Report on the Impacts of Beach Maintenance and Removal of Vegetation under Act 14 of 2003

Michigan Department of Environmental Quality

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Contents

This report was prepared by staff of the Department of Environmental Quality – Land and Water Management Division to meet the requirements of Public Act 14 of 2003. Information contained in this report includes a summary of research carried out during 2004 and 2005 by Dr. Thomas M. Burton, Michigan State University; Dr. Donald G. Uzarski, Grand Valley State University; and Dr. Dennis Albert, Michigan Natural Features Inventory – Michigan State University Extension. We greatly appreciate their technical assistance, and their permission to use the photographs and diagrams included in this report. Any inadvertent misinterpretation of their data is the responsibility of DEQ staff. Their full technical reports are attached.

Executive Summary

Part 303 – Wetlands Protection, and Part 325 – Great Lakes Submerged Lands, of the Natural Resources and Environmental Protection Act were amended in 2003 by Public Act 14 to streamline authorizations for beach maintenance and vegetation removal activities between the ordinary high water mark of the Great Lakes and the water's edge. These amendments were in response to riparian property owner complaints regarding increased growth of vegetation along the coast resulting from low water levels in the Great Lakes. Recognizing that there are ecological concerns associated with alteration of coastal wetlands, and realizing that low water levels are not a permanent condition, the Legislature placed both geographic and time limits on the provisions of Act 14. Moreover, the Department of Environmental Quality (DEQ) was required to evaluate the impacts of vegetation removal and report back to the Governor and the Legislature by January 1, 2006. The following report fulfills that requirement.

Under the provisions of Act 14, property owners in two pilot areas – Saginaw Bay and Grand Traverse Bay could be authorized to remove vegetation from shoreline areas under a Letter of Approval from the Director of the DEQ, provided that specified conditions were met. This provision will sunset on June 3, 2006. Act 14 also exempts defined "beach maintenance" activities, including mowing, raking, leveling of sand, and establishment of paths to open water until November 1, 2007.

The DEQ has been tracking the number of requests for Letters of Approval since the law was enacted in 2003. During this period, the DEQ authorized 78 of the 90 requests received. The remainder failed to meet legislatively defined criteria, or did not include complete information. The number of requests in 2005 declined in comparison to 2004 (24 as opposed to 48).

In order to evaluate the ecological impact of vegetation removal and beach maintenance, the DEQ requested the assistance of research scientists from Michigan State University and Grand Valley State University with expertise in coastal ecology. The research team evaluated the impacts of these activities during 2004 – 2005 by comparing impacted sites with nearby unaltered (reference) sites. Their findings are presented in this report and include the following:

- Clearing a swath of vegetation through a coastal marsh produces a fundamental change in the chemical and physical conditions in nearshore waters.
- These changes in turn negatively impact the larval (very young, immature) forms of important game fish, reducing or eliminating habitat for species including yellow perch, smallmouth bass, and largemouth bass.
- Adult fish netted adjacent to undisturbed areas were present in greater numbers and had higher diversity (numbers of species) than adjacent to "groomed" areas.
- Invertebrate communities (insects, snails, and other small organisms), upon which fish depend for food and nutrient cycling, were reduced by vegetation

removal and beach grooming. The number of individual organisms collected adjacent to undisturbed beaches was 29 times greater, on average, than adjacent to raked or cleared areas.

- Impacts to fish and invertebrate habitat can extend more than 150 feet on either side of a cleared area, impacting marshes in front of adjacent property owners.

- Beach raking, hand pulling of vegetation, disking, sand leveling, and (to an extent) repeated mowing were shown to rapidly destroy stands of ecologically important plants such as the bulrush, which is naturally deep-rooted and long-lived, and which serves to anchor underlying sand and soil. Where vegetation was allowed to regrow, shallow-rooted annual plants and invasive species colonized cleared areas; bulrush plants did not readily regrow.

- Qualitative observations indicate that the removal of vegetation increases the movement of sand and erosion of shoreline areas, but these impacts were not quantified under this study. Additional evaluation is needed.

Given these findings and the limited number of requests for permits to remove vegetation, the DEQ recommends the following:

1. **That vegetation removal under a letter of approval from the Director of the DEQ be allowed to sunset on June 5, 2006, as specified in Act 14. After that date, an individual permit evaluated on a case-by-case basis would be required.**

   The Department would typically recommend issuance of an individual permit for vegetation removal to control invasive species such as *Phragmites*; and to maintain recreational areas in public parks in accordance with approved management plans. Permits may also be issued on a case-by-case basis where a clear need is demonstrated, damage to coastal habitat and impacts to neighboring properties would be minimal, and mowing is not a viable alternative. Permits for vegetation removal will not be issued in designated Environmental Areas or where rare species would be impacted, except to control invasive species.

   The Department proposes development of a simplified permit application form for vegetation removal in cooperation with the Corps of Engineers. The Department anticipates action on completed applications within 60 days (well within the average Corps processing time of 151 days), with a goal of 30 days.

   Issuance of a limited General Permit for removal of vegetation from a 6 foot wide walkway to allow access to open water is also recommended (except within designated Environmental Areas or where rare species would be impacted).

2. **That exemptions for beach maintenance activities including raking, mowing, leveling of sand, and establishment of raised paths continue**

only until November 1, 2007, as specified in Act 14.

After this date certain beach maintenance activities will continue to be exempt under Part 303. These include: (a) manual de minimis removal of vegetation (hand pulling) in sparsely vegetated areas; (b) manual leveling of sand in unvegetated areas of beach above the current water's edge; and (c) manual raking of sand in unvegetated areas to remove debris, without disturbing or destroying plant roots.

The Department recommends issuance of a new General Permit as of November, 2007 to cover the following additional beach maintenance activities: (a) mowing of vegetation twice per season to a height of not less than two inches, in an area not to exceed 40 feet in width; (b) mechanical leveling of sand in unvegetated beach areas above the current water's edge; and (c) construction and maintenance of a temporary path up to 6 feet in bottom width to provide access to open water, to be constructed of sand and pebbles.

An individual permit would be required for other beach maintenance activities, including: (a) grading or leveling of sand that would alter the natural shoreline; (b) mechanical raking or disking of beach areas that will result in loss of vegetation or degrade habitat quality on the beach or in adjacent waters; and (c) large scale or frequent mowing that would significantly impact vegetation.

In evaluating permit applications, the impact on adjacent property owners and on public resources would be considered.

Permits for beach maintenance will not be issued in designated Environmental Areas or where habitat for threatened or endangered species would be adversely impacted, except to control invasive species under an approved management plan.

3. **That the DEQ provide additional information regarding the impacts of beach maintenance and vegetation removal to the public.**

4. **That the DEQ discourage the mowing of nuisance species such as *Phragmites* in order to reduce the spread of this serious nuisance species.**

5. **That the DEQ continue to support research regarding the impacts of human activity on Great Lakes coastal wetlands, with particular attention to groups of organisms that were not evaluated as a part of this study (e.g. shorebirds, waterfowl, reptiles and amphibians) as funding becomes available. Additional information is also needed on the extent of soil erosion and alteration of the physical nature of the shoreline following vegetation removal and related activities.**

Report on the Impacts of Beach Maintenance and Removal of Vegetation under Act 14 of 2003

Section I: Background Information

Water levels in the Great Lakes are subject to long term fluctuations. From 1997 to 2003, lake levels dropped by more than one meter in Lakes Michigan and Huron, reaching near record lows in 2003. During these years, declining water levels exposed normally inundated Great Lakes bottomlands, stimulating the growth of wetland vegetation.

The regeneration of vegetation during low water years is a normal component of wetland and nearshore ecology, and is moreover essential to the maintenance of healthy wetland ecosystems in the long term. Coastal wetlands, including exposed and vegetated Great Lakes bottomlands, are considered to be the most valuable ecological areas in the Great Lakes. In addition to songbirds, amphibians, reptiles, and mammals, coastal wetlands provide habitat for 90% of the nearly 200 Great Lakes fish species and two dozen waterfowl species which help fuel a two-billion dollar hunting, fishing, and wildlife watching industry. Coastal wetlands also protect water quality by absorbing polluting nutrients that can aggravate growth of unwanted algae, and they reduce erosion and sediment suspension by absorbing wave action along the shoreline.

However, given the extreme low water levels leading up to 2003, a relatively broad band of vegetation became established along some shorelines, and a number of property owners expressed the need to remove vegetation that they viewed as impeding access to open water. In addition, the growth of invasive plant species such as purple loosestrife and *Phragmites* (common reed) has expanded significantly in some areas.

In the fall of 2002, the Michigan Department of Environmental Quality (DEQ) and the Detroit District Corps of Engineers (Corps) together with several property owner and environmental interest groups formed a Shoreline Task Force to address beach maintenance during low water years. Concerns included the regulation of vegetation management by state and federal agencies, provisions for access to open water, and related beach management issues. The Shoreline Task Force issued a “Consensus Document” on April 8, 2003. The Consensus Document recognized the value of coastal wetlands, but also recommended that the Corps and the DEQ attempt to identify a simplified and expedited permit process for regulated activities.

Public Act 14 of 2003.

As the Corps and the DEQ were in the process of implementing the recommendations of the Shoreline Task Force, the Michigan Legislature passed Public Act 14 in June of 2003. This Act amended Part 303 – Wetland Protection, and Part 325 – Great Lakes Submerged Lands, to address beach maintenance and removal of vegetation between the ordinary high water mark of the Great Lakes and the water's edge. Public Act 14 defines these activities as follows:

> **"Beach maintenance activities"** means any of the following in the area of Great Lakes bottomlands lying below the ordinary high-water mark and above the water's edge:
>
> (i) Manual or mechanized leveling of sand (further defined as the relocation or grading of sand within areas that are predominantly free of vegetation).
>
> (ii) Mowing of vegetation (further defined as cutting of vegetation to a height of not less than 2 inches, without disturbing plant roots).
>
> (iii) Manual *de minimis* removal of vegetation.
>
> (iv) Grooming of soil (further defined a raking the top 4 inches of soil without disturbing plant roots, for the purpose of removing debris).
>
> (v) Construction and maintenance of a path (further defined as a temporary access walkway from riparian property to open water not exceeding 6 feet in bottom width and consisting of sand and pebbles obtained from non-vegetated areas).
>
> **"Removal of vegetation"** means the manual or mechanized removal of vegetation, other than the manual *de minimis* removal of vegetation."

Under the provisions of PA 14:

- **"Beach maintenance activities"** are exempted statewide (except in designated Environmental Areas) provided that mowing does not exceed the width of the riparian property or 100 feet (whichever is less), and all debris is disposed of properly outside of any wetland.

- The exemptions provided for beach maintenance activities expire on November 1, 2007.

- **"Removal of vegetation"** may be authorized under a general permit in response to an application by a local unit of government or a group of adjacent riparian property owners.

- **"Removal of vegetation"** is allowed within two pilot areas defined by the Director of the DEQ providing that the following conditions are met:

  (a) The landowner has received a letter of approval from the DEQ confirming at least three of the following:

  (i) The area is unconsolidated material predominantly composed of sand, rock, or pebbles, or is predominantly vegetated by non-native or invasive species.

(ii) The area met the requirement of paragraph (i) as of January 1, 1997.

(iii) The removal of vegetation does not violate Part 365 or rules promulgated under that part, or the endangered species act of 1973, Public Law 93-205, or rules promulgated under that act.

(iv) The area in which removal of vegetation may occur is not an environmental area.

(b) The area in which removal of vegetation may occur does not exceed 50% of the width of the riparian property, or 100 feet, whichever is greater, or a wider area if approved by the Director.

(c) All collected vegetation shall be disposed of properly outside of any wetland.

- The provisions for removal of vegetation within pilot areas under a letter of approval from the Director expire June 5, 2006 (three years from the effective date of Act 14).

Finally, Public Act 14 requires an evaluation of these activities, and a report to the Governor and the Legislature:

> “By January 1, 2006, the director shall prepare and submit to the senate majority leader, the speaker of the house of representatives, the standing committees of the legislature with jurisdiction primarily related to natural resources and environment, and the governor a report that evaluates the activities allowed under subsection (1), describes the impacts to the affected areas, and recommends statutory changes based upon the evaluation, if appropriate.

This report has been prepared and submitted to fulfill the requirement of Public Act 14.

Section II: Implementation of Public Act 14

Public Act 14 was given immediate effect on June 5, 2003. Information for property owners explaining provisions of the Act was posted on the DEQ website at www.michigan.gov/wetlands. In addition, a pamphlet outlining regulatory requirements associated with beach maintenance and vegetation removal, and the ecological basis for those regulations, was prepared and distributed directly to all property owners in Grand Traverse Bay and Saginaw Bay[1].

On June 17, 2003, the Director defined Saginaw Bay and Grand Traverse Bay as the two pilot areas where vegetation removal would be authorized by a Director's letter. Maps of the pilot areas are posted on the DEQ wetlands website.

Beach maintenance activities.

Because Act 14 exempts these activities, the Department has no way of knowing how many property owners took advantage of the exemptions, or to what extent coastal areas were impacted. It has been observed, however, that the impact of beach maintenance activities carried out under the Act 14 exemptions varies considerably from one site to another, as shown below.

Figure 1. Undisturbed reference site.

Figure 2. Mowed site.

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[1] Educational materials were developed and distributed in cooperation with the Tip of the Mitt Watershed Council with funding from the U.S. Environmental Protection Agency and the Great Lakes Fishery Trust. Additional technical assistance was provided at the local level by Michigan Sea Grant.

Figure 3. Site showing the impact of mowing in the previous year (background) as compared to mowing in the current year (foreground).

Figure 4. Mechanically raked site (foreground) compared to natural area (background).

Figure 5. Mechanical rake.

Figure 6. Site that has been filled with sand (or "leveled") and graded (foreground) compared to natural marsh (background).

Figure 7. Site that has been mowed and raked. (Natural marsh in background.)

Figure 8. Site that has been mowed only.

Figure 9. Site altered by hand pulling of vegetation and mowing.

Removal of vegetation under a Director's letter of approval.

Act 14 allows for removal of vegetation from the two designated pilot areas under a letter of approval from the Director of the DEQ, provided that specified conditions are met (as outlined above). Removal of vegetation is typically carried out mechanically.

Figure 10. Mechanical removal of vegetation.

In 2003 the Department received a total of 18 requests for Director's letter approvals for vegetation removal.

The Department received 15 requests for Director's letter approval for vegetation removal within the Saginaw Bay pilot area in 2003. Thirteen requests were approved, one was denied because it did not meet the requirements in Section 32516 (a), and one request was incomplete and eventually closed when the applicant did not respond to requests for additional information.

Three requests for Director's letter approvals were received and issued in the Grand Traverse Bay pilot area in 2003. In addition, 3 permit applications were received and issued within the Grand Traverse Bay pilot area for vegetation removal exceeding the limits for Director's letter approval along with other regulated activities such as filling or grading.

During 2003, three applications were also received for vegetation removal or mowing exceeding the exemption, outside of the pilot areas in Delta and Iosco counties. One application for vegetation removal outside the pilot areas was denied due to the presence of high quality wetland habitat and the availability of feasible and prudent alternatives. One permit was issued for mowing vegetation, and one application was withdrawn by the applicant.

In 2004 the Department received a total of 48 requests for Director's letter approvals for vegetation removal within the two pilot areas.

Forty-six requests for Director's letter approvals were received within the Saginaw Bay pilot area. Thirty-seven requests were issued, and 9 were denied because they did not meet the requirements in Section 32516 (a). Three permits were issued within the pilot area for mowing which exceeded the limits of the exemption, and 1 permit was issued for vegetation removal plus dredging and filling activities.

Two requests for Director's letter approvals were received and issued with the Grand Traverse Bay pilot area during 2004.

In 2004 two applications were received outside of the pilot areas, in Delta and Menominee counties, for mowing of vegetation in excess of the exemption. Both permits were issued.

In 2005 there was a significant reduction in the number of requests for Director's letter approvals for vegetation removal within the pilot areas, with a total of only 24 requests.

The Department received 16 requests for Director's letter approvals within the Saginaw Bay pilot area. All of the requests were approved. In addition, two applications were received for work which didn't qualify for Director's letter approval. One application was for mowing in excess of the exemption, and the other was for vegetation removal plus fill. Permits were issued for both projects.

Eight requests were received for Director's letter approvals within Grand Traverse Bay pilot area. Seven requests were approved. One request was incomplete and closed because the applicant failed to respond to requests for additional information.

In 2005, eleven applications were received for vegetation removal or mowing outside of the pilot areas. They were located in Menominee and Alger counties. Nine permits were issued, and one was just recently received and is still under review. One application was incomplete and closed because the applicant failed to respond to requests for additional information.

Prior to and following passage of Act 14 there was confusion among lakefront landowners and some misleading information published in the press. Because of this, the Department decided not to pursue enforcement action against landowners who removed vegetation without permits or Director's letter approvals. Instead, landowners were sent advisory letters explaining beach maintenance activities, and were encouraged to either stop the unauthorized activities or apply for the proper authorization.

General permits for removal of vegetation.

In the spring of 2004, Bangor and Kawkawlin Townships, both in Bay County, submitted applications for mowing and removal of vegetation under a General Permit. The DEQ could not process these requests because a General Permit for these activities did not yet exist. The Leelanau County Board of Commissioners and the Grand Traverse County Board of Commissioners considered applying for General Permit authorization, but ultimately voted against doing so.

On July 30, 2004, the DEQ released a Draft General Permit for public review and comment. The public comment period ended September 13, 2004. During the public comment period, 568 comments were received, including information from scientists, property owners and landowner organizations, environmental groups, and others. There were 37 comments in favor of the General Permit, and 530 that opposed issuance of the General Permit. One took no position.

The department considered these comments as well as information from other sources regarding the ecological functions of coastal wetlands. Ultimately, the Department concluded that a General Permit for vegetation removal should not be issued, since the potential impacts are not similar in nature, and because it could not be concluded that these activities would have only minimal environmental impacts when performed separately or cumulatively. In addition, it was determined that issuance of a General Permit was not in the public interest.

Section III: Scientific Evaluation of Vegetation Removal Activities

The DEQ requested the assistance of Dr. Thomas M. Burton of Michigan State University; Dr. Dennis Albert of the Michigan Natural Features Inventory -- Michigan State University Extension; and Dr. Donald G. Uzarski of Grand Valley State University to provide an objective, scientific evaluation of the impacts of beach maintenance and vegetation removal. These research scientists have extensive experience with the aquatic ecosystems in Great Lakes coastal waters, and the evaluation that they proposed both built upon and expanded their ongoing research. The Department entered into an agreement with this research team to carry out agreed upon studies with a focus on Grand Traverse Bay and Saginaw Bay. Funding to support this work was obtained from the federal Coastal Management Program, with matching funds provided by the two universities.

Complete technical reports from these studies are included with this report as,

- Attachment A: *The Effects of Coastal Wetland Fragmentation on Ambient Chemical/Physical Parameters and Fish and Invertebrate Communities,* and

- Attachment B: *The Impacts of Various Types of Vegetation Removal on Great Lakes Coastal Wetlands of Saginaw Bay and Grand Traverse Bay.*

Study Design

Beach maintenance and the removal of vegetation fragment natural coastal wetlands by creating intermittent open areas along the beach and in shallow water. The overall goal of studies carried out during the summers of 2004 and 2005 was to explore the impact of wetland fragmentation on the chemical and physical characteristics of the shore, and on biological communities (plants, fish, and invertebrates). The data that was collected was statistically evaluated, and the results were used to assess the overall impact of beach maintenance and vegetation removal on public resources.

The study compared sites that had been altered by vegetation removal or beach management with similar, nearby, unaltered – or “reference” sites. The same measurements were made at each pair of sites – i.e. at the altered site and at the unaltered reference site. The majority of site pairs were located on Saginaw Bay. Fewer sites on Grand Traverse Bay were available due to the more limited extent of natural wetlands along that coast, a lower level of beach maintenance activity, and because of the refusal of some property owners to allow sampling. Some sites in Northern Lake Huron were also included in the study to evaluate the impact of wetland fragmentation from other activities, such as establishment of boat channels through the marshes. A total of 68 sites on Saginaw Bay, 7 sites on Grand Traverse Bay, and 23 sites in Northern Lake Huron were evaluated by the research team.

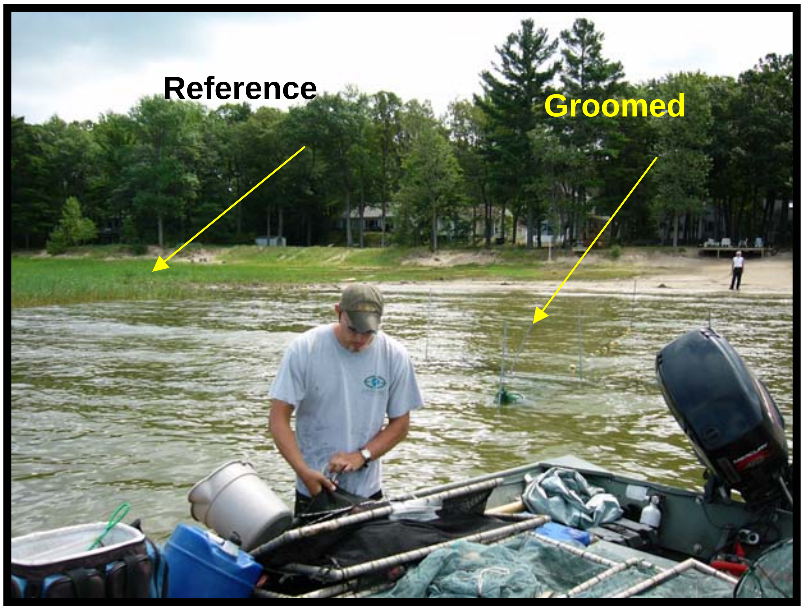


Figure 11. Sampling location near Caseville, Michigan, showing paired reference and groomed sites.

At each location, basic water chemistry measurements were made, along with measurements of physical conditions such as temperature and depth, and observations of the substrate (bottom material) present (e.g. sand or clay). Numerous biological samples were collected from paired sites in appropriate locations, and included fish (both adult fish and larval fish); plants, plant roots and rhizomes (underground stems); and invertebrates. Field work was initiated in the summer of 2004, and continued through the summer of 2005. Detailed methods are defined in the technical reports.

Summary of results

1. Chemical and physical changes.

Removal of vegetation disrupted the normal physical and chemical conditions of the wetlands. In undisturbed (reference) areas, water chemistry close to the shore is very similar to that of groundwater, because groundwater is entering the lake at this point. In addition, shallow areas that are somewhat sheltered from wave action by wetland plants warm more readily than open waters, and dissolved oxygen concentrations vary with the level of biological activity. In the outer portions of undisturbed areas -- that is, farther away from the shore – the chemistry and temperature of the water are quite similar to that of the open lakes, and the wave action is greater. Between the outer edge of the marsh and the inner marsh at the waters edge, there is a gradient of chemical and physical conditions.

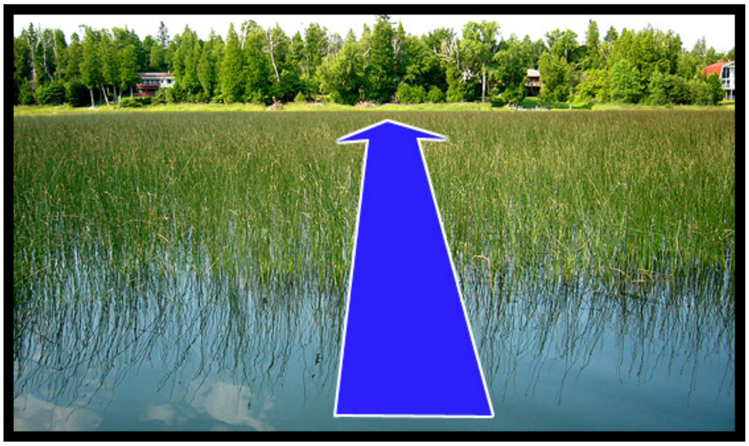


Figure 12. Water chemistry and physical conditions normally change from the outer edge of the marsh in a gradient toward the shoreline. Water chemistry near the shore resembles groundwater, while the chemistry of the open edge is essentially that of the open lake.

The numbers and types of fish and other animals in the marsh at any point are related to the chemical and physical conditions at that point, and change along the gradient from open waters to the shore. For example, larval (very young immature) yellow perch numbers are higher within the marsh than near the open water, with highest numbers occurring about 50 meters (164 feet) into the marsh.

Removal of vegetation alters this natural physical and chemical gradient. Removing vegetation opens a marsh to wave action from the lake, generating water chemistry, temperature, and other physical conditions similar to that of the open lake all the way to the shore. This change eliminates the zone where certain animals are normally located. (Figure 13). Moreover, conditions in the adjacent vegetated marsh were also changed by lateral movement of open lake water into the marsh.

Figure 13. Site where vegetation has been removed, allowing the waters of the open lake to move into the marsh, altering normal chemical conditions in the wetland and creating greater exposure to wave energy.

Data that demonstrates changes in water chemistry --- dissolved oxygen levels, pH, hardness, nutrient levels, and other parameters --- is presented in the attached technical reports.

Impact of vegetation removal on erosion. One of the goals of the 2004-5 studies was to evaluate the extent of erosion following removal of vegetation. While the research team made qualitative observations regarding erosion, the direct comparison of erosive impacts in paired sites could not be reliably measured due to the dynamic nature of the shoreline. Wave action and shoreline currents regularly move sand, so that detailed and consistent measurements cannot be readily made. For example, the erosion of surface sand exposing the underlying clay layer was observed at some sites where vegetation was removed; however, wave action subsequently moved some sand back into these locations. At other sites, sand was deeper with no underlying clay layer, and thus more difficult to evaluate. Erosive action will also vary as Great Lakes water levels rise and fall. An assessment of the overall impact of vegetation removal on erosion rates would thus require numerous measurements over time, and was beyond the scope of this study.

The research team did report that active wetland alteration – by raking, hand pulling of plants, or filling and grading of wetland swales along the beach – appeared to result in more rapid erosion of coastal sediments. The research team also observed apparent erosion where swaths of bulrush beds were removed; the water depth in these recently opened areas was somewhat greater than the depth in the adjacent vegetated marsh. No statistical analysis was made.

DEQ permit staff also made note of apparent erosion of the shoreline along Grand Traverse Bay where vegetation had been removed. They noted that the waterline moved landward wherever beach grooming had occurred.

2. Impacts on Aquatic Vegetation.

The most characteristic plant in the coastal marshes of Grand Traverse Bay and Saginaw Bay is the three-square Bulrush (*Schoenoplectus pungens*). This plant dominated 21 of 24 transects in normally vegetated areas of these marshes.

This bulrush is a perennial plant characterized by the formation of a thick mat of roots and rhizomes – or underground stems. The roots include a mass of fine root hairs near the surface, which help to bind sand in place, as well as thicker vertical roots that penetrate into deeper soils including clay or gravel where these materials are present. Rhizomes are thick, horizontal underground stems that also penetrate into deeper soils, and that persist over the winter. Rhizomes may be many feet long; the bulrush stems grow upward from the rhizomes during the growing season. Rhizomes also become thicker with age, providing a general means of evaluating the maturity of a stand of bulrushes.

Figure 14. Diagram of bulrush roots and rhizomes.

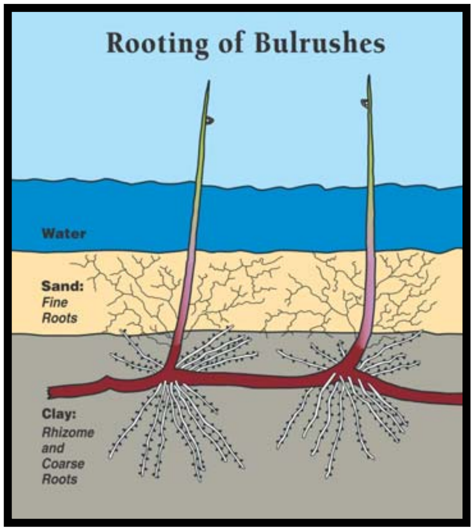


Figure 15. Cross-section of bulrush roots from a soil pit, showing fine roots at the surface, rhizomes below, and vertical roots at bottom. Fine roots are concentrated in surface sand. Thicker rhizomes and vertical roots extend into underlying clay (if present).

The impact of beach management and vegetation removal was evaluated by counting the number and species of plants in standard plots laid out along a line or transect through the sampling location, and also by digging pits and removing a standard amount of root material. Various types of plant roots were separated and weighed to evaluate the mass of material present.

Detailed records of the vegetation that was sampled, and comparisons of plots from reference sites and managed areas are included in the technical report (Attachment B). Overall findings included the following:

- Disking, raking, filling of wetland swales with sand ("leveling"), and hand-pulling were all effective at killing aquatic plants. Rhizomes and roots of perennial aquatic plants decomposed rapidly following these forms of treatment. (See Figures 16 and 17).

Figure 16. Normal bulrush rhizomes (underground stems) from a 30 cm X 30 cm soil pit, with fine roots removed.

Figure 17. Decomposing bulrush rhizomes within a month or two following filling and raking of wetland swale.

- Plant diversity (the number of species present) is much higher in undisturbed areas with no active management, or in areas that were only mowed (although mowing made it difficult for research staff to identify all plant species present).

- Mowing appears to reduce the mass of bulrush roots and rhizomes, but additional studies are needed to confirm this impact. At some mowed sites, “thatch” was removed by raking or disking, and this practice removed much of the root mass and some rhizomes. Based on preliminary observations and the reports of shoreline residents, repeated mowing is expected to reduce or eliminate bulrushes over the long term.

Figure 18. Site that has been mowed with “thatch removal”.

- Within a year or two of disking, raking, or hand-pulling, some annual plants returned, along with invasive species. Annual plants tend to be shallow rooted, without the dense matt of roots and rhizomes which serve to stabilize the sand and sediment in bulrush beds. Plant diversity in previously disturbed sites tends to be low, and non-native or nuisance species, in particular *Phragmites* (common reed) are included in the plants that do occur. Bulrushes do not colonize disturbed shorelines as rapidly as annuals and exotics.

3. Effects on Invertebrates.

Invertebrate animals are critical to the overall ecology of the Great Lakes. These organisms are not only a significant component of the food web that ultimately supports fish and other higher animals, but as a group they are also cycle nutrients in the aquatic system by breaking down organic matter. Invertebrates are typically considered in two groups by size – “microinvertebrates” or microscopic organisms, and “macroinvertebrates” which are much larger and readily visible.

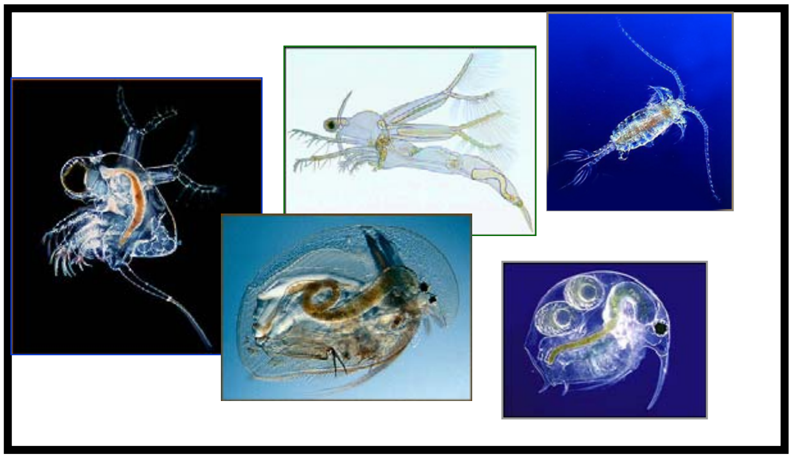


Figure 19. Typical microinvertebrates – microscopic animals – found in coastal Great Lakes waters.

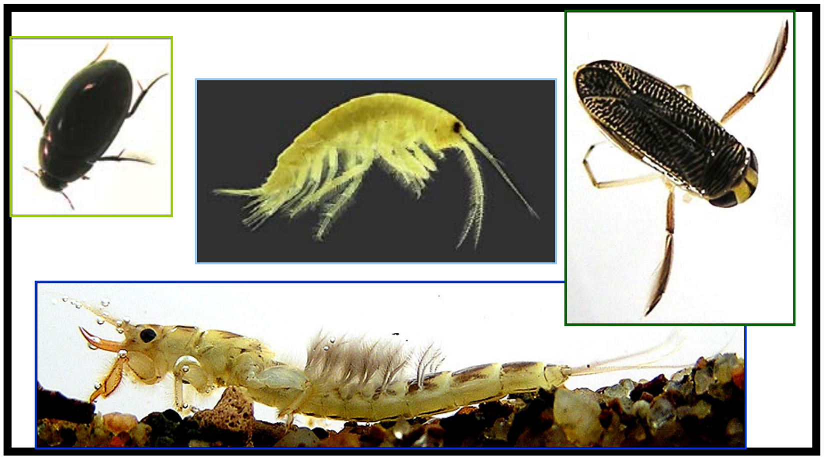


Figure 20. Typical macroinvertebrates. This group includes many kinds of insects, snails, clams, and similar organisms. Alteration of the numbers or types of these small animals can have a major impact on fish communities.

Macroinvertebrates were collected with dip nets in waters adjacent to normally unvegetated beaches, and adjacent to beaches that had been altered by raking or other removal of vegetation.

In addition, invertebrate samples were collected using light traps within vegetated marshes at specific points along two transects, one from the open edge of the marsh toward the shore, and one from the artificial edge (created by removal of vegetation) toward the center of the marsh.

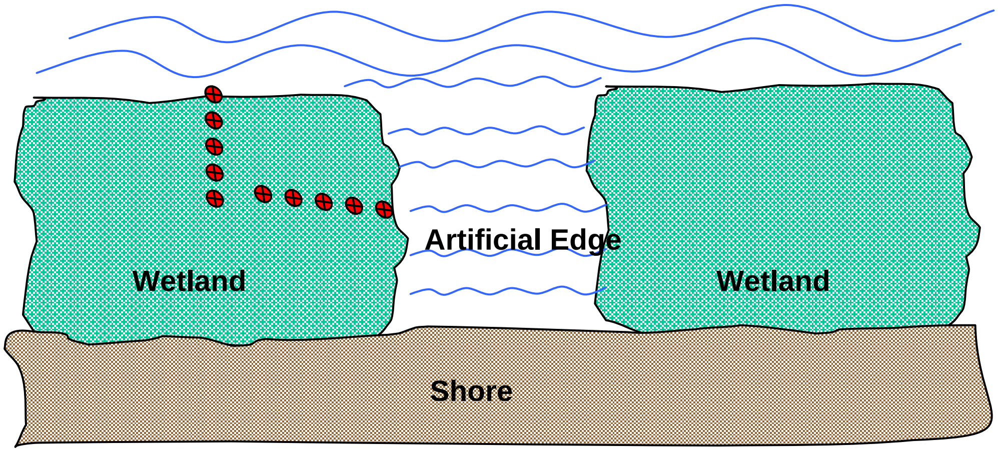


Figure 21. A fragmented Great Lakes fringing marsh showing the location of light traps for sampling larval fish and invertebrates (large red dots).

Details on invertebrate sampling methods, and a full statistical analysis of data from these samples is presented in the technical report (Attachment A). Comparisons of altered and unaltered sites during 2004 and 2005 led to the following overall conclusions:

- Mowing plant to heights above 5 cm (about 2 inches) during low water appears to cause few changes in the makeup of the invertebrate community, as long as the plant community is allowed to recover after mowing. Repeated mowing that significantly reduces or eliminates plant cover will, however, have the same impact as other forms of vegetation removal.

- The conversion of wetland plant areas to open water beaches --- by raking, disking, or other means --- results in very large and statistically significant decreases in the numbers of invertebrates present, and also in the diversity (number of kinds) of organisms that compose the invertebrate community. The number of individual organisms collected adjacent to undisturbed beaches was 29 times greater, on the average, than the number collected in raked zones. This has important potential ramifications in terms of reducing the potential food base for nearshore fish communities in the Great Lakes.

- Transect sampling within marshes (as shown in Figure 21) demonstrated that macroinvertebrates were impacted not only at the point where vegetation was removed, but in adjacent unmanaged areas. In many cases, this impact extended up to 50 meters (about 164 feet) laterally from the artificial edge created by removal of vegetation. In other words, the abundance of invertebrate animals and the diversity of macroinvertebrates was reduced at adjacent properties <u>in addition t</u>o the property where wetland vegetation was altered. Microinvertebrate impacts require additional study; however, data that is available suggests that this portion of the biological community is similarly impacted.

4. Impacts on fish.

The Great Lakes support nearly 200 species of fish. Of these, more than 90 percent utilize coastal marshes at some point in their lives.

Related studies of Great Lakes fish by members of the research team and their colleagues have suggested that coastal wetlands are likely to provide a critical refuge for native fish from invasive species such as round gobies:

> “ Based on intensive fish sampling at more than 60 sites spanning all of the Great Lakes, round gobies have not been sampled in large numbers at any wetland or been a dominant member of any wetland fish community. So, it seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of round gobies. However, water levels are low and the invasion is in different degrees of maturity in different parts of the Great Lakes, so continued monitoring will be required to confirm this possibility" ***(Jude, D.J., Albert, D., Uzarski, D.G., and Brazner, J. 2005. Lake Michigan’s coastal wetlands: Distribution, biological components with emphasis on fish and threats. In M. Munawar and T. Edsall (Eds.). The State of Lake Michigan: Ecology, Health and Management. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society. p. 439-477)***

Dr. Uzarski, Dr. Burton and their colleagues have also conducted a preliminary study on six drowned river mouth wetland-lake pairs where round goby have been documented. The results of the study indicated that wetlands always contained fewer round gobies than comparable habitat in the adjoining lake with surface water connection. In 2006, they will be expanding their study to fringing wetlands of Lakes Michigan and Huron. Additional studies that confirm the value of coastal wetlands as refuge areas for native fish would likely demonstrate an even greater basis for protection of this habitat.

<u>Sampling of adult and juvenile fish</u>
In this study, adult fish and juvenile fish were collected with fyke nets at paired reference (undisturbed) and altered sites.

Figure 22. Example of fyke net used to sample adult and juvenile fish. Six nets were set at each paired site.

Fish communities found at reference sites were clearly different than those found at beaches where vegetation had been altered. At both Saginaw and Grand Traverse Bays, the reference sites had higher fish diversity (i.e. a higher number of species), and a greater number of individuals of some species. Fish species that were present in higher numbers at reference sites than at mowed or groomed sites in Saginaw Bay included bluegill; white perch; brown bullhead; black buffalo; and various shiners and minnows. Detailed findings are presented in the technical report (Attachment A).

By contrast, fish collected in boat channels in Northern Lake Huron did not differ detectably from the fish community in adjacent wetlands. The channels were believed to be too narrow to alter the overall habitat requirements of adult and juvenile fish. However, boat channels did produce detectable difference in larval fish (very small fish that are not yet fully mobile, and are thus impacted by wave action and current to a great extent than older individuals).

DEQ permit staff also made qualitative observance of the loss of fish from small pools that were destroyed by leveling of beach areas in Grand Traverse Bay. Before these pools were eliminated, staff observed hundreds of minnows and other fish using the pools.

Larval fish evaluation.

Larval fish are very small, immature young fish that are essentially planktonic (carried by waves and currents). The larval stage of many Great Lakes fish species rely on the relatively protected conditions and abundant invertebrate food supply found in coastal marshes. Fish in this life stage were collected with light traps along transects within the marsh. As with invertebrates, the reference transect extended from the open water edge of the marsh toward the shore, while the other transect extended from the artificial edge created by vegetation removal laterally into the marsh. (See figures 21 and 24).

Figure 23. Collecting larval fish from a light trap within a Great Lakes coastal marsh.

As previously noted, different fish species are typically found at different locations within a natural undisturbed marsh. The preferred conditions for each species reflect water chemistry, physical characteristics (including substrate type and the amount of wave energy present), and the available food supply. Wave energy is greater on the lakeward edge of a natural marsh. Higher wave energy is also found nearer the artificial edge created by vegetation removal.

Again, detailed results and statistical analyses are presented in the technical report (Attachment A.) Overall results included the following.

- Larval yellow perch numbers consistently increased moving from the open water edge of the marsh toward the interior. Along the reference transect, the greatest numbers were found at 50 meters (about 164 feet) into the marsh.

  The numbers of larval yellow perch along the lateral transect clearly reflect the impact of vegetation removal. The numbers of yellow perch were generally lower along this transect – even though it was also located 50 meters from the open water side of the marsh (see Figure 24 below). This impact was not unexpected, since chemical and physical conditions near the artificial edge are similar to the open water edge.

  Fish numbers along the lateral transect varied considerably from one site to another. This suggests that some fragmented marshes may be more influenced by wave energy and lateral water movement than others (due to factors such as wind direction and depth of open water), with a parallel impact on larval fish.

- Larval smallmouth bass were most abundant at 30 meters (about 98 feet) from the open water edge of the marsh along the reference transect.

  However, smallmouth bass were not abundant at <u>any</u> point along the lateral transects, indicating that they were significantly impacted by vegetation removal and lateral movement of water into the marsh in all locations sampled. In other words, the lateral impact of open water had a large impact on larval smallmouth bass (figure 24).

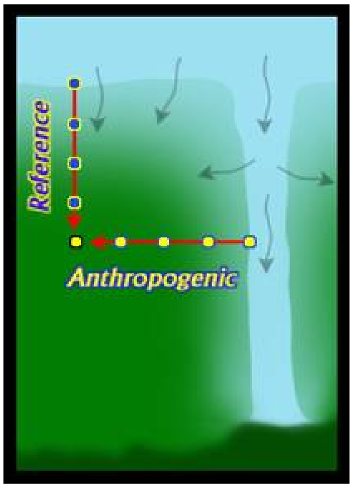


Figure 24. Generalized diagram of the movement of water from the open lake into a marsh, including lateral movement where the marsh has been fragmented by removal of vegetation. The term “anthropogenic” associated with the lateral transect refers to the fact that conditions have been altered by human activities.

- Larval largemouth bass were much more abundant farther away from the open water edge of the marsh, reaching a maximum number at 50 meters into the marsh. The same pattern was followed along the lateral transect --- that is, numbers increased with distance from the artificial edge.

- Larval killifish numbers increased toward the interior of the marsh in reference sites, with a maximum number at about 40 meters from open water. Along the lateral transect, no pattern was established. The numbers of fish present appeared to depend upon the extent of wave action resulting from vegetation removal.

- Some larval fish, such as Johnny darters, prefer a sandy habitat without vegetation, and such species *decreased* with distance into the marsh. No distinct difference was noted between number at the natural lakeward edge of the marsh and in areas where vegetation had been removed.

In summary, it is clear that the impact of vegetation removal on larval fish extends well beyond the point where vegetation has been removed. Most larval fish are less abundant near the *edge* of the marsh. This is true of the edge where vegetation is removed artificially, as well as the lakeward edge. Of particular interest and concern are the decreased abundance of some important sport fish – yellow perch, smallmouth bass, and largemouth bass.

Note that the chemical and physical impact of vegetation removal extends up to 50 meters (about 164 feet) laterally into the marsh. Thus, if a property owner leaves a zone of undisturbed vegetation 300 feet wide, but owners on either side remove vegetation, the infiltration of open lake water and increased wave energy from either side will impact the entire 300 foot “natural” zone. To view this another way, if a swath of vegetation is removed from a reach of shoreline every 300 feet, larval fish in the entire reach of shoreline will be impacted. “Fragmentation” of the marsh can thus have a very serious impact on fish production in the Great Lakes.

Section IV: Summary and Recommendations

The observations of DEQ permit staff, technical information provided to the Department in response to posting of a draft General Permit for vegetation removal, and most significantly, the findings of a research team that evaluated beach maintenance and vegetation removal over a two year period, all support the same conclusion. The alteration of vegetated areas on the Great Lakes coast between the ordinary high water mark and the waters edge has a significant adverse impact on the ecology of the Great Lakes.

Although only minor impacts were demonstrated where vegetation was mowed and then allowed to re-grow, repeated mowing was shown to reduce or eliminate stands of ecologically important plants such as bulrush. The removal of vegetation from the shoreline by this and other means, including raking, hand-pulling, disking, and mechanical clearing resulted in a reduction in invertebrates and fish in adjacent waters. Qualitative observations indicate that removal of vegetation also increases movement of sand and erosion of shoreline areas. Moreover, the limited vegetation that may re-grow following relatively minor beach disturbance tends to include exotic species and less valuable annual plants.

Clearing a swath of vegetation through a coastal marsh produces a fundamental change in the natural chemical and physical conditions in nearshore waters. Sheltered marsh zones having a low wave impact, and characterized by water chemistry similar to groundwater, are completely eliminated. These changes in turn impact both adult and larval fish species and the invertebrate communities on which they depend for food and nutrient cycling. Significantly, the removal of vegetation impacts not only the part of the shore that is directly altered, but also adjacent wetlands. Impacts can extend over 150 feet to either side of a cleared area. Thus, removal of vegetation along a reach of the shore every 300 feet will not only fragment but adversely impact the ecology and fish production along the entire reach.

While there may be circumstances where limited removal of vegetation is acceptable -- for example when invasive species are becoming established -- this activity should, in the future, be limited to those sites where qualified staff have determined that there is no feasible and prudent alternative and where ecological impacts will be minimal. **Therefore, the DEQ recommends:**

1. **That vegetation removal under a letter of approval from the Director of the DEQ be allowed to sunset on June 5, 2006, three years after the effective date of Public Act 14 of 2003, as specified in the Act. After that date, an individual permit for this activity should be required under Parts 325 – Great Lakes Submerged Lands, and 303 – Wetland Protection, of the Natural Resources and Environmental Protection Act (except for a limited General Permit as discussed below).**

   The Department would typically recommend issuance of an individual permit for vegetation removal to control invasive species such as *Phragmites*; and to maintain recreational areas in public parks in accordance with approved park management plans. Permits may also be issued on a case-by-case basis where a clear need is demonstrated, damage to coastal habitat and impacts to neighboring properties would be minimal, and mowing is not a viable alternative. However, permits for vegetation removal will not be issued in designated Environmental Areas or where threatened or endangered species would be impacted, unless it is to control invasive species under a Department approved plan.

The Department proposes development of a simplified permit application form for vegetation removal to be prepared in cooperation with the Detroit District Corps of Engineers. The Department anticipates action on completed applications using the simplified form within 60 days (well within the average Corps processing time of 151 days), with a goal of 30 days.

Issuance of a limited General Permit for removal of vegetation from a 6 foot wide walkway to allow access to open water is also recommended (except where designated Environmental Areas or threatened or endangered species would be impacted).

2. **That exemptions for beach maintenance activities including raking, mowing, leveling of sand, and establishment of raised paths continue only until November 1, 2007, as specified in Act 14.**

After this date certain beach maintenance activities will continue to be exempt under Part 303. These include: (a) manual de minimis removal of vegetation (hand pulling) in sparsely vegetated areas; (b) manual leveling of sand in unvegetated areas of beach above the current water's edge; and (c) manual raking of sand in unvegetated areas to remove debris, without disturbing or destroying plant roots.

The Department recommends issuance of a new General Permit as of November, 2007 to cover the following additional beach maintenance activities: (a) mowing of vegetation twice per season to a height of not less than two inches, in an area not to exceed 50% of the width of the property, or 40 feet in width (whichever is less); (b) mechanical leveling of sand in unvegetated beach areas above the current water's edge; and (c) construction and maintenance of a temporary path up to 6 feet in bottom width to provide access to open water, to be constructed of sand and pebbles from unvegetated bottomlands or upland riparian property.

An individual permit would be required for other beach maintenance activities, including: (a) grading or leveling of sand that would alter the natural shoreline; (b) mechanical raking or disking of beach areas that will result in loss of vegetation or degrade habitat quality on the beach or in adjacent waters; and (c) large scale or frequent mowing that would significantly impact vegetation.

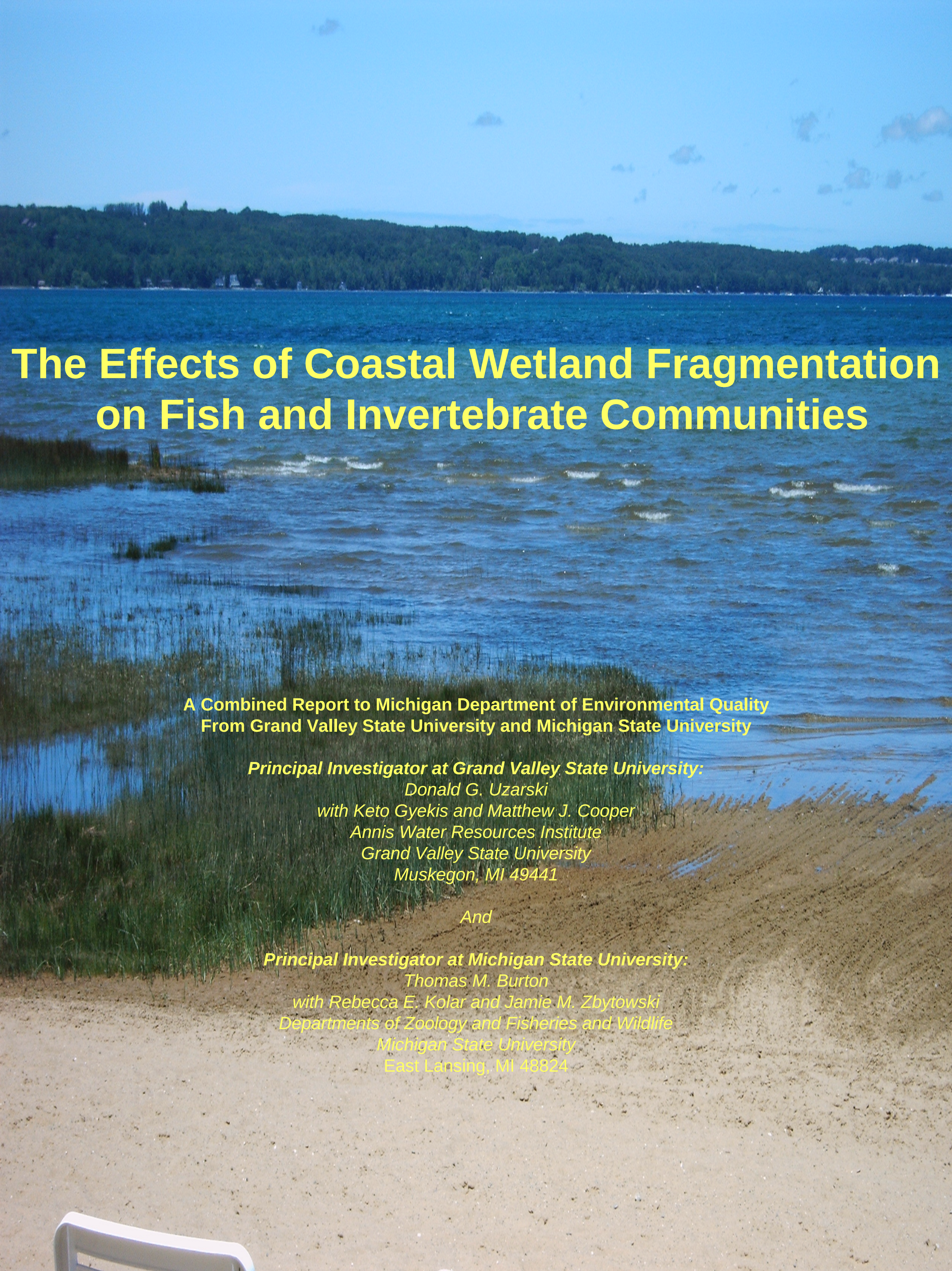
In evaluating permit applications, the impact on adjacent property owners and on public resources would be considered.

Permits for beach maintenance will not be issued in designated Environmental Areas or where habitat for threatened or endangered species would be adversely impacted, except to control invasive species under an approved management plan.

3. **That the Department provide additional information to the public to discourage practices that were not intended to be exempt, such as mowing followed by "thatch removal" -- which is not included in the definition of either mowing or raking under Public Act 14 of 2003; or filling of <u>vegetated</u> wetland swales under an exemption for "leveling of sand in areas that are predominantly <u>free of vegetation</u>."**

4. **That the Department provide additional information to actively discourage mowing of nuisance species such as *Phragmites,* since mowing fragments the stems of this plant, greatly accelerating the spread of this serious nuisance species.**

5. **Finally, that the Department continue to support research regarding the impacts of human activity on Great Lakes coastal wetlands, with particular attention to groups of organisms that were not evaluated as a part of this study (e.g. shorebirds, waterfowl, reptiles and amphibians) as funding becomes available. Additional information is also needed on the extent of soil erosion and alteration of the physical nature of the shoreline following vegetation removal and similar activities.**



The Effects of Coastal Wetland Fragmentation on Fish and Invertebrate Communities

A Combined Report to Michigan Department of Environmental Quality
From Grand Valley State University and Michigan State University

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Executive Summary

Introduction - Since pre-European settlement, approximately 70% of Great Lakes coastal wetlands have been lost (Cwikiel 1998, Krieger at al. 1992). Most remaining wetlands are highly fragmented with boat launches and navigational channels cutting through them. Fragmentation increases during low lake level years as riparian owners and developers deepen channels, create new ones, and mow or remove vegetation from the exposed bottomlands. Lake levels dropped > 1 m in Lakes Michigan and Huron from 1997 through 2003. Fragmentation accelerated during this time-period and continued through 2004 and 2005. Sand was moved and raked to create or maintain beaches, particularly in public parks, but also on some private lands. Fragmentation from mowing and movement of sand for beach nourishment, coupled with wetland fragmentation by marina and riparian owners seeking to deepen and/or widen boat channels, may have substantial and long lasting effects on wetland biota.

In 2003, the Michigan Legislature enacted legislation exempting owners of lakefront property on the Great Lakes and Lake St. Clair from obtaining a permit before conducting certain 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. Our objective in this study was to document the effects of fragmentation and mowing on invertebrates, fish, and chemical and physical processes that may have resulted from these types of activities.

Summary of Results:

1. Chemical and Physical Measurements- Removal of vegetation disrupted the ambient chemical and physical conditions of the wetlands. The fragmentation of the wetland acted as a conduit for pelagic water to infiltrate the marsh the entire width of the wetland to shore. Intact vegetation would have buffered waves and surface drift and created a relatively stagnant water column with ambient conditions more similar to groundwater close to shore. Vegetation removal eliminated the very important gradient of ambient conditions that structures biotic communities and maintains a range of wetland functions. Our past research clearly established the relationship between chemical and physical conditions and biotic communities (Uzarski et al. (in press); Uzarski et al. 2004; Burton et al. 2004; Burton et al. 2002; Burton et al. 1999). Analyses of chemical and physical data presented in this report show that vegetation removal clearly altered ambient conditions. This alteration was not only observed in locations where vegetation was removed, but also into adjacent areas where vegetation remained intact. These alterations in ambient conditions translate into an altered biotic community composition in cleared areas as well as into adjacent, seemingly unaltered, areas via an edge effect.

2. Effects of Mowing on Invertebrates - In 2004, we compared invertebrate communities associated with wetland plants in 14 pairs of mowed wetlands with invertebrate communities of un-mowed reference areas. The comparisons were between reference areas and (a) recently mowed areas with plant heights < 30 cm high and (b) less recently mowed wetlands with plant heights that had recovered to > 30 cm high. Fewer taxa (genera or families) than would be expected to be significant by chance alone were different between either of the mowing treatments and reference areas at the significance level used (alpha = 0.05). Water quality for the three treatments was also quite similar. We conclude that detectable differences among treatments, if they occurred, were below our detection limit. Mowing at heights above 5 cm during low water appears to cause few changes in invertebrate community composition as long as the plant community is allowed to recover during and after mowing.

3. Effects of Conversion of Wetlands to Open Beaches on Invertebrates - In 2005, we compared invertebrate communities of open, unvegetated shallow areas of wetlands with invertebrate communities of sandy beach areas that evidence suggested had been created from wetlands by such grooming activities as raking and movement of sand. Using a similar amount of sample effort, a total of 4,730 invertebrates were collected from seven open water reference zones, while only 118 invertebrates were collected from five open water raked zones along Saginaw Bay. These differences were significant (p=0.028). The average number of individuals collected per open water reference was 29 times greater, on average, than invertebrate densities in raked zones. Even after removing the one reference zone where 3665 invertebrates were collected from the analysis, total invertebrate density was still 8 times higher and significantly different (p=0.044) in the reference areas than in the raked areas. Shannon diversity (H') was not significantly different between reference (mean = 1.59±0.13) and groomed areas (mean=0.83±0.36) even though differences were large. However, mean species richness was significantly different between the two areas (p=0.023) with an average of 9.5±1.1 taxa per site for reference areas compared to 3.60±1.30 taxa per site for the groomed areas. Since even higher numbers per sample and a greater diversity of species were collected from vegetated reference areas just shore-ward of the shallow, un-vegetated reference areas used in the above analyses, we conclude that conversion of wetland plant areas to open beach areas results in very large and significant decreases in density and diversity of invertebrate communities. This has important potential ramifications in terms of reducing the potential food base for nearshore fish communities in the Great Lakes.

4. Juvenile and Mature Fish- There was a clear difference in fish communities between reference sites and beach maintenance activities at both Saginaw and Grand Traverse Bays. Reference sites at both locations tended to have higher fish diversity and greater number of certain taxa. Boat channels located in Northern Lakes Michigan and Huron did not have detectably different fish communities from the adjacent intact vegetation. The channels sampled were likely too small to detect great changes in fish community composition since fish are extremely mobile.

5. Larval fish -Overall, larval fish communities were certainly impacted by wetland fragmentation. The magnitude of this impact translated into the adjacent intact vegetation was most likely determined by the potential for wind and waves advecting pelagic water laterally into the intact vegetation from the wetland opening. The magnitude of the edge effect is likely quite dynamic and dependent on wind and barometric pressures. Regardless of the size of the edge effect, the location where the vegetation was removed drastically changes larval fish composition. While these areas were once inner marsh areas similar to the point where the reference and anthropogenic transects meet, removal of the vegetation created a habitat similar to the outer edge of the reference transect the entire width of the marsh all the way to shore.

6. Microinvertebrates - Community composition was predictable based on the amount of aeration at a given location. This suggests a distinct shift in zooplankton community composition as a result of the removal of the vegetation allowing for intrusion of pelagic water and the accompanying breaking waves and currents.

7. Macroinvertebrates collected using quatrefoil light traps- These light trap data show a distinct impact on invertebrate community composition, not only where vegetation was removed, but also into the adjacent, intact vegetation. In many cases, the community shift from the edge effect of the vegetation removal lasted at up to 50 m laterally from the anthropogenic edge.

Introduction

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). Wetlands remaining today are heavily fragmented. Large areas have been drained for agriculture and urbanization while boat launches and navigational channels cut through many of those that remain. These systems continue to be fragmented by additional development of the shoreline and through repeated navigation of small boats to and from docks. Fragmentation sharply increases during low lake level years as riparian owners and developers seek to deepen channels and create new ones. Lake levels dropped by more than one meter in Lakes Michigan and Huron from 1997 through 2003 and reached near record lows in 2003. Fragmentation accelerated during this time-period as riparian land owners mowed or removed wetland vegetation from recently exposed bottom lands lake-ward of their properties. The mowing and removal of wetland vegetation continued in 2004 and 2005 even though water levels increased in 2004 and during the Spring of 2005 compared to 2003 lows. Even though water levels in 2005 were higher during the spring than in they had been in 2004, they decreased from June through the rest of the summer to levels lower than those in 2004. A variety of mowing and removal techniques were employed, including mechanical removal of roots and rhizomes with tractor pulled rakes. In addition, sand was moved and raked to create or maintain beaches, particularly in public parks, but also on some private lands. Fragmentation from mowing and movement of sand for beach nourishment, coupled with wetland fragmentation by marina and riparian owners seeking to deepen and/or widen boat channels, may have substantial and long lasting effects on wetland biota. In 2003, the Michigan Legislature enacted legislation, exempting owners of lakefront property on the Great Lakes and Lake St. Clair from the requirement 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). While we had not documented such activities prior to legislative and permit changes, it seems likely that this legislative action and approval of a general permit for such activities by the U.S. Army Corps of Engineers led to major increases in fragmentation and mowing of wetlands. Our objective in this study was to document the effects of fragmentation and mowing on invertebrates, fish, and chemical and physical processes.

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

Great Lakes coastal marshes are dynamic systems, with physical, chemical, and biological characteristics differing substantially from inland marshes (Burton et al. 2002, 2004). We have observed relatively distinct chemical/physical gradients from open water to shore in these systems (Cardinale et al. 1997, 1998, Stricker 2003 and unpublished data of Uzarski and Burton). Fringing coastal wetlands occur where protection from destructive forces of wind and waves allows emergent vegetation communities to establish (Keough et al. 1999; Heath 1992; Burton et al. 2002, 2004). The degree of exposure of coastal wetlands to wave action is broadly predictive of the types of invertebrate communities occurring in them (Burton et al. 2002, 2004). Dense vegetation dampens the wave impacts, but pelagic water is advected into the outer edge of the wetland, creating a chemical/physical signature comparable to that of the open water (Cardinale et al. 1997, 1998, and our unpublished data). At the other extreme, areas of the wetland closest to shore receive little advected pelagic water, but instead receive a groundwater component that creates a very different chemical/physical environment (Stricker 2003). These two extremes in chemical/physical conditions merge along natural gradients perpendicular to shore (Figure 1). Much of our work has shown that the biota respond to, and follow, this natural gradient with shifts in community composition from open water to shore (e.g. Uzarski et al. in press, Uzarski et al. 2004, Burton et al. 2004, Burton et al. 2002, Burton et al. 1999, Cardinale et al. 1997, 1998). Coastal wetland fragmentation results in a conduit of pelagic water penetrating all the way from open water to shore. In the process, artificial edges set up short chemical/physical gradients parallel to shore (Figure 2). While community composition along the natural gradients perpendicular to shore are predictable (Burton et al. 2002, 2004), it was unclear how communities would respond to anthropogenic caused chemical/physical gradients parallel to shore caused by fragmentation. Exploring these effects, as well as making pair-wise comparisons between manipulated habitats and adjacent reference habitats, were the primary objectives of this research project. Specifically, we investigated chemical/physical impacts of fragmentation on micro and macroinvertebrates, and adult, juvenile, and larval fish. Due to their importance in aquatic energetic webs, impacts to these communities are likely felt throughout the entire Great Lakes ecosystem. We documented the effects on invertebrates and fish of fragmentation resulting from mowing, tilling, dredging, and repeated boat traffic cutting channels through vegetation. **Our overall objective was to explore the impact of wetland fragmentation on chemistry, and biodiversity of plant, invertebrate, and fish communities**. The results for the plant community were included in a report submitted in October, 2005 by Dr. Dennis Albert. The results for invertebrate and fish are included in this report.

Methods

Determination of Anthropogenic Disturbance in Each Study Area

The ecological condition of a wetland prior to fragmentation may influence differences between fragmented and intact, reference sites. For example, a perturbation such as mowing, tilling, or channelization for boat access to open water may not be detectable in the biotic community of a previously degraded wetland while the same perturbation could result in detectable impacts on a relatively pristine wetland. To account for potentially disproportionate biotic effects due to initial ecosystem integrity, we sampled sites representing the gradient of anthropogenic disturbances found in coastal wetlands of Lakes Huron and Michigan. Our past research has shown that wetlands of northern Lakes Michigan and Huron are more representative of reference conditions than wetlands of Saginaw Bay (Burton *et al*. 1999, Uzarski *et al*. 2004, Uzarski *et al*. In Press). In Saginaw Bay, a disturbance gradient exists from the more-heavily impacted inner bay to the outer bay where dilution of impacts by Lake Huron water occurs (Burton *et al*. 1999). Wetlands of Grand Traverse Bay are subject to both northern Lake Michigan water as well as local impacts from adjacent urbanization. Accordingly, sites from these ecoregions, and from multiple disturbance classes within each region, were included in this project. We used basic limnological parameters (i.e. specific conductivity, Cl, and dissolved nutrients) and on-site observations of adjacent land use and land cover to determine anthropogenic disturbance for each site to ensure that we sampled wetlands along the disturbance gradients in each region.

Chemical and Physical Measurements

Basic chemical/physical parameters collected each time biological samples were taken included Cl, SO_4 , soluble reactive P (SRP), NO_3-N, NH_4-N, total alkalinity, phenolphthalein alkalinity, temperature, dissolved oxygen (DO), percent saturation of dissolved oxygen (% DO), chlorophyll *a*, oxidation-reduction potential (redox), pH, turbidity, total dissolved solids (TDS), and specific conductivity (SpC). Temperature, DO, % DO, chlorophyll *a*, redox, pH, turbidity, TDS, and SpC were measured *in situ* using a Hydrolab Datasonde. Dissolved nutrients, Cl, SO_4, and total and phenolphthalein alkalinity were measured in the laboratory. Prior to analysis, water samples were filtered through 0.45 *u*m Millipore filters. Analytical protocols and quality control measures followed those recommended by U.S. EPA and Standard Methods (APHA 1998). Chemical and physical data were used to explain ecosystem function and to describe the mechanisms that were most likely responsible for structuring biological communities.

General Approach for Determining Effects of Wetland Fragmentation

We worked with permit applications obtained from MDEQ staff to identify lakefront areas where property owners had removed, or proposed to remove, plants from exposed bottomlands that had supported emergent plant communities when lake levels were near-normal or above average. We selected additional sites from local observations and after conversations with local land owners in an effort to represent all types of beach and wetland manipulation that had occurred in the study regions. When evidence of wetland or beach manipulation was found, we sought access to the site from property owners or from appropriate governmental employees in the case of public lands. If access was granted, we selected adjacent or nearby intact wetland habitat as a reference and sought permission to access that area as well. Site selection ultimately depended on access to private property. While access was denied to some sites, prohibiting us from including those sites in our study, we were able to include a representative sample of groomed or mowed and reference sites in the study.

In 2004, we sampled 15 paired groomed/reference Saginaw Bay sites (11 with dip nets for macroinvertebrates, 8 with fyke nets for juvenile and adult fish, and 5 with quatrefoil light traps for larval fish and micro and macroinvertebrates). We sampled 3 Grand Traverse Bay wetlands (3 with dip nets, 3 with fyke nets, and 2 with quatrefoil light traps). In 2005, we sampled 12 open beaches along Saginaw Bay (5 raked and 7 unraked) paired with adjacent wetland vegetation using timed dip net sampling. We used quatrefoil light traps to sample larval fish and macroinvertebrates in 14 fragmented wetlands of Saginaw Bay, 1 fragmented wetland of northern Lake Michigan and 3 wetlands of northern Lake Huron. We also sampled 19 wetlands fragmented by boat channels (5 in 2004; 14 in 2005) using quatrefoil light traps to sample larval fish and invertebrates.

At each sampling area, we compared biotic communities and water chemical/physical parameters of disturbed beachfront areas (e.g. tilled, mowed, or raked) or inundated habitats immediately offshore of disturbed shoreline with chemical/physical parameters and biotic communities in adjacent or nearby non-disturbed (reference) areas. Thus, the experimental design consisted of comparisons of each of the groups of organisms in the disturbed areas with the same groups of organisms in reference areas. Additionally, quatrefoil light traps (Floyd et al. 1984; Secor et al. 1992) were positioned along transects running into marsh fragments from the open water and from artificially created edges. These traps collected larval fish and micro and macroinvertebrates. Chemical/physical measurements were made along these transects as well. The two experimental designs worked in concert with one another with the comparative analyses identifying categorical differences between manipulated and reference wetlands and the transect analyses exploring spatial characteristics of fragmentation effects on community composition.

Macroinvertebrate Sampling

In 2004, macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from late July through August. Our earlier research on coastal wetlands indicated that samples taken earlier in the season contained less diversity and a greater proportion of early instars of aquatic insects, making identification more difficult. Macroinvertebrates were sampled from all major flooded plant zones at each site.

One of the most common beach maintenance activities was mowing exposed wetland plants with mowing sometimes extending into shallow water. Mowed sites were subdivided into sites that had been mowed recently, so that plant height was 30 cm or less, and sites where mowing had occurred, but plants were greater than 30 cm high. Sites where evidence of mowing was still visible (i.e. piles of cut vegetation, tire tracks, etc.) or where the local land owner told us that the site had been mowed, but with plants greater than 30 cm high, included a combination of sites mowed in 2003 and those mowed early enough in 2004 for plants to have re-grown to heights greater than 30 cm. Each disturbed site was matched with a reference site. Reference sites were chosen based on their proximity to groomed sites and were required to have the same vegetation type as the associated groomed site. Both of these criteria were necessary in order to isolate chemical/physical and biotic factors that were due to the grooming practice alone (i.e. to avoid confounding factors).

Dip net sweeps, for each replicate sample taken, were made through the water column at the surface, mid-depth and just above the sediment surface. The dip net contents were emptied into white pans, and organisms were collected on site by picking all specimens from one area of the pan before moving on to the next until either 50, 100, or 150 invertebrates were collected per replicate. As a means of semi-quantifying samples, picking of specimens was timed. Individual replicates were picked for one-half person-hour or until 150 specimens per replicate had been collected. If 150 specimens had not been collected after one-half person-hour of picking, organisms were tallied and picking continued to the next multiple of 50. Three replicates of 50, 100, or 150 specimens per replicate were collected from each major plant zone present. This sampling method was used effectively in previous research on Great Lakes coastal wetlands (Burton et al. 1999, 2002, 2004, Uzarski et al. 2004).

Preliminary observations in 2004 indicated that groomed, open beach areas supported a very low-density fauna compared to nearby areas where plant zones were still intact. In order to document and quantify these differences in 2005, we focused our macroinvertebrate sampling efforts on raked, and unraked open beach areas paired with adjacent vegetated areas to serve as reference habitats. We also used a more quantitative sampling technique so that macroinvertebrate density differences were better represented by our dataset. The revised procedure was designed to ensure that the same unit effort was expended for each replicate sample. Timed dip net sampling was used to sample the upper layer of substrate by pushing the net back and forth through the upper 3-5 cm of substrate for 3 minutes per replicate. Fine silt and detritus was removed from each sample by repeatedly washing the net contents with water. The entire rinsed sample, consisting of organisms, coarse sediments, and organic particles retained in the 0.5 mm mesh net, was preserved in 95% ethanol. Three replicate, 3-minute long sweeps, were made in each habitat sampled. All specimens were picked from the sample in the laboratory using a dissecting microscope.

Specimens were identified to lowest operational taxonomic unit, usually genus or species, and enumerated in the laboratory. Taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996), and comparison with specimens in reference collections (previously identified by taxonomic experts and maintained in the Burton laboratory) were used for identification. Macroinvertebrates were also collected with quatrefoil light traps along transects oriented into wetland fragments. For details on this sampling procedure please see "*Larval Fish, Micro and Macroinvertebrates Collected Using Quatrefoil Light Traps:*" section below.

Juvenile and Mature Fish Sampling

Fish were sampled in 2004 using six fyke nets per site with 3 nets set in disturbed and 3 set in reference areas for one net-night. Fyke nets are an effective fish sampling gear in Great Lakes coastal wetlands (Uzarski et al. In Press, Brazner et al. 1997). Site selection for fish sampling was coordinated with site selection for macroinvertebrate sampling. A number of the sites sampled for macroinvertebrates were too shallow for effective sampling of the juvenile and adult fish communities. Thus, fewer sites were included in fish community analyses in 2004 than were included for macroinvertebrates.

Two sizes of fyke nets (0.5 m x 1.0 m and 1.0 m x 1.0 m) with mesh of 5 mm were used. Smaller nets were set in water < 0.50 m deep; the larger nets were set in water from 0.50 to 1.0 m deep. Nets were set adjacent to, or in habitats of interest, with 7.3 m leads extending from the middle of each net into the area to be sampled. Each net was randomly placed perpendicular to the habitat of interest with the lead extending into the habitat. The two 1.8 m wings were set at 45^{o} angles to the lead and connected to the outer opening on each side of the net. Nets were set in the afternoon and retrieved the following morning. Fish captured in the nets were identified to species and enumerated. Voucher specimens were returned to the laboratory to confirm identification if a positive I.D. could not be determined in the field. Catches per net per night were recorded. Additionally, 10 to 20 specimens of each species were chosen at random from each net and measured.

Quatrefoil Light Trap sampling of Larval Fish and Invertebrates

Quatrefoil light traps (Floyd et al. 1984; Secor et al. 1992) were positioned along two transects, a perpendicular transect running into the marsh fragment from the open water towards shore and a horizontal transect running from the artificially created edge into the marsh parallel to the shore (Figure 3). Traps were spaced every 10 m and extended from the natural or anthropogenic edge for 40 or 50 m (depending on the size of the wetland) into the marsh. To minimize light source performance irregularities (Kissick 1993), bright, dependable, energy-efficient LED bulbs were utilized instead of chemical light sticks or traditional incandescent bulbs. Six LED bulbs, arranged in an outward-facing star pattern, were housed in a 2.5 cm (inner diameter) watertight, clear acrylic tube in the center of each quatrefoil trap (Figure 4). The bulbs were powered by four resistor-controlled C-cell batteries, also located in the watertight tube. A flexible, 30 cm heavy-duty plastic skirt was attached to the bottom of each light trap in 2004. This skirt aided in sample containment and made for efficient sample collection.

Light traps were placed in a marsh before dusk and collected after dawn. A 30.5 cm diameter, 118-um mesh plankton net was used to collect the trap contents when sampling for zooplankton. This size was sufficient for retaining most microcrustacea (Cardinale 1998). The hoop of the plankton net was placed around the bottom of the trap and slowly raised to envelop the entire trap. When the net was pulled up to the water surface (enclosing the light trap), the plastic skirt at the bottom of the trap was released and opened, allowing trap contents to exit into the plankton net. On site, the net contents were rinsed into a plastic collection bottle by spraying the exterior of the net and preserved in a 5% buffered formalin solution. After several weeks of fixation, samples were transferred to 70% ETOH preservation solution, according to Standard Methods (APHA 1998). In 2005, the plastic skirt on each trap was replaced with 500-*u*m nylon mesh net, fastened directly to the bottom of the trap, eliminating the need for a separate plankton net. Note, however, that organisms between 118 and 500 um in size would have been collected in 2004 but not in 2005. The contents of the trap were washed into the attached mesh and the entire mesh including the trapped organisms was removed and frozen immediately with dry ice. In the laboratory, samples were thawed and preserved with 70% ethanol prior to identification and enumeration.

All processing was done according to Standard Methods (APHA 1998) when applicable. Organisms larger than 1 cm (larval fish and macroinvertebrates) were manually separated out of each sample prior to sub-sampling. A Folsom plankton splitter (APHA 1998, Van Guelpen et al. 1982) was used to collect approximately 200 to 300 individuals/light trap. A Ward counting wheel was used to facilitate organism enumeration. Larval fish were identified to species level utilizing the larval fish key of Auer (1982). Microcrustacea were identified to family level when possible (Balceret al. 1984, Pennak 1989, Thorp & Covich 2001). A simple gravimetric (dry weight minus ash weight) method was used to calculate microcrustacean biomass (Oniori and Ikeda 1984). Samples were dried at 60ºC for 48 hours and then weighed to the nearest 0.0001 g. Dried samples were then combusted at 550ºC to remove all organic carbon and reweighed so that ash free dry mass could be determined by subtracting ash weight from pre-combusted dry weight.

Physical parameters measured *in situ* at each light trap location included water depth, water temperature, and turbidity. Chemical parameters measured *in situ* at each light trap location included redox potential, DO, specific conductance, chlorophyll *a* (suspended algae), total dissolved solids, and pH. A Hydrolab Corporation DataSonde 4a was used to measure all *in situ* chemical/physical parameters. Acid-washed 1L polyethylene bottles were used to collect water samples at each end of all transects for alkalinity. A sub-sample was filtered through a 0.45 um filter for nutrient analyses. Chemical analyses were conducted as recommended in Standard Methods (APHA 1998). Marsh habitat patch sizes were estimated with a geographic information system, aerial photographs, and/or with a laser range finder and compass on site.

Vegetation was characterized at each light trap location. A 0.25 m^2 PVC square quadrat was used to survey the vegetation for two squares at each light trap location by positioning the quadrat on the transect line, first with a corner touching the rear of the trap and then with a corner touching the front of the trap. Total stem densities for each vegetation group (*Scirpus*, *Typha*, *Sagittaria*, *Nuphar*, grasses, etc.) were determined within each quadrat. Average heights above the sediment of vegetation groups were also determined for each quadrat. Percent bottom cover (i.e., filamentous algae) and percent surface cover (i.e., stem wrack or *Nuphar* leaves) was recorded as well.

Statistical Analyses

Macroinvertebrates collected with dip nets: Only those taxa that comprised greater than 1% and 5% of total invertebrates caught per wetland/groomed beach area were included in analyses of community composition. Average invertebrate abundances among triplicate samples (per habitat sampled) were used as a measure of central tendency of each taxon in each habitat. For analyses of 2004 data, we used relative abundances (percent of total catch per habitat) of each taxon in the community. Since a more quantitative sampling technique was used in 2005, we were able to use true mean abundance of each taxon (per replicate). This raised our power of detection because differences in macroinvertebrate density among habitats were more accurately represented in our dataset when the quantitative sampling technique was used.

Rare taxa were included only in measures of Shannon diversity and taxa richness. All means reported included standard errors. To detect differences in Shannon diversity, taxa richness, and taxon abundances between reference and disturbed (groomed) habitats, data were subjected to non-parametric Kruskal-Wallis ANOVA and Wilcoxon signed-rank tests. Analyses were stratified by year (2004 were kept separate from 2005). Where appropriate, matched pair statistical tests (i.e. Wilcoxon signed-rank test, paired t-test) were used so that among-wetland variability was minimized and the effect of the treatment (grooming) was isolated. We decided *a priori* to compare the invertebrate communities among treatments by retaining $\alpha=0.05$ for all statistical analyses without correcting for the potentially increased Type I error rate resulting from multiple comparisons. A Bonferroni correction could have been performed (i.e., adjusted $\alpha=0.05/k$, where k equals the number of dependent variables measured), but we chose not to do so because this very conservative technique would have greatly diminished the power of our tests and increased the potential for a type II error. Therefore, we acknowledge, for these analyses, an increased probability that marginally significant p-values may be due to chance alone.

Multivariate statistics were also used to investigate relationships between macroinvertebrate communities and wetland grooming (as well as to summarize the water quality parameters that accompany these data). Macroinvertebrate community data from wetlands sampled in 2004 were subjected to correspondence analysis (CA) to relate macroinvertebrate community composition to mowing treatment. When wetlands separated according to their degree of mowing, groups of individual taxa containing the most inertia responsible for the separation were identified. Macroinvertebrate data from 2005 were also subjected to CA to identify gradients in community composition that could be explained by the raking treatment. When these gradients were found, individual taxa or groups of taxa responsible for the separation were identified.

Juvenile and Adult Fish Communities*:* Fish community data from 2004 were analyzed similarly to the dip net macroinvertebrate data. Separate correspondence analyses were conducted for Saginaw Bay, Grand Traverse Bay and Northern Lakes Michigan and Huron. This stratification of the fish dataset was done to minimize ecoregional effects between these areas. Our Saginaw Bay and Grand Traverse Bay datasets include mechanically groomed sites paired with sites containing intact vegetation. Our northern Lake Huron and Michigan dataset includes non-vegetated boat channels paired with sites containing intact vegetation.

Larval Fish, Micro and Macroinvertebrates Collected Using Quatrefoil Light Traps: Regression analysis was used to determine if biotic responses from disturbed areas showed a linear (or curvilinear) relationship with distance from the wetland edge. These relationships were then compared to the relationship between biota and distance from natural edges (along the reference transects). These comparisons were used to place anthropogenic edge effects into a spatial context relative to natural edges. Comparison of natural and anthropogenic edge effects to evaluate our hypothesis that removal of wetland vegetation impacted not only the immediate area where vegetation was removed, but that impacts also extended well into the remaining adjacent vegetated habitat. In addition to regressing data against distance into a wetland fragment, we conducted parametric and nonparametric tests (Kruskal-Wallis, Mann-Whitney U, ANOVA, paired t-tests and Students t-tests) between treatments (anthropogenic edge, reference edge, and marsh interior). Larval fish abundances were highly variable both temporally and spatially. Therefore, for each analysis we included only those sites where sample abundances for the taxon under investigation were high enough to ensure that we were accurately representing the taxon’s occurrence in the community. Larval fish abundances were square root transformed for most of our analyses to stabilize variance and remove heteroscedasticity.

Larval fish, micro and macroinvertebrate data collected with quatrefoil light traps were also subjected to multivariate analyses. These analyses were used to explain overall patterns in the dataset and relate these to potential environmental drivers (i.e. distance from an edge, substrate type, stem density, etc.). Separate correspondence analyses were conducted for macroinvertebrate data and microinvertebrate data collected in 2004. In these analyses, data from all sites were included for each group of organisms. We also stratified the dataset by site and conducted correspondence analyses on single transect pairs (reference and anthropogenic) to explore gradients in community composition at a within-site scale.

Chemical and Physical Data: Chemical and physical data were collected every time biological samples were taken. These data were subjected to parametric and nonparametric tests as well as multivariate analyses (principal components analyses) to determine if treatments (i.e. mowing, raking, and boat channel maintenance) had a statistically significant affect on the abiotic environment. Results from these analyses were then used to identify potential mechanisms structuring the biotic communities. That is, when biotic communities showed a response to a grooming treatment, the abiotic data was used to identify potential drivers of the community shift.

Results and Discussion

Chemical and Physical Measurements

Comparison of water quality parameters among mowing treatments in 2004: A total of 13 water quality parameters were measured in 2004 (Table 1). Because many water quality variables were highly correlated, we used PCA to reduce the dimensionality of the data set. Analysis returned three principal components (PCs) that explained 52% of the variance in water quality. PC 1 loaded with specific conductivity (SpC), alkalinity, and chloride (Cl^-). PC 2 loaded with temperature, dissolved oxygen, and ammonium-N (NH_4^+). PC 3 loaded with salinity, soluble reactive phosphorus (SRP), and sulfate (SO_4^{-2}). Plotting the three PCs suggested that water chemistry at less recently mowed wetlands and most recently mowed wetlands were within the range of water quality measurements found at reference wetlands (Figure 5).

We plotted means and standard errors of PCs in a two-dimensional plot (Figure 6). The means of reference and less recently mowed wetlands were more similar to one another than they were to most recently mowed wetlands. Most recently mowed wetlands exhibited greater data variability than did reference and less recently mowed wetlands. The most recently mowed wetlands separated from reference and less recently mowed wetlands in PC 1 based on SpC, alkalinity and Cl^-. This separation could reflect the tendency of mowed wetlands to be near roads and/or septic systems with more input from road salt and well water. The three treatments also separated slightly on PC 2, which was loaded with temperature, dissolved oxygen, and NH_4^+. This separation could reflect higher D.O. values resulting from wave action and/or higher rates of algal photosynthesis in the most recently mowed wetlands due to reduced vegetation cover and greater sunlight penetration.

Comparison of water quality parameters between open water reference, raked beaches, and adjacent intact vegetation in 2005: A total of 9 water quality parameters were included in principal components analyses for open water reference and open water 'raked' wetlands during 2005 (Table 2). PCA was used to reduce the dimensionality of water quality data (Figure 7). Three principal components explained 68% of variance in original water quality data. PC 1 loaded with temperature, dissolved oxygen, percent dissolved oxygen, and depth. PC 2 loaded with pH and alkalinity. PC 3 loaded with specific conductance, salinity, and turbidity. Water chemistry at 'raked' sites was within the range of water quality measurements found at reference sites. However, water quality data among raked sites appear more similar to each other than at the reference sites, since raked sites plotted in close proximity to one other (e.g., BTw, Cw, Tw) (Figure 7).

Cluster analysis was used to determine which sites were similar in water quality data (Figure 8). Cluster analysis revealed several clusters, with sites Tw (Thompson Park), Cw (Caseville), and BTw (Boutell Rd.) clustering together, demonstrating similar water quality (Figure 8). These raked sites were all public beaches or road ends with public access to beach areas.

Raked and unraked open beach areas were also compared to adjacent areas where the vegetation had not been removed. A total of 9 water quality parameters were used in these comparisons (Table 2). Because many water quality variables were highly correlated, we used PCA to reduce the dimensionality of the data set. Three principal components explained 78.7% of the variance in water quality. PC 1 loaded with temperature, dissolved oxygen, and percent dissolved oxygen. PC 2 loaded with pH and alkalinity. PC 3 loaded with SpC, salinity, turbidity, and depth (Figure 9). The main differences in water quality were not between open water and outer *Scirpus* zones, with the exception of Pinconning. Rather, the variability among sites was greater than the variability within a site.

Comparison of water quality parameters between outer reference edges and outer anthropogenic edges in 2004: Paired-t tests using five sites sampled in 2004 showed no significant differences ($p < 0.05$ or $p < 0.10$) in any chemical/physical parameter when comparing the outer most point on the reference edge with that of the outer most point on the anthropogenic edge (Figure 3). The parameters compared in the analyses included: depth, temperature, specific conductance, turbidity, pH, oxidation reduction potential, chlorophyll, percent dissolved oxygen, dissolved oxygen, alkalinity, stem density, chloride, sulfate, nitrate-N, ammonium-N, and soluble reactive phosphorous. The anthropogenic edges were located on the open water channels, created primarily to facilitate boat access to shore, that extended from the open water of the bay (pelagic water) to the shore through intact plant communities. Our results suggest that the channel created a conduit for pelagic water to penetrate the marsh all the way to shore resulting in similar water quality from the open bay to shore. Intact vegetation would have attenuated wave energy and surface drift creating a relatively stagnant water column with ambient conditions more similar to groundwater close to shore (Burton et al. 2002, 2004). Comparison of water quality of the anthropogenic edge with water quality of samples collected in the intact marsh an equal distance from pelagic water, demonstrated that every parameter was different than it would have been if the marsh had still been intact (unfragmented) (see results of regression analyses of these data). Initially, no significant difference in depth between the reference edge at the outer edge of the wetland and the anthropogenic edge well into the wetland seems counterintuitive, as the anthropogenic edge is much closer to shore. However, removal of vegetation (roots and rhizomes are known to stabilize sediments) from the channel and/or increased boat traffic through the channel may have resulted in increased erosion of the channel.

These results support our hypothesis that the abiotic environment on the margins of wetland fragments, even if very close to shore, are similar to outer wetland habitats than they would be if the marsh had not been fragmented. This anthropogenic manipulation of abiotic conditions may have repercussions on multiple levels of the ecosystem. For instance, maintaining inner marsh conditions with an abiotic environment dictated more by groundwater than by pelagic water is important for certain wetland functions (i.e. denitrification). Furthermore, much of our past research on Great Lakes coastal wetlands suggests that the structure of both fish and invertebrate communities correlates with ecosystem function as measured by relative rates of autotrophy and heterotrophy as they vary along the open water to shore physical/chemical gradient (Uzarski et al. In Press, Burton et al. 2002, 2004, Cardinale et al. 1997, 1998, unpublished data). The removal of vegetation, which allows for pelagic water intrusion into the wetland is likely to result in changes in the relative rates of productivity and respiration which, in turn, are likely to lead to major changes in ecosystem structure.

Regression analysis of water quality parameters collected in 2004 along reference and anthropogenic transects from open water to the marsh interior. Since ambient chemical/physical conditions at the anthropogenic edge of wetland fragments were very similar to outer natural edges, we conducted regression analyses to determine the nature of chemical/physical gradients from wetland fragment edges into the marsh interior. Regression analyses were conducted on chlorophyll, percent dissolved oxygen, dissolved oxygen, pH, depth, temperature, specific conductance, turbidity, oxidation reduction potential, alkalinity, chloride, sulfate, nitrate-N, ammonium-N, stem density, and soluble reactive phosphorous data along both the reference and anthropogenic transects from open water to the marsh interior. Prior to analysis, data for each parameter were standardized by calculating the difference of each observation from the mean for the respective wetland from which the observation came from (therefore, figures represent data plus or minus the mean (set at zero)). This standardization was necessary for determining chemical/physical edge effects because inter-wetland variability was substantial.

Chlorophyll, percent dissolved oxygen, dissolved oxygen, pH, depth, temperature, specific conductance, turbidity, oxidation reduction potential and alkalinity showed significant ($p<0.05$) relationships with distance into the marsh from open water along both the reference and anthropogenic transects (Figures 10 through 20). Of these, chlorophyll, percent dissolved oxygen, dissolved oxygen, and pH had significantly different slopes between reference and anthropogenic transects with the anthropogenic transect always having the steeper slope. Therefore, reference and anthropogenic data were pooled for the remaining significant relationships in order to maximize n. Stem density, chloride, and nutrient data showed no significant relationship with distance into the marsh along either the reference or anthropogenic transects.

Chlorophyll concentrations in the water column increased (Reference: $r^2=0.294$; $p=0.011$; Anthropogenic $r^2=0.538$; $p= 0.001$) with distance into the marsh (Figure 11). The increase in phytoplankton chlorophyll into the more stagnant inner marsh was likely due to a combination of reduced inorganic turbidity and reduced hydrologic mixing (e.g. see Cardinale et al. 1997, 1998). The steeper slope in chlorophyll concentrations along the anthropogenic transects was probably a result of slightly increased protection from wind and wave energy along the anthropogenic transects compared to the reference transects resulting in a more rapid transition from open water to inner marsh conditions away from the edge.

Dissolved oxygen (both percent saturation and concentration) decreased from open water into the marsh (Reference: $r^2=0.350$; $p= 0.002$; Anthropogenic $r^2=0.541$; $p < 0.001$) (Figures 12 and 13). This may seem counter intuitive since both rooted plants and phytoplankton increased. However, breaking waves and currents keep the open water areas highly oxygenated. Vegetation dampens wave penetration deep into the marsh and allows organic sedimentation to occur without this material being swept away. As this material decomposes, dissolved oxygen decreases from microbial respiration. This process is essential for nutrient cycling and food web dynamics. Further, under extremely low dissolved oxygen concentrations (especially in anaerobic microhabitats), denitrification occurs. Denitrification is the only mechanism for returning fixed nitrogen back to the atmosphere, completing the global nitrogen cycle. The steeper dissolved oxygen slope along the anthropogenic transects may indicate greater organic sediment accumulation immediately inside of the anthropogenic edge compared to a more gradual increase in organic sediment accumulation along the reference transects. The decrease in pH (Reference: $r^2=0.337$; $p= 0.002$; Anthropogenic $r^2=0.589$; $p< 0.001$) (Figure 14) along each transect can be explained by the same mechanism whereby organic sediment accumulation results in higher rates of respiration which lowers pH.

Depth decreased with distance from the open water along both anthropogenic and reference transects with similar slopes ($r^2=0.250$; $p= 0.001$) (Figure 15). The similarity in slopes suggests that erosion is taking place in the areas were vegetation had been cleared. These erosional forces seem to be cutting to a depth similar to that of the outer reference edges. Since these two transects end at the same distance into the wetland, the reference and anthropogenic relationships have similar slopes. This decrease in depth with distance into the marsh may also explain observed patterns in temperature. In the morning, temperature decreased with distance into the marsh along both the reference and anthropogenic transects ($r^2=0.407$; $p=0.006$) (Figure 16). This gradient was probably due to both groundwater influx in the inner marsh and evaporative cooling of the shallow inner wetland water column. The opposite was true during the afternoon as the temperature increased with distance into the marsh ($r^2=0.222$; $p=0.011$) (Figure 16). The smaller volume of water and lack of mixing with pelagic water in combination with the increased accumulation of organic (black) sediments in the inner marsh allows sunlight to quickly warm inner marsh water, while wave penetration and mixing with pelagic water keeps the outer marsh cooler. These differing gradients in temperature between the morning and afternoon demonstrate the relatively limited mixing that occurs between inner wetland and outer edge habitats when vegetation is left intact. Specific conductance ($r^2=0.091$; $p=0.044$) increased with distance into the marsh from both the reference and anthropogenic edges (Figure 17). This increase was most likely due to a combination of groundwater input and increased decomposition. Ground water has a relatively high concentration of dissolved ions resulting from the weathering process. Decomposition of organic matter results in increases in carbon dioxide which, in turn, forms carbonic acid which quickly dissociates producing bicarbonate and hydrogen ions, raising alkalinity and lowering pH. Approximately half of the measured specific conductance was due to bicarbonate. Hydrogen ion production as a result of decomposition of organic matter is consistent with the observed decrease in pH and increases in alkalinity (r^2=0.133; p=0.087) (Figure 19) and specific conductance from open water into the marsh. The decrease in pH was probably also responsible for the observed increase in redox potential (r^2=0.098; p=0.059) (redox potential increases approximately 59 mV per pH unit) (Figure 18). Turbidity also significantly decreased (r^2=0.141; p=0.011) (Figure 20) with distance into the marsh, perhaps due to reduced hydrologic mixing and erosion within the marsh as macrophyte stems attenuated wave energy and allowed settling of suspended sediments. Variability in turbidity deep in the marsh may be associated with patchiness of planktonic communities which develop in the clear water of inner marsh after inorganic suspended sediments have settled out. Even though macrophyte stem density appeared to increase from open water edges into vegetated marshes, we found no significant relationship with distance. This may reflect a cumulative dampening of wave energy and erosion until a threshold is reached where stem density is no longer controlled by abiotic forces such as erosion, but is controlled, instead, by competition for light and nutrients.

Our past research on Great Lakes coastal wetlands (Uzarski et al. in press; Uzarski et al. 2004; Burton et al. 2004; Burton et al. 2002; Burton et al. 1999) and the results from this study confirm that there is a relationship between abiotic conditions and biotic community composition. The above analyses document that fragmentation results in a shift in abiotic conditions reaching well into fragmented wetlands when a channel is created that allows penetration of pelagic water into inner wetland areas. Gradients in community metabolism from open water towards shore are relatively unique to Great Lakes coastal wetlands and are important to their overall function (i.e. community structure, nutrient sequestration, denitrification). The removal of vegetation alters these gradients by minimizing the area that acts as true inner wetland habitat. These effects were observed not only in the immediate area where vegetation was removed, but also extended for 40-60 m into the adjacent inner marsh, resulting in substantial areas of the marsh being modified enough to result in significant changes in community composition and ecosystem processes.

Biotic Community Effects:

Effects of Mowing on Invertebrates in 2004: Shannon diversity (H’) varied from 1.78 to 2.62 per wetland in individual wetlands (overall mean=2.20±0.15) in the 16 reference wetlands, while mean species richness ranged from 11.7 to 25.0 per wetland (overall mean=19.4±2.0) (Table 3). H’ varied from 1.47 to 2.75 (overall mean=2.16±0.22) in the 15 less recently mowed wetlands, with mean species richness varying from 9 to 28 species per replicate (overall mean=18.7±2.7) (Table 3). H’ ranged from 1.45 to 2.71 (overall mean=2.23±0.20) in the 13 most recently mowed sites, and mean species richness per replicate ranged from 8.0 to 28.7 (overall mean=20.7±3.6) (Table 3). No significant differences in Shannon diversity (p=0.441) and invertebrate taxa richness (p=0.651) were found among reference wetlands, less recently mowed wetlands, and most recently mowed wetlands (Figure 21).

Correspondence analysis (CA) was used as an exploratory technique to determine if wetlands that varied in degree of mowing differed in aquatic invertebrate community composition (e.g., separated in an ordination plot) and, if so, to determine which invertebrate taxa were responsible for the differences (e.g., identify taxa responsible for the most inertia in the separation). Correspondence analysis of invertebrate data showed that 10.27% of the total variance in the species data was explained in the first dimension and 9.61% of the variance was responsible for separation in the second dimension (Figure 22). This analysis did not reveal any distinct separation of wetlands based on the degree of mowing, and, coupled with the low percentage of variance explained by the two dimensions in the CA, suggested that invertebrate communities were similar to each other in the three different wetland treatments in 2004. Three reference areas from two sites, Bay Port swale, Bay Port *Scirpus* and Pt. Au Gres *Eleocharis*, were identified as outliers. They were removed from the analysis, and a second CA was performed. Results again showed no distinct separation of wetlands based on degree of mowing.

Invertebrate mean relative abundances (% of total catch) of taxa from reference wetlands are summarized in Figures 23-26. The mean invertebrate relative abundance of species that comprised >5% of total catch for reference wetlands included: *Caenis* (mayfly, 11.16%), *Stagnicola* (snail, 10.93%), *Hyalella* (amphipod, 6.64%), Naididae (segmented worm, 6.29%), and *Physa* (snail, 5.17%).

The most important invertebrate taxa contributing to mean relative abundance in less recently mowed wetlands are summarized in Figures 27-30. Invertebrate taxa that comprised >5% of mean relative abundance were: *Hyalella* (amphipod, 13.5%), *Physa* (snail, 8.23%), *Stagnicola* (snail, 7.54%), *Ischnura* (damselfly, 7.21%), and *Fossaria* (snail, 5.50%). Three of the five were among the five most common taxa in reference wetlands.

Figures 31-33 report the most important invertebrate taxa contributing to the mean relative abundance in the most recently mowed wetlands. The mean invertebrate relative abundance of taxa that comprised >5% of catch for this treatment included: *Stagnicola* (snail, 15.10%), *Physa* (snail, 10.88%), *Pseudosuccinea* (snail, 7.07%), Naididae (segmented worm, 6.28%), Chironomini (midge, 6.05%), and *Caenis* (mayfly, 6.01%). Four of these taxa were among the five taxa comprising >5 % of total catch in reference wetlands and two of them were among the five taxa comprising >5 % of total catch in less recently mowed wetlands.

The invertebrate communities among reference wetlands, less recently mowed wetlands, and most recently mowed wetlands were compared by analyzing taxa comprising >1% and >5% mean relative abundance. A total of 135 invertebrate taxa were collected in 2004 from 44 wetland habitats (wetlands sampled times plant zones sampled/wetland). Rare taxa comprising <1% catch for any habitat or wetland were eliminated from subsequent analyses, leaving a total of 41 taxa to compare at >1% mean relative abundance and 26 taxa to analyze at >5% mean relative abundance. Only two taxa, *Hyalella* (p=0.017) and Sminthuridae (p=0.022), were significantly different among the three treatments at >1%, and *Hyalella* was the only taxon of the 26 taxa that comprised >5% mean relative abundance that was significantly different among the three treatments. Since this is fewer taxa than would be expected to be significant by chance alone at the significance level used, we conclude that there were no detectable differences among treatments. Nevertheless, we examine the taxa that were different below in more detail.

A multiple pairwise comparison revealed that the relative abundance of Sminthuridae was statistically different when comparing reference and most recently mowed wetlands (p=0.013). A higher relative abundance of this taxa was found in the most recently mowed wetlands (overall mean=1.37%). Specific sites, such as Pt. Au Gres Park *Eleocharis*/swale and Surfwood *Eleocharis/Scirpus* had the greatest numbers of this taxon in the most recently mowed wetland zones (3.97% and 11.59% respectively) (Figure 34). Both sites included very shallow water that may have been inundated only at high points in the seiche cycle of Saginaw Bay. Water level can vary by as much as 20 cm throughout the seiche cycle based on our previous observations.

The family Sminthuridae (common name: springtails), typically feed by shredding or collecting and gathering dead plant material and microflora. They are semi-aquatic and are typically found along margins of aquatic systems on surface film (Merritt and Cummins 1996, references within). According to property owners, the most recently mowed wetlands were usually dry earlier in the season, when the mowing was generally conducted. Our reference and less recently mowed wetlands included some that may not have been dry earlier in the season (water level was higher in 2004 than it had been in 2003 when some of the less recently mowed wetlands were mowed). Thus, differences in springtails among treatments may reflect a greater likelihood that more recently mowed sites had been inundated for less time on average than had the wetlands included in the reference and less recently mowed treatments.

The other taxon that differed significantly among the three wetland treatments was *Hyallela* (scud or side-swimmer). Its mean relative abundance was significantly different between most recently mowed and less recently mowed wetlands (p=0.006), but not between wetlands in either mowing treatment and reference wetlands. Mean relative abundance of *Hyallela* was greatest in the most recently mowed wetlands (overall mean=13.54%), intermediate in reference wetlands (6.64 %), and lowest in less recently mowed wetlands (1.63 %). This crustacean is common in aquatic systems and tends to occur in relatively high densities where aquatic vegetation is present (DeMarch 1981). *Hyallela* is usually classified as a general detritivore, but collects food primarily by gathering plant and animal debris, especially diatoms and bacteria according to Hargrave (1970), and is an important food source for a variety of fish species. The lack of significant difference between less recently mowed and reference wetlands may be due to the *Hyallela* population recovering from mowing quickly after plants begin to grow back in the mowed area. However, there was also a lack of statistical difference between most recently mowed (overall mean=1.63%) and reference wetlands (overall mean=6.64%). This lack of statistical difference may be due to the large standard error associated with the mean relative abundance of *Hyallela* in reference wetlands (6.64±2.68). The most recently mowed site, Port Austin Rd- wave exposed *Scirpus,* exhibited a mean relative abundance of 9.61% and was an outlier in the most recently mowed data set. This habitat may have been misclassified as most recently mowed, since it was in an area that was inundated by about 30 cm of water, perhaps suggesting that it might not have been mowed as recently as other habitats in this category.

The paucity of statistically significant differences among treatments for other invertebrate taxa may be due to functional habitat group affiliation. Invertebrates with morpho-behavioral adaptations for utilizing vegetation, such as snails, which cling to vegetation, may not have been significantly affected by the mowing treatments. Attachment sites and stable vegetation was still available for taxa in these habitat groups during 2004 even in recently mowed sites. However, repeatedly mowing (for multiple years) could potentially lead to a build up of detritus and cause a shift in invertebrate community composition. Repeated mowing could also lead to the demise of perennial emergent vegetation with a resultant shift in invertebrate communities. Therefore, since our experimental design only compares invertebrate communities in wetlands mowed within the last year to reference wetlands, we do not view our limited findings as conclusive on the effects of longer-term mowing practices.

Effects of Raking on Invertebrates in 2005: A total of 4,730 invertebrates were collected from 7 open water reference zones, while only 118 invertebrates were collected from 5 open water raked zones along Saginaw Bay. The average number of individuals collected per zone was significantly greater (p=0.028) from open water reference zones (677.0±499.73) compared to the mean number collected per zone from open water raked zones (23.6±9.24). Thus, invertebrate densities in reference areas were 28.7 times greater than were invertebrate densities in raked zones. Dunn Road (total abundance=3,665) contributed to the large standard error for the open water reference zones. Even if we were to treat this site as an outlier and remove it from analysis, however, total invertebrate density would still be significantly different (p=0.044) between open water reference (179.0±45.56) and raked (23.6±9.24) zones with 7.6 times more invertebrates collected per zone from the reference areas than were collected from the raked areas. Even though mean Shannon diversity (H') differed substantially between open water reference zones (1.59±0.13) and open water raked zones (0.83±0.36), these differences were not quite significant (p=0.104)(Table 4). Mean species richness for reference zones (9.5±1.1), however, was significantly greater (p=0.023) than it was in raked zones (3.60±1.30) (Table 4).

The invertebrate community between open water reference and raked zones was compared (Figures 35-38) by analyzing taxa comprising >1% and >5% mean relative abundance. Rare taxa were eliminated from analysis, leaving a total of 37 taxa compared at >1% mean relative abundance and 19 taxa analyzed at >5% mean relative abundance. One taxon, *Oecetis* (Trichoptera) was significantly different between the zones at >1% (p=0.030). *Oecetis* had a mean relative abundance of 3.49±1.20 in open water reference versus 0.00±0.00 in open water raked wetlands.

Comparison of outer Scirpus versus open water wetland zones in 2005: Based on observations of reference areas, it seems likely that open beaches maintained by raking, tilling, and pulling of vegetation originally supported wetland plants. This is consistent with results reported by D. Albert for effects of beach grooming on plant communities in his companion report for this project. Thus, we decided to compare unraked, open reference areas with reference areas that had an outer *Scirpus* plant zone still intact. Any differences between these two reference zone habitats would imply that differences documented between raked and open water reference zones were potentially underestimates of changes that probably resulted from conversion of wetland plant zones to open beach habitat.

A total of 3,771 invertebrates were collected from 7 reference outer *Scirpus* zones compared to 4,730 invertebrates collected from 7 reference open water zones in Saginaw Bay. Total number of individuals (total abundance) collected in outer *Scirpus* and open water zones was not statistically different between zones (p=0.297). The average number of individuals collected per *Scirpus* zone was 538.71±142.10 while the average number of individuals collected in open water zones was 677.0±499.73. An unusually large number of invertebrates (3665) was collected from the Dunn Road open water zone. If we were to treat this data point as an outlier and remove it from the analysis, total number of individuals would be statistically (p=0.031) greater in the outer *Scirpus* (572.83± 151.11) than in the open water zones(179± 45.56) zones.

There was no significant difference (p=0.078) in mean Shannon diversity (H') between the outer *Scirpus* zones (2.01±0.14) and the open water zones (1.59±0.13)(Table4). Mean species richness per catch in the reference outer *Scirpus* zones (17.9±1.0), however, was significantly higher (p=0.031) than in the open water zones (9.5±1.1) (Table 4).

Correspondence analysis (CA) was used as an exploratory technique to determine if aquatic invertebrate community composition in outer *Scirpus* and open water wetland zones differed (e.g., did they plot separately in an ordination plot?). Correspondence analysis explained 25.36% of total variance in the species data in the first dimension and 18.41% of variance in the second dimension (Figure 39). There was a slight separation of the outer *Scirpus* and open water zones (Figure 39). Taxa most responsible for pulling outer *Scirpus* zones away from open water zones included a number of Mollusca (snails primarily) and Amphipoda taxa. Taxa most responsible for separating open water zones from the outer *Scirpus* zones included several Dipteran taxa (Figure 39).

The invertebrate community was compared between outer *Scirpus* and open water zones by analyzing taxa comprising >1% and >5% mean relative abundance (Figures 40-44). Rare taxa (<1 % of total catch) were eliminated from the analysis, leaving a total of 47 taxa compared at >1% mean relative abundance and 19 taxa analyzed at >5% mean relative abundance. Only one taxon, Chironomini, was significantly different between the zones at >1% and 5% (p=0.0001), while the snail, *Stagnicola* (p=0.090) and the amphipod, *Hyallela* (p=0.078) were only marginally significant between the zones. Chironomini was found in greatest abundance in open water zones (25.6±5.4) compared to outer *Scirpus* (2.9±0.7) zones. *Stagnicola* had a mean relative abundance of 14.5 ±4.9 in outer *Scirpus* versus 3.0±1.4 in open water. *Hyallela* had a mean relative abundance of 23.2±4.1 in outer *Scirpus* zones and 6.4±1.5 in open water zones.

Since some differences in macroinvertebrate community composition were found between open water reference and outer *Scirpus* zones, we hypothesize that differences between open water raked and *Scirpus* zones would be greater than the differences that we report between raked and unraked open water habitats. Since we hypothesize that many of the maintained open beach areas would support emergent macrophytes in the absence of maintenance, a comparison of open water raked habitats to vegetated habitats seems warranted. These comparisons represent an area of necessary future research. Furthermore, if maintained open beaches once supported emergent macrophyte communities, as we believe they did, comparisons of vegetation zones immediately adjacent to the shoreline (i.e. wet meadow zones) to maintained open water habitats would potentially reveal great differences in community composition resulting from the maintenance activity. Inner, more shoreward vegetation zones have been shown to support a much different invertebrate community than outer Scirpus zones (Burton et al. 2002 and 2004), and we hypothesize that they are also much different from the open, raked beach habitats based on our community analyses for this project and our past research on coastal wetlands of Saginaw Bay.

Effects of Grooming on Juvenile and Mature Fish: Separate correspondence analyses were performed on Saginaw Bay and Grand Traverse Bay data. Twenty-five fish taxa were collected from 16 sites on Saginaw Bay and 14 were collected from seven sites on Grand Traverse Bay. Data were not transformed prior to correspondence analysis.

Saginaw Bay sites and grooming activity at each site are listed in Table 5. Correspondence analysis revealed a dichotomy between Bayport Ref. and the other Saginaw Bay sites in the first dimension (Figure 45). This dichotomy resulted from collecting a large school of gizzard shad at Bayport Ref. and nowhere else. The second most variation was represented in dimension 2 (Figure 45) and reflected variation in fish community composition due to maintenance activities. In this dimension, a gradient of fish communities between reference and impacted sites was apparent. The taxa found more often and in higher densities at reference sites are listed in Table 6.

Sites included in the analysis of the Grand Traverse Bay data are included in Table 7. Correspondence analysis of the fish data collected from Grand Traverse Bay appears distorted since only two fish were collected at one of the sites (Figure 46). Accordingly, this site appears to overwhelm the variation in both dimensions. However, the first dimension is better represented by maintenance activities and its ordination is very similar to that of Saginaw Bay with distinct differences between reference and maintained sites. In dimension 1, reference sites were plotted on the right side of the axis, whereas maintained sites were plotted on the left. The Acme township park groomed site was plotted among the reference sites most likely because inundated vegetation was present at this site. The most important characteristic setting the Acme township park groomed site apart from the other groomed site was its lack of sand shiners. The other outlier was the ‘ungroomed’ site at the Waterfront Inn. This was an area adjacent to grooming activity with relatively sparse vegetation compared to the Waterfront Reference site. This site labeled ‘ungroomed’ in Figure 46 had a very similar fish community to the groomed sites. This was likely due to the lack of vegetation found there, making the fish community in this area more characteristic of a “groomed” site. Fish taxa that were more common and found in higher abundance at reference sites, as revealed by the correspondence analysis, are listed in Table 8. Fish taxa that were more common at maintained sites are listed in Table 9.

Comparisons of juvenile and adult fish communities between boat channels and adjacent vegetated reference habitats were made for wetlands of northern Lakes Michigan and Huron. These comparisons were made since grooming activities were not permissible in these regions and boat channel maintenance represents one of the most significant forms of fragmentation in many of the wetlands in this area. Sites included in correspondence analysis are listed in Table 10.

Correspondence analysis revealed no apparent differences in fish communities between boat channels and adjacent vegetated areas in the first 2 dimensions of the ordination (Figure 47). The majority of variation in both dimensions was due to inter-site variability rather than being due to differences in channel versus intact wetland communities. The boat channel fish community only separated from the adjacent intact wetland community for one site. This separation was due to the increased abundance of brown bullheads and blacknose shiners in the intact vegetation compared to their abundance in adjacent boat channels.

The boat channels sampled in the study may have been too narrow to serve as distinct habitats for most fish. Fish are mobile, and many taxa almost certainly had home ranges that include both vegetated and associated boat channel habitat. Even so, fish communities in these fragmented wetlands may have responded to the fragmentation caused by boat channel maintenance. We were able to detect distinct changes in the less mobile larval fish as well as micro and macroinvertebrate communities. However, juvenile and adult fish data were far too variable for us to be able to detect such a response.

Larval fish collected using quatrefoil light traps in 2005: Larval fish data were analyzed by regressing abundances against distance into the wetland fragment (similar to the 2004 chemical and physical analyses). Prior to analysis, data were square root transformed to reduce heteroscedasticity. Taxa were analyzed individually and combined in diversity metrics. Only those taxa collected in 10 or more traps were analyzed.

Several taxa showed distinct relationships with distance into the marsh on either the reference transect or the reference and anthropogenic transect combined. Those taxa included yellow perch, small mouth bass, large mouth bass, banded killifish, johnny darter, and the common carp. No significant relationships were found for the anthropogenic transect alone.

Larval yellow perch abundance increased significantly (p=0.042) from the outer edge of the reference transect to the inner marsh (Figure 48) with maximum density found at 50 m into the marsh. Densities along the anthropogenic transect showed no significant relationship with distance into the marsh. Means were relatively high along the entire transect and variance decreased from the outer edge towards the marsh interior. This pattern in the variance suggested that some of the seven marshes included in the analysis had a relatively large edge effect for larval yellow perch while others did not. The magnitude of the edge effect (distance into the marsh with which larval yellow perch densities were constrained) was likely related to effective fetch (Burton *et al*. 2004). Those wetlands with the potential for relatively large storm surges to penetrate to shore via the unvegetated area would likely exhibit the most extensive edge effect into the intact marsh. Those wetlands that are more protected from waves and storm surges likely exhibited the least extensive edge effects.

Larval smallmouth bass showed no significant linear relationship with distance into the marsh from either the reference or anthropogenic edges (Figure 49). However, visual inspection of Figure 49 suggests an increase in numbers into the marsh along the reference transect with a threshold located at 30 m from open water. This is likely why a liner regression was not significant. The anthropogenic transects reflected consistently low numbers with little variability among the four marshes included in the analysis. This consistency suggests a relatively large edge effect in these systems with respect to larval small mouth bass.

Larval largemouth bass (Figure 50) increased significantly along the reference transect (p = 0.031). The same general slope was revealed along the anthropogenic transect as well, but variability was higher among data included in this analysis (p = 0.042). The major difference between the two relationships was higher variability on the outer anthropogenic edge. Again, this variability is likely due to more open wetlands showing a more dramatic response to fragmentation.

Larval banded killifish (Figure 51) also showed a distinct relationship with distance into the marshes, with numbers increasing from open water towards the marsh interior. This relationship was significant along the reference transects (p = 0.034), but was not significant along the anthropogenic transects. Variability among the 12 marshes that contained enough banded killifish to analyze was relatively high on the anthropogenic edges suggesting, again, that the degree of hydrologic mixing controls the magnitude of the edge effect caused by vegetation removal.

Taxa that prefer sandy habitat devoid of vegetation, such as larval Johnny darters (Figure 52), decreased with distance into the marsh. Statistical significance of these relationships was marginal (p

= 0.086 and 0.070 for reference and anthropogenic transects respectively). Variability was greatest at the outermost edge of both transects. Variability in the amount of submersed vegetation and/or hydrologic mixing on the outer edges may have been responsible for the high variability in darter abundances among the 4 marshes included in the analysis.

Larval common carp abundances along reference transects increased with distance into the marsh. This relationship was significant ($p = 0.001$) (Figure 53). Again, high variability on the open water end of the anthropogenic transects resulted in an insignificant relationship between distance and carp abundances for these transects.

Overall, larval fish communities appeared to be impacted by wetland fragmentation to spatial extents much greater than the immediate areas of vegetation removal. The spatial extent and degree of edge effects on larval fish communities appears to be determined by the susceptibility of a wetland to wind and wave energy. Wind and wave energy are dampened by intact plant communities with pelagic water only being able to penetrate 50-200 m into the wetland with distance of penetration dependent on wind, waves, effective fetch, and bathymetry. Channels through the intact vegetation via wetland openings created by for boat access through open water allow pelagic water to penetrate much further into the wetland both directly via the channel and laterally for several meters on each side of the channel. Regardless of the size of edge effects, the locations were vegetation was removed supported a significantly different larval fish community than the marsh interior. Historically, the outer edges of the anthropogenic transects were inner marsh habitats with community composition probably more representative of the inner marsh. However, removal of vegetation created habitats in these areas similar to the outer edge of the reference transects (see results of chemical and physical analyses). Thus, the larval fish communities along the anthropogenic edges were highly variable and resembled communities of the outer reference edges rather than the inner marsh communities that would occurred there if no channel had been created through the wetland. In most cases, this resulted in larval fish abundances that were lower in the outer wetland habitats than in the marsh interior. Of particular interest is the decreased abundance of the important sportfishes (i.e. yellow perch, small mouth and large mouth bass) along the edges of fragmented wetlands.

Microinvertebrates collected using quatrefoil light traps in 2004: During 2004, zooplankton were collected using the quatrefoil light traps that were also used for collecting larval fish. More that 2,700,000 individuals were collected. Subsamples were identified to the family level. Eleven families were identified and analyzed using multivariate statistics (correspondence analysis) to represent the overall variability in the dataset. Results of correspondence analysis were used to determine the major environmental factors structuring community composition. Data from sites located in Saginaw Bay, Grand Traverse Bay, and Northern Lakes Michigan and Huron with fragmentation occurring from either grooming activities or boat channels were included in the analyses. Results of the analyses revealed that the region (Saginaw Bay, Grand Traverse Bay, northern Lakes Michigan and Huron) was the best predictor of community composition and was represented as a gradient in CA dimension 1 (Figure 54). Dimension 2 represented the variability that was of particular interest to our study. This dimension separated traps set in protected locations of the inner marsh from those subjected to the influences of wind and waves (the outer edges).

Dimension scores from the correspondence analysis were also tested for relationships with chemical and physical data. Dissolved oxygen concentration was the single most important variable for ordination of sites in dimension 2 (Pearson correlation: $r = 0.505$; $p < 0.001$) (Figure 55). Dissolved oxygen concentrations reflected pelagic water intrusion into the marsh. This is evident when the points in the relationship are coded based on whether the trap was located on a reference transect, an anthropogenic transect, or the corner point where the two intersect (Figure 55). The majority of the anthropogenic transect traps are plotted on the left side of the figure with some of the inner most reference transect traps plotted among these. The majority of the reference transect traps are plotted on the right side of the figure with the outer-most anthropogenic transect traps mixed in with those points. This predictable overlap in traps based on location along either the reference or anthropogenic transects in relation to the amount of aeration of the water suggests a distinct shift in zooplankton community composition resulting from the removal of vegetation allowing intrusion of pelagic water coupled with aeration due to breaking waves.

Macroinvertebrates collected using quatrefoil light traps in 2004: Macroinvertebrates were collected from fragmented wetlands in Saginaw Bay, Grand Traverse Bay, and northern Lakes Michigan and Huron using the quatrefoil light traps that were also used for collecting larval fish and microinvertebrates. More that 56,000 individuals representing 37 families were collected. Correspondence analysis was performed on the macroinvertebrate data to determine the major factors structuring community composition. Anthropogenic disturbances associated with these sites included grooming activities and boat channel maintenance.

Correspondence analysis revealed that the greatest amount of variation in the dataset was a dichotomy between northern Lake Michigan and Huron sites vs. Saginaw and Grand Traverse Bay sites. This dichotomy was most likely due to regional water quality difference coupled with differences in optimal latitudinal ranges for some taxa. Dimension 2 represented the most variation of interest to our study. This dimension separated traps set in protected locations of the inner marsh with silt substrates, from those subjected to influences of wind and waves having sandy or hard substrates (Figure 56). This global analysis did not partition sites into discrete categories based on distance into a wetland fragment. The most likely explanation for this is because inter-site variability in hydrology (protection from wind and wave energy) and/or the susceptibility of a site to pronounced edge effects, due to the extent of vegetation removal, seemed to overwhelm the variability related to distance into a wetland. Therefore, community structure was best explained by substrate type, and substrate type was influenced by whether or not vegetation was removed, as well as by the underlying bathymetry and geology at each site.

To remove the among-site variability due to ecoregion and substrate, analyses were conducted on each site individually. Each of these analyses revealed 1 gradient that was best explained by distance into a wetland fragment (on either anthropogenic or reference transects) and another gradient that represented a dichotomy between the anthropogenic and reference transects (Figures 57 and 58).

These analyses show a distinct impact on invertebrate community composition, not only where vegetation was removed, but also well into the adjacent, intact vegetation. In some cases, a community shift was detected from the anthropogenic edge of emergent vegetation to 50 m into a wetland fragment. Therefore, removal of vegetation, either by mowing, tilling, or boat channel maintenance, appears to cause a shift in invertebrate community composition that reaches well into wetland fragments.

Summary and Conclusions

Chemical and Physical Measurements:

Comparison of water quality parameters among mowing treatments in 2004: Mowing, either recently or after approximately one year, had relatively little impact on chemical and physical parameters. However, some differences may have been masked by variability among sites. Those sites that were most recently mowed did show differences in specific conductance, alkalinity, and chloride. These differences may have reflected tendency for the recently mowed wetlands to be adjacent to development.

Comparison of water quality parameters between open water reference and raked wetlands: When grab samples were collected from the centers of ‘beach’ areas where vegetation had been cleared, chemical and physical parameters fell within the ranges of vegetated reference areas, but some differences were apparent. Specifically, the greatest differences were found in dissolved oxygen and temperature, likely from the intrusion of pelagic water at the open sites, and depth likely from excess erosion where vegetation was lacking. Removal of vegetation disrupted the ambient chemical and physical conditions of the wetlands.

Comparison of water quality parameters collected in 2004 between outer edges of reference and outer artificial edges where vegetation was removed: Every parameter that we measured suggested that the artificial edge changed ambient conditions, making these areas more similar chemically and physically to an outer edge environment rather than the inner marsh that it would have been in the absence of the disturbance. The fragmentation of the wetland acted as a conduit for pelagic water to infiltrate the marsh the entire width of the wetland to shore. Intact vegetation would have buffered waves and surface drift and created a relatively stagnant water column with ambient conditions more similar to groundwater close to shore. Vegetation removal eliminated the very important gradient of ambient conditions that structures biotic communities and maintains a range of wetland functions.

Regression analysis of water quality parameters collected in 2004 along reference and anthropogenic transects from open water to the marsh interior. Our research clearly established the relationship between chemical and physical conditions and biotic communities (Uzarski et al. (in press); Uzarski et al. 2004; Burton et al. 2004; Burton et al. 2002; Burton et al. 1999). Analyses of chemical and physical data presented in this report show that vegetation removal clearly altered ambient conditions. This alteration was not only observed in locations where vegetation was removed, but also into adjacent areas where vegetation remained intact. These alterations in ambient conditions translate into an altered biotic community composition in cleared areas as well as into adjacent, seemingly unaltered, areas via an edge effect.

Effects of Mowing or Raking on Macroinvertebrates: To our knowledge, no other studies of effects of mowing or raking on invertebrates have been done on Great Lakes coastal wetlands. A few studies conducted elsewhere have documented limited effects of short-term mowing on invertebrate communities. These include studies of effects of mowing on invertebrate colonization of salt grass in Suisun Marsh in California (de Szalay and Resh 1197, 2000) and cattail wetlands in Kansas (Kostecke et al. 2005). These studies were in systems very different from Great Lakes wetlands. Even so, the impacts they documented were limited in scope to a few taxa and agreed with our results in finding limited overall impacts of short term mowing on invertebrate communities. While our data do not cover long term effects of continued mowing on invertebrates, it seems likely based on the findings of D. Albert, in his companion report, that continued mowing would result in conversion of wetlands to open beach areas. Based on our field observations and conversations with local citizens, past beach grooming activities have converted many areas of Great Lakes coast line from wetlands to open beaches. Despite this, few data on the effects of such conversion exist. Our results document major impacts of conversion on invertebrate density and species richness. Since invertebrates are relied upon as a food resource by numerous fishes, amphibians, reptiles, and waterfowl, such decreases could have long-term, negative effects on fish and wildlife uses of the Great Lakes.

Effects of Mowing on Invertebrates: Only two taxa were significantly different among reference, less recently mowed, and most recently mowed wetlands (of two sets of analyses with 41 and 26 tested respectively). More differences would have been expected by chance alone at α=0.05. The two taxa that did differ significantly (Kruskil-Wallis) among treatments did not differ consistently between reference wetlands and the two mowing treatments. This coupled with the lack of any separation that correlated with mowing treatment in correspondence analyses strongly supports the conclusion that no consistent effect of mowing on invertebrate community composition was detected.

Effects of Raking on Macroinvertebrates The effects of raking and conversion of wetlands to open beach areas on the macroinvertebrates included: (1) an 8 to 29 fold significant decrease in the number of invertebrates present, (2) a significant, nearly 3 fold decrease in taxa richness (number of "species" present), and (3) a marginally significant (p=0.11) decrease in Shannon diversity from 1.59 to 0.83. Few differences in community composition between raked and open reference areas were detected, but this may reflect the low numbers collected from the raked sites coupled with high variance in the data.

Juvenile and Mature Fish: There was a clear difference in fish communities between reference sites and beach maintenance activities at both Saginaw and Grand Traverse Bays. Reference sites at both locations tended to have higher fish diversity and greater number of certain taxa. Boat channels located in Northern Lakes Michigan and Huron did not have detectably different fish communities from the adjacent intact vegetation. The channels sampled were likely too small to detect great changes in fish community composition since fish are extremely mobile. The fish found in the channel can be considered to be associated with vegetation since the channels themselves are only approximately 10 m across. The communities may actually be responding to this impact, but our power to detect the change is quite small since juvenile and adult fish data are often extremely variable.

Larval fish collected using quatrefoil light traps: Overall, larval fish communities were certainly impacted by wetland fragmentation. The magnitude of this impact translated into the adjacent intact vegetation was most likely determined by the potential for wind and waves advecting pelagic water laterally into the intact vegetation from the wetland opening. The magnitude of the edge effect is likely quite dynamic and dependent on wind and barometric pressures. Regardless of the size of the edge effect, the location where the vegetation was removed drastically changes larval fish composition. While these areas were once inner marsh areas similar to the point where the reference and anthropogenic transects meet, removal of the vegetation created a habitat similar to the outer edge of the reference transect the entire width of the marsh all the way to shore.

Microinvertebrates collected using quatrefoil light traps: Community composition was predictable based on the amount of aeration a trap received. This suggests a distinct shift in zooplankton community composition as a result of the removal of the vegetation allowing for intrusion of pelagic water and the accompanying breaking waves and currents.

Macroinvertebrates collected using quatrefoil light traps: These light trap data show a distinct impact on invertebrate community composition, not only where vegetation was removed, but also into the adjacent, intact vegetation. In many cases, the community shift from the edge effect of the vegetation removal lasted at up to 50 m laterally from the anthropogenic edge.

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McBride of S.O.S for assistance in gaining access to study sites as well as Gary Cooper for assistance constructing quatrefoil light traps.

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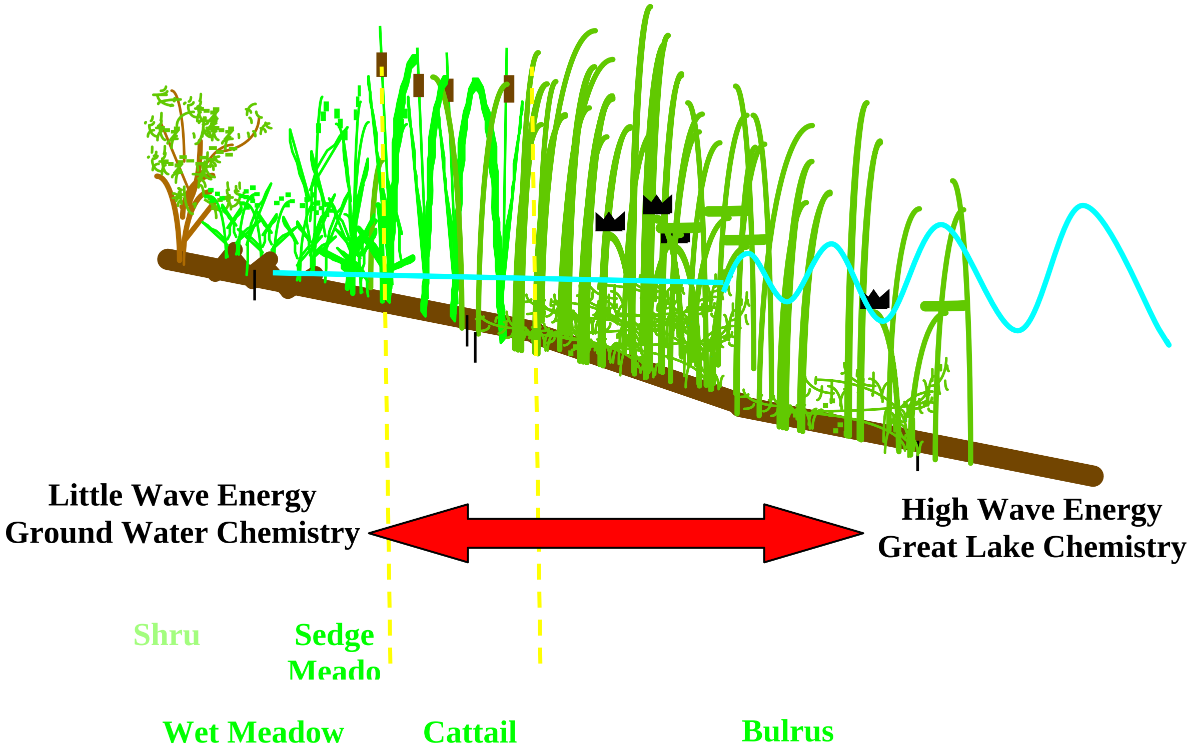


Figure 1. A cross section of a typical Great Lakes fringing marsh. Pelagic water penetrates the outer marsh and subsequently structures the biotic communities of that area. Likewise, groundwater influences the near-shore portion of the marsh shaping that community.

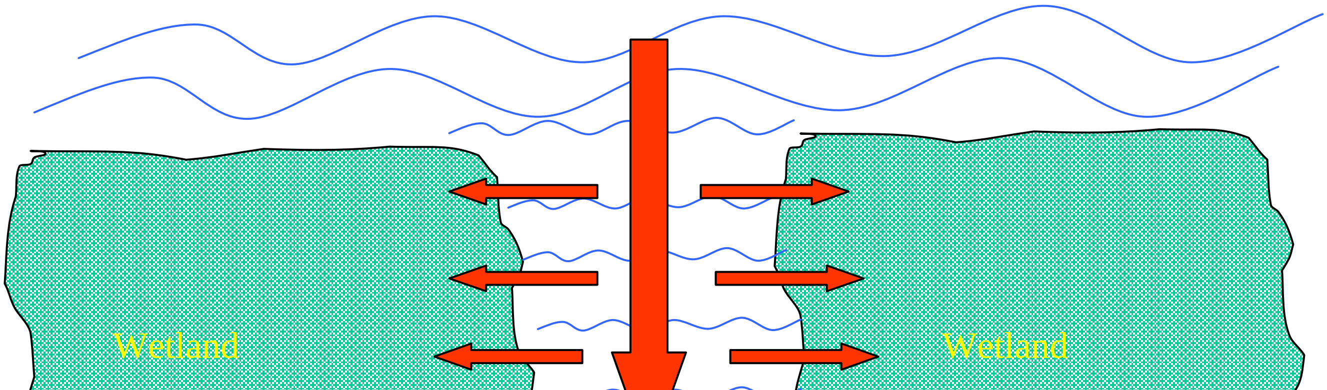


Figure 2. A fragmented Great Lakes fringing marsh. Pelagic water penetrates all the way to shore and sets up artificial chemical/physical gradients parallel to shore.

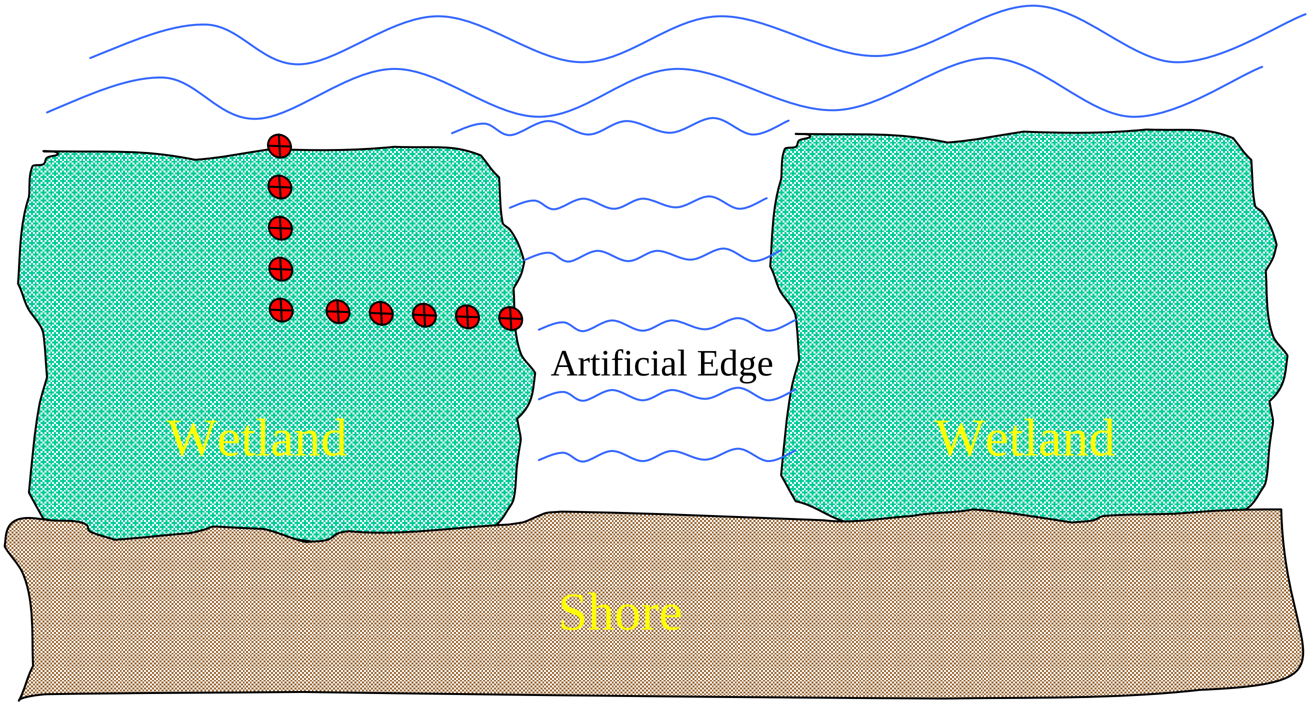


Figure 3. A fragmented Great Lakes fringing marsh showing the location of quatrefoil light traps for sampling larval fish and micro and macroinvertebrates.

Figure 4. Quatrefoil light trap used for sampling larval fish, micro and macroinvertebrates.

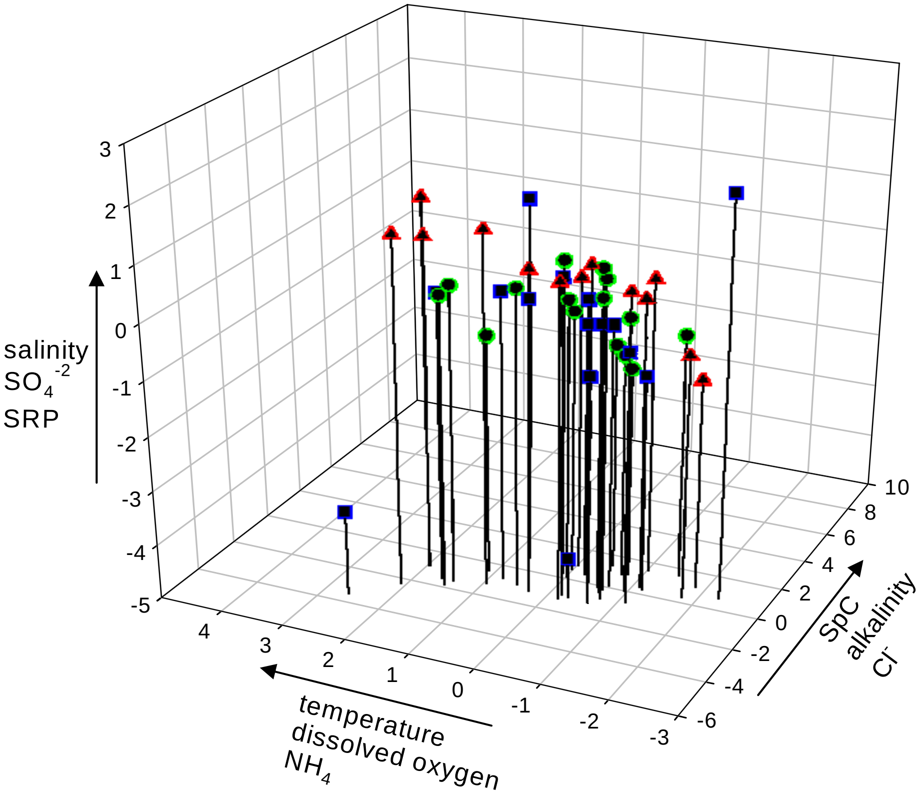
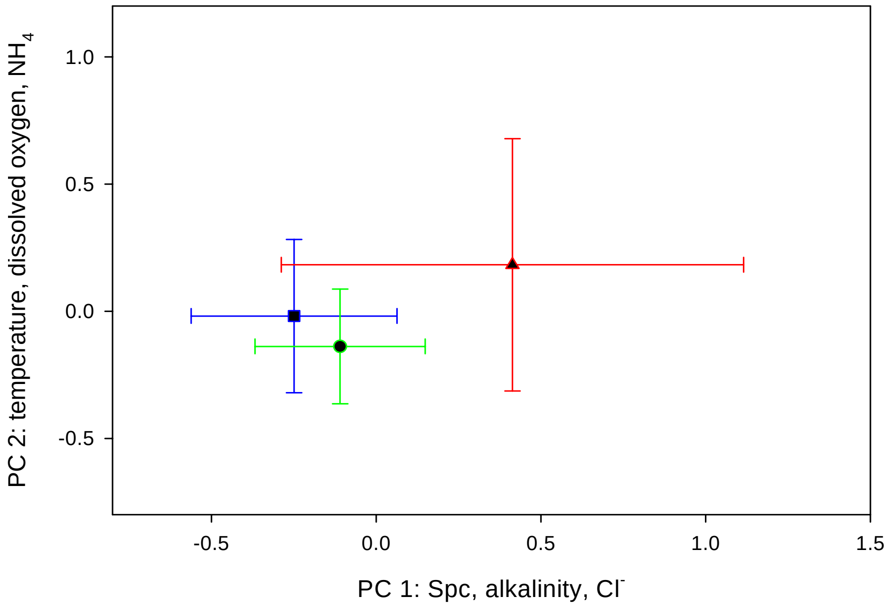


Figure 5. PCA of reference (circle), less recently mowed (square), and most recently mowed (triangle) wetlands in Saginaw Bay and Grand Traverse Bay in 2004. All three principle components explain 53% of the variation in water quality measurements.



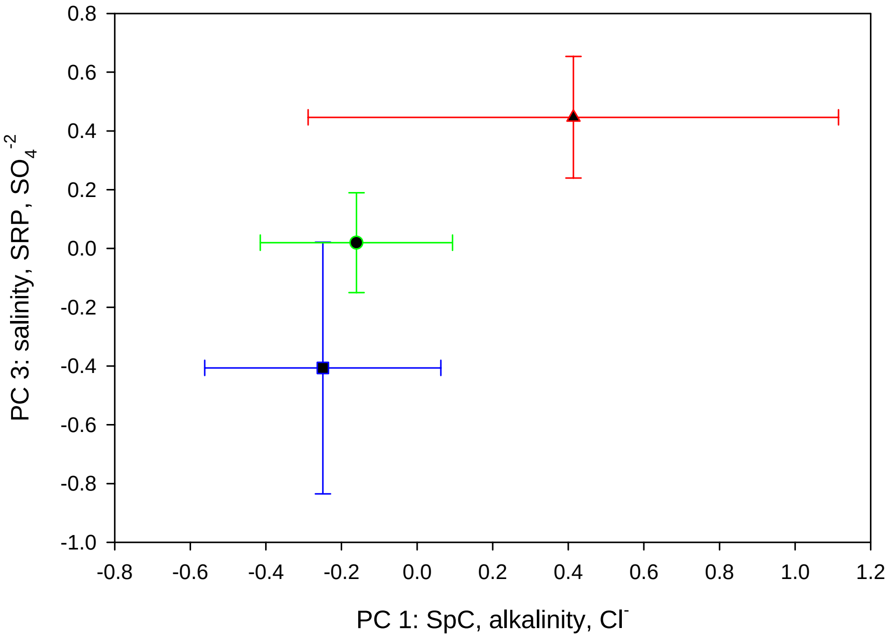
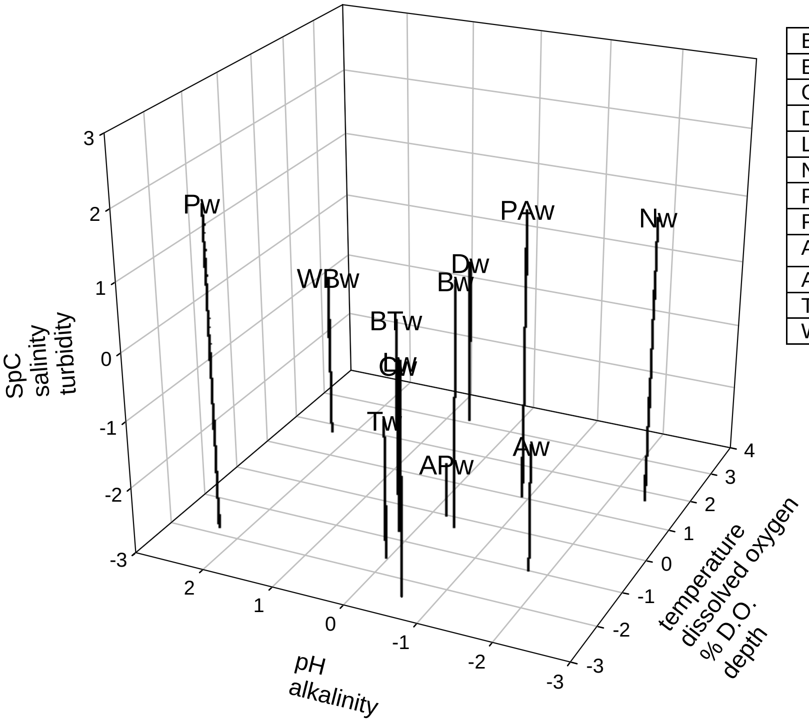


Figure 6. Mean principle component (PC) scores for the first and second PC (+/- S.E.) (top) and first and third PC (+/- S.E.) (bottom) for reference (circle,n=16), less recently mowed (square, n=15), and most recently mowed (triangle,n=13) wetlands sampled along Saginaw Bay and Grand Traverse Bay in 2004.



Bw	Bay Port	reference	open water
BTw	Boutell rd	raked	open water
Cw	Caseville	raked	open water
Dw	Dunn Rd	reference	open water
Lw	Linwood	reference	open water
Nw	Nyanquing	reference	open water
Pw	Pinconning	reference	open water
PAw	Port Austin rd.	raked	open water
Aw	Pt Au Gres	reference	open water
APw	Pt Au Gres Park	raked	open water
Tw	Thompson	raked	open water
WBw	White's Beach	reference	open water

Figure 7. Principle components analysis for chemical/physical data from raked and unraked sites sampled in 2005.

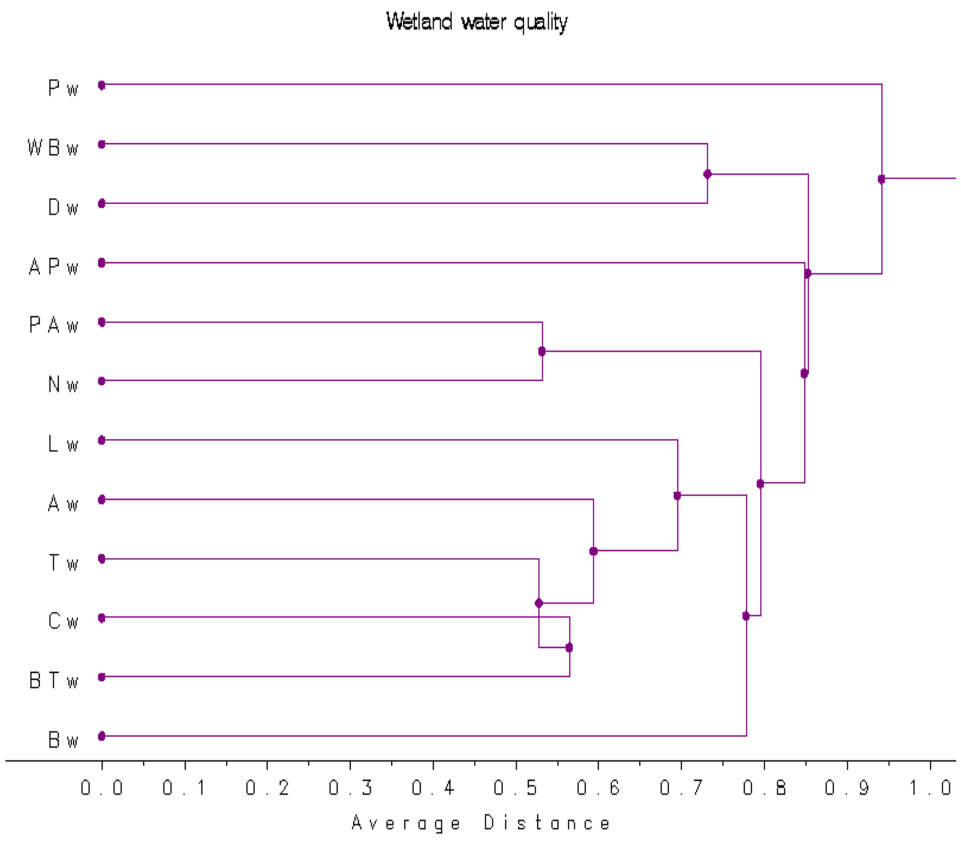


Figure 8. Dendrogram of open water ‘reference’ and open water ‘raked’ sites based on chemical/physical water quality variables. Note: Nutrient measurements were not included in cluster analysis.

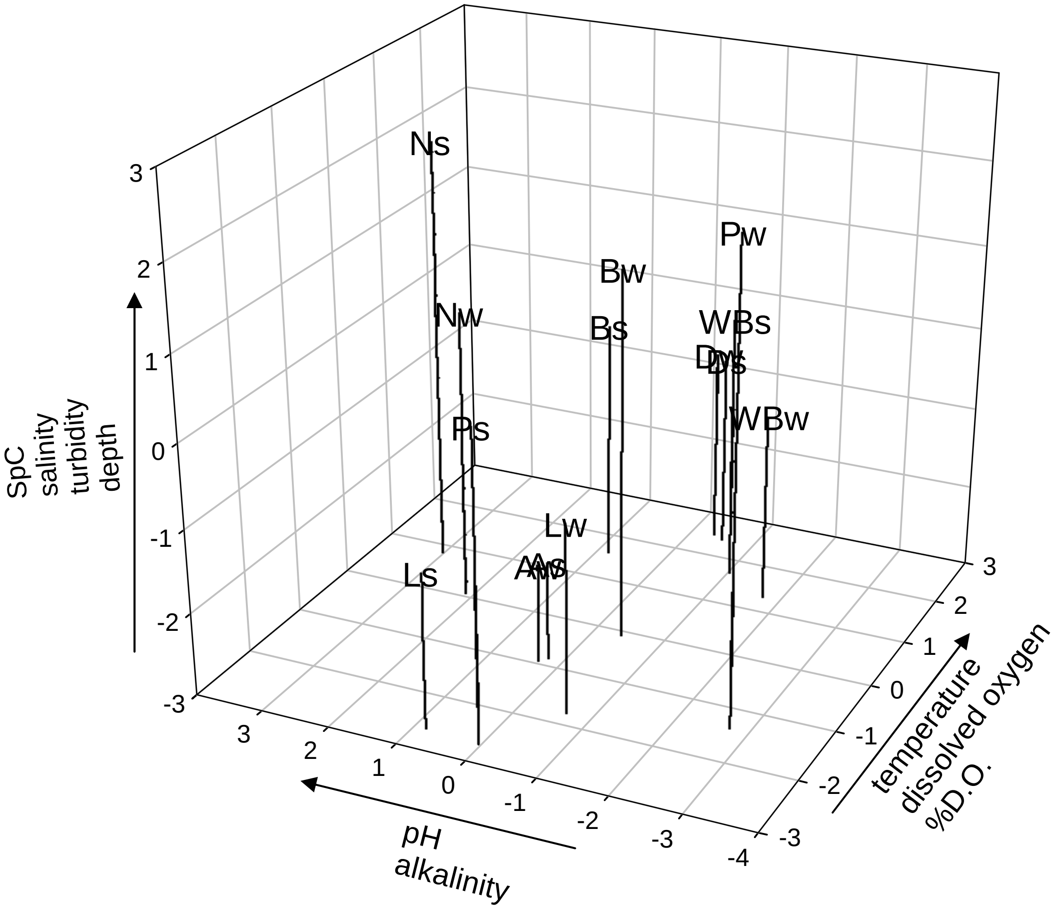


Figure 9. Three dimensional plot of PCA ordination using July 2005 chemical/physical variables from outer *Scirpus* (n=7) and open water (n=7) zones sampled along Saginaw Bay. All three principle components explain 78.7 % of the variation in water quality variables.

Bw	Bay Port	open water
Bs	Bay Port	outer *Scirpus*
Dw	Dunn Rd	open water
Ds	Dunn Rd	outer *Scirpus*
Ls	Linwood	outer *Scirpus*
Lw	Linwood	open water
Nw	Nyanquing	open water
Ns	Nyanquing	outer *Scirpus*
Ps	Pinconning	outer *Scirpus*
Pw	Pinconning	open water
As	Pt Au Gres	outer *Scirpus*
Aw	Pt Au Gres	open water
WBs	White's Beach	outer *Scirpus*
WBw	White's Beach	open water

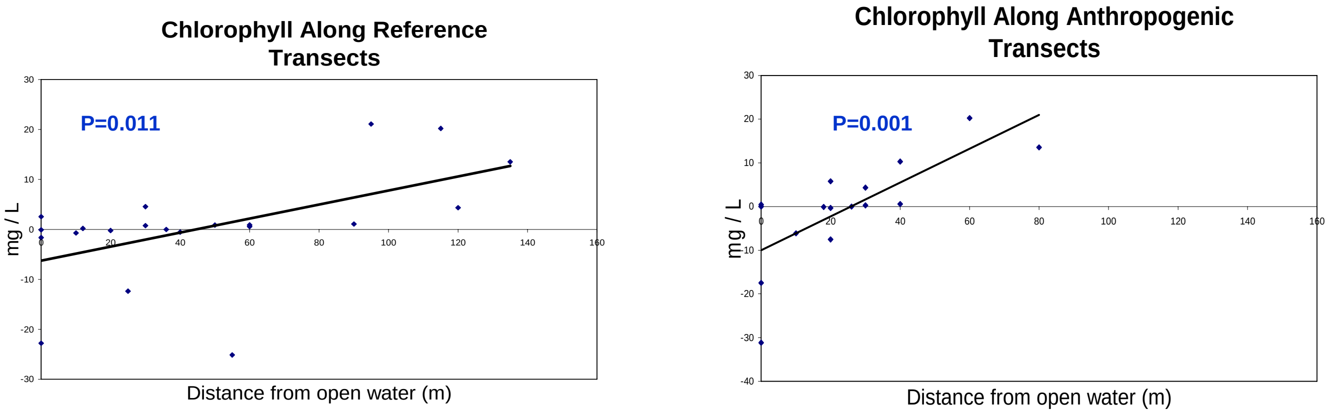


Figure 11. Relationship between chlorophyll concentration and distance into marshe fragments along anthropogenic and reference transects for wetlands sampled in 2004.

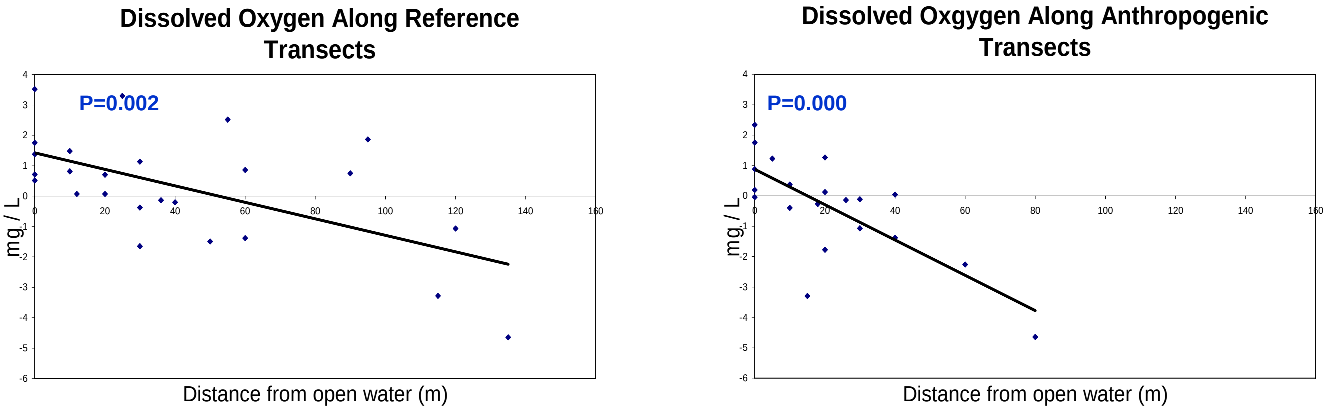


Figure 13. Relationship between dissolved oxygen concentration and distance into marsh fragments along anthropogenic and reference transects for wetlands sampled in 2004.

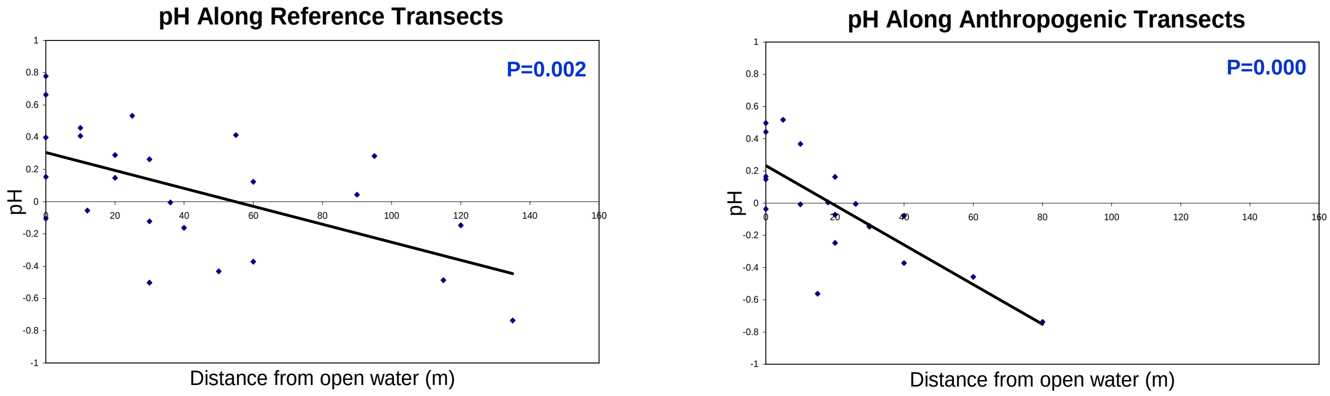


Figure 14. Relationship between pH and distance into marsh fragments along anthropogenic and reference transects for wetlands sampled in 2004.

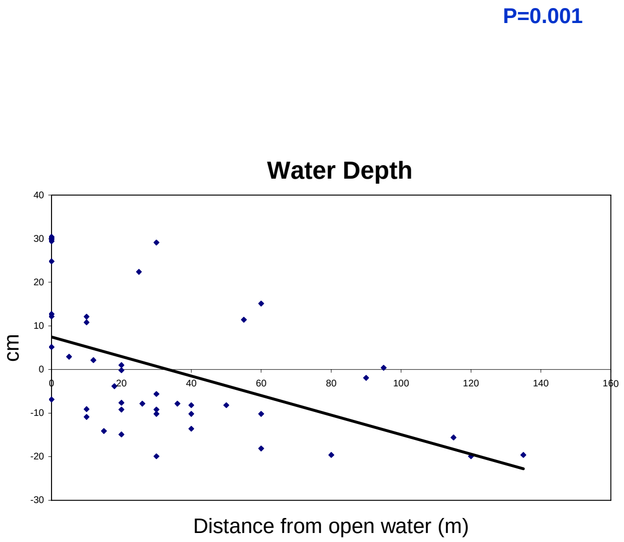


Figure 15. Relationship between depth and distance into marsh fragments along anthropogenic and reference transects (pooled) for wetlands sampled in 2004.

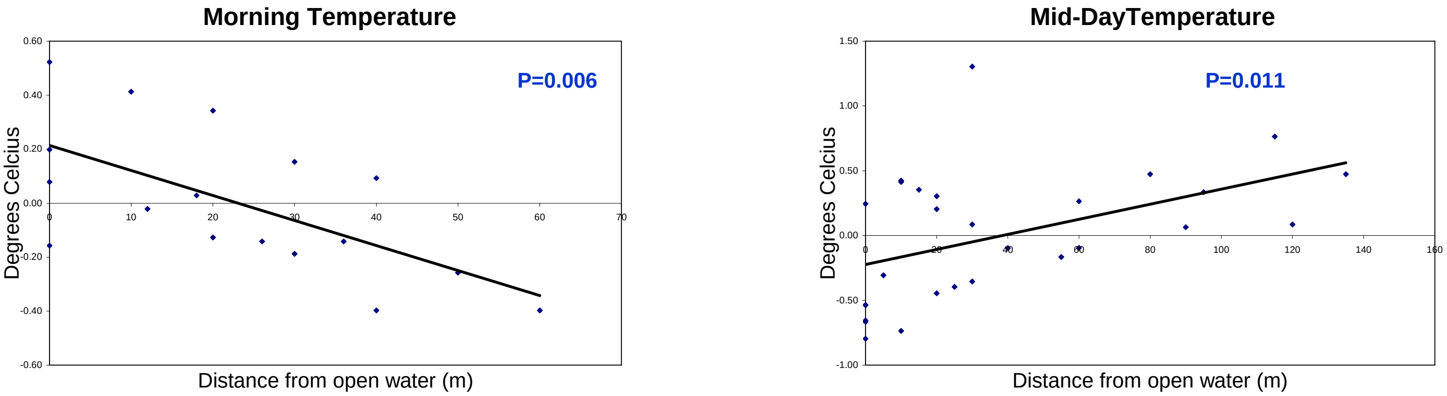


Figure 16. All reference and anthropogenic transect pairs sampled during morning had negative relationships with distance into a marsh, while all transect pairs sampled during mid-day had positive relationships with distance. Data were standardized prior to regression analysis to reduce variation among marshes.

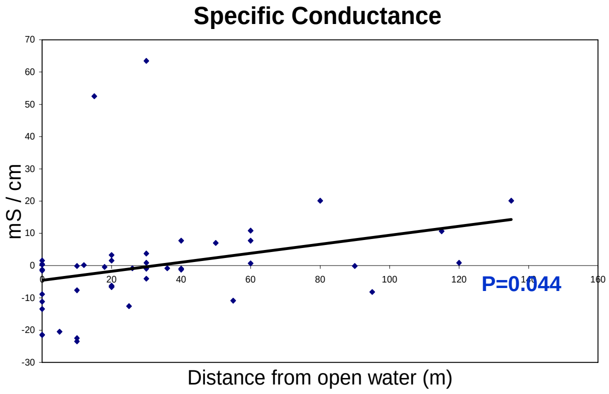


Figure 17. Relationship between specific conductance and distance into marsh fragments along anthropogenic and reference transects (pooled) for wetlands sampled in 2004.

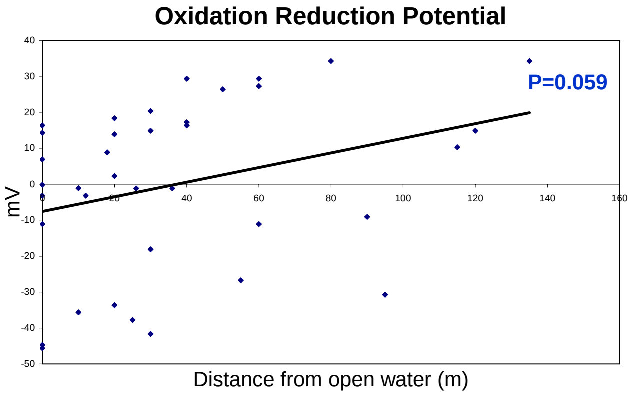


Figure 18. Relationship between oxidation reduction potential and distance into marsh fragments along anthropogenic and reference transects (pooled) for wetlands sampled in 2004.

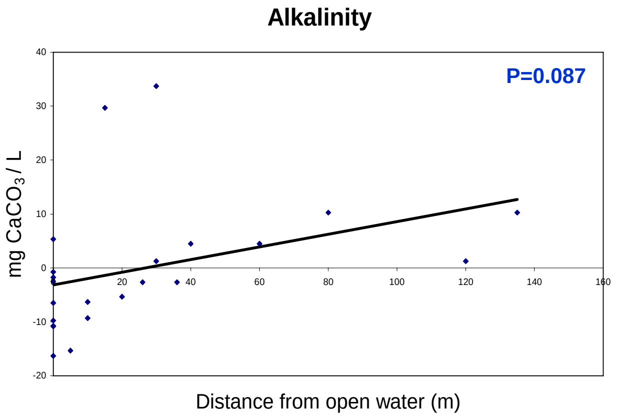


Figure 19. Relationship between alkalinity and distance into marsh fragments along anthropogenic and reference transects (pooled) for wetlands sampled in 2004.

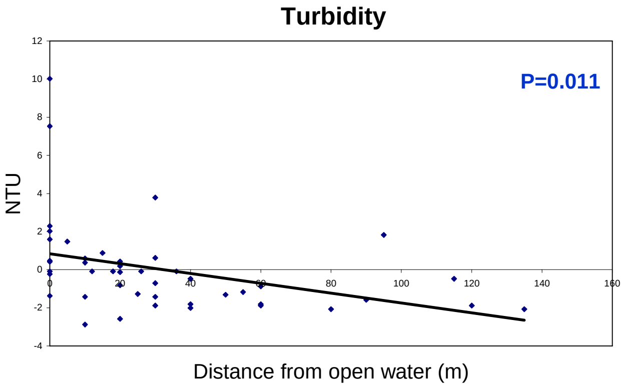


Figure 20. Relationship between turbidity and distance into marsh fragments along anthropogenic and reference transects (pooled) for wetlands sampled in 2004.

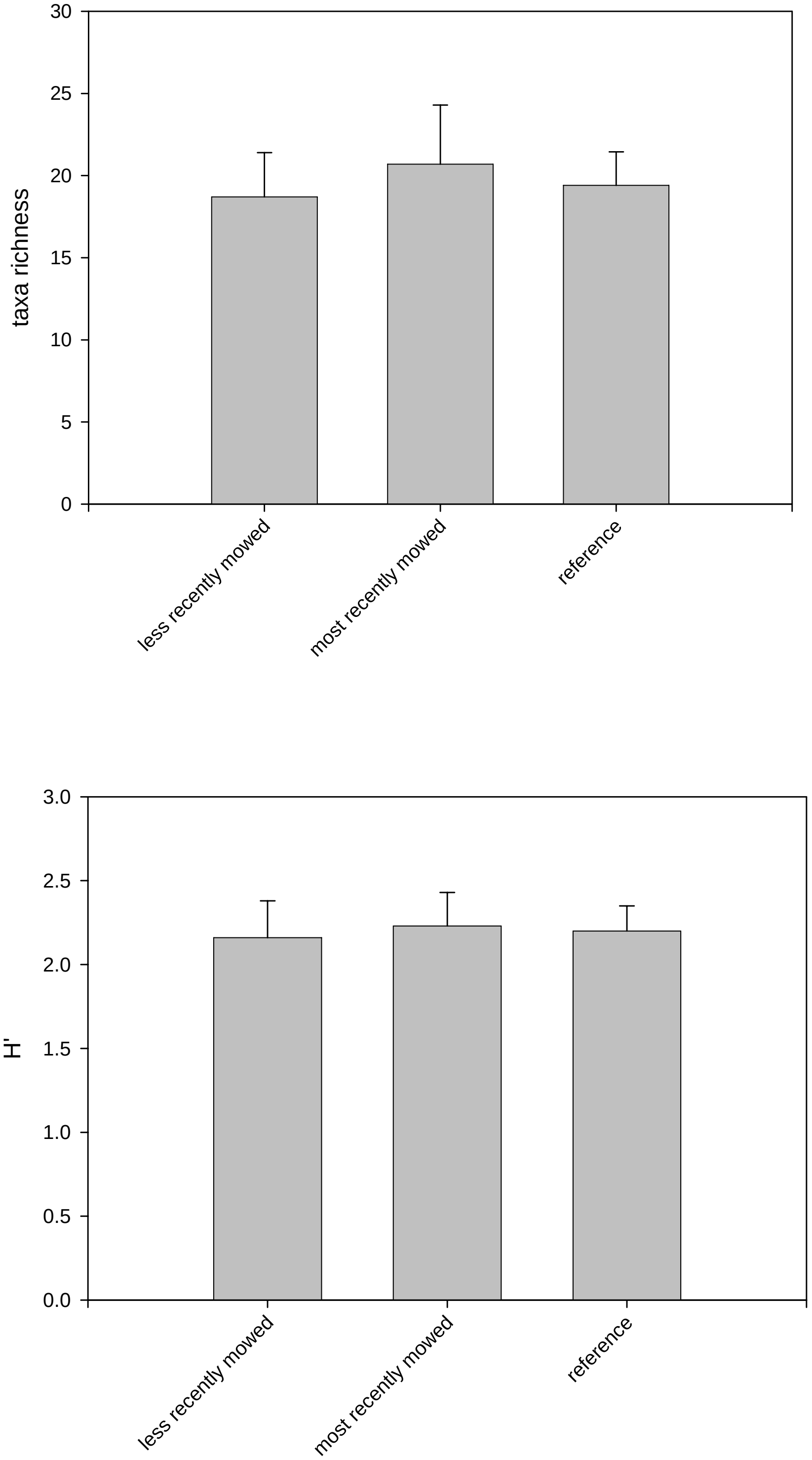
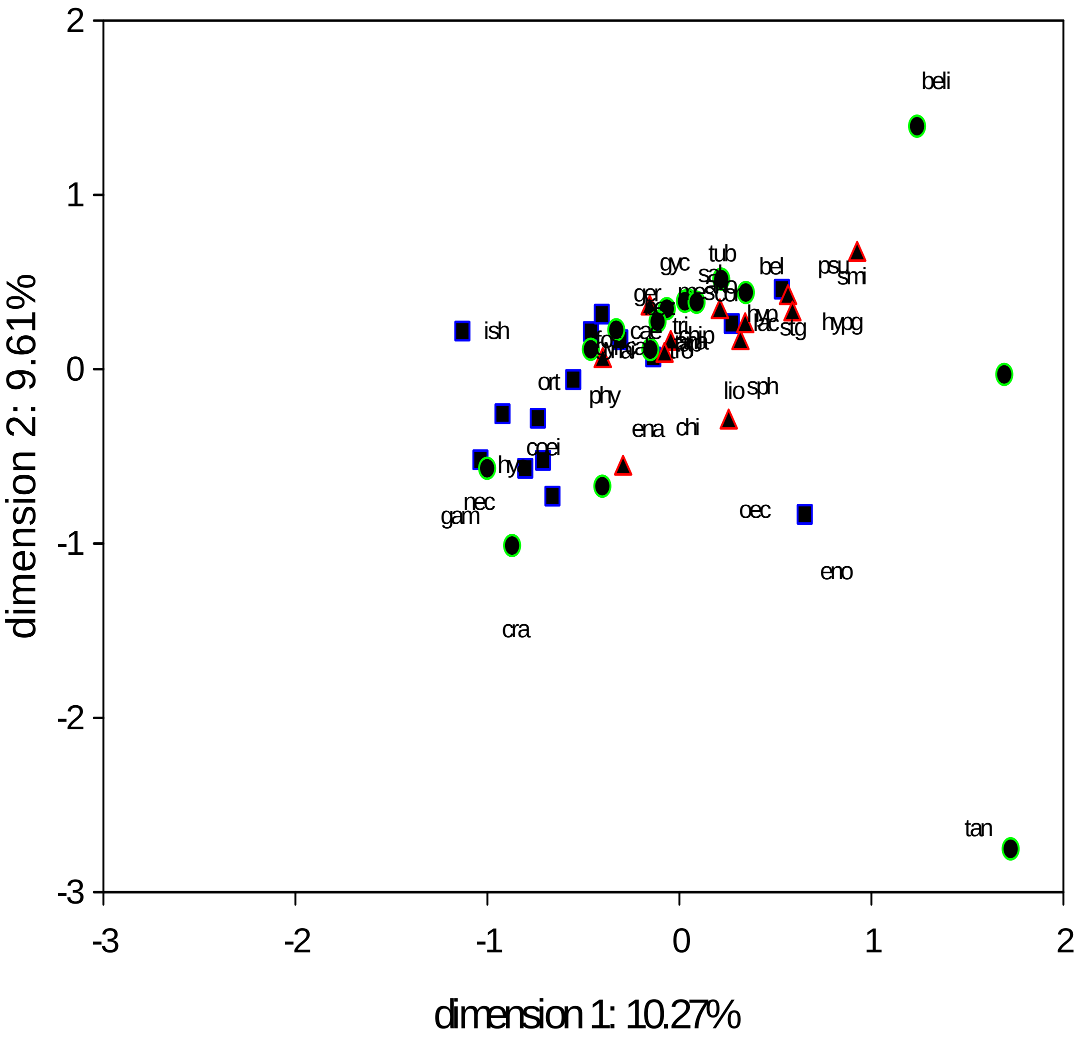


Figure 21. Invertebrate taxa richness (top) and Shannon diversity (H') (bottom) of less recently mowed (n=15), most recently mowed (n=13), and reference (n=16) sites located along Saginaw Bay and Grand Traverse Bay. Statistical analysis revealed no significant difference ($p<0.05$) among the three treatments based on taxa richness ($p=0.4407$) and Shannon diversity ($p=0.6510$).



sty	*Stylaria*
nai	Naididae
tub	Tubificidae
sph	Sphaeriidae
fos	*Fossaria obrussa*
psu	*Pseudosuccinea columella*
stg	*Stagnicola elodes*
phy	*Physa gyrina*
gyc	*Gyraulus circumstriatus*
gyr	*Gyraulus sp.*
hya	*Hyalella azteca*
gam	*Gammarus*
cra	*Crangonyx*
smi	Sminthuridae unknown
cal	*Callibaetis*
cae	Caenis
ana	*Anax junius*
ena	*Enallagma*
ish	*Ishnura*
coei	Coenagrionidae unknown
bel	*Belostoma*
beli	Belostomatidae unknown
tri	*Trichocorixa*
cor	Corixidae unknown
ger	Gerridae unknown
mes	*Mesovelia*
sal	Saldidae
oec	*Oecetis*
nec	*Nectopsyche*
hyp	*Hydroporus*
hypg	*Hydroporus/Hygrotus*
lac	*Laccophilus*
lio	Liodessus
eno	*Enochrus*
tro	*Tropisternus*
chi	Chironomini
tan	Tanytarsini
tap	Tanypodinae
ort	Orthocladinae
chip	Chironomidae pupa
bez	*Bezzia*
ano	*Anopheles*

Figure 22. Correspondence analysis of macroinvertebrates collected with dip nets in mowed and reference wetlands in 2004.

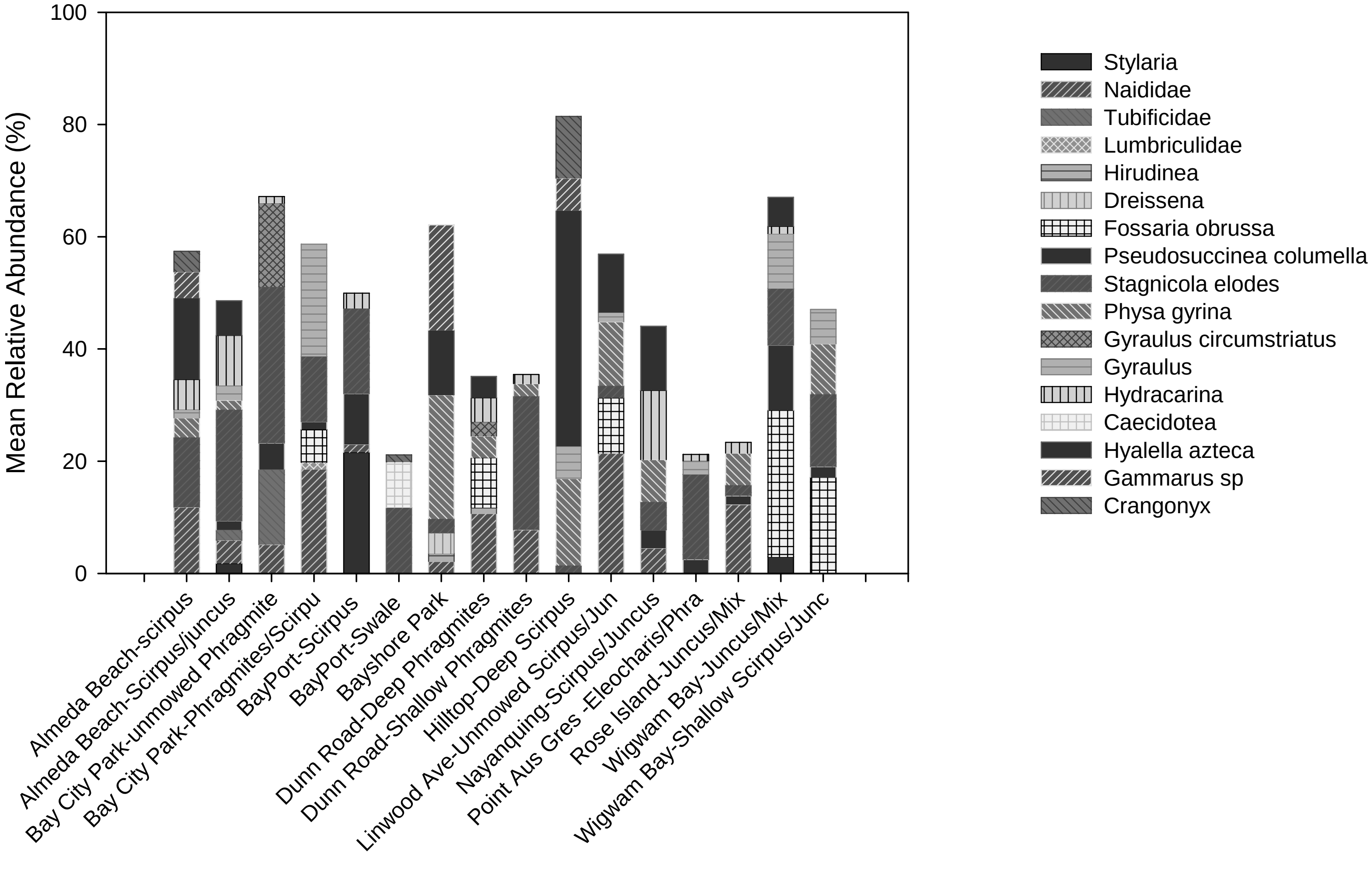


Figure 23. Mean relative abundance for non-Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘reference’ coastal wetlands.

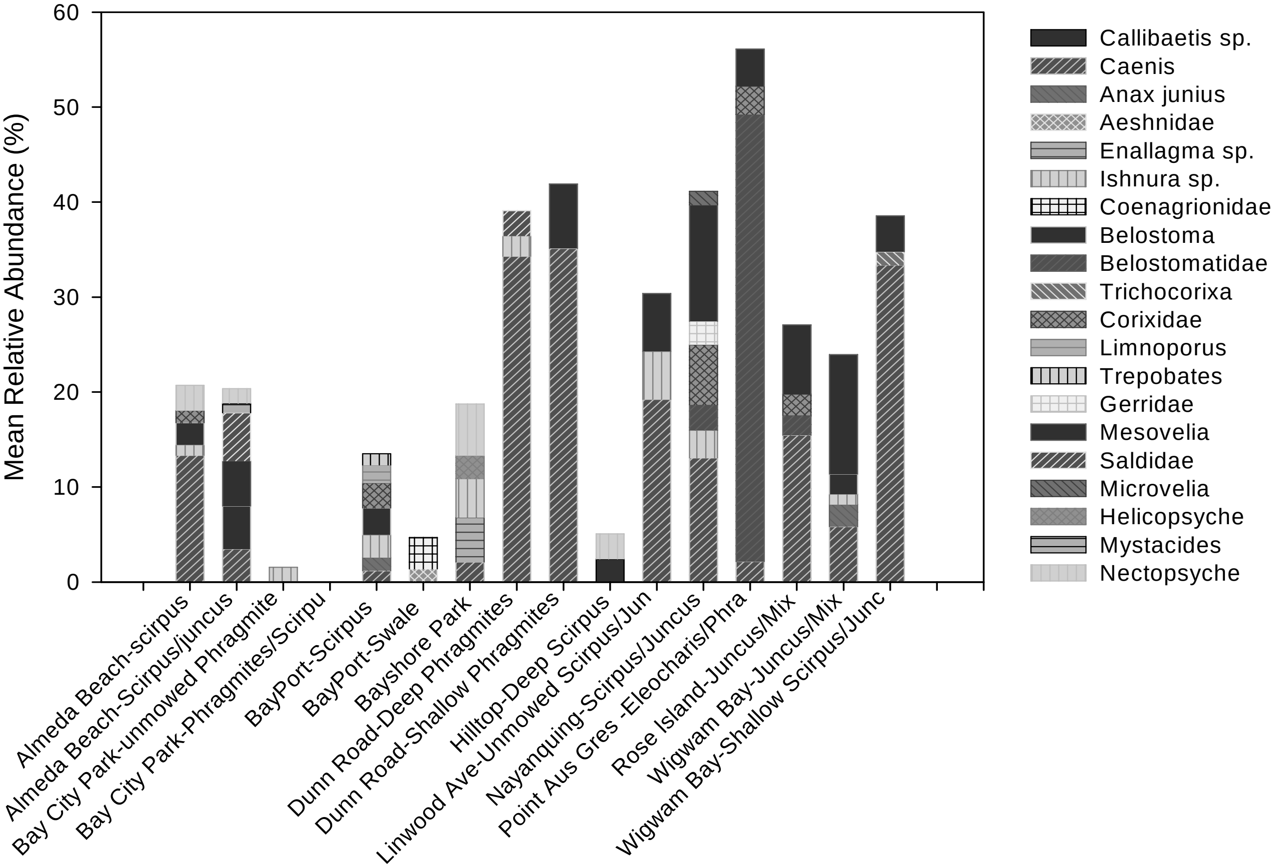


Figure 24. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘reference’ coastal wetlands.

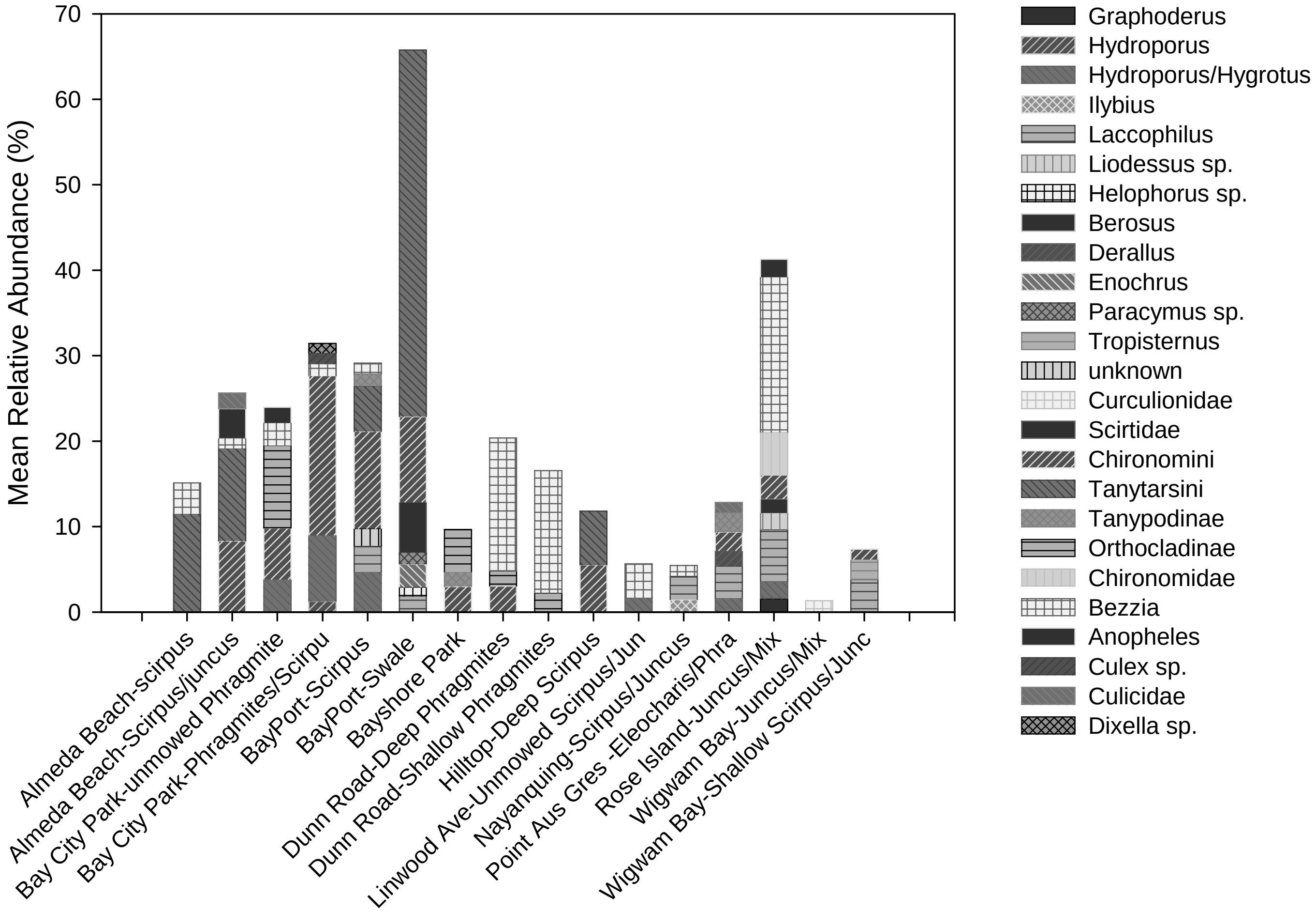


Figure 24. CON’T. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘reference’ coastal wetlands.

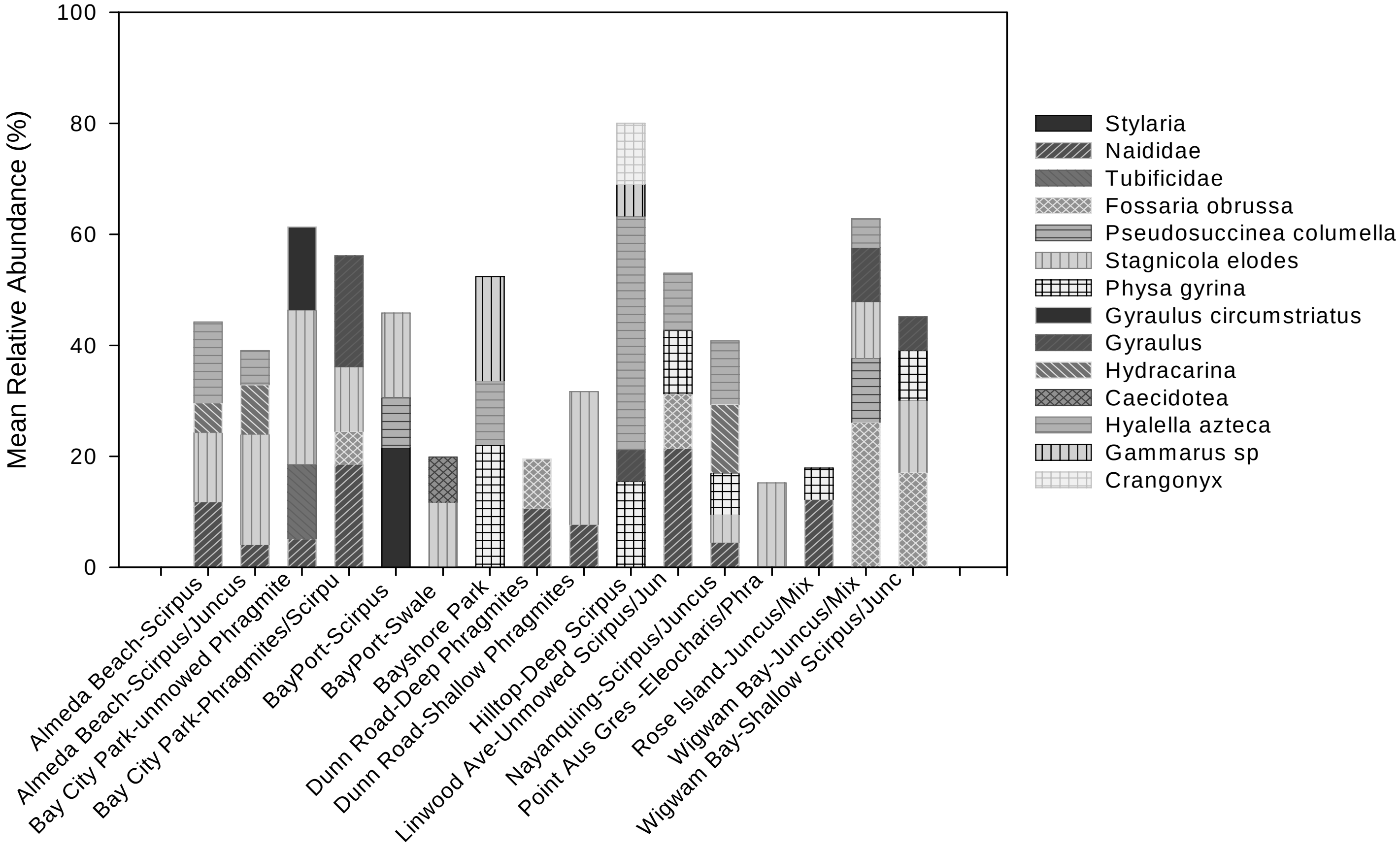


Figure 25. Mean relative abundance for non-Insecta invertebrates that comprised >5% of catch in 2004 from Saginaw Bay and Grand Traverse Bay 'reference' coastal wetlands.

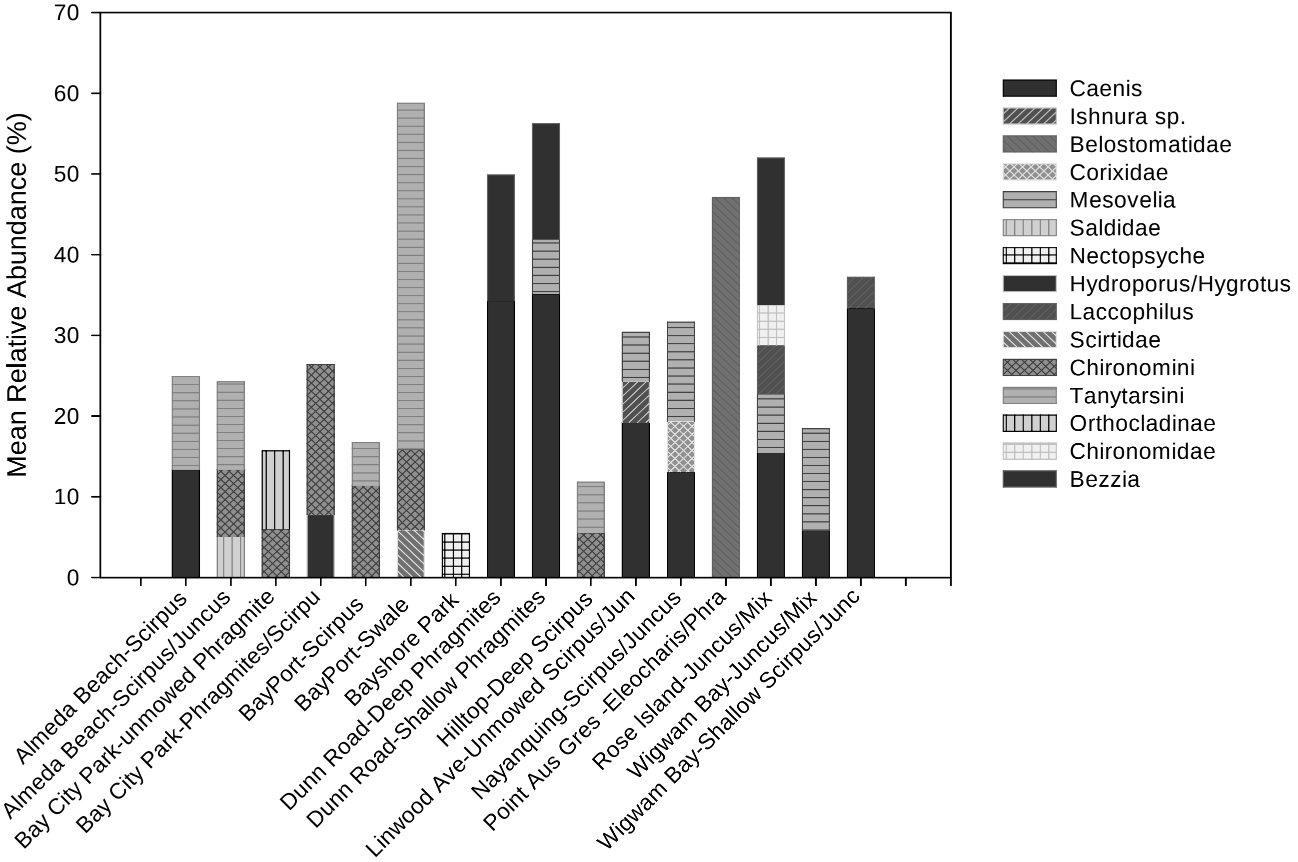


Figure 26. Mean relative abundance for Insecta invertebrates that comprised >5% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘reference’ coastal wetlands.

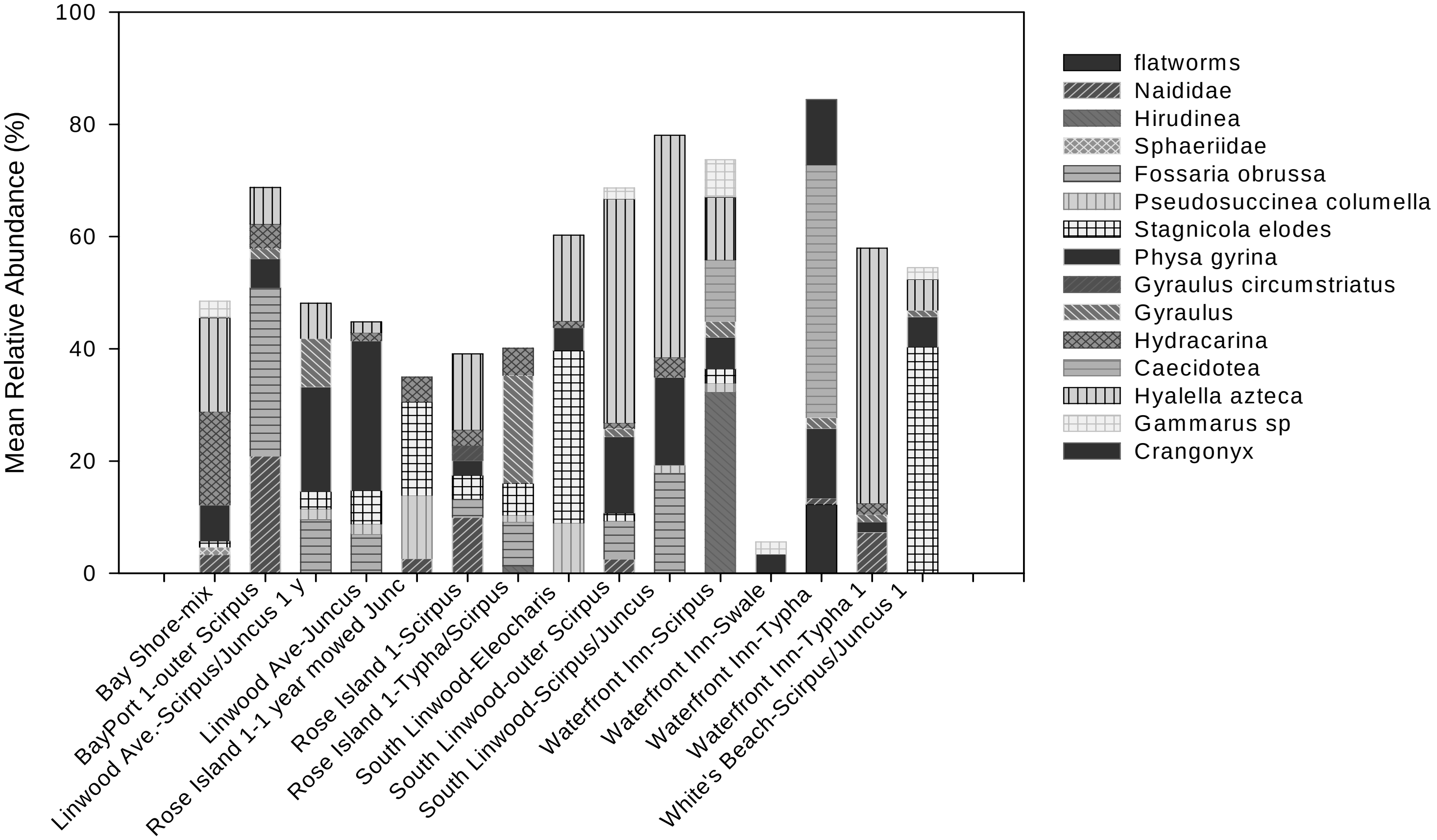


Figure 27. Mean relative abundance for non-Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘less recently mowed’ coastal wetlands.

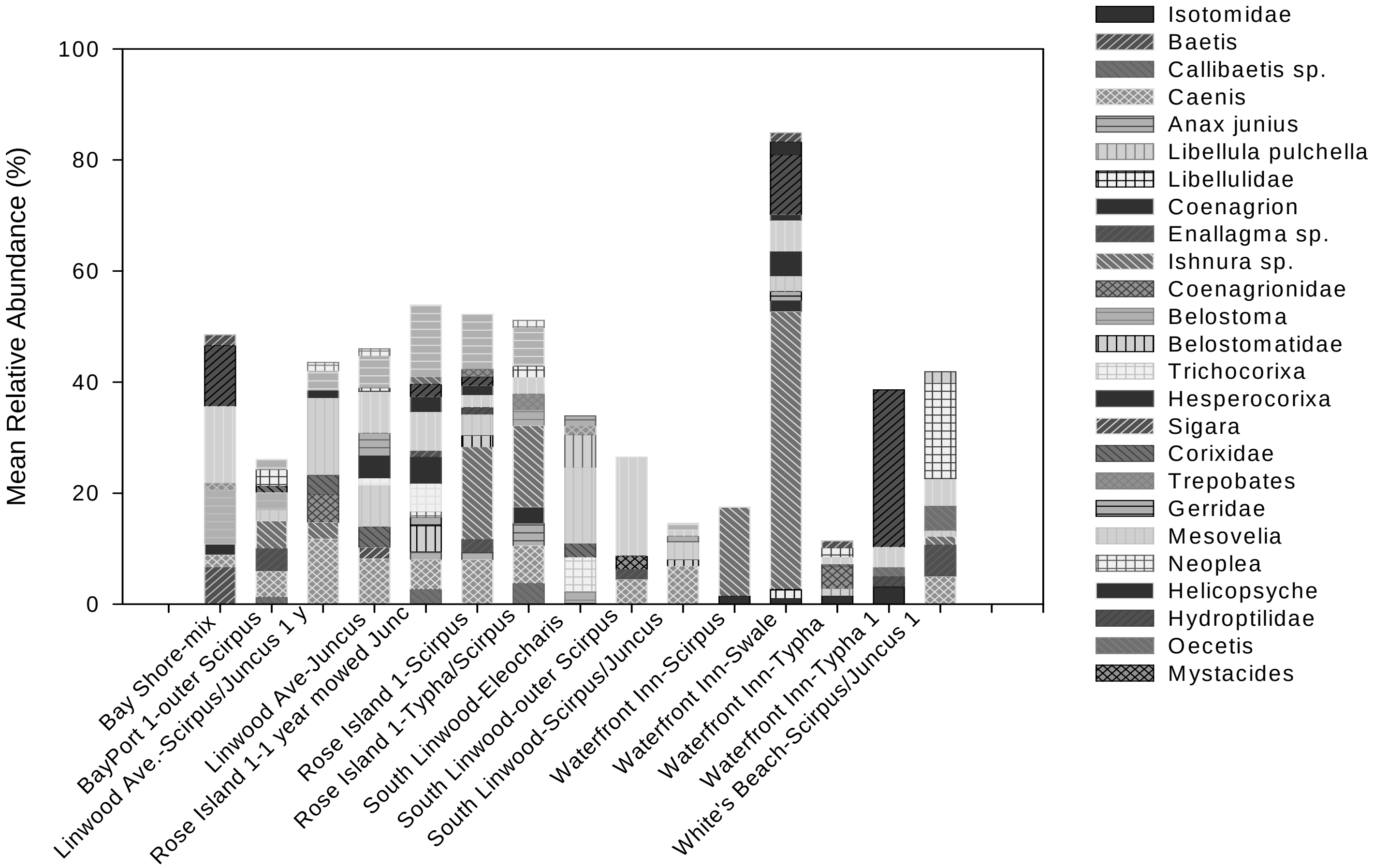


Figure 28. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘less recently mowed’ coastal wetlands.

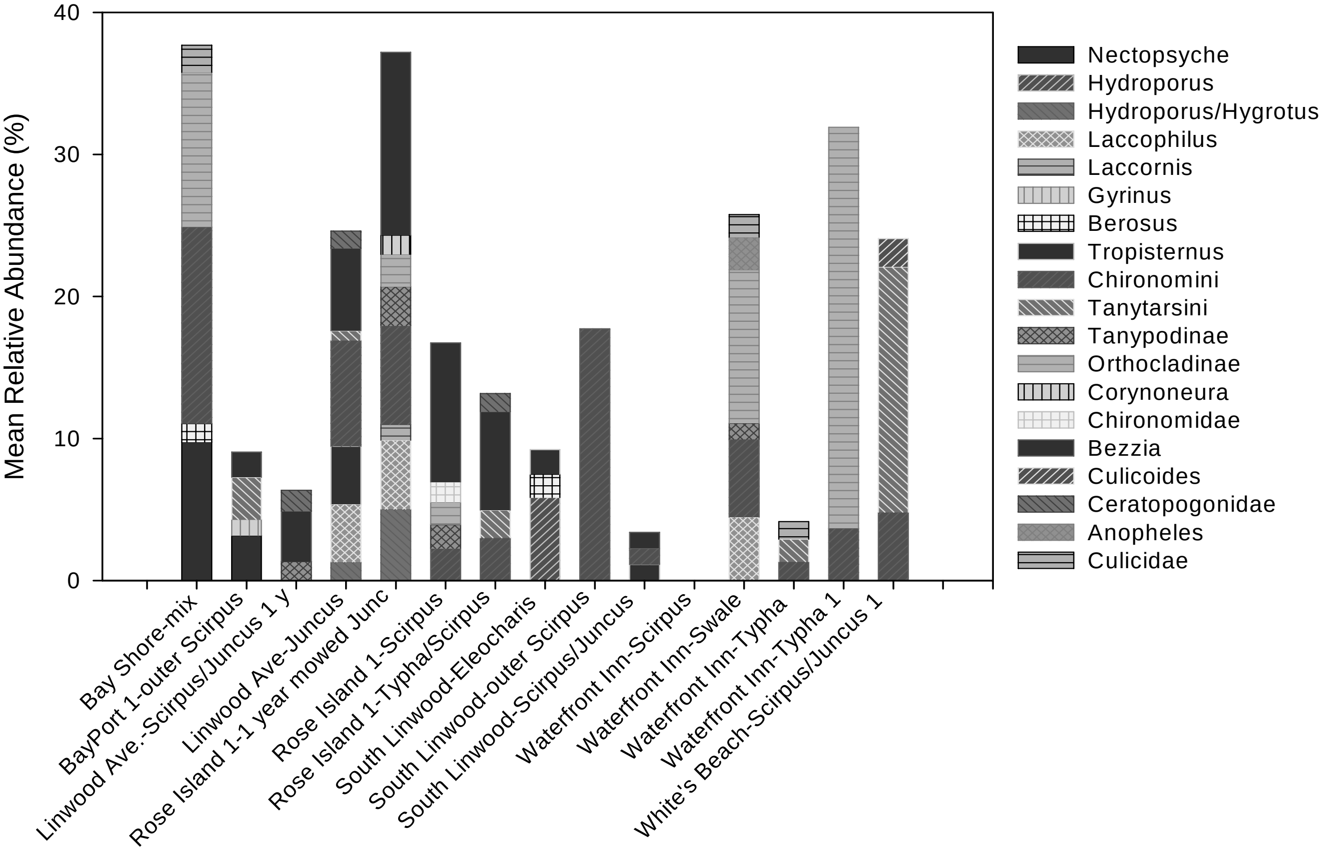


Figure 28. CONT. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘less recently mowed’ coastal wetlands.

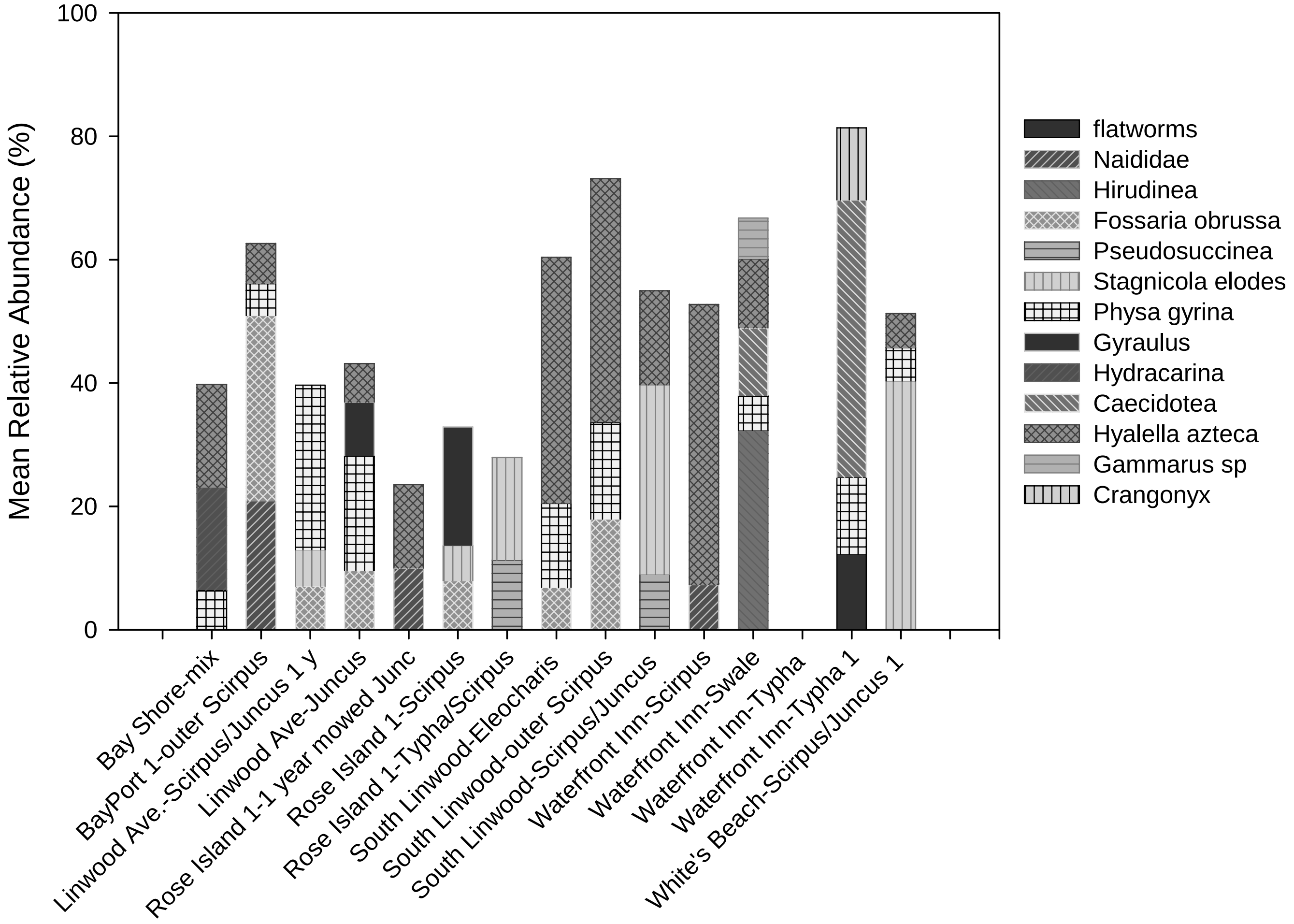


Figure 29. Mean relative abundance for non-Insecta invertebrates that comprised >5% of catch in 2004 from Saginaw Bay and Grand Traverse Bay 'less recently mowed' coastal wetlands.

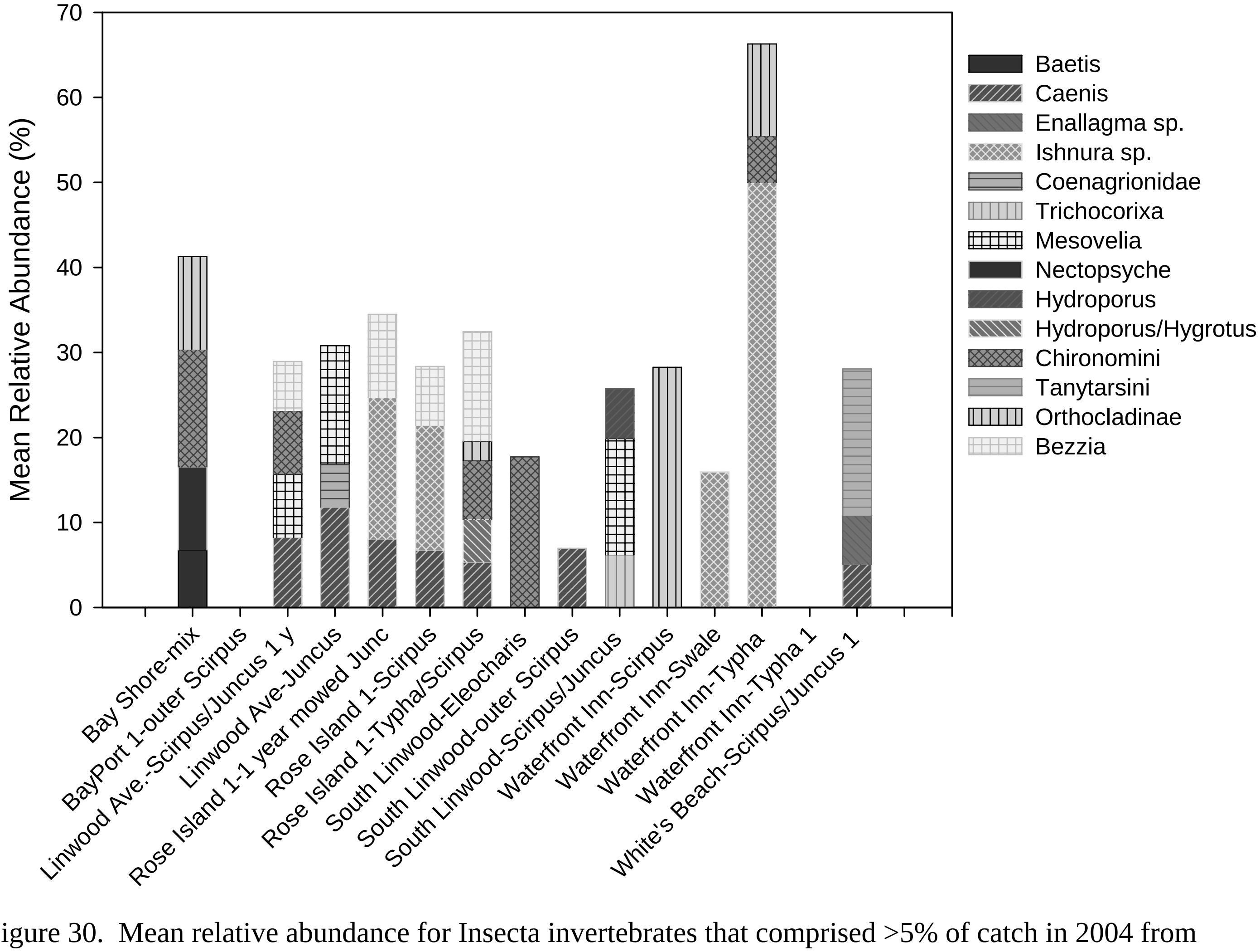


Figure 30. Mean relative abundance for Insecta invertebrates that comprised >5% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘less recently mowed’ coastal wetlands.

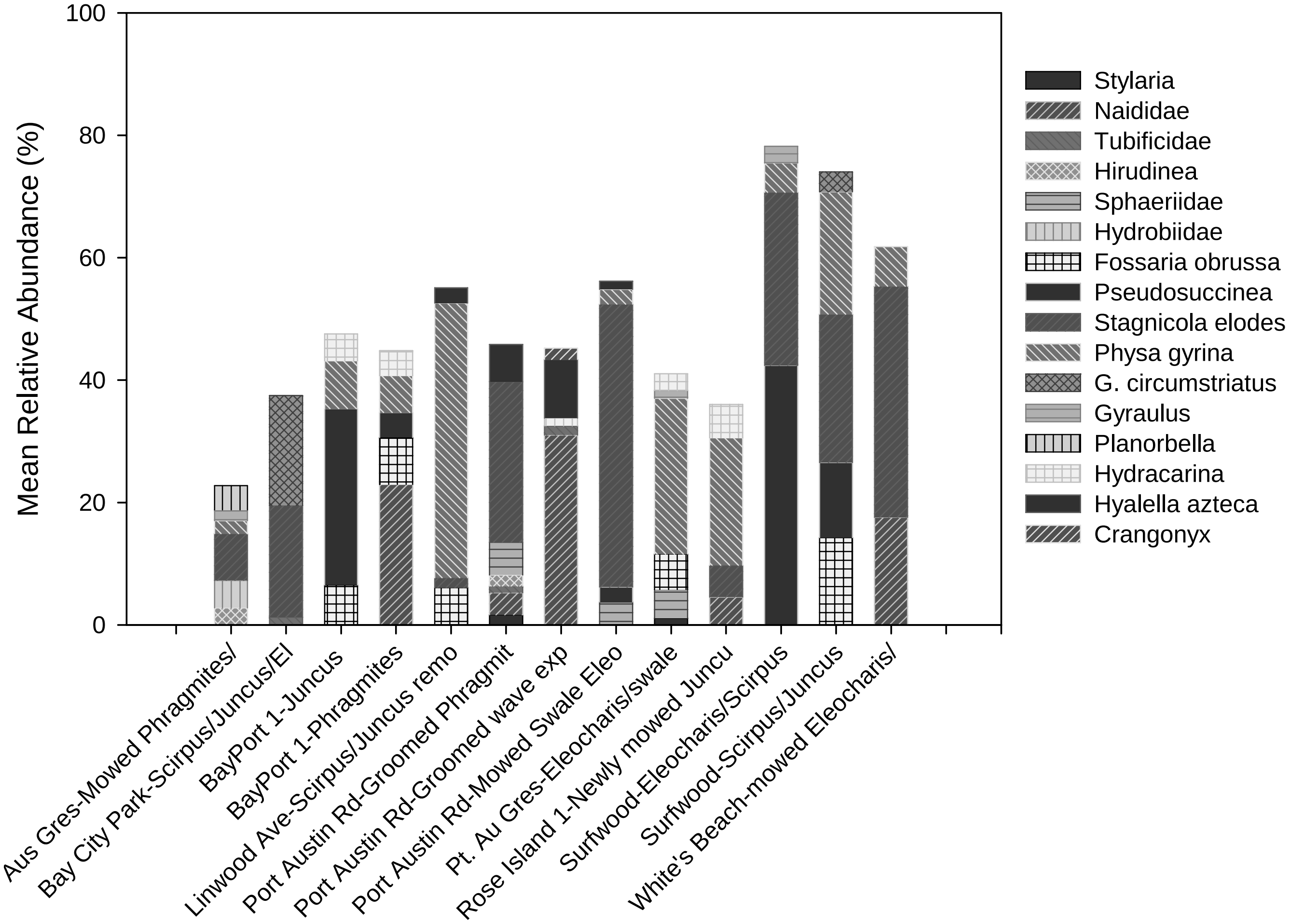


Figure 31. Mean relative abundance for non-Insecta invertebrates that comprised >1% of catch in 2004 From Saginaw Bay and Grand Traverse Bay 'most recently mowed' coastal wetlands.

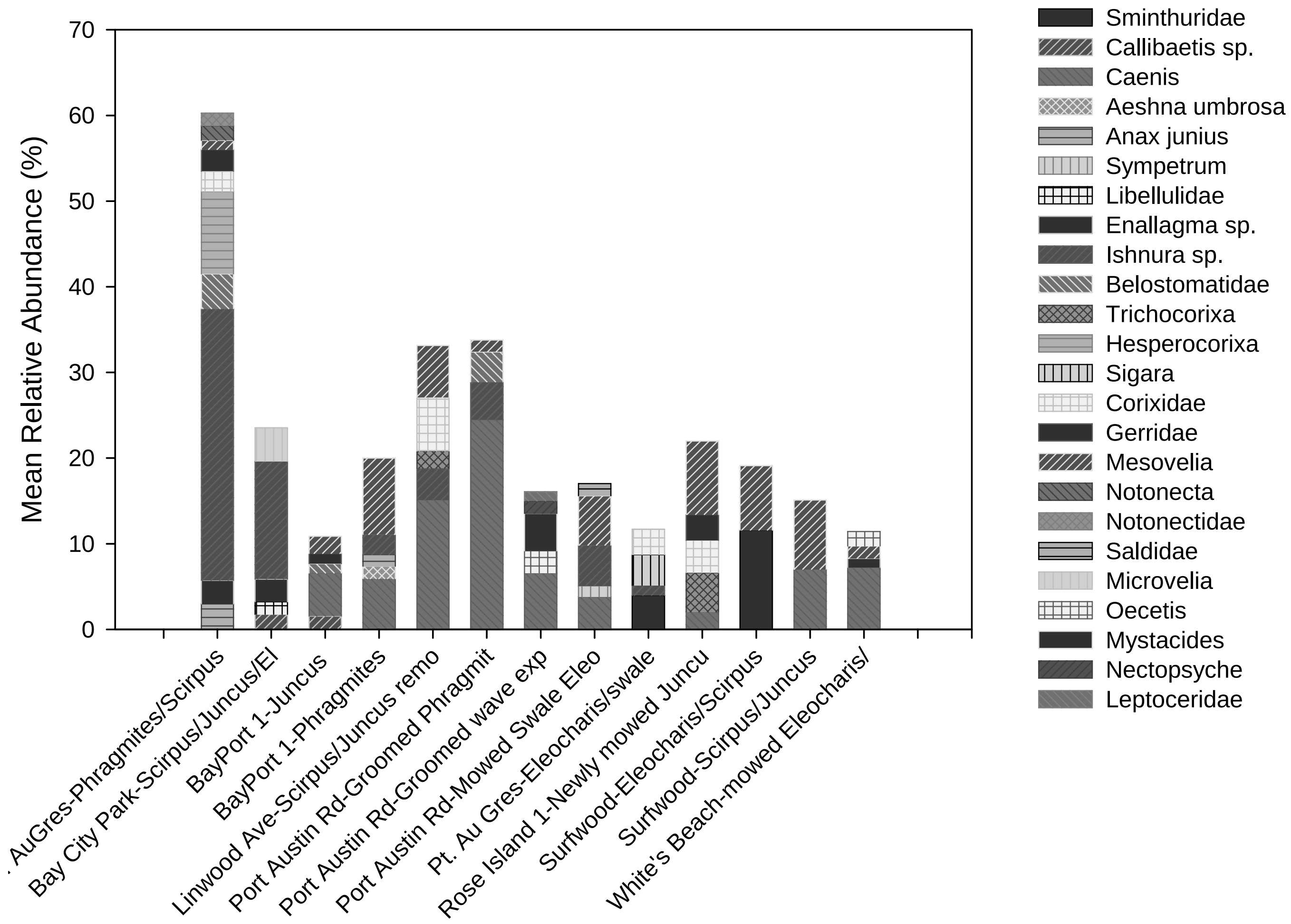


Figure 32. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘most recently mowed’ coastal wetlands.

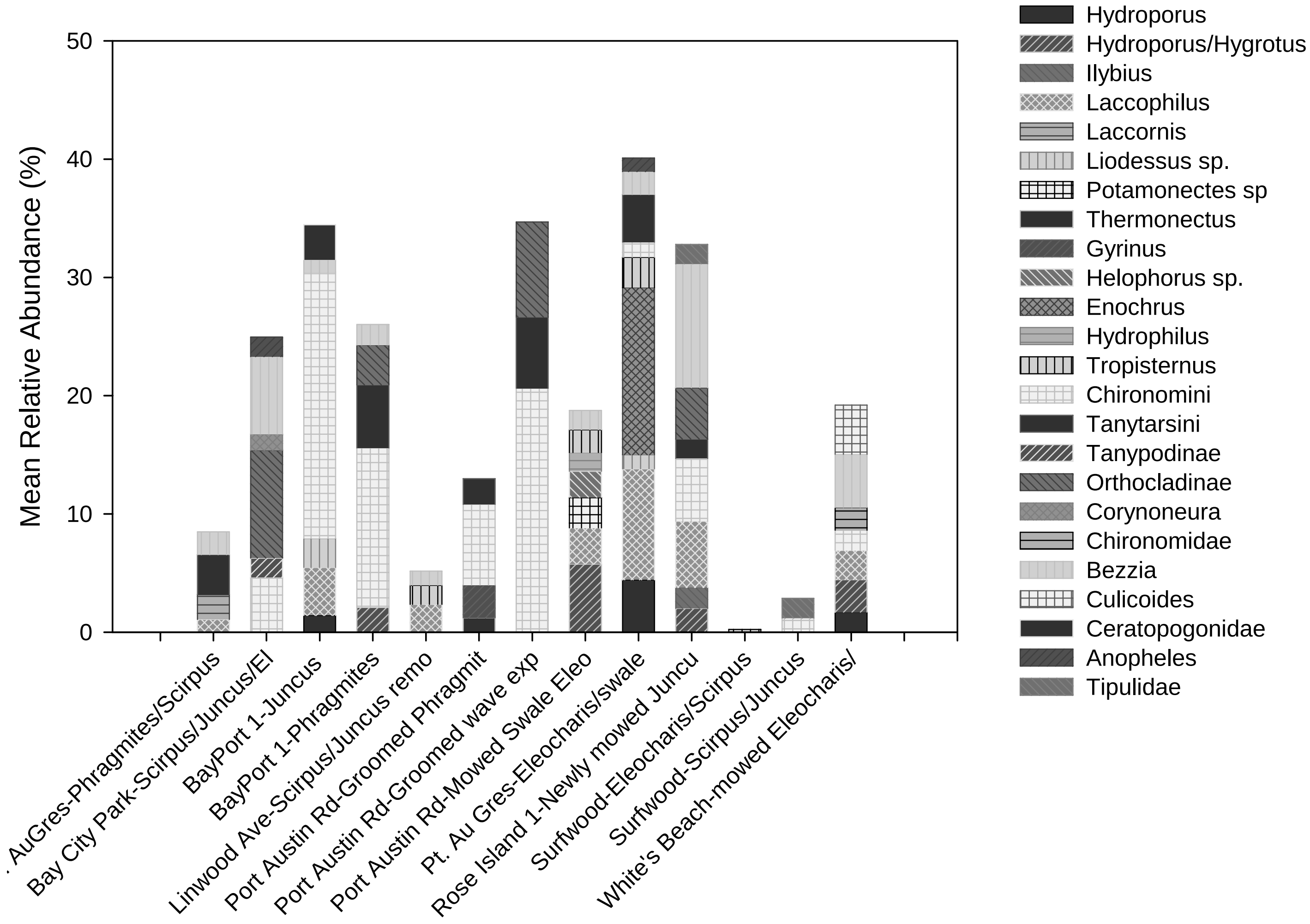


Figure 32. CON'T. Mean relative abundance for Insecta invertebrates that comprised >1% of catch in 2004 from Saginaw Bay and Grand Traverse Bay 'most recently mowed' coastal wetlands.

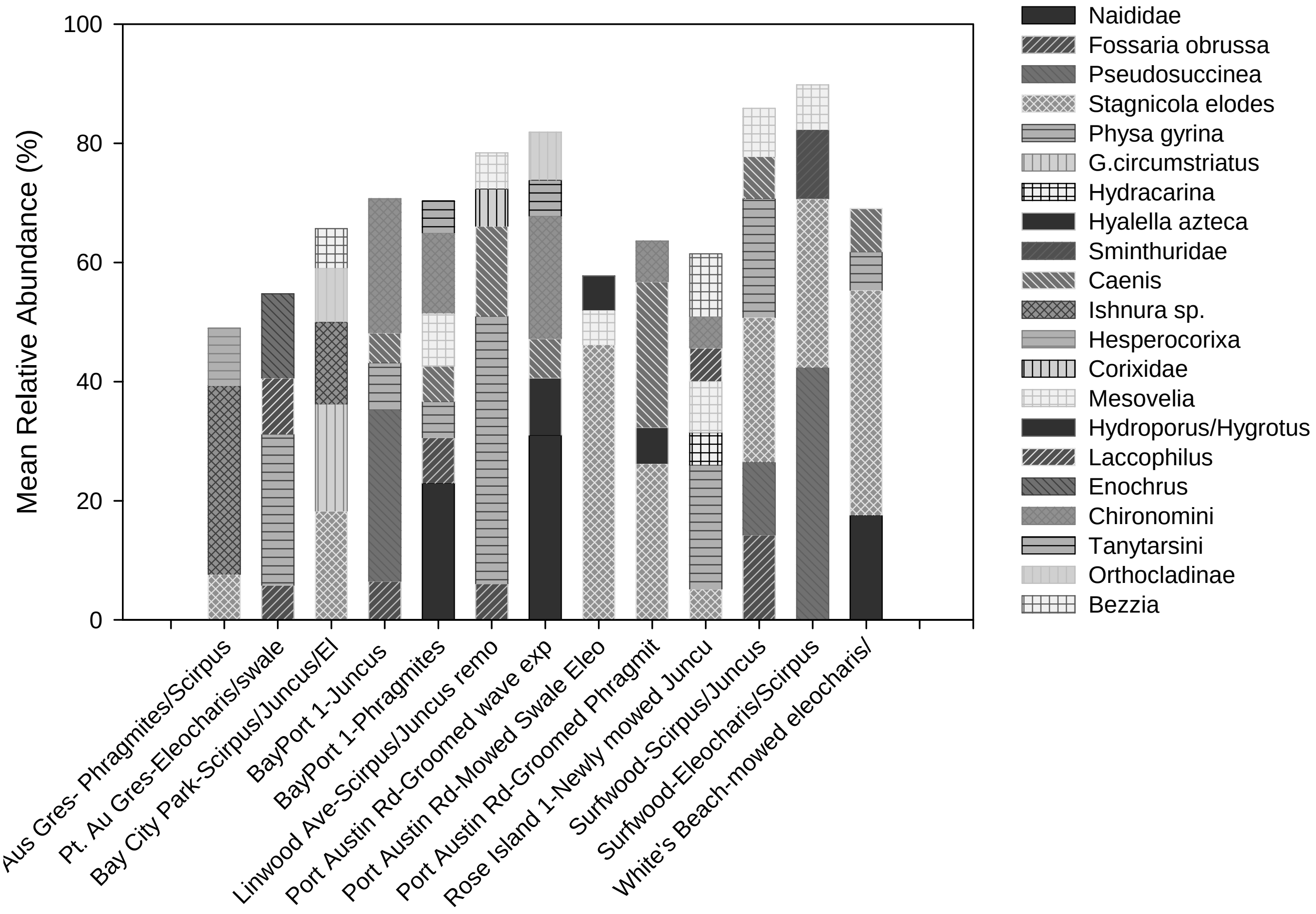


Figure 33. Mean relative abundance for non-Insecta and Insecta invertebrates that comprised >5% of catch in 2004 from Saginaw Bay and Grand Traverse Bay ‘most recently mowed’ coastal wetlands.

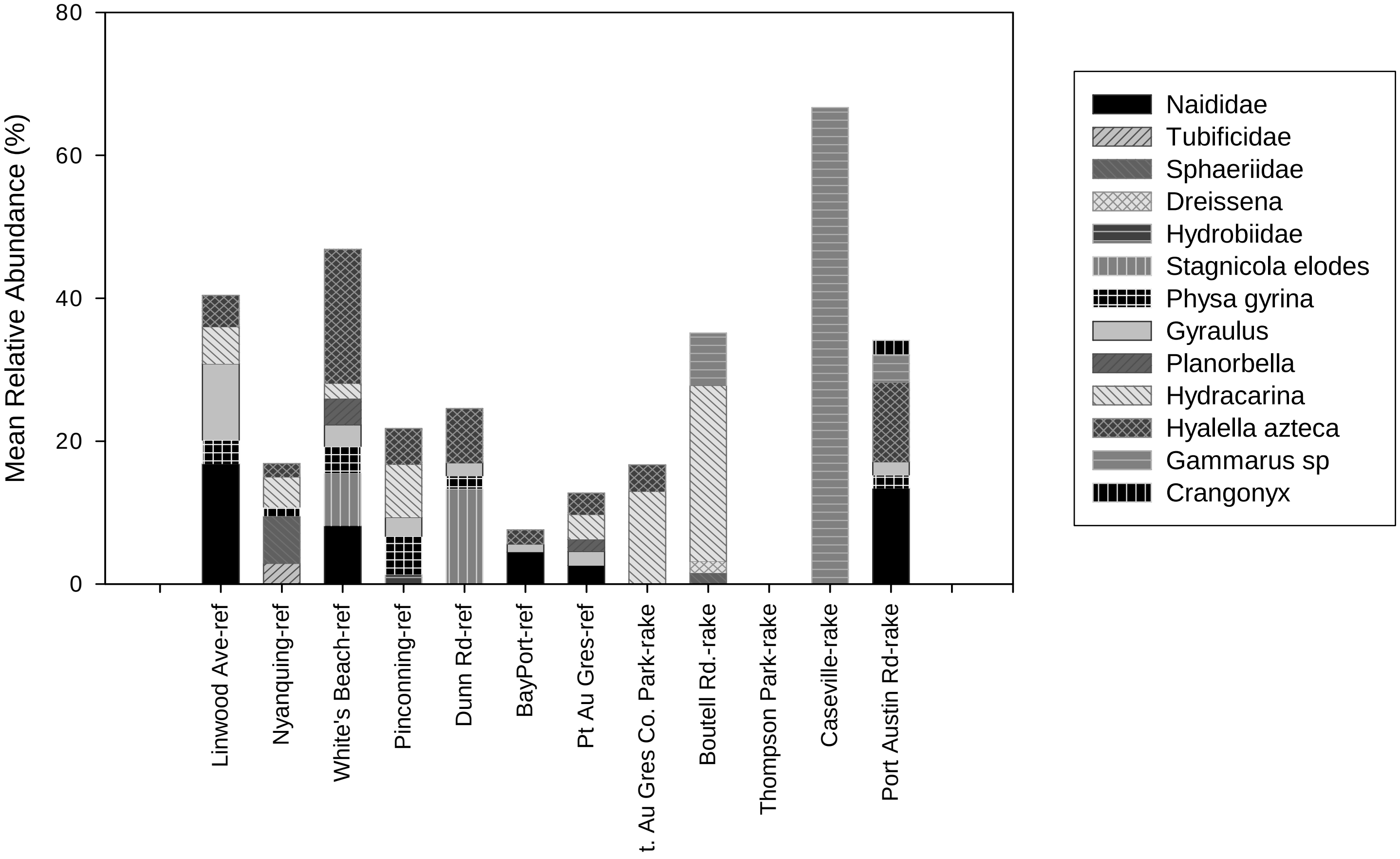


Figure 35. Mean non-Insecta invertebrate relative abundance (≥1%) collected in July 2005 from open water ‘reference’ and open water ‘raked’ zones at sites located along Saginaw Bay.

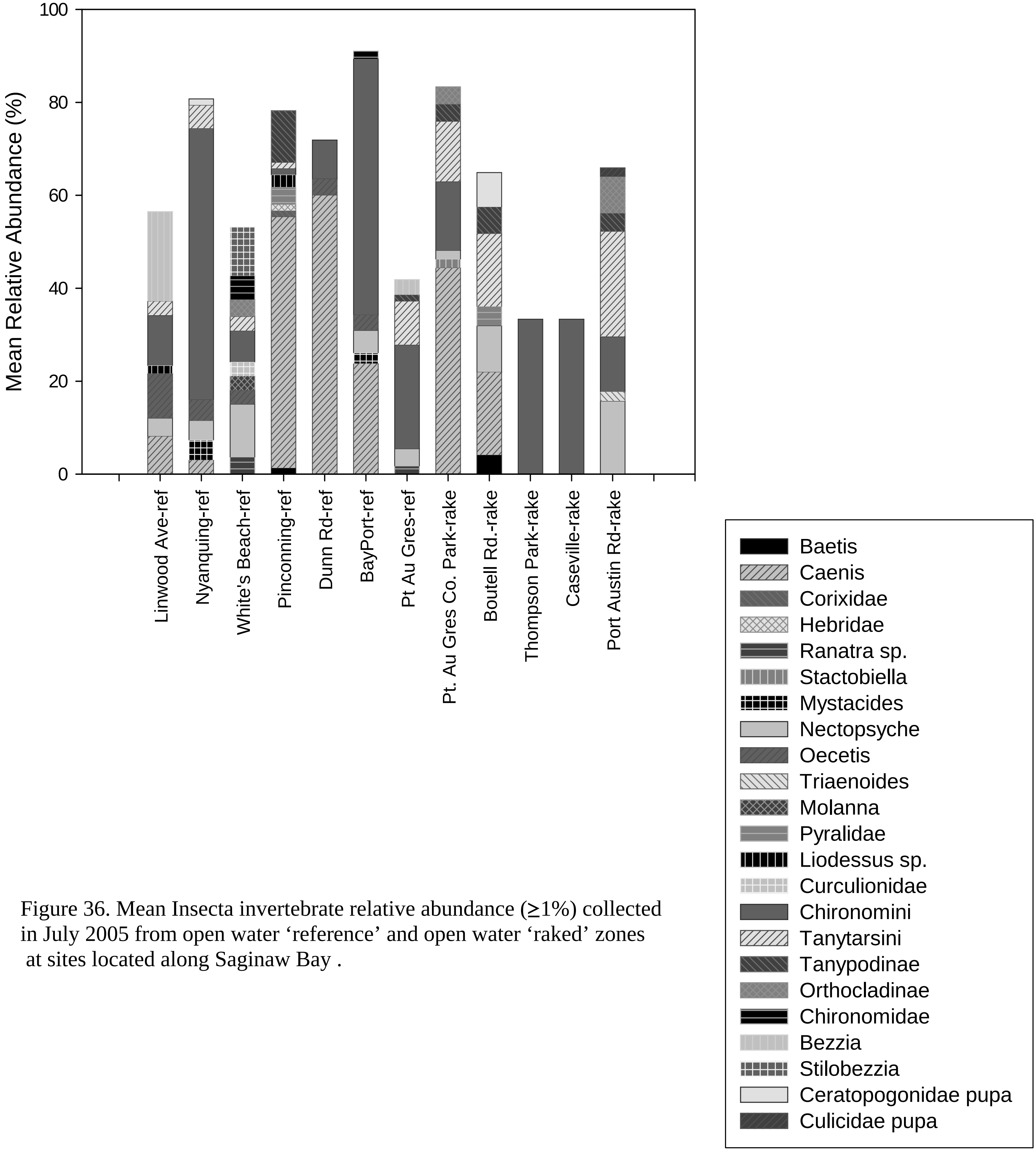


Figure 36. Mean Insecta invertebrate relative abundance (≥1%) collected in July 2005 from open water ‘reference’ and open water ‘raked’ zones at sites located along Saginaw Bay .

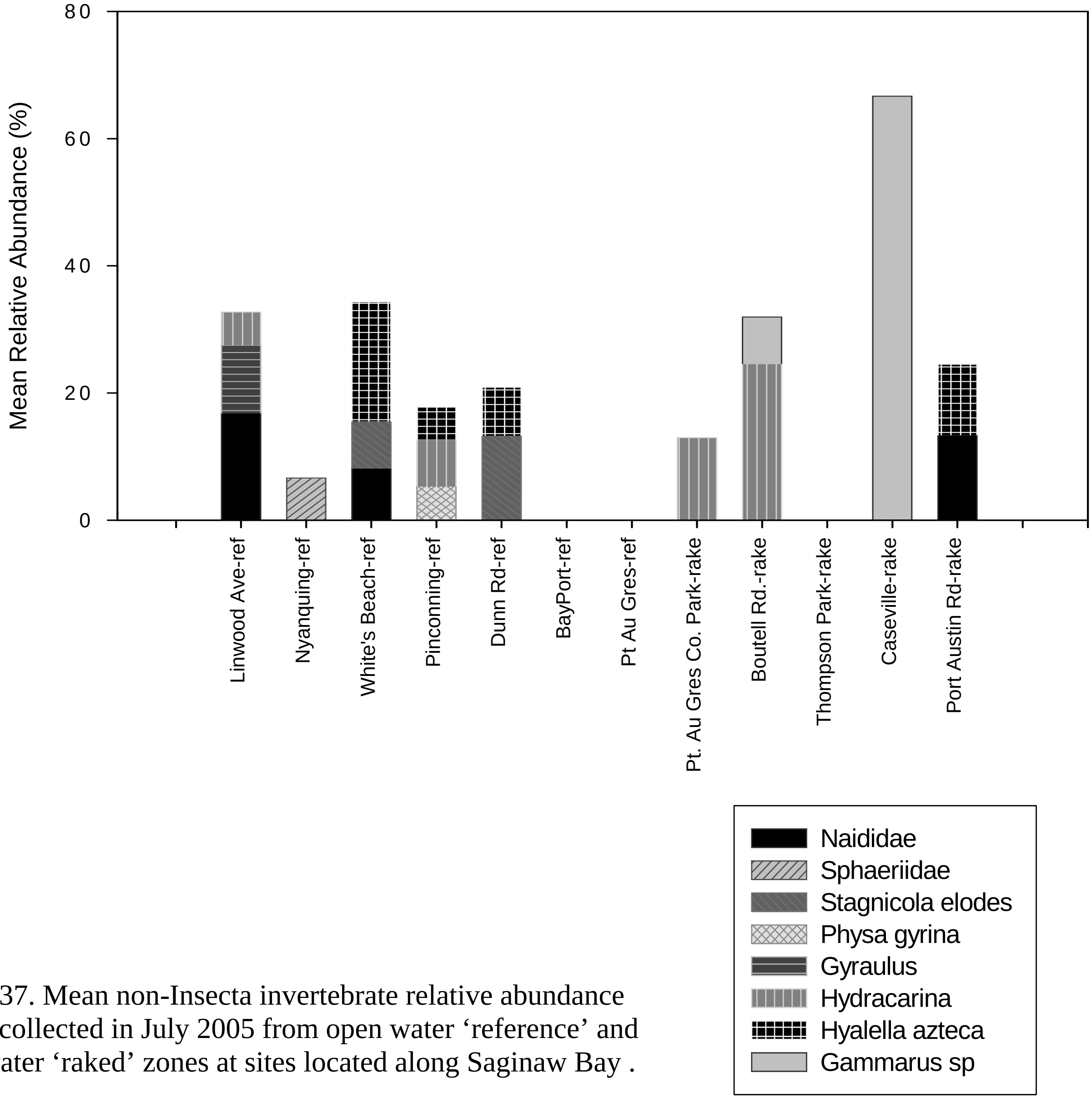


Figure 37. Mean non-Insecta invertebrate relative abundance (≥5%) collected in July 2005 from open water ‘reference’ and open water ‘raked’ zones at sites located along Saginaw Bay .

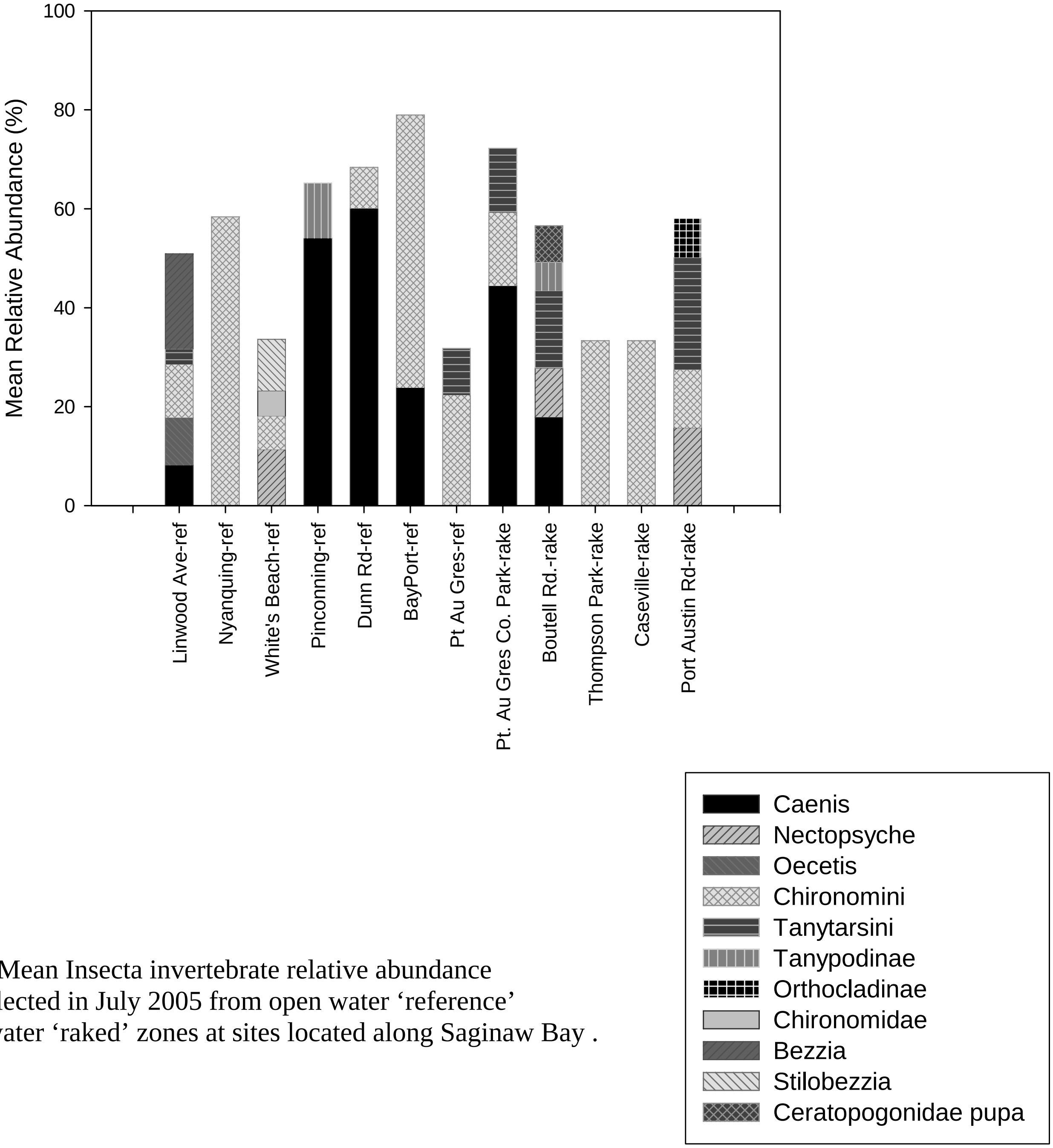


Figure 38. Mean Insecta invertebrate relative abundance (≥5%) collected in July 2005 from open water ‘reference’ and open water ‘raked’ zones at sites located along Saginaw Bay .

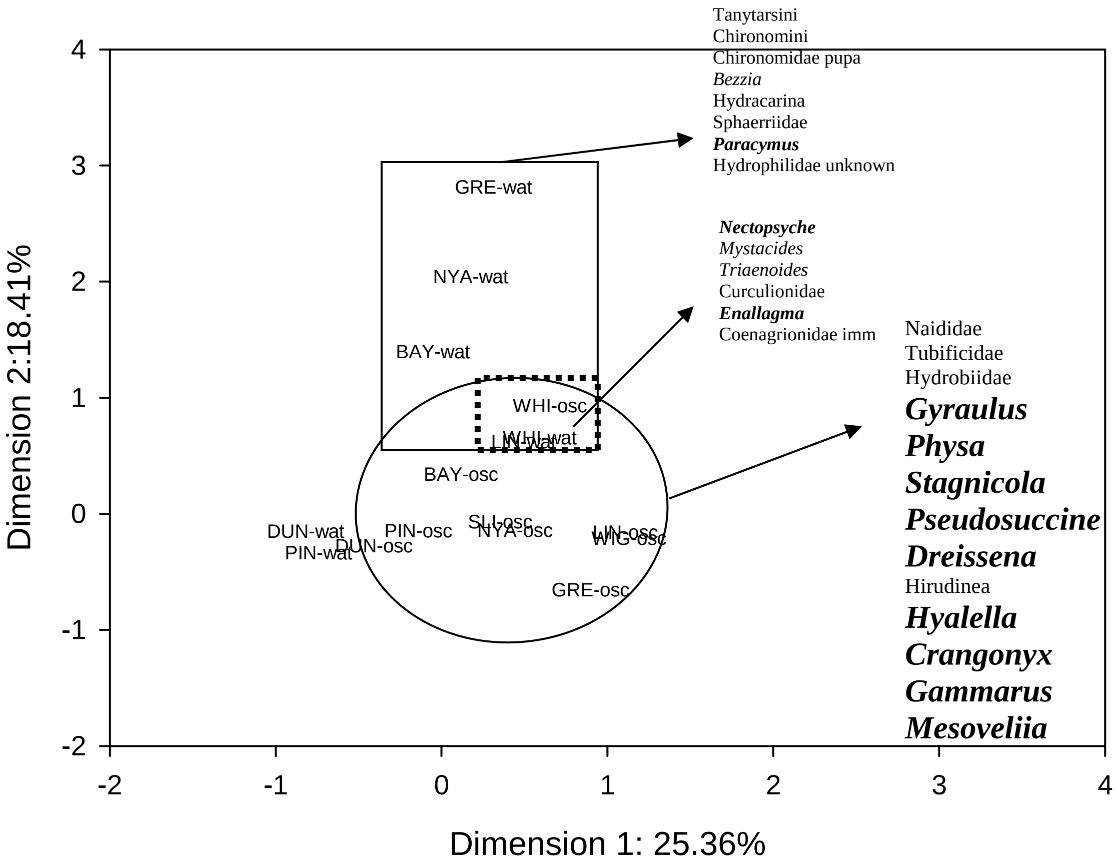


Figure 39. Correspondence analysis of July 2005 invertebrate relative abundance (%) data for taxa that made up more than 1% of relative abundance of outer *Scirpus* and open water zones. Shapes drawn around sites with taxa responsible for the most inertia separation of sites based on zone type.

BayPort	Open water	BAY-wat
BayPort	Outer Scirpus	BAY-osc
Dunn Rd	Open water	DUN-wat
Dunn Rd	Outer Scirpus	DUN-osc
Linwood Ave	Outer Scirpus	LIN-osc
Linwood Ave	Open Beach	LIN-wat
Nyanquing	Open water	NYA-wat
Nyanquing	Outer Scirpus	NYA-osc
Pinconning	Outer Scirpus	PIN-osc
Pinconning	Open water	PIN-wat
Pt Au Gres	Outer Scirpus	GRE-osc
Pt Au Gres	Open water	GRE-wat
S. Linwood	Outer Scirpus	SLI-osc
White's Beach	Outer Scirpus	WHI-osc
White's Beach	Open water	WHI-wat
Wigwam Bay	Outer Scirpus	WIG-osc

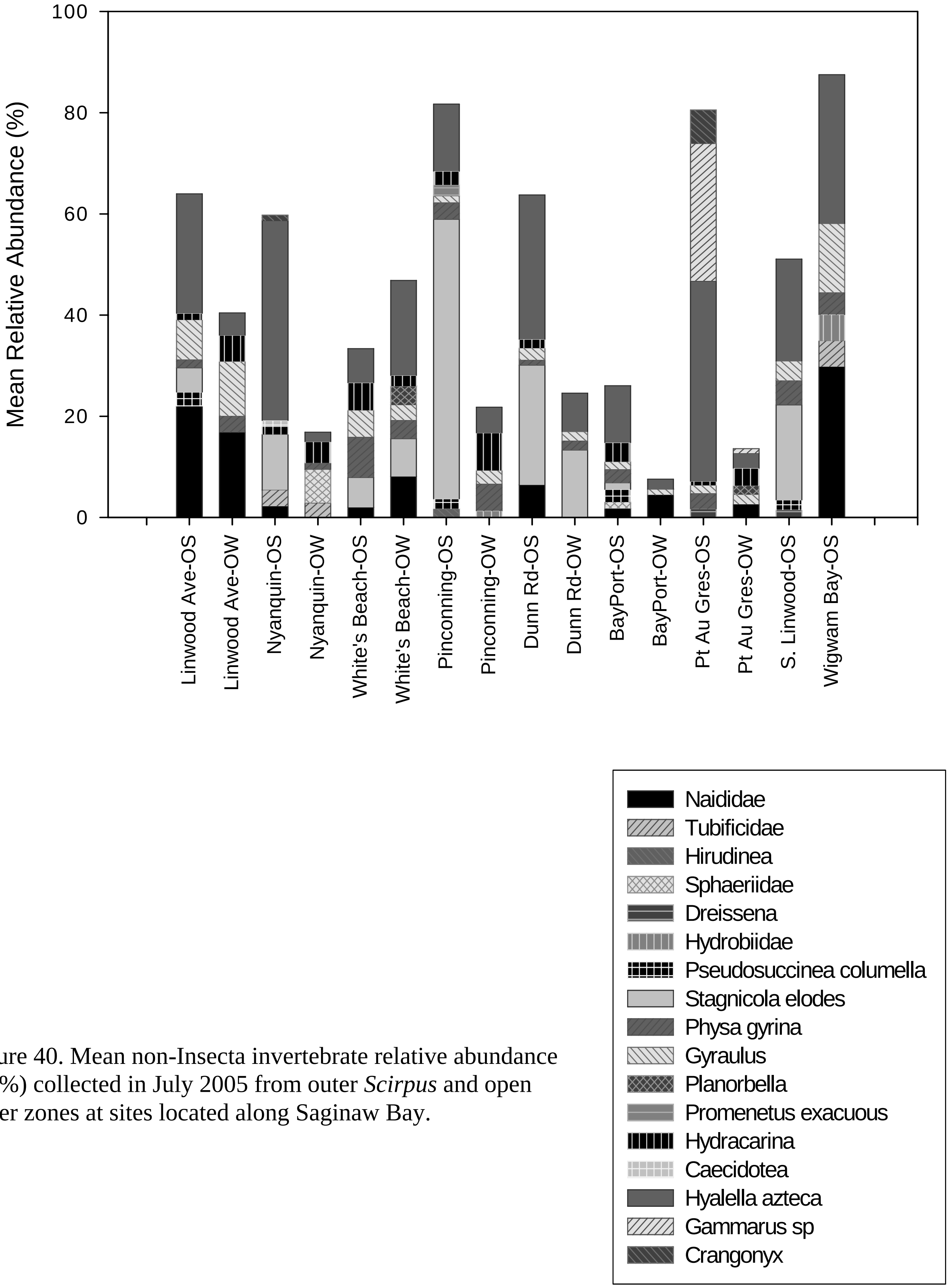


Figure 40. Mean non-Insecta invertebrate relative abundance (≥1%) collected in July 2005 from outer *Scirpus* and open water zones at sites located along Saginaw Bay.

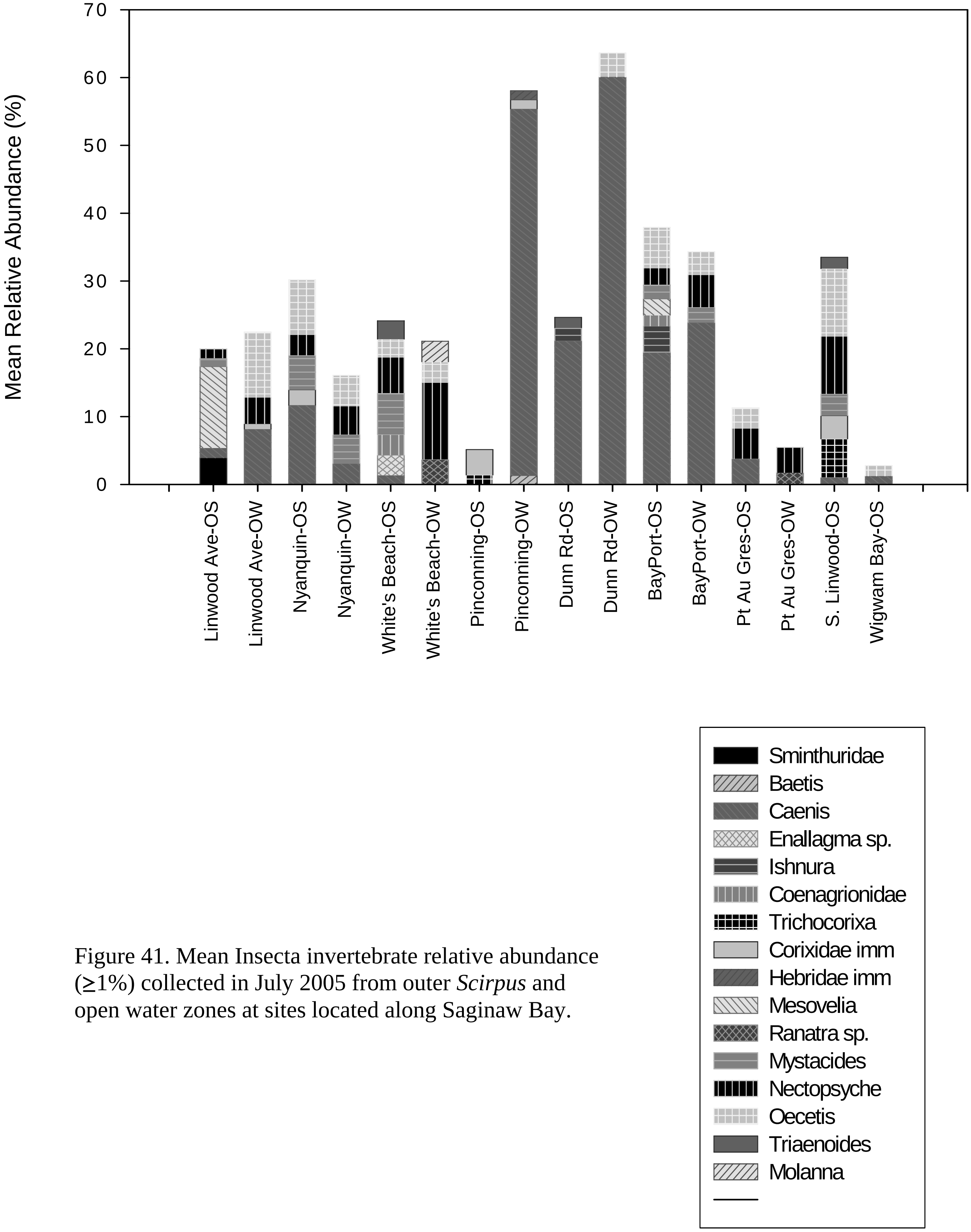


Figure 41. Mean Insecta invertebrate relative abundance (≥1%) collected in July 2005 from outer *Scirpus* and open water zones at sites located along Saginaw Bay.

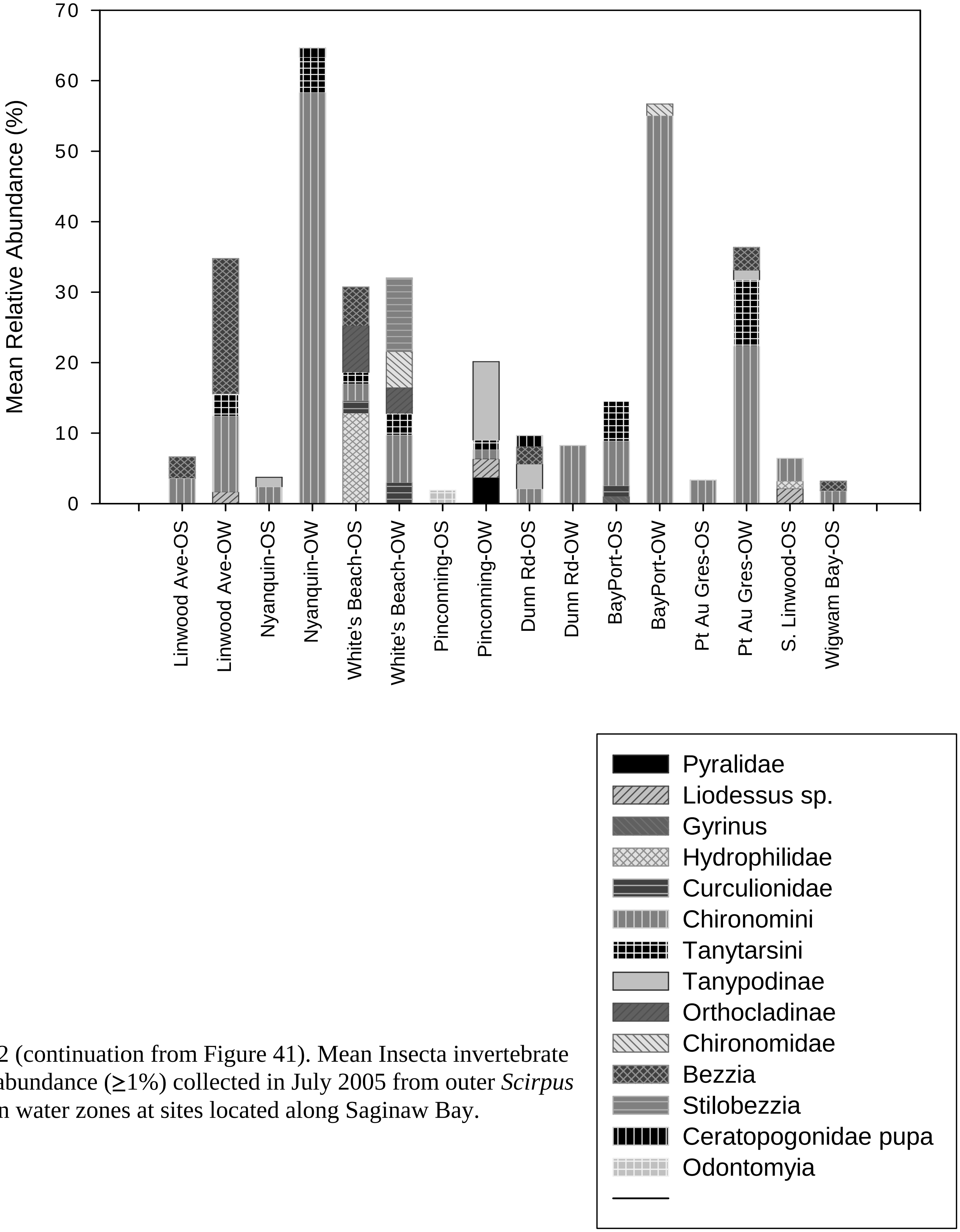


Figure 42 (continuation from Figure 41). Mean Insecta invertebrate relative abundance (≥1%) collected in July 2005 from outer *Scirpus* and open water zones at sites located along Saginaw Bay.

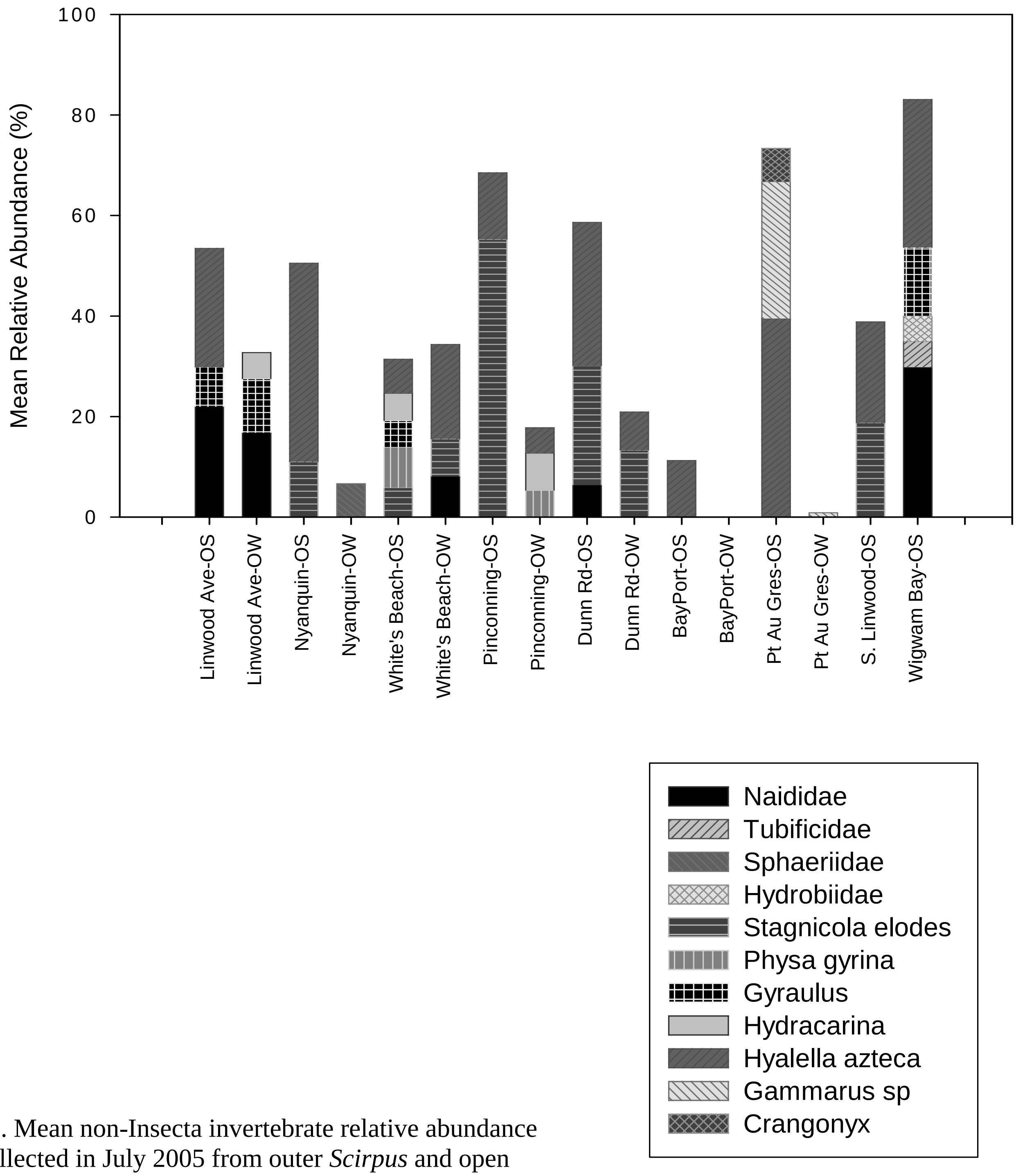


Figure 43. Mean non-Insecta invertebrate relative abundance (≥5%) collected in July 2005 from outer *Scirpus* and open water zones at sites located along Saginaw Bay.

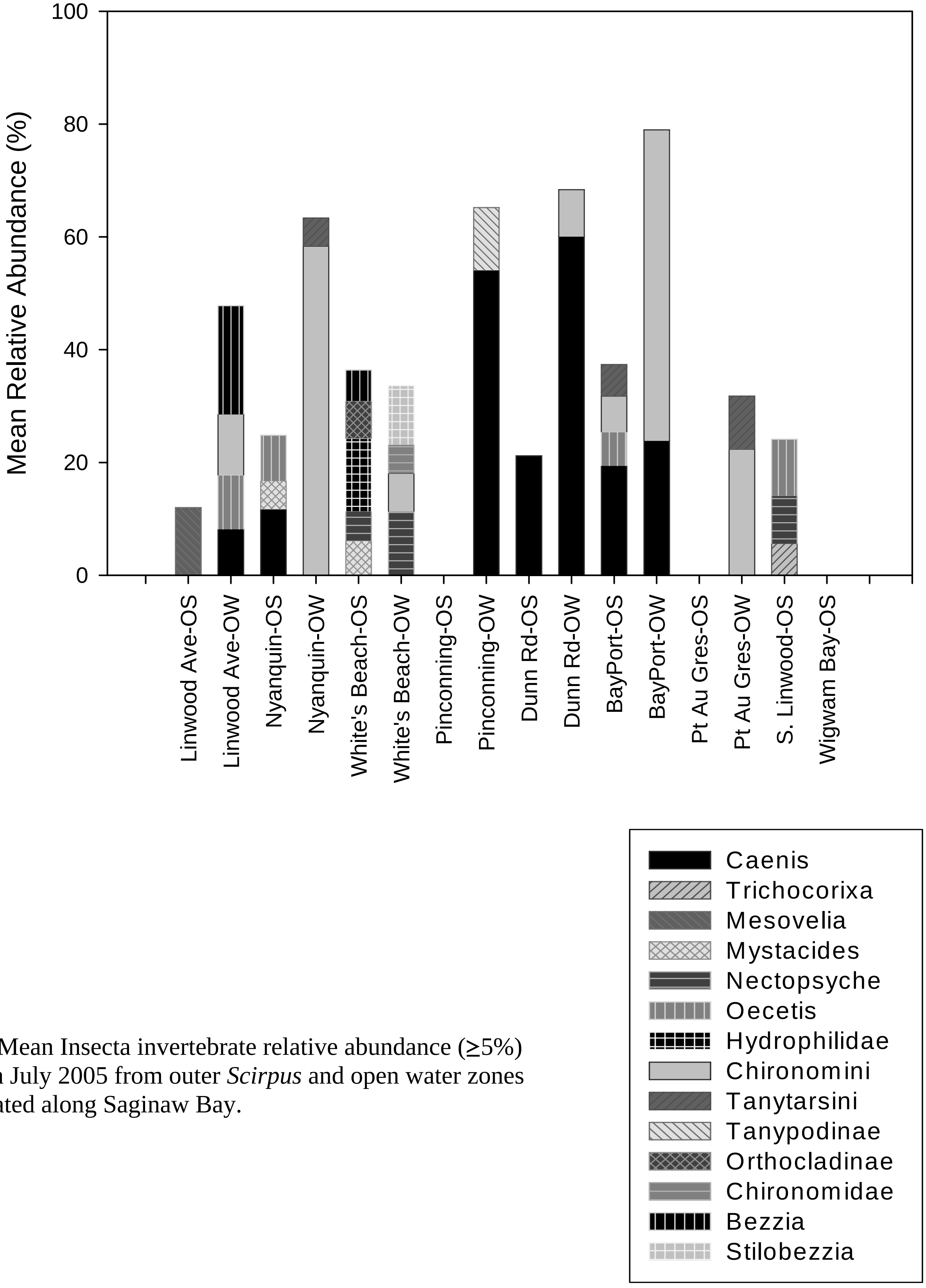


Figure 44. Mean Insecta invertebrate relative abundance (≥5%) collected in July 2005 from outer *Scirpus* and open water zones at sites located along Saginaw Bay.

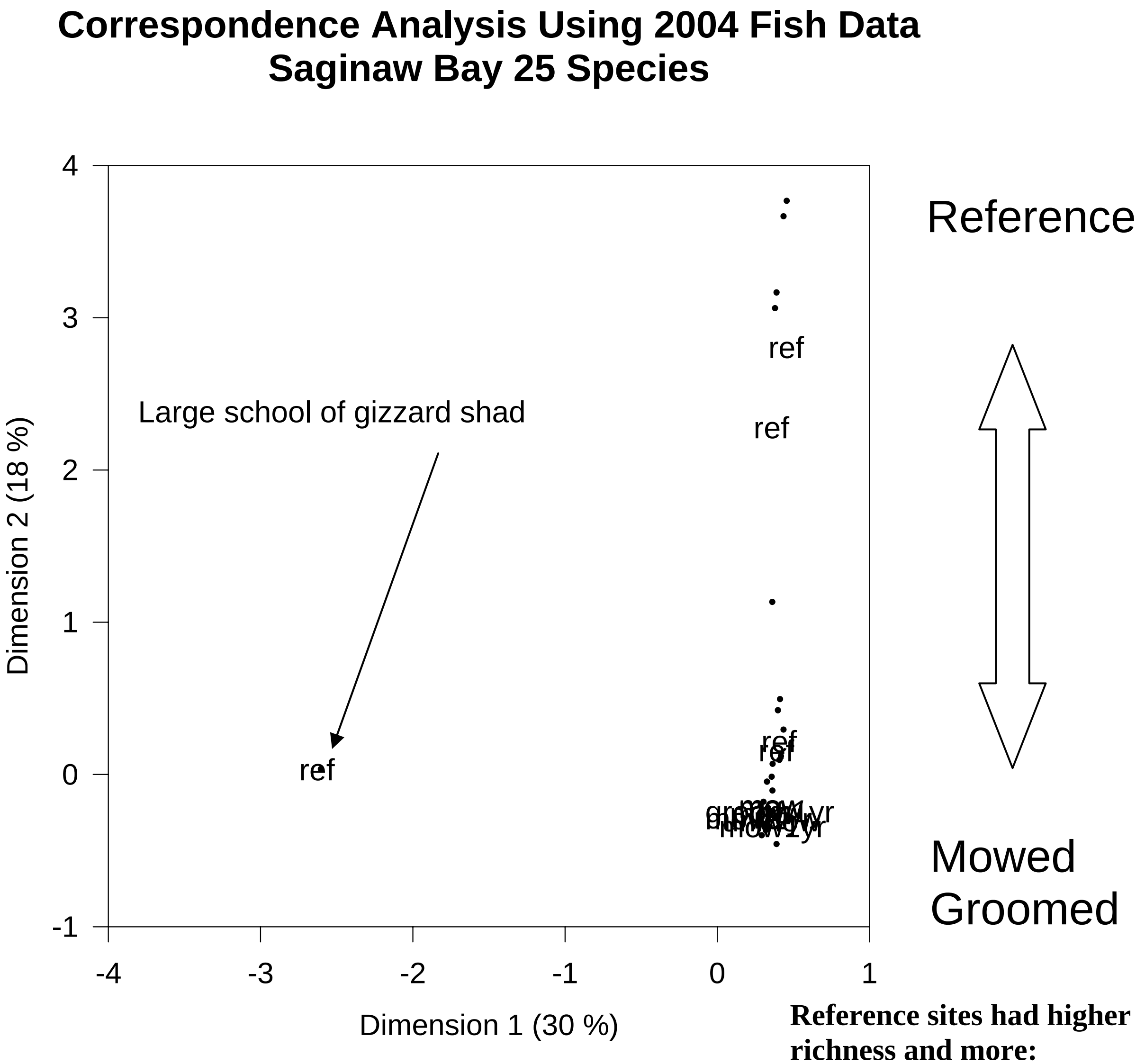


Figure 45. Correspondence analysis of fish data collected with fyke nets in coastal wetlands of Saginaw Bay. Analysis includes 25 fish species.

Reference sites had higher richness and more:

Pumpkinseed (Lepomis

Bluegill (Lepomis

Pirate Perch (Aphredoderus

Bluntnose minnow (Pimephales

Emerald Shiner (Notropis

Spottail Shiner (Notropis

Mimic Shiner (Notropis

Brown Bullhead (Ameiurus

Round Goby (Neogobius

Gizzard Shad (Dorosoma

Black Buffalo (Ictiobus niger)

White perch (Morone

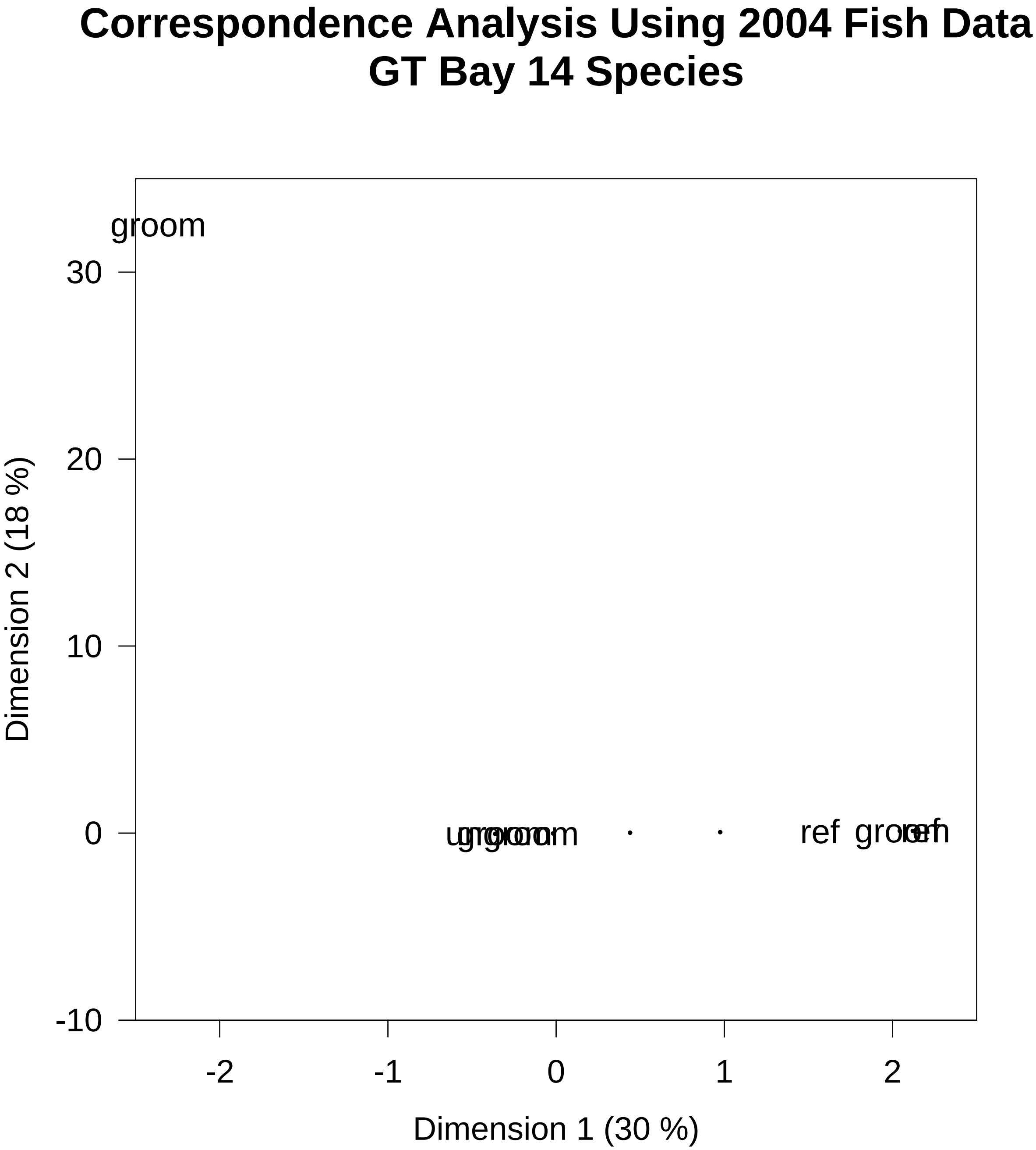


Figure 46. Correspondence analysis of fish data collected with fyke nets in wetlands of Grand Traverse Bay. Data from 14 species were included in the analysis.

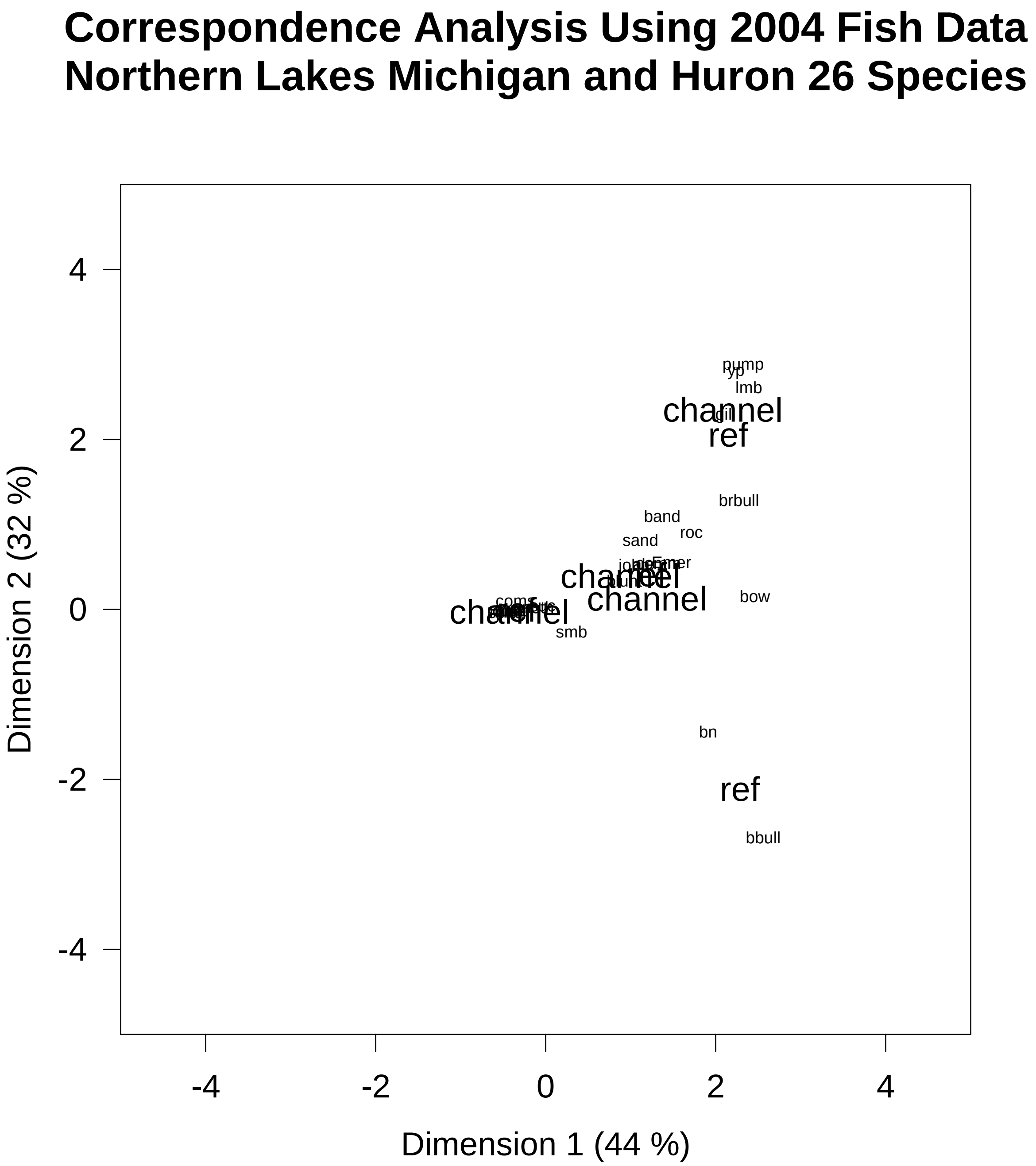
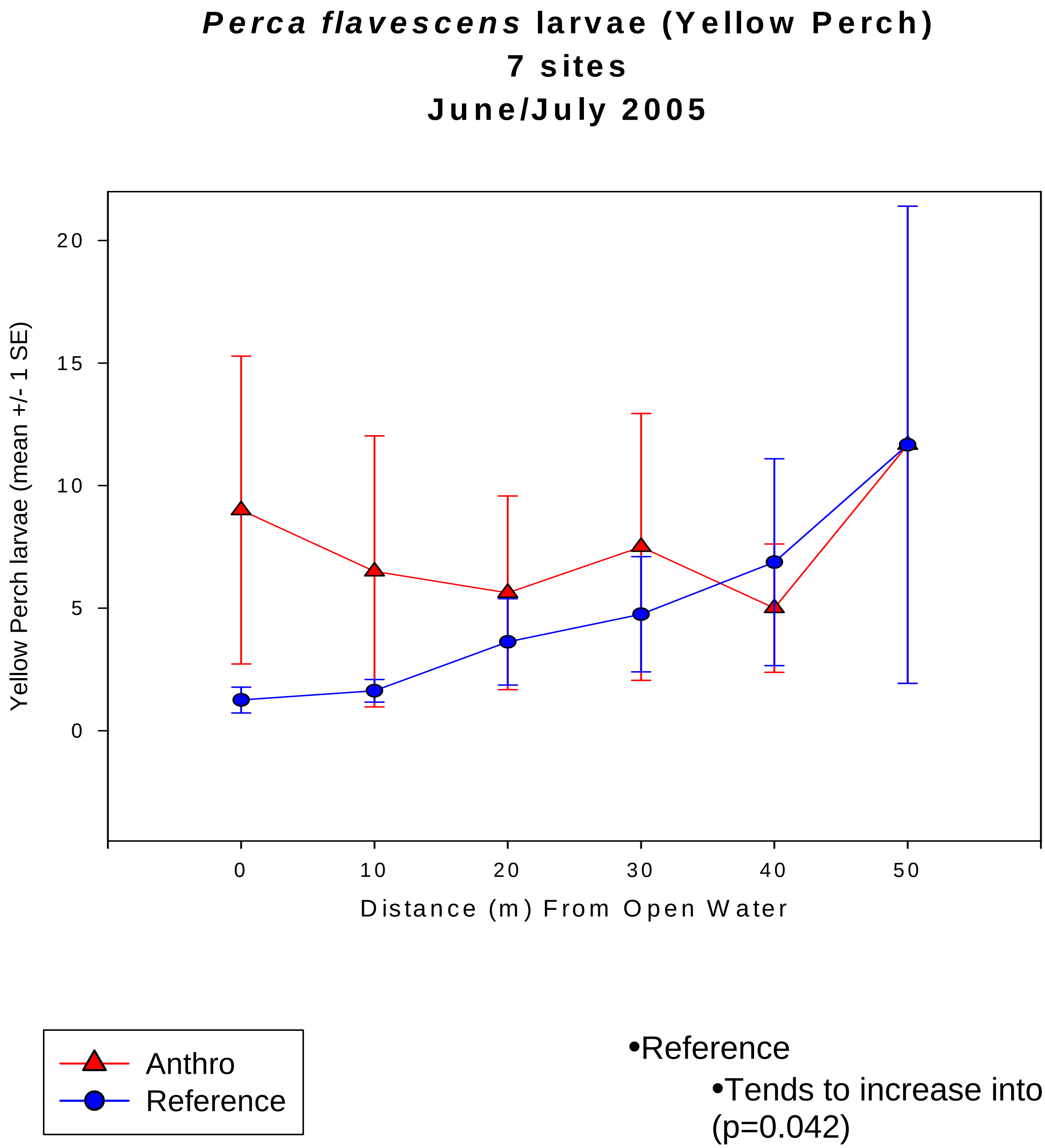


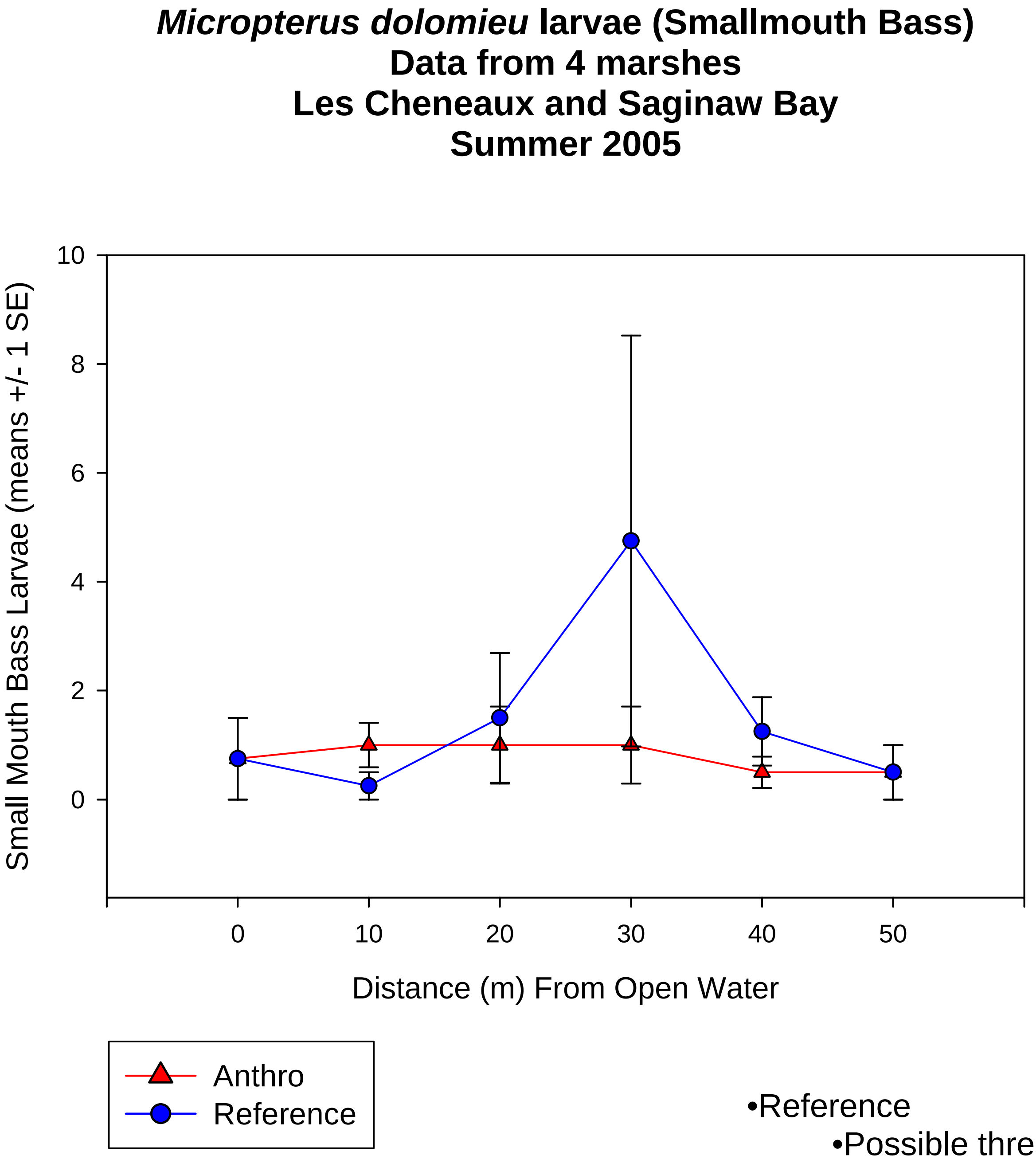
Figure 47. Correspondence analysis of fish data collected with fyke nets in wetlands of northern Lakes Michigan and Huron. Data from 26 species were included in the analysis.



- Reference
  - Tends to increase into marsh (p=0.042)

- Anthropogenic
  - Variability suggests that some marshes show great ‘edge effect’ and others do not.

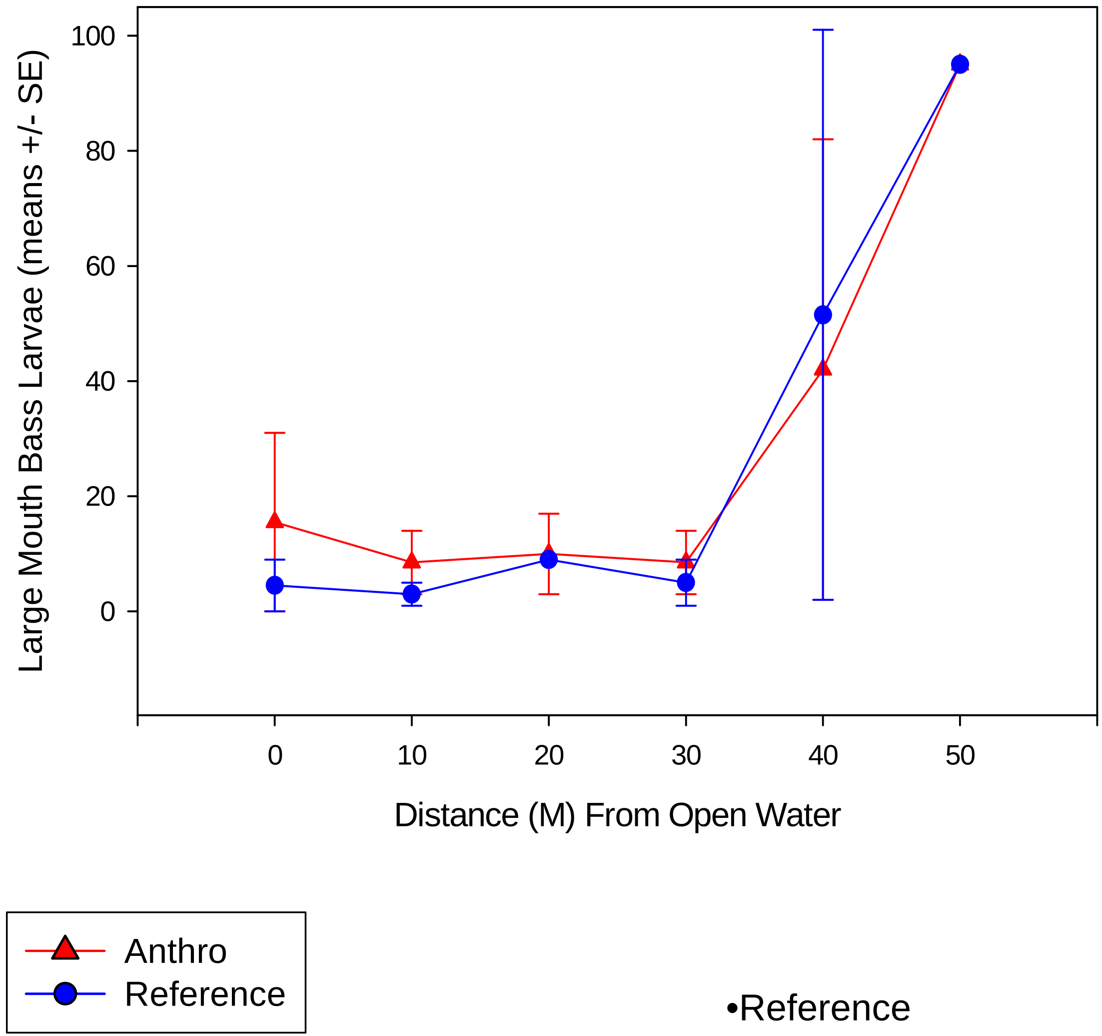
Figure 48. Larval yellow perch abundances from open water into marsh fragments along anthropogenic and reference transects.



- Reference
  - Possible threshold

- Anthropogenic
  - Large ‘edge effect’ in all 4 marshes.

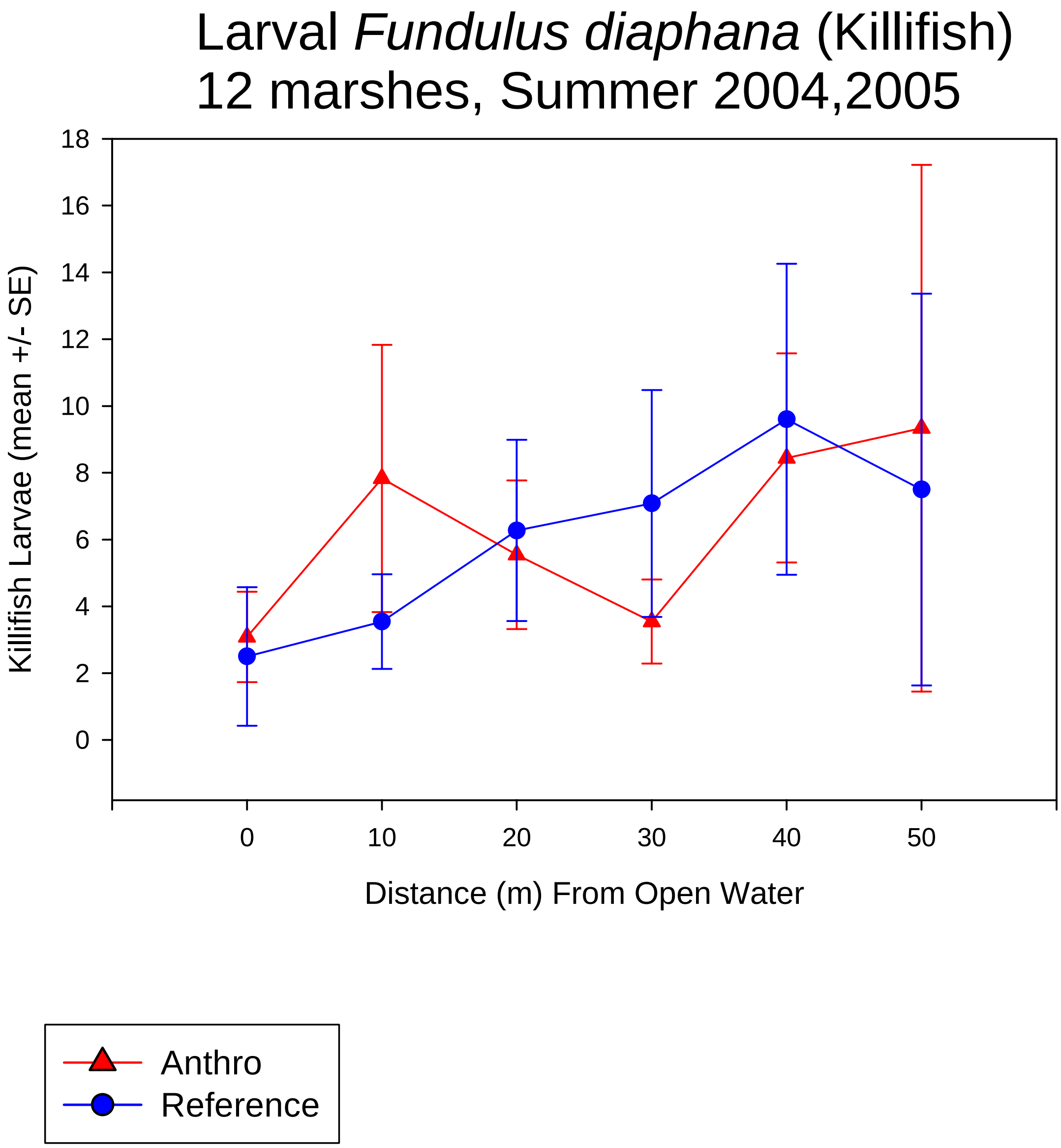
Figure 49. Larval small mouth bass abundances from open water into marsh fragments along anthropogenic and reference transects.



Micropterus salmoides larvae (Largemouth Bass
2 marshes / Saginaw Bay
June 2005

- •Reference
  - •Increase with distance (p=0.031)
- •Anthropogenic
  - •Large ‘edge effect’ (p=0.102)

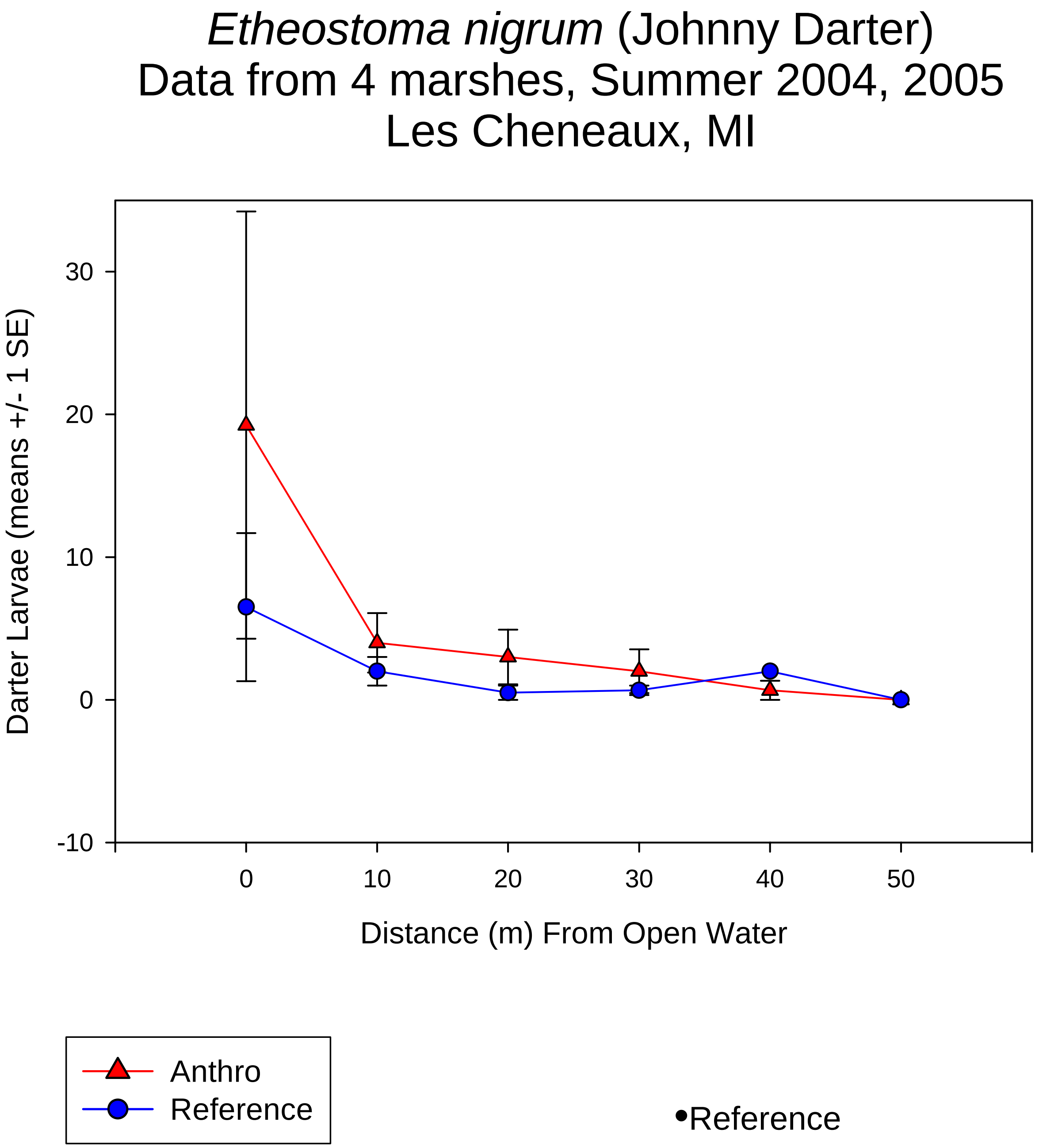
Figure 50. Larval large mouth bass abundances from open water into marsh fragments along anthropogenic and reference transects.



- Reference
  - Increase with distance (p=.034)

- Anthropogenic
  - small ‘edge effect’

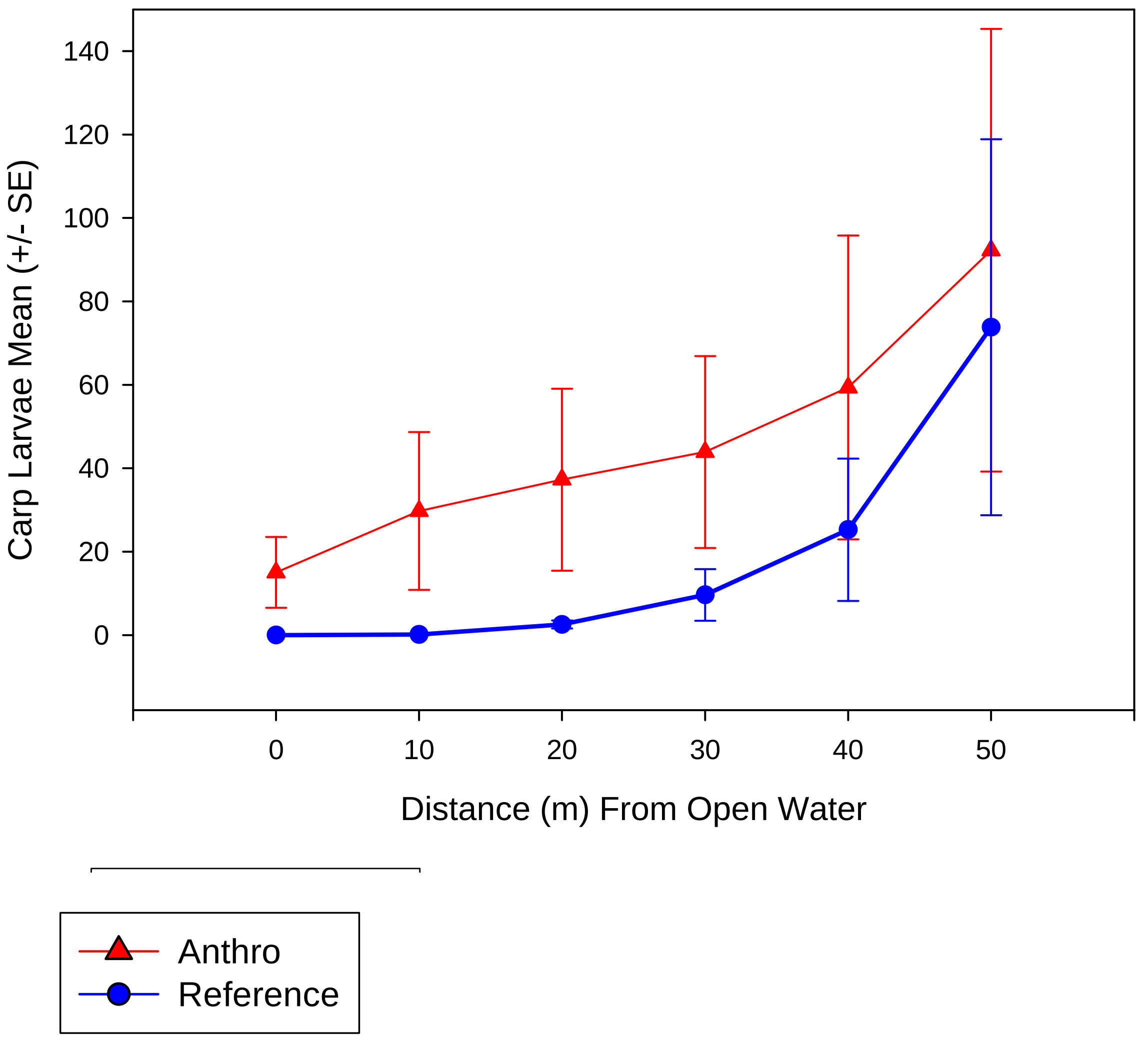
Figure 51. Larval banded killifish abundances from open water into marsh fragments along anthropogenic and reference transects.



- Reference
    - Decrease with distance (p=.086)

- Anthropogenic
    - Positive ‘edge effect’ (p=0.07)

Figure 52. Larval johnny darter abundances from open water into marsh fragments along anthropogenic and reference transects.



Cyprinus carpio (Common Carp)
Data from 8 marshes, May/June/July 2005
Saginaw Bay

- Reference
  - Increase with distance (p=0.001)

- Anthropogenic
  - Large ‘edge effect’ (p=0.184)

Figure 53. Larval common carp abundances from open water into marsh fragments along anthropogenic and reference transects.

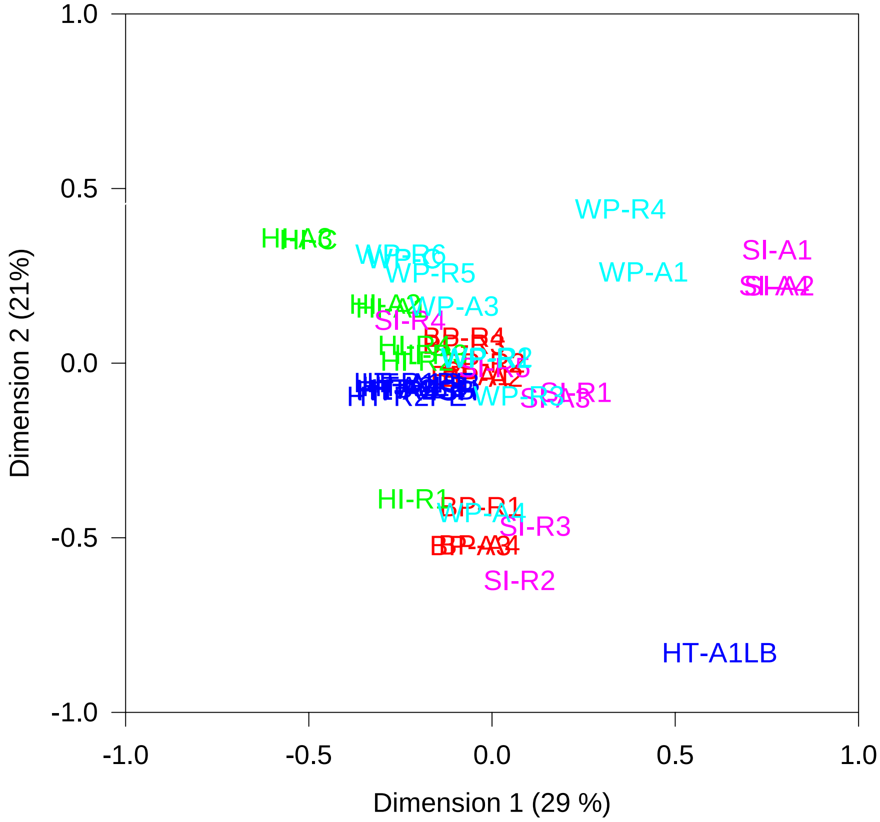


Figure 54. Correspondence analysis of microinvertebrates collected in quatrefoil light traps from coastal wetlands in 2004. Labels indicate site and position along transects. Included data from all 11 taxa captured.

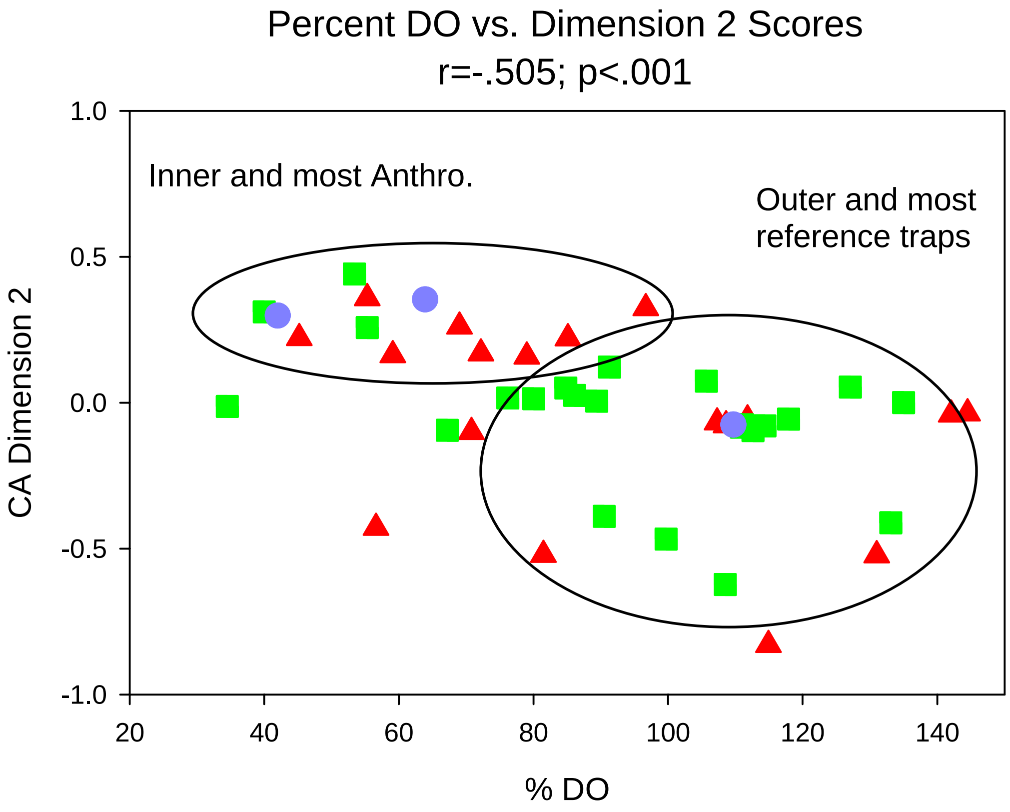


Figure 55. Correlation between CA dimension 2 scores for microinvertebrates (sampled with quatrefoil light traps) and percent saturation of dissolved oxygen in coastal wetlands (2004). Green squares represent light traps along reference transects, red triangles represent anthropogenic transects and blue circles represent corner traps.

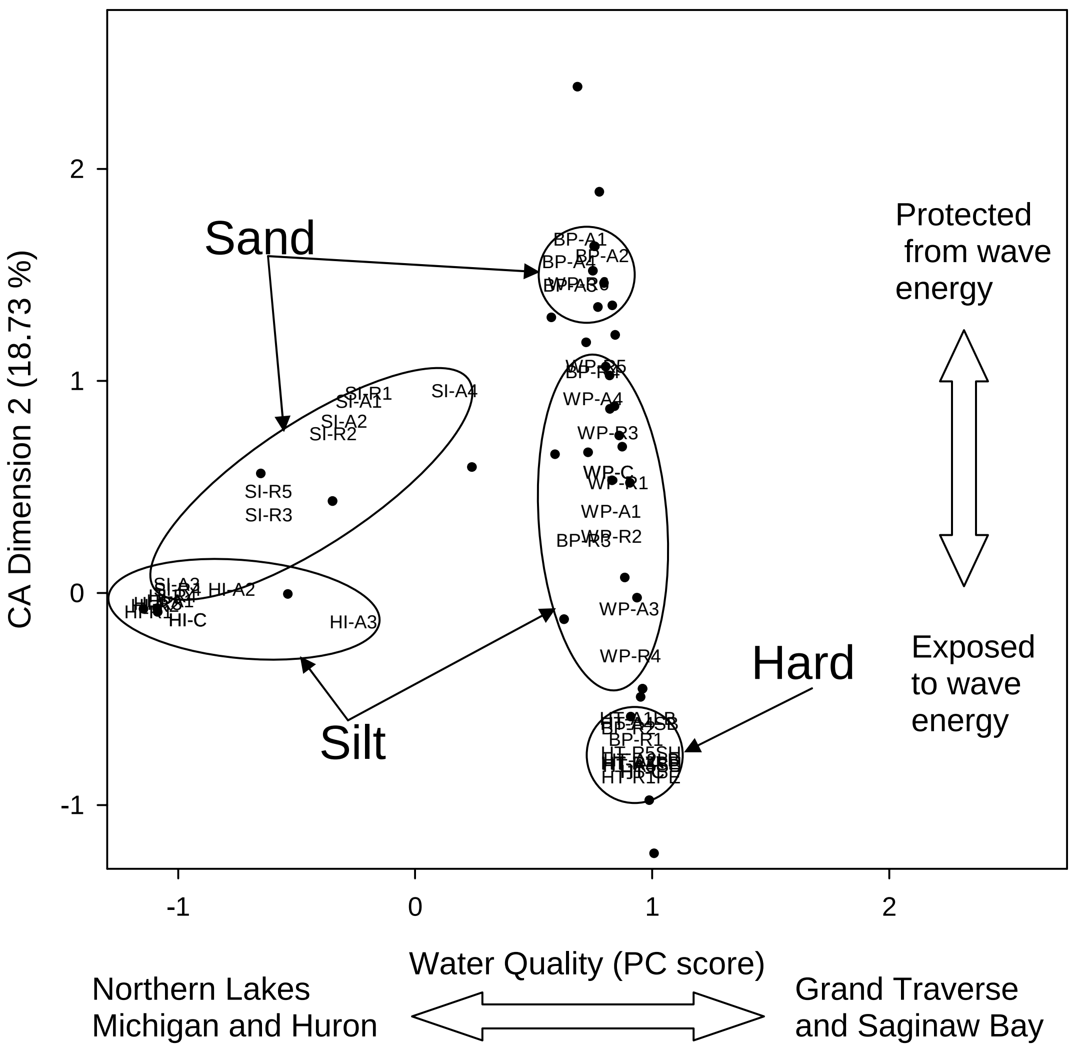


Figure 56. Correspondence analysis of macroinvertebrates collected in quatrefoil light traps in coastal wetlands of Saginaw Bay, Grand Traverse Bay, and northern Lakes Huron and Michigan in 2004. The analysis suggests a community response to pelagic mixing and substrate characteristics.

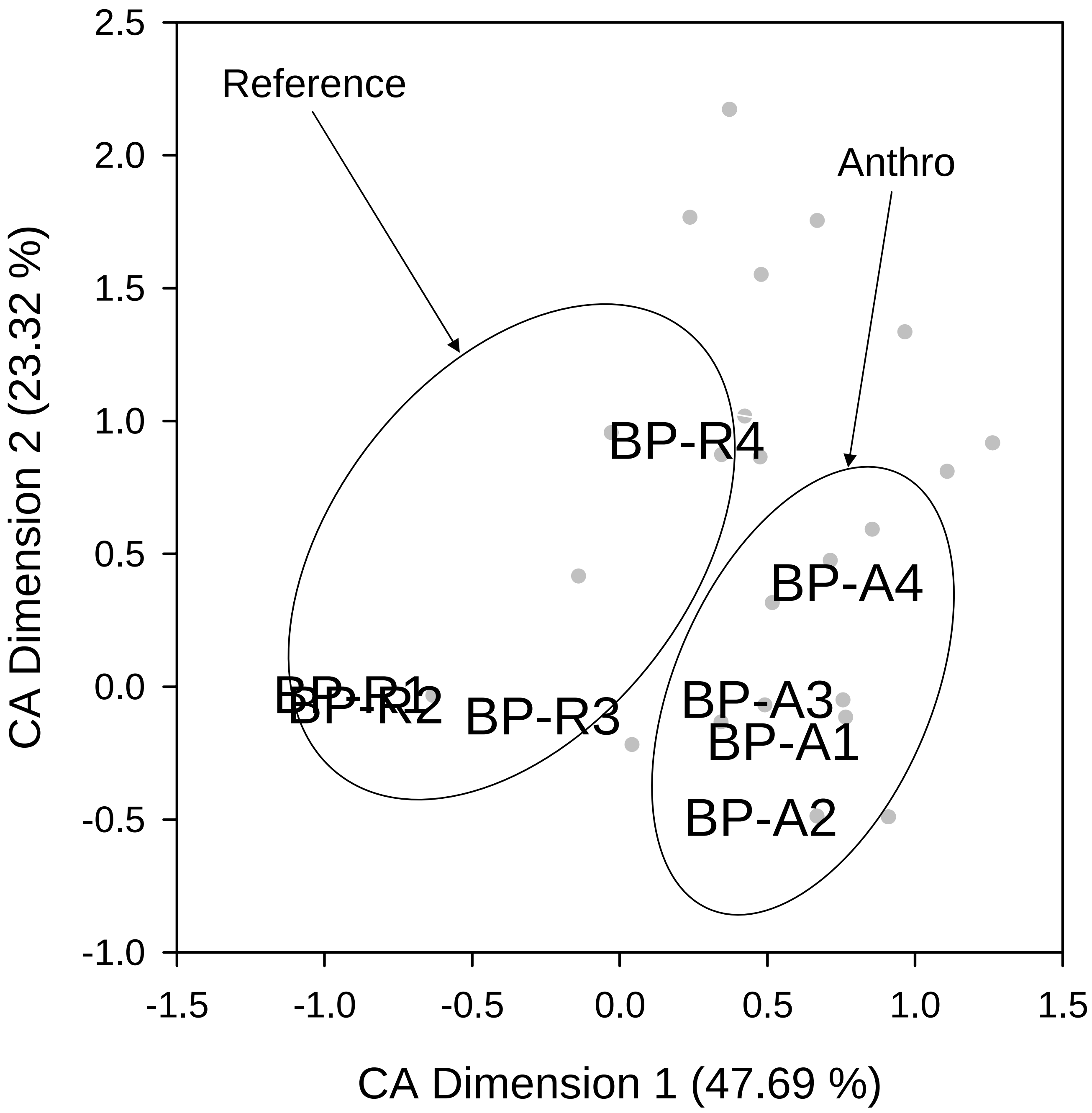


Figure 57. Correspondence analysis of macroinvertebrates collected in quatrefoil light traps at Bayport (Eastern Saginaw Bay). The analysis indicates gradients in community composition due pelagic mixing (dimension 2) and reference vs. anthropogenic edges (dimension 1).

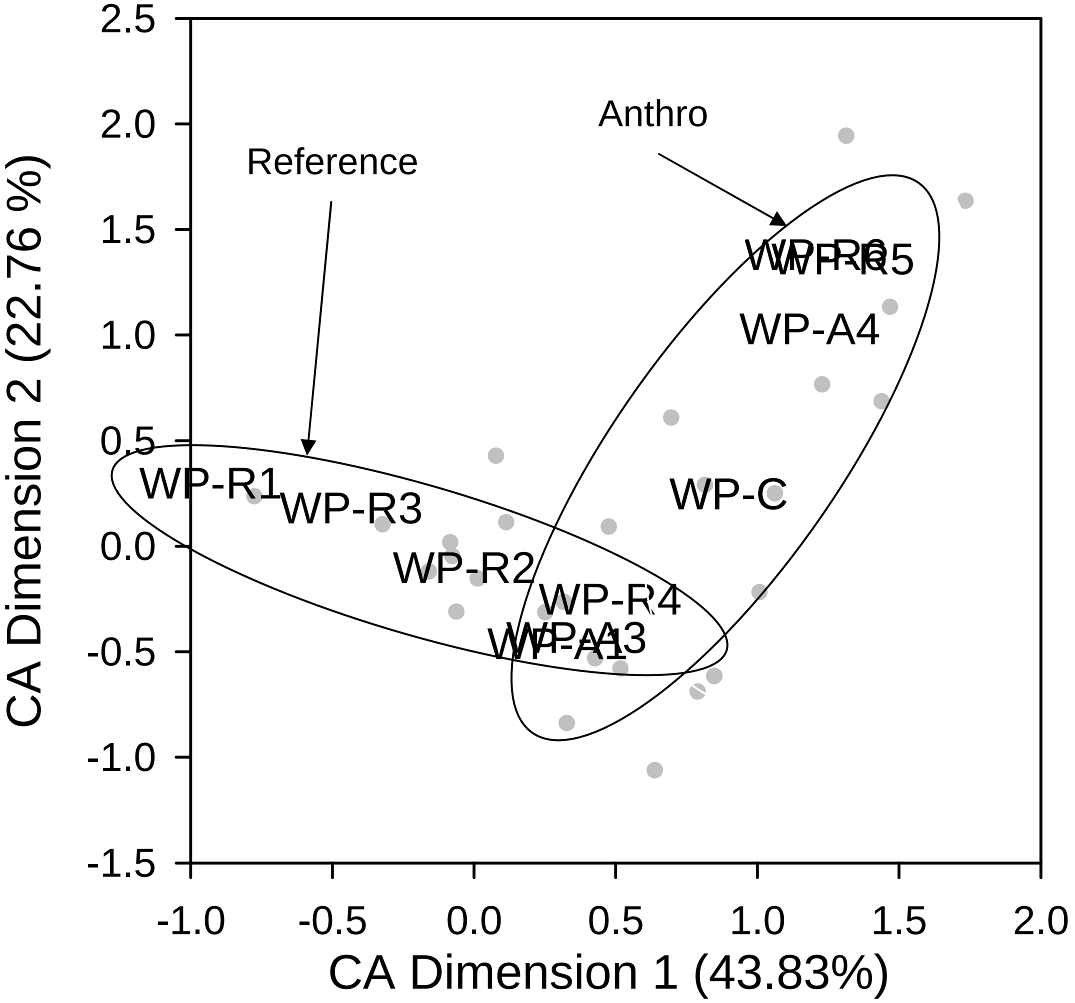


Figure 58. Correspondence analysis of macroinvertebrates collected in quatrefoil light traps at Wigwam Bay (Western Saginaw Bay). The analysis indicates gradients in community composition due pelagic mixing (dimension 2) and reference vs. anthropogenic edges (dimension 1).

Appendix A: Mean relative abundance of invertebrates collected in ‘reference’ wetlands of Saginaw and Grand Traverse Bays in 2004.

				Dunn Rd.	**Bay Port**	**Rose Island**	**Wigwam Bay**	**Bay City Park**	**Bay City Park**	**Linwood Ave**	**Almeda Beach**
				Phragmites	*Scirpus*	*Juncus* mix	*Scirp./Junc./Eleo.*	*Phrag./Scirp./Junc.*	*Phragmites*	*Scirp./Junc.*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/5/2004	7/20/2004	7/19/2004	7/21/2004	7/23/2004	7/23/2004	7/21/2004	8/6/2004
Oligochaeta		Naididae	*Stylaria*		21.57		2.95				
Oligochaeta		Naididae	unknown	1.66	1.42	12.23		18.59	5.14	21.41	11.83
Oligochaeta		Tubificidae	unknown	0.39		0.36			13.39		
Oligochaeta		Lumbriculidae	unknown					1.2	0.23		
Hirudinea			unknown	1.64				0.44	0.23	0.64	0.26
Bivalvia		Sphaeriidae	unknown					0.23			
Gastropoda		Lymnaeidae	*Fossaria obrussa*	8.88		0.83	26.12	5.98		9.87	
Gastropoda		Lymnaeidae	*Pseudos. columella*		9.56	1.57	11.62	1.36	4.73	0.86	0.26
Gastropoda		Lymnaeidae	*Stagnicola elodes*	0.78	15.22	1.99	1.12	11.62	27.85	2.19	12.48
Gastropoda		Physidae	*Physa gyrina*	3.86	0.49	5.66				11.38	3.42
Gastropoda		Planorbidae	*Gyra. circumstriatus*	2.59					14.96		
Gastropoda		Planorbidae	*Gyraulus deflectus*		0.47						
Gastropoda		Planorbidae	*Gyraulus parvus*						0.22		
Gastropoda		Planorbidae	*Gyraulus*		0.25		9.78	2.43		1.69	1.48
Gastropoda		Planorbidae	*Planorbella*					0.33			
Arachnida	Hydracarina		unknown	4.23	2.7	1.92	1.27	0.23	1.12	0.67	5.33
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*	3.82			5.19			1.36	14.57
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*								4.65
Crustacea	Amphipoda	Crangonyctidae	*Crangonyx*					0.37			3.65
Insecta	Collembola	Sminthuridae	unknown		0.23				0.22		
Insecta	Ephemerop.	Baetidae	*Baetis*				0.84				
Insecta	Ephemerop.	Baetidae	*Callibaetis sp.*							0.22	
Insecta	Ephemerop.	Caenidae	*Caenis*	34.29	1.17	15.45	5.83			19.22	13.34
Insecta	Odonata	Aeshnidae	*Anax junius*		1.42		2.34		0.89	0.39	0.26
Insecta	Odonata	Libellulidae	*Plathemis*	0.19							
Insecta	Odonata	Libellulidae	immature	0.39		0.84		0.65			
Insecta	Odonata	Coenagrionidae	*Coenagrion*				0.24		0.23		
Insecta	Odonata	Coenagrionidae	*Enallagma sp.*	0.28					0.44		
Insecta	Odonata	Coenagrionidae	*Ishnura sp.*	2.16	2.38		1.94		1.55	5.67	1.11
Insecta	Heteroptera	Belostomatidae	*Belostoma*		2.82		2.98			0.22	2.33
Insecta	Heteroptera	Belostomatidae	immature	0.62		2.14					
Insecta	Heteroptera	Corixidae	*Trichocorixa*				0.24				
Insecta	Heteroptera	Corixidae	*Sigara*		0.47	0.36				0.39	
Insecta	Heteroptera	Corixidae	immature		2.62	2.23	0.28			0.58	1.29
Insecta	Heteroptera	Gerridae	*Gerris*		0.23		0.27				0.26
Insecta	Heteroptera	Gerridae	*Limnoporus*		1.94						

Appendix A. (Continued)

				Dunn Rd.	**Bay Port**	**Rose Island**	**Wigwam Bay**	**Bay City Park**	**Bay City Park**	**Linwood Ave**	**Almeda Beach**
				Phragmites	*Scirpus*	*Juncus* mix	*Scirp./Junc./Eleo.*	*Phrag./Scirp./Junc.*	*Phragmites*	*Scirp./Junc.*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/5/2004	7/20/2004	7/19/2004	7/21/2004	7/23/2004	7/23/2004	7/21/2004	8/6/2004
Insecta	Heteroptera	Gerridae	*Trepobates*		1.18	0.36	0.27				
Insecta	Heteroptera	Gerridae	immature			0.36			0.22		
Insecta	Heteroptera	Hebridae	immature					0.92			
Insecta	Heteroptera	Hydrometridae	*Hydrometra*		0.24	0.36	0.53				
Insecta	Heteroptera	Mesoveliidae	*Mesovelia*	0.59	0.25	7.28	12.59			6.76	0.22
Insecta	Heteroptera	Nepidae	*Ranatra sp.*				0.24			0.19	
Insecta	Heteroptera	Notonectidae	immature			0.42				0.22	
Insecta	Heteroptera	Pleidae	*Neoplea*				0.28			0.19	
Insecta	Heteroptera	Veliidae	*Microvelia*		0.47						0.45
Insecta	Trichoptera		unknown								0.45
Insecta	Coleoptera	Dytiscidae	*Desmopachria*							0.22	
Insecta	Coleoptera	Dytiscidae	*Graphoderus*			1.57					
Insecta	Coleoptera	Dytiscidae	*Hydroporus*					1.26			
Insecta	Coleoptera	Dytiscidae	*Hygrotus*					0.44			
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hygrotus*		4.72	2.45	0.48	7.76	3.83	1.69	
Insecta	Coleoptera	Dytiscidae	*Ilybius*			0.42				0.22	0.22
Insecta	Coleoptera	Dytiscidae	*Laccophilus*		3.95	6.31				0.19	0.22
Insecta	Coleoptera	Dytiscidae	*Laccornis*						0.22		
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*			1.99					
Insecta	Coleoptera	Gyrinidae	*Gyrinus*				0.8				0.22
Insecta	Coleoptera	Haliplidae	*Haliplus*		0.25					0.19	
Insecta	Coleoptera	Haliplidae	*Peltodytes*				0.28				
Insecta	Coleoptera	Helophoridae	*Helophorus sp.*						0.22		
Insecta	Coleoptera	Hydrochidae	*Hydrochus sp.*		0.23						
Insecta	Coleoptera	Hydrophilidae	*Anacaena sp.*						0.23		
Insecta	Coleoptera	Hydrophilidae	*Berosus*		0.25	1.62	0.52				
Insecta	Coleoptera	Hydrophilidae	*Derallus*			0.36					
Insecta	Coleoptera	Hydrophilidae	*Enochrus*					0.44	0.23		
Insecta	Coleoptera	Hydrophilidae	*Hydrophilus*	0.23	0.56				0.44		
Insecta	Coleoptera	Hydrophilidae	*Paracymus sp.*		0.24	0.42		0.55		0.22	
Insecta	Coleoptera	Hydrophilidae	*Tropisternus*			0.78				0.22	
Insecta	Coleoptera	Hydrophilidae	unknown		1.98	0.36				0.39	
Insecta	Coleoptera	Chrysomelidae	unknown		0.24						
Insecta	Coleoptera	Curculionidae	unknown				1.34	0.6			
Insecta	Coleoptera	Elmidae	unknown						0.23		
Insecta	Coleoptera	Scirtidae	unknown					0.6	0.68		
Insecta	Diptera	Chironomidae	Chironomini	3.31	11.37	2.76	0.24	18.63	5.99	0.44	0.88
Insecta	Diptera	Chironomidae	Tanytarsini	0.97	5.34				0.44		11.53

Appendix A. (Continued)

				Dunn Rd.	**Bay Port**	**Rose Island**	**Wigwam Bay**	**Bay City Park**	**Bay City Park**	**Linwood Ave**	**Almeda Beach**
				Phragmites	*Scirpus*	*Juncus* mix	*Scirp./Junc./Eleo.*	*Phrag./Scirp./Junc.*	*Phragmites*	*Scirp./Junc.*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/5/2004	7/20/2004	7/19/2004	7/21/2004	7/23/2004	7/23/2004	7/21/2004	8/6/2004
Insecta	Diptera	Chironomidae	Tanypodinae	0.66	1.43	0.78	0.27	0.65	0.44		0.48
Insecta	Diptera	Chironomidae	Orthocladinae	1.77		0.42			9.67		0.45
Insecta	Diptera	Chironomidae	Corynoneura						0.67		
Insecta	Diptera	Chironomidae	pupa	0.23	0.76	5.26					0.44
Insecta	Diptera	Ceratopogon.	*Bezzia*	15.57	1.22	18.18	0.28	1.43	2.68	3.97	3.59
Insecta	Diptera	Ceratopogon.	pupa					0.23		0.22	
Insecta	Diptera	Culicidae	*Anopheles*		0.72	2.45	0.56	0.37	1.78		0.78
Insecta	Diptera	Culicidae	*Culex* sp.				0.24	1.37			
Insecta	Diptera	Culicidae	pupa		0.47	0.42		0.71	0.23	0.19	0.26
Insecta	Diptera	Dixidae	*Dixella* sp.					1.76			
Insecta	Diptera	Tipulidae	unknown					0.65	0.67		
Insecta	Diptera	Sciomyzidae	unknown					0.23			
Insecta	Diptera	Stratiomyiidae	*Odontomyia/Hedri.*	0.28	0.25	0.42		0.92			
Insecta	Diptera	Stratiomyiidae	*Stratiomys sp.*		0.24						

				Nayanquing	**Hilltop**	**Pt. Au Gres**	**Bayshore Pk.**	**Almeda Beach**	**BayPort**	**Dunn Road**	**Wigwam Bay**
				Scirp./Junc.	*Scirpus*	*Eleoch./Phrag.*	ungroomed	*Scirpus/Juncus*	swale	shallow *Phrag.*	*Scirpus/Juncus*
Class	Order	Family	Genus/Species	7/21/2004	8/17/2004	7/22/2004	8/31/2004	8/16/2004	7/20/2004	8/5/2004	7/21/2004
Oligochaeta		Naididae	*Stylaria*	0.49			0.95	1.77		0.22	
Oligochaeta		Naididae	unknown	4.49		0.68	2.14	4.13		7.75	0.22
Oligochaeta		Tubificidae	unknown	0.23		0.24	0.63	1.85			
Hirudinea			unknown	0.23		0.24	1.42				
Bivalvia		Sphaeriidae	unknown		0.23				0.28		
			Dreissena				3.66				
Gastropoda		Lymnaeidae	*Fossaria obrussa*								17.12
Gastropoda		Lymnaeidae	*Pseudos. columella*	3.25		2.47	0.35	1.62	0.99		1.89
Gastropoda		Lymnaeidae	*Stagnicola elodes*	5.34	1.44	15.22	2.52	19.85	11.74	23.94	12.99
Gastropoda		Physidae	*Physa gyrina*	7.48	15.45	0.24	22.79	1.63		2.15	8.92
Gastropoda		Planorbidae	*Gyraulus*		5.74	2.39	0.35	2.69		0.26	6.13
Gastropoda		Planorbidae	*Planorbella*								0.46
Arachnida	Hydracarina		unknown	12.34		1.11	0.95	8.9	0.72	1.64	0.72
Crustacea	Isopoda	Asellidae	*Caecidotea*	0.72			0.79		8.13		
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*	11.43	42.98	0.44	11.52	6.17		0.51	0.24
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*	0.25	5.69		18.74	0.76			
Crustacea	Amphipoda	Crangonyctidae	*Crangonyx*		11.45				1.28		
Crustacea	Decapoda	Cambaridae	unknown		0.89						
Insecta	Ephemerop.	Baetidae	*Baetis*				0.79				

Appendix A. (Continued)

				Nayanquing	**Hilltop**	**Pt. Au Gres**	**Bayshore Pk.**	**Almeda Beach**	**BayPort**	**Dunn Road**	**Wigwam Bay**
				Scirp./Junc.	*Scirpus*	*Eleoch./Phrag.*	ungroomed	*Scirpus/Juncus*	swale	shallow *Phrag.*	*Scirpus/Juncus*
Class	Order	Family	Genus/Species	7/21/2004	8/17/2004	7/22/2004	8/31/2004	8/16/2004	7/20/2004	8/5/2004	7/21/2004
Insecta	Ephemerop.	Baetidae	*Callibaetis sp.*		2.43		0.24		0.28	0.22	
Insecta	Ephemerop.	Caenidae	*Caenis*	13.66		2.15	2.94	3.47		35.12	33.38
Insecta	Odonata	Aeshnidae	*Anax junius*	0.25		0.24			0.5	0.47	
Insecta	Odonata	Aeshnidae	immature			0.24			1.38		
Insecta	Odonata	Libellulidae	*Celithemis*							0.22	
Insecta	Odonata	Libellulidae	*Libellula pulchella*				0.4				
Insecta	Odonata	Libellulidae	*Sympetrum*						0.28		
Insecta	Odonata	Libellulidae	immature			0.48			0.83	0.44	0.24
Insecta	Odonata	Coenagrionidae	*Enallagma sp.*			0.48	4.69	0.25		0.44	
Insecta	Odonata	Coenagrionidae	*Ishnura sp.*	2.92		0.92	4.11	0.73		0.26	0.22
Insecta	Odonata	Coenagrionidae	immature						3.36		
Insecta	Heteroptera	Belostomatidae	*Belostoma*			0.48	0.24	4.53		0.22	
Insecta	Heteroptera	Belostomatidae	immature	2.7		47.81	0.24			0.75	0.95
Insecta	Heteroptera	Corixidae	*Trichocorixa*	0.76		0.24	0.4	0.23			1.4
Insecta	Heteroptera	Corixidae	*Sigara*			0.24		0.23			
Insecta	Heteroptera	Corixidae	immature	6.36		2.99		0.47		0.23	
Insecta	Heteroptera	Gerridae	*Gerris*	0.23							
Insecta	Heteroptera	Gerridae	immature	2.45		0.28		0.7		0.26	0.22
Insecta	Heteroptera	Hebridae	immature						0.49		
Insecta	Heteroptera	Hydrometridae	*Hydrometra*								0.24
Insecta	Heteroptera	Mesoveliidae	*Mesovelia*	12.26		3.99	0.59	4.77	0.28	6.79	3.79
Insecta	Heteroptera	Notonectidae	immature	0.25		0.45					
Insecta	Heteroptera	Saldidae	immature	0.54				5.54			
Insecta	Heteroptera	Veliidae	*Microvelia*	1.44							
Insecta	Trichoptera	Leptoceridae	*Nectopsyche*		2.65		5.45	1.52			
Insecta	Coleoptera	Dytiscidae	*Coptotomus*	0.27							
Insecta	Coleoptera	Dytiscidae	*Graphoderus*				0.4				
Insecta	Coleoptera	Dytiscidae	*Hygrotus*						0.22		0.24
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hygrotus*			1.63			0.88		
Insecta	Coleoptera	Dytiscidae	*Ilybius*	1.46		0.47					
Insecta	Coleoptera	Dytiscidae	*Laccophilus*	2.79		3.74			1.88		3.89
Insecta	Coleoptera	Dytiscidae	*Laccornis*	0.47							
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*					0.25	0.99		
Insecta	Coleoptera	Gyrinidae	*Gyrinus*					0.47			
Insecta	Coleoptera	Haliplidae	*Haliplus*						0.44		
Insecta	Coleoptera	Helophoridae	*Helophorus sp.*						1.49		
Insecta	Coleoptera	Hydrophilidae	*Berosus*	0.25			0.63			0.23	0.47
Insecta	Coleoptera	Hydrophilidae	*Derallus*			1.83		0.23			

Appendix A. (Continued)

				Nayanquing	**Hilltop**	**Pt. Au Gres**	**Bayshore Pk.**	**Almeda Beach**	**BayPort**	**Dunn Road**	**Wigwam Bay**
				Scirp./Junc.	*Scirpus*	*Eleoch./Phrag.*	ungroomed	*Scirpus/Juncus*	swale	shallow *Phrag.*	*Scirpus/Juncus*
Class	Order	Family	Genus/Species	7/21/2004	8/17/2004	7/22/2004	8/31/2004	8/16/2004	7/20/2004	8/5/2004	7/21/2004
Insecta	Coleoptera	Hydrophilidae	*Enochrus*						2.76		
Insecta	Coleoptera	Hydrophilidae	*Hydrochara*						0.22		
Insecta	Coleoptera	Hydrophilidae	*Paracymus sp.*	0.76					1.38		0.72
Insecta	Coleoptera	Hydrophilidae	*Tropisternus*			0.79					2.36
Insecta	Coleoptera	Hydrophilidae	unknown			0.24					
Insecta	Coleoptera	Curculionidae	unknown			0.24					
Insecta	Coleoptera	Scirtidae	unknown						5.87		
Insecta	Diptera	Chironomidae	Chironomini	0.27	5.54	2.15	2.96	8.31	9.99	0.67	1.17
Insecta	Diptera	Chironomidae	Tanytarsini		6.3	0.67	0.24	1.86	42.89		
Insecta	Diptera	Chironomidae	Tanypodinae	0.72	0.55	2.34	1.74	0.44	0.77		0.47
Insecta	Diptera	Chironomidae	Orthocladinae	0.75			4.94			2.23	
Insecta	Diptera	Chironomidae	Corynoneura	0.23			0.24				
Insecta	Diptera	Chironomidae	pupa			0.83	0.24			0.26	
Insecta	Diptera	Ceratopogon.	*Bezzia*	1.19		0.72		1.19		14.31	
Insecta	Diptera	Ceratopogon.	*Dasyhelea*								0.24
Insecta	Diptera	Ceratopogon.	pupa	0.49		0.24	0.79			0.26	0.72
Insecta	Diptera	Culicidae	*Anopheles*	0.49				3.42			0.24
Insecta	Diptera	Culicidae	pupa	0.27		1.19		1.84			0.24
Insecta	Diptera	Tipulidae	unknown	0.23				0.45			
Insecta	Diptera	Sciomyzidae	unknown						0.28		0.22
Insecta	Diptera	Stratiomyiidae	*Odontomyia/Hedri.*	0.27				0.23		0.22	

Appendix B: Mean relative abundance of invertebrates collected in 'less recently mowed' wetlands of Saginaw and Grand Traverse Bays in 2004.

Class	**Order**	**Family**	**Genus/Species**	**S. Linwood** *Scirpus* 8/6/2004	**Rose Island 1** *Scirpus* 7/19/2004	**Rose Island 1** *Typha/Scirpus* 7/19/2004	**Waterfr. Inn** *Typha* 1 8/17/2004	**Rose Island 1** *Juncus* 7/19/2004	**BayPort 1** *Scirpus* 7/16/2004	**S. Linwood** *Scirpus/Juncus* 8/6/2004	**Waterfr. Inn** *Scirpus* 8/17/2004
Turbellaria			flatworms								0.33
Oligochaeta		Naididae	*Stylaria*		0.25	0.32					0.33
Oligochaeta		Naididae	unknown	2.53	9.99		7.3	2.62	20.91		0.66
Oligochaeta		Tubificidae	unknown					0.81			
Hirudinea				0.24	0.68	1.24		0.52	0.22		32.32
Bivalvia			*Dreissena*	0.24							
Gastropoda		Hydrobiidae		0.24							
Gastropoda		Lymnaeidae	*Fossaria obrussa*	6.83	3.27	7.94			30.02	17.93	
Gastropoda		Lymnaeidae	*Pseudos. columella*		0.93	1.18	0.63	11.28	0.44	1.33	1.58
Gastropoda		Lymnaeidae	*Stagnicola elodes*	1.38	4.2	5.69		16.62		0.9	2.55
Gastropoda		Physidae	*Physa gyrina*	13.63	2.68	0.62	1.89	0.76	5.16	15.7	5.63
Gastropoda		Planorbidae	*Gyr. circumstriatus*	0.58	2.64						
Gastropoda		Planorbidae	*Gyraulus deflectus*		0.33						
Gastropoda		Planorbidae	*Gyraulus*	1.42		19.23	1.3	0.29	1.79	0.44	2.81
Gastropoda		Pleuroceridae	unknown	0.21							
Arachnida	Hydracarina			1.02	2.78	4.83	2	4.44	4.35	3.58	0.33
Crustacea	Isopoda	Asellidae	*Caecidotea*	0.24			0.63				10.99
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*	39.92	13.55	0.65	45.43		6.52	39.49	11.17
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*	1.95		0.51					6.66
Crustacea	Amphipoda	Crangonyct.	*Crangonyx*		0.25						0.66
Insecta	Collembola	Isotomidae					3.14		0.22		1.56
Insecta	Collembola	Sminthuridae	unknown			0.51					0.63
Insecta	Ephemerop.	Baetidae	*Callibaetis sp.*			3.82		2.74	1.34	0.22	0.33
Insecta	Ephemerop.	Caenidae	*Caenis*	4.51	8.05	6.73	0.33	5.32	4.67	6.94	
Insecta	Odonata	Aeshnidae	*Aeshna umbrosa*		0.25				0.23		
Insecta	Odonata	Aeshnidae	*Anax junius*		1.31	4.06		1.46			
Insecta	Odonata	Libellulidae	*Libellula pulchella*								0.33
Insecta	Odonata	Coenagrionid.	*Coenagrion*			2.91					
Insecta	Odonata	Coenagrionid.	*Enallagma sp.*	1.85	2.4				4.1	0.67	
Insecta	Odonata	Coenagrionid.	*Ishnura sp.*	0.19	16.62	14.68	0.63	0.35	4.91		15.92
Insecta	Heteroptera	Belostomat.	*Belostoma*			2.87		0.35			0.33
Insecta	Heteroptera	Belostomat.	immature		2.07			4.61		1.12	

Appendix B. (Continued)

				S. Linwood	**Rose Island 1**	**Rose Island 1**	**Waterfr. Inn**	**Rose Island 1**	**BayPort 1**	**S. Linwood**	**Waterfr. Inn**
				Scirpus	*Scirpus*	*Typha/Scirpus*	*Typha* 1	*Juncus*	*Scirpus*	*Scirpus/Juncus*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/6/2004	7/19/2004	7/19/2004	8/17/2004	7/19/2004	7/16/2004	8/6/2004	8/17/2004
Insecta	Heteroptera	Corixidae	Trichocorixa					0.35			
Insecta	Heteroptera	Corixidae	*Hesperocorixa*		0.33						0.99
Insecta	Heteroptera	Corixidae	*Sigara*							0.44	
Insecta	Heteroptera	Corixidae	immature							0.44	
Insecta	Heteroptera	Gerridae	*Gerris*		0.34			0.29		0.23	
Insecta	Heteroptera	Gerridae	*Limnoporus*		0.67						
Insecta	Heteroptera	Gerridae	*Trepobates*			2.86					
Insecta	Heteroptera	Gerridae	immature					1.52			
Insecta	Heteroptera	Hydromet.	*Hydrometra*		0.34						
Insecta	Heteroptera	Mesoveliidae	*Mesovelia*	0.39	3.76	0.8		0.23	2	3.12	
Insecta	Heteroptera	Nepidae	*Ranatra sp.*		0.34	0.8				0.22	
Insecta	Heteroptera	Notonectidae	immature		0.25						
Insecta	Heteroptera	Pleidae	*Neoplea*			0.59		1.05		0.23	
Insecta	Heteroptera	Saldidae	immature					0.47			
Insecta	Trichoptera	Hydroptilidae			1.25		1.89				
Insecta	Trichoptera	Leptoceridae	*Triaenoides*						0.68		
Insecta	Trichoptera	Leptoceridae	*Oecetis*	0.64			1.63				
Insecta	Trichoptera	Leptoceridae	*Mystacides*	2.41							
Insecta	Trichoptera	Leptoceridae	*Nectopsyche*						3.17		
Insecta	Trichoptera	Limnephilidae							0.89		
Insecta	Lepidoptera	Unknown			0.33				0.46		
Insecta	Coleoptera	Dytiscidae	*Agabus*						0.22		
Insecta	Coleoptera	Dytiscidae	*Hydroporus*					0.23			
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hygr.*		0.25			5.02			
Insecta	Coleoptera	Dytiscidae	*Ilybius*					0.88			
Insecta	Coleoptera	Dytiscidae	*Laccophilus*		0.33			4.86		0.67	
Insecta	Coleoptera	Dytiscidae	*Laccornis*					1.11			0.64
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*	0.47						0.45	
Insecta	Coleoptera	Gyrinidae	*Gyrinus*						1.13		
Insecta	Coleoptera	Haliplidae	*Haliplus*					0.47			0.33
Insecta	Coleoptera	Haliplidae	*Peltodytes*		0.33	0.59					
Insecta	Coleoptera	Helophoridae	*Helophorus sp.*					0.29			
Insecta	Coleoptera	Hydrophilid.	*Berosus*		0.25						

Appendix B. (Continued)

Class	Order	Family	Genus/Species	**S. Linwood** *Scirpus* 8/6/2004	**Rose Island 1** *Scirpus* 7/19/2004	**Rose Island 1** *Typha/Scirpus* 7/19/2004	**Waterfr. Inn** *Typha* 1 8/17/2004	**Rose Island 1** *Juncus* 7/19/2004	**BayPort 1** *Scirpus* 7/16/2004	**S. Linwood** *Scirpus/Juncus* 8/6/2004	**Waterfr. Inn** *Scirpus* 8/17/2004
Insecta	Coleoptera	Hydrophilid.	*Derallus*								0.33
Insecta	Coleoptera	Hydrophilid.	*Enochrus*		0.25		0.63				
Insecta	Coleoptera	Hydrophilid.	*Hydrochus*					0.35	0.22		
Insecta	Coleoptera	Hydrophilid.	*Hydrophilus*					0.23	0.22		
Insecta	Coleoptera	Hydrophilid.	*Laccobius*						0.22		
Insecta	Coleoptera	Hydrophilid.	*Tropisternus*					0.58		1.13	0.33
Insecta	Coleoptera	Hydrophilid.	unknown					0.94			
Insecta	Coleoptera	Curculionidae	unknown					0.29		0.22	
Insecta	Diptera	Chironomid.	Chironomini	17.72	2.27	3.01	3.67	6.96	0.23	1.14	0.66
Insecta	Diptera	Chironomid.	Tanytarsini	0.78	0.49	1.94		0.59	2.96	0.91	0.31
Insecta	Diptera	Chironomid.	Tanypodinae	0.24	1.67	0.32		2.75		0.67	
Insecta	Diptera	Chironomid.	Orthocladinae		1.59		28.25	2.28			0.33
Insecta	Diptera	Chironomid.	Corynoneura	0.19	0.58	0.88		1.34			
Insecta	Diptera	Chironomid.	pupa		1.41	0.51				0.68	
Insecta	Diptera	Ceratopogon.	*Bezzia*	0.19	9.8	6.94	0.67	12.88	1.79	1.12	
Insecta	Diptera	Ceratopogon.	pupa			1.27			0.67		
Insecta	Diptera	Culicidae	*Anopheles*			0.8		0.29			0.33
Insecta	Diptera	Culicidae	pupa		0.68	0.62		0.29			
Insecta	Diptera	Tipulidae			0.33			0.47			
Insecta	Diptera	Stratiomyiid.	*Odontomyia* /*Hedri.*			0.29					0.66

Appendix B. (Continued)

				Waterfr. Inn	**Waterfr. Inn**	**Linwood Ave.**	**Linwood Ave.**	**S. Linwood**	**White's Beach**	**Bay Shore**
				swale	*Typha*	*Juncus*	*Scirpus/Juncus*	*Eleocharis*	*Scirpus/Juncus*	mowed
Class	**Order**	**Family**	**Genus/Species**	8/17/2004	8/17/2004	7/21/2004	7/21/2004	8/6/2004	7/21/2004	8/31/2004
Turbellaria			flatworms		12.28					
Oligochaeta		Naididae	*Stylaria*	0.23						0.46
Oligochaeta		Naididae	unknown	0.63	1.12	0.45			0.22	3.36
Oligochaeta		Tubificidae	unknown							0.76
Hirudinea				0.67	0.19			0.45		
Bivalvia		Sphaeriidae			0.24					1.3
Gastropoda		Lymnaeidae	*Fossaria obrussa*			7.01	9.6			
Gastropoda		Lymnaeidae	*Pseudos. columella*		0.19	1.8	1.87	8.97		
Gastropoda		Lymnaeidae	*Stagnicola elodes*		0.24	5.95	3.13	30.74	40.33	1.14
Gastropoda		Physidae	*Physa gyrina*	3.43	12.42	26.68	18.61	4.08	5.4	6.39
Gastropoda		Planorbidae	*Gyraulus*	0.88	1.94	0.66	8.67	0.75	1.16	
Gastropoda		Planorbidae	*Promen. exacuous*						0.22	
Gastropoda		Pleuroceridae	unknown						0.19	
Arachnida	Hydracarina			0.24		1.46	0.66	1.18	0.57	16.69
Crustacea	Isopoda	Asellidae	*Caecidotea*		44.98					
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*	0.87		1.88	6.26	15.26	5.5	16.69
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*	2.15					2.08	2.89
Crustacea	Amphipoda	Crangonyc.	*Crangonyx*		11.67			0.47		
Insecta	Collembola	Isotomidae	unknown	1.13	1.57			0.21		
Insecta	Collembola	Sminthuridae	unknown	0.23						
Insecta	Ephemerop.	Baetidae	*Baetis*							6.77
Insecta	Ephemerop.	Baetidae	*Callibaetis sp.*	0.24					0.22	
Insecta	Ephemerop.	Caenidae	*Caenis*			8.22	11.8	0.68	5.04	2.15
Insecta	Ephemerop.	Ephermerid.	*Ephemera*						0.19	
Insecta	Odonata	Aeshnidae	*Anax junius*	0.44	0.61	0.68	0.76			
Insecta	Odonata	Aeshnidae	immature				0.71			
Insecta	Odonata	Libellulidae	*Libellula pulchella*		1.31					
Insecta	Odonata	Libellulidae	immature	1.63						
Insecta	Odonata	Coenagrion.	*Enallagma sp.*	0.95					5.75	
Insecta	Odonata	Coenagrion.	*Ishnura sp.*	49.98		0.51	2.96		1.46	
Insecta	Odonata	Coenagrion.	immature		3.88	0.66	5.09			
Insecta	Heteroptera	Belostomat.	*Belostoma*			0.43		2.1		
Insecta	Heteroptera	Belostomat.	immature			0.82	0.93			

Appendix B. (Continued)

				Waterfr. Inn	**Waterfr. Inn**	**Linwood Ave.**	**Linwood Ave.**	**S. Linwood**	**White's Beach**	**Bay Shore**
				swale	*Typha*	*Juncus*	*Scirpus/Juncus*	*Eleocharis*	*Scirpus/Juncus*	mowed
Class	**Order**	**Family**	**Genus/Species**	8/17/2004	8/17/2004	7/21/2004	7/21/2004	8/6/2004	7/21/2004	8/31/2004
Insecta	Heteroptera	Corixidae	*Trichocorixa*		0.46	0.43		6.19		
Insecta	Heteroptera	Corixidae	*Hesperocorixa*	1.99						
Insecta	Heteroptera	Corixidae	*Palmacorixa*					0.25		
Insecta	Heteroptera	Corixidae	*Sigara*			2.06				
Insecta	Heteroptera	Corixidae	immature	0.2	0.48	3.68	3.45	2.5		
Insecta	Heteroptera	Gerridae	*Gerris*				0.27			
Insecta	Heteroptera	Gerridae	immature	1.62		0.45				
Insecta	Heteroptera	Hebridae	immature			0.29				
Insecta	Heteroptera	Mesoveliidae	*Mesovelia*	2.77		7.43	13.89	13.68	1.03	
Insecta	Heteroptera	Nepidae	*Ranatra sp.*	0.24			0.49		0.19	
Insecta	Heteroptera	Notonectid.	*Notonecta*						0.22	
Insecta	Heteroptera	Notonectid.	immature	0.68			0.54			
Insecta	Heteroptera	Veliidae	*Microvelia*	0.23						
Insecta	Trichoptera	Helicopsych.	*Helicopsyche*							1.91
Insecta	Trichoptera	Leptoceridae	*Oecetis*						4.5	
Insecta	Trichoptera	Leptoceridae	*Nectopsyche*							9.75
Insecta	Lepidoptera	Pyralidae	unknown						0.6	
Insecta	Coleoptera	Dytiscidae	*Graphoderus*					0.24	0.22	
Insecta	Coleoptera	Dytiscidae	*Hydroporus*					5.85		
Insecta	Coleoptera	Dytiscidae	*Hygrotus*			0.88				
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hygr.*	0.24		1.31	0.54	0.24		
Insecta	Coleoptera	Dytiscidae	*Laccophilus*	4.46		4.08	0.8	0.49		
Insecta	Coleoptera	Dytiscidae	*Laccornis*	0.2						
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*	0.71	0.22	0.29	0.27			
Insecta	Coleoptera	Haliplidae	*Haliplus*		0.24			0.49		
Insecta	Coleoptera	Hydrochid.	*Hydrochus sp.*				0.27			
Insecta	Coleoptera	Hydrochid.	*Anacaena sp.*	0.47						
Insecta	Coleoptera	Hydrochid.	*Berosus*			0.22		1.63		1.3
Insecta	Coleoptera	Hydrochid.	*Derallus*					0.9		
Insecta	Coleoptera	Hydrochid.	*Enochrus*		0.19	0.29	0.54			
Insecta	Coleoptera	Hydrochid.	*Hydrophilus*		0.24					
Insecta	Coleoptera	Hydrochid.	*Paracymus sp.*			0.88				
Insecta	Coleoptera	Hydrochid.	*Tropisternus*	0.23		4.06	0.8	1.74		

Appendix B. (Continued)

Class	**Order**	**Family**	**Genus/Species**	**Waterfr. Inn** swale 8/17/2004	**Waterfr. Inn** *Typha* 8/17/2004	**Linwood Ave.** *Juncus* 7/21/2004	**Linwood Ave.** *Scirpus/Juncus* 7/21/2004	**S. Linwood** *Eleocharis* 8/6/2004	**White's Beach** *Scirpus/Juncus* 7/21/2004	**Bay Shore** mowed 8/31/2004
Insecta	Coleoptera	Hydrochid.	unknown						0.19	
Insecta	Coleoptera	Curculionidae	unknown					0.24		
Insecta	Coleoptera	Elmidae	unknown					0.24		
Insecta	Coleoptera	Lampyridae	unknown		0.19					
Insecta	Diptera	Chironomid.	Chironomini	5.49	1.33	7.47			4.81	13.83
Insecta	Diptera	Chironomid.	Tanytarsini		1.58	0.68		0.21	17.26	0.38
Insecta	Diptera	Chironomid.	Tanypodinae	1.12	0.61	0.68	1.33			
Insecta	Diptera	Chironomid.	Orthocladinae	10.81						10.91
Insecta	Diptera	Chironomid.	Corynoneura	0.23						
Insecta	Diptera	Ceratopogon.	*Bezzia*	0.24	0.19	5.8	3.56		0.22	
Insecta	Diptera	Ceratopogon.	*Culicoides*						2	
Insecta	Diptera	Ceratopogon.	pupa			1.2	1.46	0.24		0.99
Insecta	Diptera	Culicidae	*Anopheles*	2.3	0.24		0.22			
Insecta	Diptera	Culicidae	pupa	1.59	1.23				0.43	1.89
Insecta	Diptera	Tipulidae	unknown	0.23			0.27			
Insecta	Diptera	Sciomyzidae	unknown			0.29				
Insecta	Diptera	Stratiomyiid.	*Odontomyia* /*Hedri.*		0.19		0.27			

Appendix C: Mean relative abundance of invertebrates collected in 'most recently mowed' wetlands of Saginaw and Grand Traverse Bays in 2004.

				Surfwood	**Bay City Park**	**BayPort 1**	**Arenac@Aus Gres**	**Arenac@Aus Gres**	**Linwood Ave**	**Rose Island 1**	**Pt. Austin Rd**
				Scirpus/Juncus	*Scirp./Junc./Eleo.*	*Juncus*	*Phrag.* / *Scirpus*	*Eleocharis* swale	*Scirp./Junc.*	*Juncus*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/6/2004	7/23/2004	7/19/2004	7/22/2004	7/22/2004	7/21/2004	7/19/2004	8/5/2004
Oligochaeta		Naididae	*Stylaria*					1.09		0.22	0.74
Oligochaeta		Naididae	unknown	0.46	1	0.53				4.55	31
Oligochaeta		Tubificidae	unknown		1.24					0.2	1.48
Hirudinea					0.66		2.78	0.31		0.44	
Bivalvia		Sphaeriidae					0.83	4.7			
Gastropoda		Hydrobiidae					4.48				
Gastropoda		Lymnaeidae	*Fossaria obrussa*	14.23		6.51		5.81	6.07		
Gastropoda		Lymnaeidae	*P. columella*	12.3	0.58	28.83		0.31		0.22	
Gastropoda		Lymnaeidae	*Stagnicola elod.*	24.23	18.27		7.64	0.86	1.62	5.19	
Gastropoda		Physidae	*Physa gyrina*	20.01		7.8	2.11	25.41	44.91	20.83	
Gastropoda		Planorbidae	*Gyraul. Circumst.*	3.24	17.96						
Gastropoda		Planorbidae	*Gyraulus*				1.75	1.3	0.86		
Gastropoda		Planorbidae	*Planorbella*				3.99				
Arachnida	Hydracarina			0.71	0.41	4.39	0.21	2.75	0.33	5.44	1.29
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*	0.49	0.23	0.22			2.49	0.44	9.61
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*								0.74
Crustacea	Amphipoda	Crangonyc.	*Crangonyx*							0.2	1.83
Insecta	Collembola	Isotomidae	unknown		0.37			0.54			
Insecta	Collembola	Poduridae	*Podura aquatica*					0.44			
Insecta	Collembola	Sminthuridae	*unknown*		0.6	0.75	0.21	3.97			
Insecta	Ephemerop.	Baetidae	*Callibaetis sp.*		1.78	1.54				0.2	
Insecta	Ephemerop.	Caenidae	*Caenis*	7.02	0.91	5.04			15.13	2.05	6.58
Insecta	Odonata	Aeshnidae	*Anax junius*		1	0.44	2.97		0.6		
Insecta	Odonata	Aeshnidae	immature				0.21				
Insecta	Odonata	Libellulidae	immature		1.43				0.3	0.21	
Insecta	Odonata	Coenagrion.	*Coenagrion*				0.21				0.55
Insecta	Odonata	Coenagrion.	*Enallagma sp.*		2.66		2.77				
Insecta	Odonata	Coenagrion.	*Ishnura sp.*		13.77		31.69	1.18	3.69	0.63	
Insecta	Heteroptera	Belostomatid.	*Belostoma*	0.52	0.42		0.84	0.31			
Insecta	Heteroptera	Belostomatid.	immature			1.1	4.07			0.82	0.74
Insecta	Heteroptera	Corixidae	*Trichocorixa*				0.21		2.02	4.56	
Insecta	Heteroptera	Corixidae	*Hesperocorixa*		0.21		9.63				
Insecta	Heteroptera	Corixidae	*Palmacorixa*							0.2	
Insecta	Heteroptera	Corixidae	*Sigara*		0.41	0.22		3.58		0.63	
Insecta	Heteroptera	Gerridae	*Trepobates*		0.56						
Insecta	Heteroptera	Gerridae	immature			1.19	2.54	0.42		3.02	

Appendix C. (Continued)

				Surfwood	**Bay City Park**	**BayPort 1**	**Arenac@Aus Gres**	**Arenac@Aus Gres**	**Linwood Ave**	**Rose Island 1**	**Pt. Austin Rd**
				Scirpus/Juncus	*Scirp./Junc./Eleo.*	*Juncus*	*Phrag.* / *Scirpus*	*Eleocharis* swale	*Scirp./Junc.*	*Juncus*	*Scirpus*
Class	**Order**	**Family**	**Genus/Species**	8/6/2004	7/23/2004	7/19/2004	7/22/2004	7/22/2004	7/21/2004	7/19/2004	8/5/2004
Insecta	Heteroptera	Hydromet.	*Hydrometra*			0.49					
Insecta	Heteroptera	Mesoveliid.	*Mesovelia*	8.06		2	1.06	0.21	6.04	8.59	
Insecta	Heteroptera	Nepidae	*Ranatra sp.*				0.65		0.3		
Insecta	Heteroptera	Notonectid.	*Notonecta*		0.19		1.71			0.22	
Insecta	Heteroptera	Notonectid.	immature		0.23	0.22	1.48		0.33		
Insecta	Heteroptera	Pleidae	*Neoplea*				0.43			0.22	
Insecta	Heteroptera	Saldidae	immature	0.25	0.23		0.21				
Insecta	Heteroptera	Veliidae	*Microvelia*		3.89					0.21	
Insecta	Trichoptera	Leptoceridae	*Oecetis*								2.58
Insecta	Trichoptera	Leptoceridae	*Mystacides*								4.37
Insecta	Trichoptera	Leptoceridae	*Nectopsyche*								1.45
Insecta	Trichoptera	Leptoceridae	unknown								1.09
Insecta	Coleoptera	Dytiscidae	*Graphoderus*				0.22			0.63	
Insecta	Coleoptera	Dytiscidae	*Hydroporus*			1.42	0.21	4.43		0.2	
Insecta	Coleoptera	Dytiscidae	*Hygrotus*	0.52							
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hyg.*	0.69	0.37	0.71	0.44	0.31		2.02	
Insecta	Coleoptera	Dytiscidae	*Ilybius*	0.26	0.21					1.76	
Insecta	Coleoptera	Dytiscidae	*Laccophilus*			4.06	1.07	9.4	2.35	5.6	
Insecta	Coleoptera	Dytiscidae	*Laccornis*	0.48	0.19		2.11		0.93		
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*			2.47		1.18	0.56	0.2	
Insecta	Coleoptera	Dytiscidae	*Potamonectes sp*								
Insecta	Coleoptera	Dytiscidae	*Thermonectus*					0.31			
Insecta	Coleoptera	Dytiscidae	unknown		0.56						
Insecta	Coleoptera	Haliplidae	*Haliplus*				0.85			0.22	
Insecta	Coleoptera	Haliplidae	*Peltodytes*				0.21				
Insecta	Coleoptera	Hydrophilid.	*Anacaena sp.*							0.22	
Insecta	Coleoptera	Hydrophilid.	*Berosus*	0.23	0.23	0.93		0.44			
Insecta	Coleoptera	Hydrophilid.	*Derallus*		0.23		0.21				
Insecta	Coleoptera	Hydrophilid.	*Enochrus*	0.48	0.23	0.22		14.12			
Insecta	Coleoptera	Hydrophilid.	*Hydrobius*					0.43		0.22	
Insecta	Coleoptera	Hydrophilid.	*Hydrochara*					0.43			
Insecta	Coleoptera	Hydrophilid.	*Hydrochus*	0.25	0.44						
Insecta	Coleoptera	Hydrophilid.	*Paracymus sp.*					0.76			
Insecta	Coleoptera	Curculionidae	unknown					0.22	0.3	0.22	
Insecta	Coleoptera	Elmidae	unknown		0.19						
Insecta	Coleoptera	Lampyridae	unknown			0.22					
Insecta	Diptera	Chironomidae	Chironomini	1.19	4.64	22.49		1.28	0.3	5.31	20.63
Insecta	Diptera	Chironomidae	Tanytarsini	0.23	0.62		3.36	4.03	0.89	1.63	6.01

Appendix C. (Continued)

Class	Order	Family	Genus/Species	**Surfwood** *Scirpus/Juncus* 8/6/2004	**Bay City Park** *Scirp./Junc./Eleo.* 7/23/2004	**BayPort 1** *Juncus* 7/19/2004	**Arenac@Aus Gres** *Phrag. / Scirpus* 7/22/2004	**Arenac@Aus Gres** *Eleocharis* swale 7/22/2004	**Linwood Ave** *Scirp./Junc.* 7/21/2004	**Rose Island 1** *Juncus* 7/19/2004	**Pt. Austin Rd** *Scirpus* 8/5/2004
Insecta	Diptera	Chironomidae	Tanypodinae	0.48	1.62		0.43			0.84	
Insecta	Diptera	Chironomidae	Orthocladinae		9.13		0.65		0.3	4.34	8.03
Insecta	Diptera	Chironomidae	Corynoneura		1.37						
Insecta	Diptera	Chironomidae	pupa	0.96						0.42	0.9
Insecta	Diptera	Ceratopogon.	*Bezzia*		6.54	1.07	1.93	1.94	1.19	10.49	0.36
Insecta	Diptera	Ceratopogon.	*Culicoides*	0.25	0.6						
Insecta	Diptera	Ceratopogon.	pupa			2.95			0.33		
Insecta	Diptera	Culicidae	*Anopheles*		1.66	0.22		1.15	0.3		
Insecta	Diptera	Culicidae	*Culex sp.*		0.19						
Insecta	Diptera	Culicidae	*Culiseta*		0.42						
Insecta	Diptera	Culicidae	pupa		0.37						
Insecta	Diptera	Tipulidae	unknown	1.68	0.21					1.62	
Insecta	Diptera	Sciomyzidae	unknown			0.66		0.31			
Insecta	Diptera	Stratiomyiidae	*Odontomyia*		0.63	0.22	0.43				
Insecta	Diptera	Stratiomyiidae	*Stratiomys sp.*								
Insecta	Diptera	Tabanidae	unknown								

Class	Order	Family	Genus/Species	**Surfwood** *Eleo./Scirp.* 8/6/2004	**Pt. Austin Rd** *Scirp./Junc./Eleo.* 8/5/2004	**BayPort 1** *Phragmites* 7/19/2004	**Pt. Austin Rd** *Phragmites* 8/5/2004	**White's Beach** *Eleo./Junc.* 7/21/2004
Oligochaeta		Naididae	*Stylaria*				1.65	
Oligochaeta		Naididae	unknown			22.97	3.6	17.58
Oligochaeta		Tubificidae	unknown				1.09	0.19
Hirudinea			unknown			0.32	1.83	
Bivalvia		Sphaeriidae	unknown		3.73		5.35	
Gastropoda		Lymnaeidae	*Fossaria obrussa*		0.23	7.64		
Gastropoda		Lymnaeidae	*P. columella*	42.38	2.45	4.07		0.82
Gastropoda		Lymnaeidae	*Stagnic. Elodes*	28.29	46.22		26.25	37.74
Gastropoda		Physidae	*Physa gyrina*	4.81	2.4	6.05	0.67	6.5
Gastropoda		Planorbidae	*Gyraulus*	2.72	0.23			0.19
Arachnida	Hydracarina		unknown		0.49	4.07	0.67	0.63
Crustacea	Amphipoda	Talitridae	*Hyalella azteca*		1.36	0.31	6.05	
Crustacea	Amphipoda	Gammaridae	*Gammarus sp*					0.81
Insecta	Collembola	Isotomidae	unknown	0.65	0.26			
Insecta	Collembola	Poduridae	*Podura aquatica*		0.23			
Insecta	Collembola	Sminthuridae	unknown	11.59	0.23	0.52		
Insecta	Ephemerop.	Caenidae	*Caenis*		3.81	5.92	24.47	7.24

Appendix C. (Continued)

				Surfwood	**Pt. Austin Rd**	**BayPort 1**	**Pt. Austin Rd**	**White's Beach**
				Eleo./Scirp.	*Scirp./Junc./Eleo.*	*Phragmites*	*Phragmites*	*Eleo./Junc.*
Class	**Order**	**Family**	**Genus/Species**	8/6/2004	8/5/2004	7/19/2004	8/5/2004	7/21/2004
Insecta	Odonata	Aeshnidae	*Aeshna umbrosa*			1.44		0.21
Insecta	Odonata	Aeshnidae	*Anax junius*			1.37	0.6	
Insecta	Odonata	Libellulidae	*Leucorrhinia*					0.21
Insecta	Odonata	Libellulidae	*Sympetrum*		1.28			
Insecta	Odonata	Libellulidae	immature		0.23		0.3	0.45
Insecta	Odonata	Coenagrion.	*Coenagrion*					
Insecta	Odonata	Coenagrion.	*Enallagma sp.*				0.67	1.03
Insecta	Odonata	Coenagrion.	*Ishnura sp.*		4.73	2.36	4.42	0.19
Insecta	Heteroptera	Belostomatid.	*Belostoma*				0.26	
Insecta	Heteroptera	Belostomatid.	immature			0.22	3.51	
Insecta	Heteroptera	Corixidae	*Trichocorixa*		0.23		0.41	
Insecta	Heteroptera	Corixidae	*Hesperocorixa*					0.19
Insecta	Heteroptera	Corixidae	*Sigara*		0.23			
Insecta	Heteroptera	Corixidae	immature			0.22	0.26	0.61
Insecta	Heteroptera	Gerridae	*Gerris*		0.23			
Insecta	Heteroptera	Gerridae	immature					0.21
Insecta	Heteroptera	Hydromet.	*Hydrometra*					
Insecta	Heteroptera	Saldidae	immature		1.41			
Insecta	Trichoptera	Leptoceridae	*Oecetis*					1.7
Insecta	Trichoptera	Leptoceridae	*Mystacides*				0.79	
Insecta	Trichoptera	Limnephilid.	pupa			0.22		
Insecta	Coleoptera	Dytiscidae	Agabetes		0.23			
Insecta	Coleoptera	Dytiscidae	*Hydroporus*			0.96		1.7
Insecta	Coleoptera	Dytiscidae	*Hydroporus/Hygrotus*		5.74	2.1		2.74
Insecta	Coleoptera	Dytiscidae	*Ilybius*		0.23			
Insecta	Coleoptera	Dytiscidae	*Laccophilus*		3.08	0.61	0.26	2.48
Insecta	Coleoptera	Dytiscidae	*Laccornis*		0.23			
Insecta	Coleoptera	Dytiscidae	*Liodessus sp.*					0.39
Insecta	Coleoptera	Dytiscidae	*Potamonectes sp*		2.58			
Insecta	Coleoptera	Dytiscidae	*Thermonectus*				1.22	
Insecta	Coleoptera	Gyrinidae	*Gyrinus*				2.78	
Insecta	Coleoptera	Haliplidae	*Haliplus*		0.23			0.19
Insecta	Coleoptera	Helophoridae	*Helophorus sp.*	0.64	2.2	0.32		
Insecta	Coleoptera	Hydrophilid.	*Berosus*		0.23	0.52		
Insecta	Coleoptera	Hydrophilid.	*Derallus*		0.45			0.4
Insecta	Coleoptera	Hydrophilid.	*Enochrus*		0.71	0.74		
Insecta	Coleoptera	Hydrophilid.	*Hydrochus*	0.24				
Insecta	Coleoptera	Hydrophilid.	*Hydrophilus*		1.59			

Appendix C. (Continued)

				Surfwood	**Pt. Austin Rd**	**BayPort 1**	**Pt. Austin Rd**	**White's Beach**
				Eleo./Scirp.	*Scirp./Junc./Eleo.*	*Phragmites*	*Phragmites*	*Eleo./Junc.*
Class	**Order**	**Family**	**Genus/Species**	8/6/2004	8/5/2004	7/19/2004	8/5/2004	7/21/2004
Insecta	Coleoptera	Hydrophilid.	*Paracymus sp.*		0.26	0.61		
Insecta	Coleoptera	Hydrophilid.	*Tropisternus*	0.24	1.92	0.87	0.81	
Insecta	Coleoptera	Hydrophilid.	unknown					0.23
Insecta	Coleoptera	Curculionidae	unknown			0.64	0.3	
Insecta	Coleoptera	Lampyridae	unknown			0.31		
Insecta	Diptera	Chironomid.	Chironomini		0.93	13.48	6.81	1.7
Insecta	Diptera	Chironomid.	Tanytarsini			5.33	2.18	0.41
Insecta	Diptera	Chironomid.	Tanypodinae			0.22	0.86	
Insecta	Diptera	Chironomid.	Orthocladinae		0.68	3.36	0.26	0.42
Insecta	Diptera	Chironomid.	pupa			0.93		1.94
Insecta	Diptera	Ceratopogon.	Bezzia		1.64	1.75	0.3	4.48
Insecta	Diptera	Ceratopogon.	Culicoides			0.32		4.16
Insecta	Diptera	Ceratopogon.	pupa	0.45	0.68			
Insecta	Diptera	Culicidae	pupa		0.23	0.31		
Insecta	Diptera	Stratiomyiid.	*Odontomyia*		0.23			

Appendix D: Mean relative abundance of invertebrates collected in 'raked,' 'unraked open,' and '*Scirpus*' wetlands of Saginaw Ba ay in 2005.

Appendix E. Mean abundances (per net/night) of fish captured with fyke nets in coastal wetlands of Saginaw Bay, Grand Traverse B, and Northern Lakes Huron and Michigan in 2004.

Site	**Dom. Veg.**	**Disturb. Cat.**	**Date**	Alewife (*Alosa psuedoharengus*)	Bowfin (*Amia calva*)	Quillback (*Carpiodes cyprinus*)	White sucker (*Catostomus commersoni*)	Rock Bass (*Ambloplites rupestris*)	Pumpkinseed (*Lepomis gibbosus*)	Bluegill (*Lepomis macrochirus*)	Largemouth bass (*Micropterus salmoides*)
Saginaw Bay											
Rose Island 1	*Typha*	adjacent mowing	7/19/04			0.67				1.67	1.00
Rose Island Ref.	*Scirpus*	reference	7/21/04							1.67	18.00
Bayport 1	*Scirpus*	recently mowed	7/20/04					1.00			2.00
Bayport 1	*Scirpus*	mowed 1 yr proir	7/20/04					2.50			31.50
Bayport reference	*Scirpus*	reference	7/21/04								0.67
Linwood Beach	*Scirpus*	mowed 1 yr proir	7/22/04		3.00						2.00
Linwood Beach	*Scirpus*	unmowed	7/22/04								0.50
Nainquin Pt.	*Scirpus*	reference	7/21/04								0.33
Wigwam Bay	*Scirpus*	ref. for White's Bch Rd.	8/3/04							0.33	1.00
White's Beach Rd	*Scirpus*	mowed 1 yr proir	8/3/04		0.33					0.33	3.33
Wigwam Bay	*Sagittaria*	ref. for White's Tavern	8/3/04							0.33	2.67
White's Beach Tav.	*Sagittaria*	mowed earlier in 2004	8/3/04						0.33	1.67	5.33
Sand Point	open	history of grooming	8/5/04					0.33		0.67	0.33
Sand Point	*Phragmites*	reference	8/5/04					1.67	1.00	10.33	3.67
Caseville	*Phragmites*	reference	8/5/04							1.00	
Caseville	*Phragmites*	groomed	8/5/04					1.00		0.33	
Grand Traverse Bay											
Waterfront Inn	*Typha*	reference	8/17/04				3.00				
Waterfront Inn	open	groomed	8/17/04				8.50				
Waterfront Inn	mixed	ungroomed	8/17/04				10.00				
Hilltop Rd	open	boat channel	8/18/04								
Hilltop Rd	*Scirpus*	reference	8/18/04								
Acme township pk.	*Scirpus*	groomed	9/22/04								
Acme township pk.	*Scirpus*	reference	9/22/04								
Northern Lakes Huron and Michigan											
St. Ignace	open	adj. boat channel	7/27/04				2.33	3.00			
St. Ignace	*Scirpus*	reference	7/27/04				0.67	0.67		0.33	
Mackinaw Bay	open	adj. boat channel	7/27/04				0.67	6.33	1.00		0.33
Mackinaw Bay	*Scirpus*	reference	7/27/04		0.33			7.00	1.00	0.33	1.33
Hill Island	open	adj. boat channel	7/27/04	0.33			0.33	8.00			
Hill Island	*Scirpus*	reference	7/27/04	0.33				2.67	1.00		
Moscoe Channel	open	adj. boat channel	7/27/04		0.33			14.33	49.33	2.67	14.00
Moscoe Channel	*Scirpus*	reference	7/27/04					3.67	7.00		5.00

Appendix E. (Continued)

Site	Dom. Veg.	Disturb. Cat.	Date	Smallmouth Bass (*Micropterus dolomieu*)	Yellow Perch (*Perca flavescens*)	Pirate Perch (*Aphredoderus sayanus*)	Spotfin Shiner (*Cyprinella spiloptera*)	Common Carp (*Cyprinus carpio*)	Bluntnose minnow (*Pimephales notatus*)	Common Shiner (*Luxilus cornutus*)	Emerald Shiner (*Notropis atherinoides*)
Saginaw Bay											
Rose Island 1	*Typha*	adjacent mowing	7/19/04	0.67	26.33		2.33		0.33		
Rose Island Ref.	*Scirpus*	reference	7/21/04	1.33	60.00		11.67		3.33		
Bayport 1	*Scirpus*	recently mowed	7/20/04		4.50				1.00		
Bayport 1	*Scirpus*	mowed 1 yr proir	7/20/04	1.00	82.50		27.50			11.50	
Bayport reference	*Scirpus*	reference	7/21/04		3.00						
Linwood Beach	*Scirpus*	mowed 1 yr proir	7/22/04		15.00						
Linwood Beach	*Scirpus*	unmowed	7/22/04		11.50		0.50				
Nainquin Pt.	*Scirpus*	reference	7/21/04		128.00				0.33		
Wigwam Bay	*Scirpus*	ref. for White's Bch Rd.	8/3/04		3.00	1.20					
White's Beach Rd	*Scirpus*	mowed 1 yr proir	8/3/04		11.33						
Wigwam Bay	*Sagittaria*	ref. for White's Tavern	8/3/04	0.33	10.00						0.33
White's Beach Tav.	*Sagittaria*	mowed earlier in 2004	8/3/04		37.00				0.33		
Sand Point	open	history of grooming	8/5/04		5.00				0.33		1.00
Sand Point	*Phragmites*	reference	8/5/04		8.67						
Caseville	*Phragmites*	reference	8/5/04						0.33		1.33
Caseville	*Phragmites*	groomed	8/5/04		1.00		5.67		0.33		
Grand Traverse Bay											
Waterfront Inn	*Typha*	reference	8/17/04	1.33							
Waterfront Inn	open	groomed	8/17/04	8.00	0.50						
Waterfront Inn	mixed	ungroomed	8/17/04	7.00	1.00						
Hilltop Rd	open	boat channel	8/18/04								
Hilltop Rd	*Scirpus*	reference	8/18/04			0.33					
Acme township pk.	*Scirpus*	groomed	9/22/04	0.67							
Acme township pk.	*Scirpus*	reference	9/22/04	3.33							
Northern Lakes Huron and Michigan											
St. Ignace	open	adj. boat channel	7/27/04	86.00	0.33				76.67	33.00	0.67
St. Ignace	*Scirpus*	reference	7/27/04	9.00	0.33				37.33	0.33	0.33
Mackinaw Bay	open	adj. boat channel	7/27/04	13.33	1.00				21.00		
Mackinaw Bay	*Scirpus*	reference	7/27/04	19.00	0.33				36.67		0.67
Hill Island	open	adj. boat channel	7/27/04	10.67					117.00		
Hill Island	*Scirpus*	reference	7/27/04	1.33				0.33	45.67		
Moscoe Channel	open	adj. boat channel	7/27/04	2.67	20.00				43.00	1.33	0.33
Moscoe Channel	*Scirpus*	reference	7/27/04	1.00	1.67				4.67	0.33	1.00

Appendix E. (Continued)

Site	Dom. Veg.	Disturb. Cat.	Date	Spottail Shiner (*Notropis hudsonius*)	Blacknose Shiner (*Notropis heterolepis*)	Mimic Shiner (*Notropis volucellus*)	Finescale Dace (*Phoxinus Neogaeus*)	Northern Pike (*Esox lucius*)	Banded killifish (*Fundulus diaphanus*)	Black Bullhead (*Ameiurus melas*)	Brown Bullhead (*Ameiurus nebulosus*)
Saginaw Bay											
Rose Island 1	*Typha*	adjacent mowing	7/19/04						0.67		
Rose Island Ref.	*Scirpus*	reference	7/21/04	0.67				0.33	11.00		
Bayport 1	*Scirpus*	recently mowed	7/20/04						2.00		
Bayport 1	*Scirpus*	mowed 1 yr proir	7/20/04	1.00		0.50			12.50		
Bayport reference	*Scirpus*	reference	7/21/04						1.00		
Linwood Beach	*Scirpus*	mowed 1 yr proir	7/22/04								
Linwood Beach	*Scirpus*	unmowed	7/22/04								
Nainquin Pt.	*Scirpus*	reference	7/21/04	0.33					2.00		
Wigwam Bay	*Scirpus*	ref. for White's Bch Rd.	8/3/04						0.67		0.67
White's Beach Rd	*Scirpus*	mowed 1 yr proir	8/3/04						5.67		
Wigwam Bay	*Sagittaria*	ref. for White's Tavern	8/3/04	19.33					1.33		
White's Beach Tav.	*Sagittaria*	mowed earlier in 2004	8/3/04						12.33		0.33
Sand Point	open	history of grooming	8/5/04	10.67		0.67			0.33		
Sand Point	*Phragmites*	reference	8/5/04						0.33		
Caseville	*Phragmites*	reference	8/5/04								
Caseville	*Phragmites*	groomed	8/5/04			0.67					
Grand Traverse Bay											
Waterfront Inn	*Typha*	reference	8/17/04	44.33		0.33			18.67		
Waterfront Inn	open	groomed	8/17/04	31.50					1.50		
Waterfront Inn	mixed	ungroomed	8/17/04	16.00					7.00		
Hilltop Rd	open	boat channel	8/18/04								
Hilltop Rd	*Scirpus*	reference	8/18/04	0.33							
Acme township pk.	*Scirpus*	groomed	9/22/04	4.67			0.33		7.33		
Acme township pk.	*Scirpus*	reference	9/22/04	1.33			4.00		16.67		
Northern Lakes Huron and Michigan											
St. Ignace	open	adj. boat channel	7/27/04	1496.33		704.33					
St. Ignace	*Scirpus*	reference	7/27/04	178.33	2.33	223.67		1.33			
Mackinaw Bay	open	adj. boat channel	7/27/04	0.67	1.33	1.33		0.33		4.00	1.00
Mackinaw Bay	*Scirpus*	reference	7/27/04	0.33	13.00					130.67	4.33
Hill Island	open	adj. boat channel	7/27/04	21.00	1.33	6.33			2.33	0.33	1.00
Hill Island	*Scirpus*	reference	7/27/04	1.00	3.67	1.00			1.33		0.67
Moscoe Channel	open	adj. boat channel	7/27/04		0.33	0.33			1.00	0.33	8.00
Moscoe Channel	*Scirpus*	reference	7/27/04		0.33					0.67	3.67

Appendix E. (Continued)

Site	Dom. Veg.	Disturb. Cat.	Date	Johnny Darter (*Etheostoma nigrum*)	Brook Stickleback (*Culaea inconstans*)	Brook Silverside (*Labidesthes sicculus*)	Longnose Gar (*Lepisosteus osseus*)	Round Goby (*Neogobius melanostomus*)	Gizzard Shad (*Dorosoma cepedianum*)	White Bass (*Morone chyrsops*)	Black Buffalo (*Ictiobus niger*)
Saginaw Bay											
Rose Island 1	*Typha*	adjacent mowing	7/19/04						0.67	0.33	
Rose Island Ref.	*Scirpus*	reference	7/21/04				1.33		1.00	0.33	
Bayport 1	*Scirpus*	recently mowed	7/20/04				1.00				
Bayport 1	*Scirpus*	mowed 1 yr proir	7/20/04				1.00		4.00		
Bayport reference	*Scirpus*	reference	7/21/04						81.33		
Linwood Beach	*Scirpus*	mowed 1 yr proir	7/22/04								
Linwood Beach	*Scirpus*	unmowed	7/22/04								
Nainquin Pt.	*Scirpus*	reference	7/21/04				1.33				
Wigwam Bay	*Scirpus*	ref. for White's Bch Rd.	8/3/04				0.33				4.67
White's Beach Rd	*Scirpus*	mowed 1 yr proir	8/3/04				0.67				0.67
Wigwam Bay	*Sagittaria*	ref. for White's Tavern	8/3/04						0.33		
White's Beach Tav.	*Sagittaria*	mowed earlier in 2004	8/3/04		0.33						3.33
Sand Point	open	history of grooming	8/5/04				0.33	0.33	0.33		0.67
Sand Point	*Phragmites*	reference	8/5/04				0.33				0.67
Caseville	*Phragmites*	reference	8/5/04					0.67			0.67
Caseville	*Phragmites*	groomed	8/5/04								0.33
Grand Traverse Bay											
Waterfront Inn	*Typha*	reference	8/17/04								13.67
Waterfront Inn	open	groomed	8/17/04								0.50
Waterfront Inn	mixed	ungroomed	8/17/04								2.00
Hilltop Rd	open	boat channel	8/18/04								
Hilltop Rd	*Scirpus*	reference	8/18/04								
Acme township pk.	*Scirpus*	groomed	9/22/04			0.33					0.33
Acme township pk.	*Scirpus*	reference	9/22/04								5.33
Northern Lakes Huron and Michigan											
St. Ignace	open	adj. boat channel	7/27/04	1.00							
St. Ignace	*Scirpus*	reference	7/27/04					0.67			
Mackinaw Bay	open	adj. boat channel	7/27/04	0.67							
Mackinaw Bay	*Scirpus*	reference	7/27/04	0.33							
Hill Island	open	adj. boat channel	7/27/04	4.67							
Hill Island	*Scirpus*	reference	7/27/04	1.00							
Moscoe Channel	open	adj. boat channel	7/27/04	0.67							
Moscoe Channel	*Scirpus*	reference	7/27/04								

Appendix E. (Continued)

Site	Dom. Veg.	Disturb. Cat.	Date	White Perch (*Morone americana*)	Sand Shiner (*Notropis ludibundus*)	Mottled sculpin (*Cottus bairdi*)	Longnose dace (*Rhinichthys cataractae*)	Ninespine stickleback (*Pungitius pungitius*)	Fathead minnow (*Pimephales promelas*)
Saginaw Bay									
Rose Island 1	*Typha*	adjacent mowing	7/19/04						
Rose Island Ref.	*Scirpus*	reference	7/21/04						
Bayport 1	*Scirpus*	recently mowed	7/20/04						
Bayport 1	*Scirpus*	mowed 1 yr proir	7/20/04						
Bayport reference	*Scirpus*	reference	7/21/04						
Linwood Beach	*Scirpus*	mowed 1 yr proir	7/22/04						
Linwood Beach	*Scirpus*	unmowed	7/22/04						
Nainquin Pt.	*Scirpus*	reference	7/21/04						
Wigwam Bay	*Scirpus*	ref. for White's Bch Rd.	8/3/04						
White's Beach Rd	*Scirpus*	mowed 1 yr proir	8/3/04						
Wigwam Bay	*Sagittaria*	ref. for White's Tavern	8/3/04						
White's Beach Tav.	*Sagittaria*	mowed earlier in 2004	8/3/04						
Sand Point	open	history of grooming	8/5/04	2.00					
Sand Point	*Phragmites*	reference	8/5/04	0.33					
Caseville	*Phragmites*	reference	8/5/04						
Caseville	*Phragmites*	groomed	8/5/04						
Grand Traverse Bay									
Waterfront Inn	*Typha*	reference	8/17/04		11.67				
Waterfront Inn	open	groomed	8/17/04		563.50				
Waterfront Inn	mixed	ungroomed	8/17/04		457.00				
Hilltop Rd	open	boat channel	8/18/04		0.33	0.33			
Hilltop Rd	*Scirpus*	reference	8/18/04				2.00		
Acme township pk.	*Scirpus*	groomed	9/22/04		3.00		1.67		
Acme township pk.	*Scirpus*	reference	9/22/04		12.33		4.67		1.00
Northern Lakes Huron and Michigan									
St. Ignace	open	adj. boat channel	7/27/04		0.33				
St. Ignace	*Scirpus*	reference	7/27/04			0.33		0.33	
Mackinaw Bay	open	adj. boat channel	7/27/04						
Mackinaw Bay	*Scirpus*	reference	7/27/04						
Hill Island	open	adj. boat channel	7/27/04		7.33				
Hill Island	*Scirpus*	reference	7/27/04		0.33				
Moscoe Channel	open	adj. boat channel	7/27/04						
Moscoe Channel	*Scirpus*	reference	7/27/04		1.33				

Appendix F. Chemical, physical, and sampling information for fragmented wetland sites that were sampled with quatrefoil light traps in 2004.

Site:	**Bayport**								**Hill Island**								
Position:	**N43.85513 W83.36812**								**N45.9823 W84.31752**								
Date:	**7-20-04**								**7-28-04**								
Transect Category:	**Anthro**				**Reference**				**Anthro**				**Reference**				
Distance From Open Water:	**0**	**5**	**10**	**15**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**120**	**90**	**60**	**30**	**0**
Site Code:	**BP-A1**	**BP-A2**	**BP-A3**	**BP-A4**	**BP-R4**	**BP-R3**	**BP-R2**	**BP-R1**	**HISL-A1**	**HISL-A2**	**HISL-A3**	**HISL-C**	**HISL-C**	**HISL-R4**	**HISL-R3**	**HISL-R2**	**HISL-R1**
Depth (cm):		32.0	20.0	15.0	23.5	30.1	41.2	41.8	56.0	52.0	48.0	43.0	43.0	61.0	78.0	92.0	93.0
Temp.(C)	28.77	29.00	29.72	29.66	30.61	29.61	28.57	28.51	22.78	22.96	22.74	22.62	22.62	22.60	22.44	22.18	21.88
%Dissolved Oxygen	144.5	142.1	131.0	81.5	105.7	127.1	135.0	133.1	79.0	72.2	55.3	63.9	63.9	84.8	86.1	89.4	90.5
Dissolved Oxygen (mg/L)	11.08	10.55	9.70	6.03	7.68	9.40	10.14	10.04	6.66	6.07	4.69	5.40	5.40	7.22	7.33	7.60	7.84
Specific Conductance (*u* S/cm):	335.0	336.0	334.0	409.0	420.0	350.0	333.0	335.0	191.5	192.6	194.3	193.6	193.6	192.6	193.4	191.8	191.2
Total Dissolved Solids (g/L):									0.1225	0.1235	0.1239	0.1238	0.1238	0.1232	0.1237	0.1227	0.1222
Turbidity (NTU):	5.7	7.4	4.5	6.8	4.5	5.8	6.3	6.4	7.0	2.1	2.4	3.1	3.1	3.4	3.1	5.6	15.0
pH:	8.36	8.38	8.23	7.30	7.36	8.01	8.27	8.26	6.59	6.62	6.38	6.48	6.48	6.67	6.75	6.89	6.78
Oxidation-Reduction Pot. (mv):									353	345	360	361	361	337	335	328	335
Chlorophyll (mg/L):									24.06	35.43	47.32	45.87	45.87	42.60	42.44	46.08	44.08
Alkalinity (mg $CaCO_3$/L):	95	96	105	141	145	106	102	100.5	79			82	82				80
Chloride (mg/L)	39.6	38.8	35.2	38.0	37.2	33.5	32.7	33.4	6.3			6.1	6.1				6.2
Sulfate-S (mg/L)	38.9	38.2	32.6	27.2	24.2	30.9	31.5	32.0	14.8			13.7	13.7				14.3
Nitrate-N (mg/L)	0.28	0.28	0.17	0.09	0.07	0.34	0.31	0.30	0.08			0.09	0.09				0.15
Ammonium-N (mg/L)	0.04	0.04	0.04	0.13	0.06	0.04	0.04	0.03	0.03			0.04	0.04				0.03
Soluble Reactive Phos. (mg/L):	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00				0.00

Appendix F. (Continued)

Site:	**Hilltop**											
Position:	**N44.90665 W85.62991**											
Date:	**8-18-04**											
Transect Category:	**Anthro**						**Reference**					
Distance From Open Water:	**0**	**14**	**23**	**26**	**18**	**0**	**0**	**12**	**36**	**35**	**20**	**0**
Site Code:	**HT-S1**	**HT-S2**	**HT-SC**	**HT-NC**	**HT-N2**	**HT-N1**	**HT-E1**	**HT-E2**	**HT-EC**	**HT-WC**	**HT-W2**	**HT-W1**
Depth (cm):	35.0	40.0	50.0	50.0	54.0	70.0	63.0	60.0	50.0	50.0	48.0	48.0
Temp.(C)	20.79	20.67	20.62	20.62	20.79	20.96	20.84	20.74	20.62	20.62	20.95	20.97
%Dissolved Oxygen	114.9	107.3	109.7	109.7	108.6	111.8	117.9	112.6	109.7	109.7	114.4	111.1
Dissolved Oxygen (mg/L)	10.17	9.56	9.78	9.78	9.65	9.87	10.43	9.99	9.78	9.78	10.06	9.84
Specific Conductance (*u* S/cm):	281.9	279.2	279.5	279.5	279.9	281.9	280.6	280.5	279.5	279.5	278.9	279.9
Total Dissolved Solids (g/L):	0.1807	0.1790	0.1789	0.1789	0.1790	0.1807	0.1789	0.1796	0.1789	0.1789	0.1785	0.1794
Turbidity (NTU):	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
pH:	8.62	8.66	8.70	8.70	8.71	8.87	8.60	8.65	8.70	8.70	8.69	8.63
Oxidation-Reduction Pot. (mv):	316	312	300	300	310	298	301	298	300	300	312	319
Chlorophyll (mg/L):	1.20	0.60	0.70	0.70	0.60	0.70	0.60	0.90	0.70	0.70	2.20	1.10
Alkalinity (mg $CaCO_3$/L):	104		121	121		129			121	121		119
Chloride (mg/L)	8.3		11.7	11.7		12.0	11.6		11.7	11.7		11.8
Sulfate-S (mg/L)	15.8		22.4	22.4		22.6	21.9		22.4	22.4		22.7
Nitrate-N (mg/L)	0.11		0.25	0.25		0.14	0.27		0.25	0.25		0.15
Ammonium-N (mg/L)	0.02		0.02	0.02		0.03	0.01		0.02	0.02		0.02
Soluble Reactive Phos. (mg/L):	0.01		0.01	0.01		0.01	0.00		0.01	0.01		0.02

Appendix F. (Continued)

Site:	**St. Ignace**									**Wigwam Bay**								
Position:	**N45.84738 W84.73762**									**N43.96858 W83.85805**								
Date:	**7-27-04**									**8-03-04**								
Transect Category:	**Anthro**				**Reference**					**Anthro**				**Reference**				
Distance From Open Water:	**0**	**20**	**40**	**60**	**115**	**95**	**55**	**25**	**0**	**0**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**
Site Code:	**STIG-A1**	**STIG-A2**	**STIG-A3**	**STIG-A4**	**STIG-R5**	**STIG-R4**	**STIG-R3**	**STIG-R2**	**STIG-R1**	**WP-A1**	**WP-A3**	**WP-A4**	**WP-C**	**WP-R6**	**WP-R5**	**WP-R4**	**WP-R3**	**WP-R2**
Depth (cm):	100.0	63.0	57.0	52.5	55.0	71.0	82.0	93.0	101.0	63.0	24.0	24.0	23.0	25.0	25.0	23.0	33.0	44.0
Temp.(C)	21.00	21.22	21.57	21.93	22.43	22.00	21.50	21.27	21.13	24.38	24.41	24.35	24.14	24.28	24.63	24.69	24.88	24.95
%Dissolved Oxygen	96.7	85.1	70.8	45.2	34.5	91.3	99.7	108.5	110.9	69.0	59.1	56.6	42.0	40.0	55.3	53.4	67.2	76.2
Dissolved Oxygen (mg/L)	8.48	7.41	6.18	3.88	2.86	8.01	8.66	9.44	9.66	5.58	4.82	4.59	3.32	3.21	4.50	4.32	5.40	6.18
Specific Conductance (*u* S/cm):	253.6	255.8	261.2	273.3	273.1	254.3	251.6	249.9	249.0	338.9	341.7	342.2	346.2	345.5	337.5	334.4	332.2	330.8
Total Dissolved Solids (g/L):	0.1620	0.1639	0.1672	0.1752	0.1748	0.1629	0.1610	0.1598	0.1593	0.2163	0.2190	0.2190	0.2217	0.2218	0.2162	0.2140	0.2124	0.2120
Turbidity (NTU):	11.0	3.9	3.0	2.6	3.0	5.3	2.3	2.2	2.1	5.6	4.2	3.3	2.2	2.7	2.0	7.8	3.2	4.6
pH:	7.36	7.08	6.84	6.46	6.43	7.20	7.33	7.45	7.58	8.22	8.00	7.93	7.70	7.64	7.91	7.95	8.36	8.53
Oxidation-Reduction Pot. (mv):	354	342	357	367	350	309	313	302	295	295	297	299	308	305	295	237	245	243
Chlorophyll (mg/L):	10.93	34.55	52.39	62.30	62.30	63.18	16.94	29.72	19.30	5.70	4.90	5.50	5.80	6.10	4.70	6.00	5.00	4.50
Alkalinity (mg CaCO$_3$/L):	97								98	102			109					
Chloride (mg/L)	9.9								9.8	34.3			32.7					
Sulfate-S (mg/L)	20.9								20.6	26.1			25.4					
Nitrate-N (mg/L)	0.11								0.17	0.00			0.00					
Ammonium-N (mg/L)	0.03								0.02	0.03			0.01					
Soluble Reactive Phos. (mg/L):	0.00								0.00	0.00			0.00					

Appendix F. (Continued)

	Site:	**Moscoe**												
	Position:	**N45.99129 W84.31552**												
	Date:	**7-28-04**												
	Transect Category:	**Anthro**						**Reference**						
0	**Distance From Open Water:**	**0**	**10**	**20**	**30**	**40**	**50**	**95**	**85**	**75**	**65**	**55**	**30**	**0**
WP-R1	**Site Code:**	**MOS-A1**	**MOS-A2**	**MOS-A3**	**MOS-A4**	**MOS-A5**	**MOS-C**	**MOS-C**	**MOS-R6**	**MOS-R5**	**MOS-R4**	**MOS-R3**	**MOS-R2**	**MOS-R1**
58.0	**Depth (cm):**	71.0	71.0	70.0	65.0	75.0	74.0	74.0	83.0	80.0	80.0	88.0	99.0	89.0
25.06	**Temp.(C)**	24.10	24.24	24.44	24.35	24.19	24.20	24.20	24.34	24.30	24.41	24.30	24.07	22.50
80.0	**%Dissolved Oxygen**	77.4	75.2	73.6	73.7	73.3	73.9	73.9	70.6	71.9	68.8	70.2	64.1	68.2
6.45	**Dissolved Oxygen (mg/L)**	6.36	6.17	6.04	6.04	6.02	6.10	6.10	5.84	5.90	5.71	5.73	5.25	5.56
327.3	**Specific Conductance (*u* S/cm):**	251.7	245.9	240.0	234.7	231.5	225.0	225.0	226.0	229.1	230.7	233.6	230.1	230.9
0.2094	**Total Dissolved Solids (g/L):**	0.1615	0.1580	0.1536	0.1501	0.1482	0.1446	0.1446	0.1447	0.1467	0.1475	0.1505	0.1470	0.1474
6.3	**Turbidity (NTU):**	4.2	3.9	9.1	2.5	4.7	3.0	3.0	3.1	4.1	6.7	3.0	6.1	9.8
8.85	**pH:**	7.12	7.07	7.03	7.01	7.00	6.93	6.93	6.90	6.91	6.90	6.95	6.90	6.93
233	**Oxidation-Reduction Pot. (mv):**	323	329	331	332	332	336	336	336	338	337	357	342	340
3.60	**Chlorophyll (mg/L):**	69.30	66.60	63.92	58.03	60.37	61.90	61.90	60.01	63.16	71.92	69.19	87.70	92.71
98	**Alkalinity (mg $CaCO_3$/L):**	116					101	101						107
33.5	**Chloride (mg/L)**	5.1					5.7	5.7						5.9
26.1	**Sulfate-S (mg/L)**	9.9					12.7	12.7						11.9
0.00	**Nitrate-N (mg/L)**	0.00					0.00	0.00						0.05
0.02	**Ammonium-N (mg/L)**	0.02					0.02	0.02						0.04
0.00	**Soluble Reactive Phos. (mg/L):**	0.00					0.00	0.00						0.00

Appendix G. Macroinvertebrates captured in quatrefoil light traps from fragmented coastal wetlands in 2004.

Site:	Transect Type:	Distance From Edge (m):	Code:	Aeshnidae	Aphididae	Baetidae	Baetiscidae	Belostomatidae	Caecidotea
Bayport	Anthro	0	BP-A1						1
Saginaw Bay	Anthro	5	BP-A2						
N43.85513 W83.36812	Anthro	10	BP-A3						
	Anthro	15	BP-A4					10	
	Reference	30	BP-R4	1		5			
	Reference	20	BP-R3	1		1		1	
	Reference	10	BP-R2						
	Reference	0	BP-R1						
Hill Island	Anthro	0	HISL-A1	6		2			
Northern Lake Huron	Anthro	10	HISL-A2	9		2			
N45.9823 W84.31752	Anthro	20	HISL-A3	13					
	Corner	30/120	HISL-C	19					
	Reference	90	HISL-R4	7					
	Reference	60	HISL-R3	1					
	Reference	30	HISL-R2						
	Reference	0	HISL-R1						
Hilltop	Anthro	0	HT-S1						
Grand Traverse Bay	Anthro	14	HT-S2						
N44.90665 W85.62991	Anthro	18	HT-N2						
	Anthro	0	HT-N1						
	Center	26	HT-NC						
	Reference	0	HT-E1						
	Reference	12	HT-E2						
	Reference	20	HT-W2						
	Reference	0	HT-W1						
St. Ignace	Anthro	0	STIG-A1						
Northern Lake Michigan	Anthro	20	STIG-A2			3			
N45.84738 W84.73762	Anthro	40	STIG-A3	1					
	Anthro	60	STIG-A4	2					
	Reference	115	STIG-R5	1					
	Reference	95	STIG-R4						
	Reference	55	STIG-R3						
	Reference	25	STIG-R2			2			
	Reference	0	STIG-R1						
Wigwam Bay	Anthro	0	WP-A1			25			
Saginaw Bay	Anthro	20	WP-A3	1		2		14	1
N43.96858 W83.85805	Anthro	30	WP-A4	2				4	
	Corner	40	WP-C	1		8		1	
	Reference	50	WP-R6	1					
	Reference	40	WP-R5						
	Reference	30	WP-R4	7		1		2	
	Reference	20	WP-R3			5			
	Reference	10	WP-R2	2		25			
	Reference	0	WP-R1			6			

Appendix G. (Continued)

Code:	Caenidae	Cambaridae	Ceratopogonidae	Chironomidae	Chrysomelidae	Coenagrionidae	Corixidae	Curculionidae	Dytiscidae
BP-A1	7		492	177		37	3		
BP-A2	8		784	55		75	1		
BP-A3	2		233	112		12	1		
BP-A4	8	1	26	86		4			1
BP-R4	80		137	430		43	9		2
BP-R3	2		125	47		10	2		
BP-R2	1		21	18		5			
BP-R1			12	37		10			
HISL-A1	2			2			639		
HISL-A2	3		4	3			441		
HISL-A3	1		9			1	348		
HISL-C				3		3	1699		
HISL-R4			2	1			1293		
HISL-R3			4	3			7804		
HISL-R2				7			3070		
HISL-R1				6			4899		
HT-S1	1			1					
HT-S2		12							
HT-N2	2	1							
HT-N1									
HT-NC									
HT-E1				1					
HT-E2	1	1							
HT-W2		1		4					
HT-W1	1	1		3					
STIG-A1			1	27			37		
STIG-A2			1	73			101		
STIG-A3	1		1	19			284		
STIG-A4	1		2	14		7	22		
STIG-R5	4		2	37		2	116		
STIG-R4	5			16			389		
STIG-R3			2	38			163		
STIG-R2			1	65			101		
STIG-R1				34			33		
WP-A1	54		243	112		3	4		10
WP-A3	85		17	24			1		7
WP-A4	5		8	68		1	1		1
WP-C	5		14	25			1		2
WP-R6	11		6	85		1	2		
WP-R5	9		4	30			2		
WP-R4	9		1	16		2			2
WP-R3	256		32	59		22	11		21
WP-R2	134		38	215		35	11		21
WP-R1	3			18		7	3		1

Appendix G. (Continued)

	Elmidae	Ephemeridae	Gammarus	Gerridae	Gyrinidae	Haliplidae	Hebridae	Hirundinea	Hyallela	Hydracarina	Hydrobiidae
BP-A1						1			239	113	
BP-A2									463	90	
BP-A3			1						177	121	
BP-A4			3	1				2	62	69	
BP-R4			1		15			1	413	34	
BP-R3			1						594	155	
BP-R2			1						1034	41	
BP-R1			3						1302	15	
HISL-A1			1						8	64	
HISL-A2			8		1				49	96	
HISL-A3			41						216	96	
HISL-C			2						134	64	
HISL-R4			1						13	192	
HISL-R3			7					1	2	640	1
HISL-R2								3		192	
HISL-R1			2						2	128	
HT-S1			3						29		
HT-S2			30						632	1	
HT-N2			43						360		
HT-N1			12						2592		
HT-NC		1	41						1453		
HT-E1			1						257	1	
HT-E2			10						212	1	
HT-W2			62						2133	1	
HT-W1		1	22						560		
STIG-A1			4								
STIG-A2			10								
STIG-A3			3								
STIG-A4			25							1	
STIG-R5			3								
STIG-R4			10							5	
STIG-R3			25								
STIG-R2			11								
STIG-R1			4							1	
WP-A1		2	182		18				802	72	1
WP-A3			51		21	1		4	459	5	19
WP-A4			4		8			2	83	10	
WP-C			1		9			1	80	3	
WP-R6			3		7			2	23	4	1
WP-R5			2		5	1		4	32	2	
WP-R4			74		7		2	6	535	2	14
WP-R3			656		79				280	62	4
WP-R2		1	673		114			3	1212	110	10
WP-R1			1099		1				279	34	1

Appendix G. (Continued)

	Hydrophilidae	Hydroptilidae	Leptoceridae	Leptophlebiidae	Libellulidae	Limnaeidae	Limniphilidae	Mesovellidae	Naididae	Nepidae
BP-A1			86							
BP-A2			213						8	
BP-A3	3		71			5		19	56	
BP-A4			204			11		4		
BP-R4			41		1	1		6	1	2
BP-R3			38			1		1	46	
BP-R2			12			1			12	
BP-R1			16						5	
HISL-A1										
HISL-A2										1
HISL-A3					1			1		
HISL-C										1
HISL-R4										1
HISL-R3										
HISL-R2										
HISL-R1										
HT-S1										
HT-S2			8							
HT-N2			12		2					
HT-N1			61							
HT-NC			1							
HT-E1										
HT-E2										
HT-W2			21			3	2			
HT-W1			8			2				
STIG-A1			5							
STIG-A2			3							
STIG-A3										
STIG-A4										
STIG-R5										
STIG-R4										
STIG-R3										
STIG-R2			2							
STIG-R1										
WP-A1			27							
WP-A3	1							1	2	2
WP-A4			4					11	46	2
WP-C								2	18	1
WP-R6								10	23	
WP-R5								7	28	
WP-R4			3					1	38	
WP-R3			32					10		
WP-R2			83					2		
WP-R1			13							

Appendix G. (Continued)

Code:	Notonectidae	Oligochaeta	Phryganaidae	Physidae	Planorbidae	Pleidae	Pyralidae	Sialdidae	Siphlonuridae	Stratimyidae	Tipulidae
BP-A1				3							
BP-A2				12	3						
BP-A3				37	11						
BP-A4				9	6						
BP-R4				21	24						
BP-R3				12	11						
BP-R2				2	1						
BP-R1				1	1						
HISL-A1											
HISL-A2				4					3		
HISL-A3				1					2		
HISL-C				2					2		
HISL-R4									6		
HISL-R3								1	18		
HISL-R2									12		
HISL-R1									8		
HT-S1											
HT-S2											
HT-N2											
HT-N1											
HT-NC											
HT-E1											
HT-E2											
HT-W2					2						
HT-W1					1						
STIG-A1											
STIG-A2											
STIG-A3											
STIG-A4				1							
STIG-R5											
STIG-R4											
STIG-R3		1									
STIG-R2											
STIG-R1											
WP-A1						1					
WP-A3				10	5	8					
WP-A4				6		1					
WP-C				7	3						
WP-R6				3							
WP-R5				2	2						
WP-R4				20	10	3					
WP-R3				12	6						
WP-R2				6	2						
WP-R1					3						

Appendix G. (Continued)

Code:	Turbellaria	Valvatidae	Veliidae	Total Abundance:	Taxa Richness:
BP-A1				1159	11
BP-A2				1712	11
BP-A3				861	15
BP-A4				507	17
BP-R4				1268	21
BP-R3				1048	17
BP-R2				1149	12
BP-R1				1402	10
HISL-A1				724	8
HISL-A2				624	13
HISL-A3				730	12
HISL-C				1929	10
HISL-R4				1516	9
HISL-R3				8482	11
HISL-R2				3284	5
HISL-R1				5045	6
HT-S1				34	4
HT-S2				683	5
HT-N2				420	6
HT-N1				2665	3
HT-NC				1496	4
HT-E1				260	4
HT-E2				225	5
HT-W2				2229	9
HT-W1				599	9
STIG-A1				74	5
STIG-A2				191	6
STIG-A3				309	6
STIG-A4				75	9
STIG-R5				165	7
STIG-R4				425	5
STIG-R3				229	5
STIG-R2				182	6
STIG-R1				72	4
WP-A1				1556	15
WP-A3		1		742	24
WP-A4				267	19
WP-C				182	18
WP-R6				182	15
WP-R5				130	14
WP-R4	5			760	22
WP-R3		1		1548	17
WP-R2				2697	19
WP-R1				1468	13

Appendix H. Microinvertebrates captured in quatrefoil light traps along transects in coastal wetlands in 2004. Transects were oriented from open water towards shore (reference) and from an anthropogenic edge towards the marsh interior (anthropogenic), perpendicular to reference.

Site:	**Bayport**							
Transect Type:	**Anthro**			**A**	**Reference**			
Distance From Edge (m):	**0**	**5**	**10**	**15**	**30**	**20**	**10**	**0**
Bosminiidae	49216	4496	1168	4384	1536	2848	6064	1520
Bythotrephes	0	0	0	0	0	0	0	0
Chydoridae	38354	5414	10654	11149	137245	14791	1456	5542
Daphniidae	64	16	128	192	256	288	48	16
Macrothricidae	0	0	0	0	0	0	0	0
Polyphemidae	0	0	0	0	0	0	0	0
Sididae	21982	5572	2976	1329	914	3145	4279	3398
Ostracoda	45305	10314	12480	8750	53105	13908	3801	9934
Callanoida	0	32	96	128	1280	96	128	32
Cyclopoida	576	48	432	32	2560	192	80	32
Harpaticoida	0	0	144	96	0	0	0	16

Site:	**Hill Island**								
Transect Type:	**Anthro**				**Reference**				
Distance From Edge (m):	**0**	**10**	**20**	**30**	**120**	**90**	**60**	**30**	**0**
Bosminiidae	2880	2560	0	0	0	32640	78080	15680	12480
Bythotrephes	0	0	0	0	0	0	0	0	0
Chydoridae	2496	8992	4096	9088	9088	6592	11584	3136	1952
Daphniidae	32	96	320	448	448	0	0	0	0
Macrothricidae	96	96	160	192	192	128	64	32	160
Polyphemidae	0	0	0	0	0	0	0	0	0
Sididae	5984	9696	9696	9088	9088	8832	18496	12320	12992
Ostracoda	4384	5536	5568	8704	8704	4416	4160	1696	992
Callanoida	384	192	32	192	192	192	128	0	128
Cyclopoida	2208	960	704	1600	1600	2688	9152	3104	5312
Harpaticoida	0	0	0	0	0	0	0	0	64

Site:	**St. Ignace**								
Transect Type:	**Anthro**				**Reference**				
Distance From Edge (m):	**0**	**20**	**40**	**60**	**115**	**95**	**55**	**25**	**0**
Bosminiidae	140800	97280	294400	197120	119040	198400	33920	32960	14560
Bythotrephes	5	1	3	1	0	0	1	0	6
Chydoridae	6784	9472	49920	59776	78400	36096	21440	15232	5056
Daphniidae	128	0	0	0	64	128	0	0	0
Macrothricidae	0	0	0	0	0	192	0	0	0
Polyphemidae	1280	768	0	1024	0	0	0	0	0
Sididae	12160	15040	12928	9728	6144	8192	9440	5984	6000
Ostracoda	3072	13184	16512	7040	5760	10176	9248	10400	1968
Callanoida	5632	768	2688	1792	832	3584	2784	1440	544
Cyclopoida	768	704	1024	3072	1088	576	480	160	224
Harpaticoida	0	0	0	0	0	0	32	96	0

Appendix H. (Continued)

Site:	**Hilltop**											
Transect Type:	**Anthro**						**Reference**					
Distance From Edge (m):	**0**	**14**	**23**	**26**	**18**	**0**	**0**	**12**	**36**	**35**	**20**	**0**
Bosminiidae	110	0	0	0	0	0	0	0	0	0	0	0
Bythotrephes	0	0	0	0	0	0	0	0	0	0	0	0
Chydoridae	16	10	2	2	17	13	7	5	2	2	80	13
Daphniidae	0	0	0	0	0	0	0	0	0	0	0	0
Macrothricidae	0	0	0	0	0	0	0	0	0	0	0	0
Polyphemidae	2	0	0	0	0	0	0	0	0	0	0	0
Sididae	11	11	2	2	4	38	63	0	2	2	7	4
Ostracoda	1	12	16	16	15	4	19	14	16	16	31	9
Callanoida	2	0	0	0	0	0	0	0	0	0	0	0
Cyclopoida	1	0	0	0	0	0	0	0	0	0	0	0
Harpaticoida	7	0	0	0	0	0	0	0	0	0	0	0

Site:	**Wigwam Bay**										
Transect Type:	**Anthro**				**Reference**						
Distance From Edge (m):	**0**	**20**	**30**	**40**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
Bosminiidae	27520	80	2112	0	0	0	8	32	35648	77312	432
Bythotrephes	0	0	0	0	0	0	0	0	0	0	0
Chydoridae	3264	128	328	216	216	112	16	240	8256	55808	2392
Daphniidae	576	192	248	368	368	232	144	496	0	128	16
Macrothricidae	0	0	0	0	0	0	0	0	0	0	0
Polyphemidae	64	0	0	0	0	0	0	16	0	0	0
Sididae	3584	112	392	352	352	56	52	80	1344	4736	381
Ostracoda	2368	224	192	120	120	136	44	16	1920	6272	272
Callanoida	1536	144	144	104	104	56	40	192	576	640	240
Cyclopoida	640	176	400	160	160	128	108	672	2624	4352	32
Harpaticoida	0	0	40	0	0	0	0	0	0	0	0

Appendix I. Chemical, physical, and sampling information for fragmented wetland sites that were sampled with quatrefoil light traps in 2005.

Site:	**Bay Port**									**Linwood**							
Position:	**N43.86112 W83.3592**									**N43.73924 W83.94776**							
Date:	**5/20/05**									**5/25/05**							
Category:	**Anthro**				**Corner**	**Reference**				**Anthro**				**Corner**	**Reference**		
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**
Site Code:	**BPO-A1**	**BPO-A2**	**BPO-A3**	**BPO-A4**	**BPO-C**	**BPO-R4**	**BPO-R3**	**BPO-R2**	**BPO-R1**	**LW-A1**	**LW-A2**	**LW-A3**	**LW-A4**	**LW-C**	**LW-R4**	**LW-R3**	**LW-R2**
Depth (cm)	22.9	17.8	11.4	15.2	14.0	15.2	24.1	17.8	31.8	16.5	10.2	10.2	10.2	10.2	10.2	10.2	10.2
Temp.(C)	14.16	13.77	13.20	13.54	13.99	14.58	15.14	15.57	15.07	15.65	14.61	13.41	13.80	14.06	13.88	13.98	14.42
%Dissolved Oxygen	83.5	58.8	56.4	56.3	55.6	69.1	93.9	99.9	102.4	71.9	59.5	36.1	25.6	35.8	30.8	45.3	60.1
Dissolved Oxygen (mg/L)	8.44	6.10	6.04	5.78	5.76	7.04	9.34	9.88	9.91	7.08	6.11	3.86	2.65	3.58	3.17	4.70	5.45
Specific Conductance (*u* S/cm)	661.7	608.1	578.2	580.0	590.5	390.5	482.0	420.8	526.3	599.0	601.4	655.9	619.5	338.3	578.1	583.5	559.2
Total Dissolved Solids (g/L)	0.4222	0.3890	0.3704	0.3730	0.3777	0.3144	0.3087	0.2701	0.3375	0.3839	0.3859	0.4197	0.3966	0.2188	0.3705	0.3739	0.3586
Turbidity (NTU)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
pH	8.00	8.02	8.06	8.04	7.94	8.07	8.19	8.41	8.30	8.43	8.30	8.02	7.94	7.93	7.88	7.98	8.05
Oxidation-Reduction Pot. (mv)	416	409	394	388	381	370	362	352	358	387	390	396	391	357	351	344	339
Chlorophyll (mg/L)	9.30	7.30	7.30	7.00	7.30	5.80	5.20	4.20	5.50	6.50	7.40	8.00	6.20	5.10	3.60	3.90	4.20
Alkalinity (mg $CaCO_3$/L)	180				196				131	149				211			
Chloride (mg/L)	31.4				26.3				21.0	71.1				61.5			
Sulfate-S (mg/L)	74.6				65.9				45.8	43.8				26.0			
Nitrate-N (mg/L)	5.14				0.89				1.62	0.54				0.00			
Ammonium-N (mg/L)	0.02				0.02				0.01	0.03				0.01			
Soluble Reactive Phos. (mg/L)	0.00				0.00				0.00	0.00				0.00			

Appendix I. (Continued).

	Site:	**Wildfowl Point**							**Linwood North**								
	Position:	**N43.85343 W83.3759**							**N43.74559 W83.95002**								
	Date:	**6/1/05**							**6/8/05**								
	Category:	**Anthro**			**Corner**	**Reference**			**Anthro**			**Corner**	**Reference**				
0	**Distance From Open Water:**	**0**	**10**	**20**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**
LW-R1	**Site Code:**	**WFP-A1**	**WFP-A2**	**WFP-A3**	**WFP-C**	**WFP-R3**	**WFP-R2**	**WFP-R1**	**LN-A1**	**LN-A2**	**LN-A3**	**LN-C**	**LN-R5**	**LN-R4**	**LN-R3**	**LN-R2**	**LN-R1**
12.7	**Depth (cm)**	17.8	14.0	13.3	12.7	13.3	11.4	16.5	10.2	8.9	7.6	8.9	12.7	14.0	15.2	21.0	24.8
15.30	**Temp.(C)**	19.17	18.01	16.41	17.07	17.18	17.49	18.58	25.61	24.39	25.52	25.26	23.95	24.21	24.29	24.46	24.51
70.6	**%Dissolved Oxygen**	77.5	57.7	45.9	40.2	40.7	38.0	76.3	104.3	87.0	156.9	154.7	122.8	115.4	108.3	98.7	97.6
7.03	**Dissolved Oxygen (mg/L)**	7.13	5.44	4.42	3.86	3.88	3.56	7.04	8.41	7.20	12.72	12.62	10.22	9.58	9.03	8.15	8.05
533.1	**Specific Conductance (*u* S/cm)**	340.3	367.6	391.0	446.3	442.3	421.1	373.9	405.5	422.1	451.6	423.1	411.3	411.7	418.3	414.8	407.7
0.3415	**Total Dissolved Solids (g/L)**	0.2180	0.2350	0.2479	0.2852	0.2833	0.2694	0.2165	0.2593	0.2706	0.2891	0.2634	0.2659	0.2639	0.2683	0.2655	0.2612
0.2	**Turbidity (NTU)**	2.2	0.0	0.0	0.0	0.0	0.0	1.8	2.0	2.0	1.8	1.9	3.4	2.5	3.6	2.9	3.1
8.19	**pH**	8.81	8.23	7.98	7.94	7.94	7.96	8.81	8.50	8.27	8.65	8.84	8.69	8.65	8.56	8.44	8.48
331	**Oxidation-Reduction Pot. (mv)**	318	343	359	379	387	395	375	335	355	346	343	355	361	367	379	382
4.80	**Chlorophyll (mg/L)**	5.30	5.40	3.90	4.50	5.80	3.40	4.40	2.30	3.20	4.20	3.60	3.40	2.20	2.30	2.20	2.20
159	**Alkalinity (mg $CaCO_3$/L)**	105			156			106	104			119					105
56.3	**Chloride (mg/L)**	18.6			21.5			18.4	41.7			37.2					62.2
38.4	**Sulfate-S (mg/L)**	35.2			33.2			34.9	29.7			26.2					30.1
0.23	**Nitrate-N (mg/L)**	0.00			0.00			0.00	0.56			0.22					0.58
0.01	**Ammonium-N (mg/L)**	0.03			0.02			0.03	0.05			0.03					0.05
0.00	**Soluble Reactive Phos. (mg/L)**	0.00			0.00			0.00	0.00			0.00					0.00

Appendix I. (Continued).

Site:	**Middle Passage**											
Position:	**N43.8206 W83.39673**											
Date:	**6/1/05**											
Category:	**Anthro**						**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**40**	**30**	**20**	**10**	**0**
Site Code:	**MP-A1**	**MP-A2**	**MP-A3**	**MP-A4**	**MP-A5**	**MP-A6**	**MP-C**	**MP-R5**	**MP-R4**	**MP-R3**	**MP-R2**	**MP-R1**
Depth (cm)	26.7	15.2	20.3	17.8	20.3	19.1	22.2	22.2	22.2	24.1	26.7	26.7
Temp.(C)	19.20	18.25	18.73	19.15	19.59	20.15	20.36	20.97	21.12	21.00	21.08	20.99
%Dissolved Oxygen	62.8	55.0	50.6	41.7	45.7	60.2	62.3	69.2	72.1	80.7	68.5	78.7
Dissolved Oxygen (mg/L)	5.71	5.10	4.57	3.83	4.14	5.44	5.59	6.13	6.34	7.14	6.02	6.92
Specific Conductance (*u* S/cm)	813.3	775.6	754.6	727.2	716.6	693.6	697.8	622.6	550.5	518.1	512.0	473.4
Total Dissolved Solids (g/L)	0.5198	0.4967	0.4828	0.4652	0.4586	0.4454	0.4467	0.3987	0.3524	0.3304	0.3277	0.3030
Turbidity (NTU)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	8.12	8.13	8.18	8.05	8.09	8.14	8.15	8.33	8.44	8.59	8.60	8.69
Oxidation-Reduction Pot. (mv)	324	305	305	288	268	272	266	259	262	250	256	256
Chlorophyll (mg/L)	4.70	8.10	8.70	5.40	9.80	4.70	8.20	7.50	7.00	6.90	7.40	9.40
Alkalinity (mg CaCO$_3$/L)	179						167					135
Chloride (mg/L)	91.7						54.9					26.6
Sulfate-S (mg/L)	79.7						67.1					50.8
Nitrate-N (mg/L)	0.58						0.00					0.00
Ammonium-N (mg/L)	0.06						0.04					0.09
Soluble Reactive Phos. (mg/L)	0.00						0.00					0.00

Appendix I. (Continued).

Site:	**Nayanquing South**										
Position:	**N43.80638 W83.91809**										
Date:	**6/8/05**										
Category:	**Anthro**					**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
Site Code:	**NS-A1**	**NS-A2**	**NS-A3**	**NS-A4**	**NS-A5**	**NS-C**	**NS-R5**	**NS-R4**	**NS-R3**	**NS-R2**	**NS-R1**
Depth (cm)	35.6	24.1	23.5	21.6	21.6	17.8	21.0	22.9	30.5	35.6	35.6
Temp.(C)	25.83	25.95	26.23	26.19	26.11	26.18	26.27	26.11	25.87	25.40	25.69
%Dissolved Oxygen	109.9	112.3	111.7	110.0	110.8	111.8	124.9	137.2	134.7	118.0	107.1
Dissolved Oxygen (mg/L)	8.90	9.00	8.89	8.90	8.87	9.03	10.03	11.03	11.07	9.57	7.53
Specific Conductance (*u* S/cm)	396.8	399.4	400.9	400.5	401.1	399.9	397.8	393.0	386.2	410.3	438.7
Total Dissolved Solids (g/L)	0.2540	0.2557	0.2567	0.2564	0.2568	0.2562	0.2549	0.2515	0.2471	0.2612	0.2810
Turbidity (NTU)	2.2	3.6	8.0	4.9	2.4	10.0	4.8	2.7	4.1	5.5	6.1
pH	8.65	8.70	8.63	8.70	8.68	8.71	8.88	9.02	9.03	8.79	8.55
Oxidation-Reduction Pot. (mv)	324	324	328	328	332	331	327	323	325	337	347
Chlorophyll (mg/L)	2.50	2.70	4.60	9.40	8.30	8.70	6.20	2.80	4.90	3.80	3.50
Alkalinity (mg $CaCO_3$/L)	112					115.5					120.5
Chloride (mg/L)	38.2					38.4					38.8
Sulfate-S (mg/L)	24.0					23.3					24.2
Nitrate-N (mg/L)	0.32					0.33					1.65
Ammonium-N (mg/L)	0.04					0.03					0.04
Soluble Reactive Phos. (mg/L)	0.00					0.00					0.00

Appendix I. (Continued).

Site:	**Nanyanquing North**									**Wirbel Road**								
Position:	**N43.81043 W83.91741**									**N43.87337 W83.91214**								
Date:	**6/9/05**									**6/16/05**								
Category:	**Anthro**				**Corner**	**Reference**				**Anthro**				**Corner**	**Reference**			
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**
Site Code:	**NN-A1**	**NN-A2**	**NN-A3**	**NN-A4**	**NN-C**	**NN-R4**	**NN-R3**	**NN-R2**	**NN-R1**	**W-A1**	**W-A2**	**W-A3**	**W-A4**	**W-C**	**W-R4**	**W-R3**	**W-R2**	**W-R1**
Depth (cm)	30.5	20.3	26.7	22.9	33.0	27.9	31.8	33.0	33.0	31.8	30.5	25.4	27.9	30.5	30.5	35.6	38.1	45.7
Temp.(C)	27.04	27.15	26.95	26.87	26.79	26.47	26.41	26.36	26.21	18.27	18.25	18.40	18.46	18.30	18.29	18.46	18.21	18.04
%Dissolved Oxygen	114.2	108.2	129.4	118.1	99.5	96.9	93.9	98.3	100.2	93.4	86.0	85.0	97.4	100.3	101.8	100.1	94.9	93.1
Dissolved Oxygen (mg/L)	9.00	8.50	10.23	9.43	7.92	7.73	7.51	7.86	8.12	8.73	8.05	7.93	9.05	9.39	9.59	9.30	8.91	8.80
Specific Conductance (*u* S/cm)	541.4	536.5	550.8	534.4	516.3	514.9	514.3	522.9	516.5	452.7	456.9	460.8	452.8	451.5	450.7	449.4	449.4	451.4
Total Dissolved Solids (g/L)	0.3461	0.3432	0.3525	0.3419	0.3304	0.3298	0.3295	0.3348	0.3308	0.2890	0.2927	0.2945	0.2896	0.2889	0.2881	0.2876	0.2876	0.2888
Turbidity (NTU)	3.3	3.3	4.0	2.3	4.2	2.8	3.8	3.9	7.3	4.2	4.0	4.0	3.2	3.9	5.2	4.3	6.2	5.5
pH	8.59	8.63	8.70	8.56	8.43	8.34	8.44	8.48	8.44	8.50	8.11	8.11	8.33	8.56	8.56	8.56	8.52	8.34
Oxidation-Reduction Pot. (mv)	301	298	297	301	306	308	304	318	336	286	295	289	287	277	290	292	300	307
Chlorophyll (mg/L)	3.50	5.20	4.30	3.00	7.40	4.90	5.30	3.50	3.90	5.50	5.30	5.50	5.40	6.40	7.50	5.60	6.00	6.60
Alkalinity (mg CaCO$_3$/L)	130				130				129	132				131				133
Chloride (mg/L)	63.0				55.7				55.2	34.5				34.9				32.3
Sulfate-S (mg/L)	25.2				24.5				25.6	28.0				28.7				28.0
Nitrate-N (mg/L)	2.37				2.46				3.03	2.59				2.66				2.85
Ammonium-N (mg/L)	0.11				0.08				0.06	0.02				0.02				0.02
Soluble Reactive Phos. (mg/L)	0.00				0.00				0.00	0.00				0.00				0.01

Appendix I. (Continued).

Site: **Pinconning South**
Position: **N43.82459 W83.91534**
Date: **6/9/05**

Category:	**Anthro**					**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
Site Code:	**PS-A1**	**PS-A2**	**PS-A3**	**PS-A4**	**PS-A5**	**PS-C**	**PS-R5**	**PS-R4**	**PS-R3**	**PS-R2**	**PS-R1**
Depth (cm)	44.5	26.7	30.5	34.3	34.3	34.9	33.0	37.5	49.5	49.5	58.4
Temp.(C)	27.80	28.29	28.37	28.33	28.20	28.34	28.26	27.92	27.77	27.35	27.01
%Dissolved Oxygen	154.0	148.6	126.9	111.5	101.2	108.4	142.4	151.1	144.6	148.4	130.8
Dissolved Oxygen (mg/L)	12.07	11.61	9.84	8.61	7.80	8.29	11.00	11.75	11.32	11.72	10.39
Specific Conductance (*u* S/cm)	576.7	596.7	549.5	526.3	507.2	489.9	487.0	511.0	544.6	563.8	561.0
Total Dissolved Solids (g/L)	0.3692	0.3818	0.3516	0.3660	0.3247	0.3145	0.3117	0.3272	0.3487	0.3605	0.3594
Turbidity (NTU)	3.7	7.0	3.4	6.7	2.2	1.1	1.8	2.5	3.1	2.5	3.6
pH	8.75	8.49	8.33	8.15	7.94	8.16	8.65	8.79	8.79	8.72	8.55
Oxidation-Reduction Pot. (mv)	306	314	321	329	340	330	310	307	308	312	323
Chlorophyll (mg/L)	3.50	4.20	7.80	7.10	6.90	3.00	3.30	4.40	3.90	3.10	3.30
Alkalinity (mg CaCO$_3$/L)	142					134					137
Chloride (mg/L)	56.5					49.2					54.5
Sulfate-S (mg/L)	30.2					25.9					31.0
Nitrate-N (mg/L)	5.29					0.58					5.36
Ammonium-N (mg/L)	0.04					0.02					0.03
Soluble Reactive Phos. (mg/L)	0.00					0.00					0.00

Appendix I. (Continued).

Site:	**Bay Port East**									**Hill Island**							
Position:	**N43.86112 W83.3592**									**N45.9823 W84.31752**							
Date:	**6/15/05**									**6/22/05**							
Category:	**Anthro**				**Corner**	**Reference**				**Anthro**				**Corner**	**Reference**		
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**
Site Code:	**BPE-A1**	**BPE-A2**	**BPE-A3**	**BPE-A4**	**BPE-C**	**BPE-R4**	**BPE-R3**	**BPE-R2**	**BPE-R1**	**HI-A1**	**HI-A2**	**HI-A3**	**HI-A4**	**HI-C**	**HI-R4**	**HI-R3**	**HI-R2**
Depth (cm)	34.3	25.4	22.9	22.9	30.5	27.9	24.1	19.1	40.6	61.0	61.0	55.9	64.8	61.0	67.3	69.9	77.5
Temp.(C)	16.47	15.92	16.09	16.10	16.10	16.24	16.91	17.25	17.15	20.13	20.02	19.97	19.91	19.67	19.58	19.52	19.50
%Dissolved Oxygen	73.8	50.9	35.5	38.6	33.8	29.2	41.1	87.8	92.6	82.5	82.7	87.0	86.4	89.4	90.3	88.9	88.8
Dissolved Oxygen (mg/L)	7.12	4.99	3.46	3.77	3.30	2.81	3.91	8.37	8.85	7.36	7.43	7.82	7.73	8.11	8.50	8.14	8.10
Specific Conductance (*u* S/cm)	634.4	790.4	877.7	880.1	881.4	879.1	702.2	355.9	349.7	179.6	178.5	177.3	177.0	175.9	175.5	175.5	175.1
Total Dissolved Solids (g/L)	0.4060	0.5060	0.5618	0.5631	0.5647	0.5627	0.4496	0.2278	0.2237	0.1146	0.1141	0.1134	0.1129	0.1125	0.1125	0.1128	0.1117
Turbidity (NTU)	19.9	14.6	43.3	7.1	5.5	17.0	32.0	17.5	42.1	5.6	4.9	3.8	6.8	5.0	5.3	5.4	4.8
pH	7.84	7.66	7.54	7.51	7.52	7.45	7.54	8.28	8.43	8.00	7.97	8.06	8.15	8.28	8.34	8.35	8.38
Oxidation-Reduction Pot. (mv)	315	320	323	324	377	358	336	303	359	351	351	343	335	328	328	328	327
Chlorophyll (mg/L)	21.90	31.90	42.90	29.40	29.80	33.00	39.00	19.90	16.50	1.90	1.60	1.70	1.70	1.50	1.40	1.60	1.60
Alkalinity (mg $CaCO_3$/L)	163				215				105	73				71			
Chloride (mg/L)	22.7				20.4				15.1	4.7				0.9			
Sulfate-S (mg/L)	56.4				59.7				27.4	11.0				0.2			
Nitrate-N (mg/L)	11.36				14.90				2.14	0.11				0.00			
Ammonium-N (mg/L)	0.09				0.08				0.12	0.03				0.03			
Soluble Reactive Phos. (mg/L)	0.05				0.06				0.00	0.00				0.00			

Appendix I. (Continued).

	Site:	**Quanicassi West**										
	Position:	**N43.6251 W83.74102**										
	Date:	**6/15/05**										
	Category:	**Anthro**					**Corner**	**Reference**				
0	**Distance From Open Water:**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
HI-R1	**Site Code:**	**QW-A1**	**QW-A2**	**QW-A3**	**QW-A4**	**QW-A5**	**QW-C**	**QW-R5**	**QW-R4**	**QW-R3**	**QW-R2**	**QW-R1**
83.8	**Depth (cm)**	36.8	39.4	39.4	43.2	43.2	44.5	40.6	41.9	41.9	40.6	41.9
19.24	**Temp.(C)**	19.84	19.81	19.75	19.78	19.78	19.72	19.69	19.32	19.22	19.22	19.16
89.2	**%Dissolved Oxygen**	143.1	148.4	145.2	144.4	140.9	127.1	118.0	118.0	127.1	119.8	131.6
8.23	**Dissolved Oxygen (mg/L)**	12.93	13.36	13.19	13.11	12.79	11.50	10.73	10.82	11.64	11.01	12.06
175.0	**Specific Conductance (*u* S/cm)**	490.7	502.9	508.5	503.3	504.0	505.2	507.9	501.9	503.0	503.1	502.2
0.1119	**Total Dissolved Solids (g/L)**	0.3146	0.3224	0.3255	0.3221	0.3221	0.3234	0.3251	0.3214	0.3219	0.3219	0.3213
5.4	**Turbidity (NTU)**	11.2	10.7	9.1	8.8	10.4	10.1	6.5	8.9	8.5	53.5	66.0
8.44	**pH**	9.35	9.38	9.32	9.30	9.31	9.20	9.06	9.11	9.17	9.20	9.25
325	**Oxidation-Reduction Pot. (mv)**	300	295	293	292	293	294	298	299	292	292	289
1.60	**Chlorophyll (mg/L)**	43.40	18.00	12.80	25.40	33.90	19.20	22.00	7.30	16.90	13.80	36.40
71	**Alkalinity (mg $CaCO_3$/L)**	122					122					131
4.6	**Chloride (mg/L)**	60.4					63.6					56.0
11.3	**Sulfate-S (mg/L)**	28.9					31.6					31.1
0.17	**Nitrate-N (mg/L)**	0.00					0.31					0.76
0.05	**Ammonium-N (mg/L)**	0.01					0.01					0.01
0.00	**Soluble Reactive Phos. (mg/L)**	0.00					0.00					0.00

Appendix I. (Continued).

Site:	**Pinconning Fishing Edge**										
Position:	**N43.83196 W83.91749**										
Date:	**6/16/05**										
Category:	**Anthro**					**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
Site Code:	**PF-A1**	**PF-A2**	**PF-A3**	**PF-A4**	**PF-A5**	**PF-C**	**PF-R5**	**PF-R4**	**PF-R3**	**PF-R2**	**PF-R1**
Depth (cm)	35.6	31.8	31.1	30.5	27.9	24.1	27.3	34.3	34.3	50.8	54.6
Temp.(C)	17.82	18.00	17.89	17.70	17.39	16.79	17.10	17.45	17.41	17.53	17.69
%Dissolved Oxygen	89.2	79.7	70.8	72.8	66.8	56.6	64.6	78.4	85.7	81.5	83.7
Dissolved Oxygen (mg/L)	8.34	7.45	6.66	6.92	6.37	5.46	6.24	7.48	8.08	7.67	7.93
Specific Conductance (*u* S/cm)	555.8	561.6	575.8	579.5	588.1	600.1	588.4	556.7	538.1	555.8	527.6
Total Dissolved Solids (g/L)	0.3559	0.3592	0.3682	0.3707	0.3767	0.3842	0.3768	0.3561	0.3447	0.3557	0.3373
Turbidity (NTU)	8.1	6.8	5.5	4.9	4.2	6.9	5.1	7.1	5.9	7.9	5.5
pH	8.37	8.32	8.15	8.07	7.98	7.96	7.96	8.32	8.45	8.28	8.35
Oxidation-Reduction Pot. (mv)	272	275	284	292	294	291	307	298	286	338	336
Chlorophyll (mg/L)	4.40	4.70	5.10	5.60	6.50	6.00	5.60	5.40	5.20	11.60	6.20
Alkalinity (mg $CaCO_3$/L)	139					152					136
Chloride (mg/L)	49.5					50.9					46.7
Sulfate-S (mg/L)	32.1					34.1					34.1
Nitrate-N (mg/L)	5.43					4.93					4.21
Ammonium-N (mg/L)	0.03					0.03					0.03
Soluble Reactive Phos. (mg/L)	0.00					0.00					0.00

Appendix I. (Continued).

Site: **St. Ignace**
Position: **N45.84738 W84.73762**
Date: **6/22/05**

Category:	**Anthro**					**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
Site Code:	**SI-A1**	**SI-A2**	**SI-A3**	**SI-A4**	**SI-A5**	**SI-C**	**SI-R5**	**SI-R4**	**SI-R3**	**SI-R2**	**SI-R1**
Depth (cm)	66.0	59.7	59.7	58.4	57.2	60.3	57.2	40.6	36.8	40.6	48.3
Temp.(C)	19.28	20.01	20.70	20.92	20.98	20.16	20.62	20.70	20.81	20.07	19.48
%Dissolved Oxygen	93.6	86.5	80.7	74.1	70.2	61.6	53.5	30.2	26.4	43.1	75.2
Dissolved Oxygen (mg/L)	8.58	7.81	7.21	6.56	6.28	5.16	4.76	2.62	2.28	3.87	6.89
Specific Conductance (*u* S/cm)	221.0	219.3	217.3	219.8	222.5	223.8	232.4	269.7	291.0	257.2	231.2
Total Dissolved Solids (g/L)	0.4100	0.1406	0.1391	0.1407	0.1422	0.1432	0.1488	0.1726	0.1865	0.1643	0.1484
Turbidity (NTU)	5.8	4.6	3.6	3.0	2.0	3.3	3.1	2.5	4.6	8.6	6.6
pH	8.39	8.34	8.18	8.02	7.90	7.84	7.84	7.67	7.68	7.81	8.16
Oxidation-Reduction Pot. (mv)	356	347	351	352	355	346	329	316	275	302	298
Chlorophyll (mg/L)	3.40	1.28	1.50	3.40	1.50	2.20	2.20	3.20	3.30	5.40	3.20
Alkalinity (mg CaCO$_3$/L)	85					87					94
Chloride (mg/L)	7.5					6.9					8.0
Sulfate-S (mg/L)	15.8					15.3					14.9
Nitrate-N (mg/L)	0.15					0.00					0.09
Ammonium-N (mg/L)	0.02					0.03					0.02
Soluble Reactive Phos. (mg/L)	0.00					0.00					0.00

Appendix I. (Continued).

Site:	**Hill Island**											
Position:	**N45.9823 W84.31752**											
Date:	**6/22/05**											
Category:	**Anthro**				**Corner**	**Reference**				**Anthro**		
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**
Site Code:	**HI-A1**	**HI-A2**	**HI-A3**	**HI-A4**	**HI-C**	**HI-R4**	**HI-R3**	**HI-R2**	**HI-R1**	**UB-A1**	**UB-A2**	**UB-A3**
Depth (cm)	61.0	61.0	55.9	64.8	61.0	67.3	69.9	77.5	83.8	97.8	99.1	96.5
Temp.(C)	20.13	20.02	19.97	19.91	19.67	19.58	19.52	19.50	19.24	21.91	21.94	21.91
%Dissolved Oxygen	82.5	82.7	87.0	86.4	89.4	90.3	88.9	88.8	89.2	88.8	83.9	86.0
Dissolved Oxygen (mg/L)	7.36	7.43	7.82	7.73	8.11	8.50	8.14	8.10	8.23	7.71	7.33	7.41
Specific Conductance (*u* S/cm)	179.6	178.5	177.3	177.0	175.9	175.5	175.5	175.1	175.0	182.7	182.6	182.1
Total Dissolved Solids (g/L)	0.1146	0.1141	0.1134	0.1129	0.1125	0.1125	0.1128	0.1117	0.1119	0.1172	0.1164	0.1168
Turbidity (NTU)	5.6	4.9	3.8	6.8	5.0	5.3	5.4	4.8	5.4	2.9	3.0	2.6
pH	8.00	7.97	8.06	8.15	8.28	8.34	8.35	8.38	8.44	8.47	8.50	8.54
Oxidation-Reduction Pot. (mv)	351	351	343	335	328	328	328	327	325	346	330	321
Chlorophyll (mg/L)	1.90	1.60	1.70	1.70	1.50	1.40	1.60	1.60	1.60	0.80	0.70	0.60
Alkalinity (mg $CaCO_3$/L)	73				71				71	74		
Chloride (mg/L)	4.7				0.9				4.6	5.2		
Sulfate-S (mg/L)	11.0				0.2				11.3	11.4		
Nitrate-N (mg/L)	0.11				0.00				0.17	0.00		
Ammonium-N (mg/L)	0.03				0.03				0.05	0.03		
Soluble Reactive Phos. (mg/L)	0.00				0.00				0.00	0.00		

Appendix I. (Continued).

Urie Bay						**Site:**	**Sheppard Bay**										
N45.96413 W84.34074						**Position:**	**N45.9785 W84.36133**										
6/23/05						**Date:**	**6/23/05**										
	Corner	**Reference**				**Category:**	**Anthro**					**Corner**	**Reference**				
30	**40**	**30**	**20**	**10**	**0**	**Distance From Open Water:**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**
UB-A4	**UB-C**	**UB-R4**	**UB-R3**	**UB-R2**	**UB-R1**	**Site Code:**	**SB-A1**	**SB-A2**	**SB-A3**	**SB-A4**	**SB-A5**	**SB-C**	**SB-R5**	**SB-R4**	**SB-R3**	**SB-R2**	**SB-R1**
91.4	82.6	96.5	106.7	116.8	121.9	**Depth (cm)**	96.5	99.1	94.0	97.8	97.8	96.5	101.6	106.7	109.2	116.8	111.8
21.93	21.94	21.95	21.90	21.85	21.85	**Temp.(C)**	23.67	23.50	23.48	23.37	23.21	23.18	23.02	22.95	22.85	22.78	22.61
82.3	83.0	86.9	89.1	91.7	92.3	**%Dissolved Oxygen**	87.6	81.4	84.0	81.8	83.5	83.4	84.2	86.7	87.9	88.8	94.3
7.27	7.25	7.56	7.77	7.98	8.08	**Dissolved Oxygen (mg/L)**	7.41	6.88	7.08	6.88	7.07	7.13	7.19	7.36	7.56	7.64	8.13
183.1	182.6	182.5	181.7	181.4	181.5	**Specific Conductance (*u* S/cm)**	200.1	197.2	195.9	196.1	194.8	194.8	193.7	190.5	193.4	192.8	193.0
0.1170	0.1165	0.1165	0.1165	0.1160	0.1160	**Total Dissolved Solids (g/L)**	0.1273	0.1264	0.1253	0.1255	0.1246	0.1243	0.1243	0.1220	0.1236	0.1234	0.1235
3.0	2.1	2.1	2.3	1.4	2.4	**Turbidity (NTU)**	6.2	9.2	9.1	9.1	13.0	8.2	7.5	6.7	6.3	7.0	6.3
8.53	8.55	8.65	8.71	8.81	8.78	**pH**	8.54	8.46	8.59	8.55	8.60	8.60	8.68	8.71	8.74	8.78	8.77
319	314	303	302	297	314	**Oxidation-Reduction Pot. (mv)**	296	324	288	320	325	332	326	327	320	305	328
0.60	0.60	0.60	0.60	0.60	0.70	**Chlorophyll (mg/L)**	1.90	1.70	1.50	1.50	2.00	1.40	1.50	1.60	1.50	1.60	1.70
	73				73	**Alkalinity (mg CaCO$_3$/L)**	80					78					77
	5.1				5.8	**Chloride (mg/L)**	6.6					6.7					11.4
	11.0				11.4	**Sulfate-S (mg/L)**	11.3					11.8					11.8
	0.00				0.00	**Nitrate-N (mg/L)**	0.00					0.00					0.00
	0.04				0.02	**Ammonium-N (mg/L)**	0.03					0.02					0.02
	0.00				0.00	**Soluble Reactive Phos. (mg/L)**	0.00					0.00					0.00

Appendix I. (Continued).

Site: **Nayanquing South**
Position: **N43.80638 W83.91809**
Date: **7/1/05**

Category:	**Anthro**				**Corner**	**Reference**				
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**
Site Code:	**NSJ-A1**	**NSJ-A2**	**NSJ-A3**	**NSJ-A4**	**NSJ-C**	**NSJ-R4**	**NSJ-R3**	**NSJ-R2**	**NSJ-R1**	**PFJ-A1**
Depth (cm)	50.8	37.5	36.8	34.3	33.0	33.0	34.3	41.9	48.3	34.3
Temp.(C)	18.52	18.73	18.98	18.83	18.84	18.83	18.71	18.62	18.56	21.14
%Dissolved Oxygen	77.3	76.5	70.5	66.2	64.8	74.6	77.1	82.4	89.4	107.6
Dissolved Oxygen (mg/L)	7.24	7.15	6.55	6.14	6.06	6.94	7.14	7.64	8.40	9.44
Specific Conductance (*u* S/cm)	387.4	368.3	384.8	384.3	377.7	368.3	361.4	350.6	346.6	466.4
Total Dissolved Solids (g/L)	0.2483	0.2355	0.2468	0.2457	0.2420	0.2358	0.2315	0.2242	0.2219	0.2968
Turbidity (NTU)	5.9	5.7	4.0	3.9	3.0	3.8	4.3	5.4	7.1	3.1
pH	9.06	9.17	8.76	8.71	8.61	8.95	9.07	9.21	9.38	8.95
Oxidation-Reduction Pot. (mv)	303	282	294	297	298	278	275	272	267	297
Chlorophyll (mg/L)	3.60	5.10	4.70	5.00	4.80	4.50	4.30	3.60	3.20	3.60
Alkalinity (mg $CaCO_3$/L)	97				91				83	114
Chloride (mg/L)	42.0				37.0				35.7	50.6
Sulfate-S (mg/L)	29.4				27.8				28.1	32.6
Nitrate-N (mg/L)	0.51				0.49				0.63	0.58
Ammonium-N (mg/L)	0.06				0.03				0.02	0.01
Soluble Reactive Phos. (mg/L)	0.00				0.00				0.00	0.00

Pinconning Fishing Edge
N43.83196 W83.91749
6/1/05

Anthro			**Corner**	**Reference**			
10	**20**	**30**	**40**	**30**	**20**	**10**	**0**
PFJ-A2	**PFJ-A3**	**PFJ-A4**	**PFJ-C**	**PFJ-R4**	**PFJ-R3**	**PFJ-R2**	**PFJ-R1**
32.4	34.9	34.9	29.2	38.1	43.2	45.7	50.2
20.96	20.48	19.76	19.88	20.08	20.72	21.07	21.15
90.2	88.5	83.1	96.1	96.0	94.1	101.8	104.0
7.99	7.95	7.60	8.58	8.63	8.39	8.98	9.19
463.0	462.5	519.4	529.8	508.3	445.3	402.0	373.2
0.2965	0.2964	0.3323	0.3399	0.3248	0.2851	0.2574	0.2388
2.9	2.8	1.6	1.5	2.4	3.3	4.1	6.4
8.69	8.58	8.41	8.32	8.37	8.82	9.06	9.24
305	309	313	303	294	261	263	261
3.10	3.20	3.30	3.30	3.10	3.30	3.00	3.10
			143				91
			55.3				35.8
			32.5				28.0
			0.32				0.41
			0.02				0.02
			0.00				0.00

Appendix I. (Continued)

Site:	**Linwood End**								
Position:	**N43.75044 W83.95187**								
Date:	**6/2/05**								
Category:	**Anthro**				**Corner**	**Reference**			
Distance From Open Water:	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**
Site Code:	**LE-A1**	**LE-A2**	**LE-A3**	**LE-A4**	**LE-C**	**LE-R4**	**LE-R3**	**LE-R2**	**LE-R1**
Depth (cm)	43.2	44.5	40.6	38.1	38.1	43.2	41.3	41.3	43.2
Temp.(C)	22.07	21.95	22.29	22.18	22.36	22.32	22.00	21.80	21.54
%Dissolved Oxygen	107.0	101.5	84.0	83.0	88.8	90.2	94.1	95.6	101.7
Dissolved Oxygen (mg/L)	9.29	8.77	7.27	7.21	7.67	7.82	8.18	8.35	8.72
Specific Conductance (*u* S/cm)	383.4	383.2	378.0	388.2	401.8	400.0	392.7	388.4	384.9
Total Dissolved Solids (g/L)	0.2460	0.2454	0.2419	0.2484	0.2571	0.2559	0.2513	0.2490	0.2461
Turbidity (NTU)	3.2	1.9	2.9	1.4	1.5	2.1	1.5	2.3	3.3
pH	9.80	9.68	9.56	9.39	9.29	9.43	9.63	9.65	9.64
Oxidation-Reduction Pot. (mv)	249	262	267	274	276	272	264	264	279
Chlorophyll (mg/L)	3.10	2.60	3.00	3.00	2.80	3.30	3.20	3.10	3.00
Alkalinity (mg $CaCO_3$/L)	75				85				76
Chloride (mg/L)	47.2				44.3				45.7
Sulfate-S (mg/L)	33.3				31.4				32.3
Nitrate-N (mg/L)	0.94				0.80				0.88
Ammonium-N (mg/L)	0.03				0.03				0.03
Soluble Reactive Phos. (mg/L)	0.00				0.00				0.00

Appendix J. Larval and Juvenile fish captured in quatrefoil light traps along transects in coastal wetlands in 2005. Transects were oriented from open water towards shore (reference) and from an anthropogenic edge towards the marsh interior (anthropogenic), perpendicular to reference.

Site:	**Bayport**									**Linwood**								
Transect Type:	**Anthro**					**Reference**				**Anthro**					**Reference**			
Distance From Edge (m):	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**
Larval Fish:																		
Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Carp (*Cyprinus carpio*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprinidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Banded killifish (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juvenile Fish:																		
Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1
Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Banded killifish adult (*Fundulus diaphanus)*	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

Site:	**Wildfowl Point**							**Middle Passage**										
Transect Type:	**Anthro**			**Reference**				**Anthro**						**Reference**				
Distance From Edge (m):	**0**	**10**	**20**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**50**	**50**	**40**	**30**	**20**	**10**
Larval Fish:																		
Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Carp (*Cyprinus carpio*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Cyprinidae	8	0	0	0	0	0	4	0	0	0	0	0	0	0	2	0	0	0
Banded killifish (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0
Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juvenile Fish:																		
Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	17
Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Banded killifish adult (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

	Site:	**Linwood North**									**Nayanquing South**									
	Transect Type:	**Anthro**			**Reference**						**Anthro**					**Reference**				
0	**Distance From Edge (m):**	**0**	**10**	**20**	**50**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**
	Larval Fish:																			
0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	White sucker *(Catostomus commersoni)*	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Lepomis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0
0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	31	14	17	14	82	95	101	9	9	5
0	Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Common Carp (*Cyprinus carpio*)	9	2	1	0	4	3	2	0	0	0	14	14	27	5	6	2	0	0	0
2	Cyprinidae	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
0	Banded killifish (*Fundulus diaphanus)*	0	1	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Longnose Gar (*Lepisosteus osseus*)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Fish:																			
0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Banded killifish adult *(Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

	Site:	**Nanyanquing North**									**Pinconning South**								
	Transect Type:	**Anthro**				**Reference**					**Anthro**					**Reference**			
0	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**
	Larval Fish:																		
0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Lepomis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0
0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Largemouth bass *(Micropterus salmoides)*	0	3	3	3	2	1	9	1	0	0	0	0	0	0	0	1	1	1
0	Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
0	Common Carp (*Cyprinus carpio*)	0	0	1	3	3	3	0	0	0	64	78	112	130	133	158	143	52	8
0	Cyprinidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	Banded killifish (*Fundulus diaphanus)*	1	9	0	0	0	2	1	0	0	1	0	0	0	1	0	0	3	1
0	Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	Brook Stickleback (*Culaea inconstans*)	0	4	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0
0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Juvenile Fish:																		
0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Emerald Shiner adult *(Notropis atherinoides)*	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Banded killifish adult (*Fundulus diaphanus)*	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	Brook Stickleback adult (*Culaea inconstans*)	3	19	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

		Site:	**Bay Port East**									**Quanicassi West**								
		Transect Type:	**Anthro**				**Reference**					**Anthro**						**Referenc**		
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**
		Larval Fish:																		
0	0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
0	0	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	3	4	2	7	0	0	0
0	0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	1	2	1	3	2	0	0	0
0	0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Lepomis	0	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0
0	0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	52	45	33	45	23	31	36	10	13
0	0	Common Carp (*Cyprinus carpio*)	0	0	11	25	8	12	0	0	0	42	145	159	165	209	207	37	4	3
0	0	Cyprinidae	0	0	0	0	0	0	0	0	0	2	0	2	9	1	4	0	0	0
3	1	Banded killifish (*Fundulus diaphanus)*	0	2	1	0	15	2	12	4	0	1	18	14	8	17	25	43	43	28
0	0	Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Juvenile Fish:																		
0	0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

		Site:	**Pinconning Fishing Edge**											**Wirbel Road**						
ce		**Transect Type:**	**Anthro**					**Reference**						**Anthro**					**Refer**	
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**
		Larval Fish:																		
0	0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
0	0	Lepomis	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
0	0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	Yellow Perch (*Perca flavescens*)	8	5	2	8	5	4	7	18	10	4	3	3	0	1	0	2	0	1
0	0	Common Carp (*Cyprinus carpio*)	6	1	2	5	18	0	7	1	3	1	0	0	1	0	0	0	3	4
0	0	Cyprinidae	1	3	4	7	0	1	0	1	2	7	5	0	0	0	1	0	0	8
3	0	Banded killifish (*Fundulus diaphanus)*	5	11	11	7	6	3	1	7	10	7	4	1	2	8	12	4	4	0
0	0	Johnny Darter *(Etheostoma nigrum)*	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)	0	0	0	1	0	2	0	0	0	0	0	0	0	1	0	1	0	0
0	0	Central Mudminnow *(Umbra limi)*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Juvenile Fish:																		
0	0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

		Site:	**St. Ignace**											**Hill Island**						
rence		**Transect Type:**	**Anthro**					**Reference**						**Anthro**					**Refer**	
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**
		Larval Fish:																		
0	0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Lepomis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Smallmouth Bass (*Micropterus dolomieu*)	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	Yellow Perch (*Perca flavescens*)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	1
0	0	Common Carp (*Cyprinus carpio*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Cyprinidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Banded killifish (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Johnny Darter *(Etheostoma nigrum)*	64	7	8	5	0	0	2	1	1	3	22	8	5	4	1	2	1	0
0	0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Juvenile Fish:																		
0	0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
0	0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Appendix J. (Continued)

		Site:	**Urie Bay**									**Sheppard Bay**								
rence		**Transect Type:**	**Anthro**					**Reference**				**Anthro**						**Referenc**		
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**50**	**40**	**30**	**20**
		Larval Fish:																		
0	0	Freshwater Drum (*Aplodinotus gruniens*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Clupeidae		0	0	0	0	0	0	0	0	8	0	0	2	0	2	0	1	2
0	0	Black Buffalo (*Ictiobus niger*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	White sucker *(Catostomus commersoni)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Lepomis		0	0	4	4	0	2	7	2	110	193	13	237	64	46	26	4	28
0	0	Black Crappie (*Pomoxis nigromaculatus*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*		4	3	9	9	2	16	1	0	4	0	0	1	1	0	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Smallmouth Bass (*Micropterus dolomieu*)		1	3	0	1	2	1	0	3	0	0	0	3	0	1	3	16	5
0	3	Yellow Perch (*Perca flavescens*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0	0	Common Carp (*Cyprinus carpio*)		0	0	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0
0	0	Cyprinidae		0	0	0	0	0	1	1	0	1	24	4	11	22	9	4	4	12
0	0	Banded killifish (*Fundulus diaphanus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	Johnny Darter *(Etheostoma nigrum)*		0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback (*Culaea inconstans*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Central Mudminnow *(Umbra limi)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Juvenile Fish:																		
1	0	Pugnose Shiner adult (*Notropus anogenus*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Bluntnose minnow adult *(Pimephales notatus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	11	0
0	0	Common Shiner adult *(Luxilus cornutus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	Emerald Shiner adult *(Notropis atherinoides)*		0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)		0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

		Site:	**Nayanquing South (resample)**									**Pinconning Fishing Edge (resample)**						
ce		**Transect Type:**	**Anthro**				**Reference**					**Anthro**					**Refer**	
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**	**0**	**10**	**20**	**30**	**40**	**30**	**20**
		Larval Fish:																
0	0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	Clupeidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	13	Lepomis	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	Smallmouth Bass (*Micropterus dolomieu*)	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
0	0	Yellow Perch (*Perca flavescens*)	0	1	5	2	3	8	2	2	0	0	0	1	4	3	0	0
0	0	Common Carp (*Cyprinus carpio*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	Cyprinidae	3	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0
0	0	Banded killifish (*Fundulus diaphanus)*	8	0	0	1	1	0	0	4	0	2	0	5	1	5	4	4
0	0	Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Juvenile Fish:																
0	0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	1	0	0	1	1	0	0	0	0	1	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J. (Continued)

		Site:	**Linwood End**								
rence		**Transect Type:**	**Anthro**					**Reference**			
10	**0**	**Distance From Edge (m):**	**0**	**10**	**20**	**30**	**40**	**30**	**20**	**10**	**0**
		Larval Fish:									
0	0	Freshwater Drum (*Aplodinotus gruniens*)	0	0	0	0	0	0	0	0	0
0	1	Clupeidae	0	0	0	0	0	0	0	0	0
0	0	Black Buffalo (*Ictiobus niger*)	0	0	0	0	0	0	0	0	0
0	0	White sucker *(Catostomus commersoni)*	0	0	0	0	0	0	0	0	0
0	0	Lepomis	0	0	0	0	0	0	0	1	1
0	0	Black Crappie (*Pomoxis nigromaculatus*)	0	0	0	0	0	0	0	0	0
0	0	Rock Bass *(Ambloplites rupestris)*	0	1	1	0	0	1	0	0	0
0	0	Largemouth bass *(Micropterus salmoides)*	0	0	0	0	0	0	0	0	0
0	1	Smallmouth Bass (*Micropterus dolomieu*)	0	1	0	1	1	1	0	0	0
0	0	Yellow Perch (*Perca flavescens*)	0	0	3	1	2	1	2	2	0
0	0	Common Carp (*Cyprinus carpio*)	0	0	0	0	0	0	0	0	0
0	0	Cyprinidae	0	0	0	0	1	0	0	1	0
4	0	Banded killifish (*Fundulus diaphanus)*	16	48	23	7	28	12	14	16	25
0	0	Johnny Darter *(Etheostoma nigrum)*	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0
0	0	Threespine stickleback *(Gasterosteus aculeatus)*	0	0	0	0	0	0	0	0	0
0	0	Brook Silverside (*Labidesthes sicculus)*	0	0	0	0	0	0	0	0	0
0	0	Longnose Gar (*Lepisosteus osseus*)	0	0	0	0	0	0	0	0	0
0	0	Central Mudminnow *(Umbra limi)*	0	0	0	0	0	0	0	0	0
0	0	Round Goby *(Neogobius melanostomus)*	0	1	0	0	0	0	0	0	0
0	0	Mottled sculpin (*Cottus bairdi*)	0	0	0	0	0	0	0	0	0
		Juvenile Fish:									
0	0	Pugnose Shiner adult (*Notropus anogenus*)	0	0	0	0	0	0	0	0	0
0	0	Bluntnose minnow adult *(Pimephales notatus)*	0	0	0	0	0	0	0	0	0
0	0	Common Shiner adult *(Luxilus cornutus)*	0	0	0	0	0	0	0	0	0
0	0	Sand Shiner adult (*Notropis ludibundus*)	0	0	0	0	0	0	0	0	0
0	0	Emerald Shiner adult *(Notropis atherinoides)*	0	0	0	0	0	0	0	0	0
0	0	Spottail Shiner adult *(Notropis hudsonius)*	0	0	0	0	0	0	0	0	0
0	0	Fathead minnow adult (*Pimephales promelas*)	0	0	0	0	0	0	0	0	0
0	0	Mimic Shiner adult (*Notropis volucellus*)	0	0	0	0	0	0	0	0	0
0	0	Banded killifish adult (*Fundulus diaphanus)*	0	0	0	0	0	0	0	0	0
0	0	Brook Stickleback adult (*Culaea inconstans*)	0	0	0	0	0	0	0	0	0
0	0	Ninespine stickleback adult (*Pungitius pungitius*)	0	0	0	0	0	0	0	0	0

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

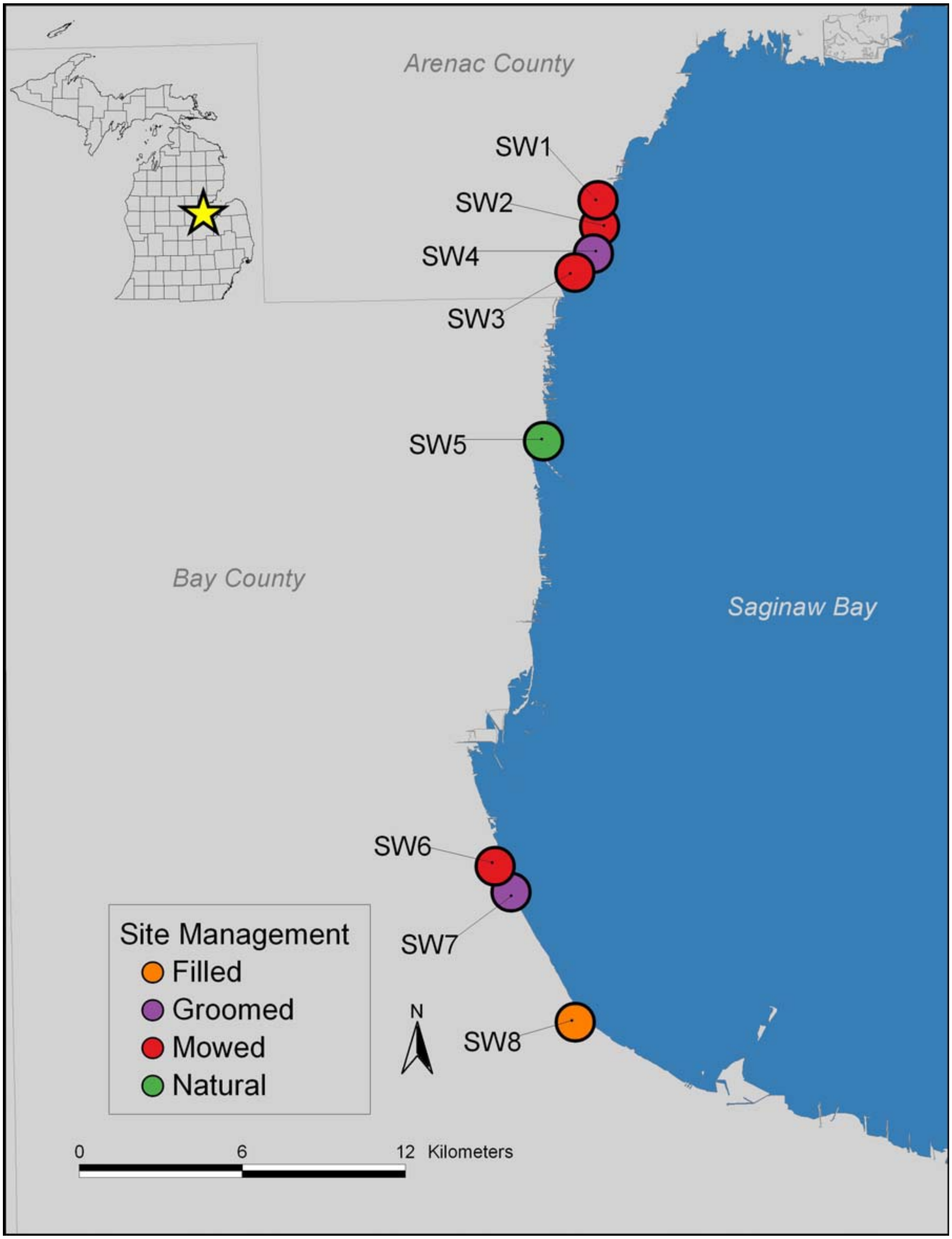


Figure 1. Sampling sites on western Saginaw Bay.

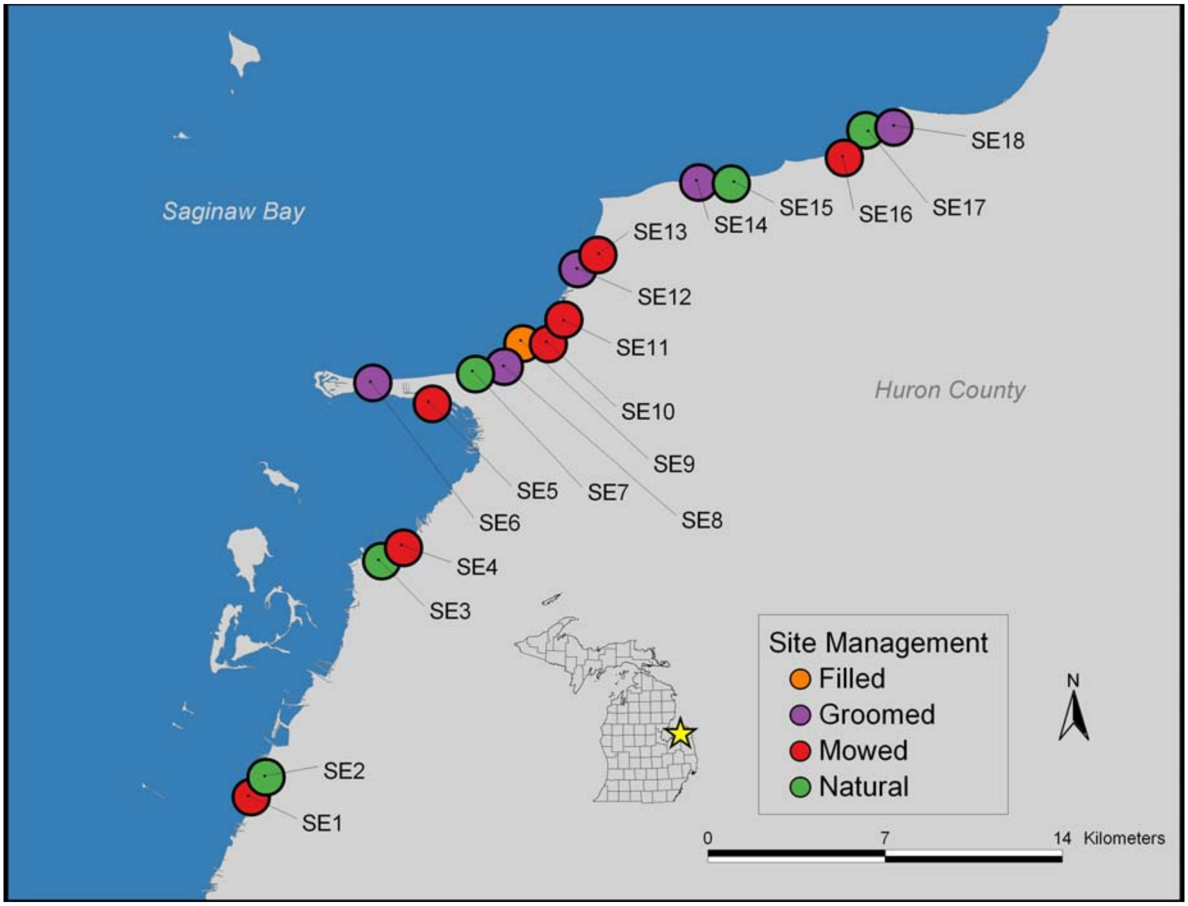


Figure 2. Sampling sites on eastern Saginaw Bay.

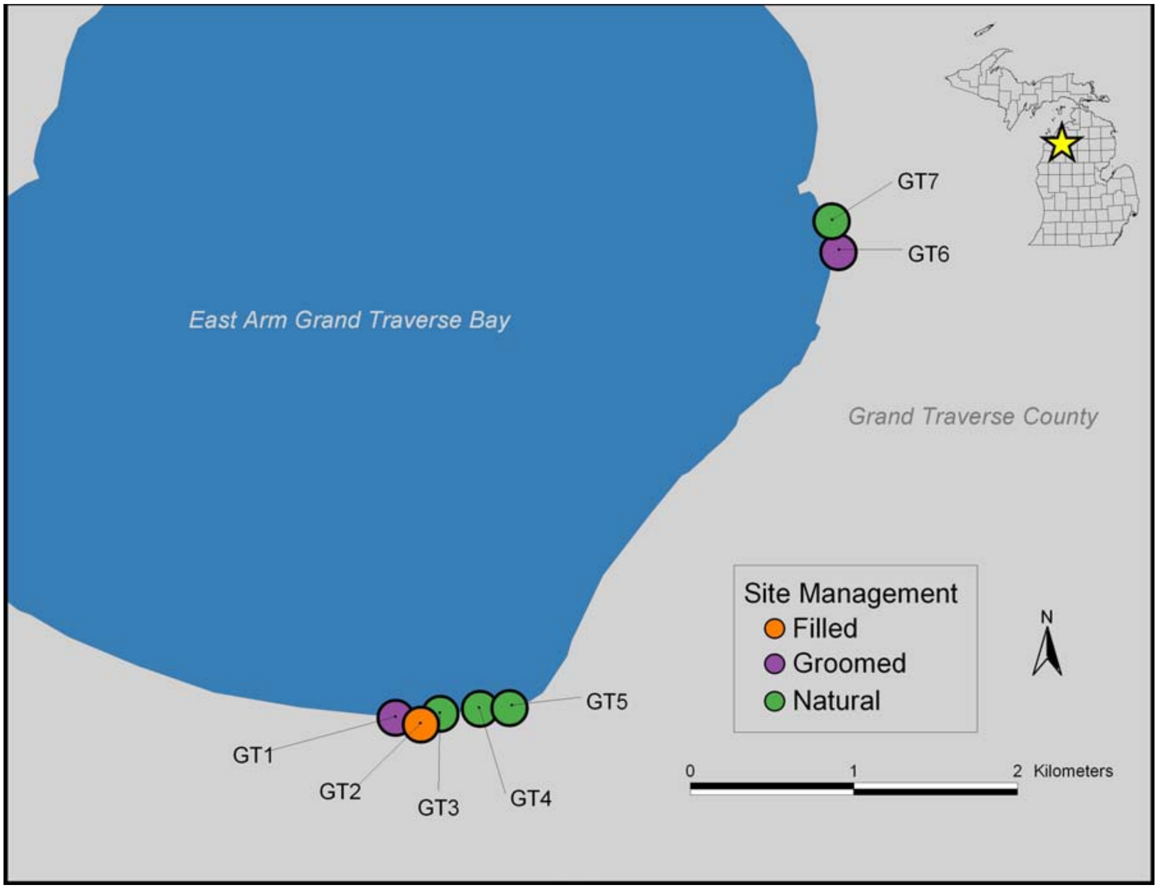


Figure 3. Sampling sites on Grand Traverse Bay.

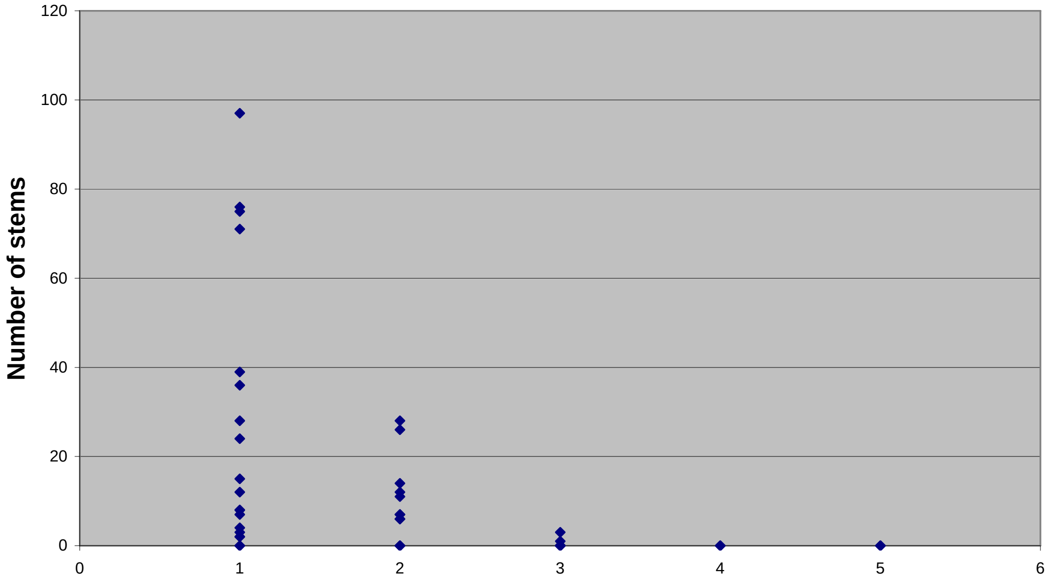
Figure 4. Rhizome and sediment sampling pit: 30 cm X 30 cm X 45 cm. This pit has sand soils underlain by clay soils.

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.

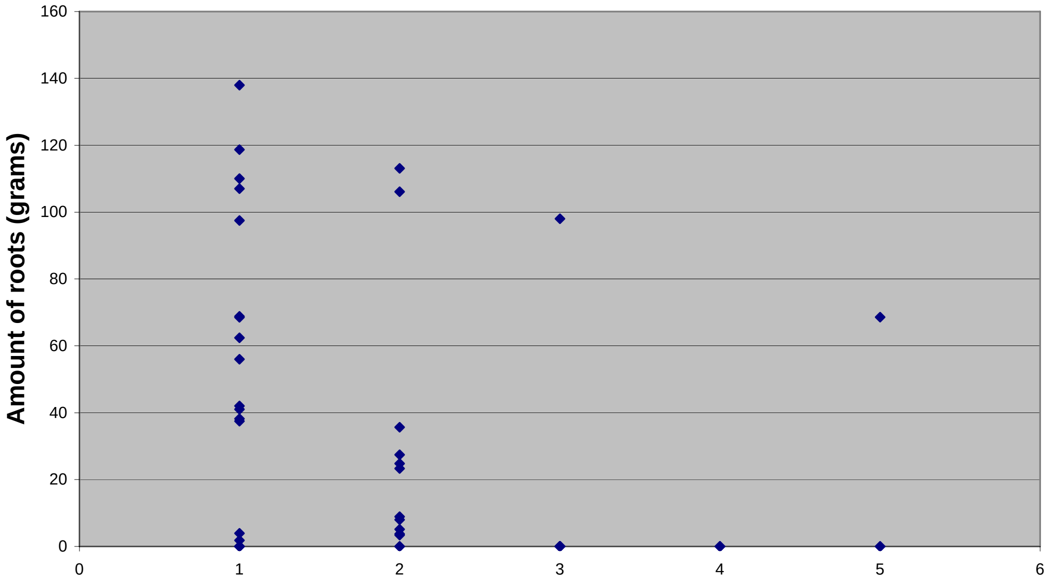
Figure 7. Large quantity of sand held by fine, surface bulrush roots.

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



Management: 1=unmanaged (n=20), 2=mowed (n=13), 3=raked (n=12), 4=handpulled (n=4), 5=filled (n=3)

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



Management: 1=unmanaged (n=20), 2=mowed (n=13), 3=raked (n=12), 4=handpulled (n=4), 5=filled (n=3)

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)

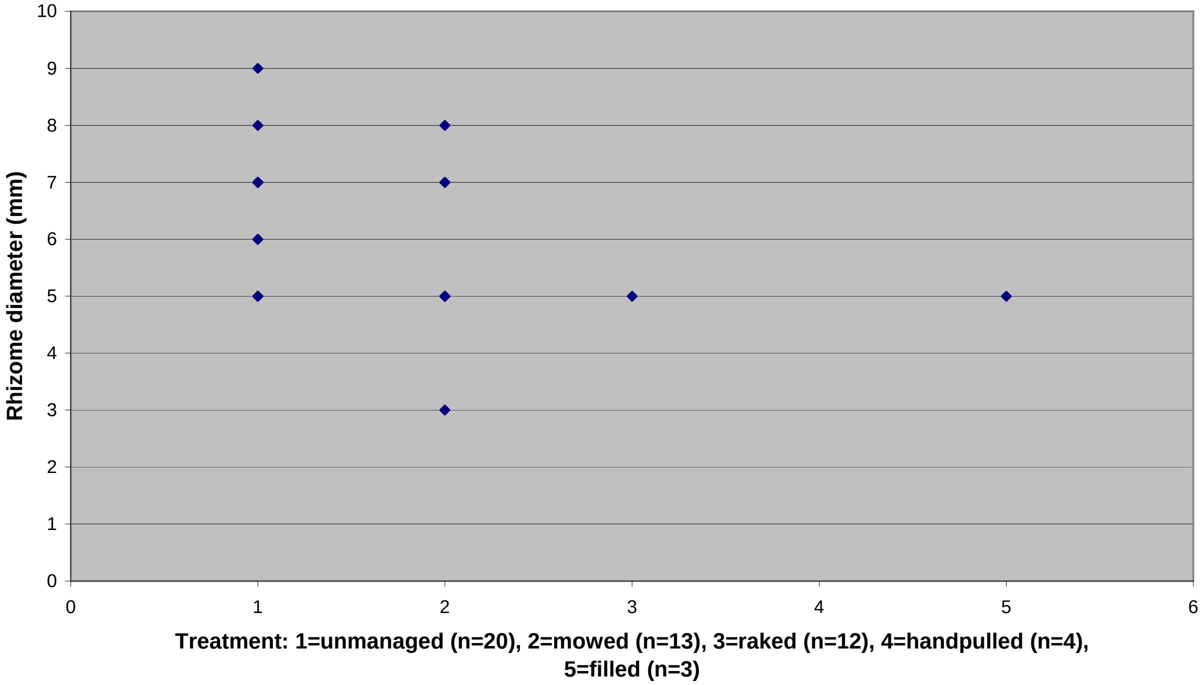


Figure 12. Average diameter of bulrush rhizome for each type of management. (p=.1911)

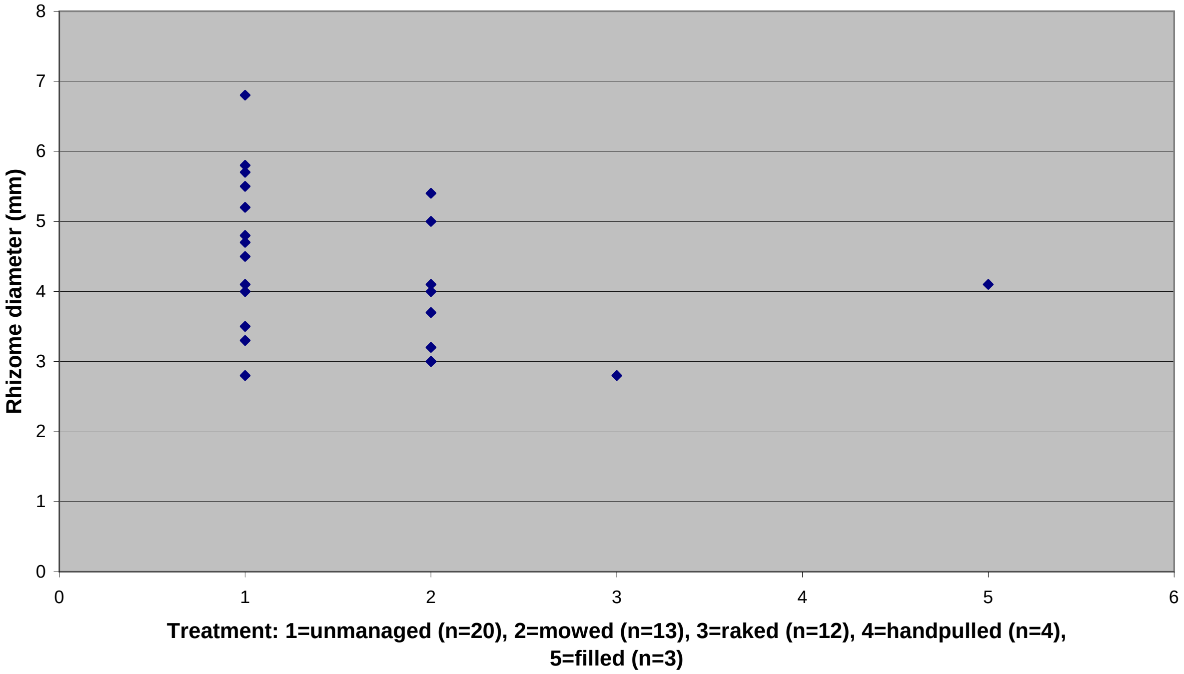


Figure 13. Four meter long bulrush (Schoenoplectus pungens) rhizome. This section of rhizome has 14 stems and the entire plant is probably much larger, based on the rhizome's diameter, which ranges from 5 to 9 mm.

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

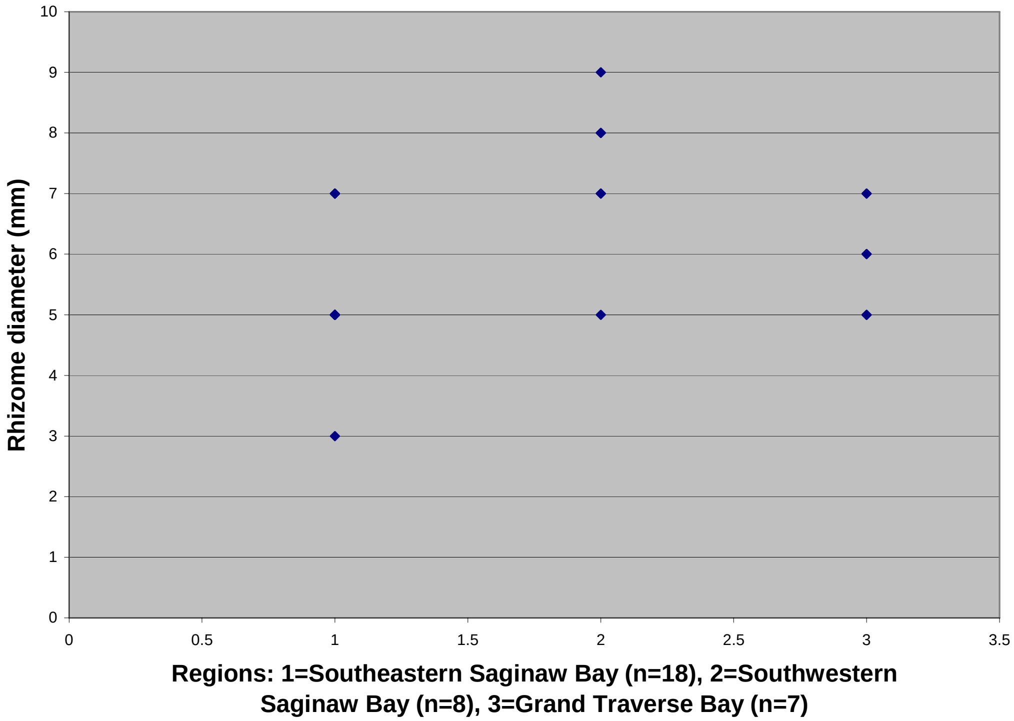


Figure 15. Average number of native plant species for each type of management (p=<.0001)

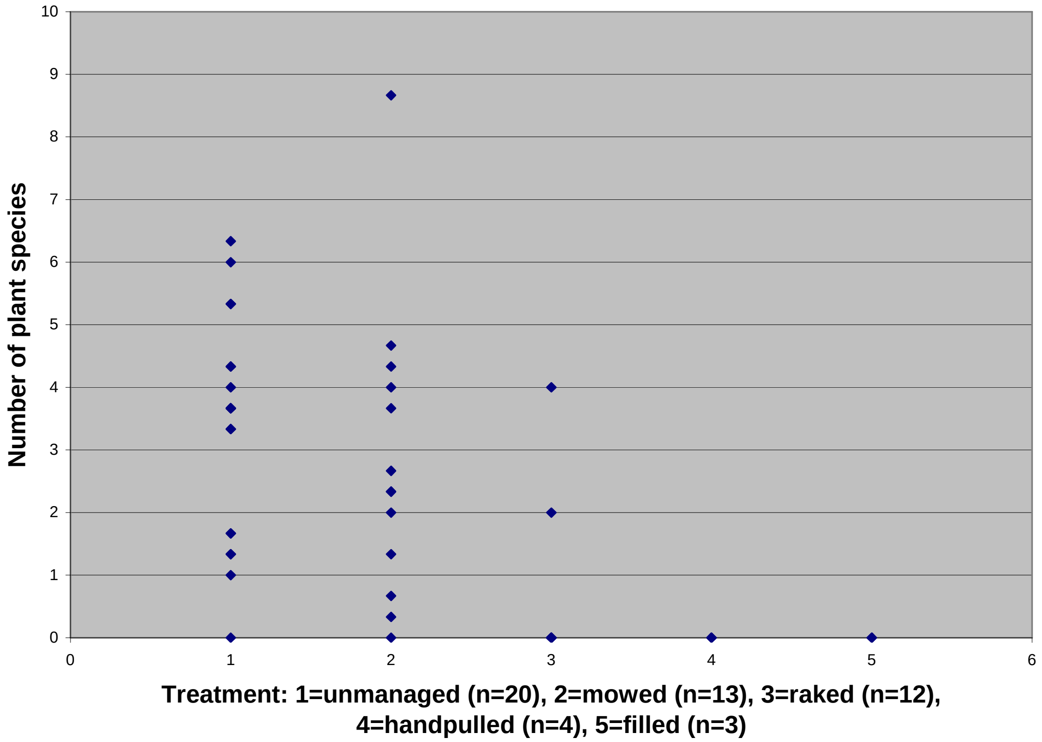


Figure 16. Mean cover value of native plants for each type of management. (p=.0001)

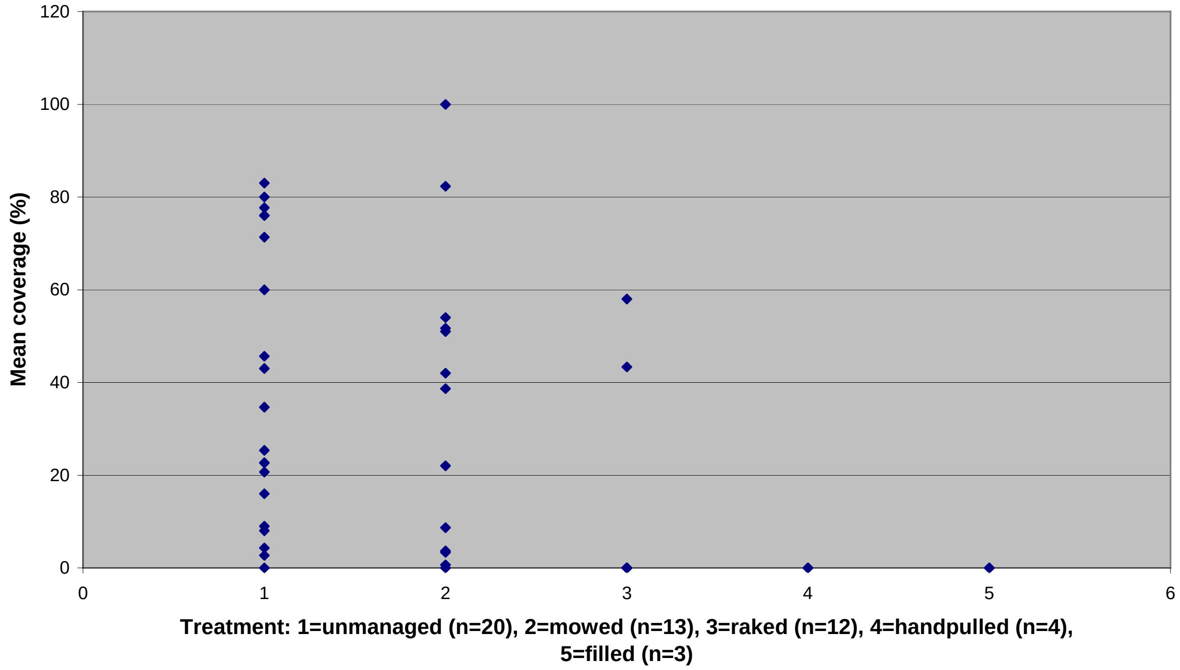


Figure 17. Average number of exotic plant species for each type of management. (p=.0016)

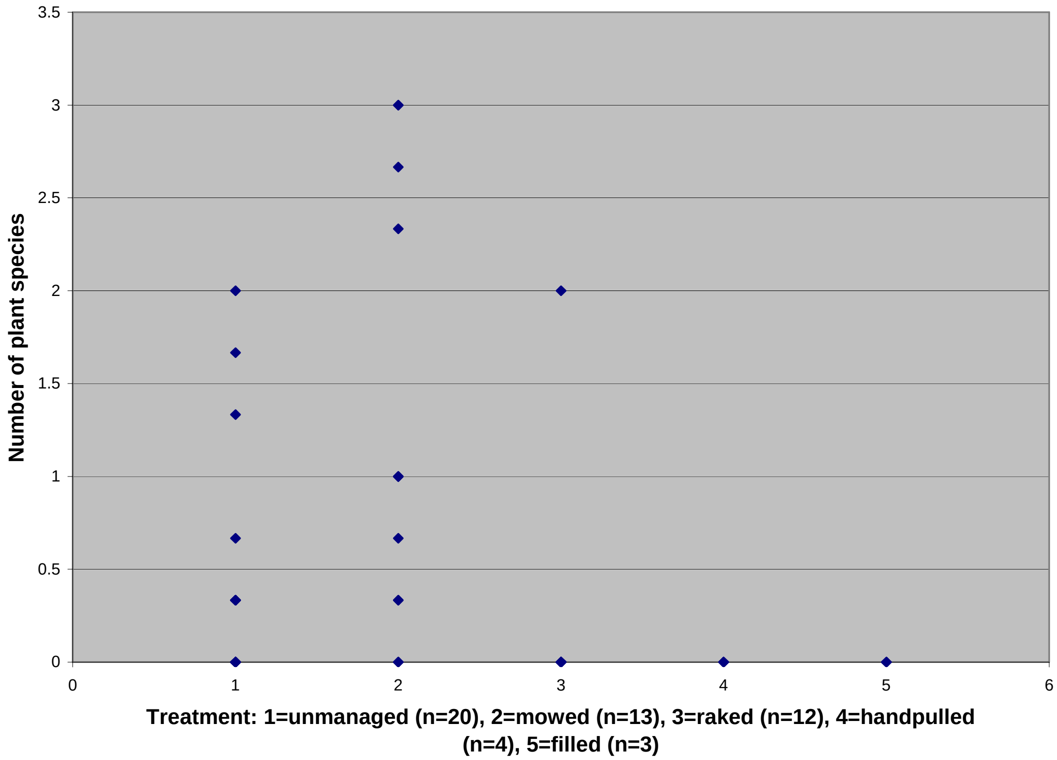


Figure 18. Mean exotic plant coverage for each type of management. (p=.0027)

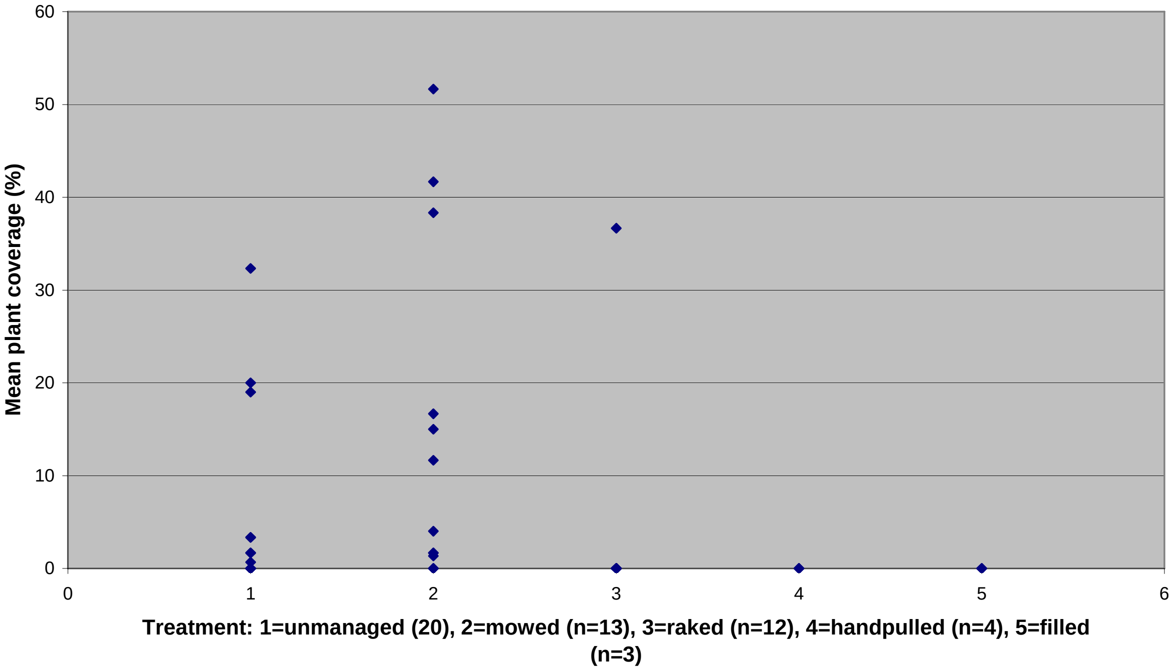
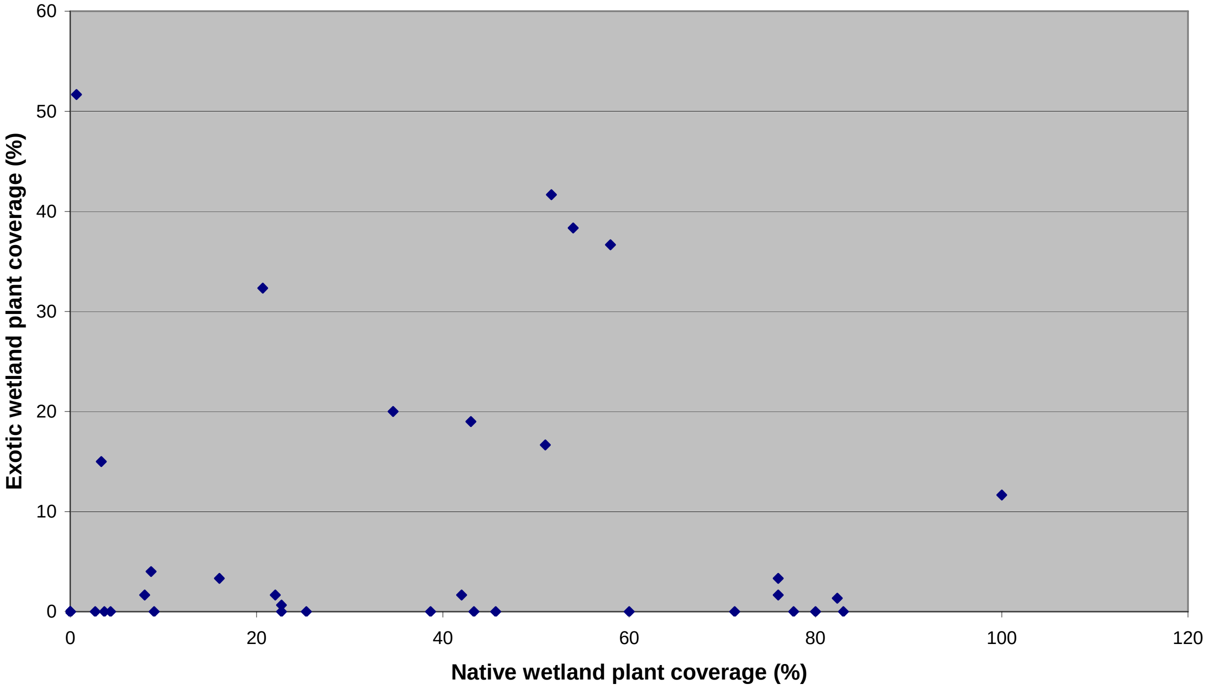


Figure 19. Comparision of native and exotic species coverage values in sample plots (n=52).



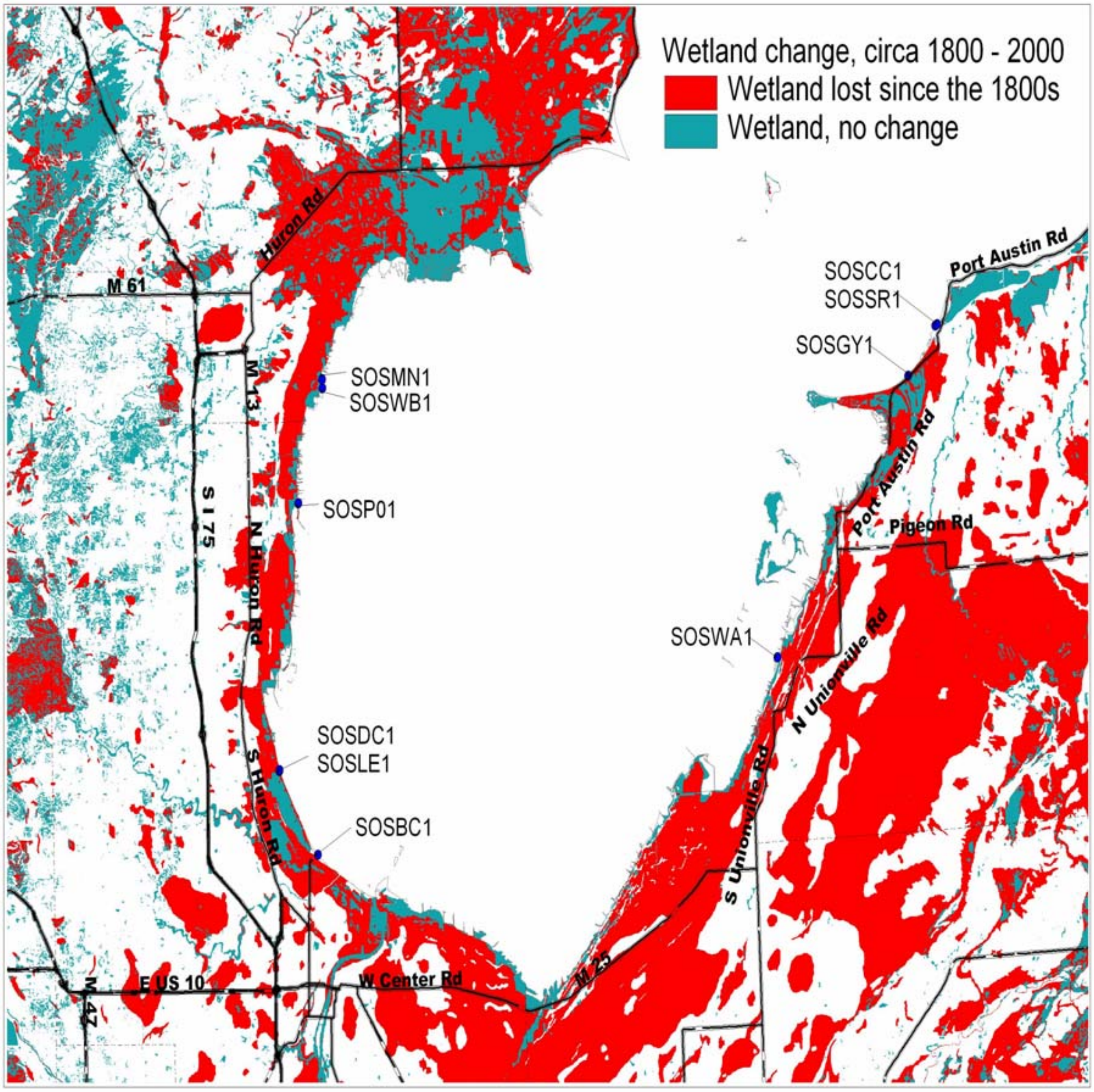


Figure 20. Original Wetland Vegetation of Saginaw Bay. Year 2004 sample sites are shown along shoreline as blue circles.

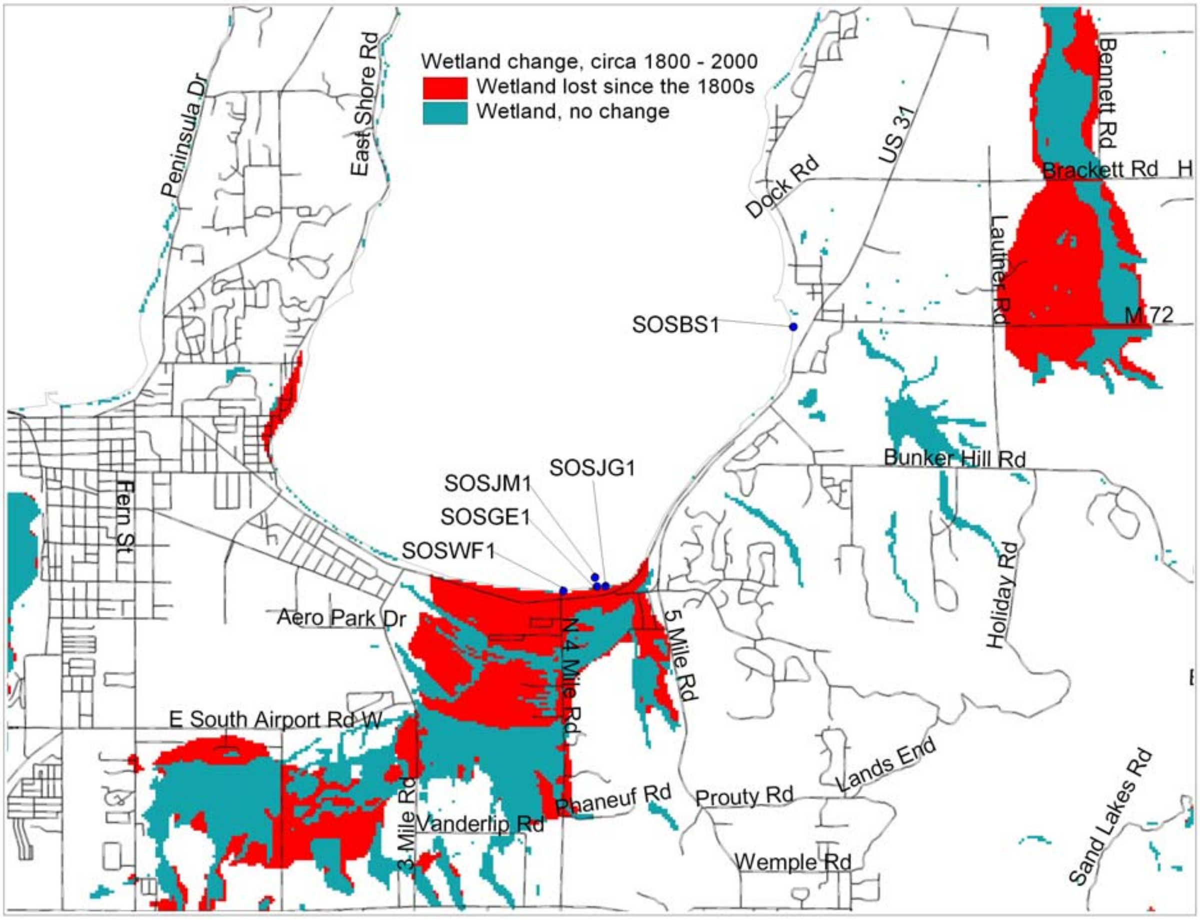


Figure 21. Original Wetland Vegetation of Grand Traverse Bay. Year 2004 sample sites are shown along shoreline as blue circles.

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.).