Final Report

to

Michigan Great Lakes Protection Fund
Office of Great Lakes
Michigan Department of Environmental Quality

Development of Indices of Biotic Integrity for Great Lakes Coastal Wetlands

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Project Title: Development of Indices of Biotic Integrity for Great Lakes Coastal Wetlands

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Introduction

Development of indicators of "ecosystem health" for Great Lakes coastal wetlands was recognized as a major need at the State-of-the-Lakes Ecosystem Conferences (SOLEC) held in Buffalo, New York in 1998 and Hamilton, Ontario in 2000. Indicators listed by the wetlands indicators task force at these conferences included indices of biotic integrity (IBI) based on macroinvertebrates, fish and plants. We proposed to develop IBI's for fish and invertebrates in this project and have made significant progress towards that goal as reported below.

We previously developed and published a macroinvertebrate based bioassessment procedure for fringing coastal wetlands of Lake Huron (e.g. Burton et al. 1999, Kashian and Burton 2000). Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using macrophytes, fish, and microinvertebrates. They identified some potential metrics but concluded that natural water level changes from those that existed during data collection were likely to alter communities enough to invalidate metrics in subsequent years. We overcame this problem for fringing coastal wetlands by developing a method based on sampling from one to four plant zones depending on the number inundated in any particular year (Burton et al. 1999). The IBI scores for a particular year were calculated by summing scores from each zone across the number of zones that were inundated in that year. As water levels decreased and zones were no longer inundated, the IBI scores which indicated the condition of the wetland changed, but metrics for even a single inundated zone proved to be effective in establishing wetland condition. Our system worked well for fringing wetlands of Lakes Huron and Michigan as water decreased by more than one meter from 1997 through 2000. Based on these results, we are confident that our macroinvertebrate IBI is valid under a wide range of water levels. One objective of the studies for this project was to finalize the invertebrate IBI for fringing wetlands and extend it to the other lakes. We achieved this objective as reported below. A second objective was to develop similar IBI's for other types of Great Lakes coastal wetlands (e.g. riverine and drowned rivermouth/estuarine wetlands). We made significant progress towards achieving that objective and have the data in hand to develop an IBI for drowned river mouth wetlands as reported below.

We are working on fish metrics that can be adjusted over water level changes and believe that a viable fish-based IBI can be developed based on these taxa. Minns et al. (1994) applied Karr's approach of using fish as indicators of stream biotic integrity (e.g., Karr 1981, Karr et al. 1986) to marshes of Great Lakes' Areas of Concern. The metrics employed by Minns et al. (1994) were sensitive to impacts on ecosystem integrity by exotic fishes, water quality changes, physical habitat alteration, and changes in piscivore abundance related to fishing pressure and stocking. Despite the research of Minns et al. and suggestions of several other authors and the SOLEC 1998 wetlands indicators task force, no widely accepted, fish based system for evaluation of ecosystem health for Great Lakes coastal wetlands has been developed. Our previous work and the work of Brazner (1997), Brazner and Beals (1997), Minns et al. (1994) and Thoma (1999) suggest that IBI development should be relatively straight-forward. Recently, Randall and Minns (2002) used an IBI to assess habitat productivity of near shores areas (including coastal wetlands) of Lakes Erie and Ontario and compared results to those obtained using the Habitat Productivity Index. One of our objectives for this study was to develop a fish based IBI for coastal wetlands with emphasis on the three upper Great Lakes. We collected or obtained data from all five Great Lakes and report progress in achieving this objective below.

Objectives

The objectives of this study were to test and develop macroinvertebrate and fish based biotic indicators of wetland ecological health that could be employed in a monitoring program by federal, state and local agencies to detect effects of anthropogenic disturbance on the biotic integrity of Great Lakes coastal wetlands. Several indicators based on fish and macroinvertebrates were recommended for use in Great Lakes Coastal Wetlands at the 2000 SOLEC. Our objective was to fully develop these indicators of ecosystem health for coastal wetlands and augment them, if possible, with additional metrics.

Methods

Site Selection

We tested and developed indicators at open lacustrine and protected embayment wetlands and at drowned river mouth wetlands selected from the U.S.A. shoreline of Lake Huron and the shoreline of Lake Michigan in the first phase of this project and sampled them in 2001 and 2002. We also re-sampled some of the sites we had sampled on previous projects from 1997 through 2000 (See Appendices A and B). In addition, we obtained data from a separately funded project (U.S. EPA through the Great Lakes Commission) from collaborators from Lakes Erie and Ontario and plan to use these data to develop system wide IBI's for all the Great Lakes.

Sampling Procedures

Description of IBI Development Methodologies Used from 1997-Present

Wetland Classification - Wetlands of the Great Lakes were classified into geomorphological classes that reflected their location in the landscape and exposure to waves and lake level changes (Albert and Minc 2001, Keough et al. 1999). For this project, we studied fringing (lacustrine) open and protected and drowned river mouth (estuarine) wetlands. However, our ultimate goal is to keep the number of IBI's required to cover all lake connected wetlands for all five lakes to a minimum.

For invertebrates, open (lacustrine) wetlands were subdivided or analyzed along a continuum of exposure to wind and waves (Burton et al. 2002; Burton et al. submitted Uzarski et al. submitted - see Appendices A and B for the submitted manuscripts). These wetlands tend to form along bays and coves and leeward of islands or peninsulas. The more open the shoreline, the more energy the wetland is exposed to from waves and storm surges until a threshold is reached where wetlands can no longer persist. Our initial faunal research in Lake Huron suggests that a system can be developed that applies to all lacustrine wetlands despite the natural exposure gradient (Burton et al. 1999, Uzarski et al. in Appendix A). However, the variation due to the exposure gradient must be accounted for when applying the sampling protocol. The location of the shoreline with respect to long shore current and wind fetch determines the type of wetland found along the shoreline (Burton et al. 2002, Appendix B).

Great-Lakes wide studies of aquatic macrophytes indicate that similar geomorphic wetland types support distinctively different plant assemblages in geographically distinct ecoregions (Minc 1997, Minc and Albert 1998 and in press, Chow-Fraser and Albert 1998). Since our macroinvertebrate IBI is based on sampling all existing plant zones, we may eventually need to refine or adjust our IBI based on plant community distribution. Further resolution of classification is defined within our IBIs by including metrics to be used only under specific circumstances. For example, a suite of metrics are developed for use in wave swept bulrush zones of unprotected coastal wetlands, but these metrics may or may not vary from those to be used where dense vegetation or a peninsula dampens waves in the same class of wetlands.

Chemical and Physical Measurements - Basic chemical/physical parameters were sampled each time biological samples were collected. Analytical procedures followed procedures recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1998). Measurements included soluble reactive phosphorus (SRP), nitrate-N, ammonium-N, turbidity, alkalinity, temperature, DO, chlorophyll *a*, redox potential, and specific conductance. Quality assurance/quality control procedures followed protocols recommended by U.S. EPA.

Determination of Anthropogenic Disturbance - Wetlands that experience a wide range of anthropogenic stressors were chosen from each class or subclass. The extent of disturbance was determined using surrounding land use data in conjunction with water quality data and site-specific observations of dredging, point-source pollution, etc. Land use was determined from existing digitized maps (the MIRIS 1978 coverage available from Michigan Department of Natural Resources), topographic maps and personal observations.

Macroinvertebrate sampling - Macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from late July through August for fringing wetlands and from June and July for drowned river mouth wetlands. In previous studies, we demonstrated that samples taken from ice-out through mid-July generally contain less diversity and a greater proportion of early instars of aquatic insects in fringing wetlands. The July-August time period is when emergent plant communities achieve maximum annual biomass and most insects are in late instar stages. Late instars are easier to identify than are early instars. Riverine wetlands likely support late instar stages of insects earlier in the season, since the channel provides a habitat where longer lived insects over winter.

Macroinvertebrates were sampled from all inundated plant zones at each site including all major emergent and wet meadow zones. If more than one dominant plant association occurred at a particular depth, invertebrates were sampled from each.

Dip nets were systematically used to sweep through the water at the surface, through the middle of the water column and just above the sediment surface to ensure that an array of microhabitats were included. In the field, samples were placed in white pans, and 50, 100, or 150 invertebrates were collected by picking all specimens from one area of the pan before moving on to the next area until 150 invertebrates had been collected or one-half-person-hour of effort had been spent on picking. If 150 specimens had not been collected at the end of one-half-person-hour of effort, picking continued to the next multiple of 50 (50, 100 or 150). Special efforts were made to ensure that smaller organisms were not missed to compensate for a natural bias towards picking the easier to detect, larger, more mobile individuals. Plant detritus was sorted for a few additional minutes after the target number of specimens had been collected to ensure that sessile species were included in the sample. Three replicate samples were collected from each plant zone to obtain a measure of spatial variance within each plant zone.

Specimens were sorted to lowest operational taxonomic unit; this was most often genus or species but for some difficult to identify groups it was Family, Tribe, etc. Taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996) were used for identification along with mainstream literature for species level. Accuracy was confirmed by expert taxonomists whenever possible.

Invertebrates were sampled from 11 wetlands in 2000 and 24 wetlands in 2001 (Tables 1 and 2) using standardized dip net sweeps, making sure to include all habitats (water column, vegetation, and sediment).

Fish sampling - Fish sampling was conducted with six fyke nets with square or rectangular openings either 0.5 m high x 1.0 m wide or 1.0 m high x 1.0 m wide leading into the series of hoops forming a funnel to the trap end. These nets were constructed of 12.5 mm or smaller mesh nets. Smaller nets were set in water approximately 0.25 m to 0.50 m deep, the larger nets were set in water depths greater than 0.50 m. Nets were set adjacent to vegetation zones of interest with leads extending into the vegetation. Six 'minnow' or smaller fish traps were also placed in the vegetation itself in each vegetation zone for one net-night. Fish were identified and enumerated before being released.

Identify and combine metrics into an IBI - Initially, correspondence analyses of invertebrate and fish community composition were used to determine if reference sites could be separated from impacted sites. When they could, individual taxa containing the most inertia responsible for separation were deemed potential metrics. Mann-Whitney U tests were used to determine whether values for these potential metrics at reference sites were significantly different from values at impacted sites. If they were, these metrics were included in the IBI. Pearson Correlation analyses was also used to link state with stressor by relating potential metrics to specific anthropogenic disturbances. Finally, stressor-land use relationships were explored to aid in management decisions.

We used medians in place of means for measuring assemblages of invertebrates. Occurrence, distribution and population size of invertebrates are highly variable in time and space. Highly variable data increases the chance that an area sampled may be unusually depleted or concentrated in constituents of a metric. If this occurs, it may be that the area is: (1) more or less isolated from anthropogenic disturbance than is the rest of the wetland, (2) receiving more or less disturbance than is typical for the entire wetland or plant zone, or (3) characterized by some unique "natural" chemical/physical component of the environment not found in the rest of the wetland. Regardless of cause, data from such unique areas are outliers and not representative of the entire wetland. Using the median in place of mean as a measure of central tendency dampens the influence of these outliers.

Continued Testing and Validation of IBI - After developing the preliminary IBI for Lake Huron (Burton et al. 1999) based on data from 1996 and 1997, we have collected data from a subset of sites of known anthropogenic disturbance each year since 1997 in order to test the ability of the IBI to separate impacted from reference wetlands over time and to check the calibration of the preliminary IBI. We continued this sampling in this project and extended it to Lake Michigan fringing wetlands. We also tested the original IBI by collecting data from additional wetlands experiencing a range of anthropogenic disturbance and using these data to test whether the IBI could successfully separate new sites into impacted and reference sites. Data from new sites and repeated sampling of sites have also been used to search for new potential metrics. We continued this process with data collected for this project and began analyses to develop a fish based IBI based on data from this and other projects.

Results

All scheduled sampling of fish and invertebrates was completed. We sampled drowned river mouth wetlands from Lakes Michigan and Superior and fringing wetlands from Lakes Huron, Michigan and Superior. All Lake Superior wetland sampling and the 2002 sampling of drowned river mouth wetlands was specifically funded by MGLPF funding. Additional sampling of drowned river mouth wetlands in 2001 was accomplished with funding from the Great Lakes Fishery Commission. Additional sampling of fringing wetlands of Lakes Huron and Michigan was accomplished with funding from the U.S. EPA funded Consortium for Great Lakes Wetland Research through the Great Lakes Commission (GLC). We established partnerships with Environment Canada and Bird Studies Canada through the additional funding from the Great Lakes Commission. With this collaboration and our data collected from 36 wetlands, we have fish data for 15,263 fish collected in 2002 during 240 net-nights from 61 wetlands and 104 plant zones from all five Great Lakes. We also have samples of invertebrates available from these wetlands with all but the drowned river mouth wetlands having been sampled during July, August and September, 2002. In addition, we collected fish and invertebrate data from a substantial number of wetlands from the three upper Great Lakes from 2000 and 2001 using funding for this project and from a previous project from MDEQ with funding from the U.S. EPA Region 5 in Chicago.

Some of the macroinvertebrate samples collected in 2000 on fringing coastal wetlands as part of a separately funded MDEQ project were processed with funds from the Michigan Great Lakes Protection Fund as part of this project. These data and the 2001 fringing wetland data have all been summarized and are included in two manuscripts submitted by invitation to the journal, *Aquatic Ecosystem Health and Management* (Appendices A and B). They are: (1) *Invertebrate Habitat Use in Relation to Fetch and Plant Zonation in Northern Lake Huron Coastal Wetlands* by Thomas M. Burton, Donald G. Uzarski, and John A. Genet; and (2) *Validation and Performance of an Invertebrate Index of Biotic Integrity for Lakes Huron and Michigan Fringing Wetlands during A Period of Lake Level Decline* by Donald G. Uzarski, Thomas M.

Burton, and John A. Genet. The second of these papers completes our development of an invertebrate-based index of biotic integrity (IBI) for fringing wetlands of northern Lake Michigan and Lake Huron. This IBI is available for use as a monitoring tool by management agencies such as MDEQ. These manuscripts are in review and, if accepted, will be published in 2004 as part of a special issue on Great Lakes wetlands. Since all 2000 data on fringing wetlands are included in these manuscripts, we will not discuss them here. The data on drowned river mouth wetlands collected in 2000 were included in the draft final report for year one of this project that has already been submitted to MDEQ. Thus, we will not include those data in this report either. In this report, we summarize data collected in 2001 and 2002 specifically for this project and some associated projects funded by other grants.

Invertebrates: Drowned River Mouth Wetlands - As reported in the final report for the first year of this project, all nine drowned rivermouth wetlands sampled in 2000 except the Pere Marquette were sampled again in 2001 (Figure 1). The only inundated plant zone present at all sites in 2001 was the *Nuphar* zone. Other plant zones present at some sites included: *Scirpus*, *Sparghanium*, *Pontederia*, *Typha*, and *Nymphaea*. These sites oriented along an axis of disturbance generally from North to South (Figure 2). The Kalamazoo River site had lowest taxa richness, partially as a result of only one plant zone being sampled (Table 1). The Muskegon and Lincoln sites had the highest taxa richness values mainly due to their diverse Hemipteran assemblages. Even though the Manistee site had the greatest number of plant zones sampled, it did not exhibit the greatest diversity.

We calculated the metrics used in our fringing wetland IBI for the drowned rivermouth wetlands to determine if any of them would orient along the disturbance gradient identified in Figure 2. Eight of these metrics placed the wetlands along the disturbance gradient; five did not (Table 1). In addition, Ephemeroptera taxa richness was low at impacted sites (e.g. Kalamazoo & Pigeon) and relatively high at unimpacted sites (e.g. Betsie, Lincoln, Manistee) and was identified as a potential new IBI metric in Table 1. We used two approaches to identify potential new metrics for these wetlands using the 2000 and 2001 data. The first approach was the box and arrow type of comparison advocated by Barbour et al. (1996) (Figure 3). The second approach involved the use of correspondence analyses coupled with testing differences between reference and impacted sites using Mann-Whitney U comparisons and examination of differences in bar graphs for 2000 (Figures 4, 5) and 2001 (Figures 6,7) to identify metrics. Four additional potential metrics were identified in this manner: (1) relative abundance of Coenagrionidae, (2) relative abundance of Mesoveliidae, (3) number of Ephemeroptera plus Trichoptera plus Odonata taxa, and (4) Shannon diversity. These four attributes were significantly (Mann-Whitney U, $p>0.05$) lower for impacted sites than for reference sites in 2000 and 2001. Coupled with the 8 others identified by calculating metrics that worked for fringing wetlands resulted in 12 potential metrics being identified. There were 19 other attributes that were significantly different in one of the two years but not in the other. These may be useful in final development of an IBI for these wetlands. Initial results were presented at the Annual Meeting of the Society of Wetland Scientists in New Orleans in June 2003. The metrics identified using 2000 and 2001 data will be tested using data from 14 drowned river mouth wetlands collected in 2002. Based on results to date, we are confident that we can develop and publish an IBI for drowned rivermouth wetlands. All 2001 invertebrate data collected from drowned river mouth wetlands for this project are summarized in Table 3. The 2002 data will be used for testing the IBI developed using the 2000 and 2001 data. This work is in progress and manuscripts on it will be submitted for publication soon. Papers resulting from this analysis will be submitted to MGLPF as they are completed.

An independent project completed by Ryan Otter for a non-thesis M.S. degree included analyses of invertebrates collected with activity traps in each of these wetlands for both 2000 and 2001 and correlated invertebrate catches in these traps with gradients of disturbance based on the land use and chloride data in Figure 2, and sulfate and nitrate data for these wetlands. Unlike the dip net derived data, activity trap data did not correlate well with disturbance gradients.

Invertebrates: Fringing Wetlands - IBI scores - We applied our modified IBI (modified from Uzarski et al. (Appendix A) to enable family-level macroinvertebrate identification) to macroinvertebrate data collected in 2002 from twenty fringing wetland sites in Lakes Huron and Michigan (Figure 8). These wetlands were sampled with a combination of funds from the MGLPF and the Great Lakes Commission (GLC) and were summarized and included in the final report to GLC. This data base is available from GLC. When the modified IBI was calculated using family level data from these 20 sites (Figure 8), sites separated along a perceived gradient of anthropogenic disturbance. IBI scores ranged from 86.1% of the total points possible at the Cedarville site to 40.9% at the Bradleyville Rd. site (Tables 4 and 5). The four sites that scored highest fell into the 'mildly impacted' category, while nine fell into the 'moderately impacted' category. The remaining seven sites were categorized as 'moderately degraded'. Three of the four sites that scored in the 'mildly impacted' range were northern Lake Michigan sites (Rapid River, Garden Bay and Ogontz Bay). The remaining four northern Lake Michigan sites were shown to be more degraded with the Big Fishdam, Ludington Park and Pt. St. Ignace sites all falling into the 'moderately impacted' category and the Escanaba site falling into the 'moderately degraded' category. All northern Lake Huron sites, with the exception of Cedarville, fell into the 'moderately impacted' category. As expected, Saginaw Bay sites had the lowest IBI scores with six of the seven sites falling into the 'moderately degraded' category (Table 4). The Jones Rd. site was among these six sites. Because *Typha* was the only vegetation zone found at the Jones Rd. site, and our *Typha* zone specific metrics are still being developed, we scored this site using the Inner *Scirpus* metrics. Therefore, the score for this site may not be an accurate reflection of its biotic integrity. Wigwam Bay was categorized as 'moderately impacted' being placed among the northern Lake Huron sites. This was expected *a priori* because Wigwam bay was located closest to the outer bay of Saginaw Bay where anthropogenic disturbances would be diluted. This site had a largely forested watershed and was located furthest from the mouth of the Saginaw River, a known source of pollution for Saginaw Bay. Tables 4 and 5 show IBI metric scores and site ranking based on the modified IBI.

Invertebrates from eight of these sites were identified to the generic level, thus our unmodified IBI (u-IBI) (Uzarski et al., Appendix A) was applied to these (Tables 6 and 7) along with the modified IBI. The ranked order of sites produced by the u-IBI with data at the higher taxonomic resolution was identical to the order produced by the modified IBI using family-level macroinvertebrate data. Once again, the Cedarville site ranked highest, scoring 86.1% of the total points possible, while the Vanderbilt Park site ranked lowest at 46.7%. Three sites, Cedarville, Mackinaw Bay and Shepard Bay fell into the 'mildly impacted' category and Pt. St. Ignace and Wildfowl Bay fell into the 'moderately impacted' category. Allen Rd. and Jones Rd. were placed into the 'moderately degraded' category while Vanderbilt Park was the only wetland to score in the 'degraded' range. Again, the Jones Rd. site was scored with Inner *Scirpus* metrics, and therefore, may be misrepresented.

Anthropogenic disturbance was characterized using analyses of 11 water chemical/physical parameters for each plant zone in each site (Table 8). These were used in conjunction with five land-use/cover parameters calculated from a 1 km buffer around each site (Table 9). Principal components analysis (PCA) of all 17 parameters was of little value in partitioning sites along a gradient of anthropogenic disturbance (Figure 9). However, a PCA including just the 11 water chemical/physical parameters revealed a gradient of anthropogenic disturbance characterized by increasing Cl, SpC, NO_3 and SO_4 in PC 2 (which explained 23.6% of variability in the data) (Figure 10). Chemical/physical parameters that could be perceived as indicators of anthropogenic disturbance did not contribute strongly to PC 1. Therefore, PC 2 scores were used to characterize water quality among wetland sites. The Jones Rd. site scored highest in PC 2 and had the highest Specifc Conductance (SpC), Cl and SO_4 of the 20 sites. Saginaw Bay sites generally scored highest in PC 2 while sites of northern Lake Huron and northern Lake Michigan scored lowest (Figure 10).

Since the PCA was conducted on chemical/physical data from individual plant zones, within-wetland spatial variability could be examined. In most cases, plant zones of a given site plotted near one another. Wet meadow zones of the St. Ignace, Shepards Bay and Big Fishdam sites, however, had significantly higher PC 2 scores than did their respective Inner and Outer *Scirpus* zones, suggesting pronounced spatial heterogeneity in water quality at those sites.

PCA of five land-use/cover parameters separated sites in three directions based on agriculture/meadow/idle land, developed land/road density and forested land (Figure 11). The Allen Rd. and Vanderbilt Park sites were characterized by a high proportion of surrounding agriculture while the Jones Rd. and Ludington Park sites were characterized by a high proportion of surrounding developed land and high road density. Sites that had high proportions of surrounding forested land included Big Fishdam, Ogontz Bay and Moscoe Channel. Most sites, however, could not be characterized as having a predominant land-use/cover type. Hence, anthropogenic disturbance could not be determined directly from the PCA of land-use/cover.

Pearson correlations between PC 2 scores of chemical/physical data and IBI scores (% possible) were conducted to test both IBIs. A significant correlation ($p<0.05$, $r=-0.503$) existed between PC 2 scores and IBI scores of individual vegetation zones using the modified IBI with family-level macroinvertebrate data (Figure 12). A Pearson correlation was also conducted between IBI scores and the means of PC 2 scores for each site (integrating all vegetation zones). This correlation was also significant ($p<0.05$, $r=-0.622$) (Figure 13).

Pearson correlations were also conducted for sites where lowest operational taxonomic unit data were available. The correlation was significant ($p<0.05$, $r=-0.599$ between u-IBI scores for individual plant zones and corresponding PC 2 scores. The best correlation ($p<0.05$, $r=-0.93$) was between mean PC 2 scores (means of all plant zones/site) and site u-IBI scores calculated using lowest operational taxonomic unit (Figure 14). The Jones Road site was excluded from analysis.

Significant correlations between PC 2 scores and IBI scores showed that the IBI functionally ranked sites along a gradient of anthropogenic disturbance. In this case, PC 2 was composed primarily of Cl, SpC, NO_3 and SO_4. These parameters can be considered surrogates for anthropogenic disturbance related to runoff from urban or agricultural areas.

Both IBIs separated more-impacted sites of Saginaw Bay from reference sites of northern Lake Huron and northern Lake Michigan. However, Wigwam Bay, the least impacted Saginaw Bay site because of its distance from the mouth of the Saginaw River and proximity to the less polluted outer bay, scored among the northern sites. The Pinconning and Wildfowl Bay sites were also a significant distance from the outlet of the Saginaw River and near the outer bay, and their respective IBI scores also reflected better water quality. The PCA did not separate Wigwam Bay, Wildfowl Bay and Pinconning from other outer Saginaw Bay sites suggesting that chemical/physical data alone could not account for a gradient of water quality in Saginaw Bay.

The Escanaba site had the lowest IBI score of any northern Lake Huron or Lake Michigan site. This low score reflects impacts on this wetland from the Escanaba River which is dammed and has a paper mill near its mouth and the expansive urbanization and industry of Escanaba. The Ludington Park site was adjacent to an urban residential area/park and near the port facilities for Escanaba and scored among the lowest three northern sites. The IBI score of the Ludington Park site may have been confounded by the morphology of the wetland. The *Scirpus* at this site was designated as 'Inner *Scirpus*' even though the site had a substantial fetch. Despite the fetch, the *Scirpus* at the Ludington Park site was partially protected by a barrier sand bar and was very dense, a characteristic of an inner *Scirpus* zone. The *Scirpus* grew in dense 'islands' unlike the vegetation zonation at any other site. This relatively unique setting makes this particular vegetation zone difficult to categorize. While this site demonstrates the problem of classification of plant zones when these zones are not discrete or are unique, the IBI still ranked the Ludington Park site as predicted by the chemical/physical analyses. Furthermore, recalculation of the IBI score for the Ludington Park site with the *Scirpus* islands classified as an outer *Scirpus* zone did not change the ranked order of sites suggesting that the IBI is robust enough to handle such discrepancies.

The Jones Rd. site was the only site sampled that did not include either a *Scirpus* or wet meadow zone. Since our current IBI depends on these types of vegetation (our *Typha* zone metrics are currently being reevaluated and improved), we could not accurately describe the Jones Rd. site. However, in our research on Great Lakes fringing wetlands, we have seen very few sites that did not contain either a *Scirpus* or wet meadow zone. In the case of Jones Rd., we scored the *Typha* zone as Inner *Scirpus*, which placed the site among the other moderately-degraded Saginaw Bay sites. The chemical/physical nature of the Jones Rd. site also suggests that the site is one of the most degraded sites sampled.

The u-IBI for lowest operation taxonomic units, as well as the modified IBI, ranked the Cedarville site as the most pristine of the 20 wetlands. However, field observations, and studies over the past six years indicate that the Cedarville site is impacted by a number of anthropogenic inputs (e.g. Burton et al. 1999, Kashian and Burton 2000). The wetland is adjacent to the city of Cedarville, adjacent to a busy boat channel and receives sewage effluent twice per year. The sediment at the Cedarville site appeared heavily organic and the *Scirpus* community was mixed with dense duckweed (*Lemna sp.*) mats and dense cover from submersed plants. Analysis of the chemical/physical nature of the Cedarville site, however, did not reflect the perceived anthropogenic disturbance and was consistent with the IBI score, which showed the site to be relatively pristine.

Fish Results- We sampled fish from a total of 36 wetlands in 2002 from the three upper Great Lakes. We subjected data from these 36 wetlands and from an additional 25 wetlands in Lakes Erie and Ontario sampled by colleagues from Canada (Joel Ingham and Steve

Timmermans) to exploratory data analyses using correspondence analyses and non-metric multidimensional scaling in conjunction with principal components analysis to identify differences, if any, between lakes, ecoregions, wetland classes, and plant zones. Fish species caught in each Lake/Ecoregion are listed in Table 10. The exploratory data analysis is the first step in development of a general and/or lake specific IBI's for the Great Lakes. We presented the results at the International Association of Great Lakes Researcher's meeting in Chicago in June 2003 and plan to prepare a manuscript on results for journal publication. These results were summarized for the final report to GLC and pertinent excepts from that report are included below. Analyses to identify suitable IBI metrics and develop a system of bioassessment for Great Lakes' wetlands is the next step to be accomplished before publication of a fish based IBI for Great Lakes coastal wetlands. This work is in progress and copies of papers that result from it will be submitted to MGLPF as they are completed.

We were able to include fish data in the initial analyses from 61 sites spanning all five Great Lakes in our analyses (5 Superior, 18 Michigan, 13 Huron, 13 Erie, and 12 Ontario) by including data from the GLC study collected by our collaborators, Joel Ingram and Steve Timmermans from Environment Canada and Bird Studies Canada respectively and our data on Lake Superior and additional Lake Huron and Lake Michigan sites from this project funded by the Michigan Great Lakes Protection Fund (MGLPF) and GLC. Specific catch data for all 36 wetlands sampled in 2002 are included in Tables 13-18. Data collected in 2001 for this project are summarized in Tables 11 and 12. Data for the 25 wetlands sampled by our collaborators are available from the Great Lakes Commission.

All of the inundated vegetation zones were fished in each of the 61 wetlands providing us with 15,263 fish from seven different plant zones (104 observations after combining replicate plant zones within wetlands) with 260 total net-nights fished. Our objective for this portion of the project was to determine if fish community composition was being structured based on lake to lake differences among the Great Lakes (Superior, Michigan, Huron, Erie, and Ontario), ecoregion (eastern Lake Superior-northern Lake Huron, Saginaw Bay-Lake Huron, northern Lake Michigan, northeastern Lake Michigan, southeastern Lake Michigan, Long Point-Lake Erie, western Lake Ontario, and eastern lake Ontario), wetland type (protected embayment, open lacustrine, barrier beach, and drowned river mouth), vegetation type (bulrush, spikerush, wild rice, lily, pickerel weed-arrowhead-arrow arum, burreed, and cattail), or chemistry and land use. The ultimate goal was to determine the feasibility of developing a Great Lakes basin wide IBI using key fish taxa that could be used without regard to ecoregional, lake to lake differences, etc.

We included fish data and the accompanying SRP, NH_4, NO_2/NO_3, SO4, Cl, DO, temperature, turbidity, sp. conductance, pH, alkalinity, Redox potential, and land use/cover data in our analyses. We ran PCA using only the abiotic data to first determine if our sites ordinated on any of the levels of interest (lake, ecoregion, wetland type, or vegetation zone). Results of these analyses (Figures 15 and 16) showed that vegetation zone was the single most important factor ordinating the sites based on these chemical/physical and adjacent land use data. The sites grouped into three major categories: 1) bulrush sites with low respiration and relatively high proportions of adjacent forests; 2) high nutrient and high percentage of adjacent agriculture cattail sites, and finally, 3) cattail sites with relatively high urbanization and urban runoff such as chloride (Figure 16).

We then performed correspondence analyses using the fish data to determine if those data alone grouped sites at any of our chosen levels (lake, ecoregion, wetland type, or vegetation zone). Initially, rare taxa were removed from the data set leaving 42 species in the analyses.

Bowfin and black bullhead overwhelmed the first and second dimensions of the analysis respectively (Figure 17). These taxa tend to school and our nets happened to catch large schools at several sites. We observed large schools of these taxa at most of our sites, and therefore, could justify removing them from our subsequent analyses, since we could attribute these large catches at a portion of our sites to happenstance alone. We continued this process, documenting the taxa removed and the justification for removal until 26 species remained (See Table 10 for fish taxa). Our goal was to use these iterations to reduce the number of taxa to a group that could represent a community typical of coastal wetlands of all five Great Lakes, and therefore, evenly distribute the sites in two-dimensional space. This even distribution of sites could then reveal the underlying factor(s) responsible for characterizing fish community composition in Great Lakes coastal wetlands, and in turn could be used to establish indicator taxa for these systems. The 26 species separated the sites based on vegetation zone similar to the PCA (Figure 18). Pearson correlation was then used to relate CA dimensions, or fish community composition, to PCs, or chemical/ physical and land use/cover data. A significant correlation ($r=0.398$, $p < 0.001$) existed between CA_1 and PC_1 establishing a relationship between fish community composition and chemistry and land use. We then superimposed our four levels as a third dimension over this relationship to discover that our chemistry and land use data were most closely related to vegetation zone (Figure 19).

In conclusion, plant community zonation was the most important variable associated with fish community composition, regardless of lake, ecoregion, or wetland type. Plant community zonation was most likely determined by hydrologic variables such as depth and duration of inundation over the growing season and across annual variations in lake levels. Within a particular hydrologic regime, nutrient concentrations and adjacent land use/cover as well as fetch and pelagic mixing probably were the driving variables associated with plant community dominance. Within specific vegetation zones, fish community composition seemed to respond to nutrient concentrations and/or fetch and pelagic mixing. However, this response could be correlative since fetch and pelagic mixing contribute to plant zonation and the dilution of nutrients and/or the amount of organic sediment accumulation. Changes in the invertebrate food base also occur in response to nutrients, fetch and pelagic mixing (Burton et al. 2002, Uzarski et al., submitted, Burton et al., submitted, Appendices A and B), and these changes may also contribute to the observed correlations between plant and fish community composition. In general, fish communities tended to move from a 'banded killifish, pugnose shiner, redear sunfish, smallmouth bass, whitemouth shiner, white sucker, and yellow perch community' to a 'brook silverside, brown bullhead, fathead minnow, golden shiner, green sunfish, and spotfin shiner community as nutrients and adjacent agriculture increased along an environmental gradient (Figure 20). These results suggest that these taxa will be useful in development of a fish based IBI for Great Lakes Wetlands.

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Table 1. Invertebrate dip net sampling in 2001 from Lake Michigan drowned rivermouth wetlands.

Site	Date Sampled	Number of Plant Zones Sampled	Number of Dip Net Samples	Total Taxa Richness	Mean Sample Taxa Richness
Lincoln	07/16/2001	2	6	51	22.2
Manistee	07/17/2001	3	9	43	19.3
Muskegon	07/06/2001	2	6	52	24.5
Pentwater	07/10/2001	2	6	42	19.2
Pigeon	07/11/2001	2	6	34	15.5
Kalamazoo	07/12/2001	1	3	16	9.3
White	07/09/2001	2	5	47	22.6
Betsie	07/19/2001	2	6	38	15.7

Table 2 - Did Fringing Wetland Metrics Plot Sites Along the Disturbance? Gradient?

Yes

- **Odonata Richness**
- **% Odonata**
- **Crustacea + Mollusca Richness**
- **Total Genera Richness**
- **% Isopoda**
- **Shannon Index**
- **Simpson Index**
- **Evenness**
- **% Ephemeroptera (New Metric)**

No

- **% Gastropoda**
- **% Sphaeriidae**
- **% Amphipoda**
- **Ephemeroptera + Trichoptera Richness**
- **% Crustacea + Mollusca**

Table 3 - Mean Relative Abundance of Invertebrates in 2001 from Drowned River Mouth Wetlands (SE in parentheses)

Taxon	Lincoln	Manistee	Muskegon	Pentwater	Pigeon	Kalamazoo	White	Betsie
Platyhelminthes								
Turbellaria	0.3 (0.2)	0.4 (0.2)	0.1 (0.1)	0.1 (0.1)	1.1 (0.6)	---	0.3 (0.2)	0.7 (0.6)
Annelida								
Hirudinea	4.2 (1.3)	1.5 (0.6)	2.7 (0.5)	0.9 (0.4)	0.3 (0.2)	---	0.2 (0.2)	0.1 (0.1)
Oligochaeta								
Naididae								
Stylaria sp.	0.3 (0.3)	1.5 (1.0)	0.2 (0.2)	---	---	---	0.6 (0.6)	---
unknown	5.1 (3.0)	0.1 (0.1)	0.2 (0.2)	---	0.2 (0.2)	---	0.8 (0.4)	---
Tubificidae	0.9 (0.5)	---	0.1 (0.1)	0.2 (0.2)	1.1 (0.8)	1.1 (0.6)	0.3 (0.2)	---
Mollusca								
Bivalvia								
Sphaeriidae	---	1.8 (0.9)	0.1 (0.1)	0.6 (0.4)	0.2 (0.2)	---	1.4 (1.0)	0.8 (0.7)
Gastropoda								
Bithyniidae								
Bithynia tentaculata	---	0.9 (0.4)	0.4 (0.2)	10.1 (2.4)	0.2 (0.2)	---	7.1 (2.9)	---
Hydrobiidae								
Amnicola sp.	0.2 (0.1)	2.9 (2.2)	---	0.5 (0.3)	---	0.4 (0.4)	---	---
Lymnaeidae								
Pseudosuccinea columella	0.5 (0.2)	0.4 (0.3)	---	0.1 (0.1)	0.5 (0.4)	---	0.2 (0.2)	0.8 (0.6)
Fossaria sp.	0.9 (0.8)	0.6 (0.4)	---	0.9 (0.5)	1.0 (0.3)	---	0.3 (0.2)	0.3 (0.3)
Stagnicola elodes	2.9 (2.3)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	---	---	---	3.1 (1.9)
Physidae								
Physa gyrina	4.1 (1.6)	11.9 (2.5)	2.0 (0.6)	3.0 (0.6)	1.5 (1.0)	---	2.6 (1.6)	5.3 (1.6)

Table 3. Con't

Planorbidae								
aulus deflectus	---	---	---	0.1 (0.1)	---	---		---
Gyraulus parvus	0.2 (0.1)	3.7 (1.4)	1.1 (0.5)	1.4 (1.1)	0.9 (0.3)	---	0.4 (0.2)	1.5 (1.1)
Heliosoma anceps	---	0.1 (0.1)	---	---	---	---	---	---
Planorbella pilsbryi	---	1.4 (0.5)	---	0.2 (0.1)	---	---	0.4 (0.3)	---
Planorbella trivolvis	---	---	---	0.4 (0.4)	---	---	---	---
Planorbella truncatum	---	---	---	0.1 (0.1)	---	---	---	---
Promenetus exacuous	---	---	---	---	---	---	0.2 (0.2)	---
Valvatidae								
Valvata sp.	---	0.6 (0.3)	0.3 (0.2)	0.3 (0.2)	---	---	0.1 (0.1)	---
Arthropoda								
Arachnida								
Hydracarina	1.2 (0.5)	2.9 (1.1)	---	---	0.4 (0.4)	---	0.3 (0.2)	0.7 (0.5)
Crustacea								
Decapoda								
Cambaridae	0.1 (0.1)	---	0.5 (0.1)	0.1 (0.1)	---	---	---	2.2 (0.9)
Amphipoda								
Gammaridae								
Gammarus sp.	28.2 (5.5)	22.9 (3.1)	22.7 (6.8)	36.6 (2.9)	41.4 (8.0)	0.6 (0.3)	24.5 (2.7)	34.9 (5.6)
Talitridae								
Hyallela azteca	2.9 (1.6)	0.1 (0.1)	4.8 (3.0)	0.2 (0.1)	---	---	3.2 (1.3)	8.7 (4.5)
Crangonyctidae								
Crangonyx sp.	---	---	0.1 (0.1)	---	---	---	---	---
Isopoda								
Asellidae *Caecidotea sp.*	3.6 (1.9)	13.1 (3.5)	7.0 (1.2)	4.4 (1.6)	8.7 (4.8)	---	1.1 (0.7)	19.1 (6.9)
Insecta								
Collembola								
Sminthuridae	0.1 (0.1)	---	---	---	---	---	---	---
Ephemeroptera								
Baetidae								
unknown	---	---	---	---	---	---	---	0.1 (0.1)

Table 3, Con't

Callibaetis sp.	0.6 (0.5)	0.5 (0.3)	0.4 (0.2)	0.4 (0.2)	---	---	1.2 (0.6)	0.2 (0.2)
Procloeon sp.	---	0.2 (0.1)	---	---	---	---	---	0.3 (0.3)
Caenidae								
Caenis sp.	---	---	0.3 (0.2)	---	---	---	---	0.1 (0.1)
Brachycercus sp.	---	---	0.2 (0.1)	---	---	---	---	0.2 (0.1)
Ephemeridae								
Hexagenia sp.	2.8 (2.6)	0.3 (0.3)	0.3 (0.2)	0.9 (0.5)	0.7 (0.5)	0.2 (0.2)	---	2.5 (1.0)
Heptageniidae								
Stenonema sp.	0.3 (0.1)	---	---	0.3 (0.2)	---	---	---	---
Odonata								
Aeshnidae								
Anax junius	0.2 (0.1)	4.1 (1.5)	2.0 (0.9)	1.6 (0.5)	1.7 (0.6)	---	1.2 (0.5)	1.9 (0.9)
Gomphidae								
Gomphus sp.	---	---	0.1 (0.1)	---	---	---	---	---
Libellulidae								
Plathemis lydia	---	---	---	---	0.2 (0.2)	---	---	---
Sympetrum vicinum	---	---	0.1 (0.1)	---	---	---	---	---
Coenagrionidae								
Enallagma sp.	0.2 (0.2)	0.4 (0.3)	0.1 (0.1)	---	---	---	0.69 (0.5)	---
Ishnura verticalis	---	0.6 (0.2)	0.1 (0.1)	---	---	---	4.57 (2.3)	0.3 (0.3)
immature	0.8 (0.6)	1.0 (0.7)	0.6 (0.3)	0.6 (0.4)	2.0 (1.2)	---	1.07 (0.3)	0.9 (0.6)
Hemiptera								
Belostomatidae								
Belostoma sp.	0.2 (0.1)	---	0.3 (0.2)	---	---	---	0.57 (0.4)	---
Corixidae								
Hesperocorixa sp.	---	---	0.4 (0.4)	---	---	---	---	---
Palmacorixa sp.	---	3.6 (1.6)	0.8 (0.6)	0.3 (0.2)	---	17.4 ####	3.13 (1.3)	---
Sigara sp.	2.1 (1.2)	---	1.5 (0.5)	1.2 (0.5)	1.1 (0.7)	1.0 (0.7)	0.21 (0.2)	---
Trichocorixa sp.	6.0 (3.7)	4.4 (1.8)	18.9 (7.1)	1.5 (0.6)	0.5 (0.2)	18.3 (6.0)	2.09 (0.7)	6.2 (5.4)
immature	6.7 (4.0)	5.2 (1.4)	10.1 (1.5)	8.2 (4.9)	2.4 (0.9)	50.3 ####	18 (5.4)	3.0 (1.4)
Gerridae								

Table 3, con't

Gerris sp.	0.1 (0.1)	---	0.3 (0.2)	0.1 (0.1)	0.2 (0.2)	0.4 (0.4)	---	---
immature	0.3 (0.2)	0.2 (0.1)	0.7 (0.5)	---	1.8 (0.9)	0.5 (0.5)	0.21 (0.2)	---
Hebridae								
Merragata	---	---	---	---	---	---	0.63 (0.6)	---
Hydrometridae								
Hydrometra sp.	0.4 (0.3)	---	---	---	---	---	---	---
Mesoveliidae								
Mesovelia	0.9 (0.6)	3.1 (0.6)	---	0.6 (0.4)	---	---	1.35 (1.0)	0.3 (0.2)
Naucoridae								
Pelocoris	---	---	0.3 (0.2)	---	---	---	---	---
Hemiptera								
Nepidae								
Ranatra sp.	---	---	0.2 (0.1)	---	---	---	0.31 (0.3)	---
Notonectidae								
Notonecta	---	---	0.5 (0.2)	---	---	---	0.15 (0.2)	---
Pleidae								
Neoplea	1.6 (1.1)	---	1.0 (0.3)	1.0 (0.4)	1.1 (0.6)	---	6.44 (1.3)	0.4 (0.2)
Saldidae								
immature	0.2 (0.2)	---	---	---	---	---	---	---
Aphididae								
immature	---	0.1 (0.1)	---	---	---	---	---	---
Trichoptera								
Bracycentridae								
Brachycentrus sp.	0.1 (0.1)	---	---	---	---	---	---	---
Hydropsychidae								
Potamyia flava	---	---	---	---	---	0.4 (0.4)	---	---
Leptoceridae								
Nectopsyche sp.	0.5 (0.3)	0.1 (0.1)	---	15.4 (2.7)	0.2 (0.2)	0.4 (0.4)	---	0.8 (0.5)
Oecetis sp.	---	0.3 (0.2)	---	---	---	---	---	---
Polycentropodidae								
Cernotina sp.	---	---	---	0.2 (0.1)	---	---	---	---

Table 3, Con't.

Phylocentropus sp.	---	0.2 (0.2)	---	---	---	---	---	0.1 (0.1)
Lepidoptera								
Pyralidae								
Acentria sp.	---	0.1 (0.1)	---	---	---	---	---	---
Coleoptera								
Chrysomelidae								
Donacia sp.	---	---	---	---	0.2 (0.2)	---	---	---
Pyrrhalta sp.	---	0.1 (0.1)	---	0.5 (0.3)	---	---	---	---
unknown	---	---	---	0.1 (0.1)	---	---	0.16 (0.2)	---
Curculionidae	0.1 (0.1)	---	0.2 (0.1)	---	---	0.2 (0.2)	---	---
Arthropoda								
Insecta								
Coleoptera								
Dytiscidae								
Coptotomus sp.	---	---	---	---	---	---	0.16 (0.2)	---
Hydrovatus	0.1 (0.1)	---	---	---	---	---	---	0.1 (0.1)
Hygrotus	---	---	2.1 (1.4)	---	---	---	0.15 (0.2)	---
Laccophilus	0.5 (0.3)	---	0.7 (0.3)	---	0.7 (0.4)	---	0.24 (0.2)	0.5 (0.3)
Liodessus sp.	---	---	0.1 (0.1)	---	---	---	---	---
Gyrinidae								
Dineutus sp.	---	---	0.2 (0.1)	---	---	0.7 (0.7)	---	---
Gyrinus	0.1 (0.1)	---	0.4 (0.3)	0.1 (0.1)	0.2 (0.2)	---	0.21 (0.2)	---
Halipidae								
Halipus	0.4 (0.2)	---	---	---	1.9 (1.1)	---	---	0.1 (0.1)
Peltodytes	---	---	---	---	0.4 (0.2)	---	0.67 (0.3)	0.2 (0.1)
Hydrophilidae								
Berosus sp.	---	---	0.1 (0.1)	---	---	---	---	---
Tropisternus	0.3 (0.2)	0.3 (0.1)	0.2 (0.1)	---	1.0 (0.7)	---	---	0.1 (0.1)
Salpingidae	0.1 (0.1)	---	---	---	---	---	---	---
Diptera								
Ceratopogonidae								

Table 3, con't

Bezzia	0.5 (0.2)	---	---	---	0.1 (0.1)	---	0.36 (0.2)	---
Probezzia sp.	0.1 (0.1)	---	---	---	---	---	---	---
Sphaeromias sp.	0.2 (0.2)	---	0.2 (0.2)	---	---	---	---	---
pupa	0.2 (0.1)	---	---	---	---	---	---	---
Chironomidae								
Chironomini	2.5 (0.7)	4.6 (2.1)	9.7 (2.9)	4.2 (1.0)	4.9 (1.7)	4.6 (2.5)	2.43 (0.7)	0.8 (0.4)
Tanytarsini	6.0 (4.3)	0.9 (0.6)	1.0 (0.4)	1.1 (0.3)	0.9 (0.5)	---	0.31 (0.2)	0.3 (0.2)
Orthocladinae	8.6 (3.8)	1.7 (0.7)	1.7 (0.4)	0.1 (0.1)	20.4 (7.4)	3.5 (1.3)	8.91 (2.3)	2.1 (1.0)
Tanypodinae	0.2 (0.1)	1.1 (0.5)	1.2 (0.3)	0.9 (0.6)	---	---	0.4 (0.3)	0.2 (0.1)
Stratiomyidae								
Odontomyia	---	---	---	0.1 (0.1)	---	---	---	---
Tabanidae	---	---	---	---	---	---	0.15 (0.2)	---

Table 4. IBI Metric Scores for family-level invertebrate data for 20 coastal wetland sites in order of decreasing IBI % score

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich TR	Crust.+Mull. %RA	Isopoda %RA
Cedarville	Inner Scirpus	5	5	7	7	7	5	1	5	7
Rapid River	Outer Scirpus	5	7	7	12	7	1		5	
	Inner Scirpus	5	5	7	7	7	1	3	5	3
	Wet Meadow	3	5	3	5	3	1			
Garden Bay	Outer Scirpus	1	1	7	8	7	1		5	
	Inner Scirpus	5	7	5	7	7	1	3	5	7
Ogontz Bay	Outer Scirpus	5	7	3	6	7	1		5	
	Inner Scirpus	5	7	5	7	7	5	3	3	3
Hessel Bay	Outer Scirpus		5	7	10	7	1		5	
	Inner Scirpus	5	5	5	7	7	1	3	5	1
Mackinaw Bay	Outer Scirpus	5	5	7	10	7	1		5	
	Inner Scirpus	5	5	5	7	7	1	3	5	0
	Wet Meadow	3	3	3	3	5	1			
Moscoe Channel	Outer Scirpus	5	3	3	6	7	1		3	
	Inner Scirpus	5	7	5	7	7	1	3	5	5
Hill Island	Outer Scirpus	5	5	5	6	7	1		5	
	Inner Scirpus	5	5	7	5	7	1	3	5	3
Wigwam Bay	Outer Scirpus	5	7	3	10	5	1		5	
	Inner Scirpus	5	5	3	3	5	1	3	5	0
	Wet Meadow	3	5	3	3	3	1			

Table 4. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Cedarville	Inner Scirpus	5	5	3	62	Mildly Impacted	72	86.11
Rapid River	Outer Scirpus	5	5	5	59			
	Inner Scirpus	5	5	5	58			
	Wet Meadow	5	5	5	35			
					152	Mildly Impacted	182	83.52
Garden Bay	Outer Scirpus	5	5	5	45			
	Inner Scirpus	5	5	3	60			
					105	Mildly Impacted	137	76.64
Ogontz Bay	Outer Scirpus	3	5	3	45			
	Inner Scirpus	5	5	5	60			
					105	Mildly Impacted	137	76.64
Hessel Bay	Outer Scirpus	5	5	3	48			
	Inner Scirpus	5	5	5	54			
					102	Moderately Impacted	137	74.45
Mackinaw Bay	Outer Scirpus	3	5	3	51			
	Inner Scirpus	5	5	5	53			
	Wet Meadow	3	5	3	29			
					133	Moderately Impacted	182	73.08
Moscoe Channel	Outer Scirpus	3	5	3	39			
	Inner Scirpus	5	5	5	60			
					99	Moderately Impacted	137	72.26
Hill Island	Outer Scirpus	3	5	3	45			
	Inner Scirpus	5	5	3	54			
					99	Moderately Impacted	137	72.26
Wigwam Bay	Outer Scirpus	5	5	5	51			
	Inner Scirpus	5	5	5	45			
	Wet Meadow				5	5 5	33	

Table 4 con't.

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich TR	Crust.+Mull. %RA	Isopoda %RA
Shepard Island	Outer Scirpus	1	1		10	7	1		5	
	Inner Scirpus	5	5	7	7	7	5	3	5	3
	Wet Meadow	3	3	3	3	5	1			
Big Fishdam	Outer Scirpus	1	1	3	6	7	5		3	
	Inner Scirpus	5	3	5	5	7	5	3	5	0
	Wet Meadow	3	3	3	3	5	1			
Ludington Park	As Inner	7	7	1	10	7	1		3	
	As Outer	7	7	1	5	7	1	3	3	0
Pt.St. Ignace	Outer Scirpus	1	1	5	6	7	5		5	
	Inner Scirpus	5	3	5	3	7	1	3	3	0
Pinnconning	Outer Scirpus	1	1	3	6	5	1		5	
	Inner Scirpus	5	7	3	5	5	1	3	3	0
Wildfowl Bay	Inner Scirpus	5	7	3	3	3	1	3	3	0
Escanaba	Outer Scirpus	1	1	3	6	1			1	
	Inner Scirpus	5	7	5	3	7	5	3	5	0
Allen Rd	Inner Scirpus	5	7	1	3	1	1	3	1	0
Jones Rd	Typha (calculated as Inner Scirpus)	5	7	1	3	1	1	3	5	0
Vanderbuilt Park	Outer Scirpus	1	1	3	6	3	1		3	
	Inner Scirpus	3	3	5	5	7	1	3	3	0
Bradleyville Rd	Outer Scirpus	1	1	1	6	1	1		3	
	Inner Scirpus	5	3	3	3	1	1	3	3	0

Table 4 con't.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Shepard Island	Outer Scirpus	5	5	5	40			
	Inner Scirpus	5	5	3	60			
	Wet Meadow	3	3	3	27			
					127	Moderately Impacted	182	69.78
Big Fishdam	Outer Scirpus	3	3	3	35			
	Inner Scirpus	5	5	5	53			
	Wet Meadow	5	5	5	33			
					121	Moderately Impacted	182	66.48
Ludington Park	As Inner	3	3	3	45	Moderately Impacted	72	62.50
	As Outer	3	3	3	43	Moderately Impacted	65	66.15
Pt.St. Ignace	Outer Scirpus	3	5	3	41			
	Inner Scirpus	5	5	3	43			
					84	Moderately Impacted	137	61.31
Pinnconning	Outer Scirpus	3	5	3	33			
	Inner Scirpus	5	5	3	45			
					78	Moderately Degraded	137	56.93
Wildfowl Bay	Inner Scirpus	3	5	3	39	Moderately Degraded	72	54.17
Escanaba	Outer Scirpus	3	3	1	20			
	Inner Scirpus	5	5	5	55			
					75	Moderately Degraded	137	54.74
Allen Rd	Inner Scirpus	5	5	5	37	Moderately Degraded	72	51.39
Jones Rd	Typha	3	5	3	37	Moderately Degraded	72	51.39
	(calculated as Inner Scirpus)							
Vanderbuilt Park	Outer Scirpus	3	5	3	29			
	Inner Scirpus	3	3	1	37			
					66	Moderately Degraded	137	48.18
Bradleyville Rd	Outer Scirpus	3	3	1	21			
	Inner Scirpus	3	5	5	35			
					56	Moderately Degraded	137	40.88

Table 5. IBI metric values for invertebrate family data for 20 fringing coastal wetlands.

Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich. TR	Crust.+Mull. %RA	Isopoda %RA
Cedarville	Inner Scirpus	2	2.70	8	20	27.42	1.35	0	79.03	39.52
Rapid River	Outer Scirpus	1	4.73	7	18	12.16	0.00	3	52.71	1.55
	Inner Scirpus	1	2.52	7	21	20.13	0.00	1	77.78	6.17
	Wet Meadow	2	17.65	4	22	15.07	0.00	1	24.66	0.68
Ogontz Bay	Outer Scirpus	1	2.08	4	12	25.00	0.00	1	47.22	0.00
	Inner Scirpus	2	9.74	6	20	6.04	1.34	2	29.87	8.24
Garden Bay	Outer Scirpus	0	0.00	7	13	20.39	0.00	4	53.40	23.21
	Inner Scirpus	2	13.18	6	19	13.33	0.00	2	64.62	20.93
Hessel Bay	Outer Scirpus	5	1.56	7	14	24.67	0.00	1	67.33	2.36
	Inner Scirpus	2	4.40	6	20	17.53	0.00	2	50.94	0.63
Mackinaw Bay	Outer Scirpus	2	1.18	7	14	19.34	0.00	3	59.68	0.00
	Inner Scirpus	2	4.86	6	23	23.61	0.00	2	50.82	0.00
	Wet Meadow	2	2.26	4	18	57.14	0.00	1	69.17	0.00
Moscoe Channel	Outer Scirpus	1	0.78	4	12	8.00	0.00	1	21.33	0.00
	Inner Scirpus	2	8.72	6	20	6.04	0.00	2	46.98	12.75
Hill Island	Outer Scirpus	1	1.94	5	11	19.44	0.00	2	45.83	11.81
	Inner Scirpus	2	4.38	8	17	43.28	0.00	3	70.15	9.70

Table 5. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Cedarville	Inner Scirpus	0.992	0.763	0.181	62	Mildly Impacted	72	86.11
Rapid River	Outer Scirpus	0.993	0.792	0.142	59			
	Inner Scirpus	1.052	0.796	0.119	58			
	Wet Meadow	1.130	0.844	0.090	35			
					152	Mildly Impacted	182	83.52
Ogontz Bay	Outer Scirpus	0.735	0.720	0.262	45			
	Inner Scirpus	1.053	0.807	0.114	60			
					105	Mildly Impacted	137	76.64
Garden Bay	Outer Scirpus	0.912	0.864	0.134	45			
	Inner Scirpus	0.979	0.775	0.161	60			
					105	Mildly Impacted	137	76.64
Hessel Bay	Outer Scirpus	0.908	0.779	0.166	48			
	Inner Scirpus	0.951	0.731	0.165	54			
					102	Moderately Impacted	137	74.45
Mackinaw Bay	Outer Scirpus	0.839	0.750	0.183	51			
	Inner Scirpus	1.063	0.777	0.135	53			
	Wet Meadow	0.896	0.714	0.201	29			
					133	Moderately Impacted	182	73.08
Moscoe Channel	Outer Scirpus	0.805	0.702	0.218	39			
	Inner Scirpus	1.014	0.842	0.115	60			
					99	Moderately Impacted	137	72.26
Hill Island	Outer Scirpus	0.871	0.818	0.164	45			
	Inner Scirpus	0.911	0.740	0.184	54			
					99	Moderately Impacted	137	72.26

Table 5. Cont. Site	Veg. Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Family TR	Gastropoda %RA	Sphearidae %RA	Ephem.+Trich. TR	Crust.+Mull. %RA	Isopoda %RA
Wigwam Bay	Outer Scirpus	1	4.90	3	14	3.92	0.00	3	30.43	0.00
	Inner Scirpus	1	5.77	4	14	3.85	0.00	3	30.43	0.00
	Wet Meadow	1	17.24	3	18	1.18	0.00	2	8.24	0.00
Shepard Island	Outer Scirpus	0	0.00	6	16	23.81	0.00	3	52.38	3.57
	Inner Scirpus	2	2.06	7	19	19.21	6.19	1	64.79	1.03
	Wet Meadow	2	1.64	6	17	62.03	0.00	0	83.54	2.03
Big Fishdam	Outer Scirpus	0	0.00	4	12	5.10	2.99	3	13.38	0.00
	Inner Scirpus	1	0.70	6	16	16.78	1.27	3	45.86	0.00
	Wet Meadow	2	4.55	6	17	28.86	0.00	2	68.46	2.68
Ludington Park	As Inner Scirpus	3	9.87	2	16	9.38	0.00	1	9.38	0.00
Pt.St. Ignace	Outer Scirpus	0	0.00	5	11	11.48	1.64	3	33.33	0.00
	Inner Scirpus	1	1.41	5	14	5.84	0.00	3	25.97	0.00
Pinnconning	Outer Scirpus	0	0.00	4	10	4.32	0.00	2	53.19	0.00
	Inner Scirpus	1	18.52	3	16	2.96	0.00	2	11.32	0.00
Escanaba	Outer Scirpus	0	0.00	3	10	0.00	3.28	2	6.90	0.00
	Inner Scirpus	1	10.96	5	14	30.13	0.68	2	39.04	0.00
Wildfowl Bay	Inner Scirpus	1	12.12	3	12	0.55	0.00	2	26.47	0.00
Allen Rd	Inner Scrirpus	2	19.08	2	13	0.00	0.00	2	5.92	0.00
Jones Rd	Typha (calculated as Inner Scirpus)	1	8.67	2	12	0.00	0.00	2	35.33	0.00
Vanderbilt Park	Outer Scirpus	0	0.00	4	10	1.56	0.00	2	12.12	0.00
	Inner Scirpus	1	1.10	5	16	9.94	0.00	3	14.36	0.00
Bradleyville Rd	Outer Scirpus	0	0.00	2	8	0.00	0.00	2	12.07	0.00
	Inner Scirpus	1	1.72	3	11	0.00	0.00	2	17.50	0.00

Table 5. Cont.

Site	Veg. Zone	Shannon Diversity	Evenness	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Wigwam Bay	Outer Scirpus	0.956	0.847	0.124	51			
	Inner Scirpus	0.997	0.853	0.127	45			
	Wet Meadow	1.057	0.859	0.111	33			
					129	Moderately Impacted	182	70.88
Shepard Island	Outer Scirpus	1.063	0.885	0.095	40			
	Inner Scirpus	0.960	0.751	0.158	60			
	Wet Meadow	0.741	0.615	0.291	27			
					127	Moderately Impacted	182	69.78
Big Fishdam	Outer Scirpus	0.727	0.673	0.285	35			
	Inner Scirpus	0.978	0.812	0.139	53			
	Wet Meadow	0.990	0.800	0.134	33			
					121	Moderately Impacted	182	66.48
Ludington Park	As Inner Scirpus	0.656	0.656	0.293	45	Moderately Impacted	72	62.50
	As Outer Scirpus				43	Moderately Impacted	65	66.15
Pt.St. Ignace	Outer Scirpus	0.867	0.795	0.171	41			
	Inner Scirpus	0.974	0.791	0.154	43			
					84	Moderately Impacted	137	61.31
Pinnconning	Outer Scirpus	0.714	0.722	0.295	33			
	Inner Scirpus	0.907	0.753	0.165	45			
					78	Moderately Degraded	137	56.93
Escanaba	Outer Scirpus	0.557	0.571	0.438	20			
	Inner Scirpus	0.971	0.834	0.125	55			
					75	Moderately Degraded	137	54.74
Wildfowl Bay	Inner Scirpus	0.862	0.795	0.157	39	Moderately Degraded	72	54.17
Allen Rd	Inner Scrirpus	0.917	0.833	0.141	37	Moderately Degraded	72	51.39
Jones Rd	Typha	0.817	0.784	0.189	37	Moderately Degraded	72	51.39
Vanderbilt Park	Outer Scirpus	0.822	0.807	0.180	29			
	Inner Scirpus	0.709	0.589	0.308	37			
					66	Moderately Degraded	137	48.18
Bradleyville Rd	Outer Scirpus	0.574	0.666	0.391	21			
	Inner Scirpus	0.875	0.829	0.147	35			
					56	Moderately Degraded	137	40.88

Table 6. IBI metric values for 8 fringing coastal wetlands using lowest operational taxonomic unit invertebrate data.

Site	Zone	Odanata TR	Odanata %RA	Crust.+Mull TR	Genera TR	Gastropoda %RA	Spaeridae %RA	Crust.+Mull. %RA	Ephem.+Trich. TR	Isopoda %RA
Cedarville	Inner Scirpus	2	2.70	8	20	27.42	1.35	79.03	0	39.52
Mackinaw Bay	Outer Scirpus	2	1.18	7	17	17.51	0.00	59.68	4	0.00
	Inner Scirpus	2	4.86	7	29	23.61	0.00	50.82	3	0.00
	Wet Meadow	2	2.26	5	23	57.14	0.00	69.17	1	0.00
Shepard Island	Outer Scirpus	0	0.00	5	19	10.81	0.00	43.24	3	3.57
	Inner Scirpus	2	2.06	8	20	19.21	6.19	64.79	1	1.03
	Wet Meadow	2	1.64	6	20	62.03	0.00	83.54	0	2.03
Pt.St. Ignace	Outer Scirpus	0	0.00	7	20	11.48	1.64	34.43	4	0.00
	Inner Scirpus	1	1.35	6	16	5.84	0.00	25.97	4	0.00
Wildfowl Bay	Inner Scirpus	2	12.12	3	14	0.55	0.00	26.47	2	0.00
Allen Rd	Inner Scirpus	3	19.21	2	18	0.00	0.00	5.96	3	0.00
Jones Rd	Typha (calculated as Inner Scirpus)	1	8.67	2	13	0.00	0.00	35.33	2	0.00
Vanderbilt Park	Outer Scirpus	0	0.00	4	11	1.54	0.00	12.12	2	0.00
	Inner Scirpus	1	1.10	3	14	9.94	0.00	14.36	3	0.00

Table 6. Cont.

Site	Zone	Family TR	Evenness	Shannon Diversity	Simpson Diversity	IBI Score		Total Possible	%Total
Cedarville	Inner Scirpus	20	0.76	0.99	0.18	62	Mildly Impacted	72	86.11
Mackinaw Bay	Outer Scirpus	14	0.73	0.91	0.18	53			
	Inner Scirpus	23	0.80	1.15	0.12	55			
	Wet Meadow	18	0.69	0.94	0.20	31			
						139	Mildly Impacted	182	76.37
Shepard Island	Outer Scirpus	16	0.90	1.17	0.07	47			
	Inner Scirpus	19	0.74	0.97	0.16	60			
	Wet Meadow	17	0.61	0.76	0.29	29			
						136	Mildly Impacted	182	74.73
Pt.St. Ignace	Outer Scirpus	13	0.85	1.05	0.12	53			
	Inner Scirpus	14	0.83	1.05	0.10	49			
						102	Moderately Impacted	137	74.45
Wildfowl Bay	Inner Scirpus	12	0.79	0.90	0.15	45	Moderately Impacted	72	62.50
Allen Rd	Inner Scirpus	14	0.80	0.98	0.13	41	Moderately Degraded	72	56.94
Jones Rd	Typha	12		0.84	0.18	37	Moderately Degraded	72	51.39
	(calculated as Inner Scirpus)		0.78						
Vanderbilt Park	Outer Scirpus	10	0.77	0.81	0.18	29			
	Inner Scirpus	13	0.56	0.64	0.34	35			
						64	Degraded	137	46.72

Table 7. IBI metric scores for 8 fringing coastal wetlands using lowest operational taxonomic unit data.

Site	Zone	Odanata TR	Odanata %RA	Crust.+Mull. TR	Crust.+Mull. %RA	Genera TR	Gastropoda %RA	Spaeridae %RA	Ephem.+Trich. TR
Cedarville	Inner Scirpus	5	5	7	5	7	7	5	1
Mackinaw Bay	Outer Scirpus	5	5	7	5	5	7	1	
	Inner Scirpus	5	5	7	5	7	7	1	3
	Wet Meadow	3	3	3		5	5	1	
Shepard Island	Outer Scirpus	1	1	5	5	7	7	1	
	Inner Scirpus	5	5	7	5	7	7	5	3
	Wet Meadow	3	3	3		5	5	1	
Pt.St. Ignace	Outer Scirpus	1	1	7	5	7	7	5	
	Inner Scirpus	5	3	5	3	5	7	1	5
Wildfowl Bay	Inner Scirpus	5	7	3	3	3	7	1	3
Allen Rd	Inner Scirpus	7	7	1	1	5	1	1	3
Jones Rd	Typha (scored as Inner Scirpus)	5	7	1	5	3	1	1	3
Vanderbilt Park	Outer Scirpus	1	1	3	3	3	3	1	
	Inner Scirpus	5	3	3	3	3	7	1	3

Table 7 Con't. Site	Isopoda %RA	Family TR	Evenness	Shannon Diversity	Simpson Diversity	Total IBI Score	IBI Class	Total Possible	%total
Cedarville	7		5	5	3	62	Mildly Impacted	72	86.11
Mackinaw Bay		5	5	5	3	53			
	0		5	5	5	55			
			3	5	3	31			
						139	Mildly Impacted	182	76.37
Shepard Island		5	5	5	5	47			
	3		5	5	3	60			
			3	3	3	29			
						136	Mildly Impacted	182	74.73
Pt.St. Ignace		5	5	5	5	53			
	0		5	5	5	49			
						102	Moderately Impacted	137	74.45
Wildfowl Bay	0		5	3	5	45	Moderately Impacted	72	62.50
Allen Rd	0		5	5	5	41	Moderately Degraded	72	56.94
Jones Rd	0		5	3	3	37	Moderately Degraded	72	51.39
Vanderbilt Park		3	5	3	3	29			
	0		3	3	1	35			
						64	Degraded	137	46.72

Table 8. Chemical/Physical data for 20 wetland sites.

Site	Vegetation Zone	Temp. C	%DO	SpC	pH	Tur	Cl mgL^{-1}	SO_4 mgL^{-1}	NO_3 mgL^{-1}	NH_4 mgL^{-1}	S.R.P mgL^{-1}	Alk (mgL^{-1} $CaCO_3$)
Hessel Bay	Outer Scirpus	21.94	97.4	197.8	8.08	5.1	4.1	9.3	0.066	0.048	0.003	82.5
Hessel Bay	Inner Scirpus	22.8	77.9	199.6	7.57	6.8	4.6	10.0	0.042	0.041	0.003	84
Mackinac Bay	Outer Scirpus	26.95	89.5	281.9	8.24	22.2	5.3	8.1	0.005	0.058	0.003	135.2
Mackinac Bay	Inner Scirpus	25.47	143.5	414.8	8.13	2.8	4.1	3.7	0.005	0.046	0.003	217
Mackinac Bay	wet meadow	29.46	139.3	445.8	8.2	8.5	4.1	2.2	0.005	0.035	0.008	237
Cedarville	Inner Scirpus	26.08	72.5	285	7.01	1.8	6.7	5.5	0.005	0.026	0.003	141.5
Moscoe Channel	Outer Scirpus	21.21	117.7	182.1	8.5	6.2	4.5	11.1	0.120	0.068	0.003	75
Moscoe Channel	Inner Scirpus	21.14	85.8	192.2	7.58	4.9	4.5	10.8	0.027	0.036	0.003	80
Hill Island	Outer Scirpus	16.18	124.1	176.6	8.37	2.4	4.9	11.8	0.110	0.015	0.003	74
Hill Island	Inner Scirpus	22.66	118.5	175.6	8.5	3	5.2	12.0	0.100	0.017	0.003	73
Shephards Bay	Inner Scirpus	28.58	77.8	271	7.41	2.5	7.0	8.0	0.005	0.024	0.003	127
Shephards Bay	Outer Scirpus	26.85	118	192	8.65	7.1	4.7	10.7	0.018	0.044	0.003	84
Shephards Bay	Wet meadow	27.1	49.8	615	7.21	4.1	15.2	0.5	0.005	0.068	0.007	309
St. Ignace	Outer Scirpus	22.05	99.7	265.9	8.69	25.3	8.6	20.8	0.065	0.032	0.003	95
St. Ignace	Inner Scirpus	22.16	108.9	262.5	8.78	14	9.8	22.3	0.100	0.018	0.003	93
St. Ignace	Juncus	21.52	120.4	712	7.9	5.6	58.5	3.1	0.005	0.036	0.003	310
Escanaba	Inner Scirpus	25.42	83.1	311	7.65	1.9	17.9	0.5	0.011	0.031	0.003	112
Escanaba	Outer Scirpus	25.15	116.8	285	8.57	2.3	10.1	15.3	0.005	0.023	0.003	103
Ludington Park	Scirpus Island	29.38	95.3	287	8.16	2.8	15.0	14.0	0.005	0.047	0.003	98
Rapid River	Outer Scirpus	24.09	78.8	352.5	7.97	5	5.5	2.7	0.005	0.027	0.003	124
Rapid River	Wet Meadow	22.89	40.1	330	7.24	1.9	5.7	3.8	0.005	0.017	0.003	153
Rapid River	Inner Scirpus	24.13	85.16	248.9	8.19	2.8	4.8	2.5	0.005	0.031	0.003	112
Rapid River	Typha	24.43	72.9	261.2	7.97	2.7	5.2	2.8	0.005	0.04	0.003	132
Ogontz Bay	Inner Scirpus	28.83	109.8	288	8.07	3.8	8.9	16.5	0.005	0.038	0.003	96
Ogontz Bay	Outer Scirpus	26.2	104.5	259.9	8.92	4.3	9.6	18.9	0.032	0.017	0.003	104
Garden Bay	Inner Scirpus	22.37	87.2	265	8.29	5.2	7.8	17.2	0.056	0.072	0.003	99
Garden Bay	Outer Scirpus	22.8	92.6	264	8.52	3.7	8.4	19.3	0.068	0.072	0.003	97
Big Fishdam	Outer Scirpus	20.75	88.4	222	8.09	11.4	6.4	13.3	0.039	0.074	0.003	84
Big Fishdam	Inner Scirpus	20.39	86.9	237	8.19	6.2	8.9	16.0	0.030	0.033	0.006	96
Big Fishdam	Juncus	18.88	88.7	462.8	8.32	3.4	25.9	8.2	0.005	0.0257	0.003	190.5
Wigwam Bay	Inner Scirpus	24.66	119.9	289.7	9.62	12.5	25.4	20.7	0.005	0.057	0.003	81
Wigwam Bay	Outer Scirpus	24.24	120.8	289.3	9.47	9.1	27.0	25.5	0.005	0.027	0.003	75.1
Wigwam Bay	Juncus	28.2	155.2	366.1	9.26	4.7	17.5	13.7	0.010	0.04	0.006	138
Pinconning	Inner Scirpus	20.99	56.6	338	7.33	2.5	30.5	20.3	0.005	0.048	0.009	98
Pinconning	Outer Scirpus	23.04	120.7	296	9.22	11.4	35.1	25.2	0.005	0.045	0.003	67.4
Vanderbilt Park	Inner Scirpus	26.02	120.5	409	8.07	3.5	26.7	14.2	0.005	0.228	0.003	158
Vanderbilt Park	Outer Scirpus	25.56	121.3	366	8.45	7.2	29.9	16.0	0.005	0.115	0.006	174
Wildfowl Bay	Inner Scirpus	23.02	108.9	278	8.92	15.2	24.8	22.8	0.005	0.044	0.003	66.1
Allen Rd.	Typha/Scirpus	23.17	112	369	8.43	8	28.9	19.6	0.005	0.032	0.003	118
Jones Rd.	Typha	22.14	34.4	672	7.57	18.5	89.7	39.5	0.300	0.105	0.003	147
Bradleyvile Rd.	Inner Scirpus	26.52	125.4	358.6	9.14	10.5	33.0	26.1	0.005	0.006	0.003	113
Bradleyvile Rd.	Outer Scirpus	21.83	100.6	343	8.71	16.1	32.3	25.7	0.005	0.008	0.003	106.5

Table 9. Land-use for a 1 km buffer around wetlands (% of upland land-use only).

Site	% Developed	% Agriculture	% Forested	Meadow & Idle	Road Density
Hessel Bay	27.21	4.44	41.48	22.72	0.0058723
Mackinac Bay	10.58	0.00	59.49	9.34	0.0022951
Cedarville Bay	31.59	6.32	44.63	12.01	0.0031305
Moscoe Channel	12.40	0.00	76.39	1.10	0.0027558
Hill Island	30.49	0.00	62.51	2.15	0.0065836
Shepards Bay	25.58	0.00	64.71	7.12	0.0034976
Point St. Ignace	33.52	0.00	44.63	21.84	0.0061498
Escanaba	66.60	0.00	31.60	1.79	0.0041785
Ludington Park	99.86	0.00	0.00	0.14	0.0136921
Rapid River	20.49	3.15	14.08	25.29	0.0026823
Ogontz Bay	1.46	2.32	77.29	0.00	0.0016185
Garden Bay	2.15	42.67	37.88	17.30	0.0027463
Big Fishdam	0.00	2.14	81.90	2.81	0.0008882
Wigwam Bay	0.00	1.28	0.00	17.54	0.0013861
Pinconning	7.32	0.36	31.28	26.84	0.0026486
Vanderbilt Park	0.00	33.70	7.39	7.20	0.0007193
Wildfowl Bay	0.00	0.00	3.92	1.44	0.0000000
Allen Road	6.57	57.69	23.90	0.21	0.0018683
Jones Road	82.23	1.20	0.36	0.00	0.0047667
Bradleyville Road	0.00	5.65	42.43	12.34	0.0009660

Table 10. Species list. * = Taxa maintained in correspondence analyses.

	Northern Lake Huron			Saginaw Bay	
	Common	**Scientific**		**Common**	**Scientific**
				Bowfin	*Amia calva*
	Alewife	*Alosa pseudoharengus*		Alewife	*Alosa pseudoharengus*
				Gizzard Shad	*Dorosoma cepedianum*
*	Spottail shiner	*Notropis hudsonius*		Spottail shiner	*Notropis hudsonius*
	Common shiner	*Luxilis cornutus*		Common shiner	*Luxilis cornutus*
	Blacknose shiner	*Notropis heterolepis*		Blacknose shiner	*Notropis heterolepis*
	Emerald shiner	*Notropis atherinoides*		Emerald shiner	*Notropis atherinoides*
*	Pugnose shiner	*Notropis anogenus*	*	Pugnose shiner	*Notropis anogenus*
*	Bluntnose minnow	*Pimephales notatus*			
	Silver chub	*Macrhybopsis storeriana*			
*	Common carp	*Cyprinus carpio*	*	Common carp	*Cyprinus carpio*
				Black redhorse	*Moxostoma duquesnei*
*	White sucker	*Catostomus commersoni*			
*	Banded killifish	*Fundulus diaphanus*	*	Banded killifish	*Fundulus diaphanus*
				Channel catfish	*Ictalurus punctatus*
	Black bullhead	*Ameiurus melas*			
*	Brown bullhead	*Ameiurus nebulosus*			
			*	Longnose gar	*Lepisosteus osseus*
*	Northern pike	*Esox lucius*			
	Ninespine stickelback	*Pungitius pungitius*			
*	Largemouth bass	*Micropterus salmoides*	*	Largemouth bass	*Micropterus salmoides*
*	Smallmouth bass	*Micropterus dolomieu*			
*	Rock bass	*Ambloplites rupestris*	*	Rock bass	*Ambloplites rupestris*
*	Bluegill	*Lepomis macrochirus*	*	Bluegill	*Lepomis macrochirus*
				White Crappie	*Pomoxis annularis*

*	Pumpkinseed	*Lepomis gibbosus*	*	Pumpkinseed	*Lepomis gibbosus*
			*	Green sunfish	*Lepomis cyanellus*
*	Redear sunfish	*Lepomis microlophus*			
				White perch	*Morone americana*
	Johnny darter	*Etheostoma nigrum*		Johnny darter	*Etheostoma nigrum*
*	Yellow Perch	*Perca flavescens*	*	Yellow Perch	*Perca flavescens*
				Round goby	*Neogobius melanostomus*
			*	Brook silverside	*Labidesthes sicculus*
			*	Freshwater drum	*Aplodinotus grunniens*

Table 10. Cont.

	Northern Lake Michigan			**Northeast Lake Michigan**			**Southeast Lake Michigan**	
	Common	**Scientific**		**Common**	**Scientific**		**Common**	**Scientific**
	Bowfin	***Amia calva***		**Bowfin**	***Amia calva***		**Bowfin**	***Amia calva***
	Alewife	***Alosa pseudoharengus***						
	Gizzard Shad	***Dorosoma cepedianum***						
	Spottail shiner	***Notropis hudsonius***		**Spottail shiner**	***Notropis hudsonius***		**Spottail shiner**	***Notropis hudsonius***
				Spotfin shiner	***Cyprinella spiloptera***		**Spotfin shiner**	***Cyprinella spiloptera***
	Common shiner	***Luxilis cornutus***		**Common shiner**	***Luxilis cornutus***		**Common shiner**	***Luxilis cornutus***
							Blackspot shiner	***????***
	Emerald shiner	***Notropis atherinoides***					**Emerald shiner**	***Notropis atherinoides***
*	**Pugnose shiner**	***Notropis anogenus***						
*	**Bluntnose minnow**	***Pimephales notatus***				*	**Bluntnose minnow**	***Pimephales notatus***
*	**Common carp**	***Cyprinus carpio***	*	**Common carp**	***Cyprinus carpio***			
							Quillback	***Carpiodes cyprinus***
				River redhorse	***Moxostoma carinatum***		**River redhorse**	***Moxostoma carinatum***
*	**White sucker**	***Catostomus commersoni***	*	**White sucker**	***Catostomus commersoni***	*	**White sucker**	***Catostomus commersoni***
*	**Banded killifish**	***Fundulus diaphanus***	*	**Banded killifish**	***Fundulus diaphanus***	*	**Banded killifish**	***Fundulus diaphanus***
							Channel catfish	***Ictalurus punctatus***
	Black bullhead	***Ameiurus melas***		**Black bullhead**	***Ameiurus melas***			
	yellow bullhead	***Ameiurus natalis***						
						*	**Tadpole madtom**	***Noturus gyrinus***

*	**Longnose gar**	***Lepisosteus osseus***						
*	**Northern pike**	***Esox lucius***				*	**Northern pike**	***Esox lucius***
				Grass pickerel	***Esox americanus vermi.***		**Grass pickerel**	***Esox americanus vermi.***
*	**Largemouth bass**	***Micropterus salmoides***	*	**Largemouth bass**	***Micropterus salmoides***	*	**Largemouth bass**	***Micropterus salmoides***
*	**Smallmouth bass**	***Micropterus dolomieu***						
*	**Rock bass**	***Ambloplites rupestris***	*	**Rock bass**	***Ambloplites rupestris***	*	**Rock bass**	***Ambloplites rupestris***
*	**Bluegill**	***Lepomis macrochirus***	*	**Bluegill**	***Lepomis macrochirus***	*	**Bluegill**	***Lepomis macrochirus***
*	**Black crappie**	***Pomoxis nigromaculatus***						
*	**Pumpkinseed**	***Lepomis gibbosus***	*	**Pumpkinseed**	***Lepomis gibbosus***	*	**Pumpkinseed**	***Lepomis gibbosus***
			*	**Green sunfish**	***Lepomis cyanellus***	*	**Green sunfish**	***Lepomis cyanellus***
*	**Redear sunfish**	***Lepomis microlophus***	*	**Redear sunfish**	***Lepomis microlophus***	*	**Redear sunfish**	***Lepomis microlophus***
	Johnny darter	***Etheostoma nigrum***		**Johnny darter**	***Etheostoma nigrum***			
*	**Yellow Perch**	***Perca flavescens***						
*	**Central Mudminnow**	***Umbra limi***				*	**Central Mudminnow**	***Umbra limi***
	Round goby	***Neogobius melanostomus***					**Round goby**	***Neogobius melanostomus***
	Burbot	***Lota lota***						

Table 10. Cont.

	Western Lake Superior			**Eastern Lake Superior**	
	Common	**Scientific**		**Common**	**Scientific**
	Spottail shiner	*Notropis hudsonius*			
	Common shiner	*Luxilis cornutus*			
	Blacknose shiner	*Notropis heterolepis*			
	Emerald shiner	*Notropis atherinoides*		Emerald shiner	*Notropis atherinoides*
	Pugnose shiner	*Notropis anogenus*	*	Pugnose shiner	*Notropis anogenus*
	Bluntnose minnow	*Pimephales notatus*			
	Creek chub	*Semotilus atromaculatus*			
	Common carp	*Cyprinus carpio*			

River redhorse	*Moxostoma carinatum*			
Black bullhead	*Ameiurus melas*			
Brown bullhead	*Ameiurus nebulosus*			
Grass pickerel	*Esox americanus vermiculatus*			
Ninespine stickelback	*Pungitius pungitius*			
Smallmouth bass	*Micropterus dolomieu*			
Rock bass	*Ambloplites rupestris*	*	Rock bass	*Ambloplites rupestris*
Bluegill	*Lepomis macrochirus*	*	Bluegill	*Lepomis macrochirus*
			Iowa darter	*Etheostoma exile*
Johnny darter	*Etheostoma nigrum*			
Yellow Perch	*Perca flavescens*	*	Yellow Perch	*Perca flavescens*

Table 10. Cont

Long Point (Lake Erie)			Western Lake Ontario			Eastern Lake Ontario	
Common	**Scientific**		**Common**	**Scientific**		**Common**	**Scientific**
Bowfin	*Amia calva*		Bowfin	*Amia calva*		Bowfin	*Amia calva*
			Alewife	*Alosa pseudoharengus*		Alewife	*Alosa pseudoharengus*
Gizzard Shad	*Dorosoma cepedianum*		Gizzard Shad	*Dorosoma cepedianum*			
			Spottail shiner	*Notropis hudsonius*		Spottail shiner	*Notropis hudsonius*
Spotfin shiner	*Cyprinella spiloptera*		Spotfin shiner	*Cyprinella spiloptera*		Spotfin shiner	*Cyprinella spiloptera*
Common shiner	*Luxilis cornutus*		Common shiner	*Luxilis cornutus*			
						Blacknose shiner	*Notropis heterolepis*
*Blackchin shiner	*Notropis heterodon*				*	Blackchin shiner	*Notropis heterodon*
		*	Fathead minnow	*Pimephales promelas*	*	Fathead minnow	*Pimephales promelas*
Emerald shiner	*Notropis atherinoides*						
*Golden shiner	*Notemigonus crysoleucas*	*	Golden shiner	*Notemigonus crysoleucas*	*	Golden shiner	*Notemigonus crysoleucas*
*Bluntnose minnow	*Pimephales notatus*	*	Bluntnose minnow	*Pimephales notatus*	*	Bluntnose minnow	*Pimephales notatus*
Hornyhead Chub	*Nocomis biguttatus*						
*Common carp	*Cyprinus carpio*	*	Common carp	*Cyprinus carpio*			
					*	White sucker	*Catostomus commersoni*
*Banded killifish	*Fundulus diaphanus*				*	Banded killifish	*Fundulus diaphanus*
*Brown bullhead	*Ameiurus nebulosus*	*	Brown bullhead	*Ameiurus nebulosus*	*	Brown bullhead	*Ameiurus nebulosus*
			yellow bullhead	*Ameiurus natalis*			
*Tadpole madtom	*Noturus gyrinus*				*	Tadpole madtom	*Noturus gyrinus*
*Longnose gar	*Lepisosteus osseus*						
*Northern pike	*Esox lucius*				*	Northern pike	*Esox lucius*
						Threespine	*Gasterosteus aculeatus*

						stickleback	
*Largemouth bass	*Micropterus salmoides*	*	Largemouth bass	*Micropterus salmoides*	*	Largemouth bass	*Micropterus salmoides*
*Smallmouth bass	*Micropterus dolomieu*						
*Rock bass	*Ambloplites rupestris*	*	Rock bass	*Ambloplites rupestris*	*	Rock bass	*Ambloplites rupestris*
*Bluegill	*Lepomis macrochirus*	*	Bluegill	*Lepomis macrochirus*	*	Bluegill	*Lepomis macrochirus*
		*	Black crappie	*Pomoxis nigromaculatus*	*	Black crappie	*Pomoxis nigromaculatus*
*Pumpkinseed	*Lepomis gibbosus*	*	Pumpkinseed	*Lepomis gibbosus*	*	Pumpkinseed	*Lepomis gibbosus*
*Green sunfish	*Lepomis cyanellus*						
					*	Redear sunfish	*Lepomis microlophus*
						White perch	*Morone americana*
*Yellow Perch	*Perca flavescens*	*	Yellow Perch	*Perca flavescens*	*	Yellow Perch	*Perca flavescens*
						Logperch	*Percina caprodes*
					*	Central Mudminnow	*Umbra limi*
Round goby	*Neogobius melanostomus*						
*Brook silverside	*Labidesthes sicculus*						

Table 11: Total Number of Each Species of Fish Collected in Fyke Nets from Great Lakes Fringing Marshes in 2001. An 'X' Indicates a Species Collected Only in Minnow Traps.

			Lake Huron		Lake Michigan				
Family	Common Name	Species	Cedarville	Mackinac	St. Ignace	Ogontz Bay	Escanaba/ Hwy 2	Ludington Park	Nahma/ Poplar Pt
Amiidae	Bowfin	*Amia calva*	0	X	0	0	0	0	0
Catostomidae	White Sucker	*Catostomus commersoni*	0	0	46	31	12	254	0
Centrarchidae	Largemouth Bass	*Micropterus salmoides*	14	9	0	0	0	0	0
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	3	26	13	6	21	0	13
Centrarchidae	Rock Bass	*Ambloplites rupestris*	23	43	5	23	4	11	6
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	3	0	0	16	0	0	0
Centrarchidae	Green Sunfish	*Lepomis cyanellus*	19	0	0	0	0	0	0
Clupeidae	Alewife	*Alosa pseudoharengus*	0	6	0	64	0	0	9
Clupeidae	Gizzard Shad	*Dorosoma cepedianum*	0	0	0	992	0	0	0
Cyprinidae	Spottail shiner	*Notropis hudsonius*	1	114	357	277	3	84	56
Cyprinidae	Common Shiner	*Luxilis cornutus*	28	1	5743	378	48	30	11
Cyprinidae	Blacknose Shiner	*Notropis Heterolepis*	0	2	1	46	16	34	16
Cyprinidae	Emerald shiner	*Notropis atherinoides*	1	0	0	2	0	0	0
Cyprinidae	Golden Shiner	*Notemigonus crysoleucas*	3	2	0	0	0	0	0
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	0	1	0
Cyprinidae	Common Carp	*Cyprinus carpio*	1	5	0	0	0	0	0
Esocidae	Tiger Muskellunge	*Esox masquinongy*	0	0	0	0	0	0	1
Esocidae	Grass Pickerel	*Esox americanus vermiculatus*	0	0	0	0	0	X	0
Fundulidae	Banded Killifish	*Fundulus diaphanus*	0	87	1	39	3	279	0
Gobiidae	Round Goby	*Neogobius melanostomus*	0	0	0	0	17	0	0
Ictaluridae	Channel Catfish	*Ictalurus punctatus*	0	0	0	0	0	0	X
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	237	503	0	175	0	2	0
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*	0	0	0	1	0	0	0
Lepisosteidae	Shortnose Gar	*Lepisosteus platostomus*	0	0	0	0	0	0	1
Percidae	Iowa Darter	*Etheostoma exile*	0	X	0	0	0	0	0
Percidae	Rainbow Darter	*Etheostoma caeruleum*	0	1	0	0	0	0	0
Percidae	Johnny Darter	*Etheostoma nigrum*	4	4	4	2	0	24	12
Percidae	Yellow Perch	*Perca flavescens*	5	1	69	8	8	3	22
Percidae	Walleye	*Stizostedion vitreum*	0	0	0	0	0	2	0
Umbridae	Central Mudminnow	*Umbra limi*	0	X	0	0	0	0	0
Unknown #7			0	0	3	0	0	0	0
		Site Totals	**342**	**804**	**6242**	**2060**	**132**	**724**	**147**

Table 12: Total Number of Each Species of Fish Collected in Fyke Nets from Great Lakes Drowned River Mouth Marshes in 2001. An 'X' Indicates a Species Collected Only in Minnow Traps.

			Lake Michigan								Lake Superior	
Family	Common Name	Species	Muskegon	White	Pentwater	Pigeon	Kalamazoo	Lincoln	Manistee	Betsie	Taquamenon	Portage
Amiidae	Bowfin	*Amia calva*	6	2	0	2	0	0	2	0	0	0
Aphredoderidae	Pirate Perch	*Aphredoderus sayanus*	2	0	0	0	0	0	0	0	0	0
Catostomidae	Shorthead Redhorse	*Moxostoma macrolepidotum*	0	1	0	0	0	0	0	0	0	0
Catostomidae	White Sucker	*Catostomus commersoni*	0	0	0	0	0	0	0	0	6	15
Catostomidae	Lake Chubsucker	*Erimyzon sucetta*	0	0	0	0	1	0	0	0	0	0
Centrarchidae	Largemouth Bass	*Micropterus salmoides*	24	2	0	0	1	1	9	0	0	0
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	0	0	0	0	0	0	0	0	1	1
Centrarchidae	Rock Bass	*Ambloplites rupestris*	0	0	0	0	2	0	3	0	10	15
Centrarchidae	Bluegill	*Lepomis macrochirus*	1	0	0	0	0	0	0	0	0	0
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	1	1	4	0	1	0	1	0	0	1
Centrarchidae	unk. sunfish	*Lepomis sp.*	3	0	0	0	0	1	56	1	0	0
Clupeidae	Alewife	*Alosa pseudoharengus*	0	0	0	0	0	0	0	0	0	58
Clupeidae	Gizzard Shad	*Dorosoma cepedianum*	0	0	0	0	1	0	0	0	0	0
Cyprinidae	Spottail shiner	*Notropis hudsonius*	25	0	2	0	48	0	3	0	8	49
Cyprinidae	Common Shiner	*Luxilis cornutus*	0	0	0	0	0	0	0	0	12	4
Cyprinidae	Blacknose Shiner	*Notropis Heterolepis*	1	0	4	0	213	0	2	2	1	0
Cyprinidae	Emerald shiner	*Notropis atherinoides*	0	0	2	0	0	0	0	2	0	0
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	0	0	1	0	0	0
Cyprinidae	Creek Chub	*Semotilus atromaculatus*	0	0	0	0	1	0	0	0	0	0
Cyprinidae	Common Carp	*Cyprinus carpio*	0	50	0	0	3	15	2	0	0	X
Esocidae	Northern Pike	*Esox lucius*	1	1	0	0	0	0	0	0	0	0
Esocidae	Grass Pickerel	*Esox americanus vermiculatus*	0	0	0	0	0	0	0	2	1	0
Fundulidae	Banded Killifish	*Fundulus diaphanus*	0	1	7	0	0	1	0	1	0	0
Ictaluridae	Channel Catfish	*Ictalurus punctatus*	0	0	0	0	1	0	0	0	0	0
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	0	0	0	0	0	0	3	2	221	31
Ictaluridae	Tadpole Madtom	*Noturus gyrinus*	1	0	1	0	0	0	0	0	0	0
Percidae	Johnny Darter	*Etheostoma nigrum*	20	0	14	4	15	3	33	1	2	0
Percidae	Yellow Perch	*Perca flavescens*	0	0	0	0	0	0	0	0	11	2
Percidae	Walleye	*Stizostedion vitreum*	0	0	0	0	0	0	0	0	1	0
Umbridae	Central Mudminnow	*Umbra limi*	1	0	0	1	2	0	0	0	0	0
		Site Totals	**86**	**58**	**34**	**7**	**289**	**21**	**115**	**11**	**274**	**176**

Table 13. Total number of fish collected in 2002 in fyke nets from northern Lake Huron fringing wetlands.

Family	Common Name	Species	Hessel Bay	Mackinac Bay	Moscoe Channel	Hill Island	Shepard Bay	Cedarville
Catostomidae	White sucker	*Catostomus commersoni*	15	0	2	1	0	0
Centrarchidae	Rock Bass	*Ambloplites rupestris*	10	3	23	2	4	3
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	0	0	2	0	4	7
Centrarchidae	Bluegill	*Lepomis macrochirus*	0	1	1	0	12	2
Centrarchidae	Redear Sunfish	*Lepomis microlophus*	0	0	0	0	40	5
Centrarchidae	Largemouth bass	*Micropterus salmoides*	1	1	6	0	4	20
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	138	57	25	39	28	5
Clupeidae	Alewife	*Alosa pseudoharengus*	2	9	15	26	63	0
Cyprinidae	Common Carp	*Cyprinus carpio*	0	1	0	0	4	2
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	1	0	0	0	0	0
Cyprinidae	Blacknose Shiner	*Notropis heteolepis*	139	138	0	0	0	0
Cyprinidae	Common Shiner	*Luxilus cornutus*	4	13	1	538	0	0
Cyprinidae	Pugnose Shiner	*Notropis anogenus*	0	0	422	54	9	3
Cyprinidae	Emerald Shiner	*Notropis atherinoides*	7	6	0	0	0	2
Cyprinidae	Blacknose Shiner	*Notropis heterolepis*	8	7	0	0	0	0
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	5	22	31	1	0	0
Cyprinidae	Silver Chub	*Macrhybopis storeriana*	0	0	0	1	0	0
Esocidae	Northern Pike	*Esox lucius*	0	0	1	0	0	0
Fundulidae	Banded killifish	*Fundulus diaphanus*	17	12	2	9	0	6
Gasterosteidae	Ninespine Stickleback	*Pungitius pungitius*	4	5	0	26	0	0
Ictaluridae	Black Bullhead	*Ameiurus melas*	0	492	174	0	2448	4554
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	0	0	1	0	1	0
Percidae	Yellow Perch	*Perca flavescens*	0	0	134	1	0	4
Percidae	Johnny Darter	*Etheostoma nigrum*	3	1	2	9	0	0

Table 14. Total number of fish collected in 2002 in fyke nets from Lake Superior fringing and riverine wetlands.

Family	Common Name	Species	Tahquamenon River*	Portage River*	Baraga*	Ojibwa Bay**	Lightfoot Bay**
Catostomidae	Redhorse sucker	*Moxostoma carinatum*	0	1	0	0	0
Centrarchidae	Rock Bass	*Ambloplites rupestris*	9	11	2	1	0
Centrarchidae	Bluegill	*Lepomis macrochirus*	1	7	1	0	0
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	0	2	0	0	0
Cyprinidae	Common Carp	*Cyprinus carpio*	0	2	0	0	0
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	4
Cyprinidae	Common Shiner	*Luxilus cornutus*	0	0	0	0	1
Cyprinidae	Pugnose Shiner	*Notropis anogenus*	11	0	0	0	4
Cyprinidae	Emerald Shiner	*Notropis atherinoides*	24	1	0	0	1
Cyprinidae	Blacknose Shiner	*Notropis heterolepis*	0	0	0	2	0
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	0	8	0	0	0
Cyprinidae	Creek Chub	*Semotilus atromaculatus*	0	0	1	0	0
Esocidae	Grass Pickerel	*Esox americanus*	0	0	0	1	0
Gasterosteidae	Ninespine Stickleback	*Pungitius pungitius*	0	0	1	0	0
Ictaluridae	Black Bullhead	*Ameiurus melas*	0	15	10	0	24
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	0	1	1	0	1
Percidae	Yellow Perch	*Perca flavescens*	3	2	0	0	105
Percidae	Johnny Darter	*Etheostoma nigrum*	0	0	0	2	1
Percidae	Iowa Darter	*Etheostoma exile*	3	0	0	0	0

* riverine wetlands, ** coastal fringing wetlands

Table 15. Total number of fish collected in 2002 in fyke nets from northern Lake Michigan coastal fringing wetlands.

Family	Common Name	Species	St. Ignace	Escanaba/ Hwy 2	Ludington Park	Rapid River	Ogontz Bay	Garden Bay	Big Fishdam
Amiidae	Bowfin	*Amia calva*	0	0	0	0	0	1	0
Catostomidae	White sucker	*Catostomus commersoni*	4	0	7	0	3	0	5
Centrarchidae	Rock Bass	*Ambloplites rupestris*	0	5	5	10	2	2	8
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	0	0	1	0	0	0	0
Centrarchidae	Bluegill	*Lepomis macrochirus*	0	1	9	352	8	0	21
Centrarchidae	Redear Sunfish	*Lepomis microlophus*	0	0	11	9	3	0	0
Centrarchidae	Largemouth bass	*Micropterus salmoides*	0	0	0	0	1	0	0
Centrarchidae	Smallmouth Bass	*Micropterus dolomieu*	6	9	1	1	1	6	2
Centrarchidae	Black Crappie	*Pomoxis nigromaculatus*	0	0	0	1	0	0	0
Clupeidae	Alewife	*Alosa pseudoharengus*	1	1	0	0	47	0	39
Clupeidae	Gizzard Shad	*Dorosoma cepedianum*	0	0	0	0	291	37	57
Cyprinidae	Common Carp	*Cyprinus carpio*	24	0	2	1	1	0	4
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	4	1	0
Cyprinidae	Common Shiner	*Luxilus cornutus*	896	6	2	1	1	25	3
Cyprinidae	Pugnose Shiner	*Notropis anogenus*	42	3	33	11	1	5	39
Cyprinidae	Emerald Shiner	*Notropis atherinoides*	8	0	0	2	101	0	0
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	153	1	0	0	0	1	7
Esocidae	Northern Pike	*Esox lucius*	0	0	0	1	0	0	0
Fundulidae	Banded killifish	*Fundulus diaphanus*	16	1	4	1	0	0	0
Gadidae	Burbot	*Lota lota*	0	0	0	0	0	0	1
Gobiidae	Round Goby	*Neogobius melanostomus*	0	4	0	0	0	0	0
Ictaluridae	Black Bullhead	*Ameiurus melas*	2	0	3	15	84	0	2
Ictaluridae	Yellow Bullhead	*Ameiurus natalis*	0	0	0	1	0	0	0
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*	0	1	0	1	7	1	1
Percidae	Yellow Perch	*Perca flavescens*	2	850	4	5	5	1	26
Percidae	Johnny Darter	*Etheostoma nigrum*	0	0	0	0	1	0	1
Umbridae	Central Mudminnow	*Umbra limi*	0	0	0	0	0	1	0

Table 16. Total number of fish collected in 2002 in fyke nets from Lake Michigan drowned river mouth wetlands (sites north of Muskegon).

Family	Common Name	Species	Arcadia River	Lincoln River	Pere Marquette	Pentwater River	White River	Muskegon River
Amiidae	Bowfin	*Amia calva*	0	0	1	346	2	2
Catostomidae	White sucker	*Catostomus commersoni*	0	1	1	0	1	1
Catostomidae	Redhorse sucker	*Moxostoma carinatum*	0	0	3	0	2	2
Centrarchidae	Rock Bass	*Ambloplites rupestris*	0	0	1	1	0	1
Centrarchidae	Green Sunfish	*Lepomis cyanellus*	0	0	7	0	0	0
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	0	0	1	0	4	1
Centrarchidae	Bluegill	*Lepomis macrochirus*	0	1	8	1	11	1
Centrarchidae	Redear Sunfish	*Lepomis microlophus*	0	0	1	2	1	0
Centrarchidae	Largemouth bass	*Micropterus salmoides*	0	0	7	0	21	0
Cyprinidae	Spotfin Shiner	*Cyprinella spiloptera*	0	0	36	0	0	0
Cyprinidae	Common Carp	*Cyprinus carpio*	0	0	0	0	49	0
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	0	1
Cyprinidae	Common Shiner	*Luxilus cornutus*	0	0	0	1	0	0
Cyprinidae	Emerald Shiner	*Notropis atherinoides*	0	0	0	0	0	3
Cyprinidae	Blackspot Shiner	*Notropis atrocaudalis*	0	0	0	0	0	2
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	1	0	244	23	111	3
Esocidae	Grass Pickerel	*Esox americanus*	0	0	0	1	0	1
Fundulidae	Banded killifish	*Fundulus diaphanus*	0	0	1	4	12	0
Gobiidae	Round Goby	*Neogobius melanostomus*	0	0	0	0	0	3
Ictaluridae	Black Bullhead	*Ameiurus melas*	1	0	0	1	1	0
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	0	0	0	0	0	1
Ictaluridae	Tadpole madtom	*Noturus gyrinus*	0	0	0	0	0	1
Percidae	Johnny Darter	*Etheostoma nigrum*	0	1	0	3	0	0
Umbridae	Central Mudminnow	*Umbra limi*	0	0	0	0	0	1

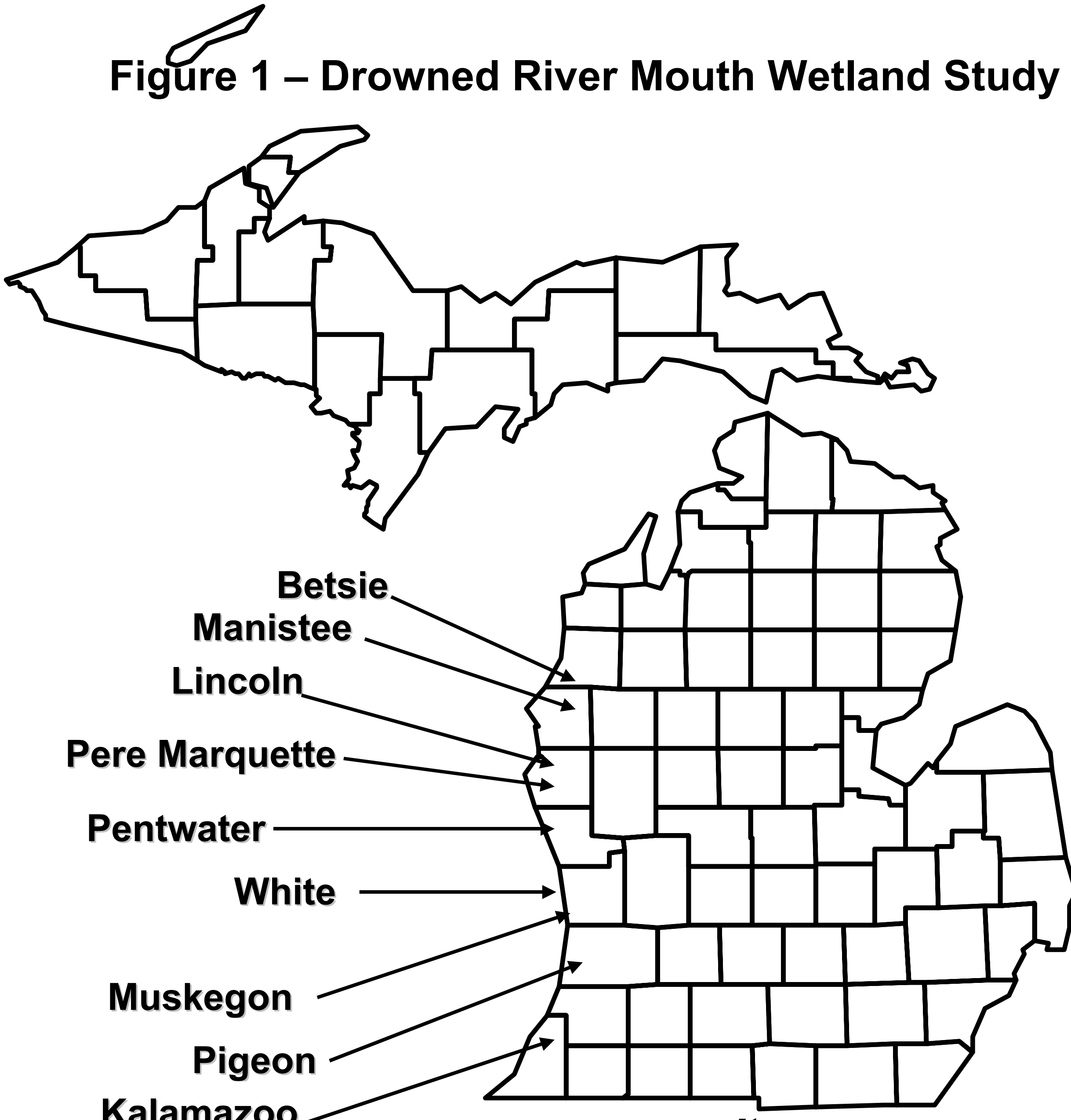
Table 17. Total number of fish collected in 2002 in fyke nets from Lake Michigan drowned river mouth wetlands (sites south of Muskegon).

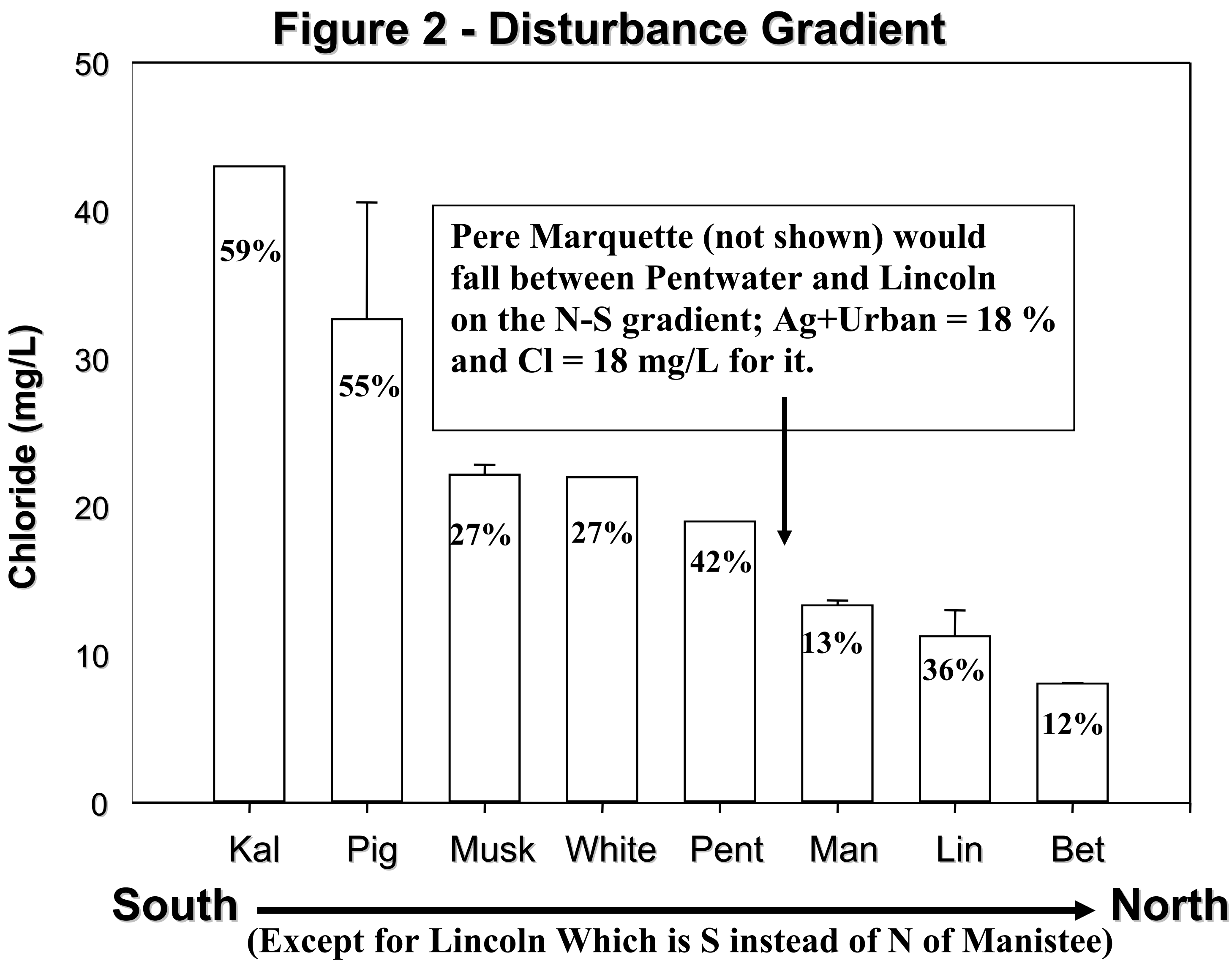
Family	Common Name	Species	Little Black Creek	Norris Creek	Grand River	Little Pigeon River	Pigeon River
Catostomidae	Quillback	*Carpiodes cyprinus*	0	0	1	0	0
Centrarchidae	Green Sunfish	*Lepomis cyanellus*	0	0	0	0	1
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	0	0	2	0	0
Centrarchidae	Bluegill	*Lepomis macrochirus*	0	0	4	1	1
Centrarchidae	Redear Sunfish	*Lepomis microlophus*	0	0	1	0	0
Centrarchidae	Largemouth bass	*Micropterus salmoides*	0	0	79	0	0
Cyprinidae	Spotfin Shiner	*Cyprinella spiloptera*	0	0	20	0	0
Cyprinidae	Bluntnose minnow	*Pimephales notatus*	0	0	0	0	1
Cyprinidae	Common Shiner	*Luxilus cornutus*	0	0	3	3	8
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	0	0	3	1	194
Esocidae	Northern Pike	*Esox lucius*	0	0	0	1	0
Gobiidae	Round Goby	*Neogobius melanostomus*	0	0	0	0	1
Ictaluridae	Brown Bullhead	*Ameiurus nebulosus*	0	0	1	0	1
Ictaluridae	Channel Catfish	*Ictalurus punctatus*	0	0	1	0	0
Umbridae	Central Mudminnow	*Umbra limi*	0	0	0	2	0

Table 18. Total number of fish collected in 2002 in fyke nets from Saginaw Bay coastal fringing wetlands.

Family	Common Name	Species	Wigwam	Pinconning	Vanderbilt Park	Wildfowl Bay	Jones Road	Allen Road	Bradleyville Road
Amiidae	Bowfin	*Amia calva*	0	2	0	0	0	0	0
Catostomidae	Black Redhorse	*Moxostoma duquesnii*	0	0	2	0	0	0	0
Centrarchidae	Rock Bass	*Ambloplites rupestris*	8	4	0	0	0	0	0
Centrarchidae	Green Sunfish	*Lepomis cyanellus*	2	0	2	0	0	2	0
Centrarchidae	Bluegill	*Lepomis macrochirus*	6	4	3	0	13	0	0
Centrarchidae	Largemouth bass	*Micropterus salmoides*	4	7	8	2	0	0	3
Centrachidae	White Crappie	*Pomoxis annularis*	0	0	17	0	0	2	0
Serranidae	White Perch	*Morone americana*	0	4	0	0	0	0	0
Clupeidae	Alewife	*Alosa pseudoharengus*	29	30	38	18	0	0	27
Clupeidae	Gizzard Shad	*Dorosoma cepedianum*	2	4	15	2	33	0	0
Cyprinidae	Common Carp	*Cyprinus carpio*	0	2	23	0	2	2	0
Cyprinidae	Common Shiner	*Luxilus cornutus*	0	17	0	0	0	0	2
Cyprinidae	Pugnose Shiner	*Notropis anogenus*	16	0	0	0	0	0	0
Cyprinidae	Emerald Shiner	*Notropis atherinoides*	12	13	7	8	0	0	4
Cyprinidae	Blacknose Shiner	*Notropis heterolepis*	0	0	0	0	33	0	0
Cyprinidae	Spottail Shiner	*Notropis hudsonius*	0	2	0	4	4	0	5
Fundulidae	Banded killifish	*Fundulus diaphanus*	4	6	5	0	8	6	2
Ictaluridae	Channel Catfish	*Ictalurus punctatus*	0	0	0	0	14	0	0
Gobiidae	Round Goby	*Neogobius melanostomus*	5	0	0	10	0	0	2
Lepisosteidae	Longnose Gar	*Lepisosteus osseus*	2	0	0	0	0	2	0
Percidae	Yellow Perch	*Perca flavescens*	2	0	14	0	15	0	2
Percidae	Johnny Darter	*Etheostoma nigrum*	0	2	0	4	0	0	0
Atherinidae	Brook Silversides	*Labidesthes s. sicculus*	0	2	0	0	0	0	0
Sciaenidae	Freshwater Drum	*Aplodinotus grunniens*	0	0	0	0	6	0	0

Figure 1 – Drowned River Mouth Wetland Study Sites





Land Cover Values for % Agriculture + % Urban in Catchments Shown as Percentages on Each Bar

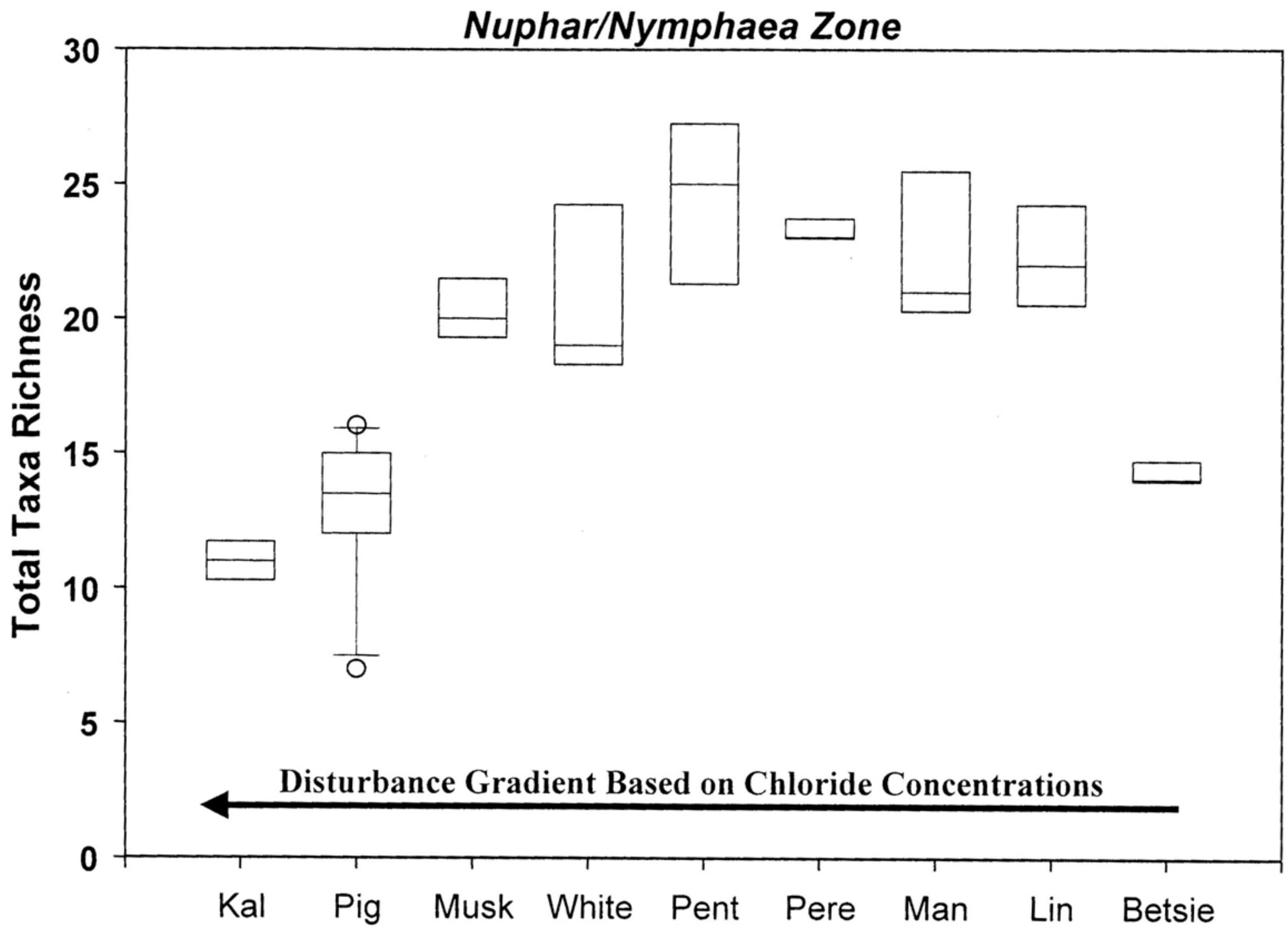
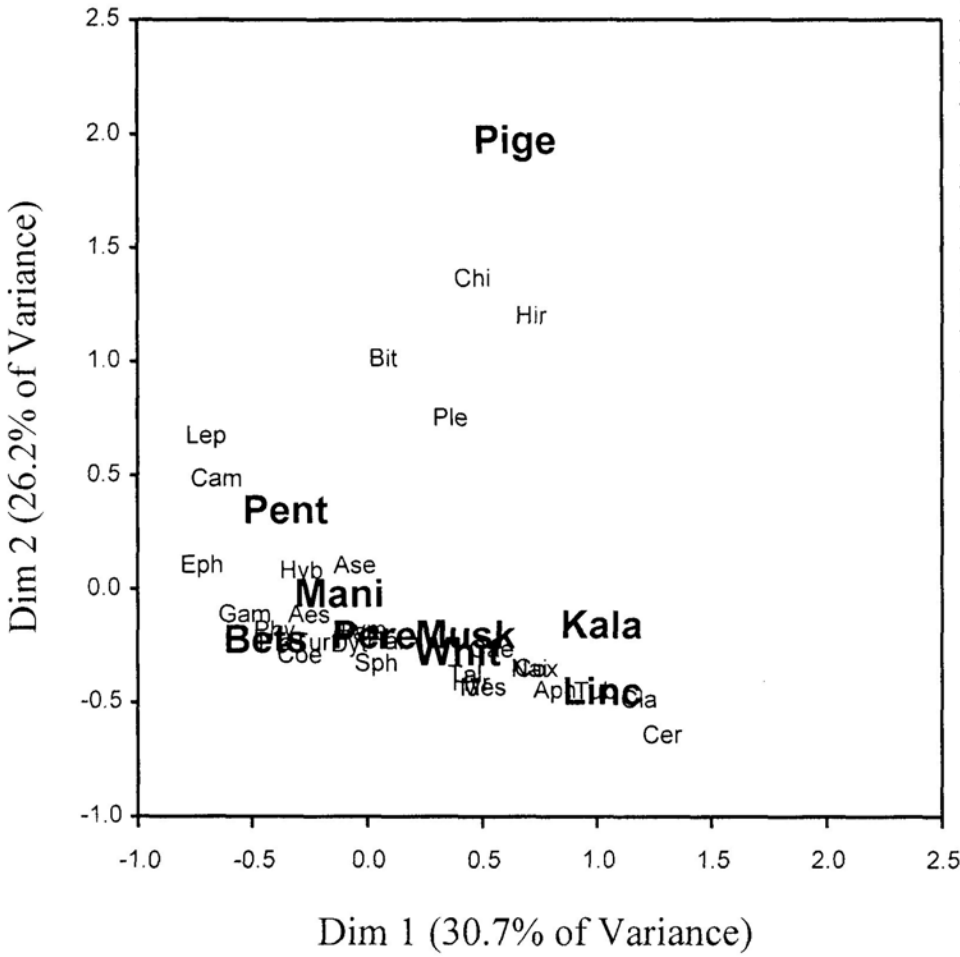


Figure 3 – Use of Box Plots to Determine if Metrics Developed for Fringing Wetlands Plotted Drowned River Mouth Wetlands Along a Disturbance Gradient.

Figure 4 – Example of Use of Correspondence Analyses to Identify Taxa Responsible for Inertia Pulling Impacted Sites Away from Reference Sites in 2000.



Reference Wetlands:
Bets = Betsie
Mani = Manistee

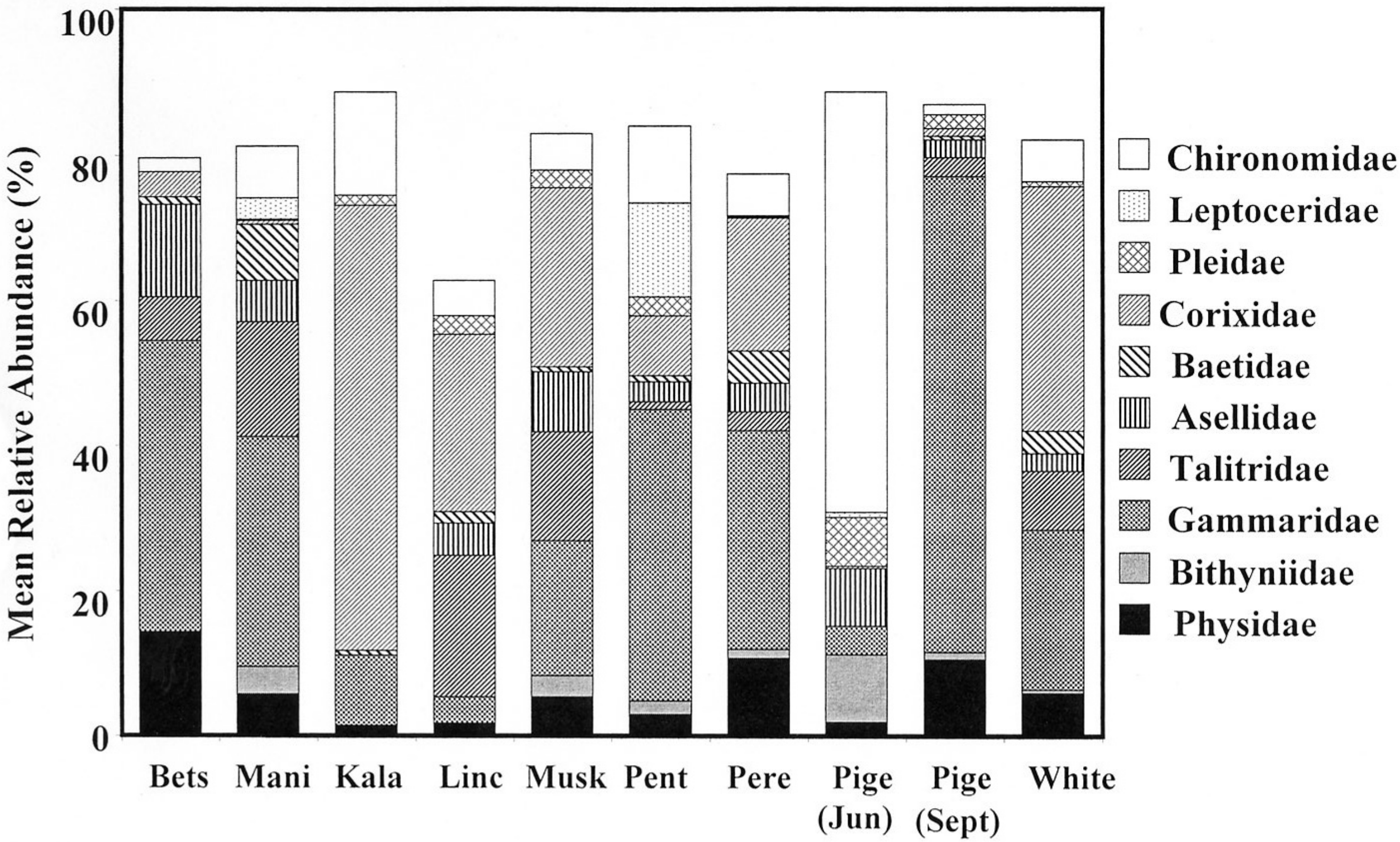
Most Impacted:
Kala = Kalamazoo
Pige = Pigeon (June)

Moderately Impacted:
Linc = Lincoln
Pere = Pere Marquette
Pent = Pentwater
Whit = White
Musk = Muskegon

Family

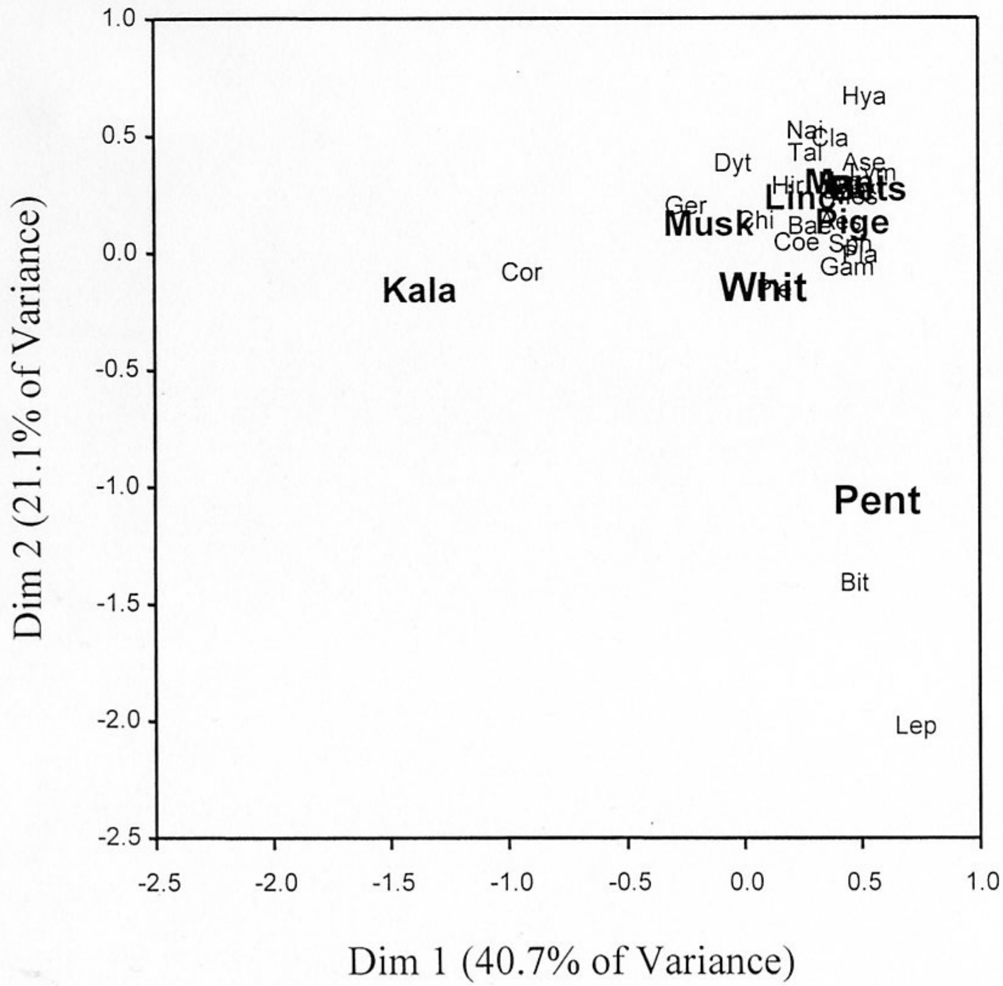
Aes = Aeshnidae
Aph = Aphididae
Ase = Asellidae
Bae = Baetidae
Bit = Bithyniidae
Cae = Caenidae
Cam = Cambaridae
Cer = Ceratopogonidae
Chi = Chironomidae
Cla = Cladocera
Coe = Coenagrionidae
Cox = Corixidae
Dyt = Dytiscidae
Eph = Ephemeridae
Gam = Gammaridae
Hal = Halipidae
Hir = Hirudinea
Hyb = Hydrobiidae
Hyr = Hydracarina
Lep = Leptoceridae
Lym = Lymnaeidae
Mes = Mesoveliidae
Nai = Naididae
Phy = Physidae
Pla = Planorbidae
Ple = Pleidae
Sph = Sphaeriidae
Tal = Talitridae
Tub = Tubificidae
Tur = Turbellaria

Figure 5 – Top 10 Invertebrate Families Collected from Drowned River Mouth Wetlands in 2000.



Note that Kalamazoo R. Wetland had greater dominance by Corixidae;Pigeon River Wetland in June had Greater proportion of Chironomidae; these two families pulled these two impacted sites away from others in CA.

Figure 6 – Example of Use of Correspondence Analyses to Identify Taxa Responsible for Inertia Pulling Impacted Sites Away from Reference Sites in 2001.



Reference Wetlands:
Bets = Betsie
Mani = Big Manistee

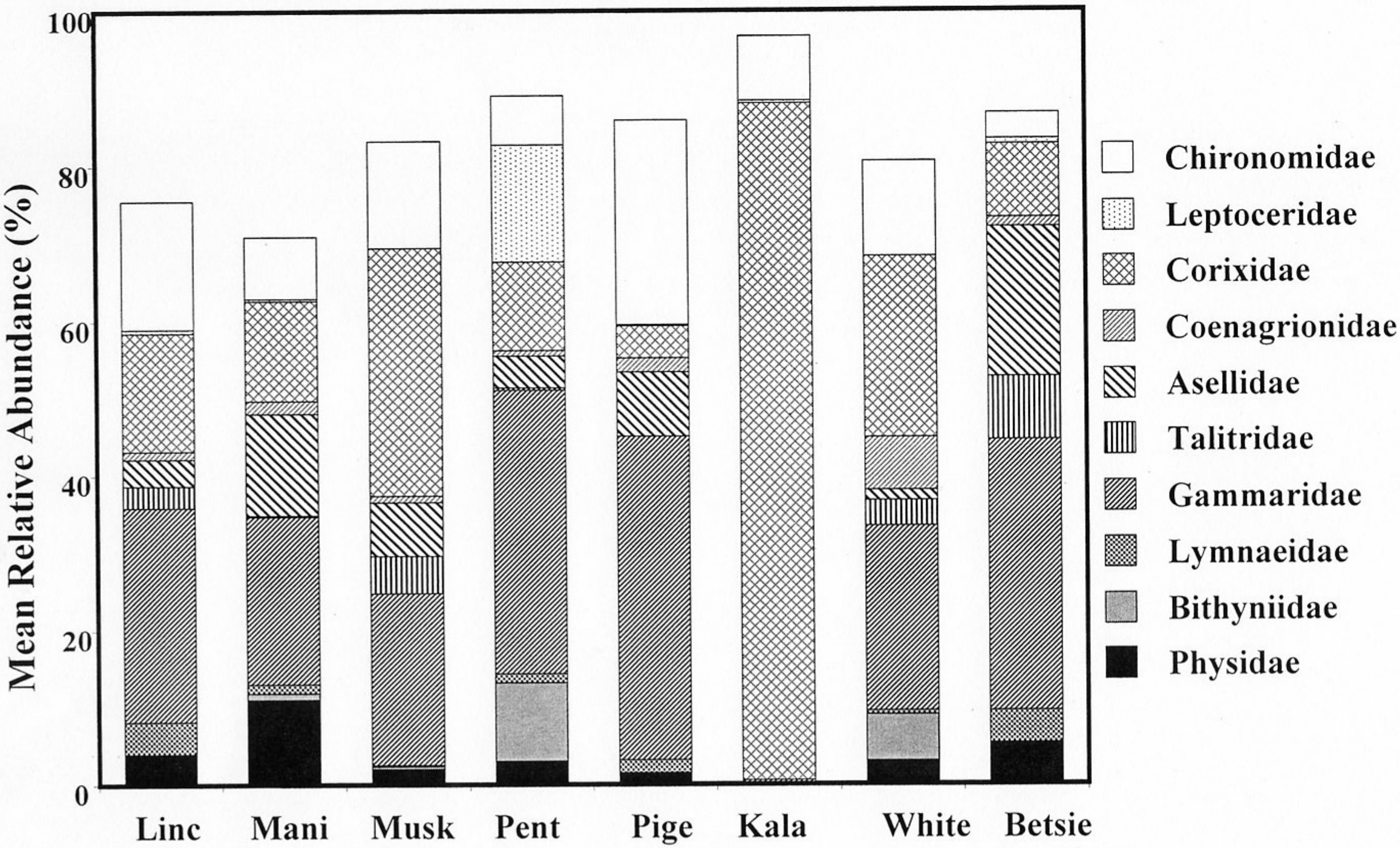
Most Impacted:
Kala = Kalamazoo
Pige = Pigeon

Moderately Impacted:
Linc = Lincoln
Pent = Pentwater
Whit = White
Musk = Muskegon

Family

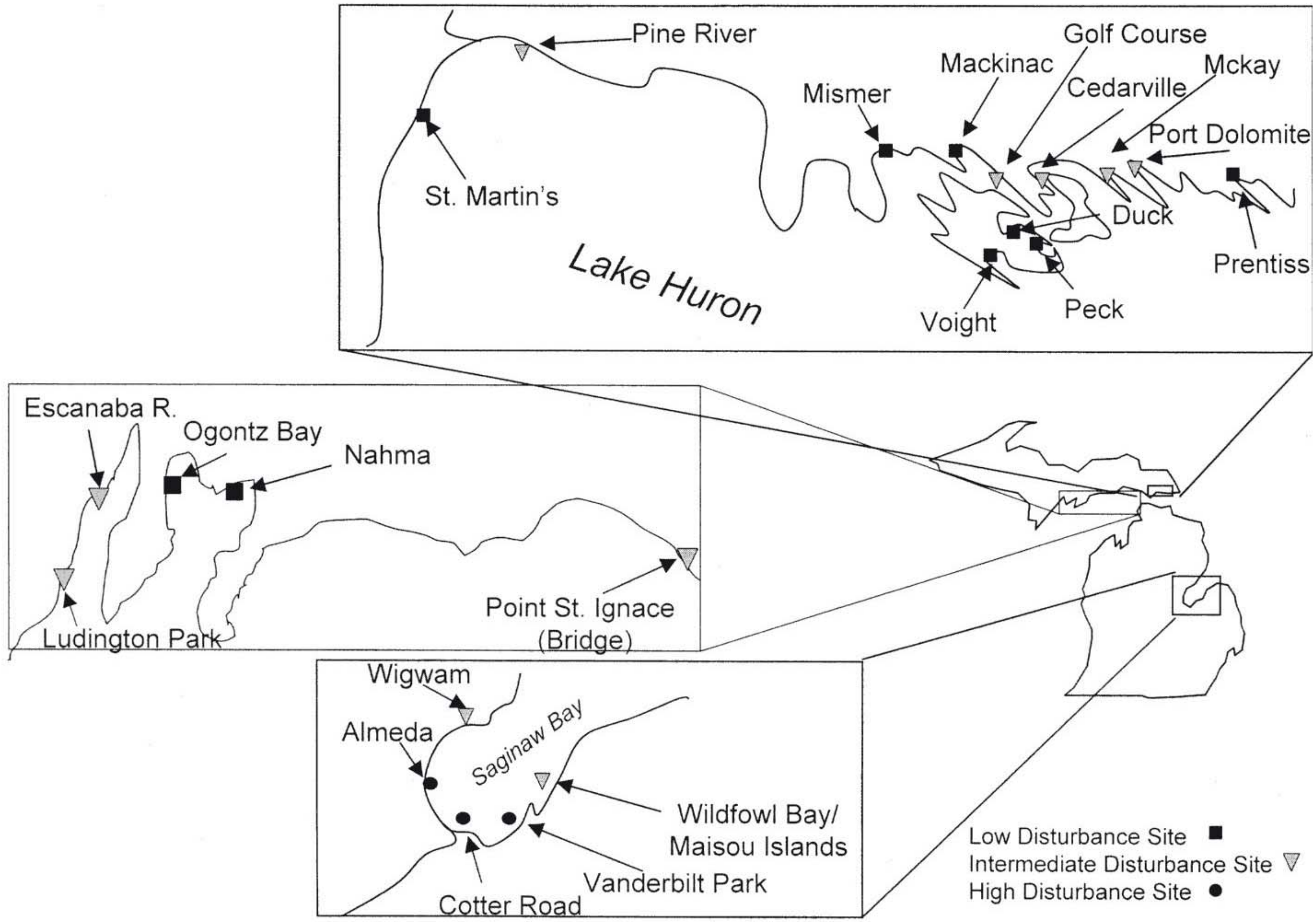
Aes = Aeshnidae
Ase = Asellidae
Bae = Baetidae
Bit = Bithyniidae
Chi = Chironomidae
Cla = Cladocera
Coe = Coenagrionidae
Cor = Corixidae
Dyt = Dytiscidae
Eph = Ephemeridae
Gam = Gammaridae
Ger = Gerridae
Hir = Hirudinea
Hya = Hydracarina
Hyo = Hydrobiidae
Lep = Leptoceridae
Lym = Lymnaeidae
Mes = Mesoveliidae
Nai = Naididae
Phy = Physidae
Pla = Planorbidae
Ple = Pleidae
Sph = Sphaeriidae
Tal = Talitridae

Figure 7 – Top 10 Invertebrate Familes Collected from Drowned River Mouth Wetlands in 2001



Note that Kalamazoo R. Wetland has greater dominance by Corixidae;Pigeon R.iver Wetland had greater proportion of Chironomidae; This pulls these impacted sites away from others in CA.

Figure 8: Map of Fringing Wetlands Sample in 200



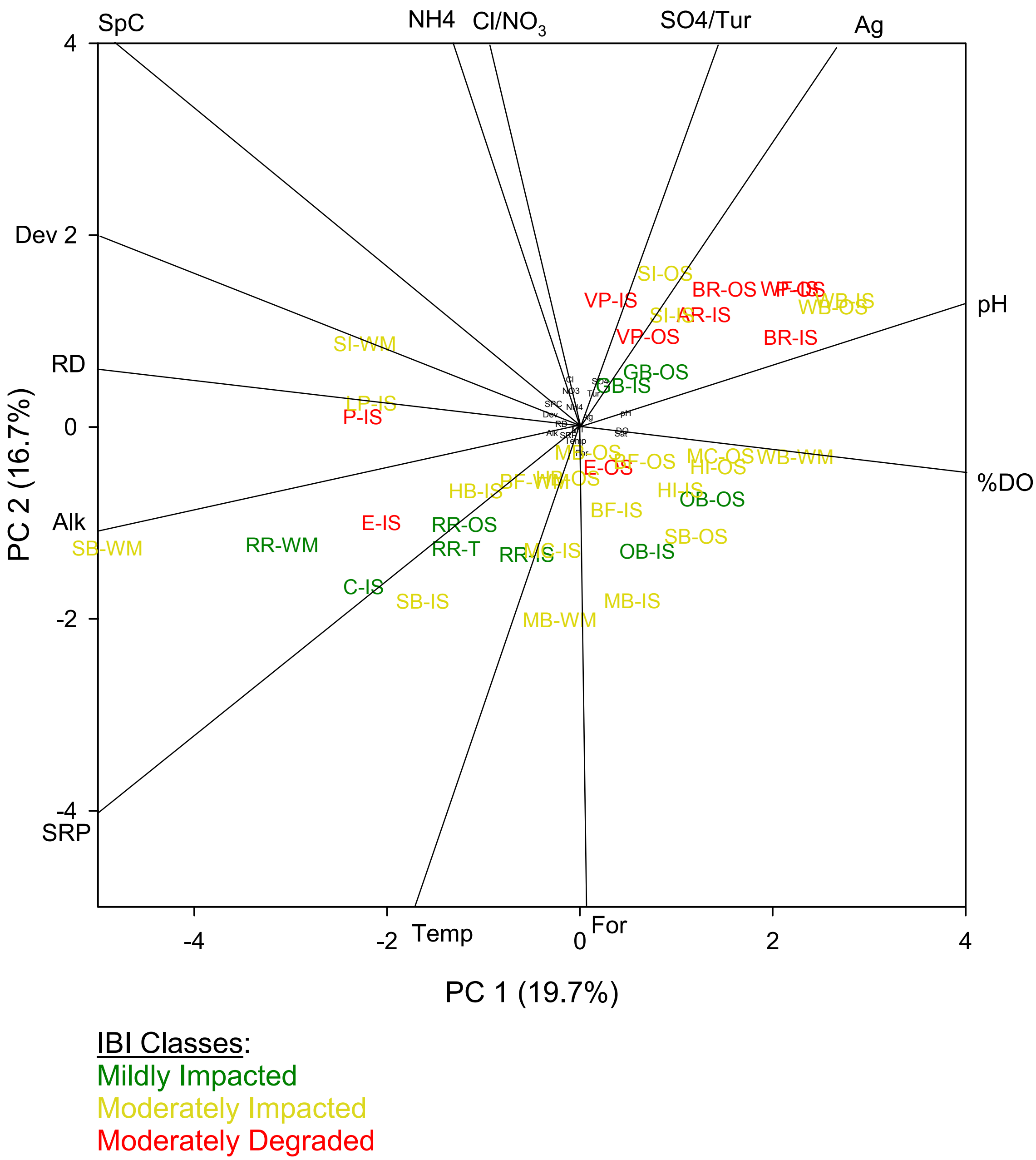


Figure 9. PCA of 20 coastal wetland sites using 17 chemical, physical and land use variables (Jones Road not shown because it lies outside plot area).

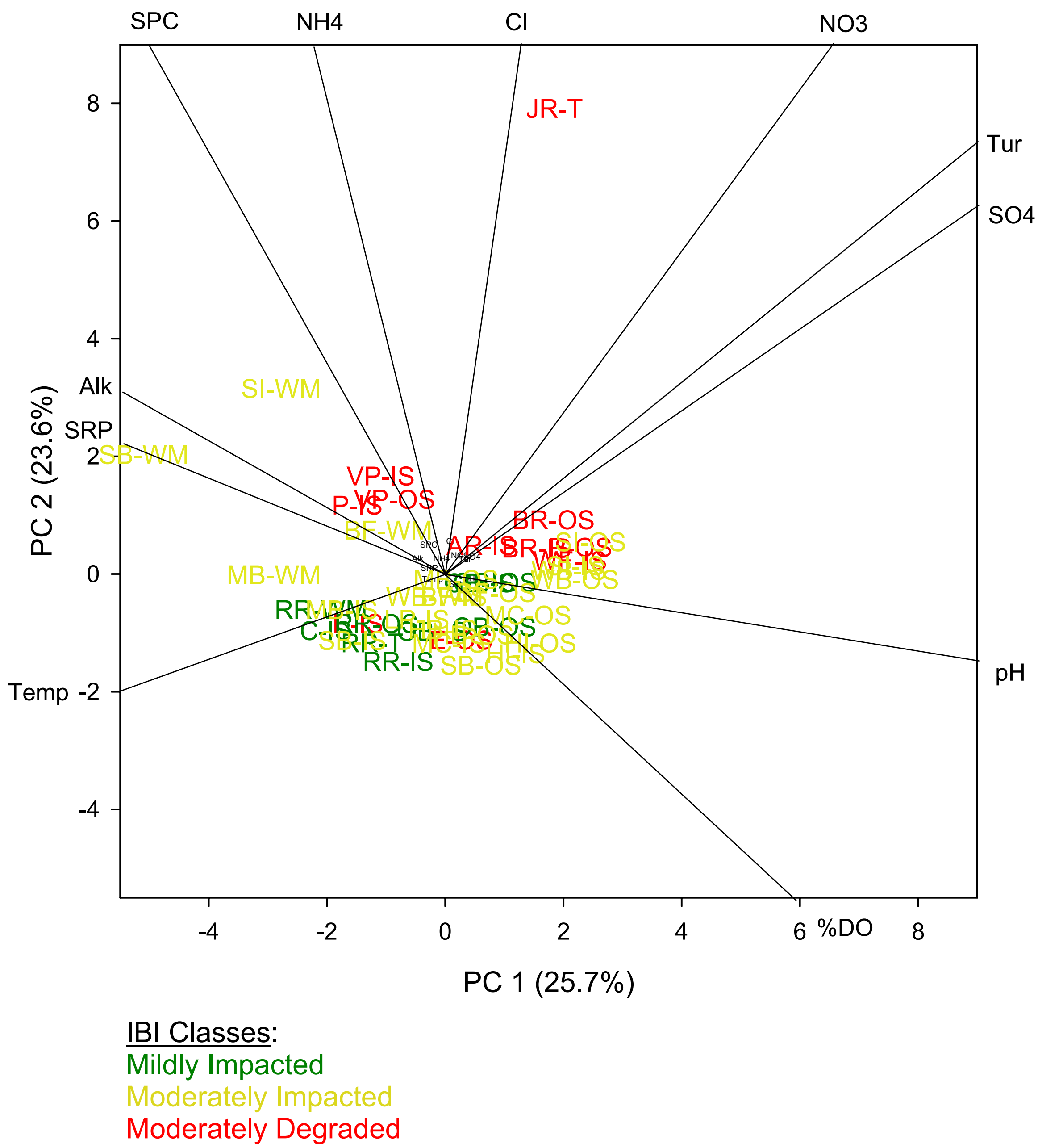


Figure 10/ PCA of 20 coastal wetland sites using 11 chemical and physical variables.

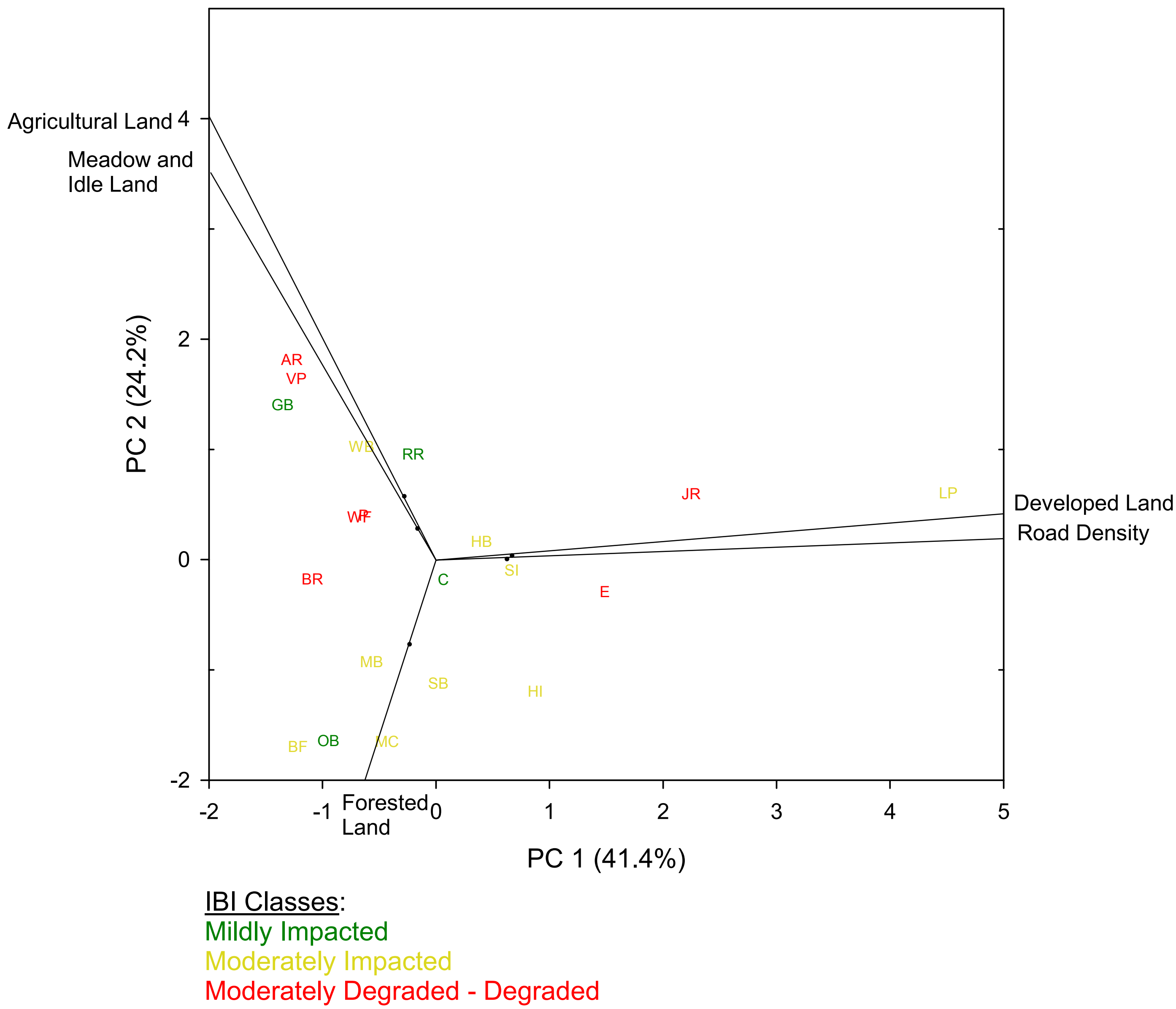


Figure 11. PCA of land use/cover parameters for 20 coastal wetlands in Lakes Michigan and Huron.

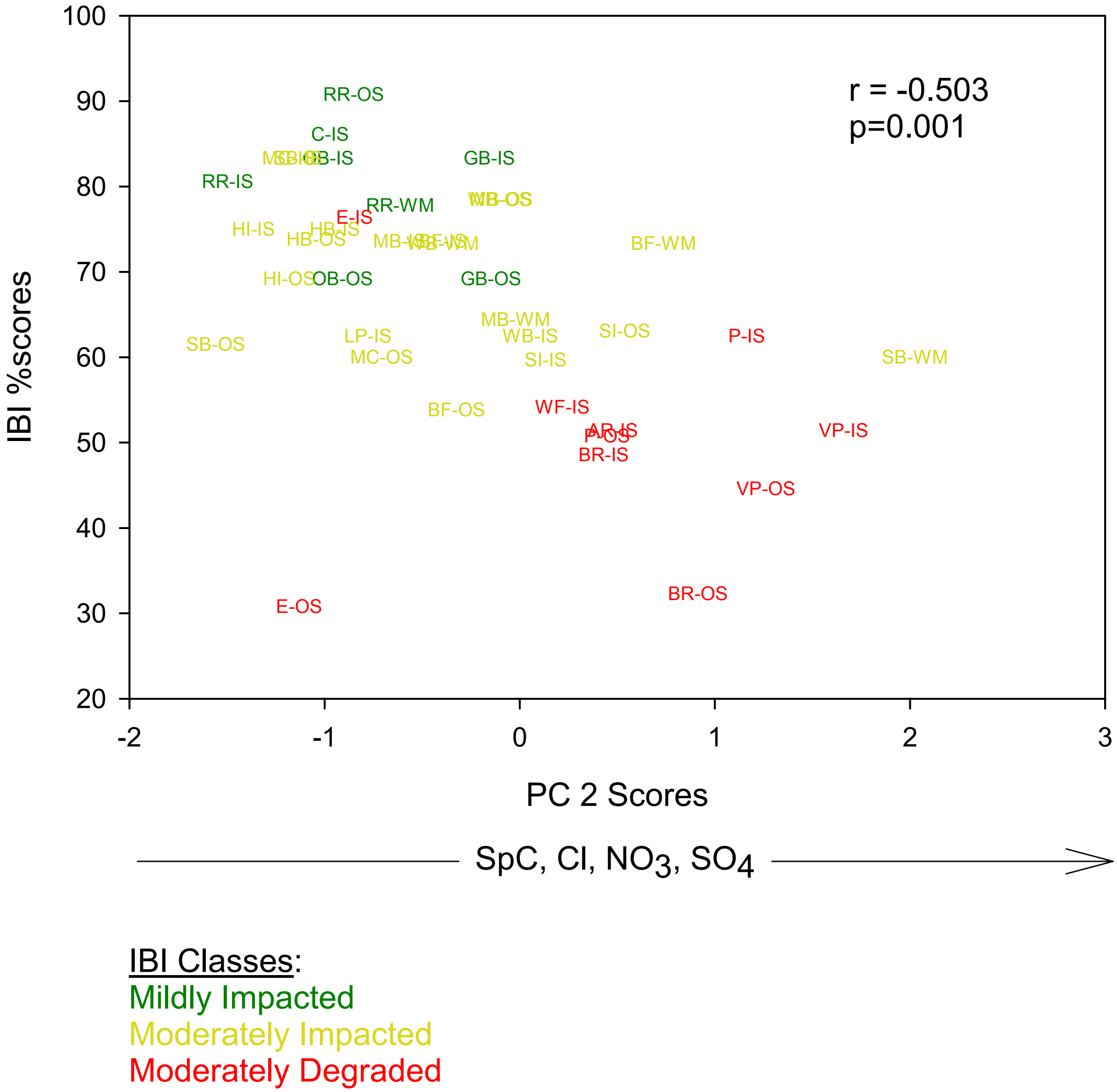


Figure 12. IBI scores (percent of total possible) for individual plant Zones vs. principal component 2 scores of chemical/physical PCA.

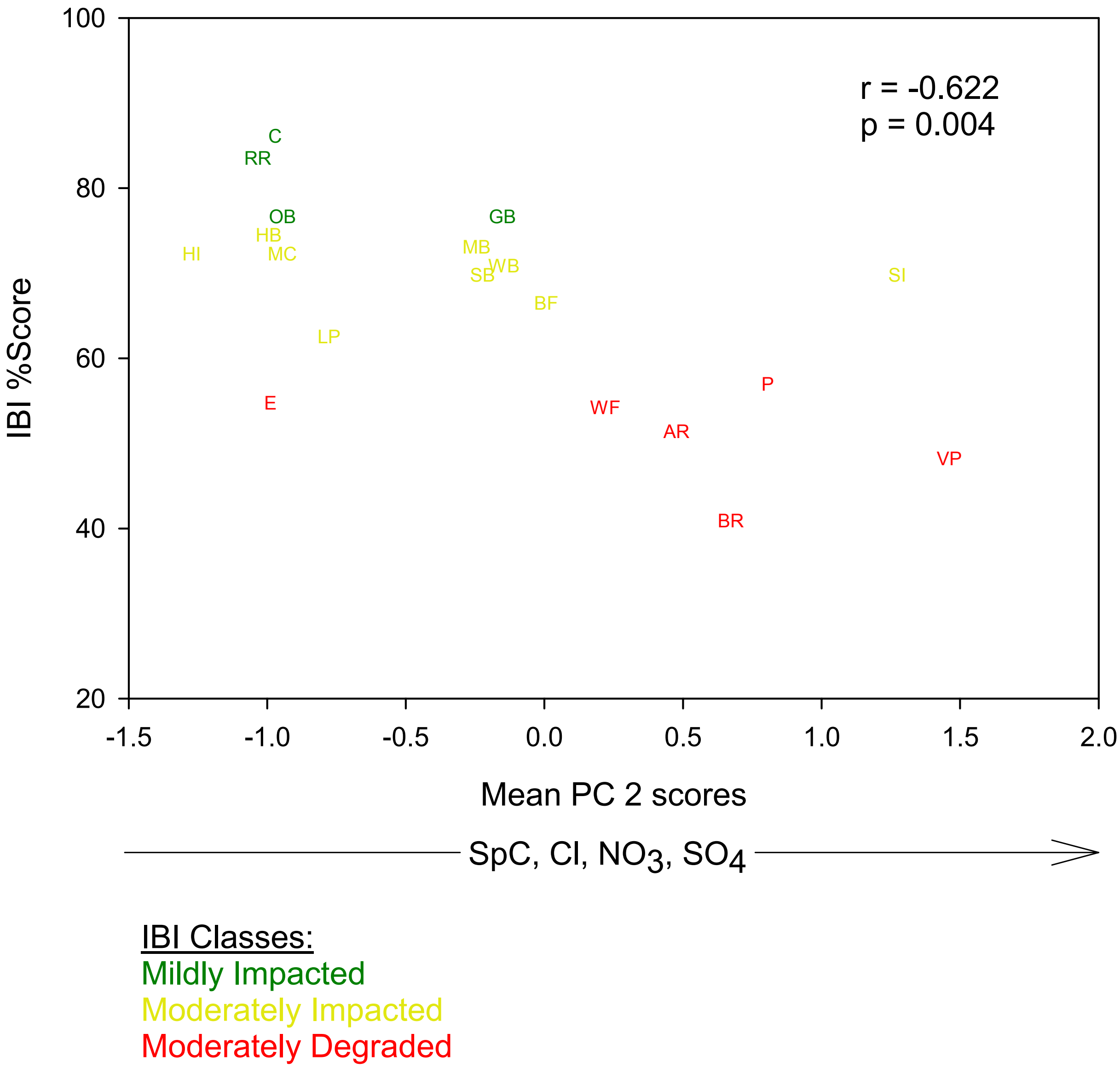


Figure 13. IBI scores (percent of total possible) vs. principal component 2 scores (means of all plant zones/site) for 20 sites.

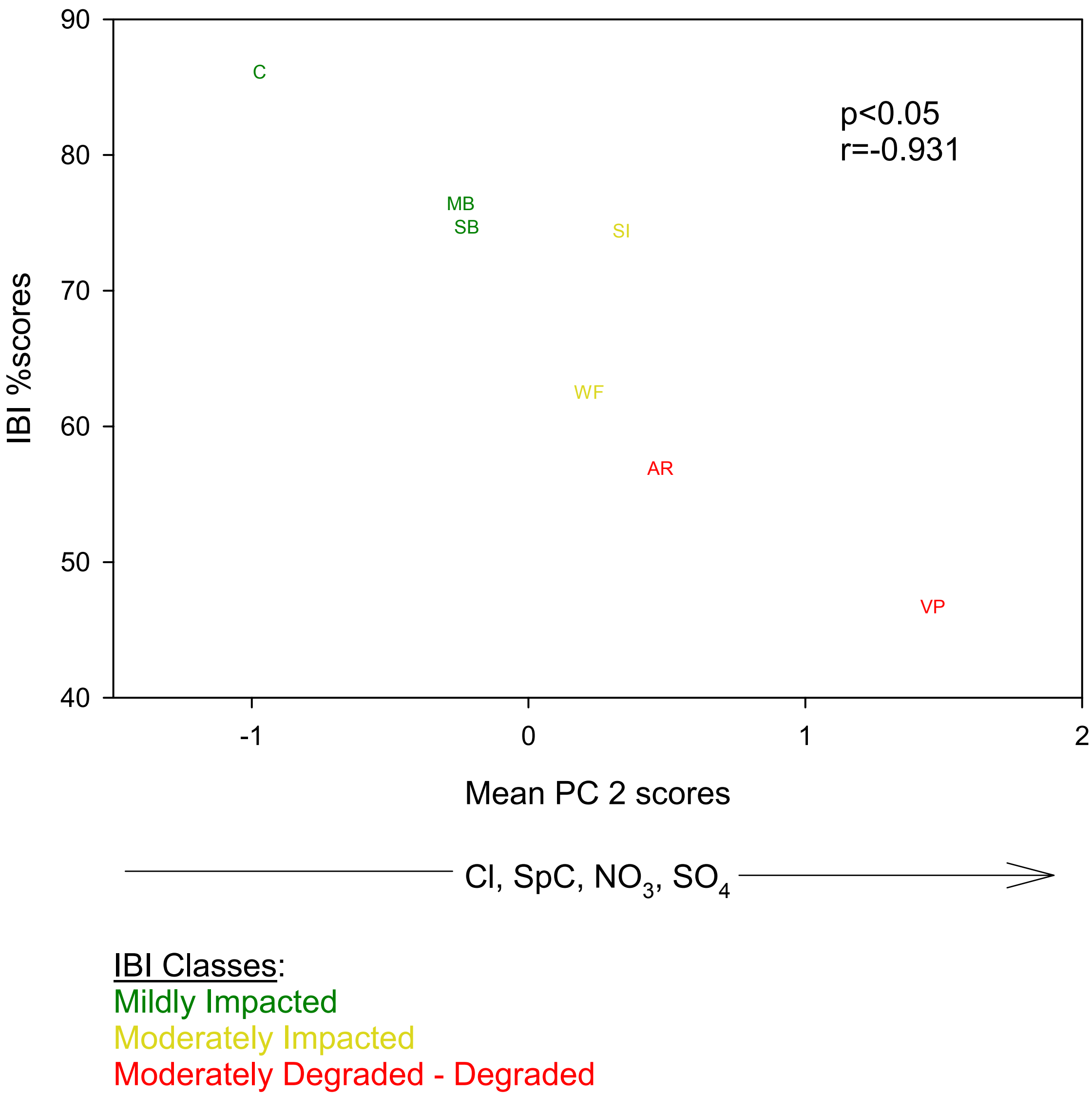
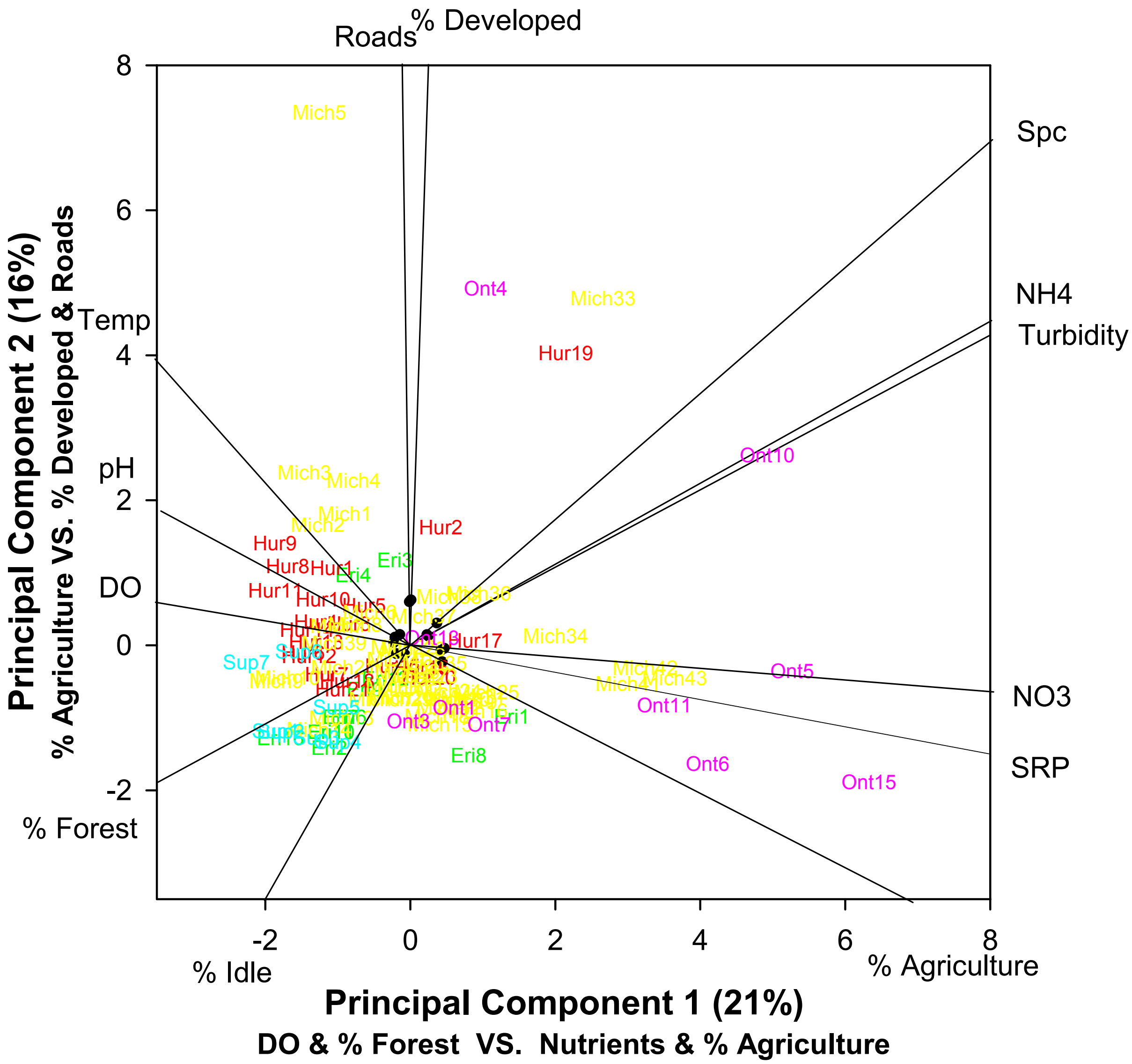


Figure 14. Macroinvertebrate IBI scores for 7 sites using data at lowest operational taxonomic unit in response to water quality measure by PC 2 Scores (means of all plant zones/site) of the chemical/physical PCA on data from 20 wetlands.



➢

Figure 15. PCA of Chemical/Physical and Land-use/cover data. Coded by lake for the 5 Great Lakes.

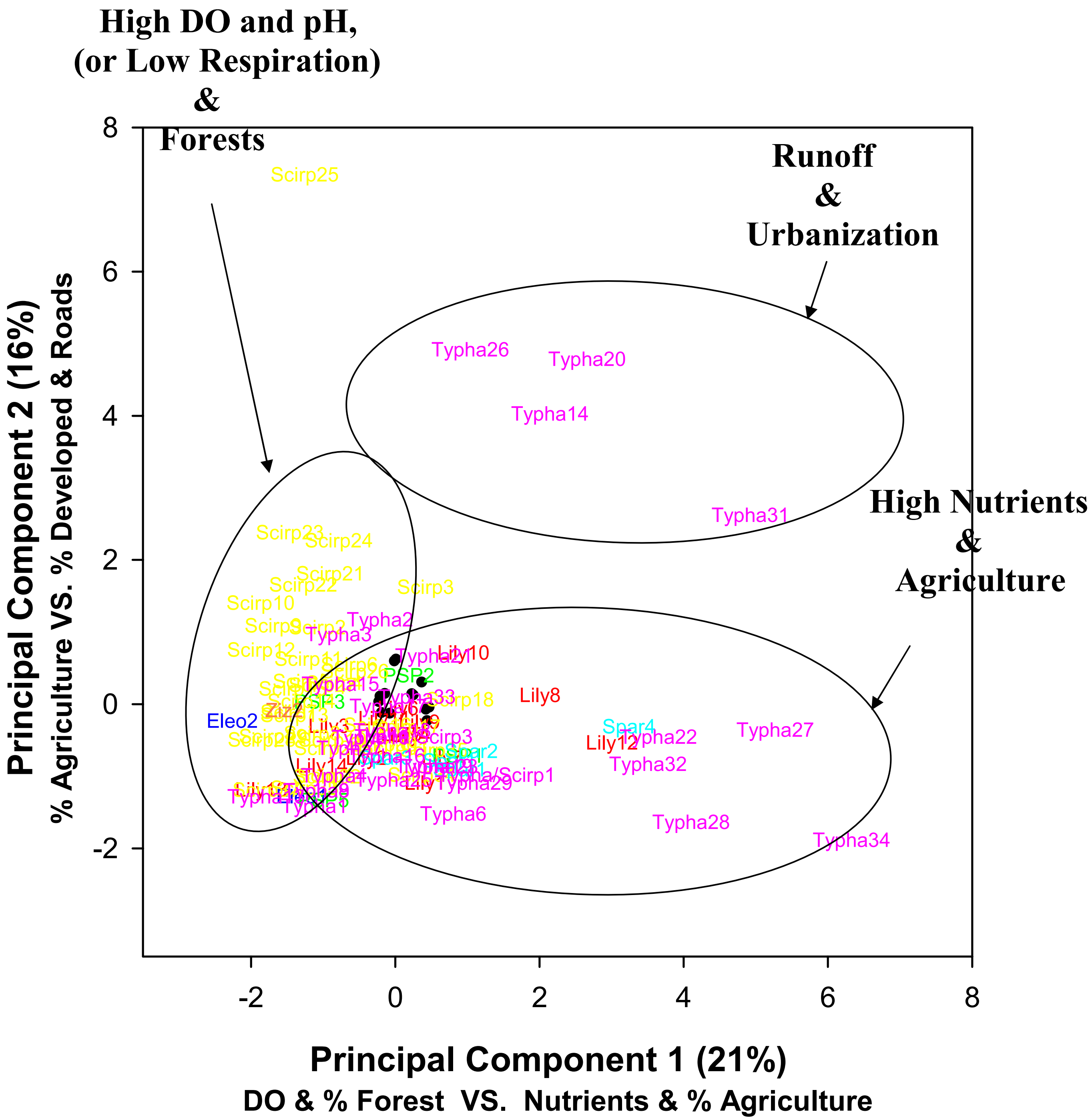


Figure 16. PCA of land-use and chemistry for 104 plant zones. Coded by plant zone. Sparganium = Sparg, Scirpus = Scirp, Floating leafed zone = Lily, Pontederia/Sagittaria/Peltandra = PSP, Typha = Typha, Zizania =Zi, Eleocharis = Eleo.

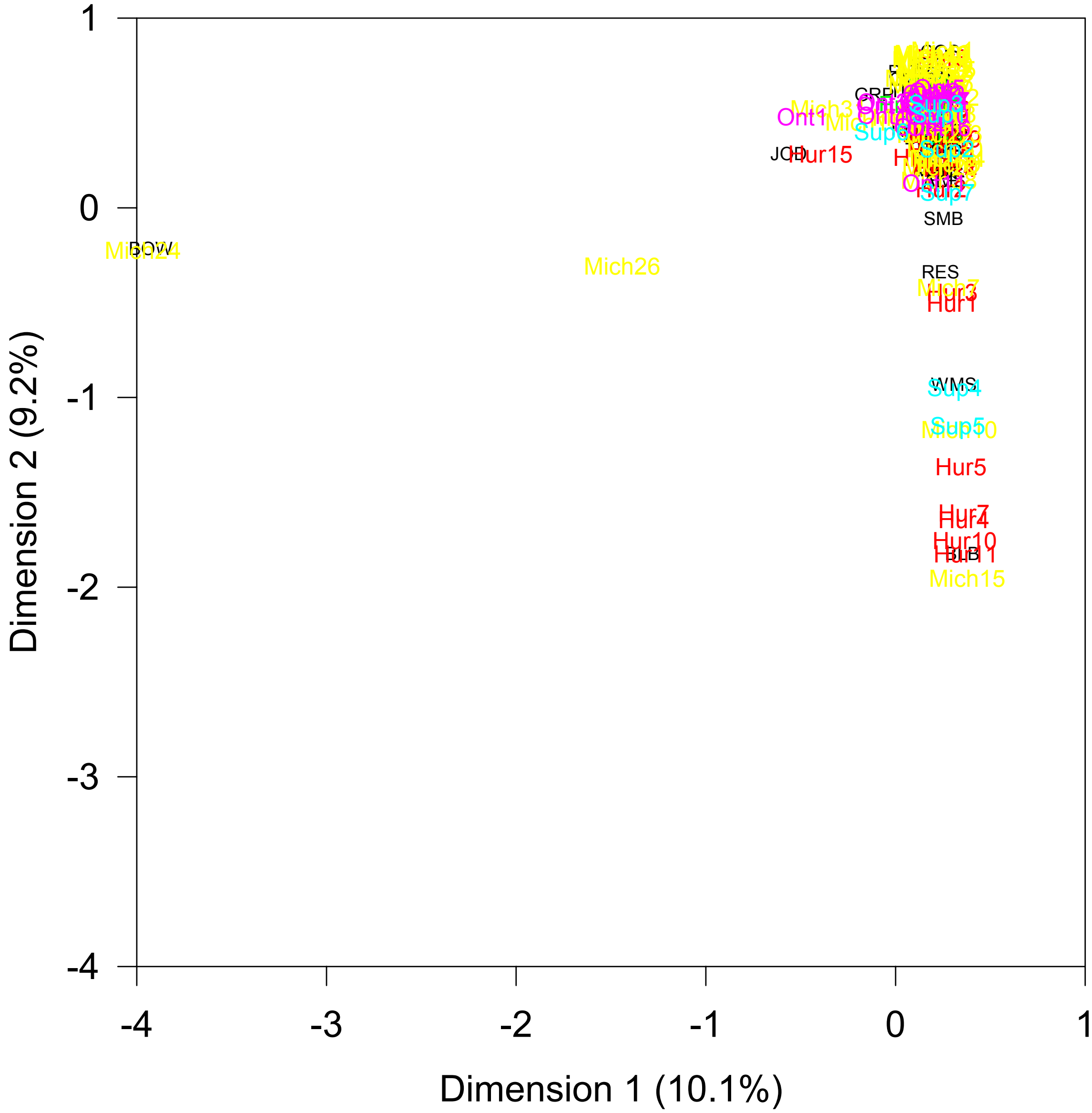


Figure 17. Correspondence analysis using 2002 fish data for 104 plant zones from all 5 Great Lakes and 42 species of fish. See Figure 16 for plant zone designations.

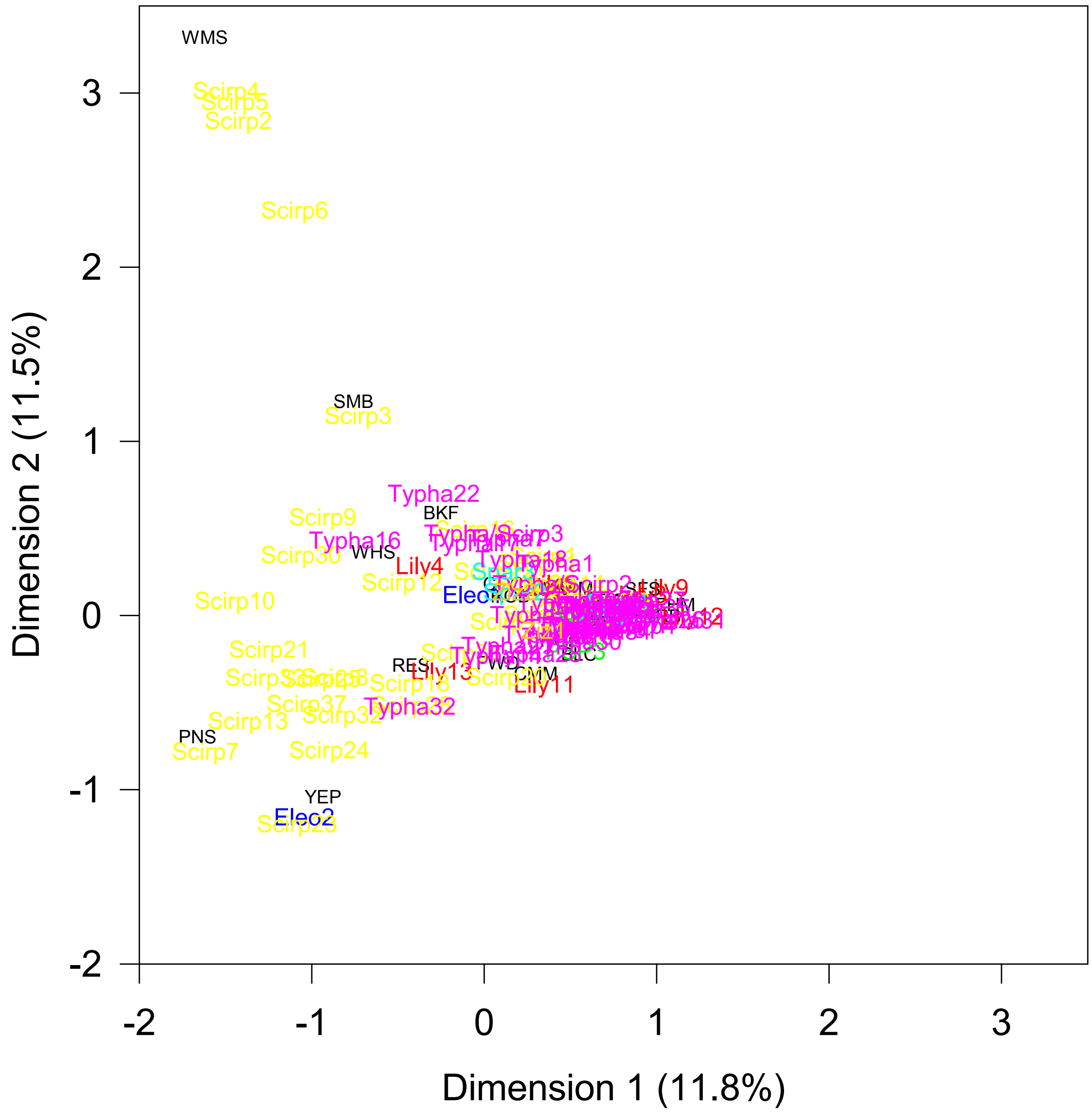


Figure 18. Correspondence analysis using 2002 fish data for 104 plant zones from all 5 Great Lakes and 26 species of fish. See Figure 16 for plant zone designations.

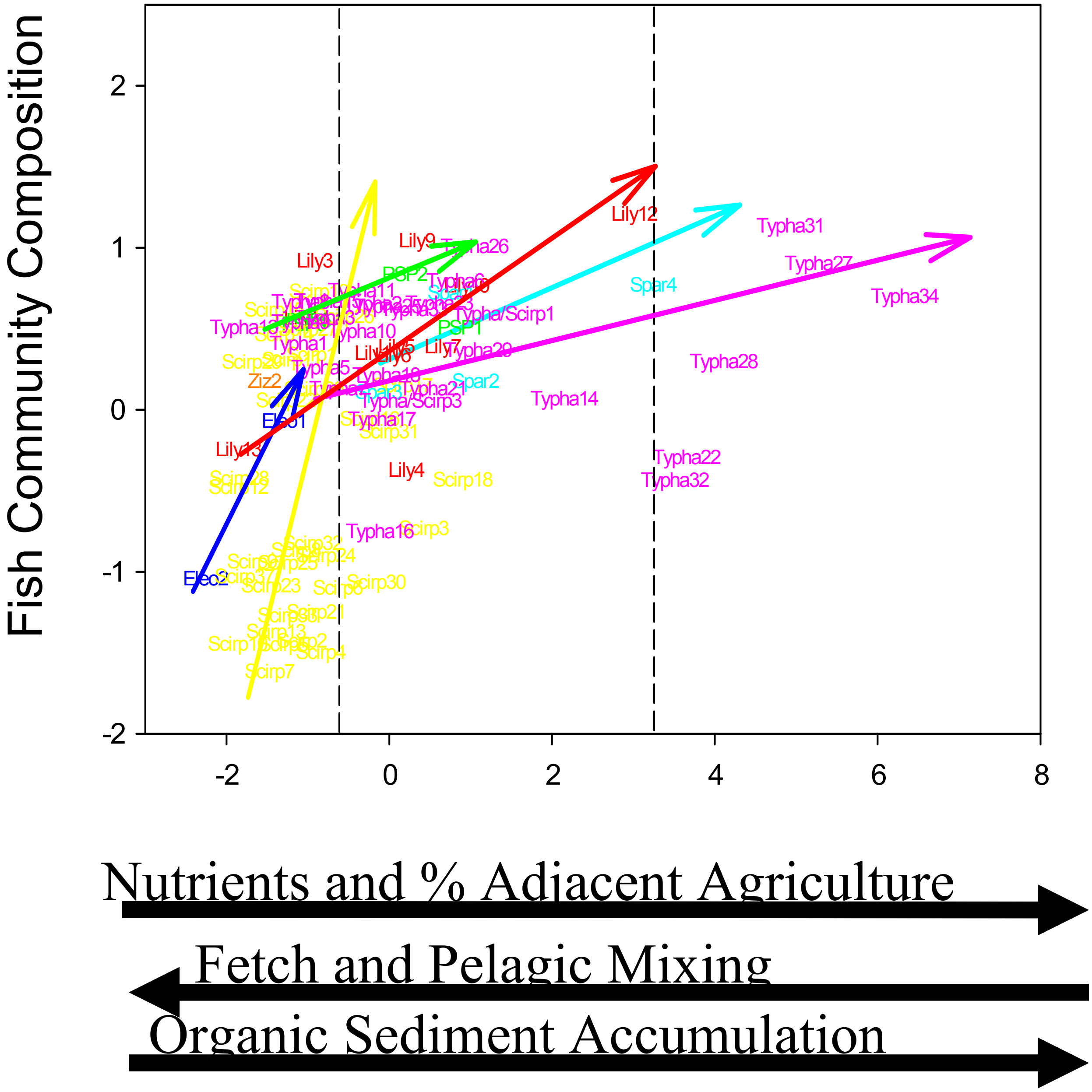


Figure 19. Correlation of fish community composition and abiotic data.

- Banded Killifish
- Pugnose Shiner
- Redear Sunfish
- Smallmouth Bass
- White Sucker
- Yellow Perch

- Brook Silverside
- Brown Bullhead
- Fathead Minnow
- Golden Shiner
- Green Sunfish
- Spotfin Shiner

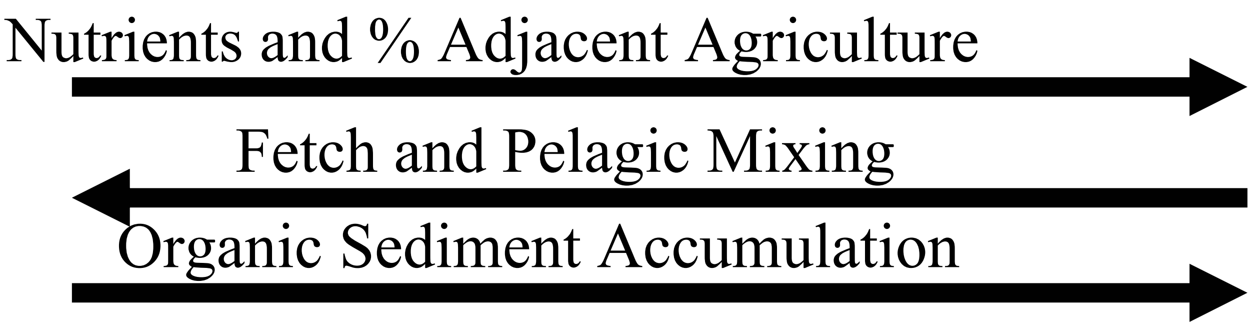


Figure 20. General trend in fish community structure.

Appendix A - Manuscript Submitted for Publication (Accepted after revision, expected publication date is 2004) to *Aquatic Ecosystem Health and Management*

VALIDATION AND PERFORMANCE OF AN INVERTEBRATE INDEX OF BIOTIC INTEGRITY FOR LAKES HURON AND MICHIGAN FRINGING WETLANDS DURING A PERIOD OF LAKE LEVEL DECLINE

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Abstract

Development of indicators of "ecosystem health" for the Great Lakes was identified as a major need at the State-of-the-Lakes Ecosystem Conference in 1998, 2000, and 2002. Our goal was to develop an invertebrate-based index of biotic integrity (IBI) that was robust to water level fluctuations and applied to broad classes of lacustrine wetlands across wave-exposure gradients. Our objectives were to evaluate the performance and test the robustness of our preliminary IBI (e.g., Burton et al. 1999) at a range of water levels, eliminate any problems with the IBI, remove the preliminary status, test the IBI on similar wetlands of Lake Michigan, and establish stressor:ecological-response relationships. Twenty-two sites, both open- and protected-fringing lacustrine marshes of Lake Huron and Michigan were selected for study. Correspondence analysis and Mann-Whitney U tests were used to test the robustness of existing metrics and search for additional metrics. Wilcoxon Signed Rank tests were used to determine if metrics were responding to inter-annual water level fluctuation. Principal components analysis and Pearson correlations were used to establish stressor : ecological response relationships. Analyses confirmed the utility of most of the metrics suggested in our preliminary IBI, but we recommended several improvements. With improvements, the IBI was able to place all sites in comparable order that we placed them *a priori* based on adjacent landuse/landcover, limnological parameters and observed disturbances. The improved IBI worked very well from 1998 through 2001 despite the substantial decreases in lake level over this time-period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the IBI could also be used for fringing wetlands of northern Lake Michigan. We are confident that our IBI is ready for implementation as a tool for agencies to use in assessing wetland condition for Lakes Huron and Michigan fringing wetlands.

Introduction

Wetlands of the Great Lakes are subject to multiple anthropogenic disturbances. These disturbances are superimposed on systems that experience a wide variety of natural stress resulting primarily from a highly variable hydrologic regime (Burton et al. 1999, 2002; Keough et al. 1999). These wetlands are classified into geomorphological classes, reflecting their location in the landscape and exposure to waves, storm surges and lake level changes (Albert and Minc 2001). Fringing wetlands form along bays and coves and leeward of islands or peninsulas. The location of the shoreline, with respect to long-shore current and wind fetch, determines the type of wetland found along the shoreline (Burton et al. 2002). The greater the effective fetch (e.g., Burton et al. In Press), the more the wetland is exposed to waves and storm surges until a threshold is reached where wetlands no longer persist. The separation of variation due to anthropogenic disturbance from variation due to natural stressors related to water level changes over long and short term periods is central to predicting community composition and in turn developing indices of biotic integrity (IBI) for these systems.

Development of indicators of "ecosystem health" for the Great Lakes was recognized as a major need at the State-of-the-Lakes Ecosystem Conference (SOLEC) in 1998 in Buffalo, New York and progress in developing indicators was the emphasis of the SOLEC Conference in 2000 in Hamilton, Ontario and again in 2002 in Cleveland, Ohio. Among the indicators listed by the task force at SOLEC 98 were indices of biotic integrity (IBIs) for coastal wetlands based on fish, plants and macroinvertebrates. These were also emphasized in the 2000 and 2002 conferences, but minimal progress in developing such indicators was reported at those conferences.

Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using fish, macrophytes, and microinvertebrates. While they found attributes that showed promise, they concluded that natural water level changes were likely to alter communities and invalidate metrics. In an earlier paper, we developed a preliminary macroinvertebrate-based bioassessment procedure for coastal wetlands of Lake Huron (Burton et al. 1999). This system could be used across wide ranges of lake levels, since it included invertebrate metrics for up to four deep and shallow water plant zones with a scoring system based on the number of inundated zones present.

While Great-Lakes wide studies of aquatic macrophytes indicate that similar geomorphic wetland types support distinctively different plant assemblages in geographically distinct ecoregions (Minc 1997, Minc and Albert 1998, Chow-Fraser and Albert 1998, Albert and Minc 2001), several plant zones are common to many of these systems. In our preliminary invertebrate-based IBI, we (Burton et al. 1999) collected invertebrates from four plant zones characteristically inundated in fringing lacustrine wetlands of Lake Huron and northern Lake Michigan during high water years, and used invertebrate metrics from each of these zones in the IBI (Burton et al. 1999). By developing metrics for each wetland plant zone across a water level gradient from wet meadow to deep-water emergents, we assumed that we could compensate for absence of the higher elevation zones (e.g., wet meadow) during low lake level years by placing more emphasis on metrics from zones that remained inundated. As lake levels have fallen sharply since 1998, we have tested this assumption and report the results in this paper.

Our goal was to develop an IBI that is robust to water level fluctuations and applies to broad classes of lacustrine wetlands across natural wave exposure gradients. The broad class of wetlands we chose for the first stage of IBI development was fringing, lacustrine marshes (Burton et al. 1999). Fringing, lacustrine marshes are the most common type of wetlands of Lake Huron and the northern shore of Lake Michigan. They were included in three classes, Northern Great Lakes marshes, Northern rich fens, and Saginaw Bay lakeplain marshes, in the classification of Great Lakes wetlands by Albert and Minc (2001). All of the wetland types included in our broader definition of fringing, lacutrine marshes are characterized by having a species of *Scirpus (*e.g., *S. acutus, S. pungens, or S. validus or combinations of two or more of these species)* as the dominant plants in the two outer emergent zones (Burton et al. 1999) and by having wet meadow zones dominated by a combination of Carex spp. (*C. stricta, C. lasiocarpa*, and/or C. viridula) and Calamagrostis canadensis. We initiated IBI development for this broad wetland class in Lake Huron (Burton et al. 1999) and have begun test it in other lakes and wetland types. However, the data presented in this paper are only from open- and protected-embayment marshes (fringing) of Lake Huron, and northern Lake Michigan.

The objectives of this study were to: 1.) evaluate the performance and test the robustness of our preliminary IBI (e.g., Burton et al. 1999) at reduced water levels when fewer plant zones per site were inundated; 2.)

identify and eliminate any problems and make improvements to the IBI where necessary 3.) remove the preliminary status from the Burton et al. (1999) IBI; 4.) test the applicability of the IBI in similar wetlands of Lake Michigan, and 5). establish stressor : ecological-response relationships that could be used to manage high quality wetlands and restore degraded ones.

Methods and Materials

Study Sites

Both open- and protected-fringing lacustrine marshes of Lake Huron and Michigan were selected for study (Fig. 1a & 1b). Site selection was based primarily on site access, inundation status, and degree of human disturbance to the marshes. Depths rarely exceeded one meter and were as shallow as 10 cm. The plant communities at each site changed along a depth gradient from open water to shore and typically included an outer *Scirpus* zone in deep, wave swept areas of the marsh, an inner *Scirpus* zone in deep areas subject to less wave impact, a transitional zone that sometimes included *Typha angustifolia* as a dominant, and a wet meadow zone. The wet meadow zones extended to upland ecosystems directly or graded into shrub and forested wetlands depending on topography of the site. The disturbance status of each site is summarized in Tables 1 and 2; the general description of each site is listed below.

Saginaw Bay Study Sites

The Wildfowl Bay sites were located on the windward and leeward sides of Maisou and Middle Grounds Islands in Wildfowl Bay, a bay on the eastern shore of Saginaw Bay (Figure 1). The sites were located approximately 1.5 km northeast of the Sumac Island public access, Huron County (T16/17N R9E). While adjacent land use and the Saginaw River undoubtedly impacted all of Saginaw Bay, these impacts were likely diluted in Wildfowl Bay due to its proximity to the outer bay. The water quality of the outer bay is better than the inner bay because of dilution of the high agricultural, urban and industrial runoff into the inner bay with Lake Huron water in the outer bay. The islands are State wildlife management areas with little direct shoreline development, although they are impacted somewhat by development on the nearby mainland. Sparse *Scirpus pungens* Vahl zones (the outer *Scirpus* zone) dominated the outer wave exposed area at the southwest end of the island. Large and distinct *Typha angustifolia* L. complexes extended along a shallow bar south from the southwest end of Maisou Island,

and one of these wave-swept stands was also sampled. In 1997, the protected interior of the island contained an extensive wet meadow dominated by *Carex* spp. and *Calamagrostis canadensis,* this zone was nearly devoid of water during 1998. Stands of *Scirpus* (including *S. pungens, S. validus,* and *S. acutus*)*, and* and *Typha (both T. angustifolia and T. latifolia L.)* were also present on the lee side of the islands.

The Vanderbilt Park site (Figure 1) was located near the park approximately 2 km north of the Michigan Department of Natural Resources (MDNR) public access near Quanicassee Road, Tuscola County (T14N R6E) (Figure 1). The site contained large, dense stands of *Scirpus pungens* that were intermixed with several other species near shore. *S. pungens* was the primary species found in the outer marsh. The emergent zone extended about 500 m into Saginaw Bay from the sandy ridge that separated the fringing wetland from swale wetlands located between outer and inner sandy ridges. A large *Typha angustifolia* stand was located in the middle of the *Scirpus* complex just north of the sampled area. There was no wet meadow area at this site. Vanderbilt Park may be among the most impacted sites in Saginaw Bay due to its proximity to dwellings and inputs from the adjacent Quanicassee River and large drainage ditches draining intensely farmed fields of potatoes, beans, and sugar beets.

The Cotter Road site located on Saginaw Bay, Bay County, (T14N R6E) (Figure 1) closely resembled the Vanderbilt Park site with respect to number of dwellings/development and inputs from agricultural drains and the Saginaw River. A narrow wet meadow containing *Carex stricta and Calamagrostis calamagrostis*, monodominant and mixed stands of *Scirpus pungens*, *Pontederia cordata*, *Phragmites australis* (Cav.) Trin. ex Steud., and nearly monodominant stands of *Typha angustifolia* were present in this marsh complex. Extensive *Typha* complexes near the open water protected the Scirpus zone; thus, an outer *Scirpus* was too sparse to be included as a distinct zone.

Almeda Beach is located on the western shore of Saginaw Bay approximately 20 km north of Saginaw River (Figure 1). Samples were collected south of Almeda Beach at the end of Coggins Road. An agricultural drainage ditch emptied into the bay approximately 100 m from the sampled area. The site had a substantial Inner *Scirpus* zone with no distinct Outer *Scirpus* zone. The outer portion of the marsh was dominated by *Typha angustifolia* and *Eleocharis* spp. The area upland of the Inner *Scirpus* zone was a mixed vegetation zone containing *Juncus* spp., *Scirpus* spp., *Salix* spp., and *Populus* spp. seedlings. Only a few dwellings were located within 1 km of this site, but there were no other obvious, contiguous sources of disturbance.

Wigwam Bay is located on the northwestern shore of Saginaw Bay approximately 40 km north of Saginaw River (Figure 1). Samples were collected from areas near the mouth of the Pine River. A very narrow band of Outer *Scirpus* was present, but the majority of the marsh consisted of Inner *Scirpus*. A transition zone from *Scirpus* spp. to *Juncus* spp. occurred very near shore. A few residences were located within 1 km of the site, but there were no other obvious, nearby sources of disturbance.

Northern Lake Huron Sites

The northern Lake Huron sites were located in the Les Cheneaux Island complex and along St. Martin's Bay, a large bay located west of the Les Cheneaux Islands at the eastern end of Michigan's upper peninsula (Figure 1). Typical plant zonation at these sites included wet meadow vegetation dominated by *Carex stricta* and/or *C. lasiocarpa* and separated from the deeper *Scirpus*-dominated emergent marsh by *Typha angustifolia*-dominated transitional communities. The inner *Scirpus* emergent zones were dominated by *Scirpus* acutus, *Pontederia cordata*, and *Eleocharis* spp., interspersed with floating-leaved plants such as *Nuphar* spp. and *Potomageton* spp. and patches of often-dense submersed plants. The outer, deeper, nearly monodominant regions of the emergent marshes were characterized by fewer stems of wave-swept *Scirpus acutus* and a few sparse patches of submersed vegetation with sandier bottoms compared to inner regions. Exceptions to this general pattern are noted below. The obvious impacts to each Lake Huron site are listed in Table 1a, while Table 1b lists the sites in order of anthropogenic disturbance.

The Mackinac Bay site (Figure 1) is an island-protected bay with a low-gradient stream running through it. A paved two-lane highway separates the upper end of the wet meadow from the rest of the marsh. Several residences with private docks and boathouses line the shore southeast of the site. Boat traffic in the marsh is limited, even though the main dredged channel through the Les Cheneaux Islands is located near the outer edge of the marsh.

The Golf Course site is located east of Mackinac Bay along the heavily used boat channel adjacent to a golf course (Figure 1). The site consists of a narrow band of *Scirpus* at the base of a fairly steep slope from the golf course.

The Mismer Bay marsh (Figure 1) is similar to the Mackinac Bay marsh in that small streams run through it. It is more wave-swept than Mackinac Bay, having only partial protection from open-lake waves resulting in a sandier bottom and no *Typha* zone. Although, the wet meadow is well established at this site. The sampled area is on the east side of the marsh east of the smaller of the two stream channels that traverse the marsh. Two residences and a dirt road are located along the eastern border of the marsh. Boat traffic is limited since the primary channel through the Les Cheneaux Islands is well away from the outer edge of the marsh.

Duck Bay is well protected on the lee side of Marquette Island, the largest of the Les Cheneaux Islands (Figure 1). The marsh area sampled supported a sparse submersed plant community interspersed with a low density, low diversity outer and inner *Scirpus* zones, a well-developed *Typha zone,* and a narrow wet meadow zone adjacent to upland forest. There were no residences and only one private dock on the shore. Boat traffic was low, since the main boat channel around the island does not enter the bay.

Two additional bays on Marquette Island were sampled. Peck Bay and its wetland are similar to the Duck Bay site but are located further south toward the open lake (Figure 1). Human impacts are low with only one residence located along the channel that leads into the wetland. Voight Bay differs in that it is on the south, windward side of the island with direct exposure to open-lake waves from Lake Huron (Figure 1). The sampled area is partially protected by low sandbars. The emergent marsh supports sparser emergent vegetation and has a sandier bottom than most sites. There are no human developments near the marsh. Boat traffic in both bays is limited, since neither are near main boat channels.

Cedarville Bay (Figure 1) is generally considered to be the most human-impacted area in the Les Cheneaux Islands (Kashian and Burton 2000). The middle of the bay is occupied by a very large island with large numbers of residences, summer homes and docks on it. The bay actually resembles a U-shaped channel, which receives very high boat traffic. The town of Cedarville, its marina, and public boat launch occupy the northwestern shore of the bay, and many private residences, businesses, and docks (private and commercial) line the mainland near the marsh. The deeper emergent marsh surrounds the stream mouth, public launch, and several docks, but is cut off from its historic wet meadow by a paved road and a lumber yard built on fill. The only remaining aquatic connection between the wet meadow and marsh is the stream, which runs through a culvert under the road and carries discharges from an upstream sewage treatment lagoon. The lagoon is usually discharged twice each year, but discharge can be more frequent in wet years. The emergent marsh in this area supports unusually dense growths of submersed plants and filamentous algae including several species such as *Myriophyllum spicatum* and *Elodea canadensis* characteristic of nutrient enriched conditions.

A paved highway separates Prentiss Bay marsh (Figure 1) from most of its wet meadow. A narrow *Typha* zone extends along the bay side of the highway. A single culvert connects the wet meadow to the deep-water zones. Anglers often put boats in near the culvert and fish at the edge of the deep marsh. The dense emergent zone is narrow, giving way to a deeper, sparse, patchy emergent zone fairly near the road. The bottom tends to have more clay than is characteristic of most marshes in this area.

The St. Martin's Bay (Figure 1) marsh was located between two parallel sandbars on an unprotected shoreline in this large bay. The inner sandbar supported upland vegetation along the top of the ridge. A wet meadow was located between the inner sandbar and the adjacent forest. A dense inner *Scirpus* zone was located between the inner and outer sand bars. The bottom of this interdunal swale was relatively sandy, and submersed plants were sparse because of exposure to waves via an opening through the outer sand bar. There was no direct wet meadow/emergent interface. A *Typha* zone occurred at the inner edge of the outer sandbar. The outer sandbar also supported a narrow upland zone at the top of the ridge. At the outer edge of the outer sandbar, a very narrow and sparse outer *Scirpus acutus* patch was present.

The Pine River site was located on the east side of St. Martins Bay (Figure 1). Only a narrow band of *Scirpus* approximately 100 m wide was present at this site. While a narrow wet meadow zone was located upland from the *Scirpus* zone, the wet meadow was never inundated during this study. The Pine River entered the bay approximately 1 km west of the site. The river drains an agricultural region with red clay soils and is always quite turbid from eroded clay particles. The turbidity plume is usually pushed by prevailing winds along the shore into and past the sampled marsh. High turbidity levels at the site reflect this.

The Port Dolomite site (Figure 1) is located on Bush Bay on the east side of the port facilities for a dolomite mining operation. McKay Bay is located on the west side of the point (Figure 1) where Port Dolomite is located. Both sites contain inner and outer *Scirpus* with little or no wet meadow zone. The Port Dolomite (Bush Bay) site has seeps that are likely from adjacent dolomite mining settling ponds. *Cladophora* can often be seen growing in or near the seeps. A small stream draining the settling ponds enters the wetland via a culvert under the road. The McKay Bay site does not have the obvious seeps or streams entering the marsh. Several dwellings are adjacent to the marsh, and boat traffic is common.

Northern Lake Michigan Sites.

Fringing wetlands similar to the ones sampled in Lake Huron are common along the northern shore of Lake Michigan. We sampled a subset of these sites in 2001 to test whether the Lake Huron IBI would work for these wetlands (Figure 1b). The disturbance status for these wetlands is summarized in Table 2a. They are listed *a priori* in order of anthropogenic disturbance in Table 2b. General descriptions are given below.

The Point St. Ignace (Mackinac Bridge) marsh was located immediately northwest of the Mackinac Bridge in Lake Michigan near the mouth of the Straits of Mackinac (Figure 1b). The bridge is heavily used by cars and trucks while the Straits experience a large volume of large freighter, commercial and recreational boat traffic. There was a rural road adjacent to the marsh with less than five dwellings located across the road from the marsh. A newly constructed building and tollbooths were located near the east side of the wetland. A narrow wet meadow zone bordered the road. A dense inner *Scirpus* zone extended approximately 200 m from shore and was bounded by a 50 m wide sparse outer *Scirpus* zone.

The Nahma and Ogontz marshes were located on Big Bay de Noc (Figure 1b). There were less than five dwellings adjacent to the Ogontz Bay marsh, and most of the adjacent riparian zone was forested. A golf course was near and several houses/summer cottages were adjacent to the Nahma marsh. The Ogontz site was adjacent to a public boat launch that could only be reached via several km of rural roads. Both sites contained relatively narrow (approximately 100 m) inner and outer *Scirpus* zones with almost no wet meadow zone.

The Escanaba/Highway 2 site was located in Little Bay de Noc adjacent to an urban area along U.S. Highway 2 approximately 2 km north of the Escanaba River. A large paper mill located just upstream of the dam near the mouth of the Escanaba River may influence this site via the river plume along the shore.

Inner and outer *Scirpus* zones were sampled. There was no wet meadow zone and only a few patches of *Typha* in this wetland.

The Ludington Park wetland was located approximately 10 km south of the Escanaba Highway 2 site in Ludington Park in downtown Escanaba. This park is located near the Escanaba waterfront in the midst of industrial, residential and commercial areas of the city. The park includes a large marina on an island. The sampled area consisted of patches of inner *Scirpus* located near a beach parking lot just west of the island near a channel that was connected to the marina via a culvert under a road. No other plant zones were inundated at this site.

Chemical and Physical Measurements

Basic chemical/physical parameters were sampled from each plant zone each time biological samples were taken. Analytical procedures followed procedures recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1998). These measurements included soluble reactive phosphorus (SRP), nitrate-N, nitrite-N, ammonium-N, turbidity, alkalinity, temperature, DO, chlorophyll *a*, oxidation-reduction (redox) potential, and specific conductance. Quality assurance/quality control procedures followed protocols recommended by U.S. EPA.

Determination of Anthropogenic Disturbance

Wetlands that experienced a wide range of anthropogenic stressors were chosen for study. The extent of disturbance was determined using surrounding land use data in conjunction with limnological data and site-specific observations such as evidence of dredging, point-source pollution, and discharge into the wetland from drainage ditches or streams. If streams entered the wetland, land use from the stream catchment was considered when determining anthropogenic disturbance.

Land use data were obtained from existing digitized maps, topographic maps, and personal observations; the primary data source was the Michigan Resource Information

System (MIRIS) Land Cover Maps based on 1978 aerial photography. These data included: percent urban and agricultural area, number of adjacent dwellings, percent impervious surface, total length of adjacent roads, and the number of connecting drainage ditches. The MIRIS data were the most recent data available to us. Visual observations of these data and current land use suggested that land use had not changed substantially for most of the wetlands included in our study.

Macroinvertebrates sampling

Macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from late July through August. July-August is when emergent plant communities achieve maximum annual biomass and larger and easier to identify, late instars of most aquatic insects are present in the marsh.

Dip net sampling consisted of sweeps at the surface, mid depth and just above the sediments. Nets were emptied into white pans and 150 invertebrates were collected by picking all specimens from one area of the pan before moving on to the next area. Special efforts were made to ensure that representative numbers of smaller organisms were picked to minimize any bias towards picking larger, more mobile individuals. Invertebrates were picked from plant detritus for a few minutes after 150 specimens were collected to ensure that sessile species were included. Beginning in 1999, we modified this procedure to limit the amount of picking-time required at each site and to semi-quantify our samples. Individual replicates were picked for one-half-person-hour, organisms were tallied, and picking continued to the next multiple of 50. Therefore, each replicate sample contained either 50, 100, or 150 organisms. This procedure made it easier to compare samples on a catch per unit effort basis. Three replicate dip net samples were collected in each plant zone to obtain a measure of variance associated with sampling.

Specimens were sorted to lowest operational taxonomic unit, usually genus or species for most insects, crustaceans and gastropods. Difficult to identify insect taxa such as Chironomidae were identified to tribe or family, and some other invertebrate groups including Oligochaetes, Hirudinea, Turbellaria, Hydracarina, and Sphaeridae were identified to family level or, in a few cases, to order. Taxonomic keys such as Thorp and Covich (1991), Merritt and Cummins (1996), and mainstream literature were used for identification. Accuracy was confirmed by expert taxonomists whenever possible.

Identify and combine metrics into an IBI; an analysis to identify new metrics and confirm metrics identified previously.

Burton et al. (1999) developed metrics for their published IBI by initially analyzing data graphically by constructing box plots including the 10th, 25th, 50th, 75th, and 90th percentiles as recommended by Barbour et al. (1996). When attributes showed an empirical and predictable change across a gradient of human disturbances, Mann-Whitney U tests were performed to test for significant differences between impacted and reference sites.

In Burton et al. (1999), we used 1997 data to develop IBI metrics for Lake Huron wetlands. We tested these metrics using 1998 data. We expanded on these analyses in this paper using the 1998 data and newly collected data from 1999 through 2001 to test the performance of the IBI during this period of rapid decline in lake levels. Additional analyses were employed to search for any new metrics that might have been missed in the initial analyses. Instead of the graphical approach used previously, we used correspondence analyses (CA) (SAS version 8, SAS Institute Inc., Cary, NC, USA) of invertebrate community composition to determine if sites would ordinate according to predetermined gradients of anthropogenic disturbance. CAs were performed individually on Inner and Outer *Scirpus* zone data. Taxa represented by less than 20 total individuals (from all replicates from all sites combined) per zone in any one year were eliminated from the analysis. This resulted in approximately 40 taxa being used in each analysis. A separate CA was conducted for each plant zone for each year for 1998, 1999, and 2000. The 1999 data were most complete and were used to identify key taxa. These key taxa were then analyzed for each of the three years from 1998 through 2000.When reference sites separated from impacted site, groups of individual taxa containing the most inertia responsible for the separation were deemed potential metrics. Mann-Whitney U tests (SYSTAT version 5.0, Evanston, Illinois) were then used to determine if density of each of these taxa at reference sites were significantly different from its density at impacted sites. This allowed us to confirm the utility of our initial metrics and identify additional ones.

Like Burton et al. (1999), we used medians in place of means as measures of central tendency for measuring assemblages of invertebrates. Invertebrate parameters are highly variable, and medians are more resistant to effects of outliers. Therefore, we used medians to dampen the influence of outliers.

Testing and Validation of IBI

We continued to collect data from a subset of the original sites of Burton et al. (1999), providing us with our best indication of temporal variability. We calculated IBI scores by site (all plant zones present) as well as by individual plant zones (simulating a situation where only one plant zone had been inundated) and compared these scores within and among years. This exercise was used to determine which, if any, individual plant zones were most subject to inter-annual variability and to identify problematic plant zones that could give conflicting results if sampled alone.

Testing Metrics Robustness from Inter-annual Variation

We used Wilcoxon Signed Rank tests (SYSTAT version 5.0, Evanston, Illinois) on individual metrics through time to search for metrics that may have been responding to water level fluctuations. Significance was set at $p < 0.05$. Analyses were only done on two Inner *Scirpus* data sets, since these two data sets were the only ones available that were large and complete enough to permit this type of analysis. The analysis comparing 1998 to 1999 metrics included data from Duck, Mackinac, Prentiss, Mismer, St. Martin's, and Cedarville (n=6). The second analysis was done using data from 1997 through 2000, but only included Duck, Mackinac, and Mismer (n=3), since these were the only wetlands sampled every year over this four-year period.

Test the applicability of the IBI in similar wetlands of Lake Michigan.

We sampled five similar fringing wetland sites in Lake Michigan (Figure 1b). We applied the IBI with improvements to those data to see if the IBI would place the Lake Michigan sites in the correct sequence along a disturbance gradient that had been identified *a priori* with land use data and other observation following the procedures detailed below. This was in attempt to provide evidence that the Lake Huron IBI could be extended to similar fringing wetlands in Lake Michigan. As a reference, we sampled many of our Lake Huron sites during this time-period as well.

Establishing Stressor - Ecological Response Relationships

Principal Components Analysis (PCA) using SAS version 8 (SAS Institute Inc., Cary, NC, USA) was used to establish PCs based on chemical/physical parameters as well as surrounding (1 km buffer) land use / cover data (MIRIS 1978). PCA was performed using SRP, NH_4, NO_3, SO_4, Cl, turbidity, chlorophyll a, alkalinity, dissolved oxygen, REDOX, and specific conductance while additional analyses were done using percent adjacent agriculture, urbanization, shrub-range land, swamps, and the total length of roads within a 1 km buffer. Pearson Correlations (SYSTAT version 5.0, Evanston, Illinois) between individual metrics and PCs were used to establish stressor-ecological response relationships. PCs were then decomposed to explore relative contributions of individual stressors. These analyses were performed on 1999 and 2001 Inner and Outer *Scirpus* data sets because they were the most complete.

Results

Testing and Validation of Preliminary IBI

We calculated IBI scores using the preliminary IBI (Burton et al. 1999). The IBI ranked the majority of wetlands in order of anthropogenic disturbance, with only zero to four site placed out of order in any given year. We evaluated the metrics for each of the four plant zones individually to determine the efficacy of an IBI based on only a single zone. The inner and outer *Scirpus* and wet meadow zone metrics worked well when present. Metrics based on the inner *Scirpus* zone proved to be almost as effective as were metrics based on summing values from all inundated zones present, and would be the single zone to use if only one zone is to be sampled. Metrics based on the *Typha* zone did not work very well. The *Typha* zone was rarely sampled, due to lack of inundation or absence at a site, and IBI metrics for this zone did not consistently rank sites by degree of disturbance. In the preliminary IBI, we proposed four diversity and richness metrics based on combined data from all zones present. These combined zone metrics proved to be ineffective in ranking sites along a disturbance gradient. Based on these results, we recommend dropping the *Typha* zone metrics from the IBI and calculating the four diversity and richness metrics for each zone rather than calculating them using combined data for all zones.

Correspondence Analyses

Correspondence analyses were performed on data from the Inner *Scirpus* zone collected from 1998 through 2000 and for the Outer *Scirpus* zone from 1999 through 2000 (the 1998 outer *Scirpus* data were excluded because data were only collected from two sites). We initially used 1999 data to identify taxa responsible for the most inertia in ordinations of the sites according to ecoregion. The 1999 data set was the most balanced with respect to number of sites sampled from each ecoregion (Saginaw Bay and northern Lake Huron sites are in two different ecoregions). Correspondence analyses ordinated 1999 Inner and Outer *Scirpus* zone site data by ecoregion (northern Lake Huron sites clustered separately from Saginaw Bay sites). We identified and removed taxa responsible for the most inertia separating the sites by ecoregion (Tables 3a and 3b) and ran the correspondence analysis again (Figure 2a). With taxa responsible for ecoregional differences removed (Table 3), the sites ordinated by disturbance (Figure 2b). The taxa showing ecoregional differences in 1999 were also removed from data from other years before running correspondence analyses, and sites for each year ordinated based on degree of disturbance after these taxa had been removed. In 2000, due to low water, we only obtained data from Northern Lake Huron. When the taxa identified as having ecoregional differences in 1999 (Table 3) were removed from the 2000 analysis, ordination based on anthropogenic disturbances was much improved even though no Saginaw Bay sites were included in the data set.

We used the CAs not only to search for additional metrics, but also to determine if any of our previous metrics may have included responses to ecoregion instead of disturbance. In the Inner *Scirpus* zone, few taxa removed due to ecoregional differences were major contributors to metrics. The caddis fly, *Oecetis*, was included in the Ephemeroptera plus Trichoptera taxa richness metric. *Oecetis* was more often found at Saginaw Bay, but was quite rare even in those sites decreasing its influence on the metric. Thus, its removal from the analyses did not have a significant effect on the metric. The Odonate, *Enallagma*, was generally common at all sites, but tended to be at higher densities in Saginaw Bay sites. Conversely, *Libellula* was more common in Northern Lake Huron than it was in Saginaw Bay marshes. Differences in these two taxa may have offset each other in the Odonata taxa richness metric and in Odonata relative abundance metric, since these metrics worked well with or without theses two genera included in the data set. The snail, *Amnicola*, tended to be more common in northern Lake Huron, and occurred in only one site in Saginaw Bay. Three other snails, *Fossaria spp.*, *Pseudosuccinea columella*, and *Physa gyrina* were all more common in Northern Lake Huron than in Saginaw Bay, contributing to separation by ecoregion. However, these taxa also separated sites based on disturbance within each ecoregion. Even though we removed these taxa from the CA so that they would not pull ecoregions apart in the analysis, we still believe these taxa are likely to be valuable metrics for an IBI. Ecoregional differences in individual taxa did affect the Gastropoda or Crustacea plus Mollusca metrics enough to warrant removing either metric from the IBI. *Dreissena* was much more common in Saginaw Bay than in Northern Lake Huron and may have counter balanced differences in some gastropod taxa in the Crustacea plus Mollusca metrics. Decapods were rarely collected, but were more common in Northern Lake Huron than in Saginaw Bay. This may reflect differences in habitat between the two ecoregions rather than differences in anthropogenic disturbance. The Northern Lake Huron sites tended to have more cobble, pebble and boulder sized rocks and more submersed plants than did the Saginaw Bay sites. Decapods were relatively rare in samples from both ecoregions, and differences between the two regions did not affect the Crustacea plus Mollusca metric.

In most cases, a genus or species associated with one ecoregion was replaced by a closely related genus or species in the other, and therefore, had little effect on the diversity and richness metrics or metrics at coarser taxonomic resolution. Three insects taxa were removed from the CAs, the family, Ceratopogonidae, a ceratopogonid genus, *Atrichopogon,* and the genus *Trichocorixa (*Corixidae). *Atrichopogon* was collected only at Saginaw Bay. *Trichocorixa* was only found at two sites in Northern Lake Huron and not at all in Saginaw Bay.

In the Outer *Scirpus* zone, two amphipods, *Crangonyx* and *Gammarus*, were more common in Saginaw Bay than in northern Lake Huron sites. Neither was used in metrics other than richness and diversity in the Outer *Scirpus*. As was the case in the Inner *Scirpus* zone, in the Outer *Scirpus* zone, the gastropod, *Fossaria*, and the Hemipteran, *Trichorixa*, were much more common in Northern Lake Huron. They were not good indicators in either ecoregion. Tubificids were common at sites in both ecoregions, however two sites in Saginaw Bay had an over abundance of Tubificidae, one was a very impacted site, and the other was one of the least impacted in that ecoregion. Two Tricoptera were removed, *Mystacides* and *Nectopsyche*. *Mystacides* was more common in northern Lake Huron, while *Nectopsyche* was more common in Saginaw Bay. The Corixid, *Sigara*, was only found at one site in northern Lake Huron and was not found in Saginaw Bay in 1999.

Correspondence analyses of the data from 1999-2000 identified the same metrics that were proposed in the preliminary IBI based on 1997 and 1998 data (Burton *et al*. 1999), thus providing support for the importance of the preliminary metrics. Two new metrics for Inner *Scirpus* were suggested by the CA results: (1). relative abundance of Isopoda (%) which decreased with disturbance, and (2) relative abundance of Amphipoda (%) which increased with intermediate disturbance.

Calculating IBI Scores with New Metrics and Category Score

Using results from calculation of preliminary IBI scores and the CAs, we dropped *Typha* zone metrics from the IBI, calculated the four richness and diversity metrics by plant zone, and adopted two new metrics for the Inner *Scirpus* zone. When the IBI scores were calculated with these changes included, the

IBI worked nearly perfectly from 1997 through 2001 (Table 4). Even without these changes, however, the preliminary IBI metrics suggested by Burton *et al.* (1999) performed reasonably well.

Use of 1/2 person-hour count

Most often, 150 organisms were collected. Occasionally 50 or 100 organisms were collected from the Outer *Scirpus* zone. While the timed count did not prove useful as a semi-quantitative metric, it did not negatively affect the IBI. We recommend its use, particularly for the Outer *Scirpus* zone where invertebrates are sparser than they are in the Inner *Scirpus* or wet meadow zones making collection of 150 individuals too time consuming for wide spread use.

IBI Response to Water Levels

We used Wilcoxon Signed Rank tests on individual metrics. There were no significant differences at the $p < 0.05$ level in Metrics over time with changing water levels for either the 1998 vs. 1999 ($n = 6$) or 1997 through 2000 ($n = 3$) analyses (Table 5). However, with more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline between 1998 and 1999.

Relating Stressor to Ecological Response

We used Pearson correlation matrices to search for relationships between chemical/physical and land-use/land-cover PCs and our metrics. We ran 302 total correlations and identified 53 significant ones (15 significant correlations would be predicted by chance alone at $p = 0.05$). We did not use a Bonferroni correction because n was low, ranging from 7 to 12. Therefore, these results should be viewed as suggesting hypotheses rather than being conclusive. These analyses suggest several possible relationships (Figure 3). Several examples of suggested relationships are also presented in Figures (4a, 4b, and 4c). Wetlands with high percentages of adjacent land use in agriculture tended to have relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate compared to wetlands with high percentages of land use in forests. If urbanization and roads were adjacent, the wetland tended to have higher chloride, nitrate, and ammonium concentrations and higher specific conductance values. If the adjacent land cover was predominantly swamps, alkalinity and specific conductance tended to be higher while $DO_{(daytime)}$, sulfate, redox $potential_{(daytime)}$, turbidity and soluble reactive phosphorous tended to be lower in the wetland. Adjacent shrub land correlated with low turbidity in the wetland. Adjacent agricultural land use and/or urbanization and roads or wetland chemical conditions that correlated with these adjacent land use/land cover parameters correlated with reduced % Sphaeriidae, % Crustacea + Mollusca, % Gastropoda, Shannon Diversity, Evenness, and % Odonata and increased Simpson Diversity. Adjacent shrub lands or decreased turbidity was also associated with lower % Sphaeriidae, % Crustacea + Mollusca, and % Gastropoda. Adjacent swamps, or the correlated chemical/physical conditions, tended to be correlated with increased Shannon Diversity, Evenness, and % Odonata. Adjacent agricultural land use or wetland chemical conditions that correlated with agriculture reduced Crustacea + Mollusca richness, Odonata richness, and total genera richness. Adjacent swamps or the related chemical/physical parameters correlated with increased Ephemeroptera + Trichoptera richness, decreased total genera richness, and decreased Simpson Diversity. Adjacent agriculture correlated with decreased % Isopoda while adjacent swamps correlated with increased % Isopoda. Finally, as urbanization and roads increased adjacent to wetlands % Amphipoda in the wetland tended to decrease.

Discussion

Performance of the IBI with New Metrics and Category Scores

Calculating the preliminary IBI (Burton et al. 1999) using data collected from 22 sites during 1997 through 2001 and using correspondence analyses to search for disturbance related metrics confirmed the utility of most of the metrics suggested previously (Burton et al. 1999). Several improvements suggested by these calculations include: 1.) adding two new metrics to the Inner *Scirpus* zone, 2.) removing the *Typha* zone from the IBI, and 3.) calculating the four diversity metrics for each individual plant zone. With these improvements, the IBI was able to place all 22 sites in the same order that we placed them in based on adjacent land use / cover, limnological parameters and other observed disturbances. The improved IBI worked very well from 1998 through 2001 despite the rather substantial decreases in lake level over this time period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the Lake Huron IBI could also be used for fringing wetlands of northern Lake Michigan (Table 6).

One of the two new metrics suggested for use in the Inner *Scirpus* zone (relative abundance (%) of Amphipoda) does not increase or decrease with disturbance the way most of the metrics do. Instead, highest values for this metric occur at intermediate levels of disturbance. Conversely, the other metric, relative abundance Isopoda (%), decreased with disturbance. One possible explanation is that Isopoda and Amphipoda compete for resources when disturbance is low with isopods being the superior competitor. As isopod abundance decreases with increases in disturbance, amphipods, which appear to be less sensitive to disturbance, are subject to less competition and increase in abundance at intermediate levels of disturbance. As levels of disturbance continue to increase, the threshold for impacting amphipods is exceeded and amphipod relative abundance also decreases. Specifically, the relative abundance of isopods tended to decrease with increasing adjacent Agriculture and/or where wetland water chemistry included relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate. Amphipods tended to decrease with increasing adjacent urbanization and roads and/or as chloride, nitrate, ammonium, and specific conductance values increased. Amphipods were much more common than isopods where sites experienced an intermediate amount of disturbance regardless of type of disturbance or ecoregion.

Due to low water, *Typha* zones were often not inundated during the period of rapid decline in lake levels from 1998 through 2001. Samples were collected from only two sites in 1998 and 1999, so our ability to test metrics for this zone was limited by sample size. Even so, the *Typha* zone metrics never ordinated the sites according to disturbance, and we recommend dropping the zone from the IBI. A possible reason for the failure of the *Typha* zone metrics to separate sites is that the *Typha* zone tends to occur in very different areas of the wetlands in the two ecoregions included in this study. *Typha* zones in the more pristine northern Lake Huron sites were located in a transitional zone between wet meadow and Inner

Scirpus. This was not the case for the more impacted Saginaw Bay sites. Monodominant stands of *Typha* were found in areas exposed to direct wave action in Saginaw Bay as well as in protected wetlands behind islands or in the middle of *Scirpus pungens* stands. Exposure to waves can play a large role in determining invertebrate community composition regardless of the extent of anthropogenic disturbance (Burton et al. 2002). We did not have enough data from the *Typha* zone to separate variance due to anthropogenic disturbance from that of wave exposure. It may be that *Typha* zone metrics would prove useful if location of the zone in relation to wave action were taken into account as it was in metrics for the two *Scirpus* zones.

We recommend calculating the four richness and diversity metrics by plant zone instead of combining all of the plant zones present (e.g., Burton et al. 1999) to calculate these metrics. Since the number of plant zones inundated varies by wetland and year, a combined calculation means that diversity is being calculated from a variable number of habitats for any given wetland or year. Since wetlands with the most structural diversity would be a function of the number of plant zones included in the calculation, and, since habitat diversity would likely be related to invertebrate diversity, the combined calculation should be dropped. By incorporating the metrics into each individual plant zone and adjusting category scores appropriately, we remove variation due to inequitable number of vegetation zones sampled.

With improvements incorporated (Table 7), we recommend dropping the 'preliminary' status from the initial IBI (e.g., Burton et al. 1999). Our data proved that this system could work well even during periods of rapid lake level decline as long as any of the three plant zones used in the improved IBI was present. The improvements and increased resolution also allowed us to introduce some new status categories. With these changes in place, we are confident that our IBI is ready for implementation as a tool for management and conservation agencies to use in assessing wetland condition for Lake Huron and Lake Michigan fringing, coastal wetlands.

Deviation from Protocol

Our protocol was developed for sampling macroinvertebrates, and field crews were told to only pick macroinvertebrates. However, it was common to have microinvertebrates such as Copepoda and

Cladocera in samples. These microinvertebrates were identified and included in the IBI database. Inclusion of such animals by our sampling crews suggests that this might commonly occur when others use the IBI. To ensure that the IBI was robust to this common error, we used those data in calculations of metrics such as percent Crustacea plus Mollusca and the total richness and diversity metrics. Inclusion of the microinveretbrates had little effect on the IBI.

Use of 1/2 person-hour count

Use of the timed count did not improve the IBI, but it did not have any negative impact on it either. The timed count reduced time in the field. Without it, two or three individuals could spend up to four hours collecting three replicate samples from the Outer *Scirpus* zone alone.

IBI Response to Water Levels

Others have suggested that the IBI approach would not work for coastal wetlands because natural water level fluctuations of the Great Lakes would likely alter communities and invalidate metrics (Wilcox et al. 2002). By sampling only defined and inundated vegetation zones, we removed enough variation associated with water level fluctuation to maintain metric consistency from year to year even though annual average lake levels increased to above average and then fell 1.08 m to near historic lows over the several year period included in our sampling effort. Except for Odonata genera richness, there were no significant differences in metric scores among years even though water levels declined. With more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline. The odonate metric played a crucial role in detecting anthropogenic disturbance within years, and the IBI was robust enough to accommodate among-year variation. Thus, we included this metric in the final IBI.

Relating Stressor to Ecological Response

It is important not only to detect anthropogenic disturbance, but also to identify which disturbance or suite of disturbances is likely to be causing most of the observed changes in IBI metrics. Once specific disturbances are identified, managers can use this information to decide on best management options. Biota usually respond to a suite of correlated ambient conditions. Multivariate analyses were used to combine parameters for more power of detection. Once relationships were established, we decomposed combined parameters to the original parameters. Such relationships are strictly correlative, cannot be used to infer causation, and must be used with caution. It is difficult to determine the impact of adjacent land use or land cover on a given fringing wetland. For example, figure 3 seems to suggest that urban areas contribute more NO_3 and NH_4 to wetlands than do Agricultural areas, since water in wetlands with adjacent urban land use contains more NO_3 and NH_4 than does water in wetlands with adjacent agricultural land use. An alternative explanation would be that increased inorganic N in the urban wetlands might not be processed as efficiently as it is in agricultural wetlands, so no conclusion about quantity of input from the adjacent area is warranted. We simply tended to find relatively higher NO_3 and NH_4 concentrations near urban areas where there was high run-off and lower productivity in the wetland. The conceptual drawing (figure 3) shows the relationships between the metrics and the appropriate land use and/or the chemical/physical parameters that correlate with that land use. It does not necessarily suggest that a given land use/land cover taken alone will create the associated chemical/physical conditions in the wetland. It does, however, provide some insight into what potentially might be causing the degradation. Confirmation of the causative agent would then need to be established using a more experimental approach.

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Table Titles

Table 1a. Northern Lake Huron and Saginaw Bay sites listed with obvious impacts.

Table 1b. Northern Lake Huron and Saginaw Bay ranked in order of disturbance.

Table 2a. Northern Lake Michigan sites listed with obvious impacts.

Table 2b. Northern Lake Michigan sites ranked in order of disturbance.

Table 3. Taxa from the Inner and Outer *Scirpus* zone that contributed to the most inertia responsible for ordinating the sites based on ecoregion in correspondence analyses.

Table 4. IBI placement of Lake Huron sites from 1997 through 2000. Each year includes IBI ranking from least impacted to most impacted with an 'X' placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and which overall category each site was placed into.

Table 5. A summary of p values for each metric in Wilcoxon Signed Ranks Tests using Inner *Scirpus* metrics from 1998 and 1999 (n=6) Corresponding to a 46 cm decrease in water levels over this period. Nearly identical results were obtained using data from 1997 through 2000 (n=3).

Table 6. IBI placement of Lake Huron and Michigan sites from 2001. Each year includes IBI ranking from least impacted to most impacted with an 'X' placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and which overall category each site was placed into.

Table 7. An index of biotic integrity (IBI) for Lakes Huron and Michigan fringing coastal wetlands.

Figure Titles

Figure 1a. Map of Michigan, USA including study sites located in Lake Huron.

Figure 1b. Map of Michigan, USA including study sites located in Northern Lake Michigan.

Figure 2a. Correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron Sites. The solid line represents an ecoregion gradient with Saginaw Bay sites toward the left side of the gradient and Northern Lake Huron sites on the right. The dashed line represents the best disturbance gradient with the most disturbed sites towards the top and the least disturbed sites near the bottom. Circles are drawn around those taxa responsible for the most inertia separating the data based on ecoregion.

Figure 2b. Second run of a correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron sites. Circled taxa from Figure 2a were removed from this analysis. The dashed line represents a disturbance gradient. The ecoregion gradient no longer exists. Circles are drawn around sites with different levels of disturbance.

Figure 3. Conceptual drawing established using chemical/physical principal components, land use principal components, and biotic metrics in a Pearson correlation matrix.

Figure 4a Principal components analysis using 1999 Inner *Scirpus* chemical/physical variables. Circles are drawn around sites with different levels of disturbance.

Figure 4b Principal components analysis of 1999 Inner *Scirpus* sites using land use / land cover variables. Circles are drawn around sites with different levels of disturbance.

Figure 4c Pearson correlation between the relative abundance of isopods and chemical/physical principal component two.

Table 1a Northern Lake Huron Site Descriptions

Site	Major Disturbance
Duck, Peck & Voight Bays	Some dwellings adjacent to the bay (Marquette Island)
Mackinac, Mismer, & Prentiss Bays	Some dwellings, highway across upper wet meadow zone
St. Martin's Bay	Limited sediment from the Pine R.
Pine River	Substantial sediment from Pine R. (St. Martin's Bay)
Golf Course	Adjacent golf course (Mackinac Bay)
Port Dolomite	Dolomite [$(Ca,Mg)CO_3$] mining
Cedarville Bay	Sewage effluent, urban runoff, marine traffic

Saginaw Bay Site Descriptions

Wildfowl Bay	Near intense agriculture and small town of Sebewaing (Island near outer bay)
Wigwam Bay	North Branch of the Pine R. draining agricultural land (40% Forested,outer bay)
Vanderbilt Park	Near Quanicassee River draining intensely farmed region
Almeda	Adjacent to intense agriculture
Cotter Road	Adjacent to intense agriculture; Near Saginaw R.

Table 1b

Sites	Impact
Northern Lake Huron Sites	
Duck Bay	Low Impact
Peck Bay	Low Impact
Voight Bay	Low Impact
Mackinac Bay	Low Impact
Mismer Bay	Low Impact
Prentiss Bay	Low Impact
St. Martin's Bay	Low Impact
Pine River	Intermediate Impact
Golf Course	Intermediate Impact
Port Dolomite	Intermediate Impact
Cedarville Bay	Intermediate Impact
Saginaw Bay Sites	
Wildfowl Bay	Intermediate Impact
Wigwam Bay	Intermediate Impact
Vanderbilt Park	Intense Impact
Almeda	Intense Impact
Cotter Road	Intense Impact

Table 2a

Northern Lake Michigan Site Descriptions

Site	Major Disturbance
Ogontz	Some dwellings adjacent to the site with an adjacent boat launch.
Nahma	A golf course and some dwellings adjacent to the site with an adjacent rural road.
Pt. St. Ignace ‘Bridge’	Adjacent to a major highway and urbanization.
Escanaba	Near urban and industrial area of Escanaba MI.
Ludington Park	Near urban and industrial area of Escanaba MI. with heavy boat traffic.

Table 2b

Northern Lake Michigan Sites

Site	Impact
Ogontz	Low Impact
Nahma	Low Impact
Pt. St. Ignace 'Bridge'	Intermediate Impact
Escanaba	Intermediate Impact
Ludington Park	Intermediate Impact

Table 3

Taxa from the Inner Scirpus zone responsible for ecoregional inertia				Taxa from the Outer Scirpus zone responsible for ecoregional inertia			
Crustacea	Decapoda			Amphipoda	Gammarid	Gammarus	
Mollusca	Bivalvia	Dreissena	polymorpha	Amphipoda	Crangonctidae		Crangonyx
Mollusca	Gastropoda	Lymnaeidae	Fossaria	Gastopoda	Lymnaeidae	Fossaria	
Mollusca	Gastropoda	Lymnaeidae	Pseudosuccinea columella	Tricoptera	Leptoceridae		Mystacides
Mollusca	Gastropoda	Physidae	Physa gyrina	Tricoptera	Leptoceridae		Nectopsyche
Mollusca	Gastropoda	Hydrobiidae	Amnicola	Hemiptera	Corixidae	Sigara	
Diptera	Ceratopogonidae		Atrichopogon	Hemiptera	Corixidae	Trichorixa	
Odonata	Libellulidae	Libellula		Tubificidae			
Odonata	Coenagrionidae		Enallagma				
Hemiptera	Corixidae	Trichocorixa					
Coleoptera	Halipidae	Halipus					
Coleoptera	Gyrinidae	Gyrinus					
Trichoptera	Leptoceridae		Oecetis				

Table 4

Year	Site	WM	OS	IS	Ex. Degraded	Degraded	Mod.Degraded	Mod. Impacted	Mild. Impacted	Reference
1997	Mackinac	x	x	x						x
	Duck	x	x	x					x	
	Mismer	x	x	x					x	
	WildFowl	x	x	x			x			
	Cotter Road	x					x			
	Vanderbilt	x	x	x			x			
1998	Peck			x						x
	Duck			x						x
	Mismer			x					x	
	Mackinac			x					x	
	St. Martins			x					x	
	Prentiss			x					x	
	Voight	x	x	x				x		
	Cedarville			x				x		
	Wildfowl	x	x	x				x		
1999	Duck Bay		x	x						x
	Mismer		x	x					x	
	Mackinac		x	x					x	
	Port Dolomite		x	x					x	
	Prentiss		x	x					x	
	St. Martins		x	x				x		
	Wigwam		x	x				x		
	Golf Course		x	x				x		
	Wildfowl		x					x		
	Vanderbilt		x	x				x		
	Almeda		x	x				x		
	Cedarville			x			x			
2000	Mismer		x	x					x	
	Duck		x	x					x	
	Mackinac		x	x				x		
	Pine River		x					x		
	Cedarville			x				x		

Table 5

Wilcoxon Signed Ranks Tests

Inner *Scirpus* Metrics:1998 vs.1999

(Water Level was 46cm lower in 1999 than in 1998)

Metric (Inner *Scirpus*)	*p*
Odonata Richness	0.083
% Odonata	0.310
Crustacea + Mollusca Richness	0.999
Genera Richness	0.157
% Gastropoda	0.180
% Sphaeriidae	0.317
Ephem + Trichop Richness	0.157
% Isopoda	0.317
Evenness	0.414
Shannon Diversity	0.999
Simpson Index	0.564

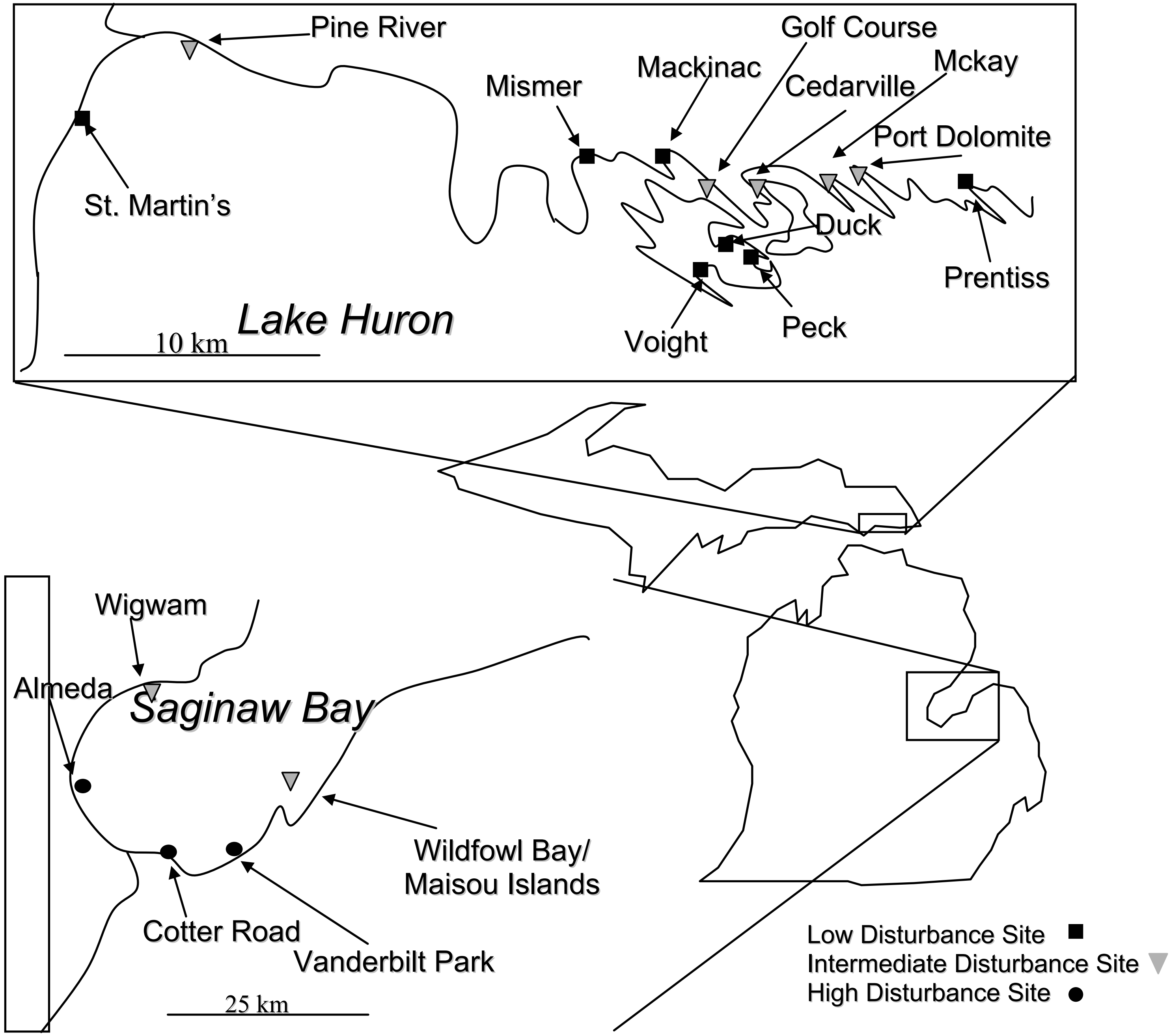
Duck, Mackinac, Prentiss, Mismer, St. Martin's, and Cedarville (n = 6)

Note: Similar results for 97 – 00 using Duck, Mackinac, Mismer (n = 3)

Table 6

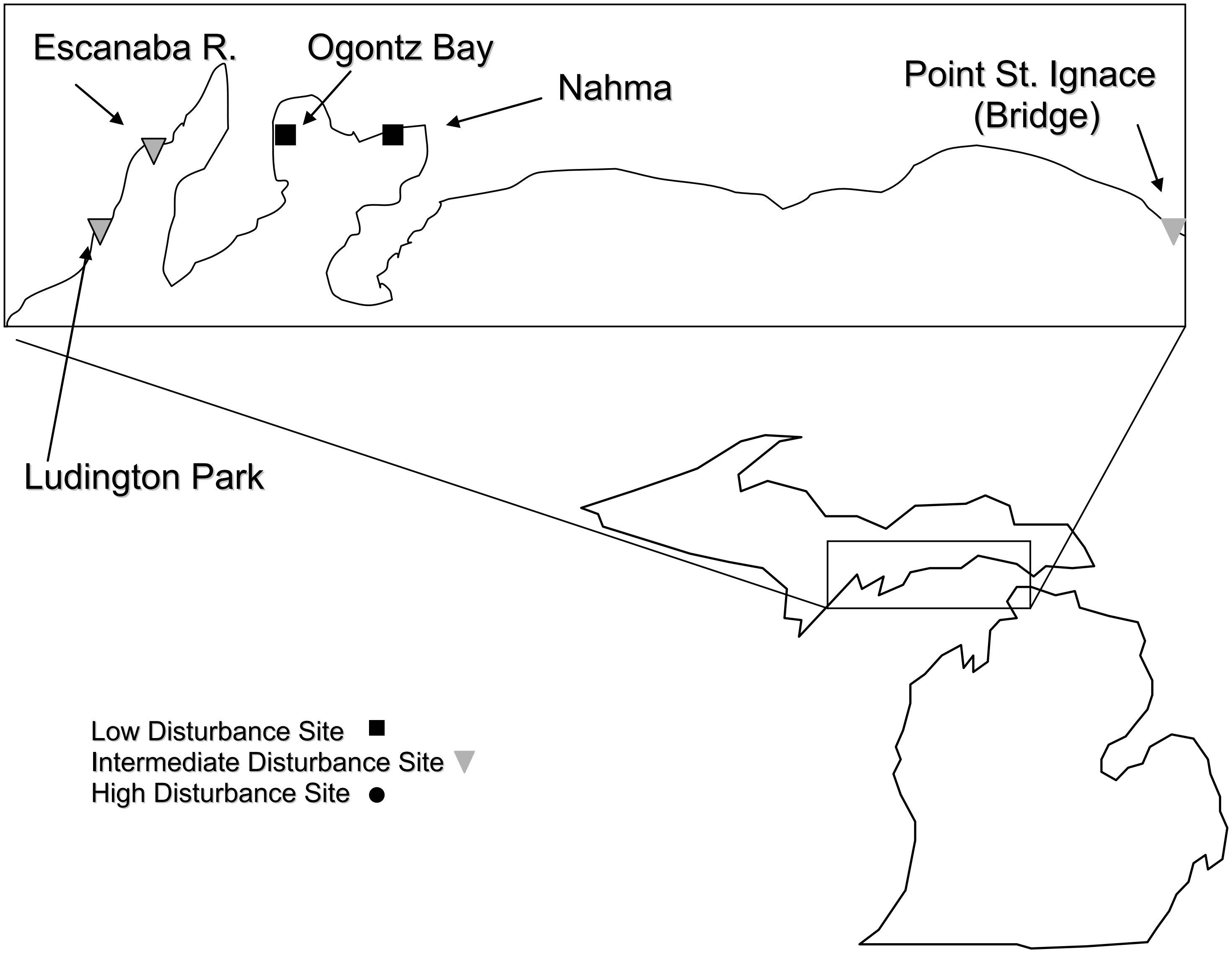
Year	Site	WM	OS	IS	Ex. Degraded	Degraded	Mod.Degraded	Mod. Impacted	Mild. Impacted	Reference
2001	Mackinac		x	x					x	
	Duck		x	x				x		
	Nahma		x	x				x		
	Ogontz		x	x				x		
	Escanaba		x	x				x		
	Bridge		x	x				x		
	Cedarville			x				x		
	Port Dolomite			x				x		
	McKay			x			x			
	Pine River		x				x			
	Ludington Park		x				x			

Figure 1a



Pine River
Golf Course
Mackinac
Mckay
Mismer
Cedarville
Port Dolomite
St. Martin's
Duck
Prentiss
Lake Huron
10 km
Voight
Peck
Wigwam
Almeda
Saginaw Bay
Wildfowl Bay/
Maisou Islands
Cotter Road
Vanderbilt Park
25 km
Low Disturbance Site
Intermediate Disturbance Site
High Disturbance Site

Figure 1b



Escanaba R.
Ogontz Bay
Nahma
Point St. Ignace
(Bridge)
Ludington Park
Low Disturbance Site
Intermediate Disturbance Site
High Disturbance Site

Figure 2a
Correspondence Analysis Using 1999 Taxa for Inner *Scirpus*

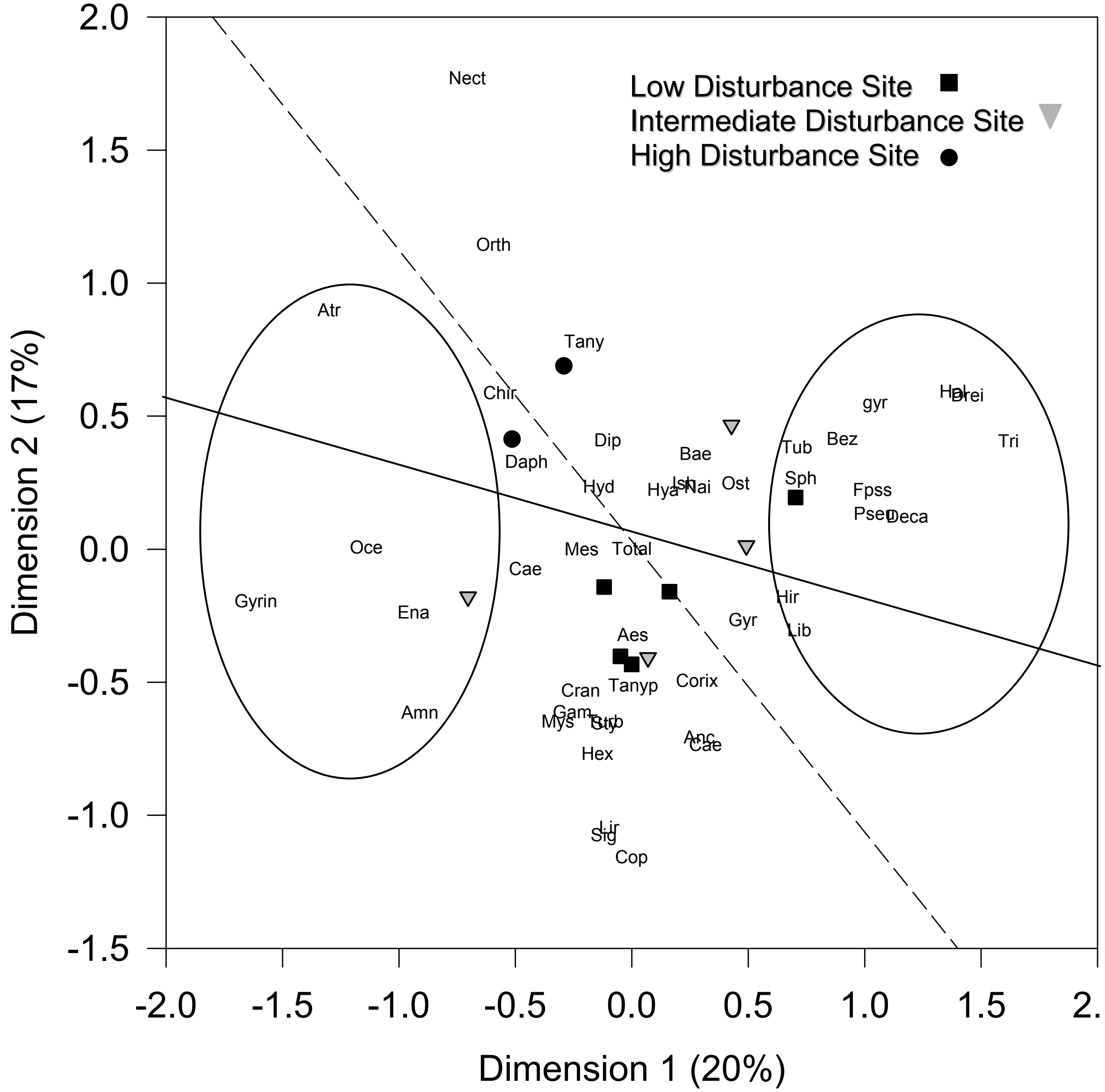


Figure 2b

Correspondence Analysis Using 1999 Taxa
Inner *Scirpus* (2nd Run)

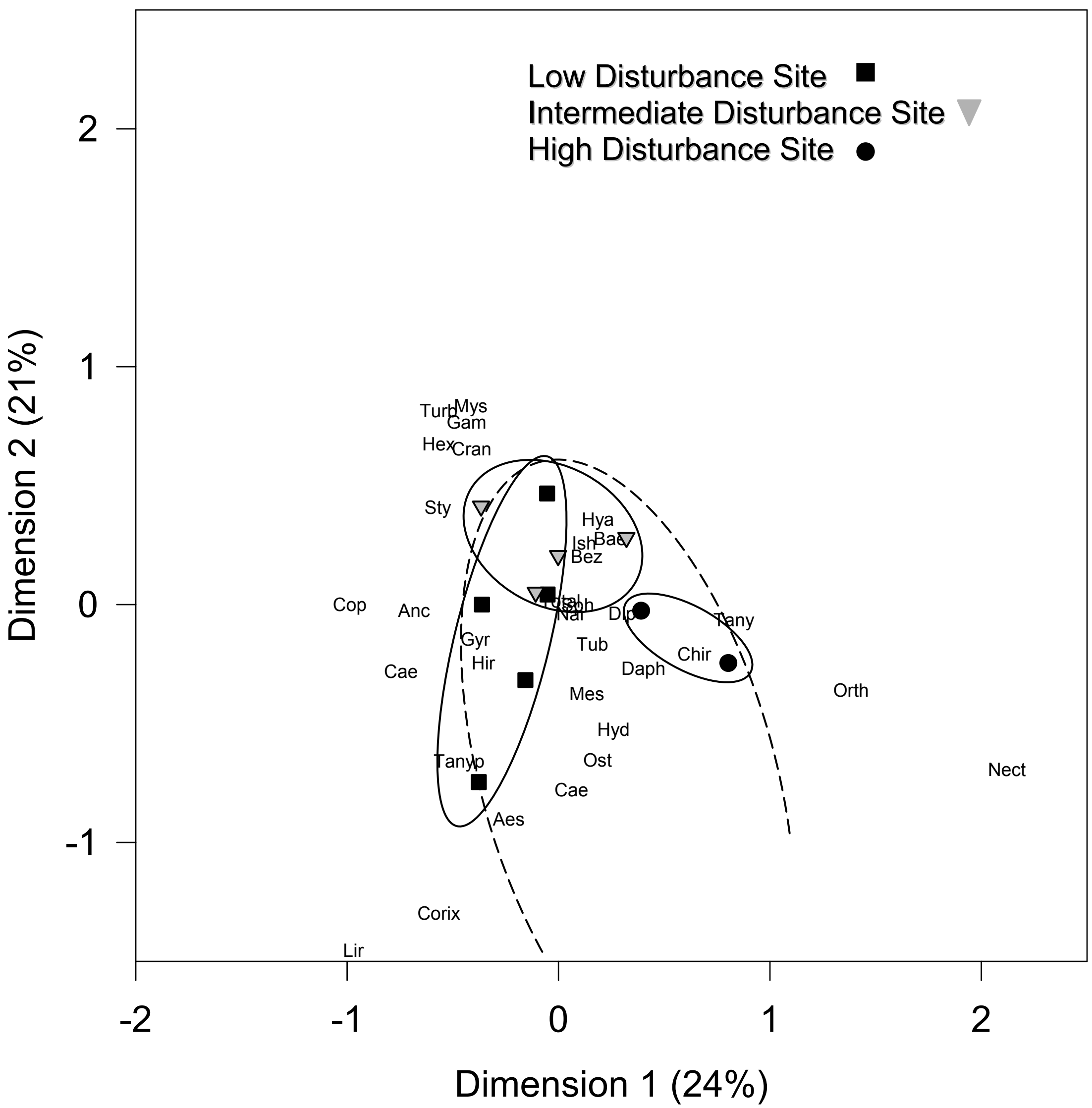
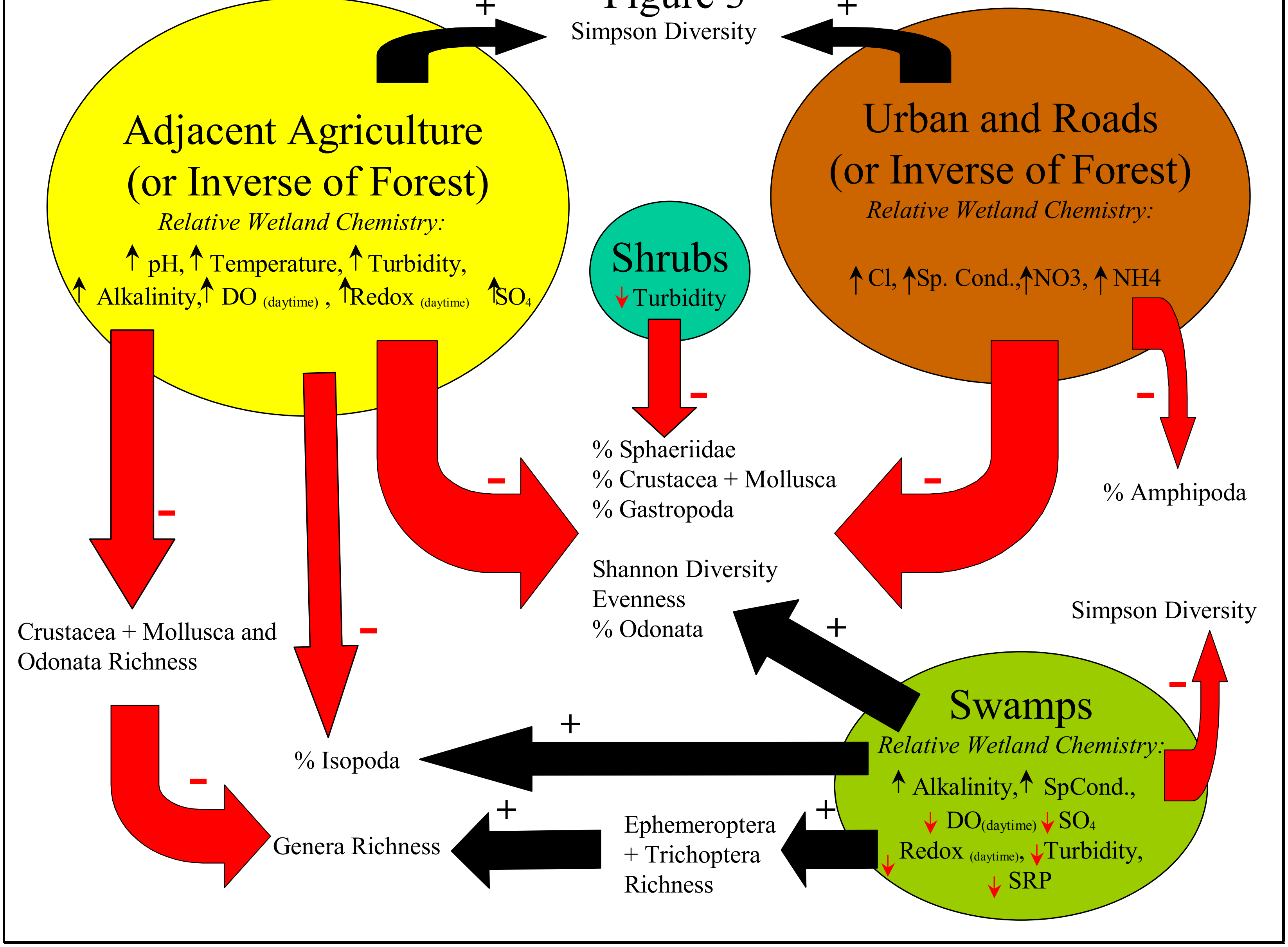


Figure 3



Simpson Diversity
+
+
Adjacent Agriculture
(or Inverse of Forest)
Relative Wetland Chemistry:
↑ pH, ↑ Temperature, ↑ Turbidity,
↑ Alkalinity, ↑ DO (daytime) , ↑Redox (daytime) ↑SO4
Shrubs
↓Turbidity
Urban and Roads
(or Inverse of Forest)
Relative Wetland Chemistry:
↑Cl, ↑Sp. Cond., ↑NO3, ↑NH4
% Sphaeriidae
% Crustacea + Mollusca
% Gastropoda
% Amphipoda
Shannon Diversity
Evenness
% Odonata
Simpson Diversity
Crustacea + Mollusca and
Odonata Richness
Swamps
Relative Wetland Chemistry:
↑ Alkalinity, ↑ SpCond.,
↓ DO(daytime) ↓ SO4
↓ Redox (daytime), ↓Turbidity,
↓ SRP
% Isopoda
Genera Richness
Ephemeroptera
+ Trichoptera
Richness

Figure 4a

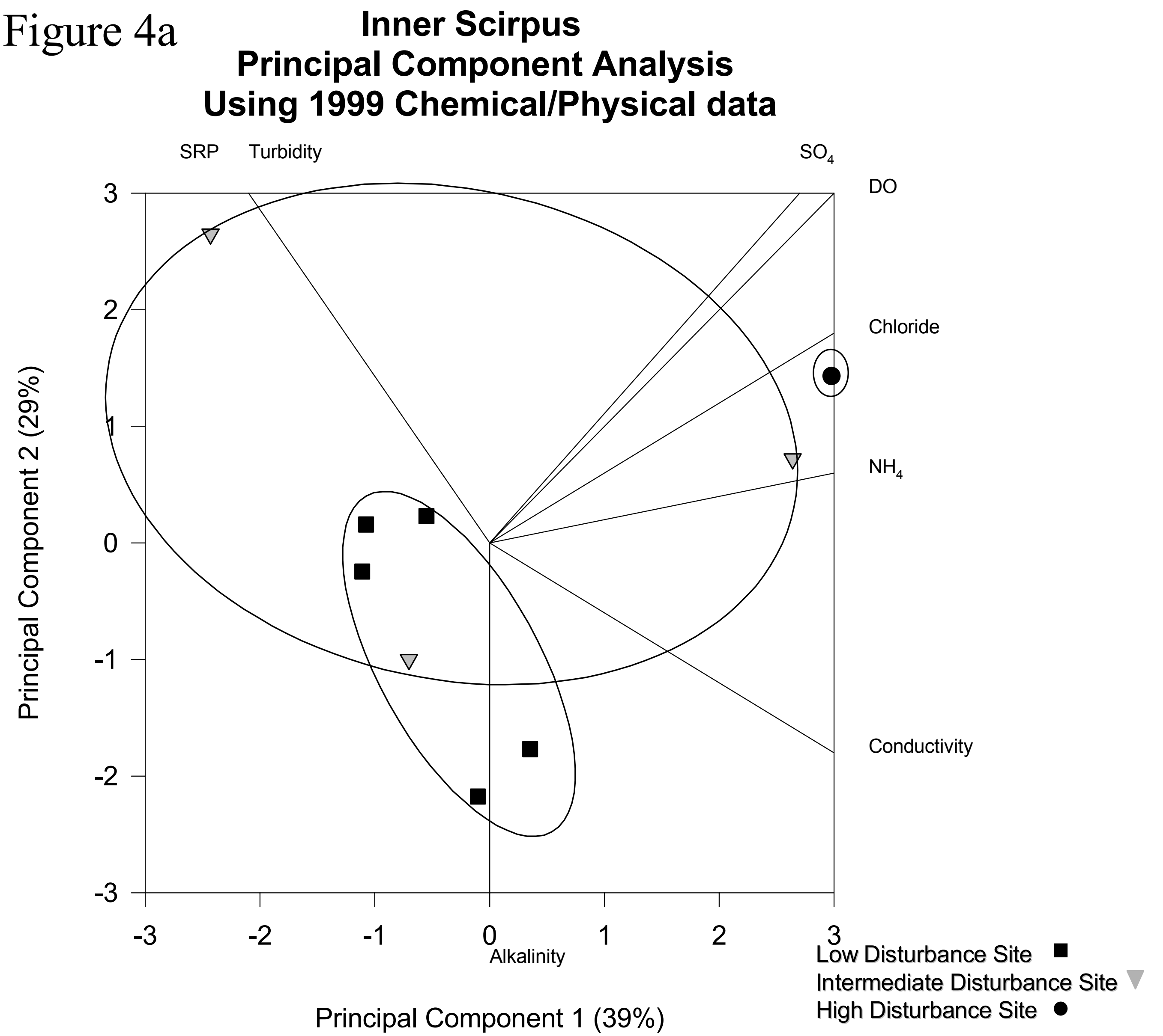

Inner Scirpus
Principal Component Analysis
Using 1999 Chemical/Physical data
SRP
Turbidity
SO4
DO
Chloride
NH4
Conductivity
Alkalinity
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
Principal Component 2 (29%)
Principal Component 1 (39%)
Low Disturbance Site
Intermediate Disturbance Site
High Disturbance Site

Figure 4b

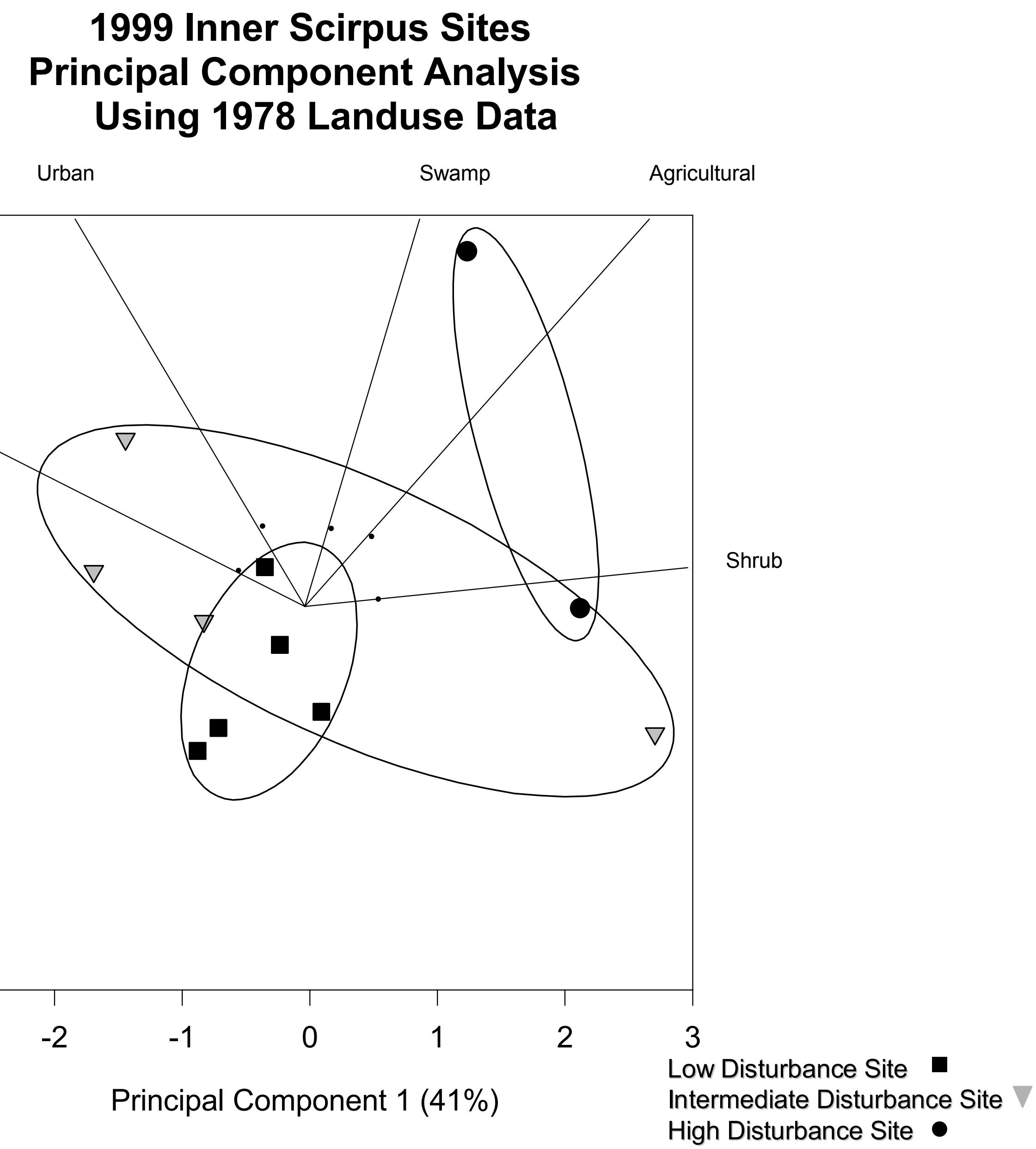
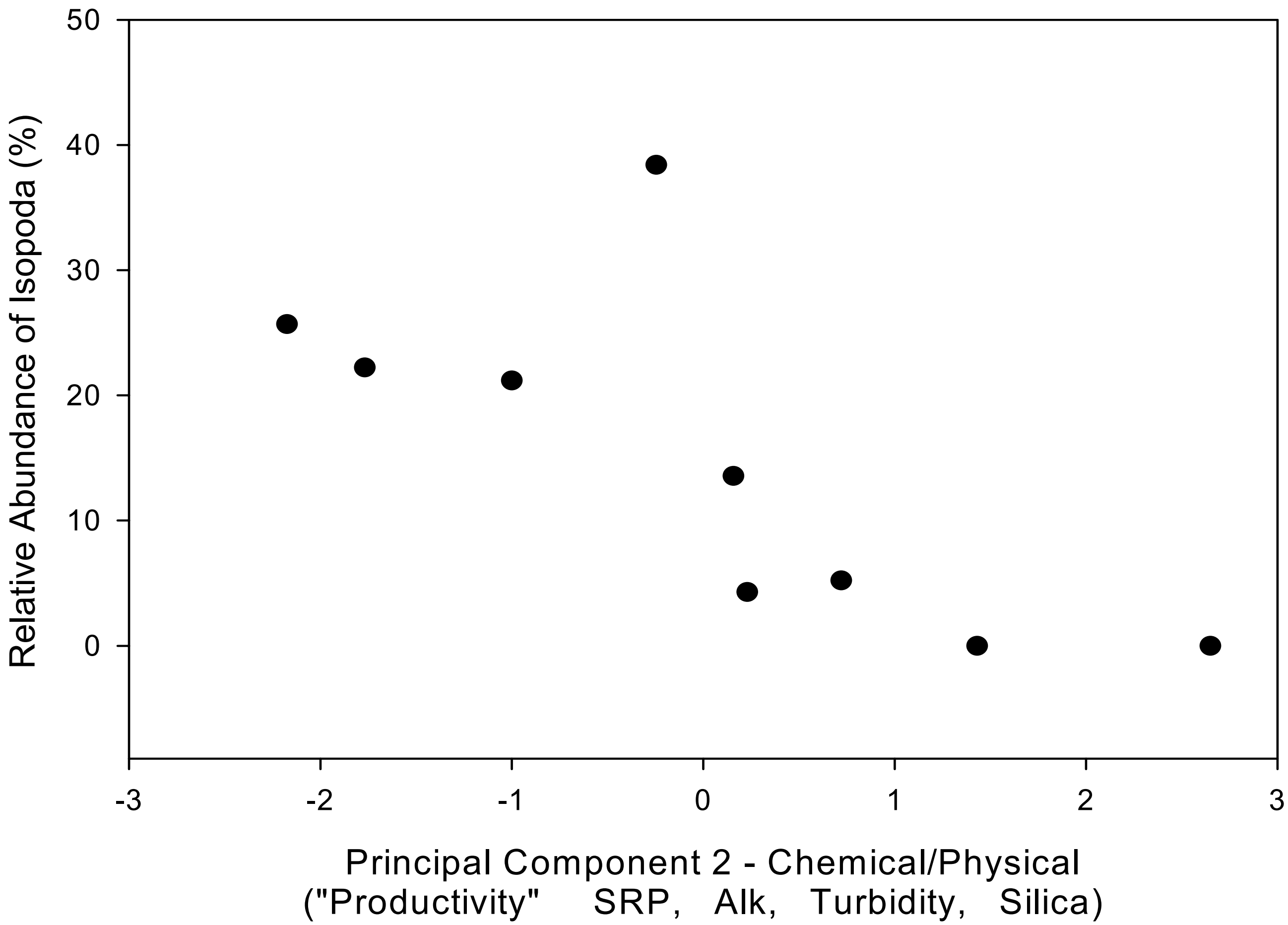

1999 Inner Scirpus Sites
Principal Component Analysis
Using 1978 Landuse Data
Urban
Swamp
Agricultural
Roads
Shrub
3
2
1
0
-1
-2
-3
Principal Component 2 (27%)
-3
-2
-1
0
1
2
3
Principal Component 1 (41%)
Low Disturbance Site
Intermediate Disturbance Site
High Disturbance Site

Figure 4c

Relative abundance of Isopoda vs. Principal Component 2 (Pearson correlation r = -0.734, p = 0.024)



Appendix B - Manuscript Submitted for Publication (if Accepted) to *Aquatic Ecosystem Health and Management*

INVERTEBRATE HABITAT USE IN RELATION TO FETCH AND PLANT ZONATION IN NORTHERN LAKE HURON COASTAL WETLANDS

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Abstract

Northern Lake Huron marshes are among the most pristine wetlands in the Great Lakes. Almost 200 invertebrate taxa were collected from eight of these marshes from 1997 through 2001. Our objective was to explore relationships between wave exposure (fetch), plant community zones and invertebrate community composition using exploratory data analysis of invertebrate abundance. Effective fetch, an exposure measure which integrates fetch along three directions, ranged from 0.4 to 35.3 km. Invertebrates were collected with dip nets from wet meadow, *Typha*, and inner and outer *Scirpus* zones from 3 very protected (fetch < 1km), 3 protected (fetch 1-10 km) and 2 exposed (>10 km) marshes. Correspondence analyses (CA) of invertebrate abundance did not plot invertebrate communities of wet meadows along fetch gradients even though 7 of 30 common taxa were significantly ($p<0.05$) correlated with fetch. After removing wet meadow data, CAs of data from remaining plant zones plotted marshes according to fetch with very protected and exposed sites at opposite ends of U-shaped gradients. Most taxa were generalists, occurred in marshes in all exposure categories, and plotted in the middle of CA plots. Characteristic taxa plotting at the very protected end of the gradient included *Gammarus*, *Crangonyx*, *Caecidotea*, Chironomini, Tanytarsini, most Gastropoda and Sphaeriidae. Characteristic taxa plotting at the most exposed end included *Sigara*, *Trichocorixa*, Naididae (*Stylaria*), Tubificidae, and *Bezzia*. We present a conceptual model of potential changes in invertebrate community composition along gradients of wave exposure. In very protected marshes, organic sediments, detritus, and plant density are higher and dissolved oxygen is lower than in exposed marshes. Conditions are too harsh for some taxa found in very protected marshes.

Key Words: Invertebrates, Habitat, Coastal Wetlands, Great Lakes, Wave Exposure, Fetch, Lake Huron

Introduction

Great Lakes coastal marshes are important feeding and nursery habitats for fish, amphibians, reptiles, birds, and mammals (Brazner 1997, Goodyear *et al*. 1982, Liston and Chubb 1985, Harris *et al*. 1983, Jude and Pappas 1992, Maynard and Wilcox 1997, Prince *et al*. 1992, Prince and Flegel 1995, Riffell 2000, Weeber and Vallianatos 2000, Whitt 1996). Invertebrates are important components of the diets of most of these vertebrates (Chow-Fraser 1998). Even though knowledge about invertebrates and their response to abiotic factors in Great Lakes coastal marshes has increased substantially in the last decade (Brady and Burton 1995, Brady *et al*. 1995, Burton *et al*. 1999, 2002, Cardinale *et al*. 1997, 1998, Gathman 2000, Gathman *et al*. 1999, Kashian and Burton 2000, Krieger 1992, Stricker *et al*. 2001, Wilcox et al. 2002), the effects of wave exposure and plant zonation on the distribution of invertebrates in wetlands has only been examined for Saginaw Bay wetlands (Burton *et al.* 2002).

Hydrology and hydrogeomorphic setting are key factors in classification of Great Lakes coastal marshes (Albert and Minc 2001, Chow-Fraser and Albert 1998, Dodge and Kavetsky 1995, Keough *et al*. 1999, Maynard and Wilcox 1997, Minc 1996, 1997, Minc and Albert 1998). Water levels in the Great Lakes vary by more than 150 cm over periods of years to decades (Burton 1985, Keough *et al*. 1999). These long term water level changes, along with changes of 20-40 cm from winter lows to summer highs, seiche-driven water level fluctuations of 10-20 cm over intervals of less than an hour to 14 hours, and storm surges of 1-2 m at infrequent intervals (Bedford 1992) may all have major impacts on invertebrate and plant communities in wetlands (Burton 1985, Keough *et al*. 1999). Relative exposure to wind and waves including storm surges and ice scour appears to be a major driving force in determining types of substrates and plant communities in coastal wetlands (Minc 1996, 1997, Minc and Albert 1998) and how rapidly plants respond to lake level changes (based on unpublished plant data from Northern Lake Huron marshes collected by D. Albert, T. Burton and D. Uzarski).

Our hypothesis is that invertebrate communities respond directly to wave exposure and lake level changes and indirectly to habitat changes that occur as plant communities respond to wave exposure and lake level changes. Separating direct effects of waves and lake level changes on invertebrates from indirect effects related to habitat changes will require an experimental approach, but some insight into the importance of each can be derived from existing data using exploratory data analysis such as correspondence analysis (CA) (Burton *et al.* 2002).

Our objective was to explore relationships between wave exposure, plant community zonation and invertebrate community composition for northern Lake Huron marshes and to compare relationships for these marshes with relationships described for Saginaw Bay marshes (Burton *et al.* 2002). We used invertebrate data collected from 1997-2001 from eight northern Lake Huron marshes to search for relationships between wave exposure and composition of invertebrate communities for four emergent plant zones. We used results to modify and apply the conceptual model developed for Saginaw Bay (Burton et al. 2002) to invertebrate communities in northern Lake Huron marshes.

Methods

Description of Study Area

Eight fringing, littoral marshes along the northern shore of Lake Huron between St. Ignace and DeTour Village, Michigan were sampled from 1997 through 2001 (Figure 1). Only Duck and Mackinac Bays were sampled all five years; Mismer Bay was sampled in all years except 2001 (Table 1). The other five marshes (Figure 1) were sampled one or more of the five years (Table 1). All marshes except McKay Bay were sampled in 1998. The eight marshes are among the most pristine wetlands in Lake Huron (Burton *et al.* 1999, Uzarski *et al.*, this issue). All marshes are part of the Les Cheneaux Islands region with the exception of St. Martin's Bay marsh. St Martin's Bay is a large bay west of the Les Cheneaux Islands (Figure 1).

Only emergent zones were sampled. Emergent zones in most marshes included wet meadow, cattail, and inner and outer *Scirpus* zones respectively from upland or adjacent swamp to open water (Burton *et al.* 1999, Uzarski *et al.*, this issue). The wet meadow was dominated by *Carex stricta* and/or *Carex lasiocarpa* and *Calamagrostis canadensis* intermixed with a high diversity of other herbaceous plants including other species of *Carex*, *Juncus*, and *Eleocharis* and scattered shrubs, particularly *Potentilla fructicosa*, *Salix*, and *Myrica gale*. The wet meadow transitioned into a narrow (25-75 m wide), dense cattail zone dominated by *Typha angustifolia* in most marshes. In Mismer and Mackinac Bays, the cattail zone consisted of scattered patches of cattail in the transitional zone between the wet meadow and *Scirpus* zones rather than as a distinct zone as in other marshes. An inner *Scirpus* zone dominated by *Scirpus acutus* and a high diversity of submersed plants extended into deeper water from the outer edge of the cattail or mixed cattail/wet meadow zones. The inner *Scirpus* zone was protected from open wave exposure by a slightly deeper, outer 50-100 m wide *Scirpus acutus* zone. The wave-swept, outer *Scirpus* zone was characterized by fewer stems of *Scirpus* per m^{-2} and higher interspersion of open water/bare substrate between *Scirpus* clumps compared to the inner *Scirpus* zone. Only scattered patches of submersed plants were present in the outer zone.

During 1997, all four zones were inundated. As lake levels fell from 1998 through 2001, progressively fewer zones were inundated. By 1999, only depressions in the inner *Scirpus* zone were inundated during low points of the seiche cycle. As water levels peaked during seiches, rising water fully inundated the inner *Scirpus* zone with standing water extending into the outer edge of the cattail or mixed cattail/wet meadow zone. The cattail and wet meadow zones were fully inundated only occasionally during large storm surges from 1999 through 2001.

St. Martin's Bay (Figure 1) marsh was located between two parallel sand ridges on an unprotected shoreline in a large bay. The inner sand ridge supported upland vegetation along the top of the ridge. A wet meadow was located between the inner sand ridge and adjacent forest. A dense inner *Scirpus* zone between the inner and outer sand ridges was partially protected from waves by the outer sand ridge, although an opening in this ridge allowed dampened waves to penetrate into the zone. A *Typha* zone occurred at the inner edge of the outer sand ridge. The outer ridge also supported a narrow upland zone at its top. At the outer edge of the outer sand ridge, a very narrow and sparse outer *Scirpus acutus* patch was present. Only the inner and outer *Scirpus* zones were included in the analyses, since the wet meadow and cattail zones were not comparable to other sites.

Wave Exposure Calculation

The degree of protection from waves and storm surges is a function of fetch. In order to quantify the amount of wave exposure each site received, effective and maximum fetch were calculated using procedures recommended by the British Columbia Estuary Mapping System (Resource Inventory Committee 1999). Using GIS software (ArcView GIS 3.2, ESRI, Inc.), fetch distances at each site were measured along three angles relative to the general orientation of the shoreline: 90^o (perpendicular), 45^o to the left of perpendicular, and 45^o to the right of perpendicular. These measurements were then used to calculate effective fetch (F_e) as follows:

$$F_e = \frac{\cos(45^o)*F_{45L} + \cos(90^o)*F_{090} + \cos(45^o)*F_{45R}}{\cos 45^o + \cos 90^o + \cos 45^o}$$

where F_{45L} = fetch distance along direction 45^o left of perpendicular, F_{090} = fetch distance at perpendicular angle, and F_{45R} = fetch distance along direction 45^o right of perpendicular (Resource Inventory Committee 1999). Maximum fetch was the largest of the three measured fetch distances.

A modification of the effective and maximum fetch wave exposure matrix (Resource Inventory Committee 1999) was used to determine the exposure category for each site (Table 1). This modification reflected the smaller range of fetch distances in the Great Lakes compared to the relatively large range in fetch distances reported for British Columbia estuaries. The eight wetlands (Figure 1) represented a gradient of exposure from very protected to exposed with effective fetch varying from 0.4 to 35.3 km (Table 1).

Sampling Procedures

Three replicate invertebrate samples were collected from each inundated emergent marsh zone with 0.5 mm mesh, D-frame dip nets in late July or early August from 1998 through 2001. In 1997, the marshes were sampled in June and August. Invertebrate samples in June included a predominance of early instars. By mid-July, most aquatic insects were present as late instars making them easier to identify. Thus, samples were collected in July or August after 1997. Dip net samples were taken by sweeping the net though the water in each plant zone at the surface, at mid depth and just above the sediments. Dip nets were emptied into a white pan, and 150 invertebrates were picked from the pan in the field. Additional dip net sweeps were taken if the first set of sweeps did not yield 150 specimens. Special efforts were made to pick a representative sample of smaller and more sessile organisms to minimize bias towards picking larger, more mobile individuals. Beginning in 1999, we limited amount of field-picking time when few specimens were collected in dip nets. Individual replicates were picked for 1/2 person-hour, organisms were tallied and picking continued to the next multiple of 50. Thus, each replicate contained either 50, 100, or 150 organisms. Most replicates contained 150 organisms except those from the outer *Scirpus* zone where fewer specimens were collected per sweep. Each replicate was preserved in 90 % ethanol in the field and processed individually in the laboratory to obtain a measure of sampling variance.

Specimens were sorted to operational taxonomic unit; usually genus or species for most insects, crustaceans and gastropods. Taxa that were difficult to identify, such as Chironomidae, were identified to tribe or subfamily, and some invertebrate groups such as Oligochaeta, Hirudinea, Turbellaria, Hydracarina, and Sphaeriidae were identified to family or order level. Taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996), and mainstream literature were used for identification. Accuracy was confirmed by experts when possible.

Statistical Methods

We used correspondence analyses (CA) (SAS version 8, SAS Institute Inc., Cary, NC, USA) of invertebrate community composition for each plant zone to determine if sites clustered in relation to fetch and/or plant zone for each year from 1997 through 2001. Taxa were included in the CA if they represented at least 1 % of mean total abundance of the invertebrate community for any plant zone in a given year. A separate CA was conducted for June and August in 1997 when all four zones were inundated in Duck, Mismer and Mackinac marshes. When sites separated according to fetch, groups of individual taxa containing the most inertia responsible for the separation were identified. Those taxa that contributed to separation of sites based on exposure over multiple years were plotted in relation to fetch and those with significant correlation coefficients were identified. Taxa responsible for most inertia separating plant zones in each year were also identified. Significant differences (alpha set at $p<0.05$) in abundance of these taxa between zones were established using Kruskal-Wallis or Mann-Whitney U tests.

To assess response of taxa to declining water levels, a repeated measures ANOVA (Systat 8.0, SPSS, Inc.) was used to determine whether significant differences ($p<0.05$) in taxa abundance occurred over time from 1997 to 2000 (time served as a surrogate for water level since lake level dropped each year from above average in 1997 to substantially below average in 2000, a 1.08 m overall drop). Various taxonomic levels were examined to identify broad-scale community shifts at the order, family, or genus level. Since Duck, Mackinac, and Mismer Bay wetlands were the only sites sampled all four years (Table 1), the analysis was limited to these wetlands. Analysis was also limited to the inner *Scirpus* zone, since it was the only plant zone sampled all four years in all three wetlands. Since time is the "within-subject" factor in this repeated measures design, it is likely that data collected in adjacent years are more correlated than are data from separated years, violating the assumption of circularity. Therefore, adjustment of F-test degrees of freedom using the Huynh-Feldt Epsilon correction (von Ende 1993) was necessary to test the null hypothesis that taxa abundance did not change over time (declining water levels).

Results

Plant Zones and Wave Exposure

Almost 200 invertebrate taxa were collected from the eight marshes from 1997 through 2001 (Table 2). Seventy-six percent of these taxa were insects. Mollusca, the second most taxa rich group, included 23 genera of snails and four bivalves (Table 2). Other important groups included Crustaceans, especially Amphipoda and Isopoda; Annelida, especially Naididae and Tubificidae; Nematoda and Cnidarians (Hydra). Lake levels dropped each year from 1997 through 2001 from a mean annual lake level of 176.97 m in 1997 to 175.93 m in 2001 (based on NOAA web site data for DeTour Village). Different numbers of wetlands were sampled from year to year with two to seven wetlands sampled in any particular year (Table 1). Varying numbers of wetlands sampled and changes in lake level from year to year made it necessary to analyze data for each year separately in order to determine relationships between fetch (intensity of wave exposure) and invertebrate community composition in each of the four plant zones.

1997 Correspondence Analyses

Duck, Mackinac and Mismer Bay marshes were sampled in 1997 when wet meadows were inundated. Wet meadows were not inundated at most sites from 1998 through 2001. The 1997 data were used to search for relationships between fetch and wet meadow invertebrate communities. Correspondence analyses (CA) of 1997 data from all plant zones (wet meadow, *Typha*, inner *Scirpus*, outer *Scirpus*) separated wet meadow zones from other plant zones in June and August (e.g. Figure 2). Grouping of wet meadow communities from the three sites away from other plant zones suggested that the wet meadow invertebrate community was substantially different from deeper water communities. Taxa with significantly (Kruskal-Wallis, $p < 0.05$) greater relative abundance in the wet meadow zone than in other plant zones in June and August included: Gerridae, *Pisidium*, *Planorbula armigera*, and *Physa gyrina*. The relative abundances of Ceratopogonidae, Tanytarsini, Dytiscidae, and *Sympetrum* were significantly greater (Kruskal-Wallis, $p < 0.05$) in wet meadows in June than in other plant zones, while *Hesperocorixa* and *Libellula* were significantly greater in wet meadows in August than in other zones.

The wet meadow invertebrate community of Duck Bay, the most protected of the three sites, plotted apart from wet meadow communities of the other two sites in both months. Taxa responsible for most inertia separating Duck from the other two sites included: *Planorbula armigera*, *Pisidium*, and Dytiscidae in both months. In June, Tanytarsini and *Libellula* were also important in separating the Duck Bay wet meadow from wet meadow communities at the other sites, while in August, *Hesperocorixa michiganensis* was one of the taxa separating Duck Bay from the other two sites.

Removal of wet meadow zone invertebrate data from correspondence analyses resulted in a clear separation of *Typha* zones from *Scirpus* zones in June but only partial separation in August (Figure 3). The grouping of *Typha* zones regardless of site suggested that wave exposure was relatively unimportant in structuring invertebrate communities in the *Typha* zone. However, *Scirpus* zones dampened the wave exposure each *Typha* zone experienced resulting in a relatively narrow gradient of exposure. Taxa with a significantly (Kruskal-Wallis, $p < 0.05$) greater relative abundance in the *Typha* zone compared to other plant zones in June included: *Crangonyx pseudogracilis*, *Caenis*, Tipulidae, and *Nehalenia irene*.

With only three marshes sampled, differences in invertebrate community composition in relation to fetch should be viewed as suggestive rather than conclusive. Once the wet meadow zones were removed from the 1997 data set, CA arranged sites according to a gradient of exposure to waves as determined by fetch calculations (Table 1), in both June and August (e.g. Figure 3) with the first two dimensions explaining at least 50% of the variance in each. In both June and August, the *Scirpus* zones at the most protected site (Duck Bay) were plotted together in the top-right corner of the plot with the perceived exposure gradient proceeding towards the bottom-left corner, where the *Scirpus* zone of the most exposed site (Mismer Bay) was located. The taxa responsible for the separation of Mismer Bay *Scirpus* zones from the more protected sites in either June or August were Baetidae (*Callibaetis* and *Procloeon*), Corixidae (*Sigara* and *Trichocorixa*), Orthocladiinae, Phryganeidae (*Agrypnia*), Oligochaeta, Lymnaeidae, and *Pyrgulopsis lustricus* (Hydrobiidae). Taxa that had a greater abundance in the most protected site (Duck Bay) *Scirpus* zones in either June or August included *Amnicola limosa*, *Bithynia tentaculata*, *Laevopex fuscus*, *Musculium securis*, Tanytarsini, Chironomini, Tanypodinae, *Caecidotea*, *Gammarus fasciatus*, and *Crangonyx pseudogracilis*. Only *Amnicola limosa*, *Bithynia tentaculata*, *Musculium securis*, and *Gammarus fasciatus* had greater abundances at Duck Bay in both months.

1998 Correspondence Analyses

In 1998, the inner *Scirpus* zones of seven marshes were sampled (all except McKay Bay - Table 1). Correspondence analysis of inner *Scirpus* data separated the very protected sites (Duck, Prentiss and Peck Bays) from the more exposed sites (Voight, St. Martins, Mismer and Mackinac) (Figure 4). The correspondence analysis resulted in a U-shaped exposure gradient beginning with Prentiss Bay (Very Protected) at the top-right and ending with Voight Bay, the most exposed site, at the top-left (Figure 4). U-shaped gradients are common in CAs when detrended techniques (DCAs) are not used. The extreme ends of the continuum tend to lack many organisms found toward the middle of the continuum making the extremes more similar to each other. As in 1997, Corixidae was an important taxon responsible for inertia separating the most exposed sites (Voight and St. Martin's) from the most protected sites. Graphs of relative abundance supported this with Corixids making up a substantially higher relative abundance in the exposed sites than in the protected ones (Figure 5). The relative abundance of Naididae, including *Stylaria*, was strikingly higher in exposed sites compared to protected and very protected ones. This may mirror results from 1997 when Oligochaeta were higher in exposed sites. However, Oligochaeta were not identified to family in 1997, so we cannot be sure that the greater oligochaete abundance in 1997 was due to Naididae as in 1998. *Bezzia* and *Hyalella azteca* were also more abundant in exposed sites than in protected ones in 1998 (Figures 4, 5). Chironomini, *Gammarus*, *Crangonyx pseudogracilis*, Ancylidae, *Oxyloma retusa*, and flatworms (Turbellaria) were more abundant in 1998 in very protected sites than in more exposed ones. *Caenis* was more common in protected sites (Mackinac and Mismer) in 1998 than in very protected or exposed sites.

1999 Correspondence Analyses

Due to decreased water levels in Lake Huron in 1999, invertebrate sampling was limited to inner and outer *Scirpus* zones at most sites. Correspondence analysis of 1999 data revealed two distinct groups representing inner *Scirpus* and outer *Scirpus* zones (Figure 6). Taxa that exhibited significantly (Mann-

Whitney U, $p < 0.05$) greater relative abundances in the inner *Scirpus* zone included *Caecidotea*, *Hyalella azteca*, *Caenis*, Aeshnidae, Libellulidae, Gerridae, *Belostoma*, *Mesovelia*, Hydrophilidae, and *Pseudosuccinea columella*. Taxa that exhibited significantly (Mann-Whitney U, $p < 0.05$) greater relative abundances in the outer *Scirpus* zone included Hydracarina, *Hexagenia*, *Sialis*, Tanytarsini, and *Amnicola*. The outer *Scirpus* zone at St. Martin's was the outlier of these two groups, perhaps due to the more intense wind and wave exposure this site received in comparison to other sites sampled in 1999. Taxa responsible for most of the inertia pulling this site away from the others included Corixidae (*Sigara*, *Trichocorixa*), *Stagnicola*, and *Helicopsyche*.

Correspondence analysis of 1999 inner *Scirpus* data again resulted in an apparent U-shaped exposure gradient with Prentiss and St Martins Bays at either end (Figure 6). Taxa with highest relative abundances in very protected sites included Orthocladiinae, *Mystacides* (Leptoceridae), and *Gammarus* (Figure 7). *Trichocorixa*, *Ishnura verticalis*, Tubificidae worms, and *Physa gyrina* all had highest relative abundances in the most exposed site sampled in 1999 (St. Martins). As in 1998, the relative abundance of *Caenis* was greater in protected sites than in very protected or exposed sites. A plot of outer *Scirpus* data failed to arrange sites according to exposure.

2000 and 2001 Correspondence Analyses

In 2000 and 2001, only the inner and outer *Scirpus* zones were sampled, since the other zones were not inundated. Correspondence analyses of these data did not reveal any distinct groupings based on plant zones in either year. However, 2000 Duck Bay inner *Scirpus* data plotted well away from inner *Scirpus* data for the other two sites (Figure 8). The fetch for the Duck Bay marsh was lower than for the other two marshes. The taxa responsible for inertia pulling Duck Bay apart from other sites included *Caecidotea*, *Bithynia tentaculata*, *Mystacides*, and Coenagrionidae. In 2000, sites were grouped by correspondence analysis in a manner similar to CA grouping in 1997 when the same sites were sampled (Figures 3 and 8). Some of the same taxa responsible for pulling the sites apart in 1997 also pulled them apart in 2000 (Figure 8). For example, Corixidae (*Sigara* and *Trichocorixa*) and *Procloeon* were important in separating Mismer from the other two sites in both 1997 and 2000. However, taxa that were not important in separating Mismer from other sites in 1997 (e.g., Sphaeriidae, *Fossaria*, *Physa gyrina*, and *Amnicola*) were important in 2000 (Figure 8).

Correspondence analysis of 2001 data plotted sites in an arrangement similar to 1997 and 2000, except that Mismer Bay was replaced by McKay Bay in 2001 as the most exposed site sampled. The corixids, *Sigara* and *Trichocorixa*, separated McKay Bay from the other sites in 2001 as they had for Mismer Bay in 1997 and 2000. *Caecidotea* and *Bithynia tentaculata* contributed to the separation of Duck Bay from the other sites in 2001 just as they had in 2000 when Mismer Bay was sampled instead of McKay Bay.

Significant Correlations within Plant Zones between Fetch and Invertebrate Relative Abundance

For each plant zone, Pearson correlation coefficients were calculated between effective and maximum fetch and the relative abundance of each taxon that made up 5 % or more of relative abundance in either *Scirpus* zone for any marsh in any year from 1997 through 2001 (a total of 30 taxa, Table 2). Correlation coefficients between effective fetch and relative abundance (Table 3) were similar to correlation coefficients between relative abundance and maximum fetch. Thus, the results for effective fetch also apply to results for maximum fetch (see Table 1 for effective and maximum fetch values for each marsh). Only 1.5 significant results per zone would have been expected by chance alone (alpha set at $p<0.05$); thus, fetch was correlated significantly more often with relative abundance of taxa than would be expected by chance alone with 7-8 significant correlations per zone (Table 3).

The majority of correlations between fetch and relative abundance were positive suggesting that most taxa were more abundant in exposed sites than in protected ones (Table 3). Taxa characteristic of exposed sites, as identified by correspondence analyses, also tended to increase in abundance with increasing fetch (e.g. Naididae, Corixidae, *Sigara*, Ceratopogonidae) when data across all years were examined (Table 3). Conversely, taxa associated with more protected sites (e.g. Chironomini, *Gammarus*) decreased in abundance as fetch increased.

Even though correspondence analyses did not plot wet meadows according to fetch, there were as many significant correlations between fetch and individual taxa in this zone as in the other three zones (Table 3). *Caenis* was positively correlated with fetch in wet meadow and inner *Scirpus* zones even though it was associated with protected sites in most years (Table 3). *Enallagma* was also positively correlated with fetch in wet meadows as were all oligochaete taxa (Table 3).

Temporal Variation Associated with Declining Water Levels

Only 7 (10%) of the taxa were significantly ($p < 0.05$) influenced by declining water levels in Lake Huron over the period from 1997 to 2000. Half of these would have been expected by chance alone since alpha was set at $p<0.05$. Most of the significant responses involved individual Odonata taxa and were not independent of each other. The dragonfly, *Epitheca*, exhibited the strongest decline in abundance ($p = 0.001$). Its decline contributed significantly to the similar trend exhibited by the suborder Anisoptera. The damselfly, *Enallagma*, was also significantly influenced by the changing water levels, but, instead of a decline each year, its abundance was significantly greater in 1998 than in any other year. The decline of *Enallagma* after 1998 influenced the four year decline of the family, Coenagrionidae, the suborder, Zygoptera, and, along with declines in *Epitheca*, may have accounted for much of the four year decline in Odonata at the order level. The caddisfly genus *Oecetis* displayed a similar pattern to *Enallagma*, with a significantly elevated abundance in 1998 and declines after that as lake levels continued to fall. Given that the number of significant correlations was only 3-4 higher than expected by chance alone and that some of the 7 significant correlations were for the same taxa at different levels of taxonomic resolution, we conclude that little, if any, evidence for change in community composition related to lake level drop was detected.

Synthesis of results

Many taxa tended to be more commonly collected in one of the three exposure categories than in the other two (Table 4). Ten taxa always occurred in highest relative abundance in the very protected marshes, while another eight taxa reached their highest relative abundance in either very protected or protected marshes. Nineteen taxa were more abundant in protected marshes than in either very protected or exposed marshes. Fewer taxa were found in highest relative abundance in exposed marshes (3) or in a combination of protected and exposed sites (5) (Table 4). Only a 7-8 of these were significantly ($p<0.05$) correlated with fetch within a particular plant zone (Table 3).

Taxa consistently important in separating very protected sites from protected and exposed sites in correspondence analyses included the amphipods, *Gammarus fasciatus* and *Crangonyx pseudogracilis*, midges in the tribes Chironomini and Tanytarsini, and Leptoceridae caddisflies, especially *Mystacides interjecta* (Table 4). As a group, snails were also much more commonly found in very protected or protected sites (Table 4), although the importance of individual snail species varied from marsh to marsh and year to year. For example, *Bithynia tentaculata* was found almost exclusively in Duck Bay, one of the very protected marshes. Other species of snails that were important in separating very protected marshes from protected or exposed sites included *Amnicola limosa* and *Oxyloma retusa*. Other mollusks found more commonly in very protected sites included the limpets (*Ferissia parallela* and *Laevopex fuscus*) and a species of fingernail clam (*Musculium securis*). At the family level, however, Sphaeriidae were found more commonly in protected sites than in very protected or exposed marshes, while another genus, *Pisidium*, was important in separating wet meadows from other habitats. Several snails were found in either very protected or protected marshes (e.g. Lymnaeidae including *Fossaria parva*, *Gyraulus*, *Physa gyrina*, *Pyrgulopsis lustricus*). The only snail taxon that reached its highest relative abundance in exposed marshes was *Valvata* (Table 4).

Taxa that were consistently more important in separating exposed marshes from protected or very protected marshes in correspondence analyses included Corixidae, especially *Sigara* and *Trichocorixa borealis* (Table 4). However, one corixid, *Hesperocorixa michiganensis*, was responsible for separating wet meadow invertebrate communities from *Typha* and *Scirpus* communities. Oligochaeta, especially Naididae (*Stylaria*) and, to a lesser extent, Tubificidae, were also important in separating exposed from protected marshes in CA plots (Table 4). Oligochaeta abundance correlated with fetch for three of the four plant zones (Table 3).

We developed a conceptual model to integrate invertebrate results along exposure gradients (Figure 9). As fetch and wave exposure increase, the outer plant community becomes increasingly dominated by widely spaced clumps of *Scirpus acutus* interspersed with sandy substrates containing little detritus, and invertebrate densities decrease (although we did not take quantitative samples, it took much longer to collect 150 specimens in outer *Scirpus* zones than it did in more protected zones). Characteristic taxa at the exposed end of the gradients differ substantially from those at the more protected end of the exposure gradient (Figure 9). Within each wetland, there is also a gradient of exposure to waves as depths increase and plant communities change from wet meadow to outer *Scirpus* zones. Wet meadows do not plot along fetch gradients in correspondence analyses and are not included in Figure 9. Along exposure gradients in each wetland, predictable changes in dissolved oxygen and dissolved ions occur as resistance from plant stems damps out wave energy and limits penetration of pelagic water into wetlands (Cardinale et al. 1997, 1998). The more exposed the wetland is, the more interspersion between stems there tends to be in the outer *Scirpus* zones, so that waves mix pelagic water farther into wetlands than in protected sites. This results in predictable changes in communities at the opposite ends of the exposure gradient (Figure 9).

Discussion

Recently, Burton et al. (2002) published a conceptual model of the effects of wave exposure and plant community zonation on Saginaw Bay wetland invertebrate communities. They based their conceptual model on comparisons of invertebrates of similar plant communities in inland, protected wetlands to littoral wetlands (e.g. cattail zones in each complex) and on comparisons between wave exposed and protected wetlands (e.g. *Scirpus* communities) on windward and lee sides of islands. They found that most invertebrate communities of littoral wetlands were likely established along a gradient of exposure with differences between plant zones being less important for exposed sites than for protected sites. Thus, their results from Saginaw Bay generally agree with our findings for northern Lake Huron marshes. However, direct comparisons for specific taxa in Saginaw Bay and northern Lake Huron marshes did not always agree even though several of the same taxa were present in both wetland complexes. Since Burton et al. (2002) did not quantify fetch for the Saginaw Bay sites, it is difficult to know where their sites fit along the fetch gradient calculated for northern Lake Huron wetlands. Therefore, only general trends in taxa abundance relative to exposure can be compared between the two regions. Some trends described for taxa in Saginaw Bay wetlands agreed with our results from northern Lake Huron wetlands. For example, Burton et al. (2002) found that Oligochaeta (Naididae, *Stylaria*), were more common in littoral than in inland marshes, and this parallels our finding that Naididae and *Stylaria* were markedly more common in exposed than in very protected marshes (Figure 9). They found that Asellidae (their Asellidae = our *Caecidotea;* we checked their samples from Saginaw Bay to confirm this) occurred in large numbers in inland and protected wetlands. Similarly, we found that *Caecidotea* tended to be more abundant in the most protected marshes (Figure 9). They found that Hydracarina (water mites) were much more common in inland or protected sites than in exposed ones, we found that Hydracarina were more likely to achieve highest relative abundances in protected rather than in very protected or exposed marshes (Figure 9). Other findings are not as comparable. For example, Orthocladiinae midges were associated with exposed sites in Saginaw Bay. While this was true for the inner *Scirpus* zone in 1997 in NLH marshes, Orthocladiinae did not exhibit any trends relative to exposure in most years and were associated with more protected sites in the outer *Scirpus* zone in 1999. The more exposed sites in Saginaw Bay may not be as exposed as the most exposed NLH marshes. The outer *Scirpus* zone of the most exposed NLH marshes may be too exposed to allow this tribe of midges to thrive. Corixidae (water boatmen) were associated with protected *Typha* and wet meadow zones in Saginaw Bay, but were consistently more abundant in the most exposed NLH marshes. This apparent disagreement may represent lack of taxonomic resolution. We found that one corixid, *Hesperocorixa*, was associated with protected *Typha* and wet meadows but that two others, *Sigara* and *Trichocorixa*, were more abundant in the most exposed marshes.

Differences in our findings may also be due to ecoregional differences, and these are detailed in the companion paper (Uzarksi *et al*., this issue). In addition, gradients in northern Lake Huron marshes (Figure 9) may differ from those described for Saginaw Bay (Burton *et al*. 2002), especially within individual marshes. The greatest differences are related to water quality. Saginaw Bay drains a large agricultural watershed, and pelagic water is highly turbid, nutrient enriched, and exposed to more agricultural chemicals than is pelagic water of northern Lake Huron (Uzarski *et al*., this issue). Thus, exposure gradients within individual marshes in Saginaw Bay include an increase in turbidity with exposure due to mixing of turbid, pelagic water into the outer marsh (Cardinale *et al*. 1997, 1998). Northern Lake Huron wetlands drain primarily forested watersheds and pelagic waters of Lake Huron are much less turbid than pelagic waters of Saginaw Bay. Thus, risk of fish predation increases from wet meadow to outer *Scirpus* zones in northern Lake Huron marshes (Gathman 2000), but decreases with exposure in Saginaw Bay marshes due to turbidity limiting detection of prey by visual predators (Cardinale *et al*. 1998). This may account for some differences in the two areas.

Gathman (2000) conducted research in 1996 and 1997 in Mackinac Bay marsh, one of the eight marshes included in our analyses (Figure 1) and found that depth was more important than plant zonation in determining invertebrate community composition. This too parallels our finding that exposure (which would correlate with depth within a marsh) was more important than plant zonation in determining community composition after wet meadow data were removed from analyses.

Our findings and those of others suggest that invertebrate communities in marshes are made up of many generalists which occur across all plant zones regardless of fetch (wave exposure) and a smaller number of specialists that are found on either end of the exposure gradient (Figure 9). Wet meadow communities are well protected from waves by outer plant zones and do not tend to relate to fetch in correspondence analyses. Wet meadows contain several taxa that are more abundant there than elsewhere (e.g. Dytiscidae, Gerridae, *Pisidium*, *Planorbula armigera*, *Hesperocorixa michiganensis*). There are enough of these taxa to make this zone plot away from other plant zones in correspondence analyses. Gastropoda are important taxa in the wet meadow zone, and they appear to be affected by differences in water chemistry, structural habitat complexity, and plant dominance in northern Lake Huron wetlands (Keas 2002). Even though the wet meadow zone is protected, a few taxa are correlated with fetch. These may be taxa that migrate into or out of the zone from deeper water where they are periodically exposed to wave action. Gathman (2000) described migrants from deeper water as being important in wet meadows in late season for Mackinac Bay, one of our study sites.

The *Typha* zone invertebrate community is also well protected from waves by the two *Scirpus* zones, but a few taxa in this zone also correlate with fetch (exposure to waves). The two *Scirpus* invertebrate communities are much more exposed to waves, and invertebrate communities in them tend to plot in relation to fetch and away from the more protected zones in correspondence analyses. Even so, the same number of taxa correlate with fetch in each of the four plant zones (7-8 per zone, Table 3). We conclude that fetch and plant community composition are important parameters in understanding habitat requirements of coastal wetland invertebrates with fetch being important for comparisons among several wetlands while plant community composition is more important in determining invertebrate species composition along exposure gradients within individual marshes.

The next step in understanding these relationships will need to involve experiments with individual species groups in order to establish how each species is affected by wave exposure and the concomitant changes in plant community composition and structure. It is also likely that biotic interactions such as predation pressure and competition will shift as habitats change in relation to fetch and lake levels (Gathman 2000), and these factors will also have to be examined before a true understanding of community dynamics in coastal wetlands can be achieved.

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Table Legends

Table 1. Fetch, corresponding exposure categories, and year(s) sampled for each wetland.

Table 2. List of taxa collected from Northern Lake Huron marshes, 1997-2001. * indicates taxa with relative abundance of 1 % or more for any plant zone - used in correspondence analyses; ** indicates taxa with greater than 5 % relative abundance for inner *Scirpus* zones for one or more sites - included in calculation of correlation coefficients.

Table 3. Significant Pearson correlation coefficients between taxa and effective fetch for marshes sampled from 1997-2001. Taxa with a relative abundance of 5 % or more in *Scirpus* zones were analyzed (N = 30, see Table 2; 12 of these Taxa were not significantly correlated with fetch in any plant zone and are not listed). NS = not significant, * = $p<0.05$; * = $p<0.001$; nc = none collected from zone.

Table 4. Taxa with highest relative abundance (%) in an exposure category (indicated by an x). VP (very protected), P (protected), Ex (Exposed) indicate that taxa were more abundant in that category.

Figure Legends

Figure 1. Map of northern Lake Huron showing location of study sites.

Figure 2. Correspondence analysis of 1997 (August) invertebrate relative abundance (%) data for all plant zones for taxa that made up more than 1 % of relative abundance for any site or plant zone for Duck (D), Mackinac (M), and Mismer (Mi) Bay marshes. Numbers after site codes correspond to plant zones as follows: 1 = wet meadow, 2 = *Typha*, 3 = inner *Scirpus*, 4 = outer *Scirpus*.

Figure 3. Correspondence analysis of 1997 (August) invertebrate relative abundance (%) data from *Typha*, inner *Scirpus*, and outer *Scirpus* plant zones (wet meadow excluded) for taxa that made up more than 1 % of relative abundance for any site or plant zone for Duck (D), Mackinac (M), and Mismer (Mi) Bay marshes. Site and plant zone codes as in Figure 2.

Figure 4. Correspondence analysis of 1998 invertebrate relative abundance (%) data for taxa that made up more than 1 % of relative abundance for any site for the inner *Scirpus* zone at Peck, Prentiss (Pren), Duck, Mackinac (Mack), Mismer (Mism), St. Martins (StM), and Voight (Voig) Bay marshes.

Figure 5. Relative abundance of dominant (> 5%) invertebrate taxa from the inner *Scirpus* zone in 1998. Marshes are plotted so that fetch increases from Peck to Voight Bay marshes (see Table 1).

Figure 6. Correspondence analysis of 1999 invertebrate relative abundance (%) data for taxa that made up more than 1 % of relative abundance for inner and outer *Scirpus* zones at: Prentiss (Pr), Duck (D), Mackinac (M), Mismer (Mi), and St. Martins (SM) Bay. Plant zone codes as in Figure 2. Duck Bay was the only site where *Typha* was sampled in 1999 (D2).

Figure 7. Relative abundance of dominant (> 5%) invertebrate taxa collected from the inner and outer *Scirpus* zones in 1999.

Figure 8. Correspondence analysis of 2000 invertebrate relative abundance (%) data for taxa that made up more than 1 % of relative abundance for any site for the inner and outer *Scirpus* zones. Site and plant zone codes as in Figure 2.

Figure 9. Conceptual model showing relationship of invertebrate community composition to gradients of environmental parameters expected to change in relation to fetch.

Table 1. Fetch, corresponding exposure categories, and year(s) sampled for each wetland.

Site	Modified Effective Fetch (km)	Maximum Fetch (km)	Exposure Category	Year(s) Sampled
Voight Bay	35.3	84.3	Exposed*	1998
St. Martin's Bay	12.1	18.8	Exposed**	1998, 1999
Mismer Bay	3.1	6.2	Protected	1997-2000
McKay Bay	1.8	3.8	Protected	2001
Mackinac Bay	1.3	2.2	Protected	1997-2001
Duck Bay	0.8	1.1	Very Protected	1997-2001
Prentiss Bay	0.5	0.6	Very Protected	1998, 1999
Peck Bay	0.4	0.7	Very Protected	1998

* classified as semi-exposed; ** classified as semi-protected by Resources Inventory Committee (1999); we recommend changing semi-exposed and semi-protected to exposed for Great Lakes wetlands.

Table 2. List of taxa identified to lowest operational taxonomic unit collected from Northern Lake Huron marshes, 1997-2001.

Taxa

- Cnidaria
    - Hydra
- Platyhelminthes
    - Turbellaria*
- Nematoda
- Annelida
    - Hirudinea*
    - Oligochaeta**
        - Lumbriculidae
        - Naididae**
            - _Stylaria sp._**
        - Tubificidae**
    - Polychaeta
        - _Manayunkia speciosa_
- Mollusca
    - Bivalvia
        - Dreissenidae
            - _Dreissena polymorpha_**
        - Sphaeriidae**
            - _Musculium securis_*
            - _Pisidium casertanum_*
            - _Pisidium sp._*
    - Gastropoda
        - Ancylidae**
            - _Ferrissia parallelus_*
            - _Laevapex fuscus_*
        - Bithyniidae
            - _Bithynia tentaculata_**
        - Hydrobiidae
            - _Amnicola limosa_**
            - _Probythinella lacustris_
            - _Pyrgulopsis lustricus_**
        - Lymnaeidae*
            - _Acella haldemani_*
            - _Fossaria dalli_
            - _Fossaria parva_*
            - _Lymnaea stagnalis_*
            - _Pseudosuccinea columella_*
            - _Stagnicola elodes_*
            - _Stagnicola exilis_
        - Physidae
            - _Physa gyrina_**
        - Planorbidae**
            - _Gyraulus deflectus_**
            - _Gyraulus parvus_**
            - _Planorbella trivolvis_
            - _Planorbula armigera_*
            - _Promenetus exacuous_
        - Pleuroceridae
            - _Elimia sp._
        - Succineidae
            - _Oxyloma retusa_*
        - Valvatidae
            - _Valvata sp._
        - Viviparidae
            - _Campeloma decisum_
- Arthropoda
    - Arachnida
        - Hydracarina**
        - Oribatei
    - Crustacea
        - Amphipoda
            - Crangonyctidae
                - _Crangonyx pseudogracilis_**
            - Gammaridae
                - _Gammarus fasciatus_**
                - _Gammarus pseudolimnaeus_*
            - Talitridae
                - _Hyalella azteca_**
        - Cladocera
        - Copepoda
        - Decapoda*
            - Cambaridae
                - _Orconectes sp._
        - Isopoda
            - Asellidae
                - _Caecidotea sp._**
                - _Lirceus lineatus_**
        - Ostracoda
    - Insecta
        - Collembola
            - Poduridae
                - _Podura aquatica_

Table 2. continued

Taxa
Ephemeroptera
Baetidae**
Callibaetis sp.**
_Centroptilium sp._*
Cloeon sp.
Paracloeodes sp.
_Procloeon sp._*
Caenidae
Brachycercus sp.
Caenis amica**
_Caenis latipennis_*
Caenis youngi**
Caenis spp.**
Ephemerellidae
Ephemerella sp.
_Eurylophella temporalis_*
Ephemeridae
Ephemera sp.
Hexagenia limbata
Hexagenia spp.**
Heptageniidae
Stenonema sp.
Odonata
Aeshnidae*
_Aeschna canadensis_*
Aeschna interrupta
Aeschna eremita
_Anax junius_*
Gomphaeschna furcillata
Basiaeschna janata
Boyeria sp.
Corduliidae
Cordulia sp.
Dorocordulia libera
Epitheca princeps
_Epitheca spinigera_*
Neurocordulia sp.
Gomphidae
Arigomphus sp.
_Gomphus spicatus_*
Libellulidae
_Leucorrhnia intacta_*
_Leucorrhnia frigida_*
_Libellula quadrimaculata_*
Libellula sp.**
Perithemis sp.
Plathemis lydia.
Sympetrum obtrusum**
_Sympetrum semicinctum_*
_Sympetrum vicinum_*
Macromiidae
Macromia illinoiensis
Coenagrionidae
Enallagma carunculatum
Enallagma geminatum
Enallagma hageni**
Enallagma sp.**
Ishnura verticalis**
Nehalennia irene**
Lestidae
Lestes congener
_Lestes disjunctus_*
Lestes sp.
Hemiptera
Belostomatidae
_Belostoma sp._*
Corixidae
Hesperocorixa kennicotti
_Hesperocorixa michiganensis_*
_Palmacorixa buenoi_*
_Sigara lineata_*
_Sigara transfigurata_*
_Sigara trilineata_*
_Sigara variabilis_*
Sigara spp.**
Trichocorixa borealis**
immature**
Gerridae*
_Gerris sp._*
Limnoporus sp.
Neogerris sp.
Trepobates sp.
Hydrometridae
Hydrometra sp.
Mesoveliidae
Mesovelia sp.**
Nepidae
Ranatra sp.

Table 2. continued

Taxa
Notonectidae
Buenoa sp.
Notonecta sp.
Pleidae
Neoplea striola
Saldidae
Saldula sp.
Veliidae
Microvelia sp.
Megaloptera
Sialidae
*Sialis sp.***
Trichoptera
Helicopsychidae
Helicopsyche borealis
Hydroptilidae
Hydroptila sp.
*Oxyethira sp.**
Leptoceridae
Ceraclea sp.
*Mystacides interjecta***
*Nectopsyche sp.**
*Oecetis sp.**
*Trianodes sp.**
Ylodes sp.
Limnephilidae
Anabolia sp.
Arctopora sp.
Goerinae
Grammotaulius sp.
Lenarchus sp.
Limnephilus sp.
*Nemotaulius sp.**
Molannidae
*Molanna sp.***
Phryganeidae
*Agrypnia sp.**
Banksiola sp.
*Fabria sp.**
Phryganea sp.
Ptilostoma sp.
Polycentropodidae
*Cernotina sp.**
Cyrnellus sp.

Taxa
Neureclipsis sp.
*Phylocentropus sp.**
Polycentropus sp.
Lepidoptera*
Pyralidae*
Acentria sp.
*Parapoynx sp.**
*Petrophila sp.**
Coleoptera
Chrysomelidae
*Donacia sp.**
Neohaemonia sp.
Prasocuris sp.
Curculionidae*
Lixus sp.
Dytiscidae*
Celina sp.
Dytiscus sp.
*Hydaticus sp.**
*Laccophilus sp.**
Rhantus sp.
Uvarus sp.
Elmidae
Dubiraphia sp.
Gyrinidae
Dineutus sp.
*Gyrinus sp.**
Haliplidae
Haliplus sp.
Peltodytes sp.
Helophoridae
Helophorus sp.
Hydraenidae
Hydraena sp.
Hydrophilidae*
Anacaena sp.
Cymbiodyta sp.
Hydrochara sp.
Paracymus sp.
*Tropisternus sp.**
Scirtidae
Cyphon sp.
Diptera
Ceratopogonidae*

Table 2. continued

Taxa	Taxa
Atrichopogon sp.	Empididae
*Bezzia sp.**	Pelecorhynchidae
*Probezzia sp.**	*Glutops sp.*
Sphaeromias sp.	Psychodidae
Chironomidae	Sciomyzidae
Chironomini**	*Sepedon sp.*
Tanytarsini**	Stratiomyidae
Orthocladinae**	*Stratiomys sp.*
Corynoneura sp.	Tabanidae
Tanypodinae**	Tipulidae*
Culicidae	Thaumaleidae
Anopheles sp.	*Thaumalia sp.*
Mansonia sp.	
Uranotaenia sp.	

* = relative abundance of 1 % or more in one or more zones, ** = relative abundance of 5 % or more in *Scirpus* zones for one or more marshes. Taxa noted with * or ** were included in correspondence analyses. Taxa noted with ** were included in correlations with fetch for each zone (Table 3).

Table 3: Significant Pearson correlation coefficients between taxa and effective fetch for marshes sampled from 1997-2001. Taxa with a relative abundance of 5 % or more in *Scirpus* zones were analyzed (N = 30, see Table 2; 12 of these Taxa were not significantly correlated with fetch in any plant zone and are not listed). NS = not significant, * = p<0.05; * = p<0.001; nc = none collected from zone.

Taxa	Wet Meadow	*Typha*	Inner *Scirpus*	Outer *Scirpus*
Oligochaeta	0.535*	NS	0.525**	NS
Naididae	0.906**	NS	0.599**	0.338*
Stylaria	0.862**	n/a	0.501**	NS
Tubificidae	0.550*	NS	NS	NS
Planorbidae	NS	0.552*	NS	0.347*
Gyraulus	NS	0.514*	NS	NS
Hydracarina	NS	0.903**	NS	NS
Amphipoda, *Gammarus*	-0.415*	NS	NS	NS
Baetidae	NS	0.491*	NS	NS
Caenidae, *Caenis*	0.692*	NS	0.358*	NS
Coenagrionidae, *Enallagma*	0.848**	NS	NS	NS
Corixidae	NS	0.775**	NS	0.588**
Sigara	NS	0.605*	NS	0.380*
Trichocorixa	nc	nc	NS	0.655**
Leptoceridae	NS	0.652*	-0.259*	NS
Chironomini	NS	NS	-0.212*	NS
Orthocladiinae	NS	0.492*	NS	0.384*
Ceratopogonidae	NS	NS	0.674**	0.315*

Note: Pearson correlation coefficients between these taxa and maximum fetch was similar with the same taxa showing significant correlations for both effective and maximum fetch.

Table 4. Taxa with highest relative abundance (%) in an exposure category (indicated by an x). VP (very protected), P (protected), Ex (Exposed) indicate that taxa were more abundant in that category.

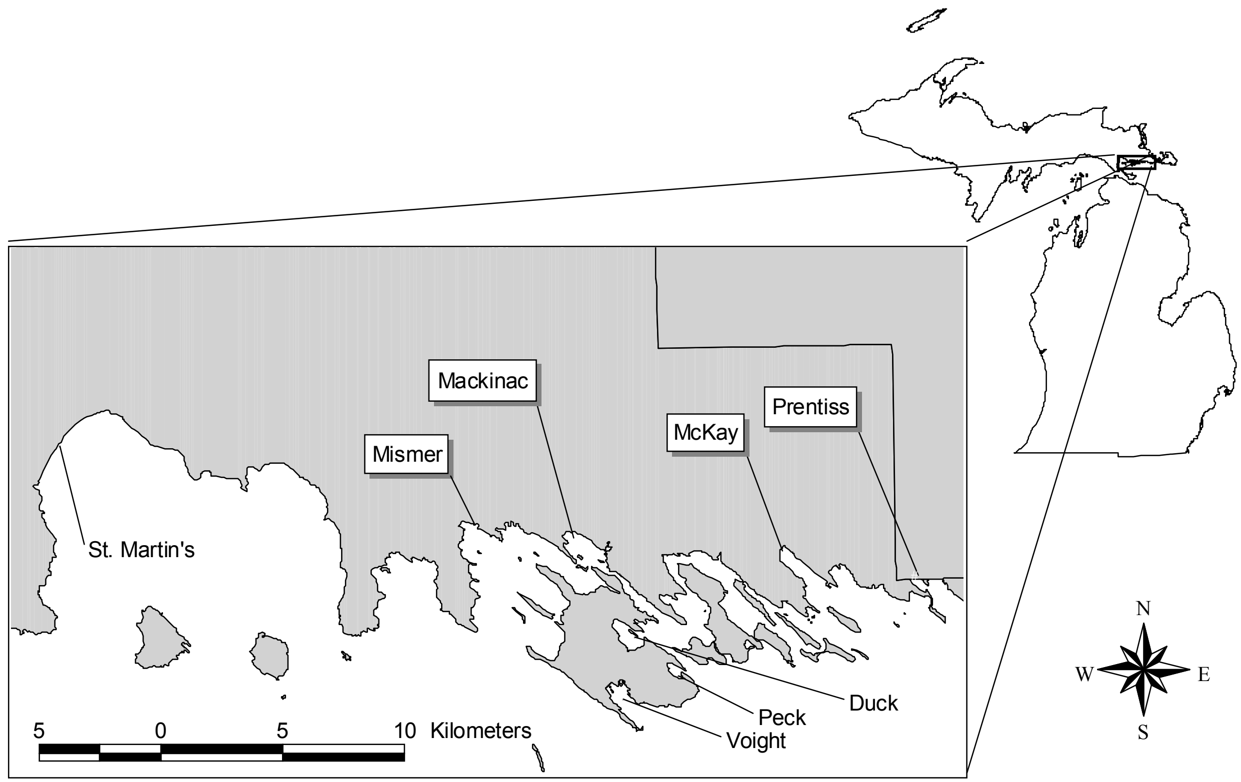
Taxa in Very Protected Marshes	1997 (June)	1997 (Aug)	1998	1999	2000	2001
Gammarus		x	x	x	x	
Chironomini	x		x	x		
Caecidotea	P	x		P	x	x
Mystacides				x	x	
Tanytarsini	x			x		P
Crangonyx	x		x			
Bithynia		x			x	
Amnicola	x	x			P	
Laevopex		x				
Musculium	x					
Oxyloma			x			
Ferrissia			x			
Cernotina			x			
Coenagrionidae				P	x	
Enallagma	P		x			
Orthocladiinae	P			x		
Belostoma				x		P

Taxa in Protected Marshes	1997 (June)	1997 (Aug)	1998	1999	2000	2001
Hydracarina	x	x	x	x	x	x
Tanypodinae	x	VP	x	x	x	
Hyalella azteca	x					x
Corixidae	x	x	Ex		x	x
Sigara	x	x			x	x
Trichocorixa	x			Ex	x	x
Phryganeidae	x	x				
Pyrgulopsis	x					
Ceratopogonidae		x				
Libellulidae		x	x			
Caenis		x	x	x	x	
Physa gyrina		x		Ex	x	x
Lepidoptera		x				
Callibaetis		x			x	x
Procloeon		x				
Mesovelia				x		
Sphaeriidae				x	x	
Hirudinea				x	x	
Tubificidae				Ex	x	
Naididae			Ex		x	
Gyraulus					x	x

Fossaria					x	
Lymnaeidae						x
Gerridae						x

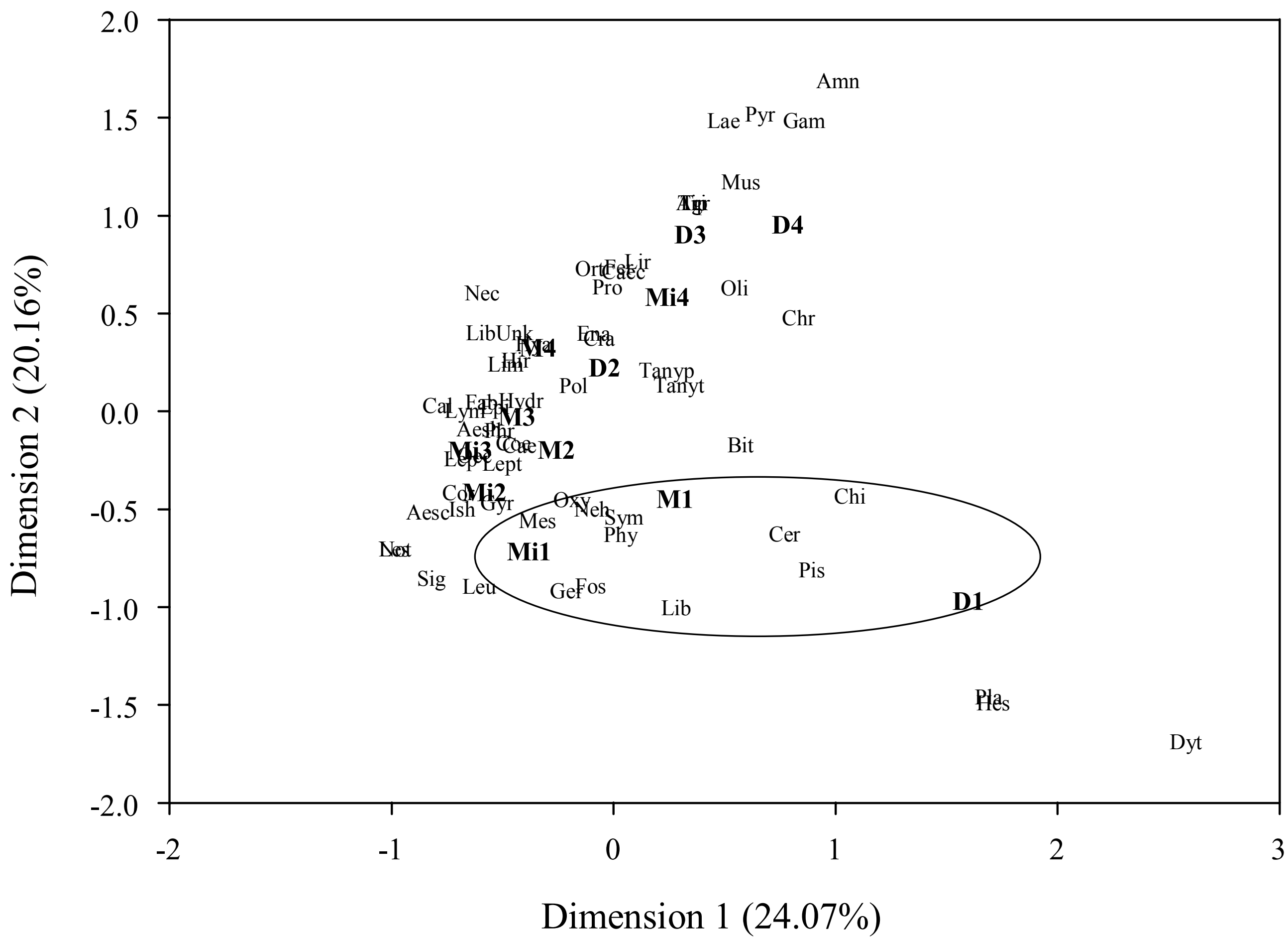
Taxa in Exposed Marshes	1997 (June)	1997 (Aug)	1998	1999	2000	2001
Bezzia			x			
Valvata				x		
Ishnura				x		

Figure 1



Mackinac
Prentiss
McKay
Mismer
St. Martin's
Duck
Peck
Voight
5 0 5 10 Kilometers
N
W
E
S

Figure 2



Dimension 2 (20.16%)
Dimension 1 (24.07%)
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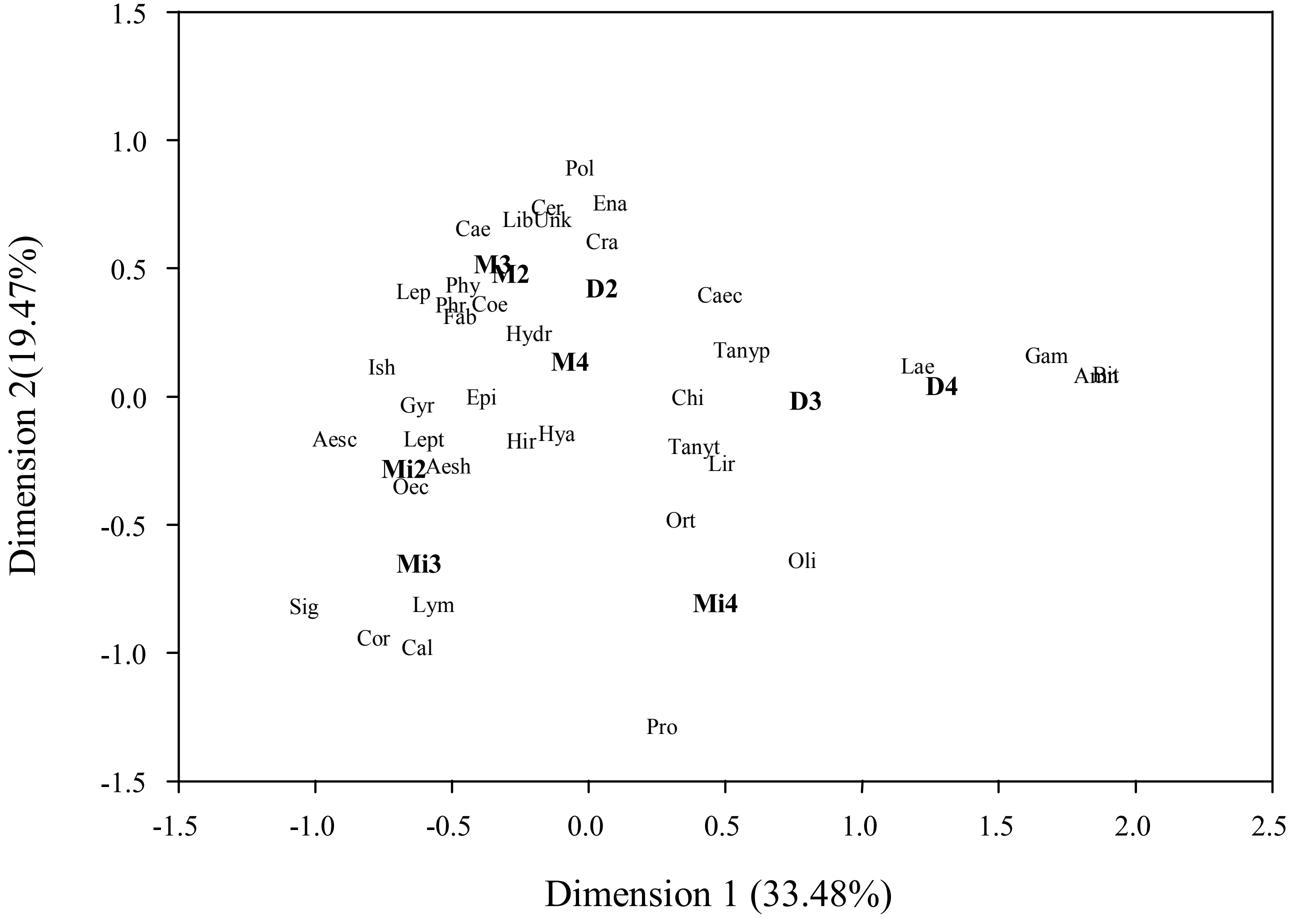
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2
-1
0
1
2
3
Amn
Lae
Pyr
Gam
Mus
D4
D3
Oli
Chr
Mi4
Nec
Pro
Pol
D2
Tanyp
Tanyt
M3
M2
Mi3
Bit
Mi2
M1
Chi
Mes
Sym
Phy
Cer
Mi1
Pis
Sig
Leu
Fos
Lib
D1
Dyt
Aesc
Ish
Gyr
Lept

Figure 3



Dimension 2(19.47%)
Dimension 1 (33.48%)
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1.0
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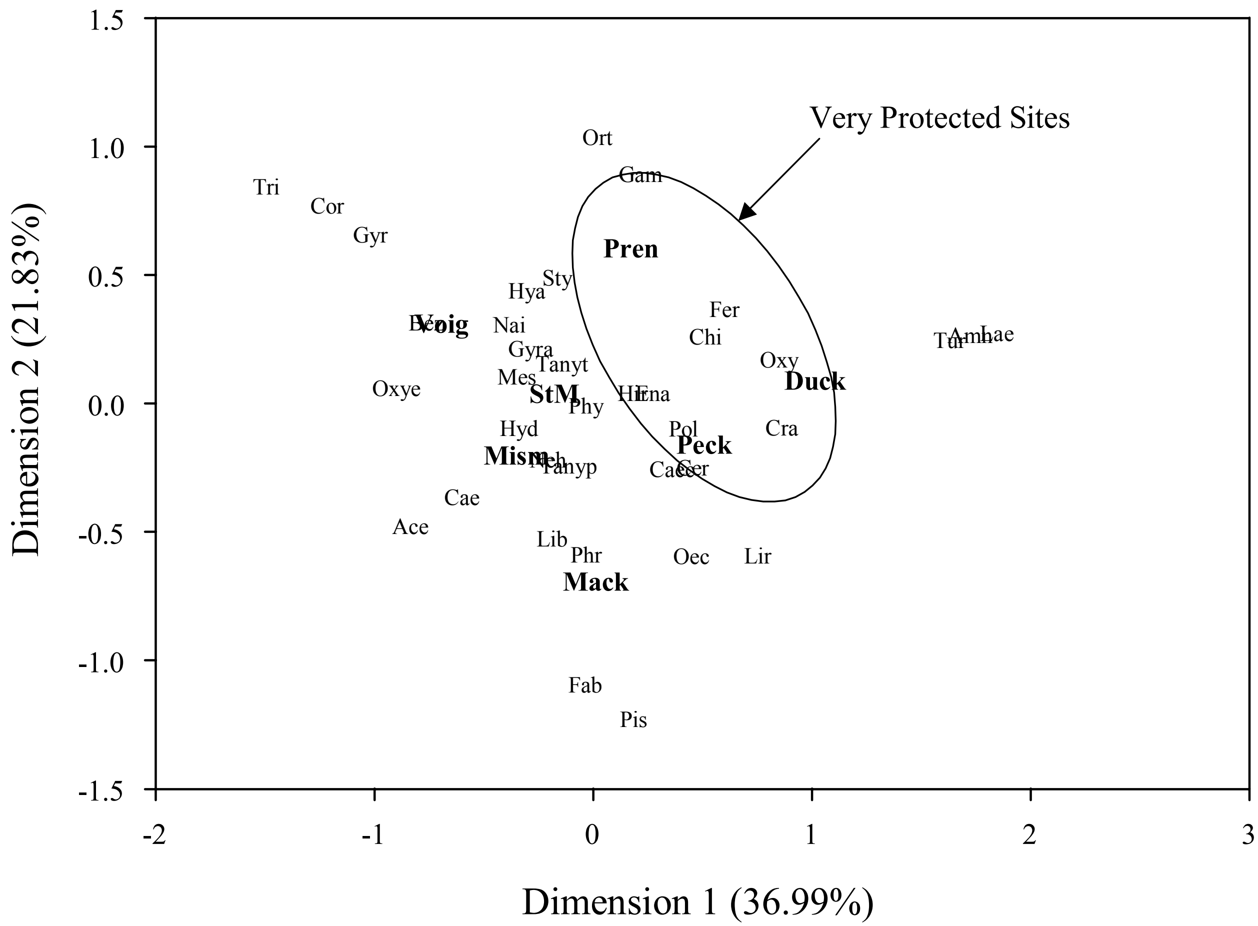
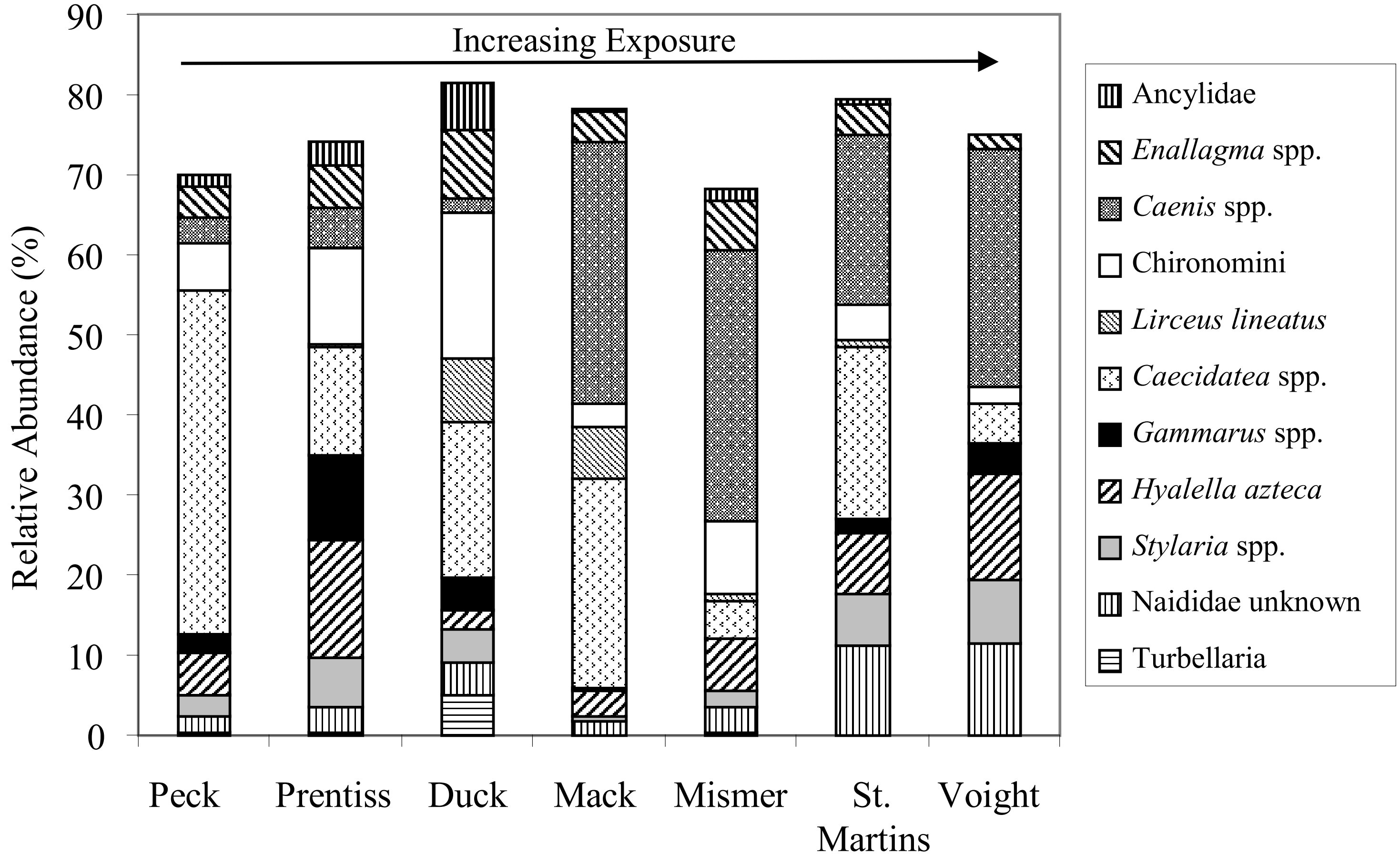
0.0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Pol
Cer
Ena
Lib
Unk
Cae
Cra
M3
M2
D2
Caec
Lep
Phy
Phr
Coe
Fab
Hydr
Tanyp
M4
Ish
Lae
D4
Gam
Chi
D3
Gyr
Epi
Aesc
Lept
Hir
Hya
Tanyt
Lir
Mi2
Aesh
Oec
Ort
Oli
Mi3
Sig
Lym
Mi4
Cor
Cal
Pro

Figure 4



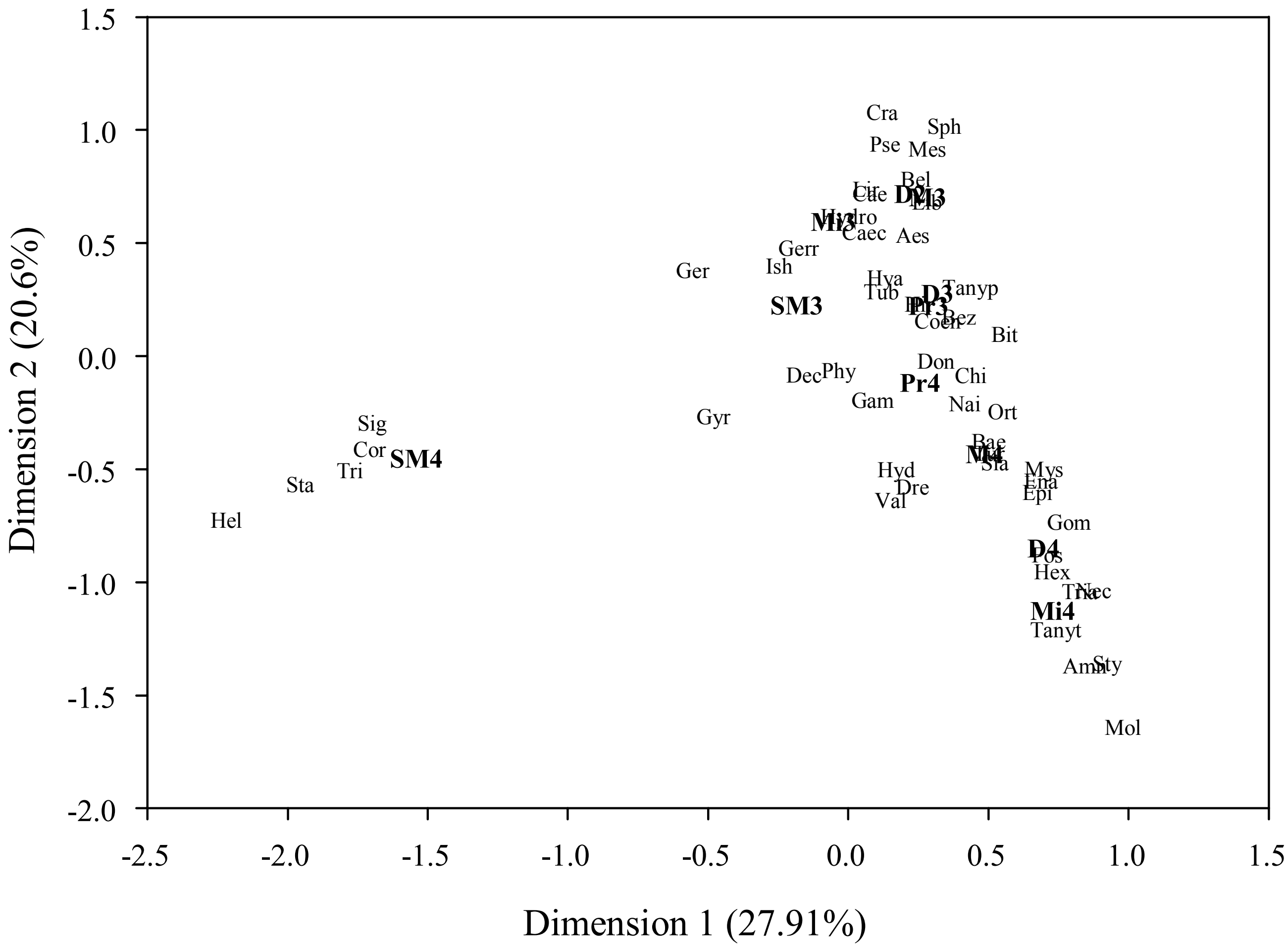
Very Protected Sites
Dimension 2 (21.83%)
Dimension 1 (36.99%)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2
-1
0
1
2
3
Ort
Gam
Tri
Cor
Gyr
Pren
Hya
Sty
Voig
Nai
Gyra
Fer
Chi
Tanyt
Mes
Oxy
Duck
Tur
Amh
Lae
Oxye
StM
Phy
Ena
Hyd
Pol
Cra
Peck
Mism
Tanyp
Cer
Cae
Ace
Lib
Phr
Oec
Lir
Mack
Fab
Pis

Figure 5



Increasing Exposure
Relative Abundance (%)
90
80
70
60
50
40
30
20
10
0
Peck
Prentiss
Duck
Mack
Mismer
St. Martins
Voight
Ancylidae
Enallagma spp.
Caenis spp.
Chironomini
Lirceus lineatus
Caecidatea spp.
Gammarus spp.
Hyalella azteca
Stylaria spp.
Naididae unknown
Turbellaria

Figure 6



Dimension 2 (20.6%)
Dimension 1 (27.91%)
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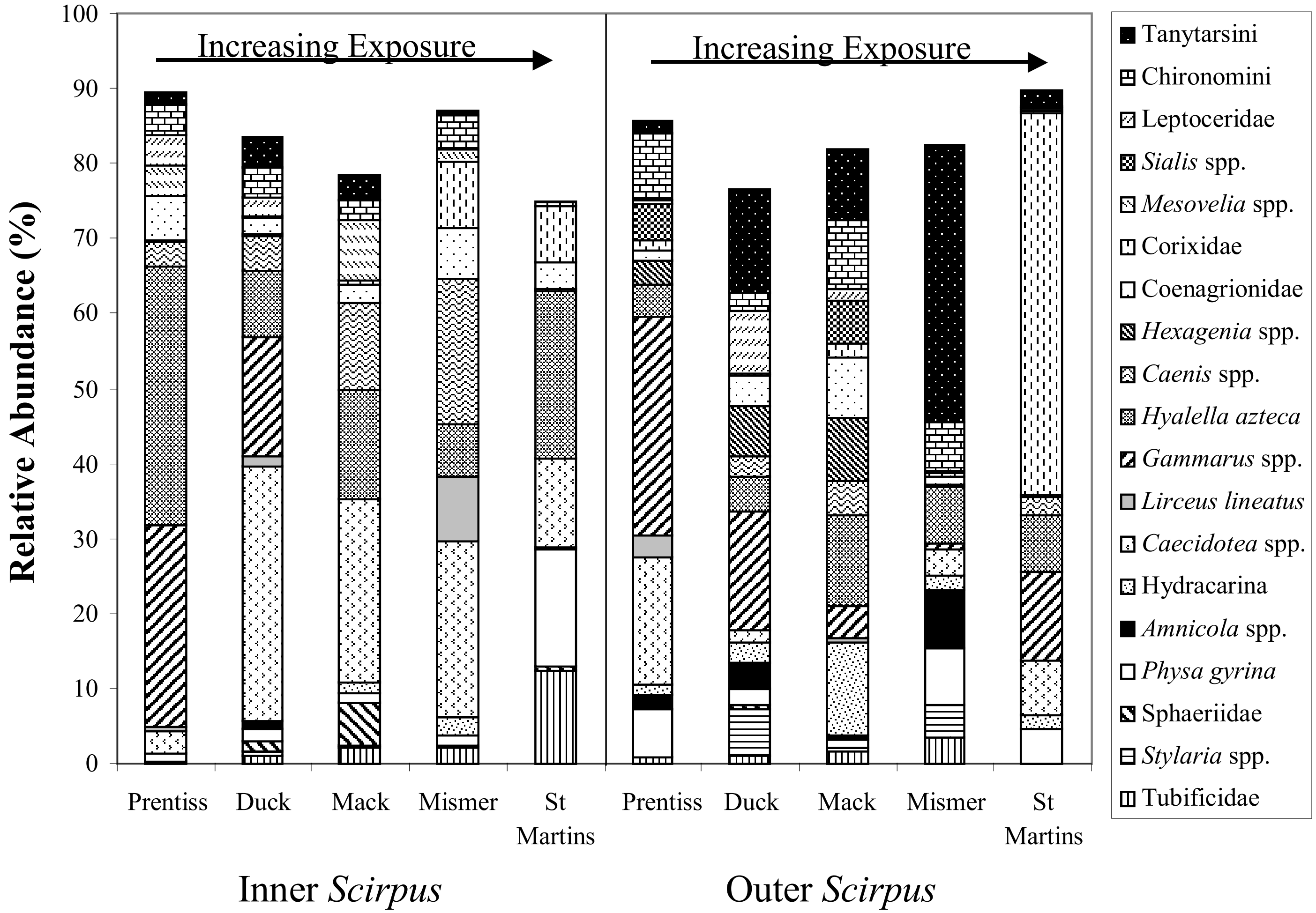
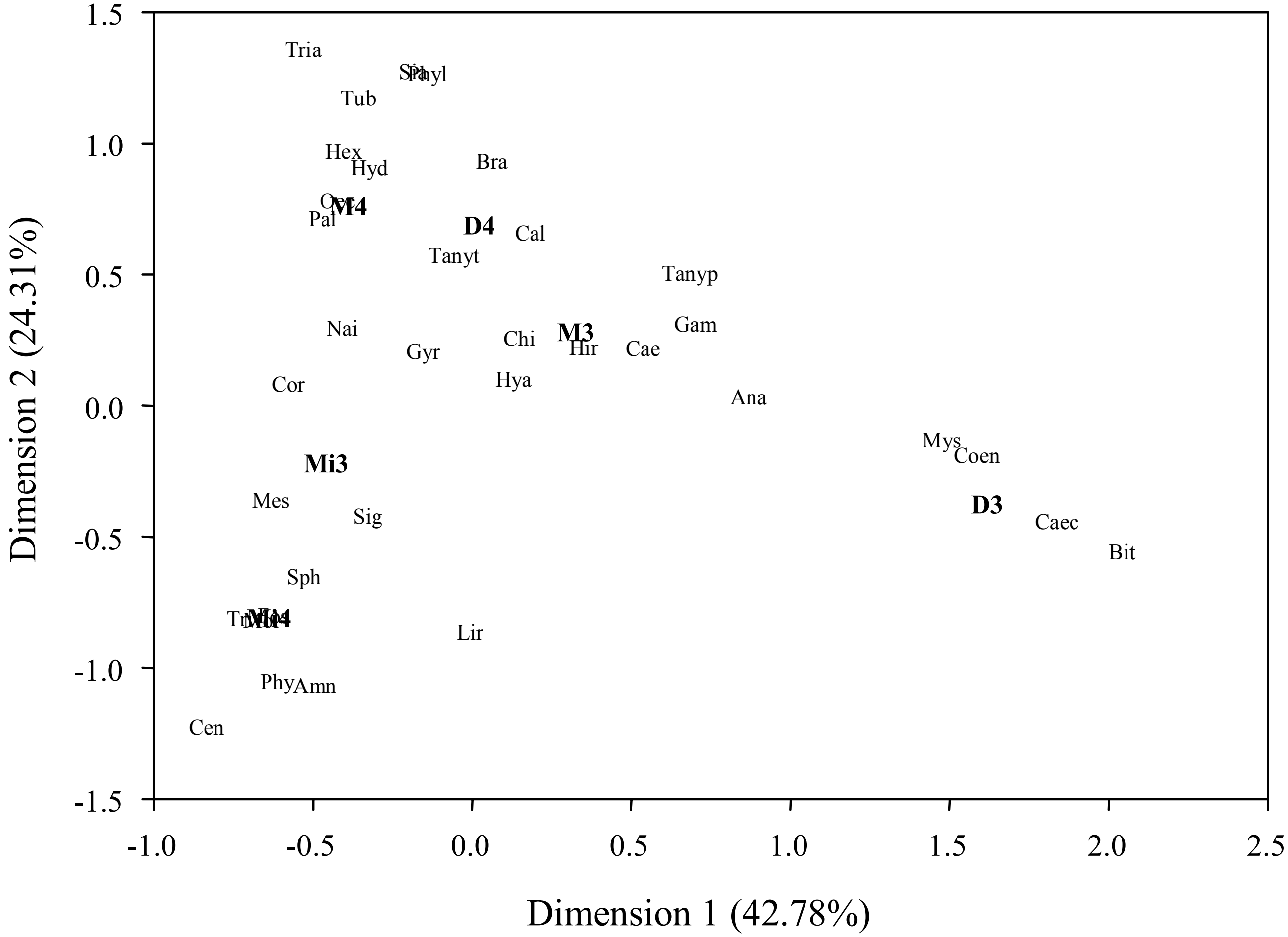
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Cra
Sph
Pse
Mes
Bel
Mi3
Caec
Aes
Gerr
Ger
Ish
Hya
Tub
Tanyp
D3
SM3
Pr3
Coen
Bez
Bit
Don
Dec
Phy
Chi
Pr4
Gam
Nai
Ort
Gyr
Sig
Cor
SM4
Tri
Sta
Hel
Hyd
Dre
Val
Mys
Ena
Epi
Gom
D4
Hex
Mi4
Tanyt
Sty
Mol

Figure 7



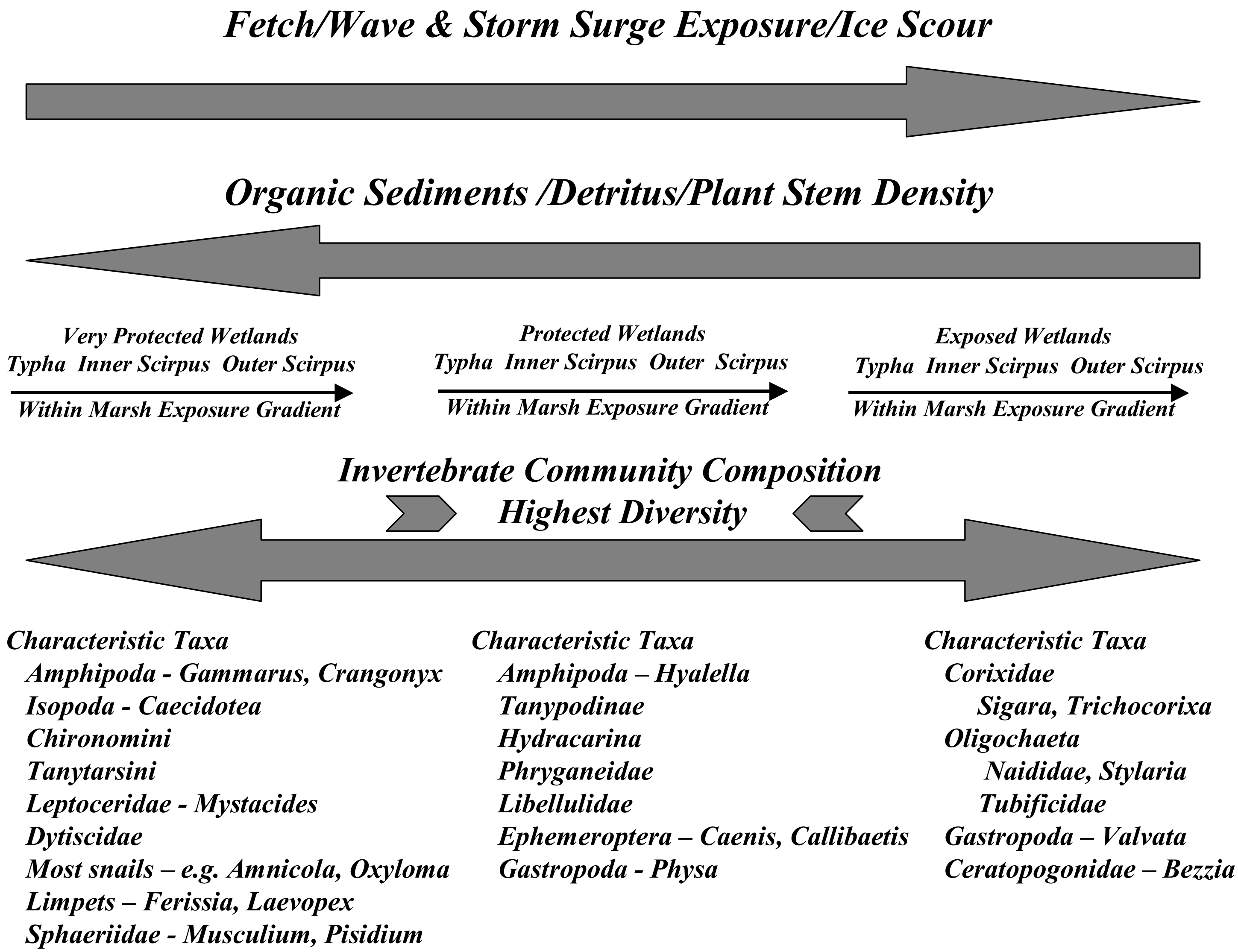
100
90
80
70
60
50
40
30
20
10
0
Relative Abundance (%)
Increasing Exposure
Increasing Exposure
Prentiss
Duck
Mack
Mismer
St Martins
Prentiss
Duck
Mack
Mismer
St Martins
Inner *Scirpus*
Outer *Scirpus*
Tanytarsini
Chironomini
Leptoceridae
Sialis spp.
Mesovelia spp.
Corixidae
Coenagrionidae
Hexagenia spp.
Caenis spp.
Hyalella azteca
Gammarus spp.
Lirceus lineatus
Caecidotea spp.
Hydracarina
Amnicola spp.
Physa gyrina
Sphaeriidae
Stylaria spp.
Tubificidae

Figure 8



Dimension 2 (24.31%)
Dimension 1 (42.78%)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Tria
Phyl
Tub
Hex
Hyd
Bra
M4
Pal
D4
Cal
Tanyt
Tanyp
Gam
Nai
Chi
M3
Cae
Gyr
Hya
Cor
Ana
Mys
Coen
Mi3
D3
Mes
Sig
Caec
Bit
Sph
Lir
Phy
Amn
Cen

Figure 9


Fetch/Wave & Storm Surge Exposure/Ice Scour
Organic Sediments /Detritus/Plant Stem Density
Very Protected Wetlands
Typha Inner Scirpus Outer Scirpus
Within Marsh Exposure Gradient
Protected Wetlands
Typha Inner Scirpus Outer Scirpus
Within Marsh Exposure Gradient
Exposed Wetlands
Typha Inner Scirpus Outer Scirpus
Within Marsh Exposure Gradient
Invertebrate Community Composition
Highest Diversity
Characteristic Taxa
Amphipoda - Gammarus, Crangonyx
Isopoda - Caecidotea
Chironomini
Tanytarsini
Leptoceridae - Mystacides
Dytiscidae
Most snails – e.g. Amnicola, Oxyloma
Limpets – Ferissia, Laevopex
Sphaeriidae - Musculium, Pisidium
Characteristic Taxa
Amphipoda – Hyalella
Tanypodinae
Hydracarina
Phryganeidae
Libellulidae
Ephemeroptera – Caenis, Callibaetis
Gastropoda - Physa
Characteristic Taxa
Corixidae
Sigara, Trichocorixa
Oligochaeta
Naididae, Stylaria
Tubificidae
Gastropoda – Valvata
Ceratopogonidae – Bezzia