The Impacts of Various Types of Vegetation Removal on Great Lakes Coastal Wetlands of Saginaw Bay and Grand Traverse Bay

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INTRODUCTION

It has been estimated that approximately 70 % of Great Lakes coastal wetlands have been lost to anthropogenic disturbance since European settlement; loss in the lower lakes is nearly 95 % in some areas (Cwikiel 1998, Krieger at al. 1992). Many of the wetlands remaining today are heavily fragmented, with large areas drained for agriculture and urbanization while boat launches and navigational channels cut through many of those that remain. The systems continue to be fragmented by additional development of the shoreline. Fragmentation sharply increases during low lake level years as riparian owners and developers seek to deepen channels and create new ones. Lake levels have dropped by more than one meter in Lakes Michigan and Huron from 1997 through 2003 and reached near record lows in 2003. Lake levels remained low in 2004 and 2005. Fragmentation accelerated markedly during this time-period as landowners sought to remove wetland vegetation from the recently exposed beach areas in front of their properties. This removal of wetland vegetation continued in 2005, even though water levels have increased somewhat from 2003 lows. A variety of techniques have been employed, ranging from mowing to mechanical removal of roots and rhizomes using farming and construction equipment. In addition, sand has been moved to and from specific beach areas to create or maintain beaches, particularly in public parks but also on some private lands. The resulting increased fragmentation may have substantial and long lasting effects on wetland biota.

Recently, the Michigan Legislature enacted legislation, exempting owners of lakefront property on any of the Great Lakes and Lake St. Clair from having to obtain a permit before conducting maintenance activities such as mowing and removal of washed up aquatic vegetation on exposed bottomlands between the ordinary high water mark and the existing water’s edge. The legislation also allowed mechanical removal of certain types of vegetation from certain areas after obtaining a letter of approval or permit from the Director of the Michigan Department of Environmental Quality (MDEQ). Many areas of the Great Lakes shoreline are likely to undergo sharp increases in fragmentation of wetlands as a consequence of this legislative action and approval of a general permit for such activities by the U.S. Army Corps of Engineers.

The effects of habitat fragmentation have been described for many terrestrial systems (Aizen & Feinsinger 1994, Chen & Spies 1992, Dale et al. 2000, Diffendorfer et al. 1995, Essen 1994,; Groom & Grubb 2002, Jokimaki et al. 1998, Jules 1998, Laurance et al. 2001, Manolis et al. 2002, McKone et al. 2000, Pasitschniak & Messier 1995), but very few studies have been conducted on wetland fragmentation. Those studies that have been conducted on wetlands focused on amphibians (Findley & Houlihan 1997, Gibbs 2000, Knutson et al. 1999, Lann & Verboom 1990), birds (Benoit & Askins 2002), and plants (Hooftman et al. 2003, Lienert & Fischer 2003). Only one study was conducted on Great Lakes coastal wetlands (Hook et al. 2001), and in the authors focused on a very small area of northern Lake Huron. No study, to our knowledge, has characterized shifts in ambient chemical/physical parameters and related these shifts to changes in plant communities, micro and macroinvertebrates and adult, juvenile, and larval fish.

Great Lakes coastal marshes are dynamic freshwater systems, with physical, chemical, and biological characteristics drastically differing from inland marshes. We have observed relatively distinct chemical/physical gradients from open water to shore in these systems. Fringing coastal wetlands occur almost exclusively in embayments, where protection from destructive forces of wind and waves enables unique vegetation communities to become established (Albert and Minc 2001, 2004; Burton et al. 2002, Heath 1992, Keough et al. 1999). The open embayments of Saginaw Bay and Grand Traverse Bay, where this study will focus, are subject to more wave action than many smaller, well protected bays, and the open vegetation zones reflect this increased wave energy (Albert et al., in press). The broad bulrush beds dampen the wave impacts, but the outer edge of the wetland maintains a chemical/physical signature comparable to that of the open water. In contrast, areas of the wetland closest to shore receive less wave energy and a greater component of groundwater instead, resulting in a very different chemical/physical signature. These two extremes in chemical/physical conditions merge along a long natural gradient perpendicular to shore. Much of our work has shown that the biota respond to this natural gradient with shifts in community composition from open water to shore (Burton et al. 1999, Burton et al. 2002, Burton et al. 2004, Uzarski et al. 2004, Uzarski et al. (in press)).

While we can predict biotic community composition along the long natural gradients perpendicular to shore, it is unclear how these communities respond to modified anthropogenic gradients. In this study we are focusing on the effects on fragmentation on the biota, with particular emphasis on effects of beach grooming activities on this fragmentation. The study emphasized Saginaw Bay wetlands and wetlands along the Grand Traverse Bay portion of the Lake Michigan shoreline. The original plan of the study was to compare relatively large blocks of adjacent Great Lakes habitat under different types of management, including unmanaged, mowed, raked or tilled, dredged, and hand pulled to remove aquatic vegetation. Our sampling design changed when it became apparent that it was seldom possible to find relatively large immediately adjacent parcels being managed in several different ways. When we found adjacent parcels being managed in different ways, we could often not get permission from landowners to sample the parcels. It became clear in 2004 that gaining access to fragmented sites was our largest hurdle. As a result, sampling points representing different treatments were located as near as possible to each other, with additional physical sampling of the geomorphic context to determine if the treatments were geomorphically equivalent.

METHODS

General Approach for Determining Effects of Wetland Fragmentation

We worked with MDEQ staff, members of the SOS organization, and other private organizations to identify lakefront areas where property owners have recently conducted or have proposed to conduct removal of plants from exposed bottomlands that currently support or previously supported emergent plant communities. We sampled 8 such areas along the western Saginaw Bay shoreline (Figure 1), 18 areas on eastern Saginaw Bay (Figure 2), and 7 areas along the Grand Traverse Bay shoreline (Figure 3). The Grand Traverse sites were centered in areas where Michigan's Department of Environmental Quality had granted permits to groom shoreline, primarily for hotels, resorts, and park facilities. Along Saginaw Bay, sampling was conducted in areas where private landowners or park facilities had been granted permits, in several communities in Arenac, Bay, Tuscola, and Huron Counties.

While the fish, invertebrate, and plant sampling crews coordinated identification of sampling sites, sampling restrictions for these different organisms resulted in sampling being conducted in different specific sites by these teams. The information from these components is expected to complement each other by creating a broader evaluation of the entire coastal habitat.

The original sample design called for paired sampling of unmanaged sites with plowed or raked sites and mowed sites within the same ownership or immediately adjacent ownerships. As we began searching for sampling sites, it became clear that there were few ownerships in which it was possible to sample more than one type of management. The sampling was changed to allow nearby ownerships under different management regimes within an ecologically similar area of shoreline to be sampled to compare response of vegetation and sediments.

Determination of Overall Anthropogenic Disturbance

The initial ecological condition of a wetland is important to evaluating the effects of recent anthropogenic disturbance. This condition was investigated using historic aerial photography and interviews with local landowners. In some cases older anthropogenic disturbances were identified through investigations of the coastal sediments along transects.

Vascular Plant Sampling

Vascular plant sampling was conducted along 33 transects in three regions, Grand Traverse Bay, Western Saginaw Bay, and Eastern Saginaw Bay (Figures 1-3). Western and eastern Saginaw Bays were separated due to perceived differences in the geomorphic conditions along the shoreline. Of the 33 sites visited, 24 were sampled in 2004 and 23 in 2005. Fourteen of the sites studied in 2004 received some level of resampling in 2005. For most sites revisits were focused on collecting information on changes in wetland or beach width between 2004 and 2005, but further vegetation sampling was conducted at some sites as well.

In addition, several sites were visited in both 2004 and 2005 as potential sampling sites, including sites within all three regions. Visits were also conducted to shoreline areas of the St. Clair River Delta (Harsens Island and mainland), Lake St. Clair, and Lake Erie to determine if there were potential sampling areas, as we had been told there was strong interest in clearing shoreline vegetation in these areas as well. No sampling was conducted in these areas, as the combination of extensive hardened shoreline and water levels high enough to cover the bottom sediments to the edge of seawalls lead us to determine that conditions were not equivalent to those found on either Saginaw Bay or Grand Traverse Bay.

Sampling consisted of three components. The first component of the vegetation study was investigation of species dominance and diversity in the disturbed and reference areas; first year sampling demonstrated that "edge" sampling for vegetation was typically not possible because of land-use intensity on both Saginaw and Grand Traverse Bays. Sampling was conducted in five treatments, 1) unmanaged, 2) mowed, 3) raked (including plowing or disking), 4) handpulling of plants, and 5) sand filling of wetland depressions.

For investigation of diversity and species dominance, plant coverage was estimated (percent) in three 0.5 X 0.5 meter quadrats within each treatment (disturbed or reference), for the inner and outer emergent zone. For most of the sites sampled in 2004 on both Saginaw and Grand Traverse Bays, the wet meadow zone was lacking and sampling therefore concentrated on the zone dominated by typical emergent vegetation, even if this zone was not flooded. For bulrushes (*Schoenoplectus pungens*, *S. tabernaemontani*, and *S. acutus*), stem counts were also conducted in each quadrat. Plant data was utilized to evaluate 1) overall species diversity and 2) exotic species presence and coverage. Major differences in annual vs. perennial dominance were also investigated. Unknown plants were collected for identification and nomenclature was based on Herman et al. (2001).

The second component of the vegetation study was the quantification of fine roots and rhizomes in the disturbed and undisturbed treatments. Quantification of the amount of rhizome and fine root production, along with recording surface sand depth, is meant to allow evaluation of the sediment retention by each treatment. We hypothesize that the severity of disturbance and the duration of effects of fragmentation are likely to be considerably longer if disturbance is severe enough to destroy the roots and rhizomes of extant plant communities. Conversely, if roots and rhizomes are not destroyed, fragmentation effects may not be as severe or last as long, and the system may recover quickly from disturbance as lake levels rise.

Quantification of effects of disturbance on roots and rhizomes, was determined from root samples taken from both unmanaged and disturbed sampling points. Root samples consisted of 45-cm deep blocks of surface sand and underlying clay, 30 X 30 cm in surface area (Figure 4). At each site, one or more of these blocks were collected in the disturbed and unmanaged areas. Samples within the emergent marsh were taken 25 and 75 meters from the wet meadow-emergent marsh boundary, or when the vegetation zones was too narrow to allow collection at these points, at the bottom of the swale closest to the wet meadow and one to five meters from the water's edge, in shallow water. Both fine roots and rhizomes were separated from the sediments at the sampling sites, air dried for several days in screen trays, dried in a oven at 65 ºC for 24 hours, and weighed to within 0.1 gm. Aboveground vegetation was also dried and weighed utilizing the same methodology.

The length of rhizome was computed for bulrushes, cattails, and reed (*Phragmites australis*). No attempt was made to quantify the length of rhizomes for other species, or the length of fine roots for any species. The diameter of dried bulrush (*Schoenoplectus pungens* only) rhizomes was compared for all sites in an attempt to compare the ages of bulrush populations at different sites.

For the rhizomes, which may persist for several years, recent, intact rhizomes were separated from older, partially decomposed rhizomes to more accurately evaluate the effect of disturbance upon subsequent rhizome production. The distribution of roots and rhizomes by sediment type, sand or underlying clay was quantified. Separation of roots and rhizomes was done by soaking and spraying the sediments and roots with water, followed by drying and weighing of root materials.

A third component of the vegetation study was creating elevation and vegetation transects perpendicular to the shoreline to determine if there are different types of shoreline involved in the study. At 5 to 10 meter intervals along the transect, with the distance between points determined by the width of the wetland or shoreline segment, the elevation, substrate, and number of bulrush stems were recorded. The number of bulrush stems was recorded in a 0.5 X 0.5 meter quadrat at each sampling point along the transect.

Depth of Sand Measurement. As part of the plant sampling, the depth of sand over the underlying clay substrate was measured for each treatment (disturbed and reference areas) to evaluate the effect of vegetation management upon surface sediment retention. Initial investigations indicated that the fine roots of wetland plants retain and stabilize surface sands. Sand depth was also measured at 5 or 10 meter points along a transect from the shoreline to the end of vegetation for each treatment at each site. Sand depths were taken within a two-week period in 2004 for all sites on Saginaw Bay and within a week period for Grand Traverse Bay. Sand depths were taken over a similar time frame at sites added in 2005. Sand depth determinations were restricted to the emergent marsh zone, as the narrow wet meadow zone is an extremely dynamic zone where sand depth variability is expected to be too high to allow information to be meaningfully interpreted. Global positioning (GPS) was utilized along the transect to allow future comparison of sediment depths for the 2004-2005 sample points.

Data Analyses for Vascular Plants. Wilcoxon / Kruskal-Wallis Rank Sum tests were used to determine if disturbed sites of Saginaw and Grand Traverse Bays were significantly different from associated reference sites. Differences evaluated include overall species diversity, overall species coverage, number and coverage of exotic plant species, and number of stems for three-square bulrush (*Schoenoplectus pungens* or *Scirpus americanus*). Root and rhizome weight within the sediment blocks of disturbed and reference sites were also compared using Wilcoxon / Kruskal-Wallis Rank Sum tests, as were the relationship between the amount of roots (and rhizomes) and the depth of sand over clay. The Wilcoxon / Kruskal-Wallis Rank Sum test, computed using the statistical package JUMP, was utilized because of 1) unequal sample sizes among treatments, and 2) non-normal distributions (Sokal and Rohlf 1981, Neter and Wasserman 1974).

RESULTS

Vegetation Analysis

Dominance of Bulrush. *Schoenoplectus pungens*, a bulrush commonly known as “three-square”, is one of the most characteristic wetland plants in shallow waters of both Saginaw and Grand Traverse Bays. Along elevational transects, three-square dominated almost all unmanaged and mowed sampling points, typically occurring in over 80 percent of the points along a given transect. Of 24 vegetated transects, only three of were not dominated by three-square, and these were in areas where there was extremely high levels of human management on the beach or where wave energy was high, such as areas on Port Austin Road just north of Sand Point. Figures 5 through 7 show three-square rhizomes from an unmanaged site, Pinconning Bay. Figure 5 shows the thick mat of roots and rhizomes, often reaching 20 cm (8 inches) or more in thickness, with fine, sand binding roots at the surface, rhizomes below these roots, and long, relatively thick vertical roots that bind the sediments below the rhizomes. Figure 6 shows the network of rhizomes from a 30 cm X 30 cm square plot, while Figure 7 illustrates the sand held within a 30 cm X 30 cm x 45 cm block of roots and rhizomes.

In the individual sampling points for comparison of vegetation response to different types of management, three-square was also an important dominant plant at almost all vegetated sites on both Saginaw and Grand Traverse Bays (Figure 8). Both unmanaged and mowed sites had statistically greater numbers of stems of three-square than paired raked, handpulled, or sand filled sites (p=<.0001). All but two of 20 unmanaged sites had three-square in the 30 cm X 30 cm sampling plots, and the highest number of three-square stems in a single plot was 97. While three-square was an important species in most of the mowed sites, four of 13 mowed sites had no visible bulrush stems in the plot, and the number of stems was generally much lower in mowed sites than unmanaged sites. Mowing makes it much more difficult to see three-square stems, so there were likely more stems of bulrush present than identified in any of these mowed sampling plots.

In contrast, almost no stems of bulrush were present in sampling plots that had been regularly raked or where handpulling of wetland plants had occurred, nor were there stems present following filling of wet swales or depressions with sand (Figure 8). The only exception was Whites Beach Township Park, where one and three stems of bulrush were found in the two plots that had been raked a couple years prior to our sampling. Based on the presence of abundant annual wetland plants, it did not appear that the site had been raked during the years we were sampling (2004 or 2005).

Native plant and bulrush root quantities. To further evaluate the presence and importance of wetland plants at managed sites, roots and rhizomes were weighed from all sampling plots, with a focus on some of the larger wetland plants, three-square, *Phragmites australis* (reed), and cattail (*Typha* spp.). Rhizomes of bulrush, reed, and cattail were separated and weighed separately. For fine roots, species could be weighed by species if only one species occurred in the plot. Fine roots of mixed samples could not be reliably separated, and were thus combined during the drying and weighing process and the weight of mixed samples was separated into finer classes based on the ratio of rhizome weights in the sample.

Analysis of bulrush roots (including rhizomes) verified the importance of three-square in the study area (Figure 9). Bulrush roots were typically the most common roots in the sample for both unmanaged and mowed treatments, which had significantly more bulrush roots than the raked, handpulled, or sand-filled treatments (p=.0011). Of the 12 raked sites, the only one that contained bulrush stems in 2004 had been raked earlier during the summer of 2004 and the rhizomes had not yet broken down. When this site was revisited in 2005, no roots remained, only a band of dark, highly decomposed organic material 3 to 4 cm thick. Similar bands of dark, fine organic soils were found at several of the raked sites. One of the three sites where a bulrush-dominated swale had been filled with sand also had partially decomposed rhizomes when it was sampled in 2004 (Figure 10), shortly after sand had been deposited. The filled swale had only finely decomposed organics when revisited in 2005. Thus bulrush (three-square) mortality and root decomposition are relatively rapid, taking only one to two years.

While rhizomes and stems remain viable when wetland vegetation is mowed, it appears that the mowing may result in a loss of both aboveground and below ground biomass. This biomass loss could not be adequately addressed in this study, as only one site could be identified where direct comparisons could be made between adjacent mowed and unmowed areas. At this sampling site, Phragmites had established in the mowed area and it's competition for light, moisture, and nutrients may have been more significant in reducing the biomass of bulrush than the mowing. A more detailed sampling protocol will be needed to adequately address this question.

To further evaluate the effect of various treatments on bulrushes, the maximum and mean diameters of bulrush rhizomes were examined for all sites and treatments (Figures 11 and 12). Bulrushes are a long-lived perennial species, whose rhizomes increase in diameter over time, with the maximum observed diameter of 9 mm in our study areas. To improve our understanding of the rooting pattern for three-square, a four meter (14 ft) section of rhizome was removed from a marsh on Saginaw Bay (Figure 13). This section of rhizome supported fourteen stems that grew on short lateral rhizomes; the entire length of this plant's rhizome is probably much greater than four meters. For this plant, the diameter of the oldest section of rhizome is about 9 mm, while the youngest portion has a diameter of 5 to 6 mm. During the study, rhizome diameters were found to range from 2 to 9 mm in diameter. The maximum diameter of the rhizomes from mowed and unmanaged sites was between 8 and 9 mm (Figure 11). The largest rhizome diameter of unmanaged bulrush samples was 9 mm, while the largest mowed rhizomes were 8 mm in diameter. Thus it appears that some of the mowed sites were long-term wetlands with large, older bulrush plants, not just young plants that established recently as water levels dropped.

Comparison of the mean diameter of bulrush rhizomes (Figure 12) shows that rhizomes from mowed samples are generally smaller in diameter than rhizomes from unmanaged samples, however this is not a statistically significant difference (p=.1911). Difference in mean rhizome diameter may reflect several factors that require further investigation. These factors may include 1) greater competition from annual plants resulting in reduced rhizome diameter growth, 2) re-absorption of nutrients from the rhizomes, resulting in reduced rhizome diameter, or 3) inclusion of wetlands of different ages (and therefore rhizome diameter) in the study.

Further analyses of the maximum rhizome diameter by region, with regions described as Grand Traverse Bay, Western Saginaw Bay, and Eastern Saginaw Bay, identified a statistically significant difference (p=.0329) in maximum rhizome diameter between regions (Figure 14). This difference is likely the result of different long-term dynamics in these three regions, with many Eastern Saginaw Bay and Grand Traverse Bay wetlands disappearing during high-water periods. Several land managers and landowners in both regions have claimed that the wetlands in these regions appeared only recently, about six years ago when water levels dropped. The small bulrush rhizome diameters in most of the wetland in these regions seem to support the assertion that the wetlands (and their plants) are only 5 or 6 years old.

Plant Species Diversity. Plant species diversity is often considered an important method for evaluating wetland quality. Recent studies of Great Lakes coastal wetlands assert that plant diversity has to be considered in a regional context to be meaningful for Great Lakes wetlands (Albert and Minc 2004, Albert et al. 2005). These studies also emphasize that plant diversity in Great Lakes wetlands can change over time as water levels fluctuate. All of our sampling for this study was conducted in 2004 and 2005, two years with similar low water levels. Thus combining data from the two years should not alter results of our data analysis. However, some data analysis also compared the samples from different regions (Grand Traverse Bay, Western Saginaw Bay, and Eastern Saginaw Bay) to determine if physical differences between shorelines were responsible for differences in the vegetation of the coastal wetlands.

In this study, the number of native plant species found at a site differed significantly (p=<.0001) by management treatment, with unmanaged and mowed sites displaying much greater plant diversity than raked, hardpulled, and sand-filled sites (Figure 15). The average number of native wetland plants found at a sampling point ranged from zero to over 8 for mowed sites and from zero to over 6 for unmanaged sites. The species present was a mix of annual and perennial wetland plants. For the three more intensive management treatments, raking, handpulling, and filled, almost no plants were found at the sampling points (Figure 15). The only two raked samples that had any vegetation were at Whites Beach Township Park, where annuals had established since the site was last raked. At these two sites there were also very low levels of bulrush, which may have survived the raking, or established as seedlings following raking. Overall, the unmanaged plots had wetland plant diversity that was higher than on mowed plots, although this may have been an artifact of being unable to identify some mowed plants to the species level. Direct comparison of native plant diversity could not be made between mowed and unmanaged sites for most sites, as there was only one site where unmanaged and mowed treatments could be found side by side.

Native plant coverage (percent) is also a measurement used to compare quality of sites. Again, unmanaged and mowed sites had statistically greater native plant coverage than the more intensively managed sites, which had been raked, handpulled, or sand filled (p=.0001, Figure 16). The mean coverage for unmanaged sites ranged from zero to 83%, while mowed sites ranged from zero to 100% coverage. The only intensively managed sites that supported plants were two previously mentioned raked sites at Whites Beach Township Park, which had between 40 and 60% coverage, mostly of annual aquatic plants.

Exotics plant diversity and coverage have also been used as indicators of wetland quality; high numbers of exotic species or high coverage of exotic plants are considered indicators of wetland degradation. On our sample plots, both unmanaged and mowed sites had statistically greater numbers of exotic species than intensively managed sites (raked, handpulled, and sand filled) (p=.0016, Figure 17). Again, the only raked site with exotic plants was Whites Beach Township Park, where two upland exotic plants, *Hieracium* sp. (hawkweed) and *Plantago major* (plantain), were found. The highest numbers of exotic plants were found on mowed sites, with the highest average number of exotic plants per plot being three. At many sites the exotic plants consisted of a mix of upland and wetland plants.

Probably a more important measure of wetland degradation than the number of exotic species is the total coverage of exotic plants. The unmanaged and mowed sites had statistically greater coverage of exotic plants (p=.0027) than sites raked, handpulled, or filled sites (Figure 18). The highest coverage of exotic species occurred on mowed sites, where three sites had high coverage values ranging from 38 to 52 percent. Both unmanaged and mowed sites had *Phragmites australis*, one of the larger and more aggressive of the Great Lakes exotic plant species.

Of the nineteen plots that contained exotic plants, only three contained greater coverage of exotic plants than native plants (Figure 19). Two of these sites had been mowed, while the third site was surrounded by mowed properties. *Phragmites australis* was the dominant exotic plant for all three of these sites.

Sediment analysis. Sediment textures and depths were studied along with water depths and elevations on transects to allow comparison of sediment movement and change resulting from different management regimes. One of the primary interests was to first determine which sites had clay or other fine-textured soils below the surface sands, as there was indication from earlier studies on Saginaw Bay on Lake Huron and Cecil Bay on Lake Michigan that clay underlying surface sand might be important for anchoring bulrushes in an erosive coastal environment. Following determination of the presence of a clay subsoil, the importance of the vegetation for holding surface sands could be evaluated. Our sampling quickly demonstrated that underlying clay soils were not as widespread as had originally been assumed. Previous sampling of coastal wetlands in Saginaw Bay had identified numerous sites where clay soils were only a few inches below the surface. These sites included Pine River in northwestern Saginaw Bay, Whites Beach and Pinconning further south in Arenac and Bay Counties, and Bradleyville Road, King Road, Thomas Road, and other sites between the Quanicassee River and Sebewaing. In our present study, clay was encountered at sites between Whites Beach (Arenac County) and Linwood, but most of the sites south of Linwood and along the eastern shore of Saginaw Bay did not have clay within 45 cm (18 inches) of the surface. Other sites included within this study that had clay subsoil within 45 cm were sites on Rose Island, at Bay Port, and a single site about a mile north of Sand Point along Port Austin Road (M-25). Nearby sites along Port Austin Road did not have an underlying clay layer within 45 cm. None of the sites on Grand Traverse Bay had clay or fine-textured soils near the surface.

No statistical analyses were conducted on the soil texture results for a number of reasons. First, where clay soils were encountered in western Saginaw Bay, land-use history resulted in a high amount of sediment variability, with thick sand fill immediately adjacent to sites where sand appeared to have been removed entirely or moved closer to shore for beach enhancement. In eastern Saginaw Bay, clay was less commonly encountered, and these clay soils were not in areas where there were multiple management types to compare. Another complicating factor was that many of the Grand Traverse Bay sites had a dense, thick band of gravel that extended below the sand, making it impossible to get deep core samples of the sediment.

While the results from the texture analysis did not provide the intended information, they did provide some insights into coastal processes that justify further study. For most of the clay-rich samples, there was abundant gravel at the surface of the clay and in the clay deposits themselves. This probably indicates that storms and wave action has eroded fine-textured tills and lacustrine deposits, creating a protective lag of gravel at the surface of the clay. This layer may provide additional protection for bulrush rhizomes that are located in the clay. The large segment of rhizome shown in figure 13 was just below this gravel layer for much of its length. It may be that much of the sand found above the clay and gravel was locally derived by wave erosion from the fine-textured (clay) till that can still be found below.

Similarly, on Grand Traverse Bay there is a thick gravel lag that is regularly found just below the surface sands. The prevalent sediments around Grand Traverse Bay are also fine-textured, but the gravel layer resulting from wave erosion may have been too thick to allow these fine-textured soils to be encountered during sampling. In our sampling of Grand Traverse Bay, bulrush rhizomes were only encountered in the surface sands, with minimal growth extending into the underlying gravel.

Elevation transects. Elevation transects were established with the hope of identifying different types of shoreline that supported wetland plants in the study areas. The two types that appear to be represented in the study areas were *open embayment* and *swale complexes* (Albert *et al*. in press). *Open embayments* characterize sections of shoreline with relatively small amounts of lacustrine sand and low slope gradients. This type was well represented from sampling sites along western Saginaw Bay, from Whites Beach to Linwood (including the unmanaged areas of Pinconning), around Bay City, and near Rose Island further to the east.

These open embayments typically have very low slope gradients, with only 10 cm (4 inches) or less of elevation change per 10 m (30 feet) of transect being typical. In unmanaged marshes there tended to be slightly more elevation variability, with 30 cm (12 inch) beach ridges or sand spits occurring at intervals along the marsh transect. These features were evident in many managed sites as well, but appeared to be greatly diminished by mowing, raking, disking, and other forms of sediment manipulation.

Another characteristic of most of the open embayment sites was the presence of clay lacustrine or till within a few centimeters of the surface, beneath a shallow sand veneer. At Whites Beach, with the exception of the Township Park, where a thick layer of sand had been deposited in the past, all sites had clay subsoils. At Linwood the clay subsoil was present to the northwest near Lebourdais Road, but was not encountered further to the southeast near Boutell Road. Clay was also present at Rose Island several miles east of Bay City. No clay was encountered in transects along the western shore of Sand Point.

In areas where there is more erosive wave action, the actual shoreline supports no or very narrow zones of aquatic vegetation. In these erosive areas, the zone of aquatic vegetation is often not located on the shoreline itself, but in narrow swales behind a beach ridge. This type of shoreline has been called *open shoreline*. Behind the shore, many of these open shorelines have a broad complex of wetlands, which occupy swales between parallel beach ridges; these complexes have been called *dune and swale complexes.* The topographic maps of Saginaw Bay and Grand Traverse Bay indicate that our sampling areas are located along the shoreline of extensive dune and swale complexes. Maps of the original vegetation based on the early 1800 surveys of Saginaw Bay and the 1840s surveys of Grand Traverse Bay document extensive wetland complexes in both areas (Figures 20 and 21). In western Saginaw Bay, where there is less sand, the beach ridges are low, but can be seen to extend more than a mile inland in many places. The patterning of these ridges is difficult to see, as agricultural and residential management has obscured the low ridges. In contrast, there is much more sand movement and deposition in eastern Saginaw Bay, The dune and swale complexes from Sand Point to Port Austin are clearly visible on topographic maps and aerial photos, extending more than a mile inland over most of the shoreline, and protected as Port Crescent and Sleeper State Parks.

Grand Traverse Bay also has a large dune and swale complex where Traverse City is currently located (Figure 21). Urban development has altered the distinctive pattern of the wetland complex, but some of the features can be seen in earlier aerial photographs and topographic maps.

The *dune and swale complexes* formed over several thousand years (Thompson 1992; Thompson and Baedke 1995, 1997). The persistent wetlands occurring behind larger, more permanent sand ridges, and any wetlands that form in swales along the immediate shoreline are prone to be eroded away during high water periods. This erosion was seen along open shoreline of northern Lake Michigan and Lake Huron in 1987, when extensive areas of dead bulrush rhizome were exposed near Ogontz and Nahma Bays on Lake Michigan and east of the Carp River and on southern Marquette Island on Lake Huron (Albert et al. 1987, and Albert, personal observations). Many of these bulrush beds did not re-establish following the drops in water level during the late 1980s. Between Bay Port and Port Austin, the land managers and landowners report the complete loss of vegetation along the shore during high water, consistent with our observations on northern Lake Michigan in 1987.

While active management of these wetlands by filling the swale, raking, or hand pulling aquatic plants appears to result in more rapid erosion of coastal sediments, our transect data could not verify this. The reason for this is that the width of the shoreline beach or swale seldom remains the same for long distances. This is seen along Grand Traverse Bay, where aerial photos document a rapid natural widening of the wetland swale (where we did our sampling) in 1939 prior to heavy urban development of the shoreline. This widening occurs in roughly the same place today. Similarly, a rapid change in beach width can be seen on historic photos south of Linwood, where our data showed a rapid narrowing of the beach and swale. North of Sand Point along M-25 (Port Austin Road) the beach widens until the river mouth at Caseville, where it gradually narrows further north. None of our sampling pairs documents a sharp enough change in beach width to allow that change to be linked to a specific management activity.

Comparison of paired aerial photos from high and low water years demonstrate that the wetland swales disappear or become much less distinct during high water years. This can be seen just south of Caseville (Figures 22 and 23) and at Sleeper State Park (Figures 24 and 25), in two sets of photos from 1964 (low water) and 1982 (higher water).

A comparison of the topographic cross sections identified a few diagnostic differences between more permanent marshes and those that are eroded by high water levels. The primary difference is that even in low-water periods, the temporary wetlands have little or no vegetation extending out into open water; the vegetation only persists behind a protective beach ridge. In contrast, permanent marshes typically have broad zones of emergent marsh that extend into open water beyond a protective beach ridge. The narrowest of these zones in the permanent wetlands was 40 meters, but those in western Saginaw Bay could be several 100 meters wide. However, there is a large amount of variability in these wetlands. The extreme erosive sites in eastern, such as Oak Beach Park, Thompson State Park, and Sleeper State Park (points SE 14-18 on Figure 2), have wetland vegetation growing in shallow swales above the present lake level, with no standing water at the surface of the wetland and no wetland vegetation extending into Saginaw Bay. Some of the broader swales in eastern Saginaw Bay can be 50 meters wide, with water levels influenced directly by the lake. On Grand Traverse Bay, the broadest flooded swales were more than a hundred meters wide, and there was typically a protective beach ridge. These ridges were dynamic, with abundant eroded bulrush and rush (*Juncus balticus*) rhizomes along the bay's edge. At one site the ridge was transitional, forming a shallow submerged sand bar during sampling in 2004, and exposed in 2005.

Another difference that appears in eastern Saginaw Bay sites is the steepness of the beach. While the Grand Traverse Bay and the western Saginaw Bay sites tend to have a gentle slope and only low upland beach ridges one to two meters high, the eastern Saginaw Bay sites have large, steep beach ridges three to eight meters high along their inland edge. At these sites, the wetland vegetation is only present in relatively narrow depressions or low areas. During high-water conditions, wave action rapidly erodes away the small shoreline beach ridge and wetland swale to the edge of the higher inland dune, leaving no wetland vegetation intact. This is the scenario described by the landowners on Port Austin Road and by the park managers at Sleeper State Park. It probably also characterizes several other parks with bulrushes along the shoreline, including Port Crescent State Park, Thompson State Wayside, and Orchard Beach County Park.

DISCUSSION

Response of vegetation to management

Disking, raking, or hand pulling. At all sites where aquatic vegetation had been regularly raked or hand pulled, there was little or no vegetation remaining (Figures 8, 15, 16, 17, 18). Investigation of the sediment also showed that there were no persistent rhizomes or roots present (Figures 9, 11, 12, 14). In most cases all that remained was a zone of organic enrichment where the roots and rhizomes had been prior to management; when aerated and killed by mechanical disturbance, the rhizomes and roots broke down within a single growing season. Sites with a long history of raking or hand pulling often had little or no remnant organic materials, even though adjacent properties had wetland plants in them. At these sites, vegetation often ended abruptly at property boundaries.

At some sites where disking had been done in recent years, a thin layer of annual or short-lived perennial aquatic or upland plants had established, typically with rooting concentrated within a few centimeters at the soil surface. Otherwise, there was almost no remaining rhizomes or dense roots of aquatic perennials, even where these plants had been encountered immediately following disking or deposition of additional sand.

Long-term landowners mentioned raking and pulling weeds back as far as the 1930s. One woman at Whites Beach mentioned that maintaining an open beach was part of the subdivision's membership agreement.

Sand fill. At three sites a swale or depression supporting aquatic vegetation had been filled with sand from outside the site. In all three cases, sampled in 5 different locations within these sites, there was no successful regeneration of the plants in the year following management. In three of the samples, vegetation including intact rhizomes had been observed or collected during the summer of 2004. Upon revisit during the summer of 2005 there was a band of rotting vegetation, but no identifiable roots, rhizomes, or aboveground plant parts where the vegetation had originally been growing. In two of the five sites there were no intact roots or rhizomes when they were visited in original 2004 sampling. Another site with sand fill, White's Beach County Park, had also been disked in 1999 or 2000. When it was sampled in 2004, there were almost no remaining bulrush stems, although bulrush had been observed immediately following disking in 2000 in small quantities. Annual and small perennial aquatic plants, along with both annual and perennial exotics have established following this treatment and a narrow zone of scattered bulrush grows near the outer margin of the wetland.

Sand fill is typically done in combination with several other forms of management. These can include disking, raking, and hand pulling of plants. While some landowners limited their filling to a narrow path across the swale, other private owners and businesses filled their entire wetland swale. Other types of management may be best categorized as filling, including movement of sand with bulldozers or similar heavy equipment. All of these management forms either remove roots and rhizomes or bury them. All seem equally successful in at least the short term elimination of long-lived aquatic plants, including bulrushes.

Mowing. Many sites were mowed. In fact, it was difficult to find sites that had not been mowed sometime during the growing season and some sites where permission was granted to sample the vegetation in early summer, had been mowed prior to our return for sampling. Landowners or neighbors often indicated that the "unmanaged" wetland vegetation had actually been mowed or raked in earlier years. Vegetation diversity remained relatively high following mowing (Figure 15-18). While many aquatic plant species were able to survive mowing, it was often impossible to identify plants to the species level – identifications were often to genus. More detailed analysis of the quantity of roots and rhizomes indicated that while bulrush was able to survive mowing, the amount of root biomass appeared to decline considerably for many mowed sites. One concern about this conclusion is that it is often difficult to evaluate the full range of management activities that have occurred at a site. At some sites management was not restricted to mowing, but also consisted of "thatch removal", which appeared to be either shallow disking or raking that resulted in major loss of fine roots and removal of large amounts of rhizomes. This was especially prevalent near Caseville and Sand Point. In one site with "thatch removal", large diameter rhizomes were present, indicating older bulrush plants, but the amount of these rhizomes was very low, probably as a result of the thatch removal procedure. Fine roots had not broken down after the thatch removal, so relatively large quantities were present in 2005, but based on results seen at other sites, these roots will likely decompose by 2006.

Although mowing may generally allow perennial marsh vegetation to persist, it has probably been effectively used as a tool for eliminating or reducing levels of bulrush and cattail significantly. For example, at White's Beach an elderly woman remembers mowing the bulrushes in the 1930s with the specific intent of killing the plants when water levels rose, thus improving the "beach".

Marsh geomorphology

In both Grand Traverse and Saginaw Bays, the wetlands would be considered *open embayments* or *open shoreline* backed by *dune and swale complexes*. Along these shorelines, wave energy can be strong and the shoreline often consists of a series of low beach ridges with adjacent swales, sometimes extending more than a mile inland. The low ridges also extend out into shallow waters of the bays and can often be easily seen on aerial photographs and are seen in elevation transects from the upland into the bay. This is best seen along western Saginaw Bay at Pinconning Park. In areas where there is more active sediment transport, it is common to see a beach ridge along the edge of the open lake, separating most of the wetland from the open lake. Wetland vegetation is best developed behind the beach ridge, in the shallow swale, but also on the beach ridge itself. At more erosive sites, there is no vegetation extending beyond the shoreline into the open lake. In several places vegetation had established on open sand near the lake, but was being actively eroded by waves from the open lake or bay. The dynamic nature of the shoreline environment is part of the reason that restriction of beach grooming has been so controversial.

Response of marsh vegetation to water level changes

In many of the areas sampled, landowners maintain that the wetland vegetation was not present during high water periods, and that it is a product of the low water levels. In many cases this perception is probably correct. A longer view of the wetland creation process indicates that many of these wetlands actually consist of a series of swales and adjacent beach ridges, with a gradual addition of wetland swales as the water levels of the Great Lakes gradually fall, as has been happening over the last 10,000 years. If water levels continue to fluctuate up and down, the wetlands may appear and disappear many times before a permanent swale develops. The process of erosion during high water conditions has been documented by long-term staff at Sleeper State Park, and has also been described by many long-term private landowners. Most of the private landowners have built seawalls on the inner beach ridge, thus eliminated continued inland erosion of the ridge where their homes are often located.

During our sampling, these organic materials were encountered in all three sampling regions (Figure 26). *Chara*, or stonewort, was the most typical plant forming a dense mat of wetland vegetation. Stonewort is among the common algae that grow profusely in the shallow, warm, calcium-rich waters of the swales, breaks down rapidly to produce these organic deposits.

SUMMARY

1. Disking, raking, filling of swales, and hand-pulling of aquatic plants were all effective at killing aquatic plants. Rhizomes and roots of perennial aquatic plants, including bulrush, decomposed rapidly following these forms of treatment.
2. Plant diversity is much higher in areas with no active management or in areas only mowed. Complete diversity is difficult to document in mowed areas, as many species can only be identified to genus. There may be reduced belowground biomass in bulrushes following prolonged mowing, but further investigation is needed to adequately document this.
3. Within one or two years following disking, raking, or hand-pulling of vegetation, annual plants return. Diversity tends to be low, with both upland and wetland species present, including exotic species. Bulrushes do not colonize these disturbed shorelines as rapidly as annuals and exotics.
4. While killing aquatic vegetation appears to have resulted in increased sediment erosion, it was not possible to document this with certainty.
5. Vegetation patterns along the shoreline varies due to the dynamics of different wetland types. *Open embayments* have broad bands of emergent vegetation continuing out into shallow open water of the bay. *Open shorelines* (often backed by *dune and swale complexes*) with greater wave erosion, only support wetland vegetation behind a coastal beach ridge, in a protected swale. The vegetation of open shorelines is more prone to disappear due to erosion when high-water levels return, as documented along northern Lake Huron and Lake Michigan, and as reported by coastal landowners and managers on both Saginaw Bay and Grand Traverse Bay.
6. Shoreline management has been very widespread and is often not well documented. The result of this management is that sediments and vegetation has often been managed in certain areas for decades, making cause and effect relationships difficult to accurately document. Both aerial photos and local landowners indicated that wetland areas have often been dredged for local marina construction or filled for use as beach. Unfortunately, such activities may no longer be apparent after decades of changing land ownership and use, but can alter the vegetation and sediment characteristics greatly.
7. Local landowners have a rich oral history that can provide valuable insights for understanding present vegetation (biotic) conditions. Examples include elderly landowners managing to kill bulrushes in the 1930s, park managers remembering marsh and bluff loss during high water conditions, and landowners discuss importance of seawalls not just for high water conditions, but also reducing effects of ice scouring along the shoreline.

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FIGURES

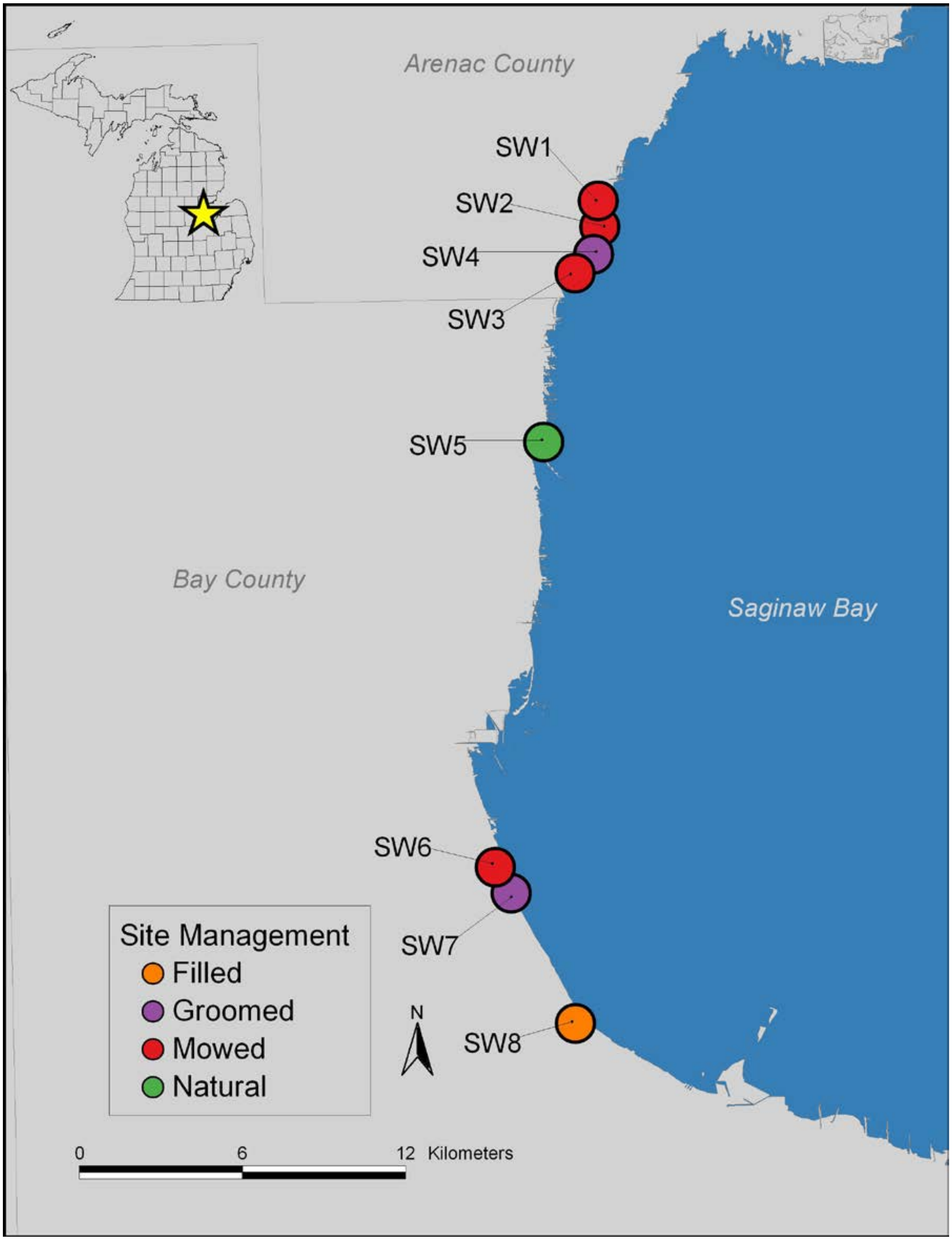


Figure 1. Sampling sites on western Saginaw Bay.

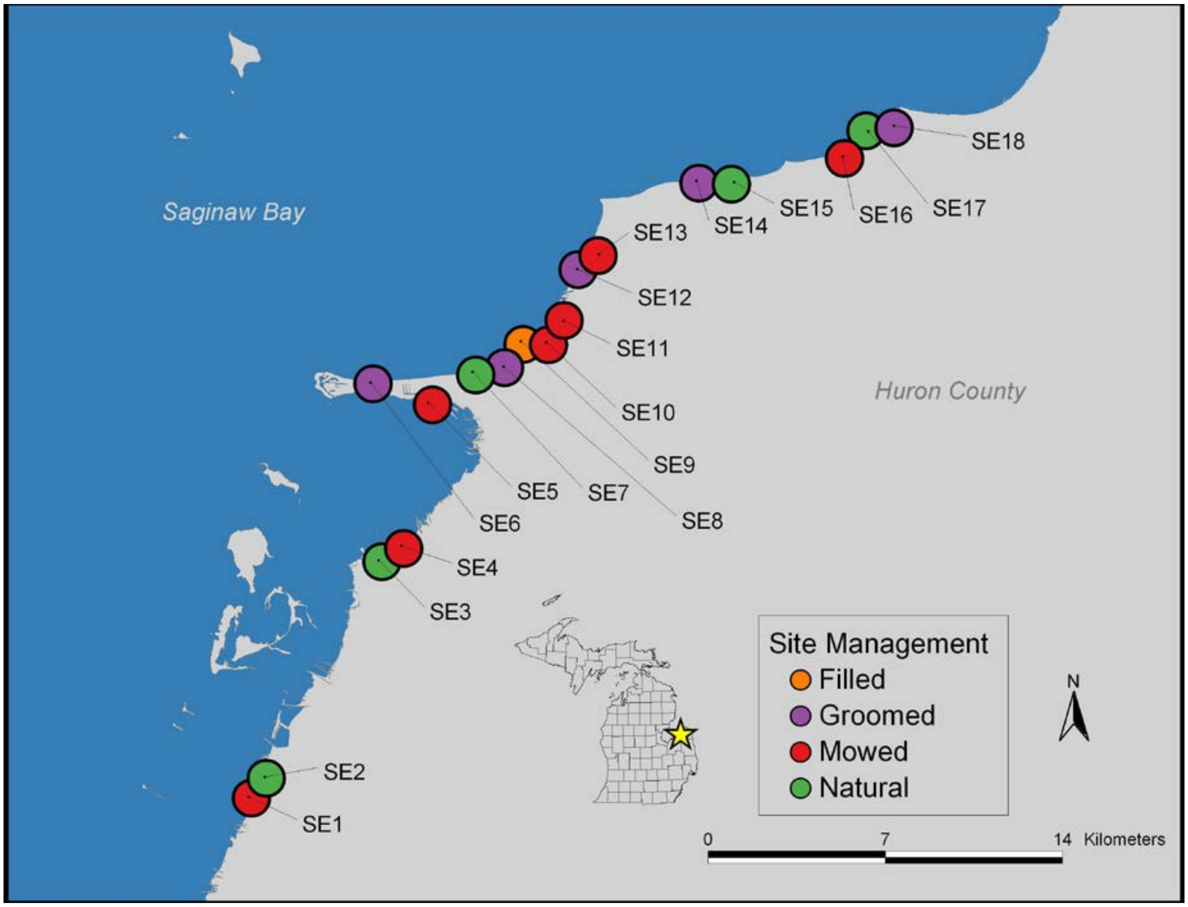


Figure 2. Sampling sites on eastern Saginaw Bay.

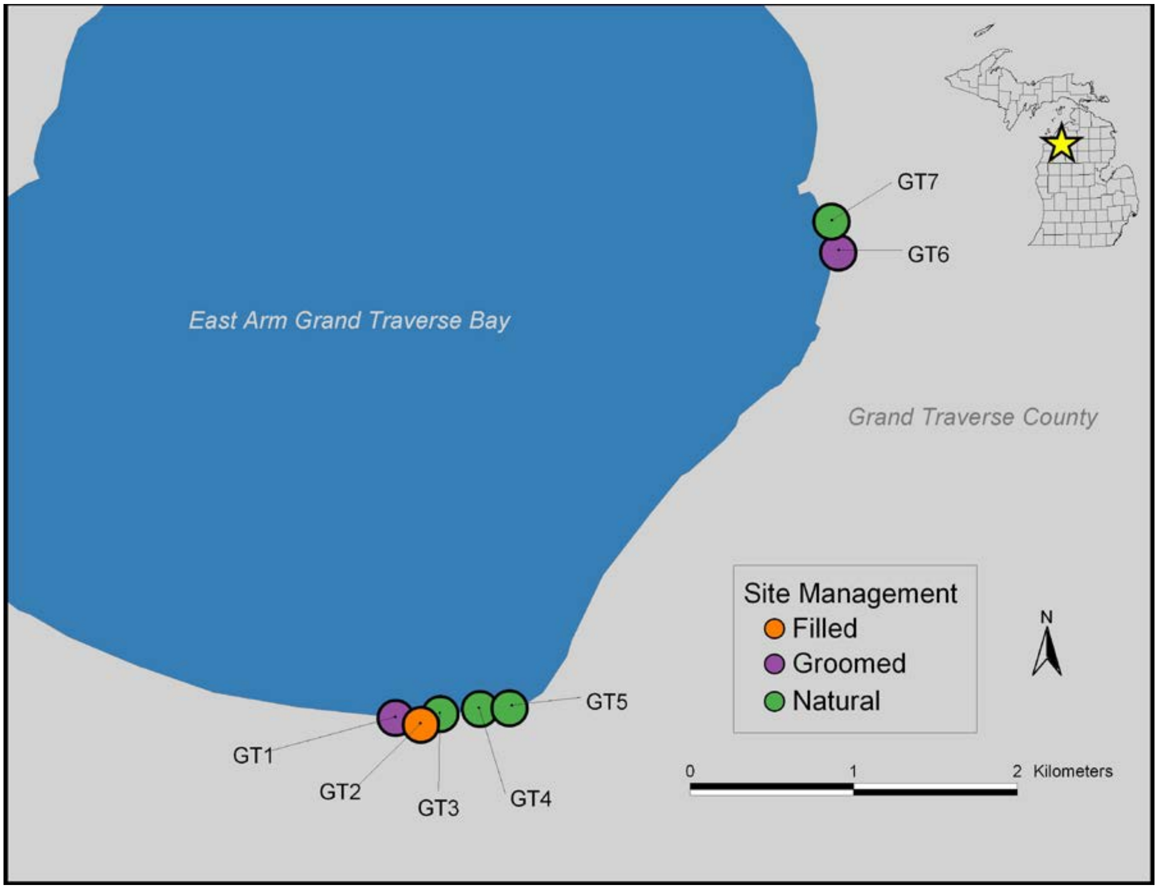


Figure 3. Sampling sites on Grand Traverse Bay.

Figure 4. Rhizome and sediment sampling pit: 30 cm X 30 cm X 45 cm. This pit has sand soils underlain by clay soils.

Figure 5. Cross-section of bulrush roots from soil pit: fine roots at surface, rhizomes below, and vertical roots at bottom. Fine roots concentrated in sand, rhizomes and vertical roots in underlying clay.

Figure 6. Bulrush rhizomes from 30 cm X 30 cm soil pit, with fine roots removed.

Figure 7. Large quantity of sand held by fine, surface bulrush roots.

Figure 8. Number of bulrush stems for each type of management. (p=<.0001)

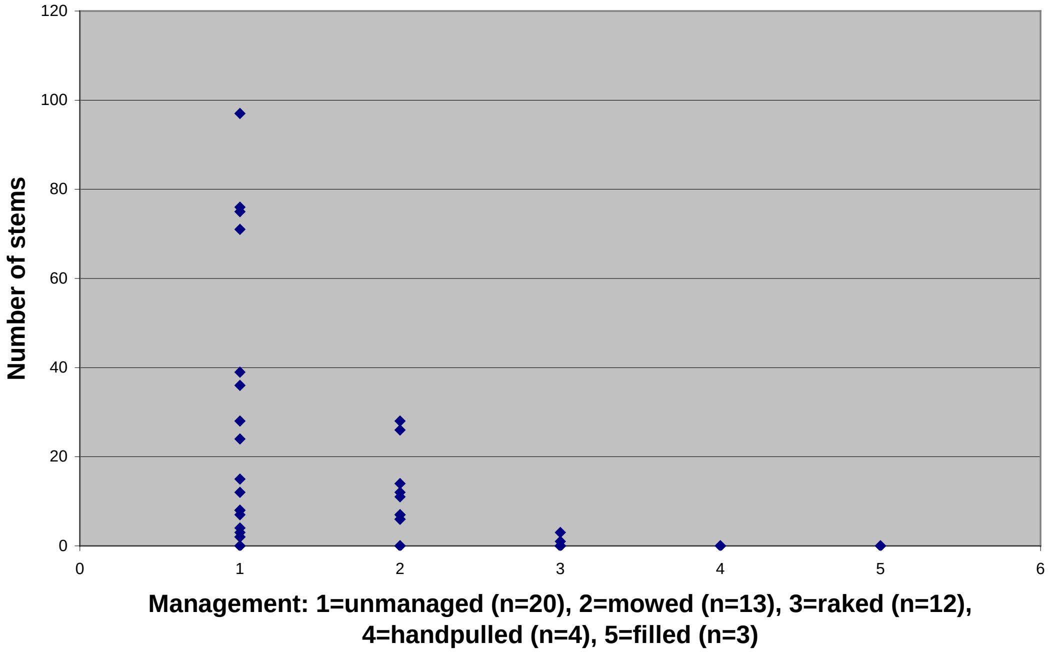


Figure 9. Amount of bulrush roots for each type of management. (p=.0011)

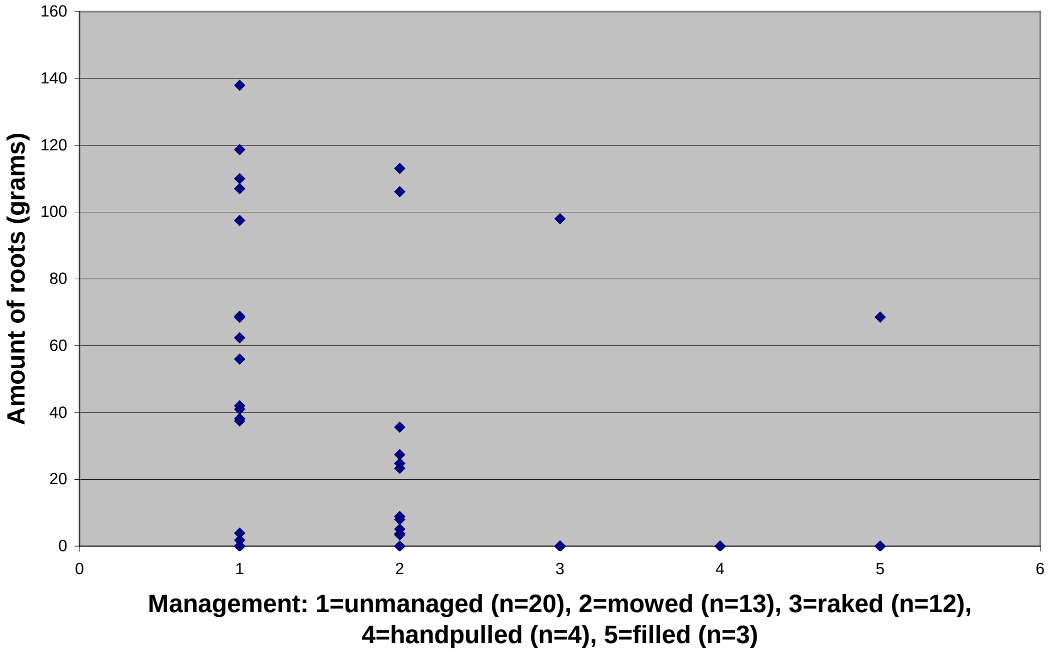


Figure 10. Decomposing bulrush rhizomes within a month or two following filling and raking of wetland swale.

Figure 11. Maximum diameter of bulrush rhizomes by type of management. (p=.1945)

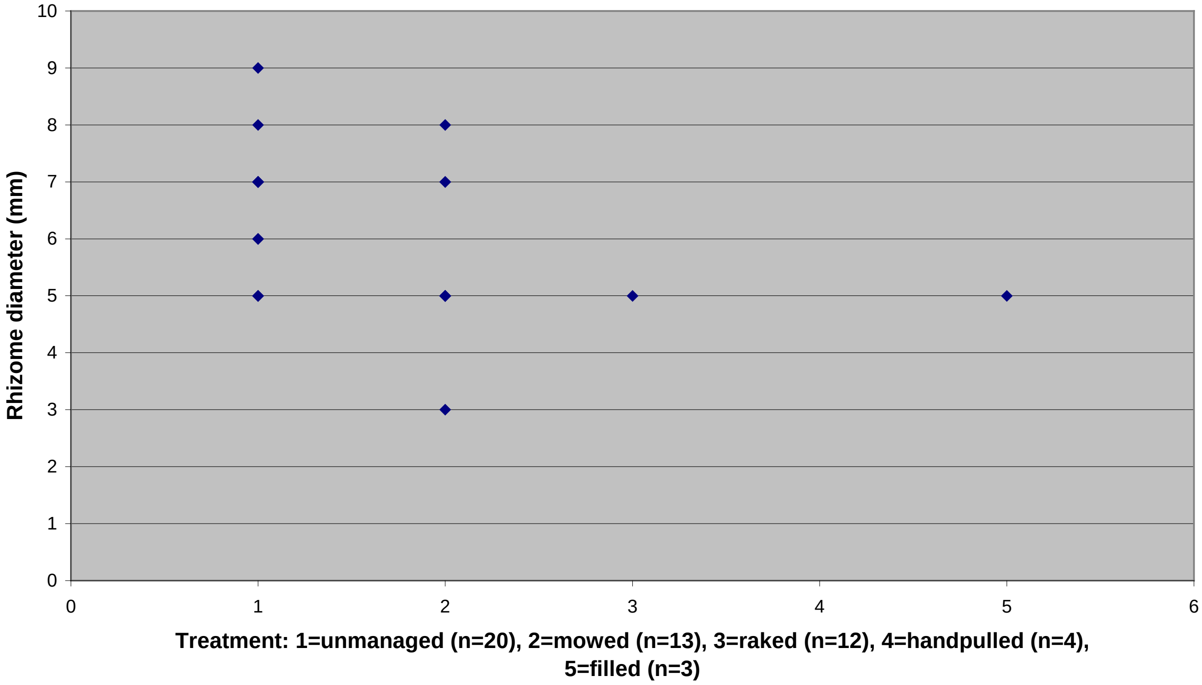


Figure 12. Average diameter of bulrush rhizome for each type of management. (p=.1911)

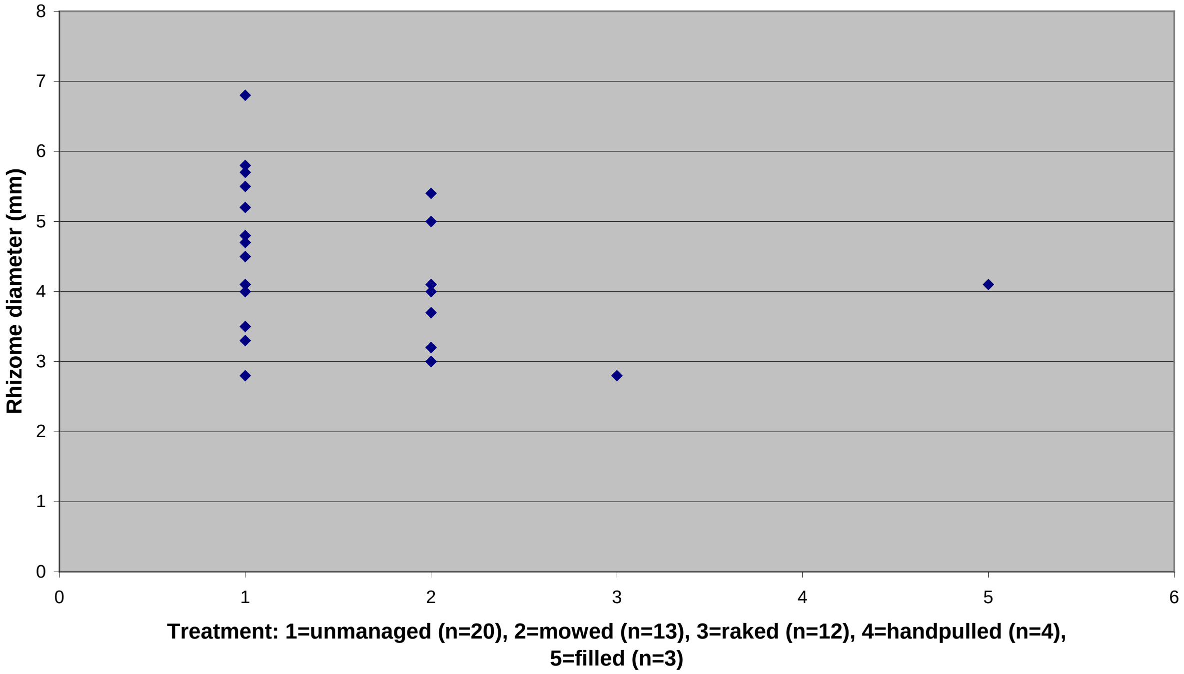


Figure 13. Four meter long bulrush (Schoenoplectus pungens) rhizome. This section of rhizome has 14 stems and the entire plant is probably much larger, based on the rhizome's diameter, which ranges from 5 to 9 mm.

Figure 14. Maximum diameter of bulrush rhizomes by region. (p=.0329)

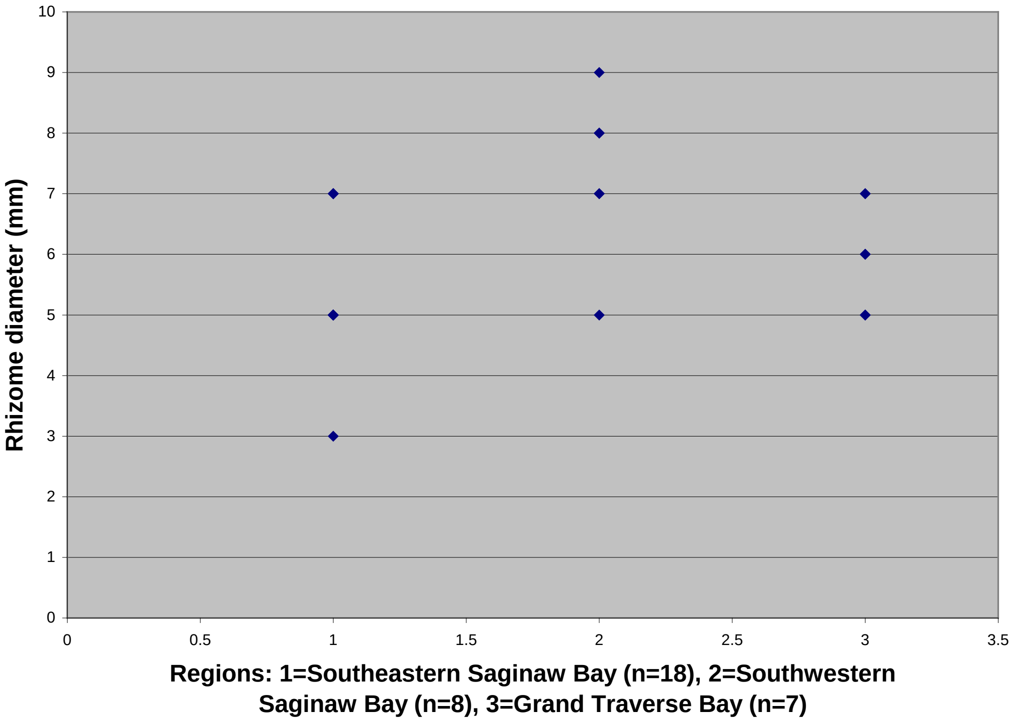


Figure 15. Average number of native plant species for each type of management (p=<.0001)

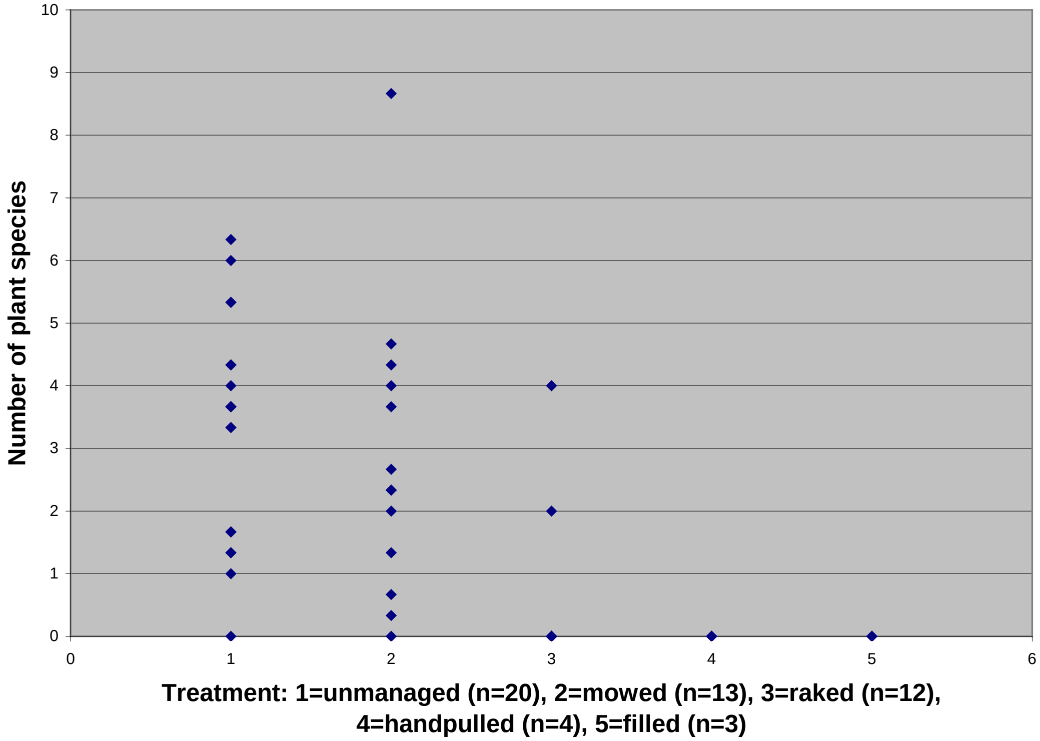


Figure 16. Mean cover value of native plants for each type of management. (p=.0001)

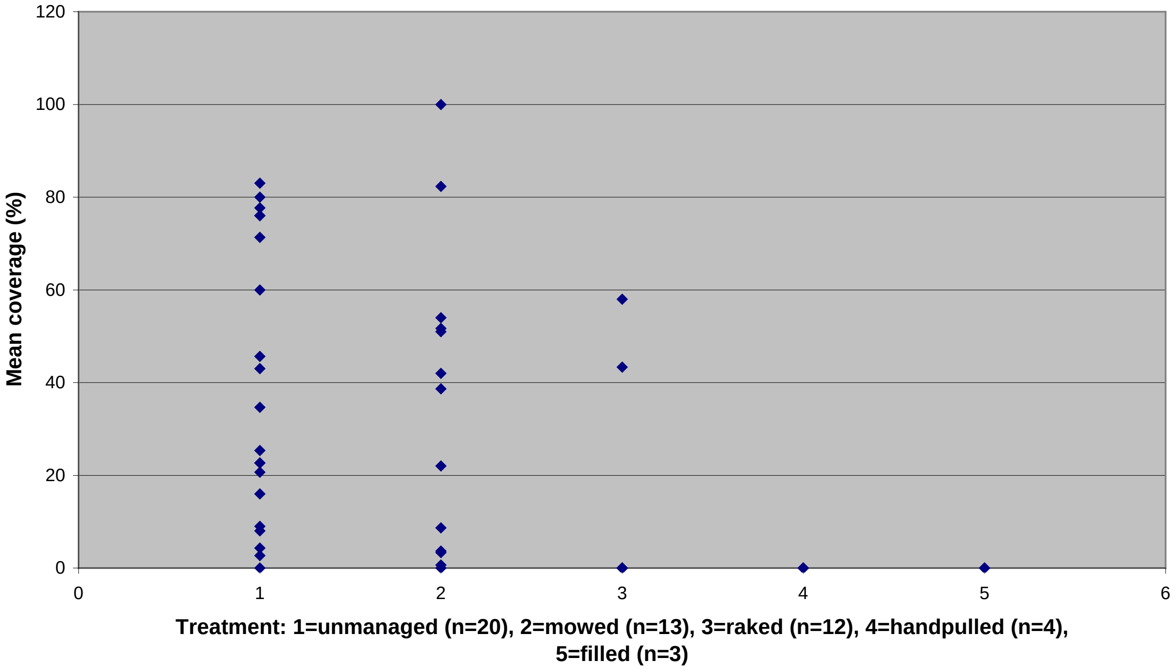


Figure 17. Average number of exotic plant species for each type of management. (p=.0016)

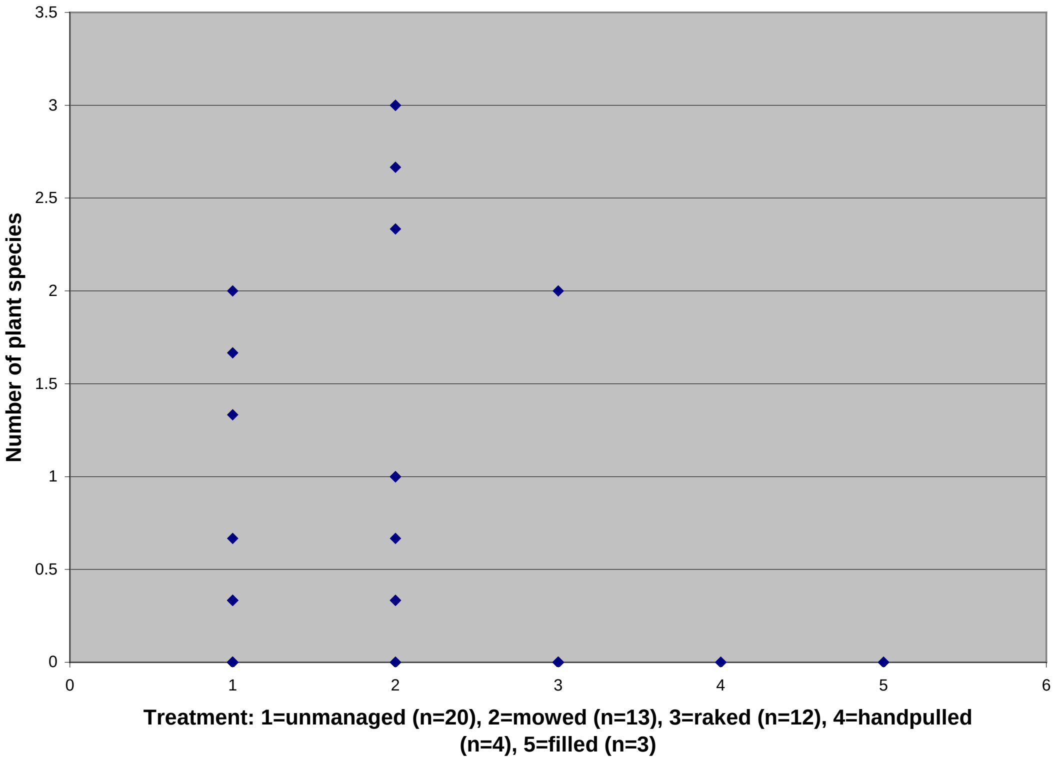


Figure 18. Mean exotic plant coverage for each type of management. (p=.0027)

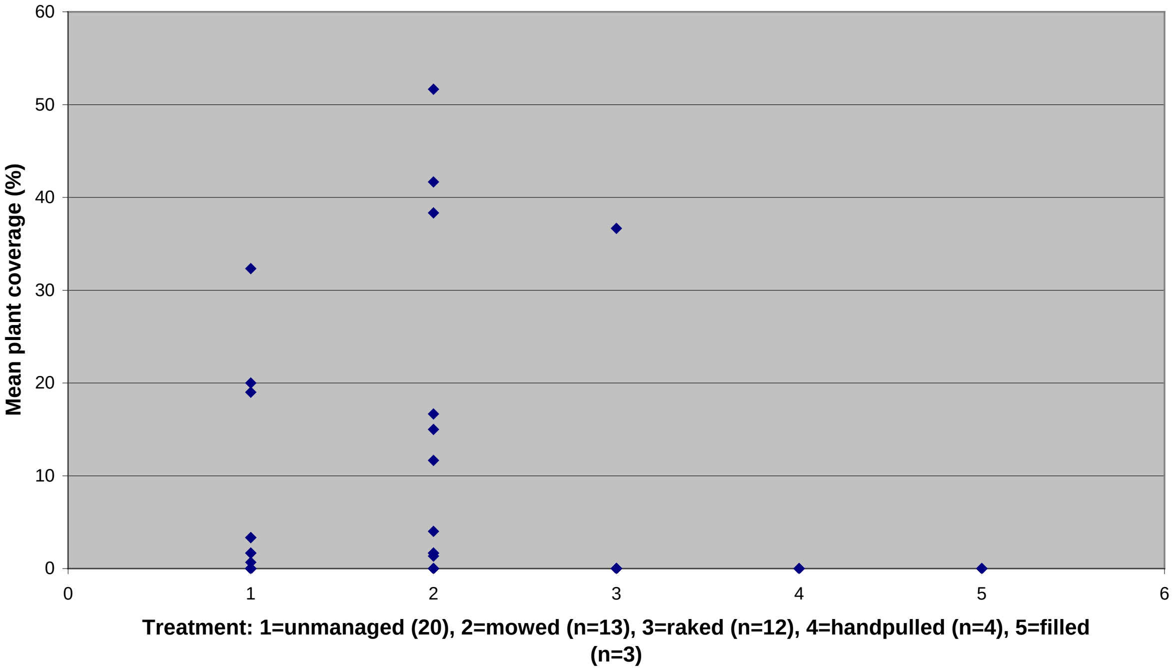
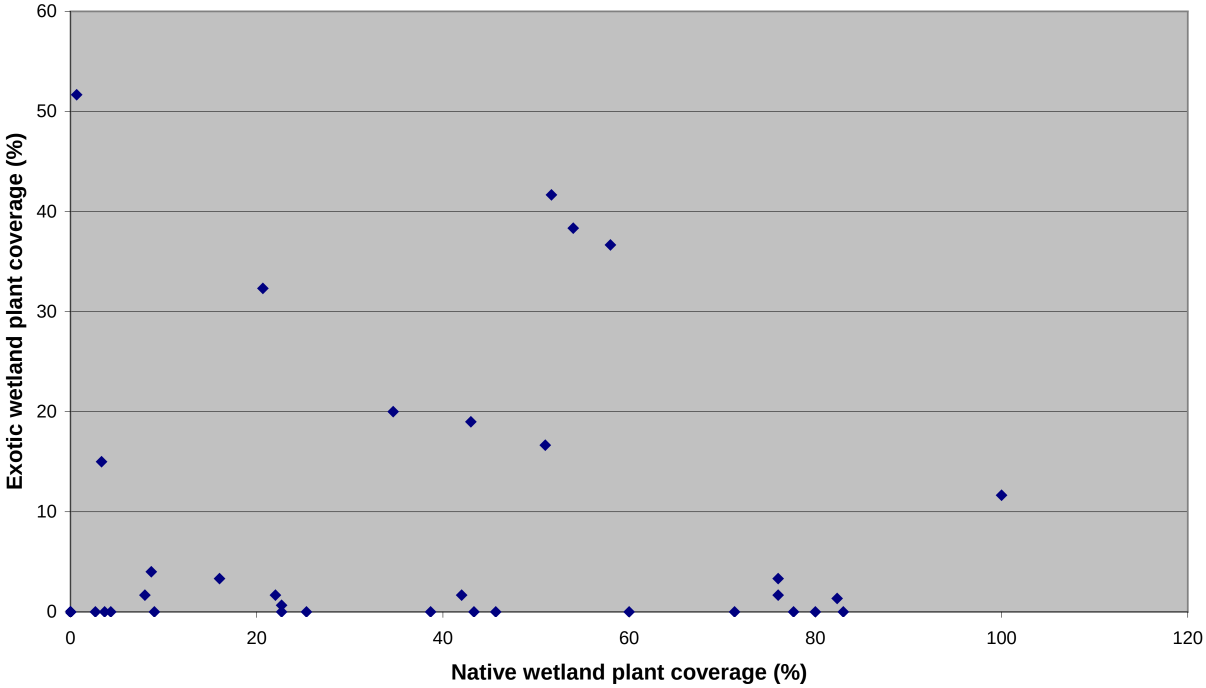


Figure 19. Comparision of native and exotic species coverage values in sample plots (n=52).



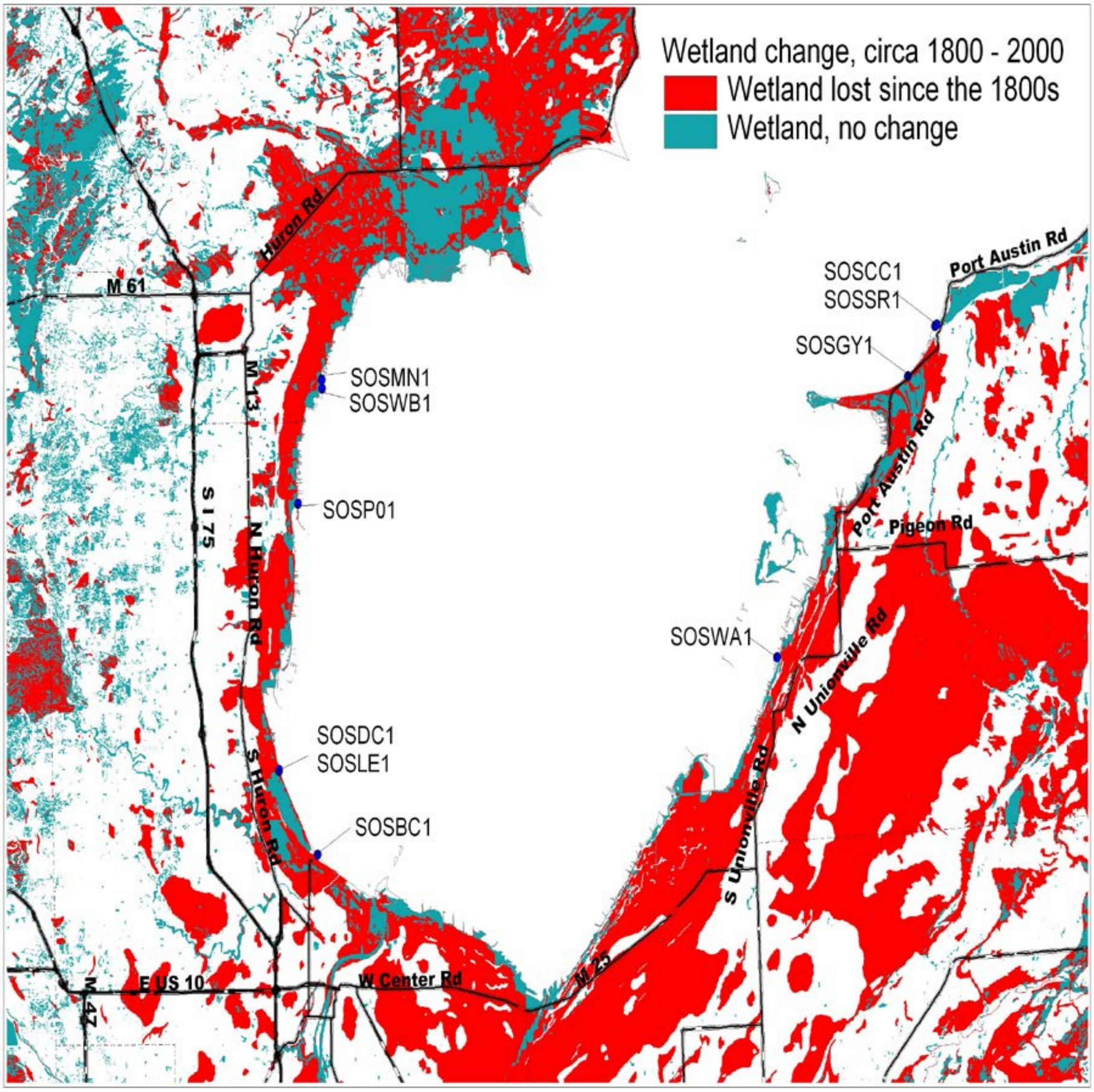


Figure 20. Original Wetland Vegetation of Saginaw Bay. Year 2004 sample sites are shown along shoreline as blue circles.

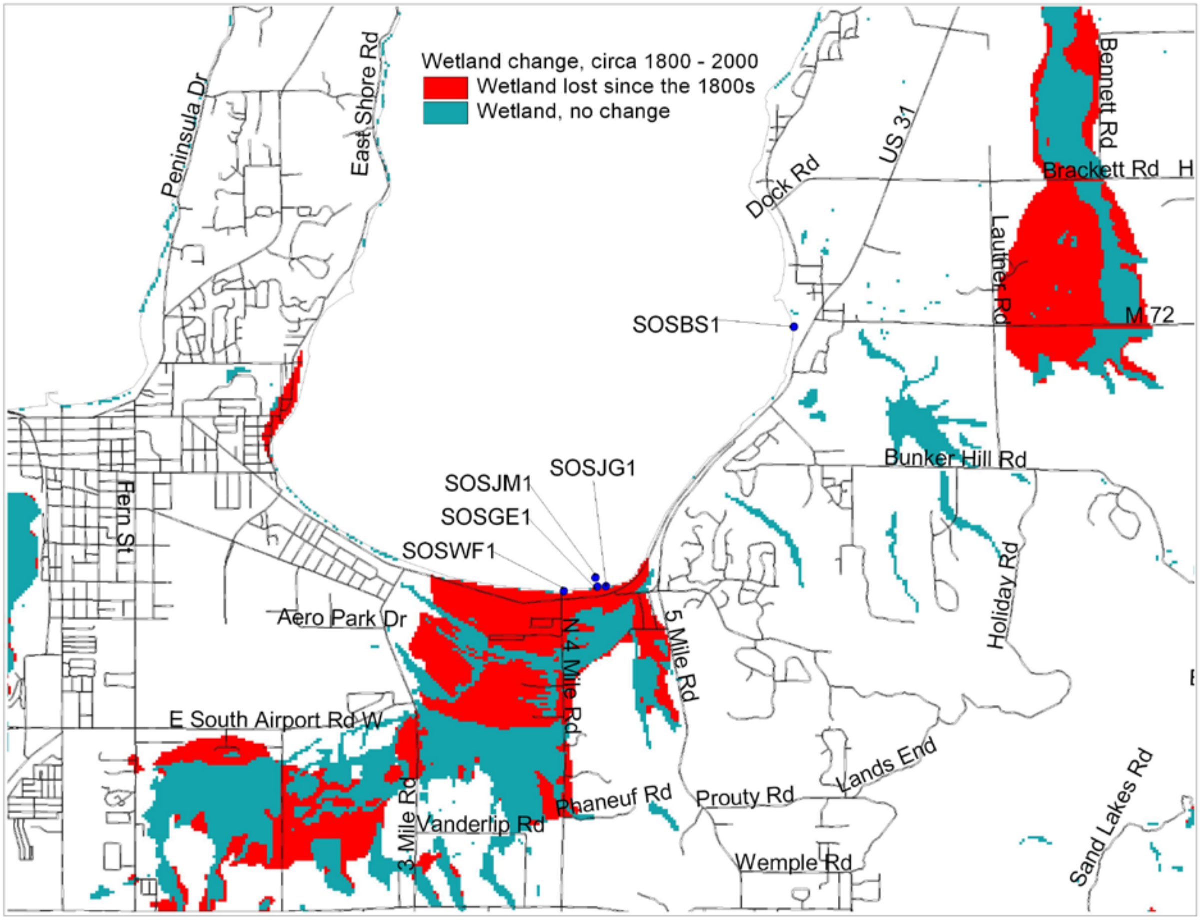


Figure 21. Original Wetland Vegetation of Grand Traverse Bay. Year 2004 sample sites are shown along shoreline as blue circles.

Figure 22. Aerial photo of Caseville area in 1964 low-water conditions. Note extensive wetlands along shoreline.

Figure 23. Aerial photo of Caseville area in 1982 high-water conditions. Note reduced wetlands along shoreline.

Figure 24. Aerial photo of Sleeper State Park area in 1964 low-water conditions. Note extensive wetlands behind shoreline beach ridge.

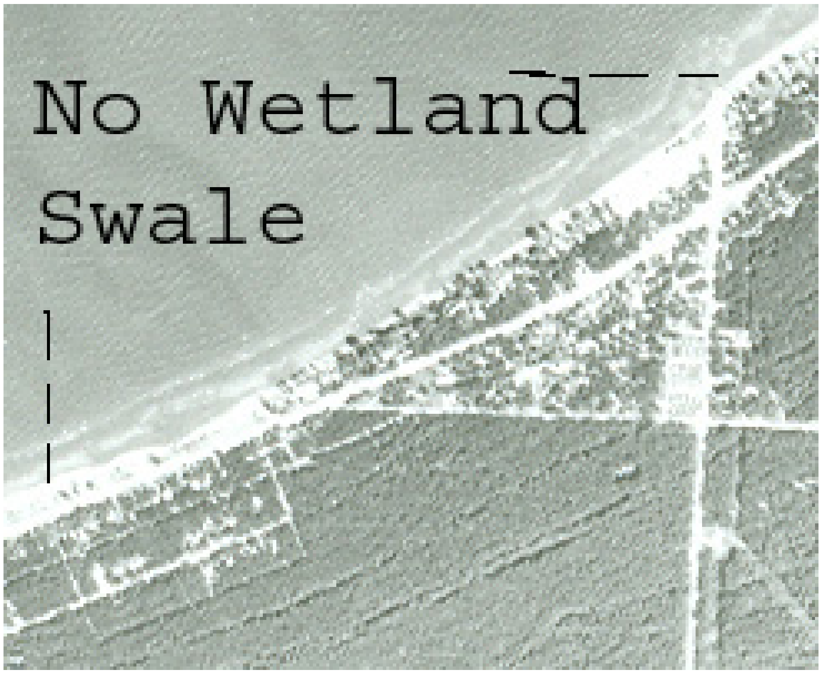


Figure 25. Aerial photo of Sleeper State Park area in 1982 high-water conditions. Note lack of wetlands and narrow shoreline.

Figure 26. Surface organic material at sampling site north of Caseville on eastern Saginaw Bay. The dark organic material is formed from decomposing algae, in this case stonewort (*Chara* sp.).