and *P. australis* were all in sandy, loose soils that fell away from the rhizomes upon extraction of the stems. *S. americanus* populations however, were in more clay-like organic soil that held together upon extraction of the plant plugs. Thus, a clump of soil, stems, rhizomes, and possibly seeds were transplanted, whereas the other species only had the stems and rhizomes being transplanted. In addition, the plugs may have prevented the highly damaging grazing that was done to *S. pungens* by making the rhizomes more difficult to remove. Although the stems were often cut, indicating grazing, the plugs and rhizomes were rarely removed. Even though species with soil plugs grew better, all three species transplanted were successfully established at the MSU pond with only the stem and rhizome.

S. americanus was also successful in the pot experiment. This species produced an average of two new shoots per pot at the Dow pond when it was saturated with salt water. Although it only grew half as well as pots at the MSU pond (producing an average of 4 new stems per pot), it still was able to grow successfully. Thus, this species would be a good candidate to plant at the Dow pond.

The least salt tolerant species was *T. angustifolia*, however, it was the second best grower in the transplant experiment. The highest salt tolerance reported for this species is near 20 ppt (McMillan 1959), which is near the highest salinity reported for the 2001 summer at the Dow pond. *T. angustifolia* was abundant on the edges of an adjacent pond, thus as the Dow pond becomes fresher, this species will likely become more abundant at the pond since it is an aggressive invader of open wetlands (Hammer 1992, Prach and Wade 1992).

Differences between plots within populations on the same sampling dates were probably mostly affected by wind and grazing. For *T. angustifolia* at the Dow pond, the middle plot consistently had more live stems and taller stem lengths. The middle plot may have been partly protected by the wind by the first plot of *T. angustifolia* that was directly west of the middle plot (Figure 4). The first *S. americanus* plot at the Dow pond may have been affected by grazing. This plot was between two *S. pungens* plots, which were the most heavily grazed species in this experiment (Figure 4). In addition, this plot had one plug that was completely pulled out by grazers, and it was also the only plot for several samplings that had any dead plugs (2 out of 15).

At the MSU pond, the plot farthest east consistently had fewer stems or shorter stems lengths for all three species. This would also indicate that wind my have caused the differences between the plots within this population. Based on the blueprints of the MSU pond, the east end of the pond is most exposed with a less steep slope of a hill and no trees.

Unfortunately, this transplant study was not continued into a second year since funding from Dow was not renewed. Had the study continued, I would have done additional studies to determine if the plants that were transplanted in the first year were well enough established to survive the winter. Tracking the stem counts and stem heights would have been continued into the second year to determine over-winter survival rates.

Furthermore, growth studies of these four species should be conducted in the N-S and E-W ponds, which have fresher water. Part of the project goals for the Dow pond was to decrease the salinity of the pond water. Conducting these growth studies in the N-S and E-W ponds could indicate the desired salinity level for the main pond at which successful of transplanting and revegetating of the main pond could occur. Other variations of this transplant study would be to find additional plant species (see App. A) that may tolerate this salinity and conduct similar growth experiments.

An additional study would be to push topsoil into the pond, especially near areas where *P. australis* patches were well established. This plant was growing along the edges, mainly where soil had been pushed into the pond, but it did not appear to be growing on the pond sediments. Although in some areas, *P. australis* had sent horizontal shoots into the pond water, suggesting this species is tolerant of the saline pond water. If *P. australis* expanded to the topsoil, it would help determine if *P. australis* is prohibited from growing in the pond because of the sediments or due to the some other factor. Additionally, the chemistry and engineering groups working on this project suggested that a topsoil cap be placed over the gel-like pond sediments to decrease the diffusion of salt into the pond water in order to freshen the water. This experiment of capping the sediments would be beneficial to both reduce the salt content of the pond water and to help establish plant growth.

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Table 1. Water chemistry data from the Dow pond, MSU pond, and the Maple River salt seep, the source of the *S. americanus* population. "n.d." indicates non-detectible, and "—" indicates parameters not sampled.

Parameter	Dow pond	MSU pond	Maple River
Dissolved oxygen (mg/L)	7.8-8.7	10.7-14.8	--
% oxygen saturation	92.9-103%	120%-165%	--
Conductivity (uS)	24,000-38,500	720-747	531-3471
Alkalinity (mg $CaCO_3$/L)	67-75	180-194	159-361
PH	8	7.76-7.85	6.98-7.89
NO_3 -N (mg N/L)	0.13-0.24	12	n.d-7.95
NH_4 -N (mg N/L)	0.69-0.77	0.00011-0.00015	n.d.-.27
Potassium (K, mg/L)	414-441	--	n.d-13.5
Calcium (Ca, mg/L)	5400-5795	--	67-1110
Ortho-Phosphorus (mg/L)	n.d.	$3.9x10^{-5}$-$4.2x10^{-5}$	0.01-0.08
Manganese (Mn, mg/L)	0.2	--	0.02-0.9
Sodium (Na, mg/L)	1728-1874	--	11-666
Chloride (Cl, mg/L)	12,315-14,065	29	68-1800

Table 2. Total number of live stems for all 45 plugs at the initial and final sampling for both the Dow and MSU ponds. Also shown is the total number of live stems before watering with salt water at the Dow pond. The number in parenthesis indicates the number of live plugs, indicated by the presence of living stems.

	Dow			MSU	
Species	Initial	Before salt	Final	Initial	Final
P. australis	124 (45)	29 (7)	18 (4)	--	--
T. angustifolia	58 (45)	91 (37)	57 (31)	79 (45)	303 (44)
S. americanus	307 (45)	413 (43)	356 (38)	314 (45)	4849 (44)
S. pungens	119 (45)	47 (18)	28 (7)	162 (45)	934 (41)

Table 3. Initial average stem number per plug and stem lengths per plug with standard deviation at the Dow and MSU ponds with the t and p values. A * indicates a significant difference between populations (p=0.05).

Species		Dow	MSU	t	p
T. angustifolia	# stems	1.29 ±0.458	1.76 ±0.933	2.96	0.005*
	Stem lengths	136 ±20.3	173 ±30.3	6.48	>0.001*
S. americanus	# stems	6.82 ±3.68	6.98 ±2.72	0.25	0.807
	Stem lengths	45.8 ±24.2	55.8 ±16.14	2.08	0.046*
S. pungens	# stems	2.64 ±1.03	3.60 ±1.59	3.54	0.001*
	Stem lengths	60.3 ±18.7	61.9 ±18.9	0.71	0.483

Table 4. The average number of stems per plug and stems lengths per plug with standard deviations comparing the Dow and MSU plant populations before (Aug 14) and after (Oct 10) watering with salty pond water at the Dow pond plots with the t and p statistics. All number of stems and stem lengths were significantly different in the two populations (p=0.05).

Species		Dow		MSU	t, p	
	Dates	Aug 14	Oct 10	Aug 8	Aug 14	Oct 10
T. angustifolia	# stems	2.02 ±1.45	1.27 ±1.07	6.73 ±2.93	10.4, >0.001	11.5, >0.001
	Stem lengths	42.2 ±37.2	63.7 ±18.2	173 ±30.3	15.6, >0.001	9.49, >0.001
S. americanus	# stems	9.17 ±5.83	7.91 ±6.26	108 ±38.7	17.5, >0.001	17.4, >0.001
	Stem lengths	17.4 ±10.6	29.7 ±15.8	87.1 ±9.54	31.1, >0.001	20.9, >0.001
S. pungens	# stems	1.04 ±1.86	0.622 ±1.65	20.8 ±16.8	7.88, >0.001	7.82. >0.001
	Stem lengths	11.3 ±8.08	34.0 ±18.3	64.8 ±23.7	3.31, 0.016	0.94, 0.014

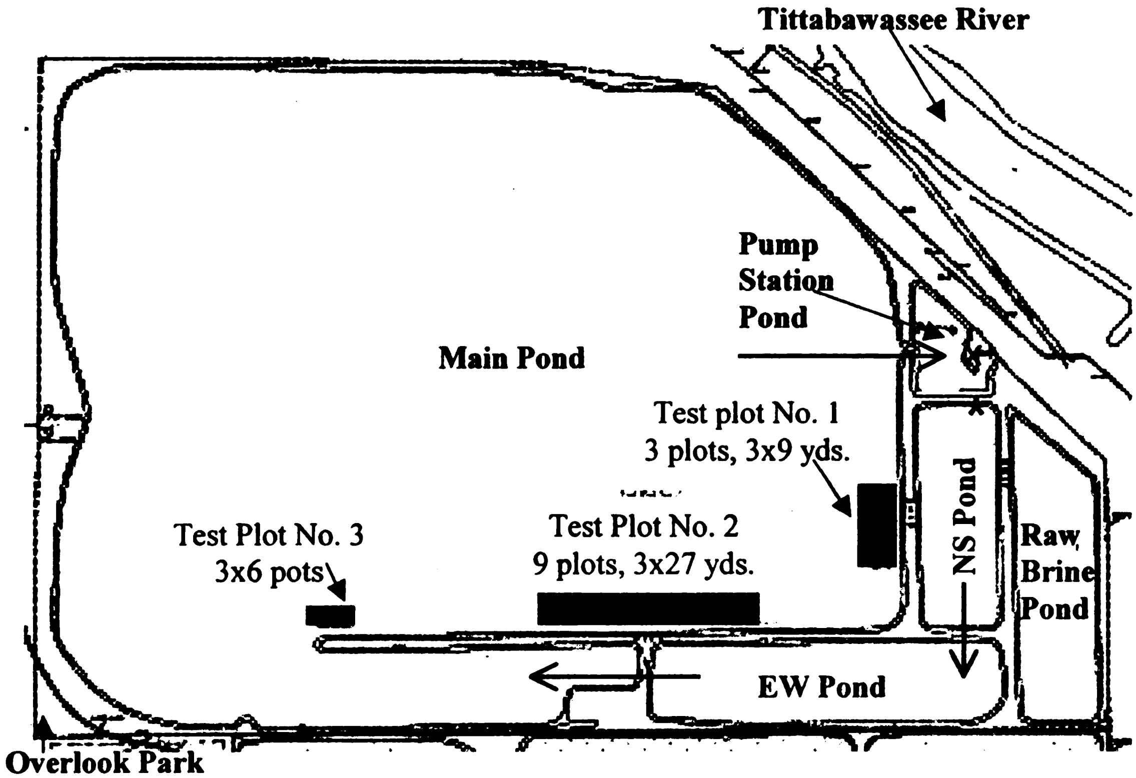

Figure 1. Experimental plot locations at the brine pond complex showing the four interconnected ponds with the inlet source (*), outlet pump (x), and direction of water flow indicated by the thick black arrows (→). From the pump station pond outlet (x), the water is pumped into the Tittabawassee River. The Raw Brine Pond is not connected to the brine pond complex and was not examined in this study. The dark gray boxes show the locations of the experimental growth plots (test plots no. 1 and 2) and pot experiment (test plot no. 3).

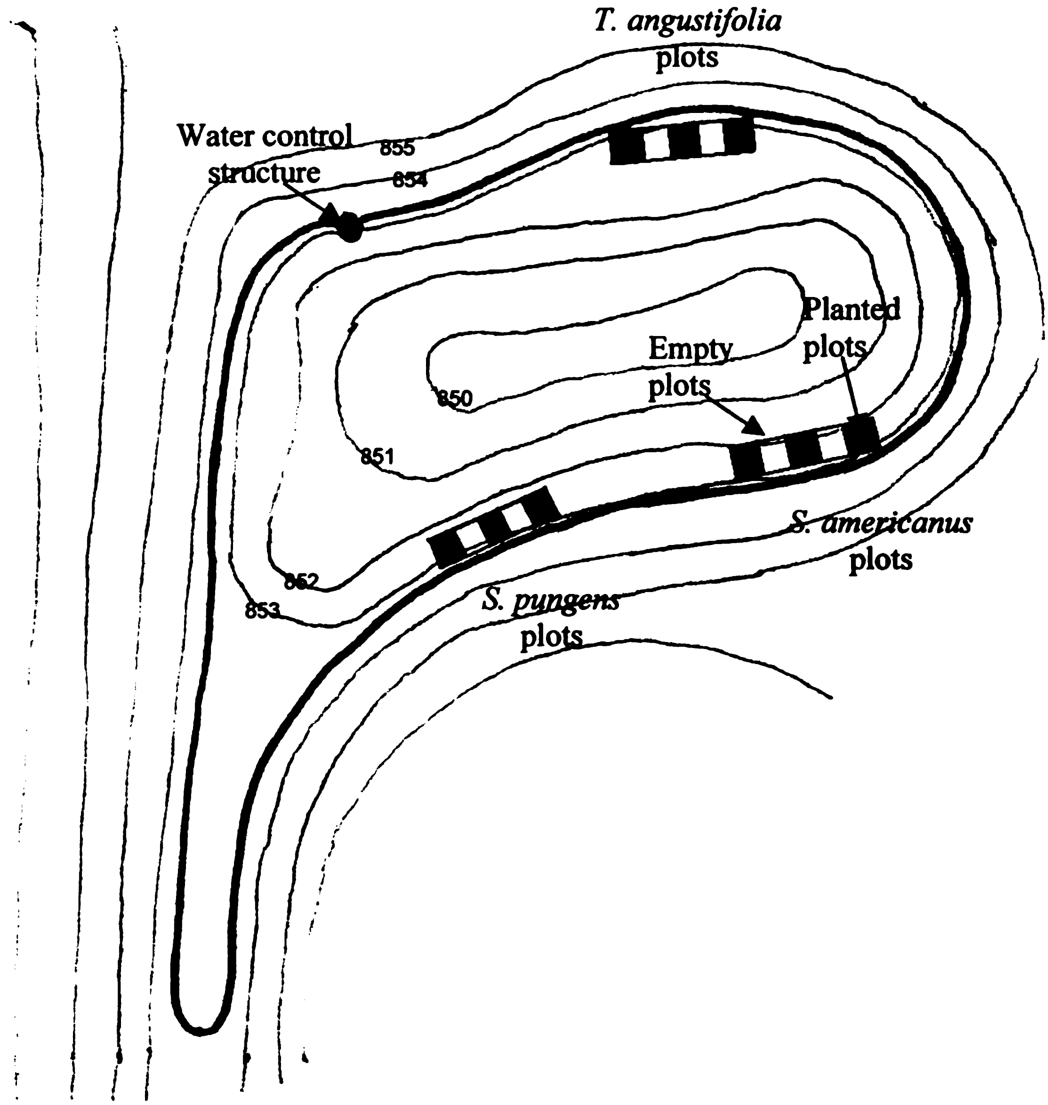

Figure 2. The MSU pond with location of plots and species planted. Grey plots indicate plots that were planted and white plots indicate empty or unplanted plots.

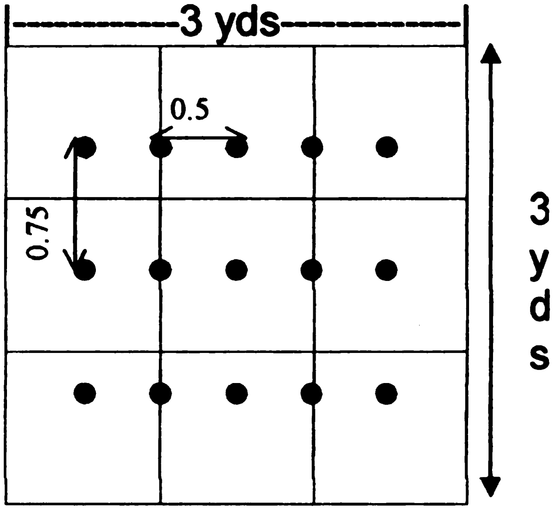

Figure 3. The individual plot design for the Dow and MSU ponds showing the locations of each of the 15 plant plugs (black dots) and the spacing (in yards) between each plug.

Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9
Typha	**Typha**	**S. pun**	**S. am**	**S. pun**	**Typha**	**S. am**	**S. pun**	**S. am**

Figure 4. Plot layout showing the random placement of the *Typha angustifolia* (*Typha*), *Schoenoplectus pungens* (*S. pun*), and *S. americanus* (*S. am*) at the Dow pond. Plot 1 is facing west and plot 9 is facing east.

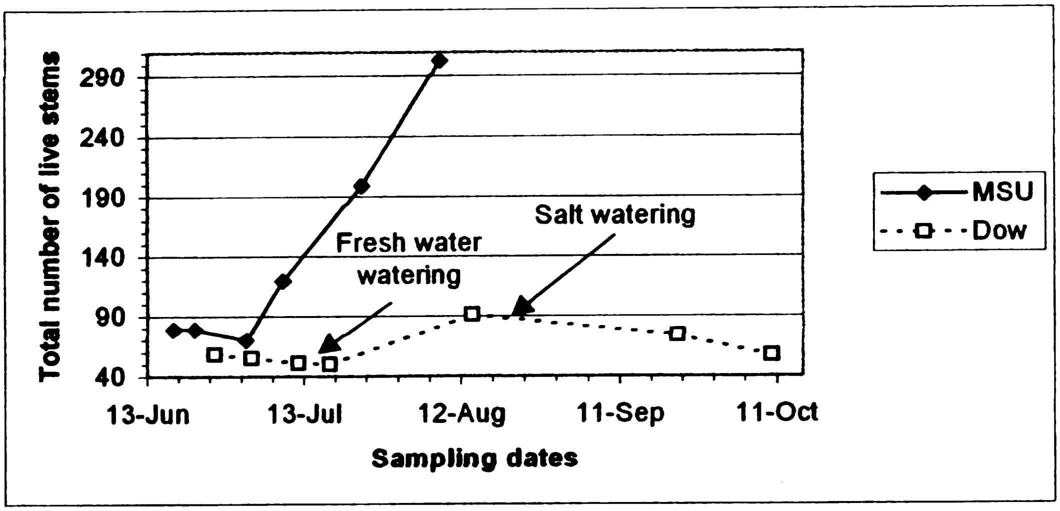

Figure 5. Total number of living stems per sampling date for *Typha angustifolia* at the MSU and Dow ponds. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond.

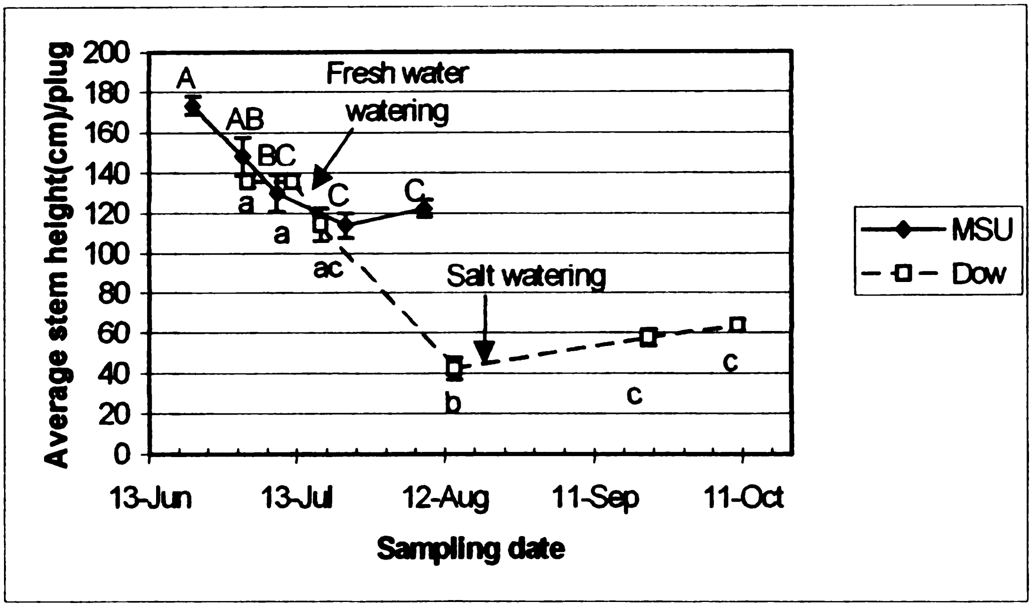

Figure 6. Average stem lengths per plug for the whole population of *T. angustifolia* at the MSU and Dow ponds. Different capital letters of indicate significant differences in stem lengths between sampling dates at the MSU pond and different lower case letters indicate significant differences in stem length between sampling dates at the Dow pond. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond

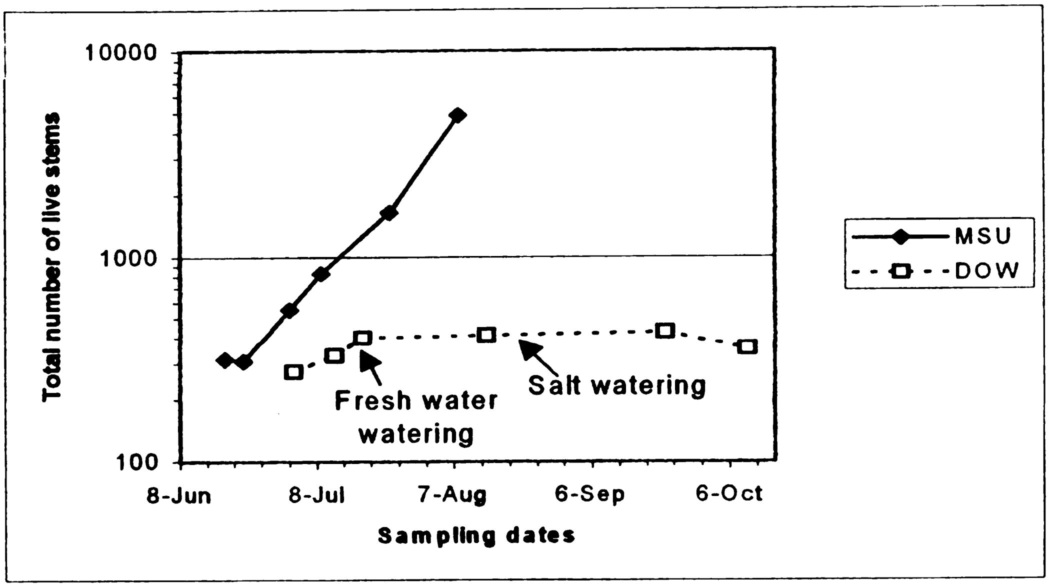

Figure 7. Total number of live stems per sampling date for *Schoenoplectus americanus* at the MSU and Dow ponds. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond. Note: the y-axis is in log scale so differences in the number of stems in the Dow population can be seen more clearly.

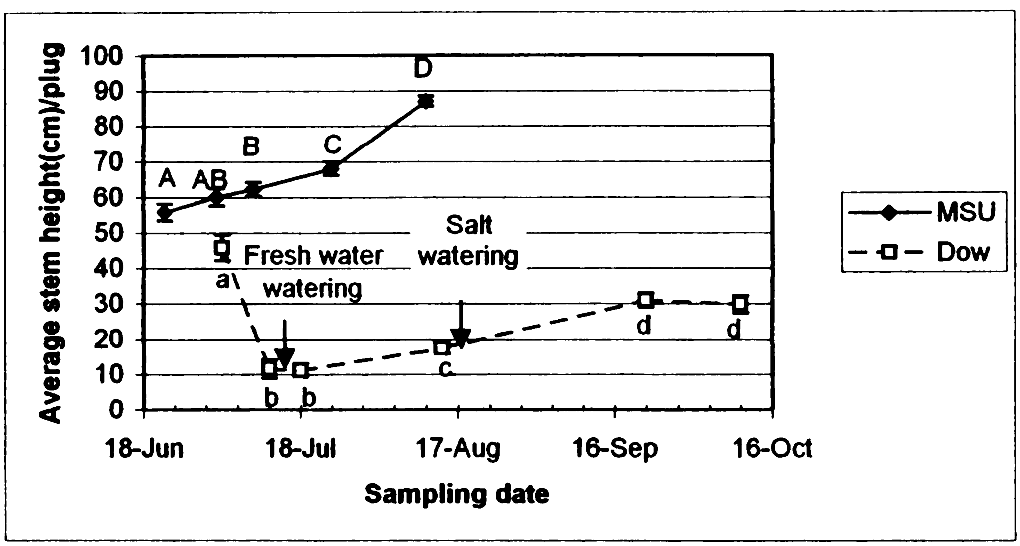

Figure 8. Average stem lengths per plug for the whole population of *S. americanus* at the MSU and Dow ponds. Different capital letters indicate significant differences in stem lengths between sampling dates at the MSU pond and different lower case letters indicate significant differences in stem length between sampling dates at the Dow pond. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond.

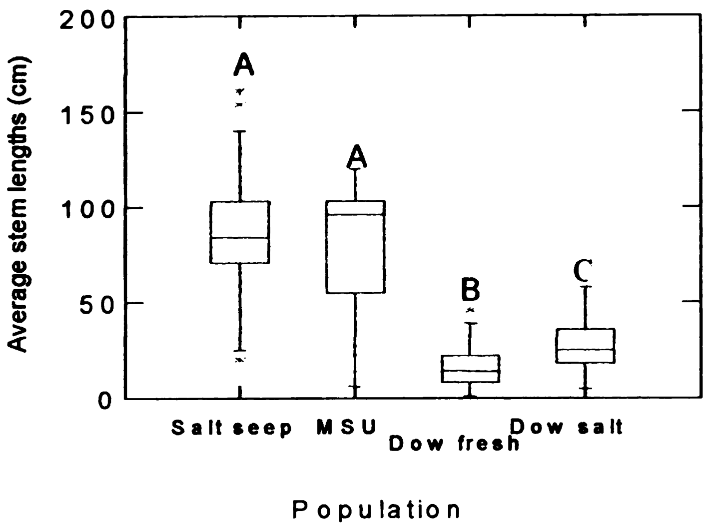

Figure 9: Box plot comparing the average stem lengths of *S. americanus* populations from the Maple River salt seep (Salt seep), the MSU pond (MSU), the Dow pond before being watered with salt water (Dow fresh) and after salt water (Dow salt). The different letters indicate a significant difference between the population's heights. * indicate outliers in the stem heights.

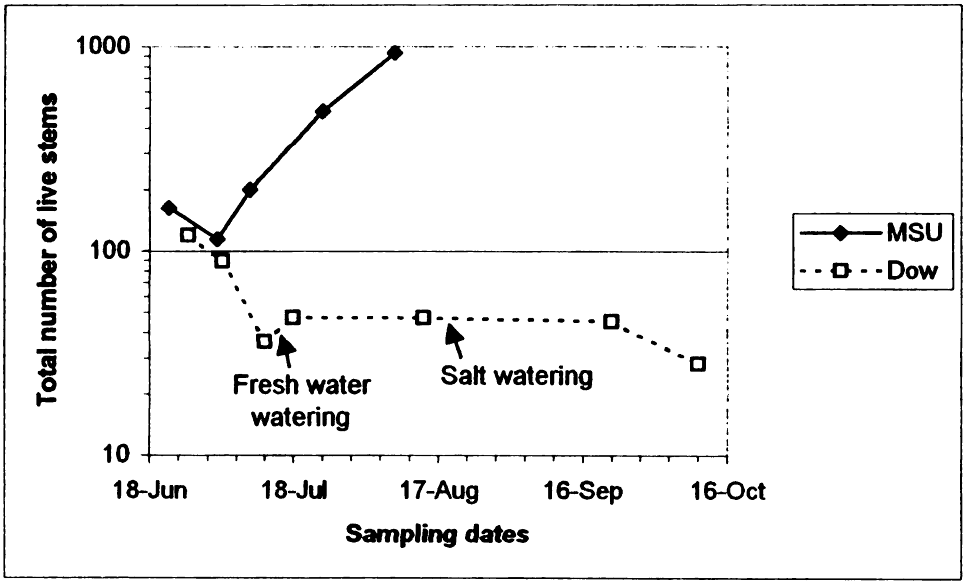

Figure 10. Total number of live stems per sampling date for *Schoenoplectus pungens* at the MSU and Dow ponds. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond. Note: the y-axis is in log scale so differences in the number of stems in the Dow population can be seen more clearly.

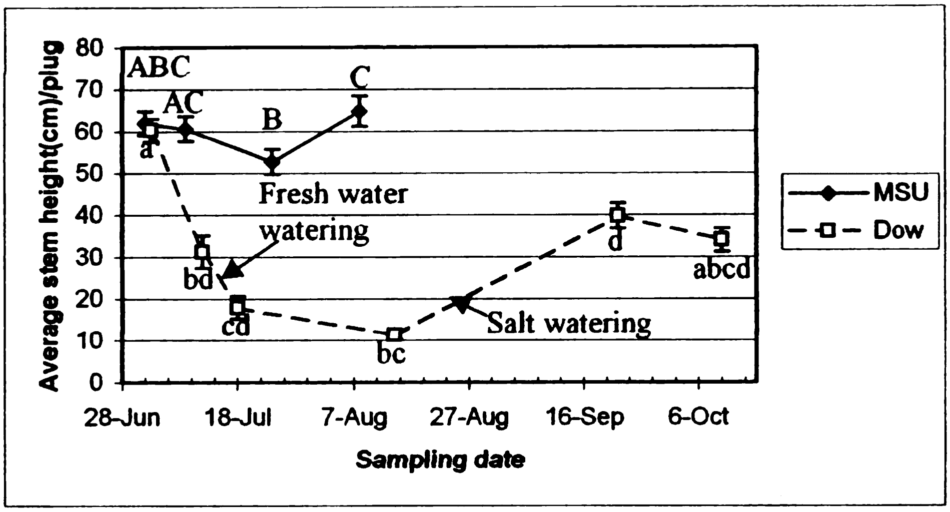

Figure 11. Average stem lengths per plug for the whole population of *S. pungens* at the MSU and Dow ponds. Different capital letters indicate significant differences in stem lengths between sampling dates at the MSU pond and different lower case letters indicate significant differences in stem length between sampling dates at the Dow pond. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond.

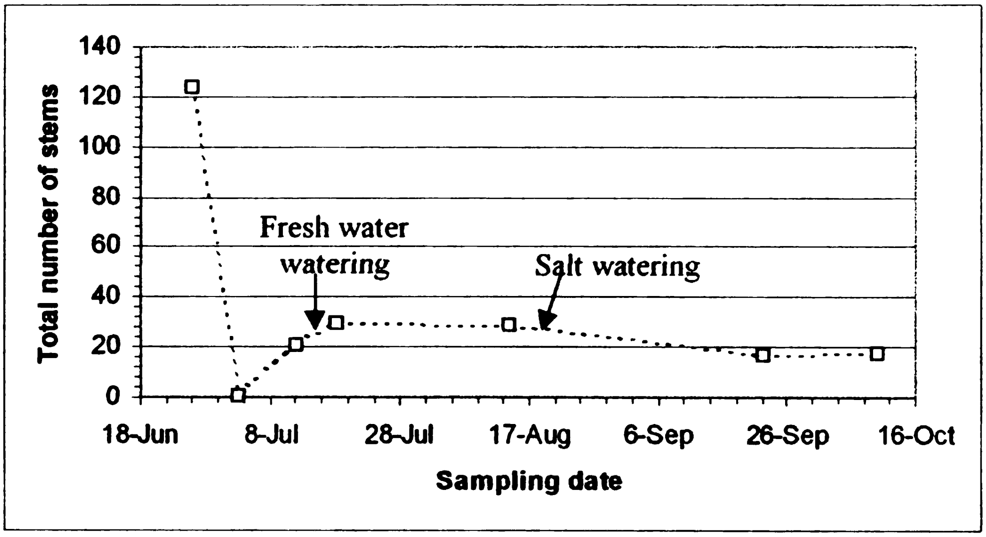

Figure 12. Total number of live stems per sampling date for *Phragmites australis* at the Dow pond. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond.

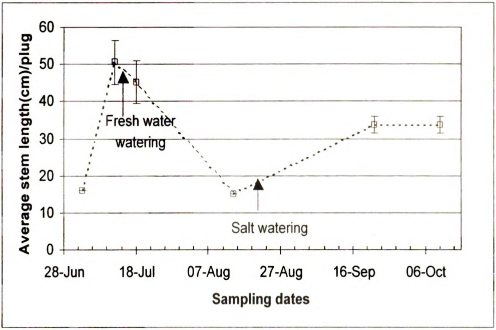

Figure 13. Average stem lengths per plug for the whole population of *P. australis* at the Dow pond. No differences were seen in the average lengths per sampling date. Arrows indicate where watering occurred with fresh water and salt water at the Dow pond.

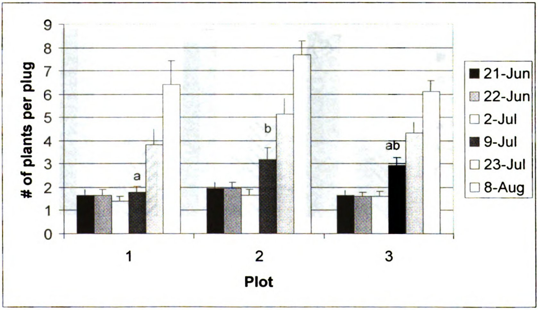

Figure 14. Average number of live plant stems per plug per plot for *T. angustifolia* at the MSU pond. Significant differences in number of stems per sampling are indicated by different letters above the bars.

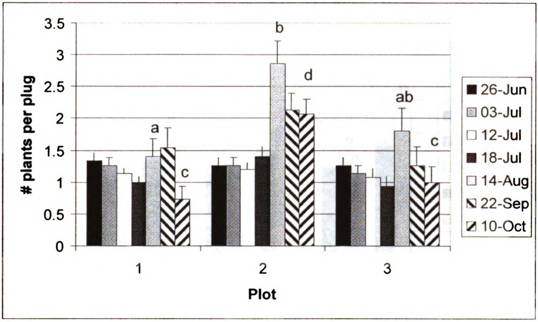

Figure 15. Average number of live plant stems per plug per plot for *T. angustifolia* for the Dow pond. Significant differences in number of stems per sampling are indicated by different letters above the bars. Solid bars indicate watering with fresh water and striped bars indicate watering with saline pond water.

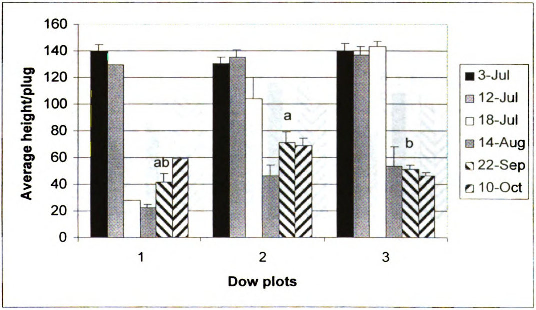

Figure 16. Average stem lengths per plug per plot of *T. angustifolia* for the Dow pond. Significant differences in number of stems per plot per sampling are indicated by different letters above the bars. Solid bars indicate watering with fresh water and striped bars indicate watering with saline pond water.

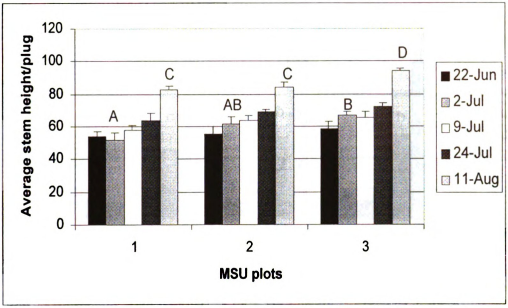

Figure 17. Average stem lengths per plug per plot for *S. americanus* at the MSU pond. Significant differences in number of stems per plot per sampling are indicated by different letters above the bars.

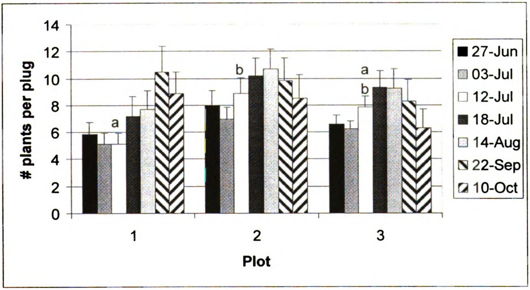

Figure 18. Average number of live plant stems per plug per plot for *S. americanus* for the Dow pond. Significant differences in number of stems per sampling are indicated by different letters above the bars. Solid bars indicate watering with fresh water and striped bars indicate watering with saline pond water.

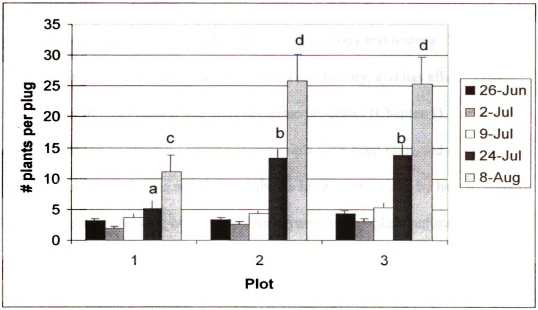

Figure 19. Average stem lengths per plug per plot for *S. pungens* at the MSU pond. Significant differences in number of stems per plot per sampling are indicated by different letters above the bars.

Chapter 5: Conclusions

Salt has played a major role in human physiology and history. It has been used for preserving food, has influenced economics and history, and has affected the environment through natural and anthropogenic processes (Chapter 1). In the environment, many naturally saline environments have been impacted or destroyed by human influences, whereas new saline habitats have been created by human activities. These new saline areas are often a problem because they replace natural freshwater habitats (i.e. from road salting or sewage), prohibit the intended use of the land (i.e. agriculture and irrigation in arid regions), or are waste products that pose problems for disposal (i.e. from chemical processes in industry).

In this thesis, I examined the effects of salts on the plant assemblage of a rare natural salt seep wetland in Michigan (Chapter 2). These seeps result from salt deposit from Paleozoic seas that covered Michigan, but few salt seeps remain. Due to their unique environment, they contain rare and endangered halophytic species, Olney's three-square bulrush (*Schoenoplectus americanus*) and the spike rush, (*Eleocharis parvula*), which should be preserved and protected. The abundance of these rare species is correlated with high conductivity and low levels of soluble reactive phosphorus.

The second area I examined was the effects of salt on the biota of an unusually saline pond (for the state of Michigan) that was created to contain spent brine at the Dow plant in Midland, Michigan (Chapter 3). The Dow pond had four ponds that were sequentially connected along a salinity gradient from the input area in the N-W pond to intermediate levels of salinity in the E-W pond to the highest levels of salinity in the main and outlet ponds with salinity varying from less than one fourth the salinity of sea water in the N-W pond to two-thirds the salinity of seawater in the main/outlet pond. However, the ion concentrations were different from seawater with less magnesium than seawater with ionic concentrations in decreasing order dominated by chloride, calcium, sodium, and potassium. The diversity of algae, plants, and invertebrates was low in the pond. However, algae, plant and invertebrate diversity decreased along the salinity gradient with highest diversity in the freshest pond and lowest diversity in the pond with highest salinity. Much of this increase in diversity appeared to be correlated with invasion of the fresher N-S and E-W ponds by *Chara*, a macroalga, which provides food and cover for invertebrates, waterfowl and other wildlife. If dilution of the ponds continues as a consequence of the freshening of brine well inputs as these wells are remediated, establishment of a more complex and diverse food web may follow.

Finally, I conducted experiments on the effects of saline water from the Dow Main Pond on transplant survivorship and growth of four wetland plants (Chapter 4) (*S. americanus, S. pungens, Typha angustifolia,* and *Phragmites australis*). These four emergent plants were transplanted into growth plots at the Dow pond in mid June. Since transplanting occurred later in the season than was ideal, a transplant experiment (excluding *P. australis*) was set up at a nearly fresh water storm retention pond on the campus of Michigan State University as a reference in order to document that these species could be successfully transplanted at such a late date in the season. Only *S. americanus* (Olney's three-square bulrush) increased in number of live stems (by 16%) and showed potential for establishment and growth when irrigated or transplanted into Dow brine pond water. All other species decreased in number of live stems from the initial planting when irrigated or transplanted into brine pond water. In contrast, survivorship and growth was high in the fresh water storm water retention pond at MSU. No species grew as well at the Dow pond as at the MSU pond. All species grew well and more than tripled their original number of live stems at the MSU pond. Problems at the Dow pond included the fact that the plots were not inundated late in the season as I had expected them to be and problems with geese eating the transplanted plants. The fact that *S. americanus* (Olney's three square bulrush) was able to add some shoots under such harsh conditions, suggests that this species may have some promise for establishment if sediments can brought in to cover the margins of the pond and establishment experiments can be conducted so that the plots are inundated soon after transplanting. Experiments to confirm this and that *P. australis* can be encouraged to colonize such areas by sending rhizomes from existing stands should be the next line of investigation. *P. australis* is successfully colonizing areas where soil existed or was pushed into the wetlands suggesting that it is also a viable species for providing cover around the edges of the ponds. However, establishment of *S. americanus*, a less invasive species, would be a preferred option if further experiments confirm that it will grow in the pond.

APPENDICES

APPENDIX A

SALT TOLERANT WETLAND PLANTS OF MICHIGAN

Appendix A: Salt tolerant wetland plants of Michigan. Origin indicates native (N) or introduced (I) species. Tolerance indicates the level of salinity tolerated or the habitat of each species. Reference numbers in parentheses refer to the numbered references at the end of the table.

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Acorus calamus	Sweet flag	N(23)	0-10ppt(16)	(4)
Agropyron repens	Quackgrass	I(18)	4-500mS/m cond(15)	(2)
Agrostis gigantea	Red top bent grass	I(17)	TDS 0.03-0.68% (13)	Called *A. alba* (2)
Alisma plantago-aquatica	Water plantain	N(5)	<0.5ppt(16)	In area with minimum 1.4 Cl^- ppt soil salinity (4)
Andropogon scoparius	Little bluestem	N(5)	Salt marsh borders(8)	
A. virginicus	Broom-sedge	N(5)	High marshes(8)	
Asclepias incarnata	Swamp Milkweed	N(5)	<0.5ppt(16)	In area with minimum 1.0 Cl-ppt soil salinity (4)
Aster brachyactis	Rayless aster	I(14)	50-1500 mS/m (15)	Saline roadside median (14)
A. lanceolatus	Pannicled aster	N(23)	4-1500 mS/m (15)	Called *A. simplex* (4)
A. subulatus	Saltmarsh aster	I(14)	5.5-36.3ppt (6)	Saline roadside median (14)
Atriplex patula	Spearscale	I(14)	<52dS/m(24), 4-36.2ppt(6)	Called *A. hastata* , saline roadside median (14)
Bidens aristosus	Beggarstick	N(5)		Saline roadside median(14)
Boltonia asteroides	False aster	I(20)	Tidal marsh(8)	
Calamagrostis canadensis	Blue joint	N(5)	<0.5ppt(16), 4-200mS/m(15)	In area with minimum 1.3 Cl^- ppt soil salinity (4)
Callitriche hermaphoroditica	Water-starwort	N(5)	Br water (8) 4-200 mS/m (15)	Rare in MI (13)

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Carex lacustris	Sedge	N(5)	<0.5ppt(16)	In area with minimum 1.6 Cl^- ppt soil salinity (4)
C. lasiocarpa	Sedge	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
C. praegracilis	Sedge	I(14)	4-500mS/m (15)	
C. sartwellii	Sedge	N(5)	4-500mS/m (15)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
Centarium pulchellum	Century plant	I(14)		Saline roadside median (14)
Chara spp.	Muskgrass	N(3)	50-10000 mS/m(15)	
Chenopodium glaucum	Goosefoot	I(14)	Saline roadside median(14)	
C. rubrum	Coast-blite	I(19)	Salt marsh(8), 4-1500mS/m (15)	
Cladium mariscoides	Twig-rush	N(5)	Br water(8)	
*Crypis (Heleochloa) Schoenoides**		I(14)		Saline roadside median (14)
Cyperus erythrorhizos	Sweet-rush	N(5)	Salt marsh(8)	
C. odoratus	Sweet-rush	N(5)	Br-salt shores(8)	
Danthonia spicata	Poverty grass	N(5)		(2)
Dipsacus lacinaiatus	Cut-leaf teasel	I(5)		Saline roadside median (14)

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Dulichium arundinaceum	3-way sedge	N(5)	<0.5ppt(16)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
Echinochloa walteri	Wild millet	N(5)	Br water(8)	
Elatine minima	Waterwort	N(5)	Tidal shores(8)	
Eleocharis parvula	Dwarf spike rush	N(3)		Threatened in MI(16)
E. rostellata	Spike rush	N(23)	Br or salt marsh(8)	(21)
Eleodea canadensis	Waterweed	N(5)	Up to 10ppt(16)	
Equisetum pratense	Meadow horsetail	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Erechtites hieracifolia	Fireweed	N(5)		In area with minimum 1.6 Cl^- ppt soil salinity (4)
Eupatorium maculatum	Joe-pye-weed	N(5)		In area with 1.4 Cl^- ppt soil salinity (4)
E. perfoliatum	Boneset	N(5)		In area with 1.6 Cl^- ppt soil salinity (4)
Euphorbia polygonifolia	Seaside spurge	N(19)	Beaches(8)	
Festuca arundinacea	Tall fescue	I(18)	0-20ppt (22)	
Festuca ovina	Sheep fescue	I(18)	Salt marsh(8)	
F. rubra	Red fescue	N,I (18)	Br meadow(8)	MI has both native and introduced strains(18)
Fraxinus pennsylvanica	Red/green ash	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Galium obtusum	Bedstraw	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Helianthus petiolaris	Plains sunflower	I(14)		Saline roadside median (14)

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Hibiscus moscheutos	Swamp mallow	N(5)	Up to 15ppt(16)	Rare but secure in MI (12)
Hierchloe odorata	Sweet grass	N(5)	Brackish(8), 4-200mS/m(15)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
Hordeum jubatum	Squirrel tail grass	I(5)	25ppt NaCl(10)	(8)
Iris versicolor	Wild blue flag	N(5)	Fw to moderate Br water (16)	
I. virginica	Southern blue flag	N(5)		In area with minimum 1.6 Cl^- ppt soil salinity (4)
Juncus balticus	Rush	N(23)	4-4500mS/m (15)	Saline roadside median (14)
J. canadensis	Rush	N(5)	Br marsh(8)	
J. gerardii	Black grass	I(18)	0-20ppt(22)	
J. scirpoides	Rush	I(18)	Saline marsh(8)	Threatened in MI (12)
Kochia scoparia	Summer cypress	I(14)	4-4500mS/m (15)	Saline roadside median (14)
Lactuca saligna	Willow-leafed lettuce	I(14)		Saline roadside median (14)
Lemna minor	duckweed	N(5)	0.17-16.65ppt(9)	
Leptochloa fascicularis	Salt meadow grass	I(18)	Br marsh(8)	
Lycopus uniflorus	Northern bugleweed	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Lysimachia nummularia	Money wort	I(20)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Mentha arvensis	Wild mint	N(20)	4-500mS/m (15)	In area with 1.6 Cl^- ppt soil salinity (4)
Melilotus alba	White sweet clover	I(19)		(2)
Mikania scandens	Climbing hempweed	I(20)	Salt marsh edge(8)	Apparently expatriated from MI (12)
*Muhlenbergia asperifolia**	Scratch grass	I(14)	200-4500mS/m (15)	Saline roadside median (14)
Myriophyllum exalbescens	Water-milfoil	N(5)	Br ponds(8), 4-500mS/m(15)	
M. spicatum	Eurasian Water-milfoil	I(19)	0.17-13.32ppt (9)	
Najas flexilis	Naiad	N(5)	Br water(8)	
N. guadalupensis	Naiad	N(5)	10ppt(9)	
Nuphar advena	Yellow pond-lily	N(23)	Tidal waters(8)	
Oenothera fruticosa	Sundrops	N(5)	Br-saline marshes(8)	
Onoclea sensibilis	Sensitive fern	N(5)	<0.5ppt(16)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
Panicum virgatum	Switch grass	N(5)	<10ppt(16), 2-20ppt(6)	
Peltandra virginica	Arrow-arum	I(18)	0.0-2.88(6)	

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Phragmites australis	Reed	N(5)	<20ppt(16), 0-27.5ppt (6)	Saline roadside median (14),(4)
Phyla lanceolata	Frog-fruit	N(5)	Br sands, marshes(8)	
Plantago arenaria	Psyllium	I(14)		Saline roadside median (14)
P. major	Common plantain	I(20)	Br-saline shores (8), 4-500mS/m (15)	
Pluchea odorata	Salt-marsh fleabane	I(5)		(2)
*Poa glaucifolia***		I(14)		Saline roadside median (14)
Polygonum achoreum	Knotweed	N(5)	Saline marsh(8)	
P. arifolium	Tear-thumb	N(5)	Br habitats(8)	
P. aviculare	Knot weed	I(5)		Saline roadside median (14)
P. hydropiperoides	Mild water-pepper	N(5)	Br habitats(8)	
P. punctatum	Water-smartweed	N(5)	Br tidal shore(8)	
P. sagittatum	Tear-thumb	N(5)	Br areas(8)	
Portulaca oleracea	Purslane	I(23)		In area with minimum 1.4 Cl^- ppt soil salinity (4)
Potamogeton crispus	Pondweed	I(18)	Br ponds(8)	

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
P. filiformis	Narrow-leaved pondweed	N(5)	Br water(8)	
P. filiosus	Leafy pondweed	N(5)	Br water(8)	
P. friesii	Fries's pondweed	N(5)	Br water(8)	
P. pectinatus	Sago pond weed	N(5)	50-10000mS/m (15)	
P. perfoliatus	Reed head grass	N(23)	Up to 5ppt(16)	
P. richardsonii	Clasping leaf pondweed	N(5)	40-500mS/m (15)	
P. vaginatus	Pondweed	N(5)	Br water(8)	
Potentilla anserina	Silverweed	N(23)	Salt marsh(8), 50-4500mS/m (15)	
Puccinellia distans	Alkali grass	I(14)	5.6-20.8ppt Cl^- (13)	Saline roadside median (14)
Ranunculus cymbalaria	Seaside buttercup	N(5)	Br marshes(8), 50-1500mS/m (15)	Threatened in MI (12)
R. hispidus	Swamp buttercup	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity called *R. septentrionalis* (4,18)
R. sceleratus	Cursed crowfoot	N(5)	Br habitats(8)	
Rhynchospora macrostachya	Horned-rush	N(5)	Salt marsh(8)	Rare but secure in MI (12)

Appendix A (Continued)

Scientific Name	Common Name	Origin	Tolerance	Comments & (References)
Rumex maritimus var. *fueginus*	Golden dock	N(5)	Br-saline marshes (8), 4-1500mS/m(15)	
Rumex orbiculatus	Great water dock	N(5)		In area with 1.6 Cl^- ppt soil salinity (4)
Ruppia maritima	Ditchgrass	N(5)	5-35ppt (16)	Threatened in MI (12)
Sagittaria graminea	Arrowhead	N(5)	Fw to br water (16)	
S. rigida	Arrowhead	N(5)	Br water(8)	
Salicornia europaea	Glasswort	N(19)	>25pptNaCl (10)	(2),Native stature is questionable(19)
Samolus parviflorus	Water pimpernel	N(5)		In area with minimum 1.4 Cl^- ppt soil salinity, called *S. floribundus* (4,20)
Schoenoplectus acutus	Hard stem bulrush	N(5)	4-1500mS/m (15)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
S. americanus	Olney's three square	N(3)	<15ppt(16), 0-26ppt (6)	(3),(21),(11)Threatened in MI(12)
S. cyperinus	Wool-grass	N(5)	Salt marsh streams(8)	
S. fluviatilis	River bulrush	N(5)	<0.5ppt(16), 4-500mS/m(15)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
S. maritimus	Bayonet-grass	I(18)	Br-saline marsh(8), 50-4500mS/m(15)	
S. pungens	Three square bulrush	N(5)	<5ppt(16) 0-28.8ppt(6)	Saline roadside median (14),(4)

Appendix A (Continued)

Scientific Name	Common Name	Native	Tolerance	Comments & (References)
S. tabernaemontani	Soft set bulrush	N(5)	Up to 5ppt(16), brackish(8)	
Setaria faberi	Giant foxtail	I(14)		Saline roadside median (14)
S. glauca	Yellow foxtail	I(18)	Slight br(8)	
Sisyrinchium atlanticum	Blue-eyed-grass	I(18)	Salt marsh edges(8)	
Sium suave	Water parsnip	N(5)	Fw to bk(16), 4-500mS/m(15)	In area with minimum 1.4 Cl^- ppt soil salinity (4)
Solanum dulcamara	Nightshade	I(20)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Solidage sempervirens	Seaside goldenrod	I(14)	Br-saline habitats(8)	Saline roadside median (14)
Spartina patens	Salt meadow cordgrass	N(18)	<35ppt (16), 0-53.8ppt(6)	(2), Introduced from East of MI according to Reznick (14)
S. pectinata	Cordgrass	N(5)	Up to 3ppt(16)	Saline roadside median(14)
Spergularia marina	Sand spurrey	I(14)	>25ppt NaCl (10)	Saline roadside wetland, Called *S. salina* (14,18)
S. media	Sand spurrey	I(14)		Saline roadside wetland, Called *S. maritima* (14,18)
Spiranthes vernalis	Spiral orchid	I(18)	Salt marshes(8)	
Sporobolus asper		I(14)		Saline roadside median (14)
Suaeda calceoliformis	Sea-blite	I(14)	>25ppt NaCl (10)	Saline roadside median (14)

Appendix A (Continued)

Scientific Name	Common Name	Native	Tolerance	Comments & (References)
Teucrium canadense	Wood-sage	N(5)	Salt marsh(8)	
Thelypteris palustris	Marsh fern	N(5)	<0.5ppt(16)	In area with minimum 1.0 Cl^- ppt soil salinity (4)
Trifolium repens	White clover	I(19)	0-10ppt(22)	
Triglochin maritimum	Arrow-grass	N(23)	Br-salt marsh(8), 200-4500mS/m(15)	
T. palustre	Arrow-grass	N(23)	Br-salt marsh(8)	
Typha angustifolia	Narrow-leafed cattail	I(5)	<15ppt(16), 0-17ppt(6)	
T. latifolia	Common cattail	N(5)	<0.5ppt(16), 0-11ppt(6)	In area with minimum 1.3 Cl^- ppt soil salinity (4)
Urtica dioica	Stinging nettle	N(5)		In area with minimum 1.0 Cl^- ppt soil salinity (4)
Vallisneria americana	Tape grass, wild celery	N(5)	0-5ppt(16), 10ppt(9)	
Zannichellia palustris	Horned pondweed	N(5)	Br water(8), 50-4500mS/m (15)	
Zizania aquatica	Wild rice	N(23)	Br water(8)	var *aquatica* threatened in MI (12)

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APPENDIX B

LIST OF PLANT SPECIES AT THE MAPLE RIVER SALT SEEP

Appendix B. Plants found at the Maple River salt seep with names (scientific names taken from Voss, * indicates from Gleason and Crongquist, ** indicates Smith), frequency indicating percent of plots each species was present, location (Sc=*Schoenoplectus americanus* dominated area, Ty=*Typha* spp. dominated area, FW=forested wetland, and UP=upland area). If a year was mentioned in the comments section, that species was only found in that year.

Plant species	Common name	Frequency	Location	Comments
Schoenoplectus americanus (Pers.) Volk.ex Schinz & R. Keller**	Three-square bulrush	65	Sc	Michigan endangered species, very abundant
Aster lanceolatus Willd.	Panicled aster	77	Sc, FW, Ty	Very abundant
Typha angustifolia L.	Narrow leaf cattail	66	Ty, Sc, FW	May be *T. latifolia*, 2001, Edge of Sc patch
Typha latifolia L.	Common cattail	17	Sc, Ty	May be *T. angustifolia*, 2001, Edge of Sc patch
Typha spp.	Cattails	65	Ty, Sc	Mixed *Typha* spp., only for 2000
Eupatorium perfoliatum L.	Boneset	37	Sc	
Eupatorium maculatum L.	Joe-pye weed	12	Sc	
Phalaris arundinacea L.	Reed canary grass	11	Ty, Sc	Small patch on north edge of Sc patch
Atriplex patula L.	Spearscale	44	Ty, Sc	Non-native of Michigan, 2001
Eleocharis parvula (R. & S.) Link	Dwarf spike rush	3	Sc	Michigan endangered species, by seep in 2001
Metha arvensis L.	Wild mint	63	Sc, FW, Ty	
Scuttelaria galericulata L.	Marsh skullcap	29	Sc, FW, Ty	
Acorus calamus L.	Sweet flag	14	FW, Ty, Sc	Edge of Sc patch
Onoclea sensiblis L.*	Sensitive fern	11	FW, Sc	Edge of Sc patch
Quercus spp.	Oak sapling	6	FW	2001
Acer spp.	Maple sapling	14	FW, Ty, UP	
Ulmus spp.	Elm sapling	6	FW	
Solidago spp.	Goldenrod	9	UP, Sc	
Prunus spp	Cherry sapling	6	FW, UP	
Peltandra virginica (L.) Schott & Endl.	Arrow-arum	6	FW	2001
Lonicera spp.	Honeysuckle	6	UP	2001

Appendix B (cont.)

Plan species	Common name	Frequency	Location	Comments
Toxicodendron radicans (L.) Kuntze	Poison Ivy	9	UP, FW	
Parthenocissus spp.	Virginia creeper	6	UP	2001
Frageria virginiana Miller	Wild strawberry	6	UP	
Taraxacum officinale Wiggers	Dandelion	6	UP	2001
Polygenum spp.	Smartweed	6	UP	2000
Equisetum spp.	Horsetail	6	UP, Sc	Edge of Sc patch
Galium spp.	Bedstraw	14	UP, FW	
Plantago spp.	Plantain	6	FW	2000
Linaria spp.	Toad flax	6	UP	2000
Trifolium spp.	Clover	6	UP	2000
Cornus stolonifera Michaux	Red-osier	6	UP	2000
Potentilla simplex Michaux	Cinquefoil	6	UP	2000
Chrysosplenium americanum Hooker	Golden saxifrage	11	FW	
Aquilegia spp.	Columbine	6	UP	2001
Pilea spp.	Nettles	23	Ty, Sc, FW	
Thelypteris palusteris Schott*	Marsh Fern	6	FW	2001
	Grass #1	11	Ty	2001
	Grass #2	6	UP	2001
	Grass #3	6	UP	2001
	Burr1	6	UP	2001
	Burr 2	6	UP	

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