Ecological Characteristics of Nearshore Areas Along Six Great Lakes Shorelines

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Lake Erie Geology Group
Sandusky, OH

For:
Great Lakes Protection Fund
Chicago, IL

August 5, 2002

Report Number 2002-19

Michigan DNR

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INTRODUCTION

Humans have dramatically altered the Great Lakes Basin and nearshore areas of the basin through activities related to agriculture, single family residences, urban development, industry and navigation (Edsall 1996). The nearshore zone of the Great Lakes has been most severely impacted by chemical pollution and organic enrichment resulting from heavy industrialization and dense urbanization (Krieger 1984). The nearshore zone is of particular concern because it factors significantly in the life history of many Great Lakes native species. For example, more than 75% of Great Lakes fish species' young-of-the-year and approximately 65% of fish species adults use gravel, sand or silt substrates in nearshore areas as habitat (Lane et al. 1996a, Lane et al. 1996b). The nearshore zone begins at the shoreline or the lakeward edge of coastal wetlands and extends offshore to the point where the thermocline typically intersects the lakebed in late summer to early fall. This generally coincides with the 10-m depth contour in Lake Superior and the 30-m depth contour in the remaining Great Lakes due to their southern placement and wider water temperature range (Bennett 1978).

Great Lakes nearshore ecosystems have been poorly studied historically, likely due to the logistical difficulties involved in conducting surveys and a general perception of these areas as "wet deserts" that are faunally depauperate. Thus, responses of nearshore communities to environmental changes associated with human land uses along shorelines are not well understood, although there have been some studies that link sedimentation and nutrient enrichment to spawning habitat loss (e.g., Edsall and Kennedy 1995) and shifts in community structure (e.g., Johnson and Brinkhurst 1971), respectively. Some patterns of habitat change have also been described, at least in general terms. For example, hardening of shorelines to prevent natural erosion processes alters nearshore littoral transport of materials, eliminates nearshore migration as Great Lakes water levels change and reduces aquatic habitat diversity (SOLEC 1996). In addition, straightened shorelines lose structural irregularities that drive variation in alongshore currents and cause local variation in substrates (SOLEC 1996). While these physical processes and changes are known to exist, responses of nearshore communities to these changes are poorly known. Given the importance of nearshore areas to Great Lakes fauna over multiple taxonomic groups, changes in community structure could have dramatic effects on Great Lakes fisheries and productivity over time. Understanding nearshore community responses to changes in environmental properties of shoreline and nearshore areas would contribute greatly to managers' abilities to make informed decisions about development and other activities that can influence this significant ecological zone of the Great Lakes.

The ecosystem approach to management relies on a complex, holistic balancing of socioeconomic and environmental factors (Christie et al. 1986). Ecosystem management seeks to maintain high levels of biological integrity (Karr and Dudley 1981) and ecological integrity (Pimentel et al. 2000) within a regime of anthropogenic development. Biological integrity is the ability of an ecosystem to support and maintain a balanced, integrated and adaptive organismal community comprised of species and characterized by functional organization comparable to natural habitats of a region of interest (Karr 1981). The concept of ecological integrity is not altogether different from that of biological integrity and reflects the capacity of an ecosystem to withstand stress (e.g., stochastic events), continue to support successful community function, and attain optimal developmental processes unconstrained by anthropogenic influence (Westra 1994).

In an effort to facilitate the development of enhanced, broad-scale ecosystem management strategies for Great Lakes shorelines and nearshore areas, we conducted ecological studies of six nearshore areas associated with varying shoreline types. We sought to identify patterns of community response to shoreline properties and nearshore substrate stability related to shoreline/nearshore processes. We hypothesized that nearshore community parameters would exhibit greater biological integrity in nearshore areas associated with lower levels of shoreline development and structure placement. We also hypothesized that biological community parameters would exhibit greater biological integrity in nearshore areas characterized by higher substrate stability regimes.

METHODS

Nearshore ecological properties, including physical habitat and aquatic communities, were surveyed in three areas of the Great Lakes Basin during 1999 and 2000, including the southern shore of Lake Erie (SLE) and the eastern (ELM) and western (WLM) shores of Lake Michigan. These surveys were used to provide a preliminary characterization of the nearshore ecosystems associated with varying shoreline types in each lake area. Selected sampling sites fell into two main groups. The first group of sites, hereafter referred to as the unique sites (UQ), included examples of characteristic shoreline types unique to each lake area. Sheldon Marsh (SM, Erie Co., Ohio) was characterized as a shallow embayment of Lake Erie with organic rich sandy and muddy-sand substrates. The Ludington site (LD, Mason Co., Michigan) was characterized as a dune/sandy beach shoreline with a nearshore area comprised of an extensive sand sheet. Port Washington (PW, Ozaukee Co., Wisconsin) was characterized as a high bluff (i.e., >35m) shoreline with mixed sand and glacially deposited nearshore substrates (e.g., cobbles and boulders). The second group, hereafter referred to as the mid-bluff sites (MB), included examples of moderate bluff (i.e., <15m) shorelines with typically sand-starved nearshore areas that occurred in all three lake areas surveyed. Mid-bluff sites included Painesville (PV, Lake Co., Ohio), St. Joseph (SJ, Berrien Co., Michigan) and Two Rivers (TR, Manitowoc Co., Wisconsin). Substrates at these sites were variable, although they were principally comprised of sparse sandy areas with exposed cobbles, boulders and clay.

At each site, three transects were established perpendicular to the shoreline with sampling stations at one, three and six meter water depths along each transect (Figure 1). Nearshore substrate characteristics at each sampling station were determined based on bottom grab samples and SCUBA reconnaissance. A Petit Ponar grab was deployed from the boat to provide an initial characterization of local substrates. High-volume samples indicated that soft substrates (e.g., sand) were prevalent at the sampling station, while sparse grab samples suggested the presence of hard substrates and/or clay. Divers assessed substrates at stations with sparse grab samples to determine the local substrate composition.

Three animal community types were sampled along each of the transects: benthic (bottom-dwelling) invertebrates, planktonic (water-column dwelling) invertebrates and fish. Three samples were collected at each sampling station to characterize the benthic community. Benthic samples were collected using a Petit Ponar dredge (0.023m^2) at stations with soft sand/silt substrates. At sampling stations dominated by rocky, hard or clay substrates, surveyors with SCUBA equipment used a custom vacuum sampler to remove biota from a 0.063m^2 template area (Figure 2). Stations with both hard and soft substrates were sampled proportionately using both methods to reflect the relative contribution of each substrate type in the vicinity of the sampling station. Benthic samples were preserved using 95% ethanol (EtOH) in the field, and invertebrates were later identified to the lowest practical level and counted in the laboratory. Only non-dreissenid (i.e., zebra mussel) benthic taxa were used in benthic community analyses because dreissenids were not reliably and comparably collected in benthic samples during the surveys. Other organisms included in the samples that are not characteristically associated with benthic substrates (e.g., planktonic species) were identified for presence only. Benthic invertebrate data were standardized by

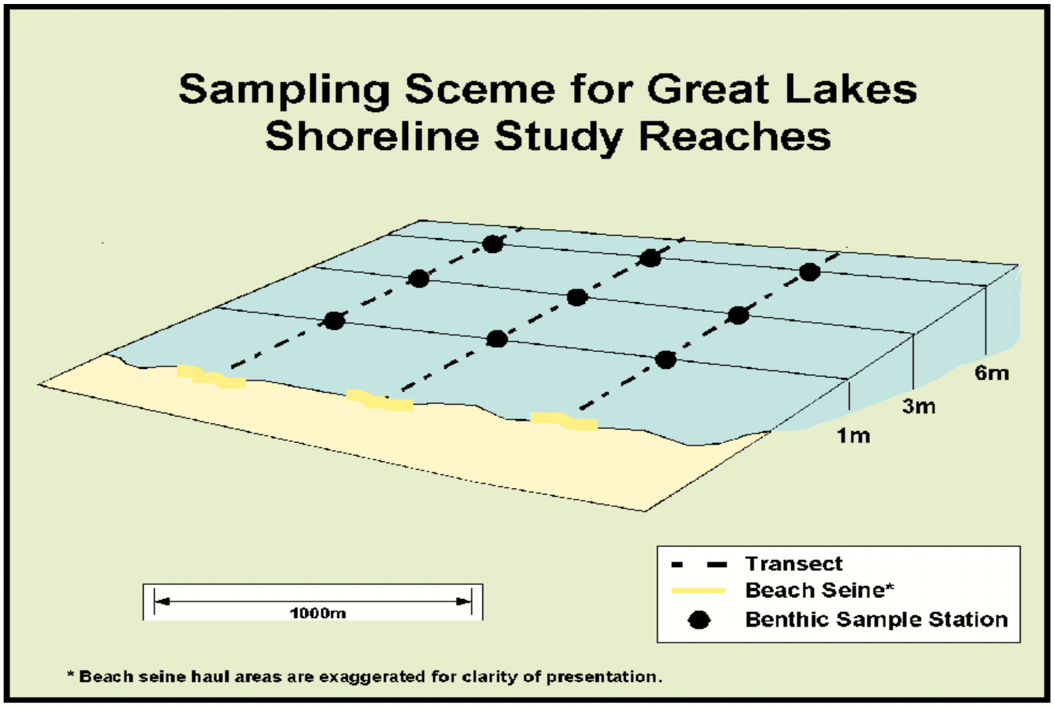

Figure 1. Aquatic community sample design for surveys conducted in selected Great Lakes nearshore areas during 1999 and 2000.

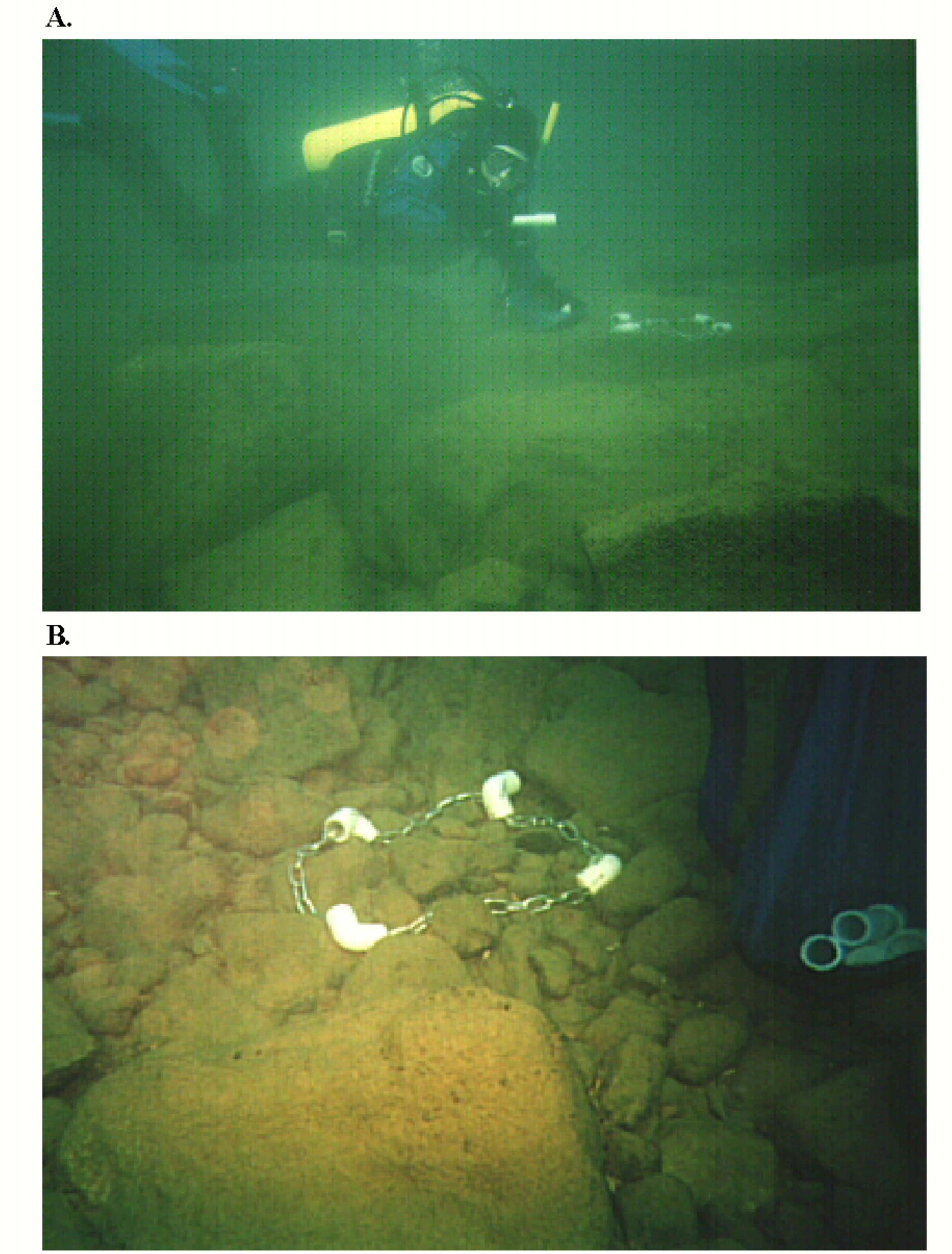

Figure 2. A) MNFI diver collecting hard substrate benthic samples using a custom vacuum sampler. B) Benthic sampling template used to define a fixed sampling area for benthic samples in hard substrate habitats.

dividing the number of invertebrates present in a sample by the area sampled using each technique (i.e., vacuum and Ponar) to provide density measurements for each taxonomic and/or functional group. Benthic species richness measures were also determined for each site to be used in the data analyses. Benthic invertebrates were grouped into functional groups that often fell along formal class divisions (Insects, Gastropods) or other similar groupings (Oligachaeta, Peracarida).

The planktonic invertebrate community was sampled using three vertical tows of a 30-cm diameter, 90-cm long, 80-µm mesh plankton net at each sampling station. For each sample, the plankton net was deployed from the boat and allowed to sink to the lake bottom. It was then towed vertically through the water column, effectively sampling a volume of water from the lake bottom to the surface. Plankton samples were preserved in 95% EtOH and zooplankton were later identified to the lowest feasible taxonomic level and enumerated in the laboratory. Data were standardized by dividing the number of individual zooplankton in each sample by the volume of the water column sampled (i.e., depth multiplied by the area of the net opening) to produce a density measurement (number/m^3) for each taxonomic and/or functional group. Zooplankton were classified primarily by coarse taxonomic groups (Cladocera, Calanoida, and Cyclopoida) as a surrogate for functional group analysis.

Shallow water and nearshore fish communities were sampled using beach seines and gill nets. Three replicate beach seine hauls were used to characterize the shallow water fish communities (i.e., <1m) at each transect. A 10-m, 6.4-mm mesh seine was hauled for a 30-m distance parallel to the shore after dusk for each replicate. Nearshore fish communities were sampled using three limited-duration scientific gillnet (38m) sets. Gillnets were anchored at the 3m depth station along each transect and were deployed from a boat in an offshore direction resulting in a perpendicular orientation with respect to the shoreline. One gillnet was set along each transect after sundown and was fished for a maximum of four hours. Fish captured using the beach seines and gillnets were identified, counted and released. Mortality rates for all fish samples collected were negligible. Beach seine and gillnet data were standardized by calculating catch per unit effort (CPUE) estimates for each sample. These CPUE estimates were used as surrogates for density measures for fish species and overall fish communities. Fish species richness measures were determined for each site, and fish species were classified according to feeding guild (i.e., piscivore, planktivore and benthivore) and species origin (i.e., native, exotic and stocked) for analysis.

An analysis of variance (ANOVA) was conducted using density and CPUE data for each taxonomic group as appropriate (benthic invertebrates, zooplankton and fish). Shoreline type (UQ vs. MB) and lake area (SLE, ELM, WLM) served as main effects in the analysis, including the interaction term (shoreline type X lake). Lake area was included as a main effect due to obvious differences in trophic status among the SLE, ELM and WLM nearshore areas. Significant main effects were further analyzed using a Tukey's HSD test for pairwise differences. An alpha level of 0.05 was used for all statistical tests.

Biological community data were also analyzed based on the substrate stability regime of the survey sites. Sites were grouped into two substrate stability classes (high and low) based on side scan sonar mosaic interpretations conducted by Ohio Geological Survey Division staff to describe site substrate characteristics in 1999 and 2000. ANOVAs were conducted for all biological community data using substrate stability as a main effect to detect significant differences in community structure among sites with varying substrate stability characteristics. An alpha level of 0.05 was used for these statistical tests.

RESULTS

Summary

Biological communities were surveyed in nearshore areas associated with the six Great Lakes shoreline study sites primarily during summer and early fall of 2000 (Table 1). Weather and mechanical problems prevented temporally continuous sampling of all sites, necessitating the use of benthic data from the Painesville, OH, site that were collected during summer 1999. Mean water temperatures at the sites ranged from 8.1 to 24.1 °C, and mean dissolved oxygen (DO) concentrations ranged from 7.9 to 12.8mg O_2/l (Table 2), although temporally discontinuous observations of both temperature and DO precluded any comparisons of these data among shoreline types, lake areas or sites. Benthic samples were comprised of nine coarse taxonomic groups that included 19 morphospecies classifications (Appendix A). Twenty-seven fish species were observed across all survey sites, including seven non-native species (Appendix B). Several of these non-native species, all salmonids, are stocked and managed to support recreational fisheries. Seventeen zooplankton morphospecies/species were observed across all sites, including two non-native species, the fish hook water flea, *Cercopagis pengoi*, and the spiny water flea, *Bythotrephes cederstroemi* (Appendix C). Physical habitats ranged widely in terms of local nearshore substrate composition. Predominant substrates observed among the sites were sands, thin sands (e.g., thin layers of sand over clay), organic-rich sands, muddy-sands, clays, and cobble and boulder glacial deposits (Table 3). Specific ecological properties are detailed in the following site descriptions.

Site Descriptions

Sheldon Marsh, OH

The SM site was characterized by a eutrophic embayment dominated by sand, thin-sand and muddy-sand substrates with isolated areas of exposed clay during summer 2000 (Table 3). Sand loss was comparatively low at SM between 1999 and 2000, and the areal extent of stable sand substrates was the second highest of all sites surveyed (Table 3). The local benthic habitat supported a moderate number of invertebrate morphospecies (10) and moderate overall densities of benthic organisms compared to other nearshore areas sampled (Appendix A and Table 4). The densities and relative abundance values for both oligochaetes and leeches were the highest observed among study sites (Tables 4 and 5). Both taxonomic groups are characteristic of the organic rich sands that dominated SM substrates. Gastropods occurred with the greatest relative abundance at SM (Table 4), although gastropod densities at SM were low compared to most other study sites (Table 5). Numerous spent dreissenid shells were present at the site, although very little favorable habitat was identified within the nearshore reach, and very few live individuals were observed.

The moderately diverse fish community (12 species) of the SM site included taxa that are generally tolerant of warmer, more turbid water conditions, including *Morone chrysops*, *Ictalurus punctatus* and the non-native *Dorosoma cepedianum* (Appendix B). Juvenile stages of many fish species were particularly abundant at the site, suggesting that SM provided suitable nursery habitat for multiple game and non-game fish species. Overall shallow water fish CPUE at SM was the second highest observed (Figure 3), and both *M. chrysops* and *D. cepedianum* occurred with the greatest CPUE and relative abundance observed among sites (Tables 6 and 7). Piscivores occurred with the highest CPUE and relative abundance observed among all sites (Figures 4 and 5), reflecting the importance of the site as significant nursery habitat. Shallow water benthivore CPUE and relative abundance were both comparatively low (Figures 6 and 7, respectively). The SM site was characterized by moderate shallow water planktivorous fish CPUE and relative abundance compared to SLE and ELM sites (Figures 8 and 9). Native shallow water fish CPUE and relative abundance were moderate in comparison with most sites (Figures 10 and 11, respectively). Shallow water non-native fish CPUE and relative abundance measures at SM were both high in comparison with most other shallow water communities sampled (Figures 12 and 13).

Nearshore fish overall CPUE was the highest observed among sites (Figure 14), and nearshore planktivore and piscivore CPUE measures were also high compared to the other nearshore areas sampled (Figures 15 and 16). Nearshore benthivore CPUE was generally similar to other nearshore areas sampled (Figure 17). The relative abundance of nearshore planktivores was comparatively high at the SM site, although much lower than the SJ site (Figure 18). Relative abundance measures for nearshore benthivores were low and piscivore relative abundance measures were generally comparable to other nearshore fish communities sampled (Figures 19 and 20, respectively). Nearshore native fish CPUE was comparatively high at the SM site (Figure 21), and nearshore non-native fish CPUE was the highest observed during the study (Figure 22). The relative abundance of native fish in SM nearshore fish communities was moderately low (Figure 23) and the relative abundance of non-native nearshore fish moderately high (Figure 24) in comparison to other sites surveyed.

Zooplankton taxa richness at SM (10) was comparable to other study sites (Appendix C). Overall SM zooplankton, cladoceran, *Daphnia sp*, calanoid, cyclopoid and nauplii densities were the highest observed among all study sites (Table 10). This was not surprising given the high productivity of phytoplankton indicated by the murky water conditions. These high densities of plankton contributed to the importance of this site as nursery habitat for fish. The relative abundance measures for SM zooplankton taxa indicated perhaps the most even zooplankton community observed among sites (Table 11). The relative abundance and density of exotic zooplankters (*B. cederstroemi*) observed at the SM site were very low in comparison to most other nearshore sites sampled (Tables 10 and 11).

Painesville, OH

The PV site's substrates were primarily thin sand over clay (61%), sand (23%) and cobble/boulder glacial deposits (16%) based on side scan sonar data collected during Summer 2000. Sand loss between 1999 and 2000 at the PV site was the second largest observed (30%) (Table 3). Benthic communities at the PV site were characterized by the lowest morphospecies richness observed (4), and included insects, primarily chrionomids with some *Stenonema sp.* (Insecta, Ephemeroptera, Heptageniidae), amphipods and zebra mussels (Appendix A). Overall

Table 1. Biological sample dates for nearshore areas in Lakes Erie and Michigan during the summers of 1999 and 2000. P = benthic Ponar grab sample; V = benthic vacuum sample. *Benthic invertebrates collected from two transects. **Beach seines and gillnets completed along two transects.

	Study Site					
Taxonomic Group	**Sheldon Marsh**	**Ludington**	**Port Washington**	**Painesville**	**St. Joseph**	**Two Rivers**
Zooplankton	**15-Aug-00**	**24-Aug-00**	**13-Sep-00**	**07-Jun-00**	**22-Aug-00**	**10-Oct-00**
Benthic Invertebrates	**15-Aug-00 (P)**	**24-Aug-00 (P)**	**13-Sep-00 (V/P)**	**10-Aug-99* (V)**	**22-Aug-01 (P)**	**10-Oct-00 (V/P)**
Shallow Water Fish (Beach Seines)	**15-Aug-00**	**24-Aug-00**	**12-Sep-00**	**3-Oct-00****	**21-Aug-00**	**26-Sep-00**
Nearshore Fish (Gillnets)	**15-Aug-00**	**24-Aug-00**	**12-Sep-00**	**7-Jun-00****	**21-Aug-00**	**25-Sep-00**

Table 2. Mean water temperature and dissolved oxygen measures for nearshore study sites in Lakes Erie and Michigan at the time biological community samples were collected during the summer of 2000.

Study Site	**Sample Date**	**Water Temperature (°C)**	**Dissolved O_2 (mg O_2/l)**
Sheldon Marsh	**15-Aug-00**	**24.1**	**7.9**
Painesville	**07-Jun-00**	**16.2**	**9.6**
Ludington	**24-Aug-00**	**19.6**	**8.9**
St. Joseph	**22-Aug-00**	**19.4**	**8.9**
Port Washington	**13-Sep-00**	**10.1**	**9.5**
Two Rivers	**10-Oct-00**	**8.1**	**12.8**

Table 3. Substrate compositions and characteristics (% of survey area) of nearshore areas adjacent to six Great Lakes shorelines surveyed during summer 2000. Substrate data were interpreted from side-scan sonar mosaics. Classifications of sites according to overall substrate stability and associated shoreline types are provided. Sites surveyed include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Survey Site					
Substrate Type	**SM**	**PV**	**LD**	**SJ**	**PW**	**TR**
Sand Substrates (% of site)	**65**	**23**	**100***	**66**	**34**	**17**
Thin-Sand Substrates (% of site)	**18**	**61**	**0**	**24**	**25**	**49**
Muddy-Sand Substrates (% of site)	**17**	**0**	**0**	**9**	**0**	**0**
Cobble/Boulder Substrates (% of site)	**0**	**14**	**0**	**0**	**41**	**35**
Substrate Change, 1999 to 2000 (% of site)	**21**	**12**	**0**	**25**	**9**	**31**
Sand Lost (% of 1999 sand)	**14**	**30**	**0**	**17**	**15**	**56**
Area of Stable Sand Substrate (% of site)	**63**	**13**	**100***	**57**	**37**	**13**
Substrate Stability Class	**High**	**Low**	**High**	**High**	**High**	**Low**
Shoreline Class	**Unique**	**Mid-Bluff**	**Unique**	**Mid-Bluff**	**Unique**	**Mid-Bluff**

* Actual sand composition and substrate stability for the LD site are unknown, but are assumed to be high in comparison to other sites given the near-infinite extent of the sand sheet in the vicinity of the shoreline reach surveyed.

Table 4. Mean densities (±1 standard error) of benthic taxonomic groups observed in nearshore areas of six Great Lakes shorelines surveyed during the summers of 1999 and 2000. Sites surveyed include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Study Site					
Taxonomic Group	**SM**	**PV**	**LD**	**SJ**	**PW**	**TR**
Insects	**88.6±19.9**	**42.3±21.2**	**228.7±41.4**	**531.4±87.9**	**269.9±91.8**	**15.6±3.1**
Chironomidae larvae	**87.0±20.1**	**42.3±21.2**	**219.0±41.0**	**508.9±85.2**	**268.9±91.9**	**12.6±3.0**
Oligachaetes	**219.0±71.0**		**8.1±4.0**	**202.9±67.9**	**88.0±36.9**	**11.5±9.1**
Amphipods/Isopods	**1.6±1.6**	**14.1±14.1**			**470.1±262.4**	**472.7±136.9**
Leeches	**61.2±31.5**				**23.6±11.7**	
Crayfish					**4.8±3.5**	
Sphaerid clam	**4.8±4.8**		**3.2±3.2**	**1.6±1.6**	**4.8±4.8**	
Zebra mussel	**17.7±10.7**	**28.2±11.2**			**6.9±4.9**	**12.0±6.4**
Gastropods	**4.8±3.5**		**6.4±3.8**	**1.6±1.6**	**5.4±2.5**	**15.0±10.9**
Total Density of Benthos	**397.7±86.6**	**84.6±35.1**	**246.4±45.4**	**737.5±145.1**	**873.6±262.0**	**526.9±163.3**

Table 5. Mean relative abundance (±1SE) measures for benthic taxonomic groups observed in nearshore areas of six Great Lakes shorelines surveyed during the summers of 1999 and 2000. Sites surveyed include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Study Site					
Taxonomic Group	**SM**	**PV**	**LD**	**SJ**	**PW**	**TR**
All Insects	**0.29±0.07**	**0.25±0.01**	**0.82±0.07**	**0.72±0.07**	**0.42±0.08**	**0.09±0.04**
Chironomidae Larvae	**0.29±0.07**		**0.78±0.07**	**0.66±0.07**	**0.40±0.07**	**0.04±0.02**
Oligachaetes	**0.37±0.08**		**0.02±0.01**	**0.16±0.05**	**0.18±0.06**	**0.05±0.04**
Amphipods/Isopods	**0.04±0.04**	**0.04±0.04**			**0.25±0.08**	**0.58±0.09**
Leeches	**0.07±0.03**				**0.05±0.03**	
Crayfish					**<0.01**	
Sphaerid Clams	**0.01±0.01**		**<0.01**	**<0.01**	**<0.01**	
Zebra Mussels	**0.07±0.03**	**0.26±0.12**			**<0.01**	**0.01±0.01**
Gastropods	**0.04±0.03**		**0.01±0.01**	**<0.01**	**<0.01**	**0.02±0.01**

Table 6. Mean (±1SE) relative abundance measures for fish species observed in beach seine hauls conducted during surveys of shallow water fish communities associated with six Great Lakes shoreline areas. Densities are also provided for fishes grouped according to trophic status and origin. Survey sites include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Shallow Water Species																
Site	**Yellow Perch**	**Small-mouth Bass**	**White Bass**	**Gizzard Shad**	**Golden Red-horse**	**White Perch**	**Rainbow Trout**	**Emerald Shiner**	**Spottail Shiner**	**Brook Silver-side**	**Trout-perch**	**Banded Killifish**	**Long-nose Dace**	**Mottled Sculpin**	**Rainbow Smelt**	**Alewife**	**Round Goby**
SM			**0.19±0.06**	**0.58±0.09**		**0.06±0.03**		**0.12±0.11**	**<0.01**	**<0.01**							**0.04±0.04**
PV						**0.02±0.02**	**0.02±0.02**	**0.55±0.45**	**0.17±0.17**						**0.02±0.02**		**0.19±0.19**
LD	**<0.01**		**0.03±0.03**	**0.03±0.01**				**0.08±0.07**	**0.54±0.18**	**0.08±0.03**	**<0.01**		**<0.01**		**0.02±0.02**	**0.24±0.13**	
SJ	**0.02±0.02**	**0.01±0.01**			**0.04±0.04**			**0.10±0.04**	**0.22±0.09**	**0.05±0.05**	**0.01±0.01**	**<0.01**	**0.26±0.23**			**0.29±0.10**	
PW										**0.03±0.03**			**0.90±0.09**			**0.07±0.06**	
TR									**<0.01**				**0.93±0.04**	**0.02±0.02**		**0.05±0.05**	

Table 7. Mean (±1SE) catch per unit effort (number individuals/beach seine haul) for fish species observed during surveys of shallow water fish communities associated with six Great Lakes shoreline areas. Survey sites include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Shallow Water Species																	
Site	**Yellow Perch**	**Smallmouth Bass**	**White Bass**	**Gizzard Shad**	**Golden Redhorse**	**White Perch**	**Rainbow Trout**	**Emerald Shiner**	**Spottail Shiner**	**Brook Silverside**	**Trout-perch**	**Banded Killifish**	**Longnose Dace**	**Mottled Sculpin**	**Rainbow Smelt**	**Alewife**	**Round Goby**	**Overall CPUE**
SM			**20.3±11.6**	**88.3±50.2**		**5.0±2.1**		**18.7±14.8**	**0.3±0.3**	**0.7±0.7**							**0.7±0.7**	**134.0±65.7**
PV			**0.7±0.8**			**0.3±0.4**	**0.3±0.4**	**3.0±1.2**	**3.3±4.1**						**0.3±0.4**		**3.7±4.5**	**11.7±9.4**
LD	**0.7±0.7**			**7.7±6.7**				**34.3±32.4**	**67.0±20.6**	**11.7±7.2**	**0.3±0.3**		**0.3±0.3**		**1.7±0.9**	**85.7±72.5**		**209.3±132.4**
SJ	**0.3±0.3**	**0.3±0.3**			**0.7±0.7**			**13.7±12.2**	**25.0±22.0**	**10.0±10.0**	**0.3±0.3**	**0.3±0.3**	**7.3±6.8**			**29.3±24.4**		**87.3±64.4**
PW										**0.3±0.3**			**72.7±32.5**			**1.3±0.7**		**74.3±31.8**
TR									**0.3±0.3**				**43.7±18.9**	**1.0±1.0**		**0.7±0.3**		**45.7±19.4**

Table 8. Mean (±1SE) catch per unit effort (CPUE) measures for fish species observed in gill nets fished during surveys of nearshore fish communities associated with six Great Lakes shoreline areas. CPUE measures are also provided for fishes grouped according to trophic status and origin. Survey sites include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Nearshore Fish Species																
Site	**Yellow Perch**	**Walleye**	**Lake Trout**	**Smallmouth Bass**	**White Bass**	**Gizzard Shad**	**Freshwater Drum**	**White Sucker**	**Longnose Sucker**	**Golden Redhorse**	**Channel Catfish**	**Common Carp**	**White Perch**	**Brown Trout**	**Coho Salmon**	**Chinook Salmon**	**Overall CPUE**
LD						**0.13±0.13**		**0.77±0.77**							**0.13±0.13**	**0.26±0.26**	**1.28±0.78**
PV	**0.11±0.11**	**0.98±0.79**			**2.59±1.03**	**0.21±0.02**	**3.56±2.22**				**2.56±0.11**	**0.10±0.10**					**10.10±1.90**
PW	**0.12±0.12**		**0.34±0.19**					**0.24±0.24**	**0.27±0.14**					**0.34±0.19**		**0.22±0.22**	**1.53±0.53**
SJ	**0.29±0.15**	**0.41±0.05**		**0.22±0.22**		**3.89±1.49**	**1.62±0.59**			**0.41±0.05**						**0.26±0.26**	**7.10±1.91**
SM	**0.14±0.14**	**3.49±1.53**			**1.62±0.44**	**3.06±1.16**	**1.16±0.49**				**1.45±0.46**	**1.45±0.16**	**4.21±1.46**				**16.59±4.48**
TR	**0**														**0.33±0.33**	**0.67±0.67**	**1.00±1.00**

Table 9. Mean (±1SE) relative abundance measures for fish species observed in gill nets fished during surveys of nearshore fish communities associated with six Great Lakes shoreline areas. CPUE measures are also provided for fishes grouped according to trophic status and origin. Survey sites include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Nearshore Fish Species															
Site	**Yellow Perch**	**Walleye**	**Lake Trout**	**Small-mouth Bass**	**White Bass**	**Gizzard Shad**	**Fresh-water Drum**	**White Sucker**	**Long-nose Sucker**	**Golden Redhorse**	**Channel Catfish**	**Common Carp**	**White Perch**	**Brown Trout**	**Coho Salmon**	**Chinook Salmon**
SM	**0.01±0.01**	**0.21±0.05**			**0.10±0.01**	**0.21±0.04**	**0.06±0.02**				**0.09±0.01**	**0.25±0.05**				
PV	**0.01±0.01**	**0.09±0.06**			**0.29±0.16**	**0.021±0.002**	**0.32±0.16**				**0.26±0.06**	**0.01±0.01**				
LD						**0.05±0.05**		**0.29±0.29**							**0.11±0.11**	**0.22±0.22**
SJ	**0.03±0.02**	**0.048±0.002**		**0.03±0.03**		**0.44±0.15**	**0.19±0.07**			**0.048±0.002**						**0.03±0.03**
PW	**0.06±0.06**		**0.17±0.10**					**0.11±0.11**	**0.39±0.31**					**0.17±0.10**		**0.11±0.11**
TR															**0.11±0.11**	**0.22±0.22**

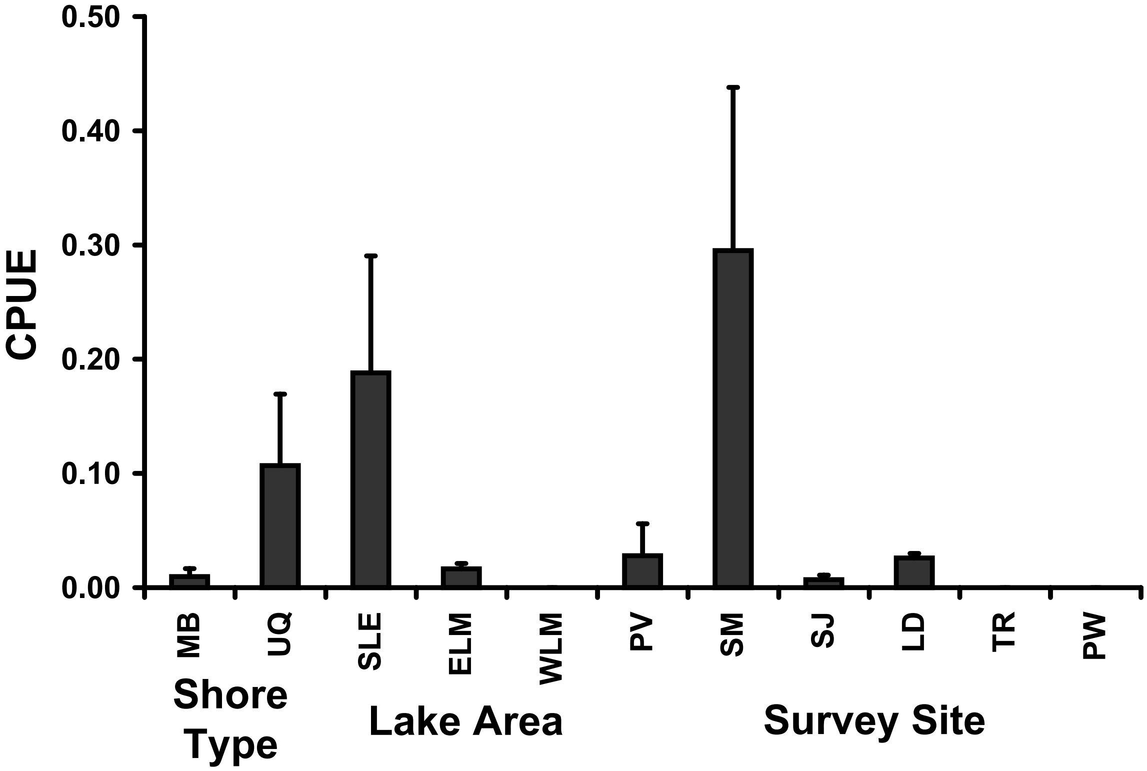

Figure 3. Overall shallow water fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) overall fish CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

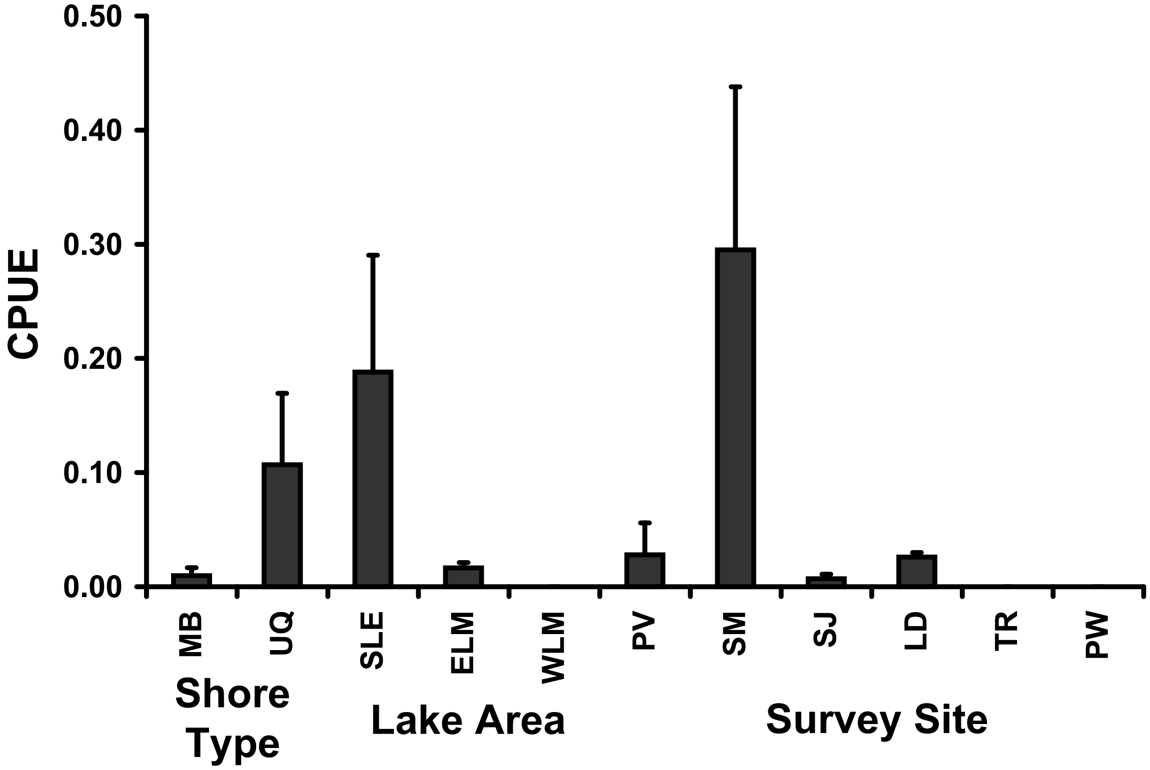

Figure 4. Shallow water piscivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water piscivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

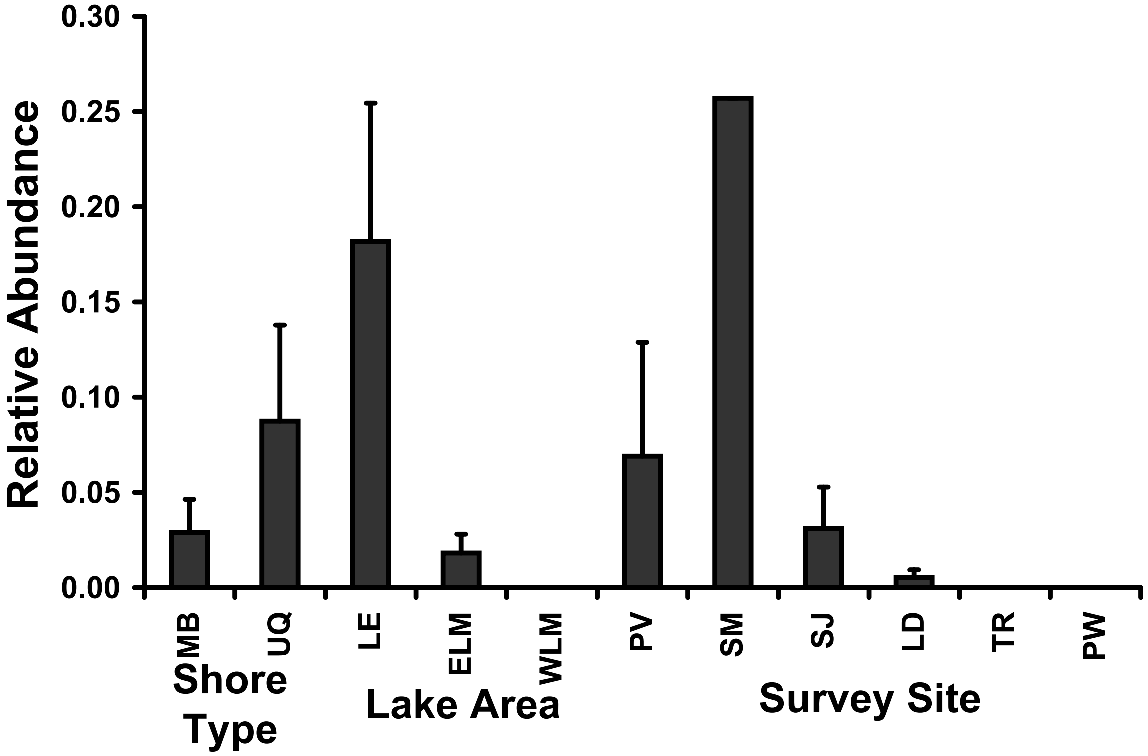

Figure 5. Shallow water piscivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water piscivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

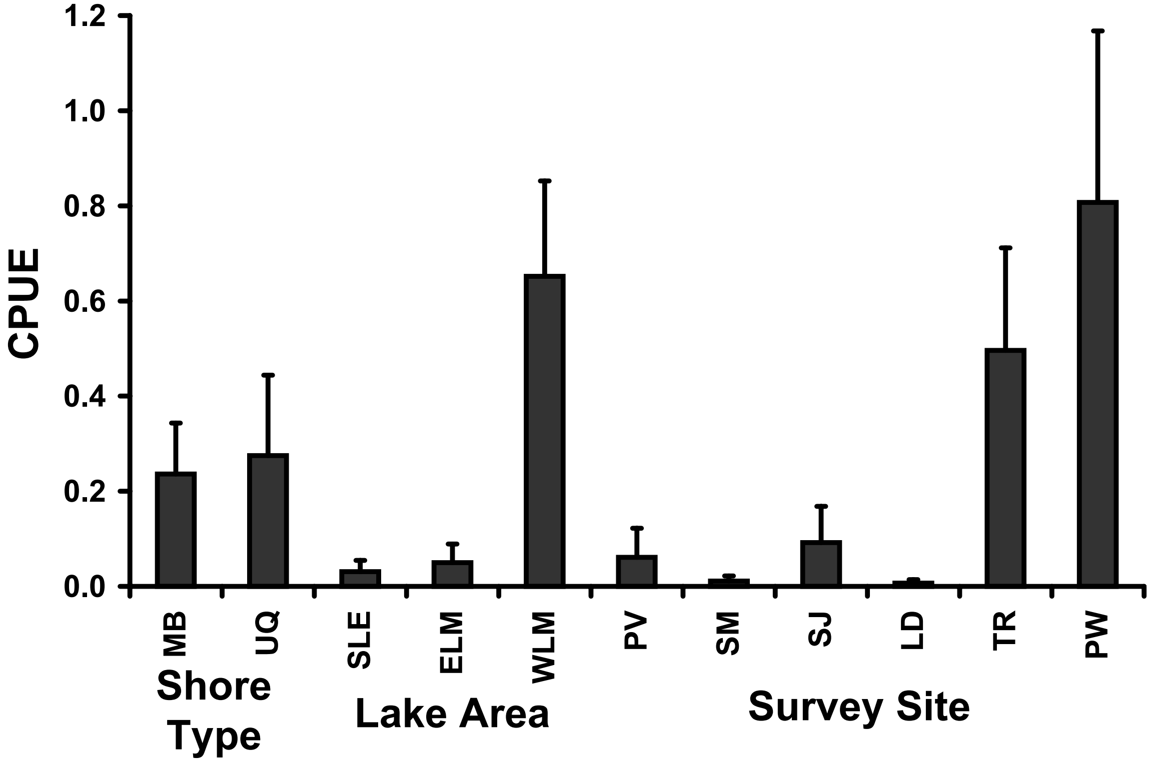

Figure 6. Shallow water benthivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water benthivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

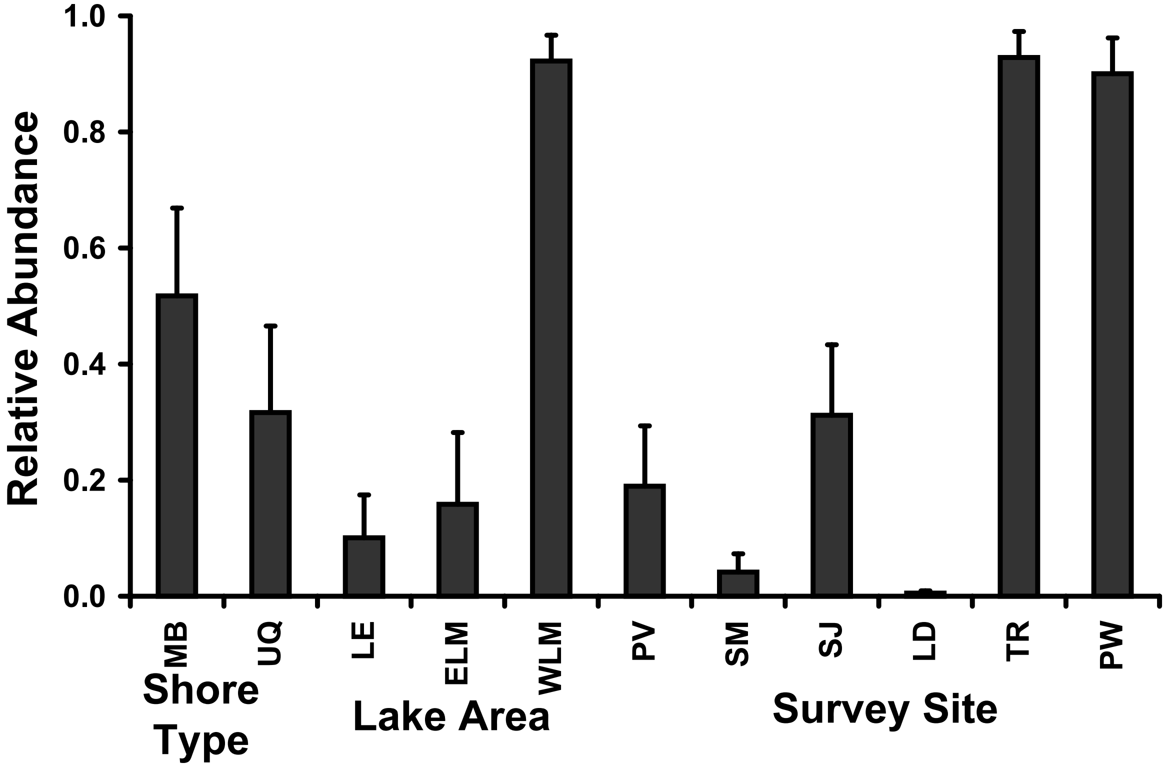

Figure 7. Shallow water benthivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water benthivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

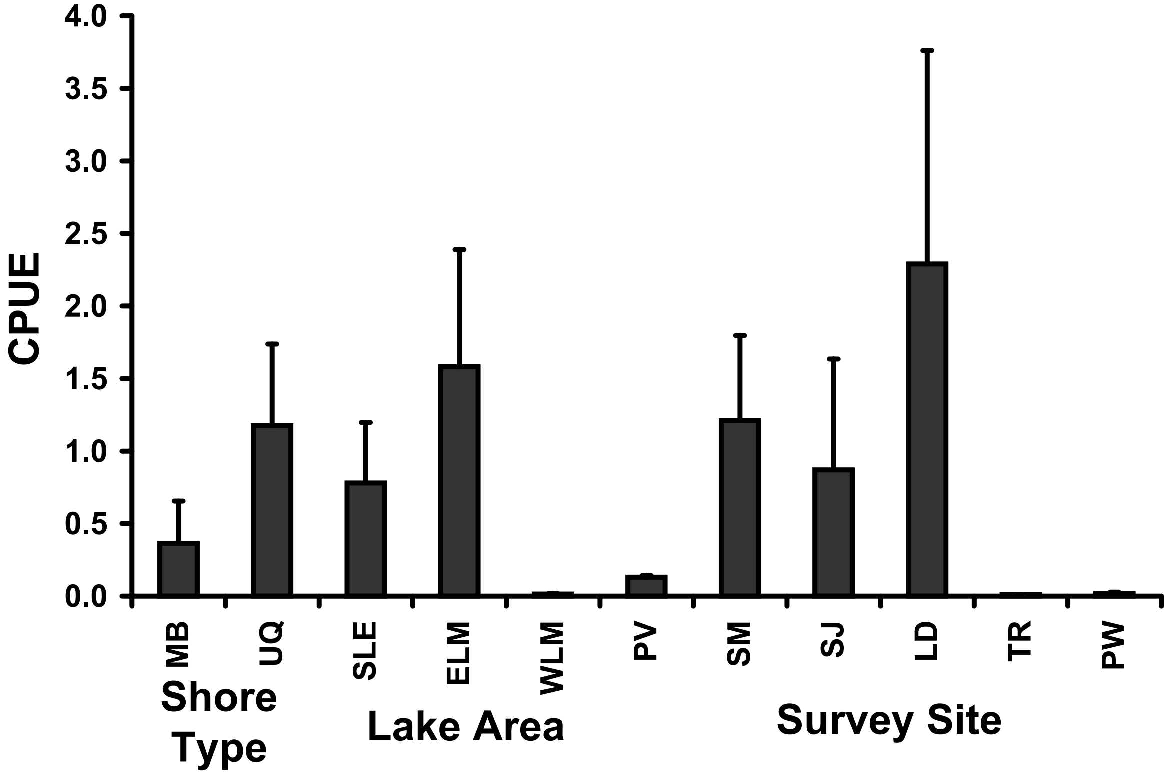

Figure 8. Shallow water planktivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water planktivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

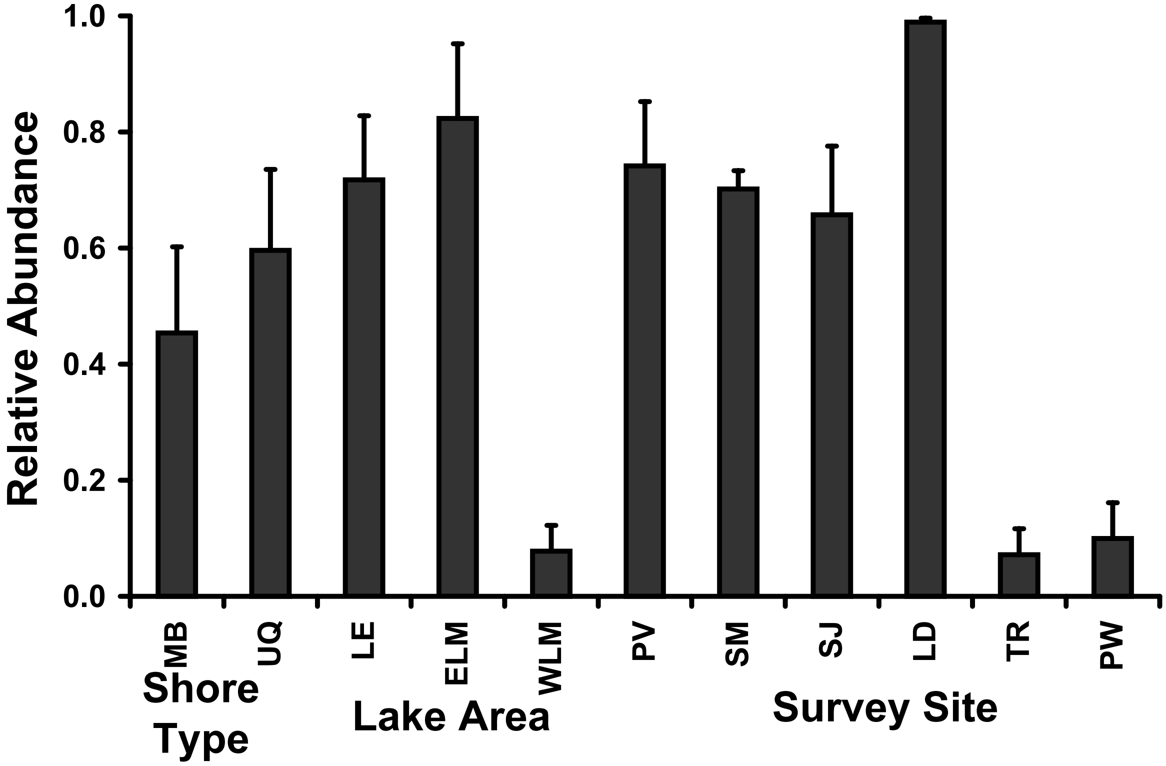

Figure 9. Shallow water planktivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water planktivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

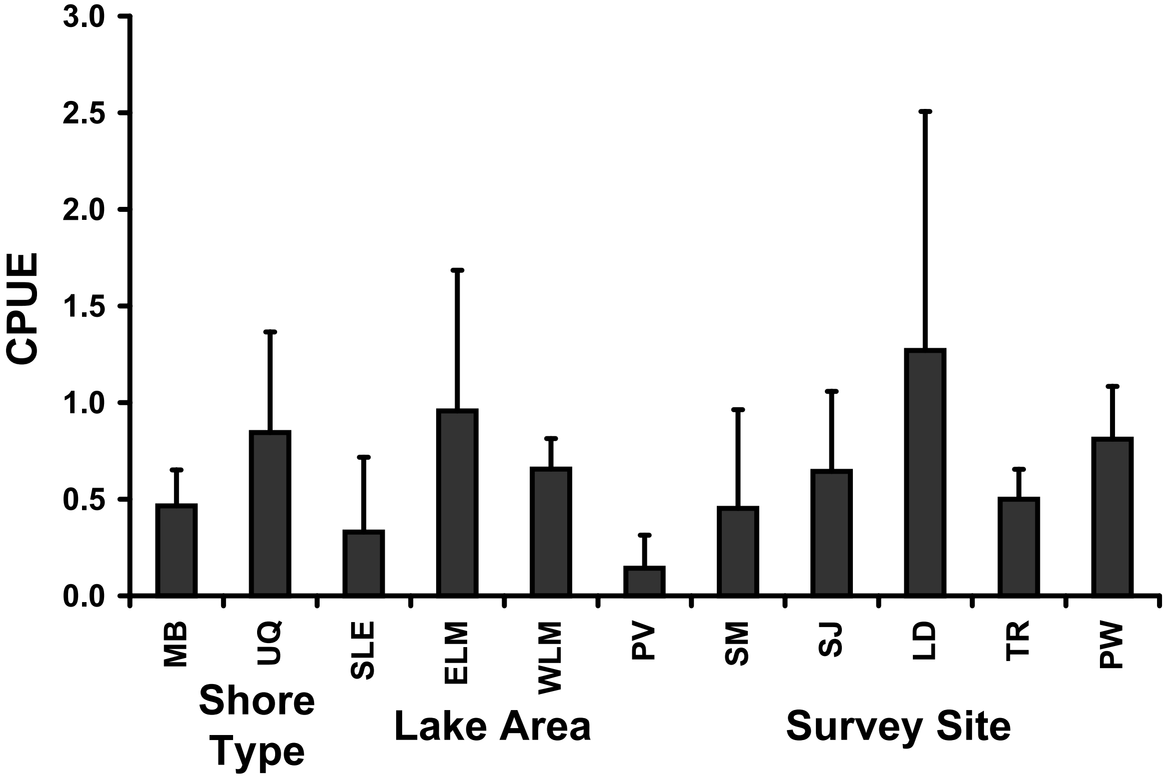

Figure 10. Shallow water native fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water native fish CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

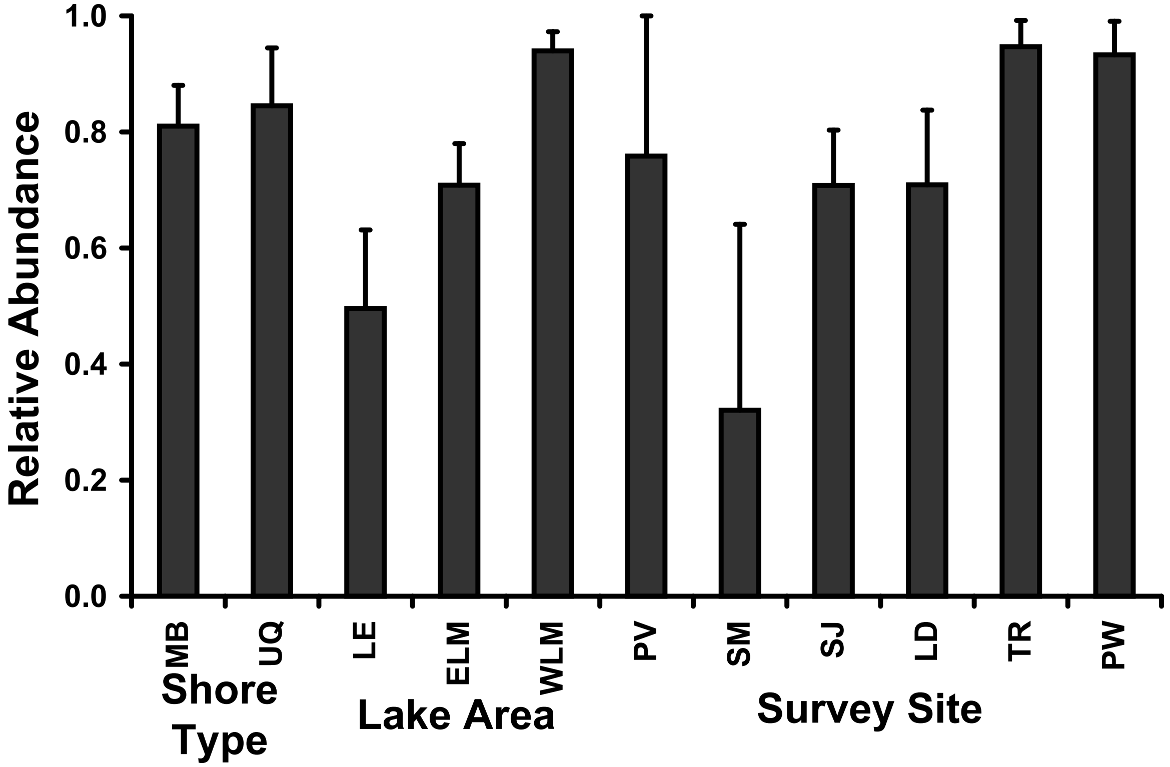

Figure 11. Shallow water native fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water native fish relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

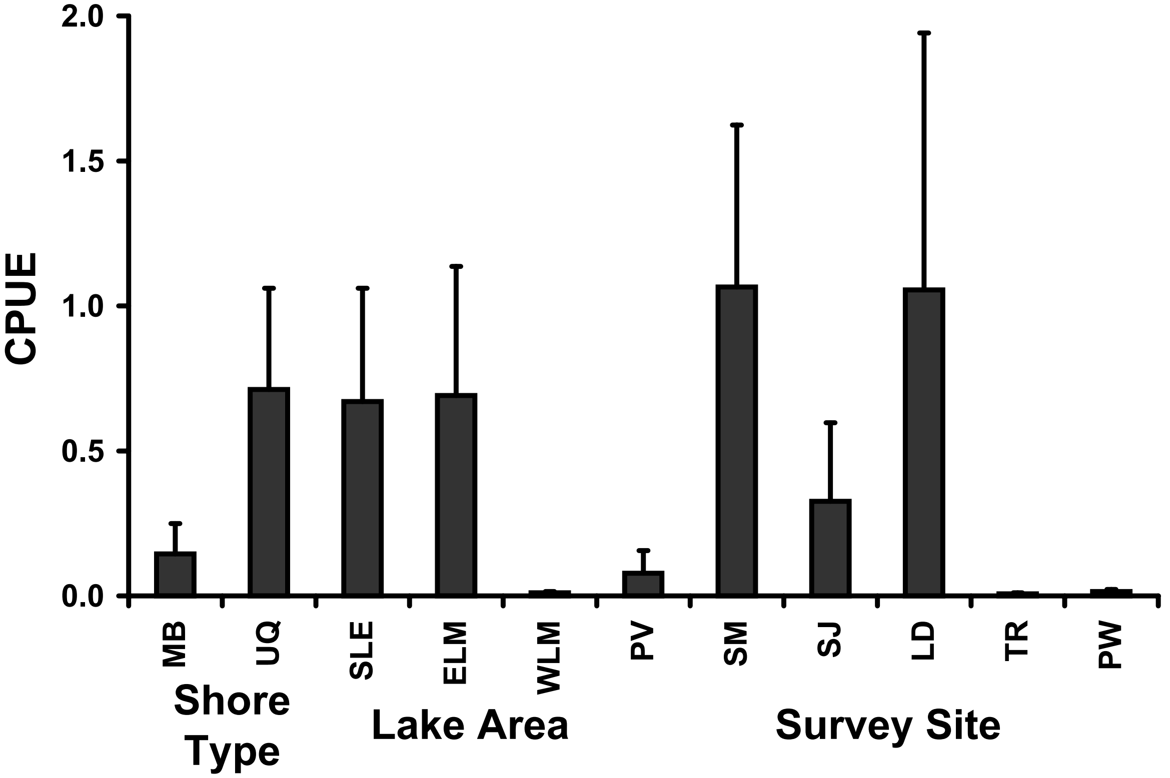

Figure 12. Shallow water non-native fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean shallow water non-native fish CPUE values (±1 SE) are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

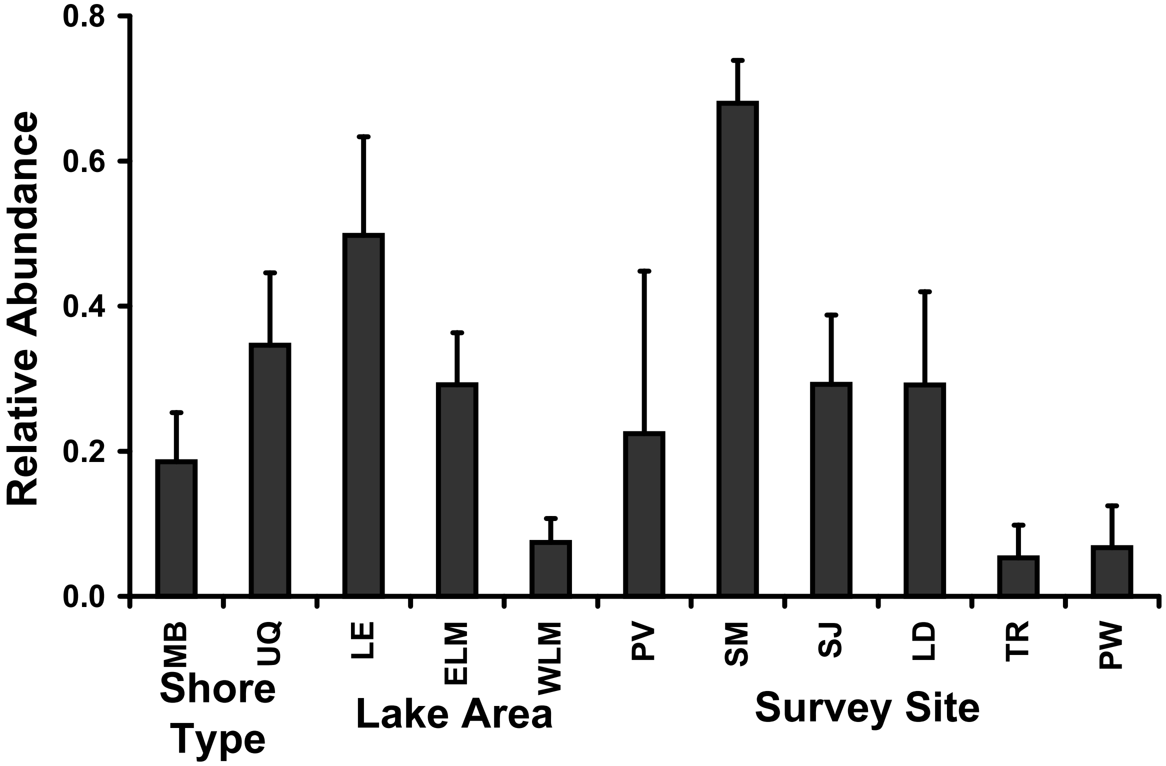

Figure 13. Shallow water non-native fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) shallow water non-native fish relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

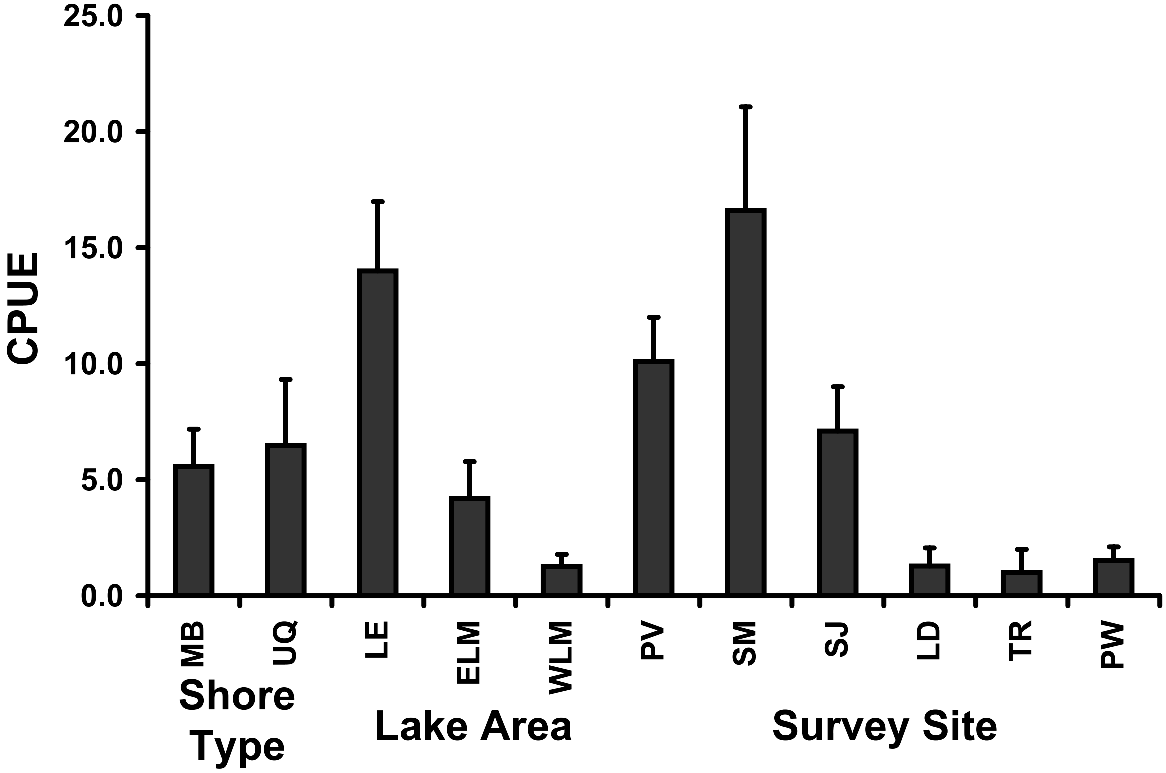

Figure 14. Overall nearshore fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) overall nearshore fish CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

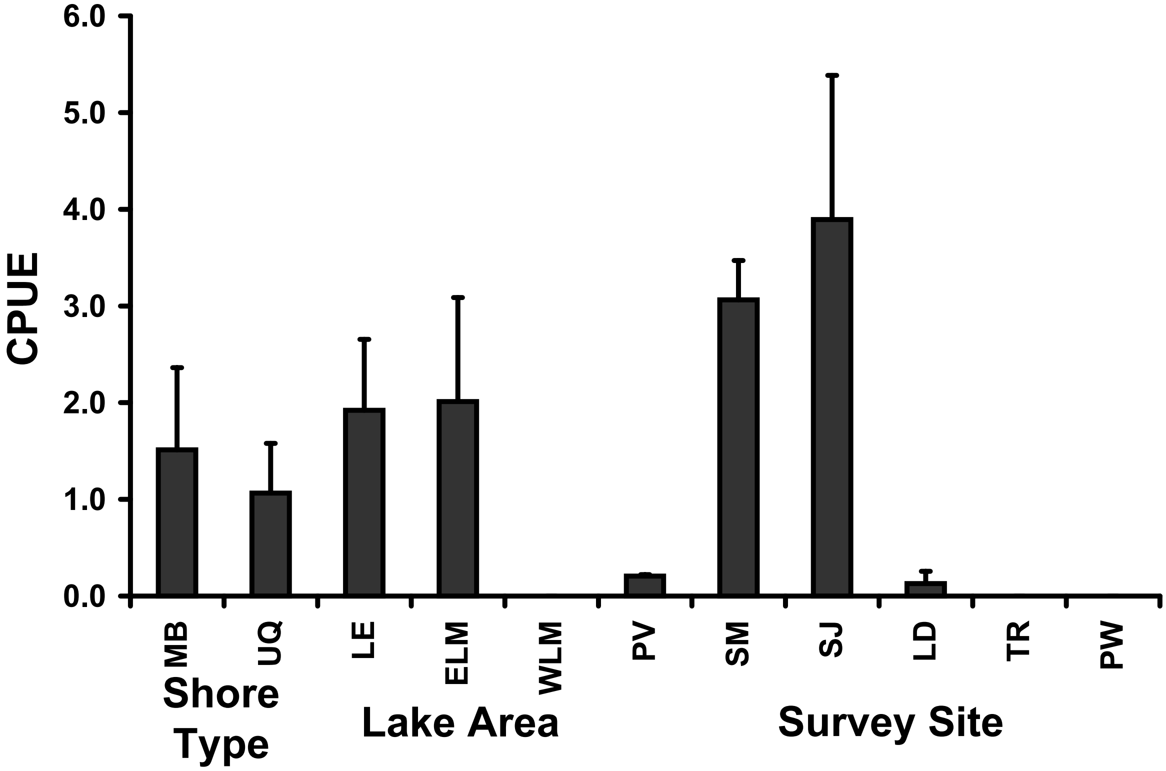

Figure 15. Nearshore planktivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore planktivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

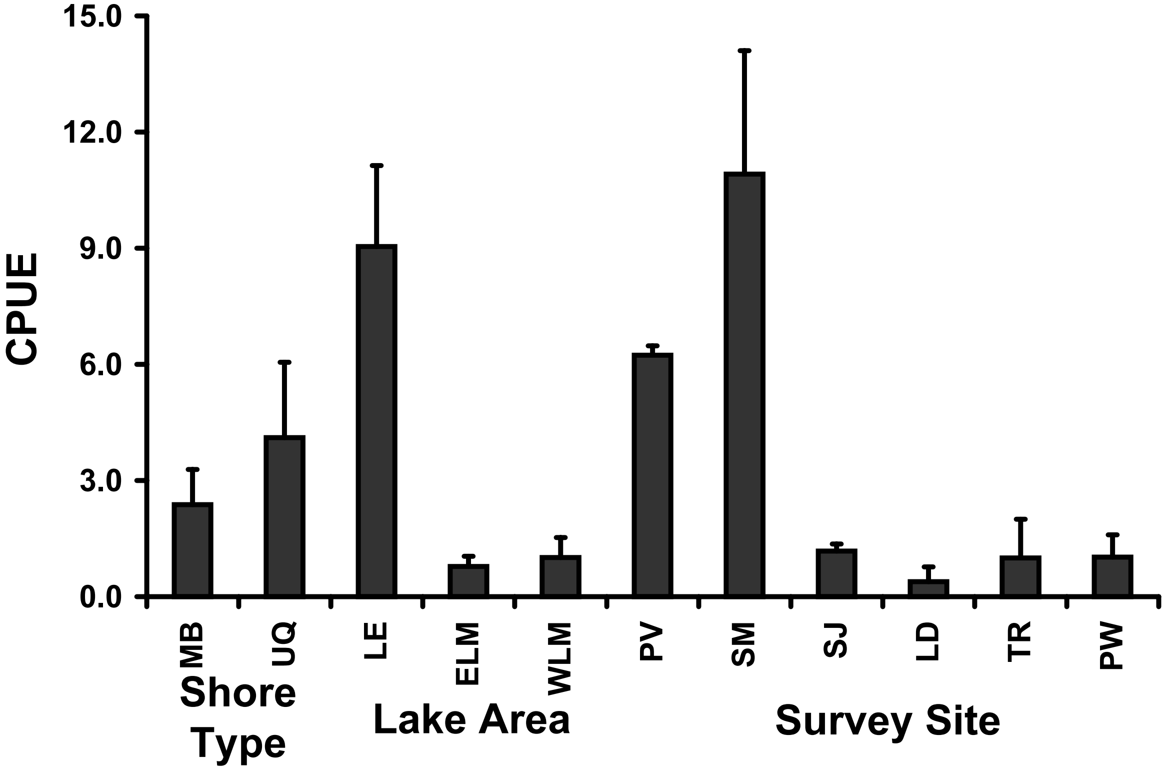

Figure 16. Nearshore piscivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore piscivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

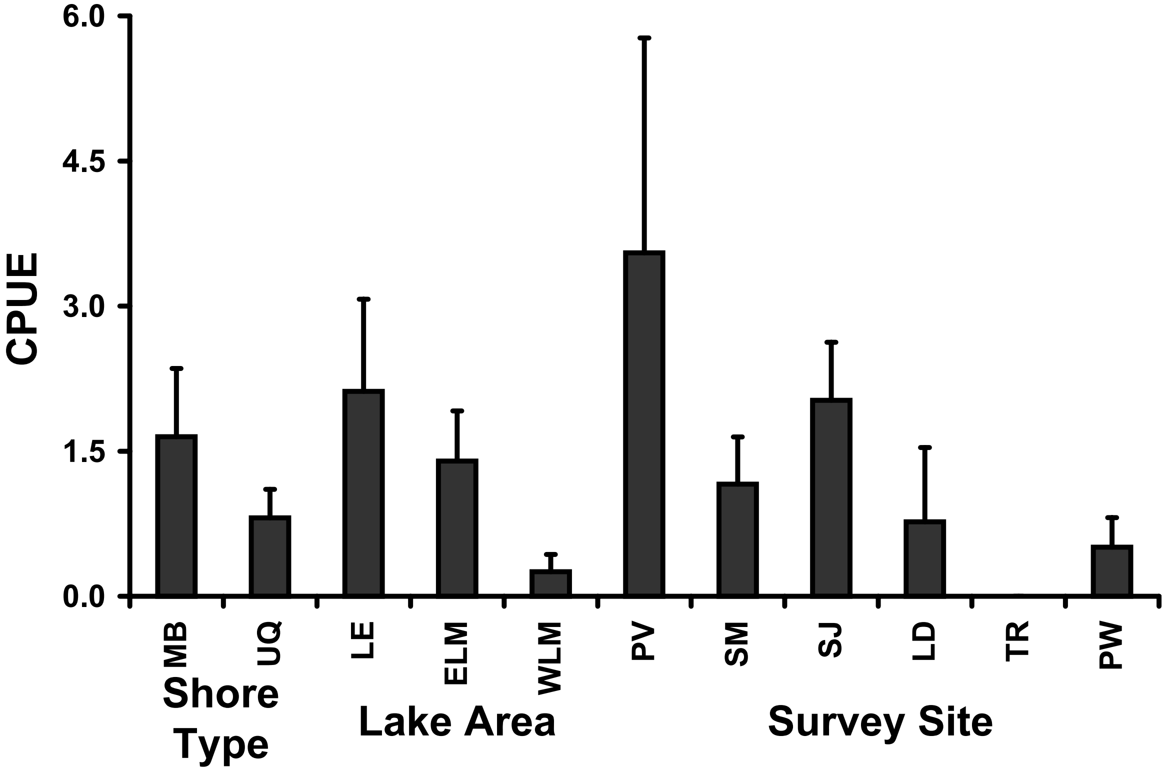

Figure 17. Nearshore benthivorous fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore benthivore CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

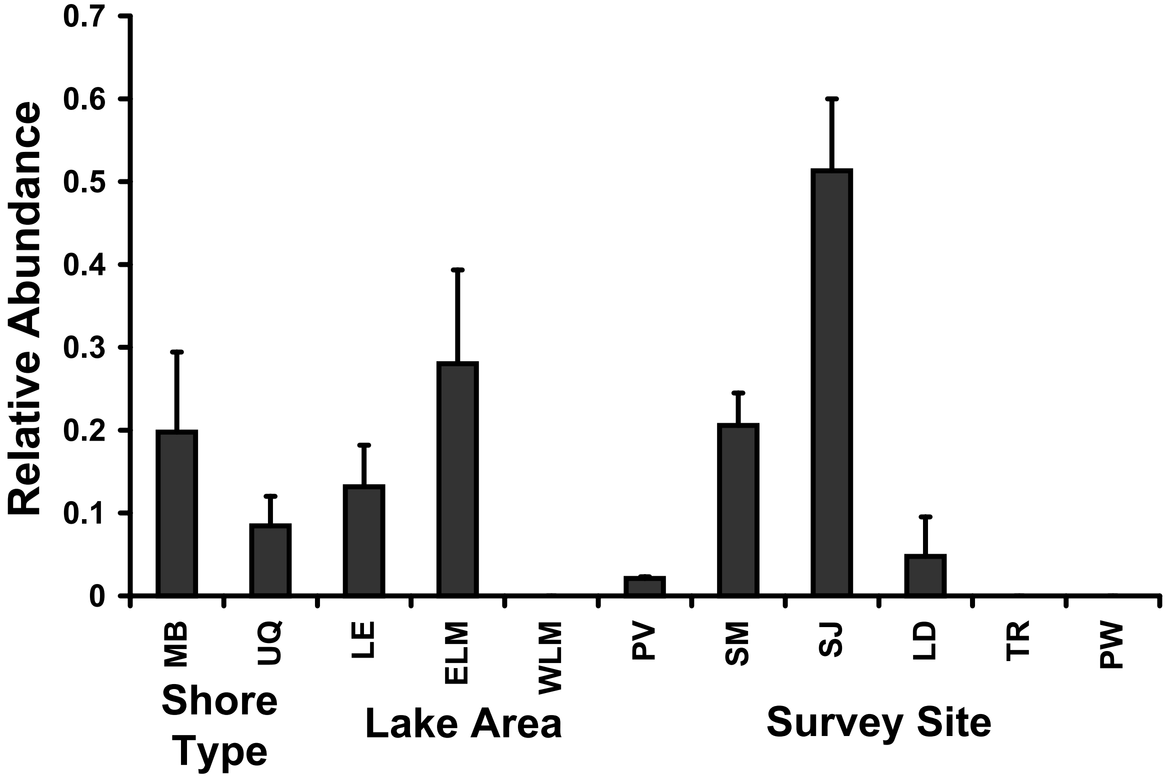

Figure 18. Nearshore planktivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore planktivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

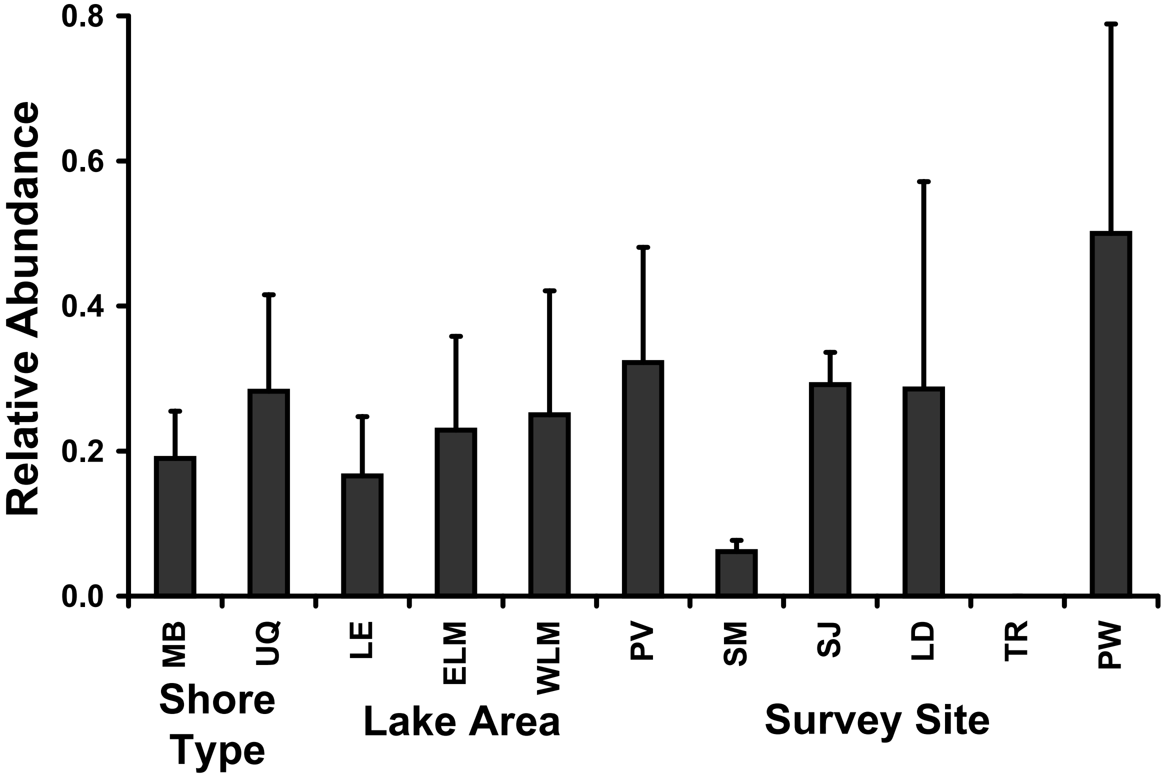

Figure 19. Nearshore benthivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore benthivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

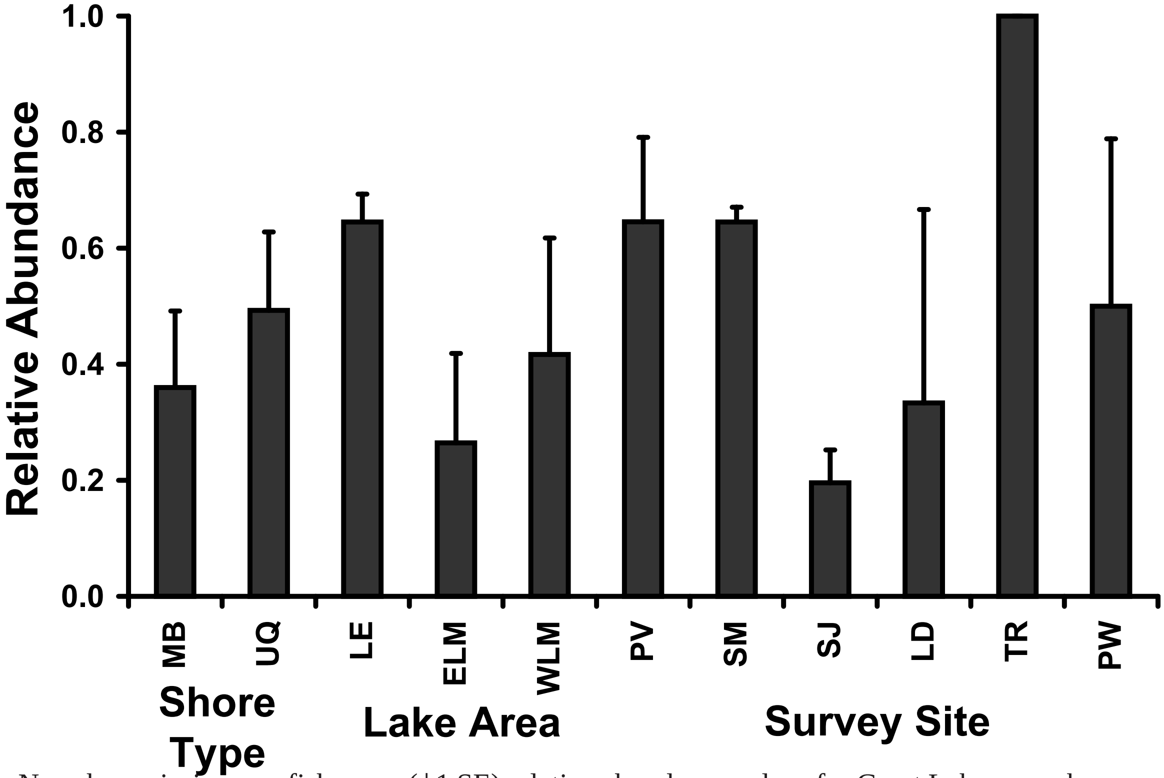

Figure 20. Nearshore piscivorous fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore piscivore relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

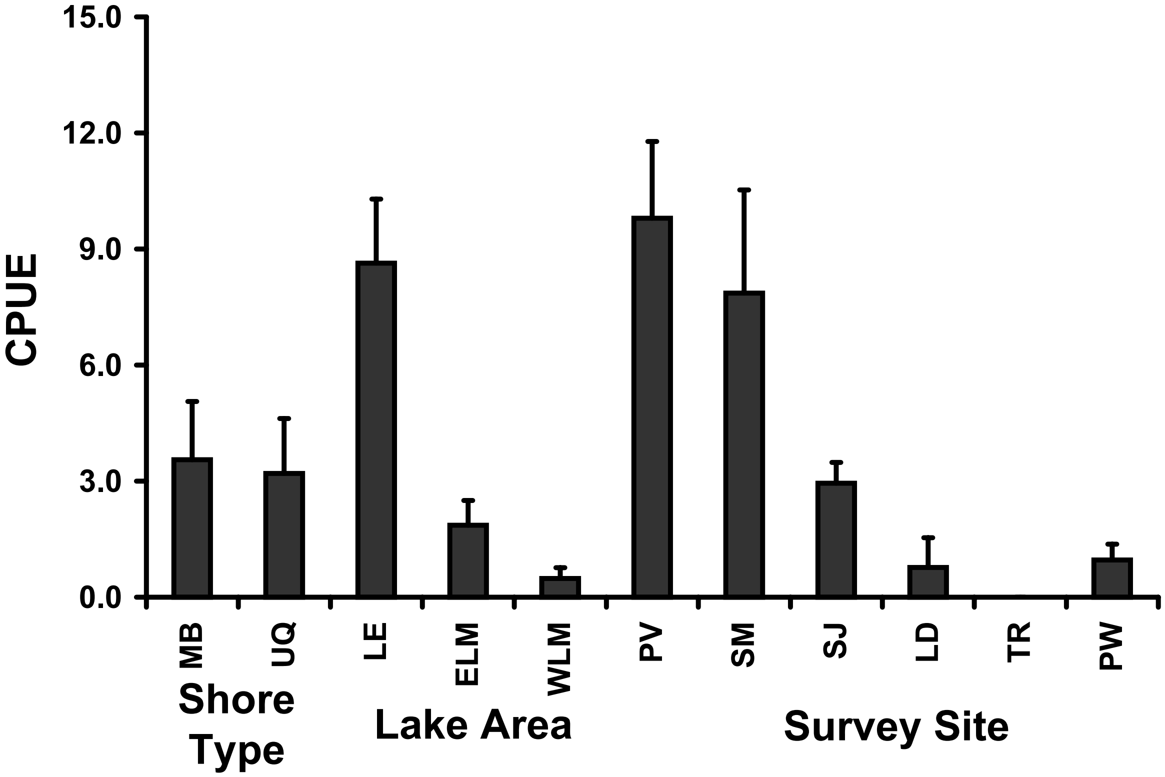

Figure 21. Nearshore native fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore native fish CPUE values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

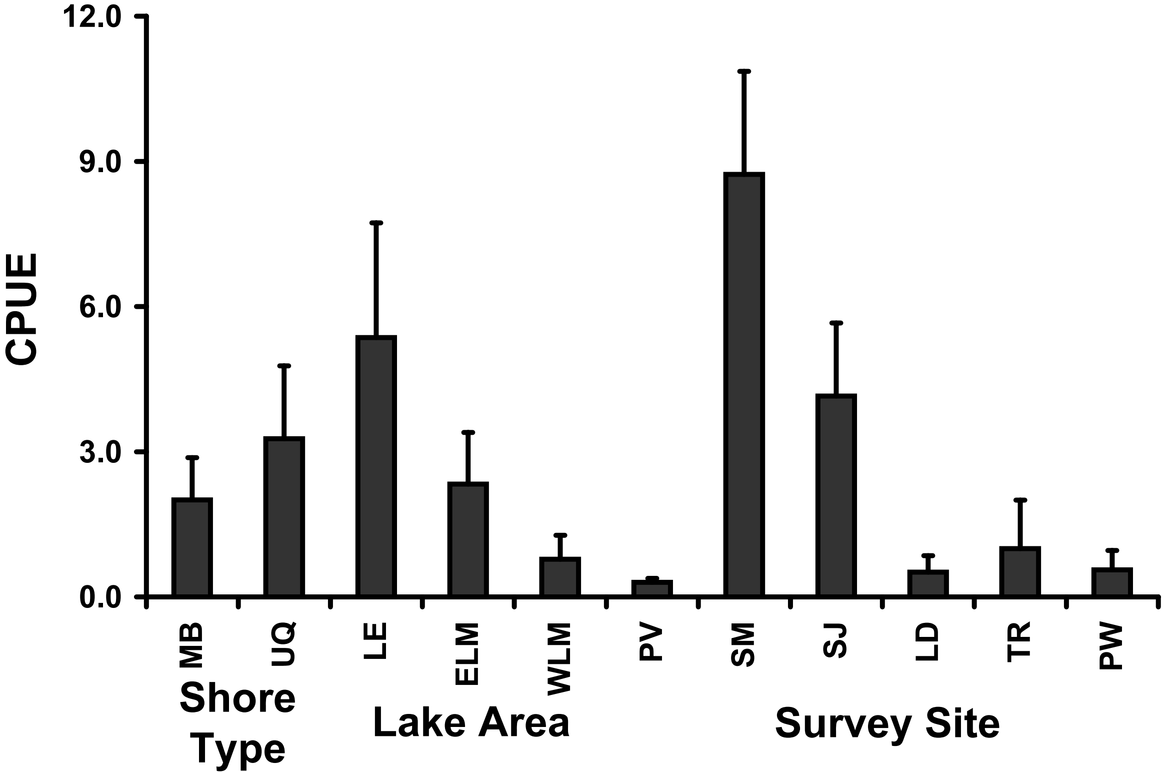

Figure 22. Shallow water non-native fish mean (±1 SE) catch per unit effort (CPUE) values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean nearshore non-native fish CPUE values (±1 SE) are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

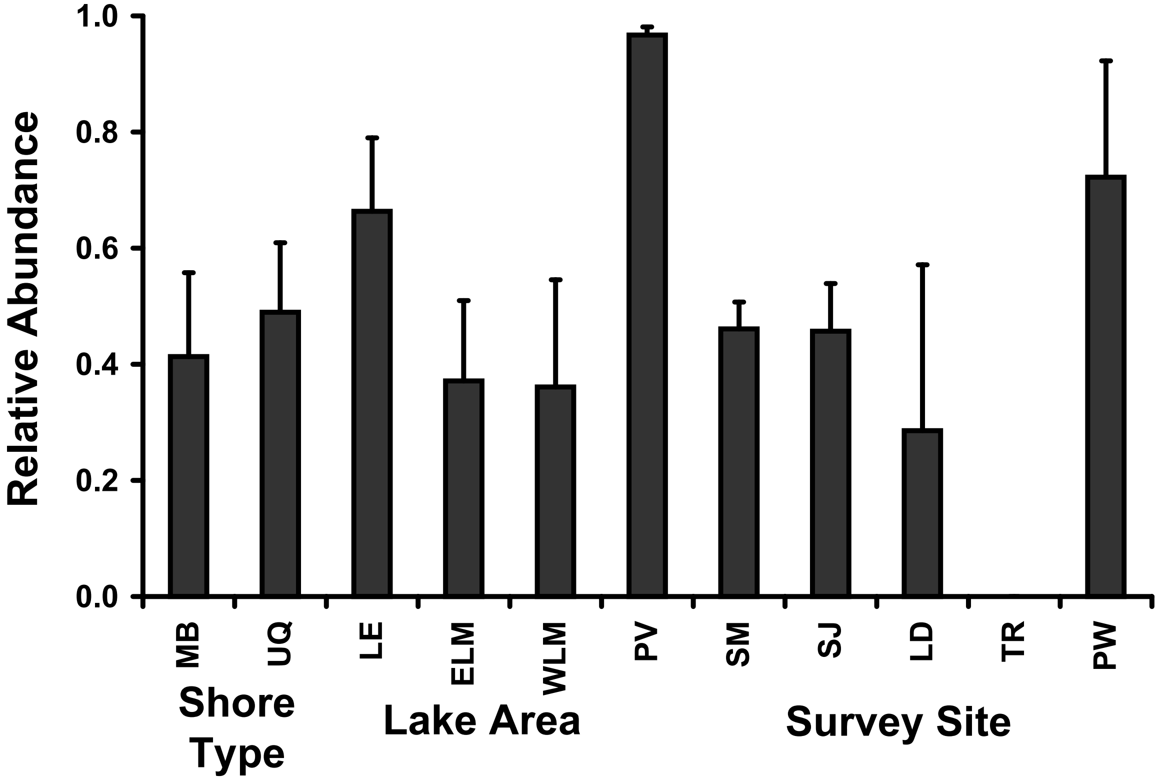

Figure 23. Nearshore native fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore native fish relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

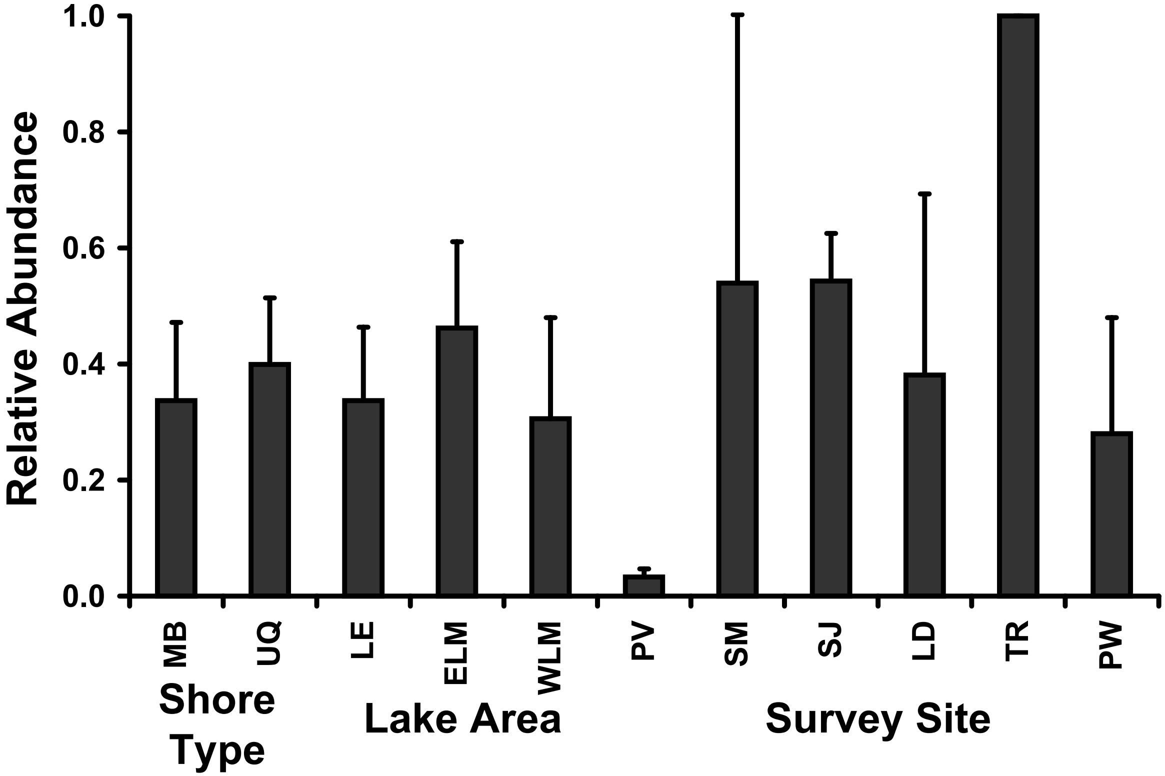

Figure 24. Nearshore non-native fish mean (±1 SE) relative abundance values for Great Lakes nearshore areas associated with shorelines at Painesville, OH (PV), Sheldon Marsh, OH (SM), Saint Joseph, MI (SJ), Ludington, MI (LD), Two Rivers, WI (TR) and Port Washington, WI (PW). Mean (±1 SE) nearshore non-native fish relative abundance values are provided for sites grouped by shoreline type, mid-bluff (MB) and unique (UQ), as well as lake area, including southern Lake Erie (SLE), eastern Lake Michigan (ELM) and western Lake Michigan (WLM).

Table 10. Mean densities (±1 standard error) of major zooplankton taxonomic groups observed in nearshore areas of six Great Lakes shorelines surveyed during the summers of 1999 and 2000. Sites surveyed include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Study Site					
Taxonomic Group	**LD**	**PV**	**PW**	**SJ**	**SM**	**TR**
Exotic Species	**2.3±0.9**	**0.04±0.04**	**1.4±1.0**	**63.3±11.1**	**0.2±0.1**	**0.01±0.01**
Cladocerans	**19.0±3.4**	**717.6±141.8**	**25.7±12.4**	**11.4±2.8**	**1428.1±170.4**	**9.6±3.5**
Daphnia	**0.7±0.6**	**43.3±7.8**	**2.7±0.9**	**0.5±0.3**	**950.9±94.2**	**5.3±3.5**
Calanoids	**12.0±2.6**	**36.0±13.7**	**64.7±15.3**	**2.7±0.7**	**590.3±65.9**	**50.1±5.3**
Cyclopoids	**5.0±1.5**	**258.7±40.7**	**103.9±29.3**	**3.0±0.7**	**381.4±53.5**	**26.8±5.6**
Harpacticoid	**0±0**	**0.4±0.3**	**1.1±0.8**	**0±0**	**0±0**	**0.07±0.05**
Nauplii	**27.7±5.2**	**4.2±1.4**	**242.0±56.5**	**7.0±2.3**	**946.0±139.8**	**74.5±7.6**
Total Zooplankton	**66.7±8.8**	**1060.3±148.2**	**441.5±92.5**	**87.9±13.3**	**4297.0±415.0**	**166.4±15.0**

Table 11. Mean relative abundance (±1 strandard error) of zooplankton taxonomic groups observed in nearshore areas of six Great Lakes shorelines surveyed during the summers of 1999 and 2000. Sites surveyed include Ludington, MI (LD); Painesville, OH (PV); Port Washington, WI (PW); Saint Joseph, MI (SJ); Sheldon Marsh, OH (SM); and Two Rivers, WI (TR).

	Study Site					
Taxonomic Group	**LD**	**PV**	**PW**	**SJ**	**SM**	**TR**
Exotic Species	**0.04±0.01**	**<0.01**	**<0.01**	**0.68±0.05**	**<0.01**	**<0.01**
Cladocerans	**0.29±0.04**	**0.64±0.04**	**0.04±0.01**	**0.13±0.03**	**0.32±0.02**	**0.05±0.01**
Daphnia	**0.01±0.01**	**0.05±0.01**	**<0.01**	**<0.01**	**0.24±0.03**	**0.03±0.01**
Calanoids	**0.20±0.03**	**0.04±0.01**	**0.14±0.01**	**0.05±0.01**	**0.14±0.01**	**0.31±0.02**
Cyclopoids	**0.08±0.01**	**0.26±0.03**	**0.21±0.03**	**0.04±0.01**	**0.09±0.01**	**0.15±0.02**
Nauplii	**0.38±0.04**	**<0.01**	**0.59±0.04**	**0.09±0.03**	**0.21±0.02**	**0.46±0.03**
Harpacticoid	**0±0**	**<0.01**	**<0.01**	**0±0**	**0±0**	**<0.01**

densities of benthic organisms were by far the lowest observed among sites (Table 4), although zebra mussels were visibly estimated to occur in the highest densities at the PV site compared to all other survey sites.

Overall fish species richness at the PV site (13) was high in comparison with other study sites (Appendix B). The shallow water fish community at PV was dominated by *Notropis atherinoides* and also included *Morone americana*, *Notropis hudsonius*, *Osmerus mordax*, the stocked salmonid *Onchorynchus mykiss* and the non-native *Neogobius melanostomus* (Table 6, Appendix B). Shallow water fish total CPUE was low compared to most other surveyed sites (Figure3). Shallow water planktivore CPUE was low (Figure 8), although planktivores dominated the shallow water fish community (Figure 9). Shallow water piscivore CPUE and relative abundance were also very low (Figures 4 and 5). The relative abundance of native fish in shallow water samples was comparable to most sites (Figure 11), and while non-native fish CPUE was low (Figure 12), the relative abundance of non-native fish in shallow water fish communities was generally comparable to other sites surveyed in SLE and ELM (Figure 13).

Overall nearshore fish CPUE was comparatively high at the PV site (Figure 14). *Morone chrysops*, *I. punctatus* and *Aplodinotus grunniens* were particularly abundant at the site (Tables 8 and 9). Nearshore planktivore CPUE and relative abundance were both very low compared to the SM and SJ sites, although they were similar to LD and higher than the WLM sites (Figures 15 and 18). Nearshore piscivore and benthivore CPUE values were comparatively high (Figures 16 and 17, respectively), although the relative abundance of both groups was similar to other nearshore fish communities sampled (Figures 20 and 19, respectively). Native fish CPUE was particularly high at the PV site, and was most similar to the SM and SJ sites (Figure 21). The relative abundance of native nearshore fish was the highest observed (Figure 23), and non-native fish CPUE and relative abundance measures were the lowest observed among sites (Figures 22 and 24).

Overall zooplankton densities were the second highest observed among sites (Table 10). Cladocerans and cyclopoids dominated the zooplankton community and comprised the highest proportion of zooplankton communities observed among sites (Table 11). Very few non-native zooplankters comprised the PV zooplankton community (Tables 9 and 10).

Ludington, MI

The LD site was characterized by an extensive sand sheet that yielded primarily sand substrates with little organic content in nearshore areas. Given the characteristics of the site, there was no significant change in the availability of sand expected within the time frame of this study. The homogenous sand substrate habitat supported a moderately low number of benthic taxa overall (Appendix A). The mean relative abundance of aquatic insect larvae at the LD site was high, although insect densities were moderate compared with other nearshore sites (Table 4). Insect communities were comprised primarily of tube-dwelling midge larvae (Diptera: Chrionomidae, Table 5). There was no evidence of the presence of dreissenids at the LD site, and the mean relative abundance and density of oligochaetes were both very low (Tables 4 and 5). The mean relative abundance of gastropods (*Valvatta* sp.) was low, although the mean density of gastropods was moderate in comparison with the other study sites (Table 4).

Overall fish species richness at LU was moderately high (Appendix B). The shallow water fish collected in beach seine hauls included *Percopsis omiscomaycus*, *Notropis atherinoides*, *N. hudsonius* and young-of the-year *Perca flavescens* (Table 6). *N. hudsonius* was observed in the greatest relative abundance and density observed among sites (Table 6). The non-native *Alosa pseudoharengus* also occurred with relatively high relative abundance and density at LD (Tables 6 and 7). Total shallow water fish and planktivore CPUE measures were among the highest observed among sites (Figures 3 and 8, respectively). Shallow water fish communities were primarily comprised of planktivores (Figure 9) with very few benthivores (Figures 6 and 7) and piscivores (Figures 4 and 5). Native shallow water fish CPUE and relative abundance were generally comparable to other sites given the high degree of variability of LD samples (Figures 10 and 11). Non-native shallow water fish CPUE was among the highest observed, although it was highly variable among samples (Figure 12). The relative abundance of non-native shallow water fish was moderate compared to other survey sites (Figure 13).

Overall nearshore fish CPUE at LD was relatively low (Figure 14), although *Catostomus commmersoni*, a desirable native fish species, occurred in the highest relative abundance observed among sites (Table 9). The CPUE and relative abundance of nearshore planktivores were very low (Figures 15 and 18, respectively), and while nearshore predator CPUE was very low compared to SLE sites, it was largely similar to other Lake Michigan sites (Figure 16). The relative abundance of nearshore piscivores was low but characterized by high variability (Figure 20). Native and non-native nearshore fish CPUE were both low compared to SLE and SJ, although they were largely similar to WLM sites (Figures 21 and 22), and the relative abundance of non-native nearshore fish was similar to most other sites (Figure 24).

Zooplankton taxa richness at LU (10) was similar to other sites surveyed in the study (Appendix C). Overall LD zooplankton densities were low in comparison with other sites, particularly Lake Erie sites, and exotic zooplankters comprised a small proportion of the zooplankton community (Tables 10 and 11). Nauplii, cladocerans and calanoids were the most prevalent taxa comprising the LD zooplankton community (Table 11).

St. Joseph, MI

The SJ site substrates were comprised of sand (66%), thin sand over clay (24%), muddy sand (9%) and cobble/boulder glacial deposits (1%) (Table 3). Sand loss at the site between 1999 and 2000 was 17%, and was more similar to the unique sites surveyed (15-17% loss) than the other mid-bluff sites (30-56% loss) (Table 3). Benthic community morphospecies richness (10) was moderate compared to the other survey sites (Appendix A), and overall benthic densities were among the highest observed during the study (Table 4). Benthic communities were dominated by insects, predominantly chironomids and ceratopogonids, and chironomid densities were the highest observed during the study (Table 4). The relative abundance of chironomids was also among the highest observed for the study (Table 5).

Fish species richness (14) at the SJ site was the highest observed for all sites, in part because the shallow water fish community was the richest observed among sites (Appendix B). Shallow water fish communities were dominated by *R. cataractae*, *N. hudsonius* and *A. pseudoharengus*, and also included *Fundulus diaphanus*, *P. omiscomaycus*, *L. sicculus*, *M. erythrurum*, *Micropterus dolomieu*, *N. atherinoides*, and *P. flavascens* (Table 6). Three of these species were only observed at the SJ site, including *F. diaphanus*, *M. erythrurum* and *M. dolomieu*. Overall shallow water fish CPUE was moderately high compared to other study sites (Figure 3). Planktivores and benthivores dominated shallow water fish samples with a few juvenile piscivores also present (Figures 9, 7 and 5, respectively). Overall native fish CPUE was similar to most sites and non-native fish CPUE was moderately higher at SJ (Figures 10 and 12, respectively). The relative abundance of these groups was also generally similar to most other sites (Figures 11 and 13).

The nearshore community included seven fish species: *M. erythrurum*, *M. dolomieu*, *D. cepedianum*, *S. vitreum*, *P. flavascens*, *O. tshawytscha* and *A. grunniens*. *D. cepedianum* and *A. grunniens* were particularly abundant at the site (Table 9). Overall nearshore fish CPUE was moderately high compared to the other sites (Figure 14), and several species exhibited the highest CPUE observed in the study at SJ (Table 8). Native fish CPUE was high compared to other Lake Michigan sites (Figure 21), and native nearshore fish relative abundance was moderately high compared to other study sites (Figure 23). Non-native nearshore fish occurred in the second highest CPUE observed, although and non-native fish relative abundance was largely similar to other sites (Figures 22 and 24, respectively).

The non-native zooplankters *C. pengoi* and *B. cederstroemi* dominated SJ zooplankton communities, while cladocerans, calanoids, cyclopoids and nauplii comprised the remaining zooplankton community (Tables 10 and 11, Appendix C). Overall zooplankton densities at the SJ site were the second lowest observed, although exotic zooplankton densities were by far the highest among all sites (Table 10).

Port Washington, WI

The PW site was characterized by varied substrates, including areas of sand (39%), thin sand (20%), and cobble/boulder glacial deposits (41%) (Table 3). Benthic taxa richness was the highest observed among sites (15, Appendix A). The rocky substrates of the Port Washington site supported *Oecetis sp.* larvae (caddisflies, Trichoptera), as well as crayfish (Decapoda) and snails (Gastropoda) in very low numbers (Table 4, Appendix A). Crayfish, *Oecetis* sp. and snails of the genus *Elimia* were observed only at the PW site (Appendix A). Benthic densities at PW were the highest observed among sites (Table 4.) Aquatic insect larvae, amphipods/isopods, and oligochaetes were the most abundant taxa in PW benthic communities (Table 5).

Overall PW site fish species richness (9) was moderately low compared to the other survey sites (Appendix B). *Rhinichthys cataractae* dominated shallow water native fish communities at PW and occurred in the highest mean densities observed among sites (Tables 6 and 7). Overall shallow water fish CPUE at PW was moderate compared to other study sites (Figure 3). Benthivores comprised the bulk of PW shallow water fish communities (Figure 7), and mean CPUE for shallow water benthivores was particularly high (Figure 6). Planktivores were nearly absent from PW shallow water fish samples (Figures 8 and 9), and no piscivores were present in PW shallow fish communities sampled. Native shallow water fish

CPUE was comparable to other sites surveyed (Figure 10), and the relative abundance of native shallow water fish was among the highest observed (Figure 11). Non-native shallow water fish CPUE and relative abundance measures were very low at PW (Figures 12 and 13, respectively).

Nearshore native fish species included *C. commersoni*, *Catostomus catostomus*, *P. flavascens* and *Salvelinus namaycush*. *C. catostomus* and *S. namaycush* were only observed at the PW site and comprised a large portion of the nearshore community at the site (Table 9). Several non-native and stocked fish species were also observed at the PW site, including *A. pseudoharengus*, *Salmo trutta*, and *Onchorhynchus tshawytscha*. *S. trutta* was only observed at the PW site. Overall nearshore fish CPUE was relatively low, although comparable to most other Lake Michigan survey sites (Figure 14). Planktivore and benthivore CPUE values were low at PW, although comparable to other Lake Michigan sites (Figures 15 and 17, respectively). Stocked salmonids were abundant in nearshore fish samples and comprised the only nearshore non-native species captured at the site. Most piscivores were salmonids, and piscivore CPUE and relative abundance measures were similar to other Lake Michigan sites (Figures 16 and 20). Native and non-native nearshore fish CPUE measures were comparably low, although similar to other Lake Michigan sites (Figures 21 and 23, respectively).

Zooplankton taxa richness at PW (10) was generally similar to the other survey sites (Appendix C). Zooplankton densities at PW were moderately low compared to Lake Erie sites, although they were the highest observed for Lake Michigan sites (Table 10). Nauplii, cyclopoids and calanoids occurred in relatively high densities at PW (Table 10). Nauplii comprised the bulk of the zooplankton community at PW (Table 11), and exotic zooplankters were numerically scarce (Tables 10 and 11) at PW.

Two Rivers, WI

During summer 2000, the TR site substrates were comprised of sand (17%), thin sand over clay (49%) and cobble/boulder glacial deposits (35%). The TR site had the greatest change in availability of sand substrates of any of the surveyed sites, with a net sand loss of 56% between 1999 and 2000 (Table 3). The TR site had the second highest benthic morphospecies richness (13 species) of all sites (Appendix A). Gastropods were particularly diverse at the TR site, including four genera, *Physa* sp., *Valvatta* sp., *Elimia* sp. and *Bithynia* sp. The gastropod genus *Bithynia* was only observed at the TR site. Gastropods at TR also occurred in the highest densities observed among the surveyed sites (Table 4). Amphipods occurred in high densities at the TR site compared to most other sites (Table 4) and comprised the largest proportion of the TR benthic community, the highest relative abundance of amphipods observed at any surveyed site (Table 5). Overall aquatic insect and chironomid densities were the lowest observed in the study (Table 4). Reconnaissance dives in 1999 noted no evidence of *D. polymorpha* at the site, although small zebra mussels completely covered the surfaces of hard substrates in 2000.

Overall fish species richness at TR (6 species) was very low compared to other sites surveyed (Appendix B). Shallow water fish observed included *Cottus bairidi* (the only site at which this species was observed), *R. cataractae*, *N. hudsonius* and the non-native *A. pseudoharengus*. *R. cataractae* dominated the shallow water fish community at TR (Table 6), although overall shallow water fish CPUE was among the lowest observed for the study (Figure 3). Benthivores dominated the shallow water fish community at TR (Figures 6 and 7). Planktivores were nearly absent from the TR shallow water fish samples (Figures 8 and 9), and no piscivores were present in the beach seine samples. Native shallow water fish CPUE was moderate compared to the other sites (Figure 10), while the relative abundance of native fish in shallow water communities was among the highest observed (Figure 11). Non-native fish species CPUE was very low (Figure 12), and non-native fish comprised a small portion of the shallow water fish community (Figure 13).

Nearshore fish species observed were restricted the stocked salmonids *O. tshawytscha* and *O. kisutch*. Mean nearshore fish CPUE was among the lowest observed (Figure 14), and the nearshore fish community was comprised solely of piscivores and non-native stocked species.

Overall zooplankton densities were moderately low for the TR site (Table 10). The zooplankton community was dominated by nauplii and calanoids with some cyclopoids and very few cladocerans, daphnia, and harpacticoids (Table 11). Exotic zooplankters were uncommon and comprised only a small portion of the community (Tables 10 and 11).

Shoreline and Lake Area Effects

Benthic Invertebrates

Total benthic invertebrate densities (excluding zebra mussels) were not significantly different between shoreline types or among lake areas (F=0.9, p>0.30 and F=2.2, p>0.10, respectively, Table 12). Aquatic insect mean densities were not different between the shoreline types (F=0.16, P>0.68), although they were higher at ELM

Table 12. Native benthic invertebrate community mean (±1S.E.) densities (number of individulals/m^2) segregated according to coarse taxonomic groups. Overall density of benthic organisms is also provided.

		Benthic Invertebrate Taxonomic Group					
		Aquatic Insect Larvae	**Oligachaetes**	**Amphipods/ Isopods**	**Gastropods**	**Sphaerid Clams**	**Total Benthic Density**
Shoreline Type	**Mid-Bluff**	**251.4±52.0**	**79.3±31.5**	**211.1±67.9**	**7.9±5.4**	**0.7±0.7**	**588.1±97.2**
	Unique	**210.6±36.6**	**108.2±28.6**	**102.7±47.4**	**5.9±2.2**	**17.4±8.5**	**575.6±71.5**
Lake Area	**Lake Erie**	**69.1±16.0**	**164.3±55.4**	**2.1±1.5**	**2.4±2.4**	**32.6±18.3**	**519.0±104.9**
	East Lake Michigan	**385.7±52.7**	**89.4±34.7**	**0.0±0.0**	**4.0±2.1**	**2.4±1.8**	**527.4±85.7**
	West Lake Michigan	**172.3±54.9**	**53.4±21.5**	**416.2±101.7**	**12.9±6.7**	**2.6±2.6**	**683.5±110.8**
Survey Site	**Painesville, OH**	**10.6±5.3**	**0.0±0.0**	**3.5±3.5**	**0.0±0.0**	**0.0±0.0**	**22.9±9.2**
	Sheldon Marsh, OH	**88.6±19.9**	**219.0±71.0**	**1.6±1.6**	**3.2±3.2**	**43.5±24.1**	**648.4±124.6**
	St. Joseph, MI	**539.5±88.3**	**173.9±66.0**	**0.0±0.0**	**1.6±1.6**	**1.6±1.6**	**785.8±149.5**
	Ludington, MI	**231.9±41.2**	**4.8±2.7**	**0.0±0.0**	**6.4±3.8**	**3.2±3.2**	**268.9±49.8**
	Two Rivers, WI	**17.7±3.6**	**2.5±1.9**	**526.3±149.5**	**17.9±6.3**	**0.0±0.0**	**577.7±158.3**
	Port Washington, WI	**315.3±98.3**	**100.3±39.5**	**314.5±138.3**	**8.2±4.3**	**5.0±5.0**	**781.1±155.5**
Substrate Stability	**High**	**293.6±37.7**	**124.7±27.3**	**76.8±35.6**	**4.8±1.7**	**13.4±6.4**	**628.6±65.7**
	Low	**15.7±0.9**	**1.8±1.4**	**383.7±115.7**	**13.0±9.8**	**0.0±0.0**	**426.4±122.6**

Table 13. Native benthic invertebrate community mean (±1S.E.) relative abundance measures segregated according to coarse taxonomic groups.

		Benthic Invertebrate Taxon				
		Aquatic Insect Larvae	**Oligachaetes**	**Amphipods/ Isopods**	**Gastropods**	**Sphaerid Clams**
Shoreline Type	**Mid-Bluff**	**0.39±0.05**	**0.07±0.02**	**0.25±0.05**	**0.010±0.004**	**0.001±0.001**
	Unique	**0.49±0.05**	**0.17±0.04**	**0.09±0.03**	**0.007±0.003**	**0.02±0.01**
Lake Area	**Lake Erie**	**0.20±0.04**	**0.24±0.06**	**0.03±0.02**	**0.005±0.005**	**0.03±0.01**
	East Lake Michigan	**0.75±0.05**	**0.08±0.03**	**0±0**	**0.007±0.003**	**0.003±0.003**
	West Lake Michigan	**0.27±0.05**	**0.10±0.03**	**0.43±0.06**	**0.013±0.005**	**0.002±0.002**
Survey Site	**Painesville, OH**	**0.25±0.10**	**0±0**	**0.04±0.04**	**0±0**	**0±0**
	Sheldon Marsh, OH	**0.18±0.05**	**0.32±0.08**	**0.02±0.02**	**0.01±0.01**	**0.04±0.02**
	St. Joseph, MI	**0.69±0.07**	**0.15±0.05**	**0±0**	**0.002±0.000**	**0.002±0.002**
	Ludington, MI	**0.83±0.06**	**0.01±0.01**	**0±0**	**0.01±0.01**	**0.005±0.005**
	Two Rivers, WI	**0.09±0.04**	**0.01±0.01**	**0.62±0.09**	**0.02±0.01**	**0±0**
	Port Washington, WI	**0.45±0.07**	**0.19±0.06**	**0.25±0.08**	**0.004±0.002**	**0.004±0.004**
Substrate Stability	**High**	**0.53±0.04**	**0.17±0.03**	**0.07±0.03**	**0.01±0.01**	**<0.01**
	Low	**0.13±0.07**	**<0.01**	**0.46±0.05**	**0.0±0.0**	**0.02±0.01**

sites compared to both WLM and SLE sites (F=12.1, p<0.001) (Table 12). A significant interaction (F=12.3, p<0.001) between shoreline type and lake area indicated that aquatic insect density patterns were inconsistent between shoreline types for the lake areas surveyed. Aquatic insect mean densities were lower at MB sites in SLE and WLM, although this pattern was reversed in ELM, where the MB site had higher aquatic insect densities compared to the UQ site (Table 12). The mean relative abundance of aquatic insects in benthic communities was higher for the UQ shoreline type (F=6.3, p<0.015) and was also higher in ELM compared to the other lake areas (F=44.4, p<0.001) (Table 13). A significant interaction (F=4.5, p<0.015) indicated that patterns of aquatic insect relative abundance were not consistent between shoreline types among the lake areas surveyed. The MB site had a higher mean relative abundance of aquatic insects in SLE, while the UQ sites had higher mean aquatic insect relative abundance measures in both ELM and WLM (Table 13).

Mean oligochaete densities were not different between shoreline types (F=1.3, p>0.25) or among lake areas (F=0.6, p>0.50) (Table 12). A significant interaction (F=7.2, p<0.002) between shoreline type and lake area indicated that oligochaete densities exhibited inconsistent patterns between shoreline types among the lake areas surveyed. Oligochaete densities were higher at UQ sites in SLE and WLM, but were lower at the UQ site in ELM (Table 12). The mean relative abundance of oligochaetes in benthic samples was higher for UQ sites (F=7.3, p<0.01), but was not different among lake areas (F=0.9, p>0.40) (Table 13). However, patterns of oligochaete mean relative abundance between shoreline types were not consistent among lake areas, with higher oligochaete mean relative abundance at UQ sites in SLE and WLM and lower oligochaete mean relative abundance at the UQ site in ELM (F=9.8, p<0.001, Table 13).

Mean amphipod/isopod densities were not different between shoreline types (F=0.8, p>0.35), although they were significantly higher in WLM compared to the other lake areas (F=14.7, p<0.001) (Table 12). There was no interaction between shoreline type and lake area for the amphipod/isopod density analysis (F=0.9, p>0.35). The mean relative abundance of amphipods and isopods was significantly higher at MB sites (F=8.3, p<0.006) and in WLM (F=44.9, p<0.001) (Figure 13). However, there was a significant interaction between shoreline type and lake area (F=8.1, p<0.001), likely due to the absence of amphipods and isopods at the ELM sites (Table 13).

Mean gastropod and sphaerid clam densities were not different between shoreline types (F<0.1, p>0.90 and F=2.6, p>0.10, respectively) or among lake areas (F=1.6, p>0.20 andF=1.2, p>0.28 respectively) (Table 12). There was no interaction between shoreline type and lake area for the gastropod or sphaerid clam ANOVAs (F=0.8, p>0.45 and F=1.4, p>0.25, respectively). The mean relative abundance values for gastropods and sphaerids were not different between shoreline types (F<0.1, p>0.90 and F=2.2, p>0.10, respectively) or lake areas (F=1.3, p>0.25, F=0.98, p>0.35, respectively) (Table 5). There was no interaction between shoreline type and lake area for sphaerid mean relative abundance values (F=1.1, p>0.30), although there was a marginally significant interaction between shoreline type and lake area for gastropods (F=3.5, p<0.035).

Zooplankton Communities

Total mean zooplankton densities were higher for the UQ shoreline type (F=54.8, p<0.001) and were highest for the SLE lake area (F=104.4, p<0.001) (Table 14). A significant interaction between the main effects indicated that differences in mean zooplankton densities varied between shoreline types in an inconsistent manner among lake areas surveyed (F=40.8, p<0.001). Mean zooplankton densities were higher for UQ sites in SLE and WLM, but were lower at the ELM UQ site compared to the MB site (Table 14).

Mean densities and the mean relative abundance of cladocerans were higher for the UQ shoreline type (F=12.2, p>0.002 and F=7.6, p<0.007, respectively) and were also higher in SLE compared to both ELM and WLM (F=94.0, p<0.001 and F=150.9, p<0.001, respectively) (Tables 14 and 15). A significant interaction between shoreline type and lake area for both density and relative abundance measures (F=10.3, p<0.001 and F=45.1, p<0.001, respectively) reflected that these properties of cladoceran communities varied inconsistently with respect to shoreline types among the lake areas surveyed (Tables 14 and 15).

The mean density and relative abundance values for daphnia were higher for the MB shoreline type (F=79.0, p<0.001 and F=41.1, p<0.001, respectively) and were highest for the SLE lake area (F=87.9, p<0.001 and F=86.0, p<0.001, respectively) (Tables 14 and 15). An interaction between shoreline type and lake area indicated that the degree to which daphnia densities and relative abundance values varied was inconsistent between shoreline types for the lake areas surveyed (F=74.2, p<0.001 and F=49.7, p<0.001, respectively) (Tables 14 and 15).

Calanoid densities were greater for UQ shorelines (F=61.1, p<0.001) and were highest for the SLE lake area (F=55.1, p<0.001), although a significant interaction (F=50.1, p<0.001) indicated that the degree to which calanoid densities were different between shoreline types varied among lake areas (Table 6). Differences in calanoid densities between shoreline types were far more pronounced in SLE compared to the other lake areas

Table 14. Zooplankton community mean (±1S.E.) densities (number of individulals/m^3) segregated according to coarse taxonomic groups for shoreline types, lake areas and sample sites surveyed in Great Lakes nearshore areas during Summer 2000. Non-native zooplankton includes two species, *Cercopagis pengoi* and *Bythotrephes cederstroemi* .

		Zooplankton Taxonomic Group							
		Cladocerans	***Daphnia***	**Calanoids**	**Cyclopoids**	**Harpacticoids**	**Nauplii**	**Non-Native**	**Total Zooplankton Density**
Shoreline Type	**Mid-Bluff**	189.7±50.9	13.2±2.9	29.2±4.7	76.9±16.4	0.12±0.07	32.0±5.0	23.2±5.4	364.2±61.4
	Unique	490.9±93.0	318.1±58.9	222.3±36.7	163.4±26.8	0.38±0.27	405.2±66.2	1.3±0.5	1601.7±255.5
Lake Area	**Lake Erie**	1143.9±127.1	587.9±87.5	368.6±57.0	332.3±36.8	0.15±0.10	569.3±108.5	0.2±0.1	3002.3±255.5
	East Lake Michigan	15.3±2.3	0.6±0.3	7.4±1.5	4.0±0.8	0.00±0.00	17.5±3.2	32.3±6.9	77.1±8.0
	West Lake Michigan	17.7±6.5	4.0±0.8	57.4±8.1	65.3±15.7	0.61±0.41	158.2±30.5	0.7±0.5	303.9±50.1
Survey Site	**Painesville, OH**	717.6±141.8	43.3±7.8	36.0±13.7	258.7±15.7	0.37±0.25	4.2±1.4	<0.1	1060.3±148.2
	Sheldon Marsh, OH	1428.1±170.4	950.9±94.2	590.3±65.9	381.7±53.5	0.00±0.00	946.0±139.8	0.2±0.1	4297.0±415.0
	St. Joseph, MI	11.4±2.8	0.5±0.3	2.7±0.7	3.0±0.7	0.00±0.00	7.0±2.3	63.3±11.1	87.9±13.3
	Ludington, MI	19.0±3.4	0.7±0.6	12.0±2.6	5.0±1.5	0.00±0.00	27.7±5.2	2.3±0.9	66.7±8.8
	Two Rivers, WI	9.6±3.5	5.3±1.4	50.1±5.3	26.8±5.6	0.07±0.05	74.5±7.6	<0.1	166.4±15.0
	Port Washington, WI	25.7±12.4	2.7±0.9	64.7±15.3	103.9±29.3	1.14±0.81	242.0±56.5	1.4±1.0	441.5±92.5
Substrate Stability	**High**	374.4±67.1	240.9±39.1	169.0±24.7	124.4±19.8	0.29±0.18	308.4±44.4	16.4±3.1	1233.9±173.6
	Low	292.8±103.4	20.5±28.4	44.4±38.0	119.6±30.5	0.19±0.28	46.4±68.5	<0.1	523.9±267.7

Table 15. Zooplankton community mean (±1S.E.) relative abundance values (number of individulals/m^3) segregated according to coarse taxonomic groups for shoreline types, lake areas and sample sites surveyed in Great Lakes nearshore areas during Summer 2000. Non-native zooplankton includes two species, *Cercopagis pengoi* and *Bythotrephes cederstroemi* .

		Zooplankton Taxonomic Group						
		Cladocerans	*Daphnia*	Calanoids	Cyclopoids	Harpacticoids	Nauplii	Non-Native
Shoreline Type	Mid-Bluff	0.22±0.02	0.09±0.01	0.16±0.01	0.13±0.01	<0.01	0.39±0.03	<0.01
	Unique	0.23±0.03	0.03±0.004	0.15±0.02	0.14±0.02	<0.01	0.21±0.03	0.24±0.04
Lake Area	Lake Erie	0.45±0.03	0.16±0.02	0.10±0.01	0.16±0.02	<0.01	0.13±0.02	<0.01
	East Lake Michigan	0.21±0.03.	0.01±0.01	0.12±0.02	0.06±0.01	0.00±0.00	0.24±0.03	0.35±0.05
	West Lake Michigan	0.04±0.01	0.02±0.004	0.23±0.02	0.18±0.02	<0.01	0.53±0.03	<0.01
Survey Site	Painesville, OH	0.64±0.04	0.05±0.01	0.04±0.02	0.26±0.03	<0.01	<0.01	<0.01
	Sheldon Marsh, OH	0.32±0.02	0.24±0.02	0.14±0.01	0.09±0.01	0.00±0.00	0.21±0.02	<0.01
	St. Joseph, MI	0.13±0.03	<0.01	0.05±0.01	0.04±0.01	0.00±0.00	0.09±0.03	0.68±0.05
	Ludington, MI	0.29±0.04	0.01±0.01	0.20±0.03	0.08±0.01	0.00±0.00	0.38±0.04	0.04±0.01
	Two Rivers, WI	0.05±0.01	0.03±0.01	0.31±0.02	0.15±0.02	<0.01	0.46±0.03	<0.01
	Port Washington, WI	0.04±0.01	0.01±0.002	0.15±0.01	0.21±0.03	<0.01	0.59±0.04	<0.01

surveyed (Table 6). Mean relative abundance of calanoids within zooplankton communities was not significantly different between shoreline types (F=3.6, P>0.05), although it was statistically higher in WLM compared to the other lake areas (F=30.4, p<0.001) (Table 7). A significant interaction between shoreline type and lake area indicated that patterns of calanoid relative abundance were not consistent among lake areas. In SLE and ELM, calanoid mean relative abundance was greater at UQ sites, although in WLM calanoid mean relative abundance was greater at the MB site (Table 7).

Cyclopoid densities were higher for the UQ shoreline type (F=7.8, p<0.007) and were highest for the SLE lake area (F=60.5, p<0.001) (Table 14). There was no interaction between shoreline type and lake area for the cyclopoid density analysis (F=2.1, p>0.10). The mean relative abundance of cyclopoids within zooplankton communities was not different between shoreline types (F=1.5, p>0.20), although it was significantly higher for SLE and WLM compared to ELM (F=20.4, p<0.001) (Table 15). A significant interaction between shoreline type and lake area indicated that cyclopoid relative abundance varied inconsistently between shoreline types among the lake areas sampled (F=16.7, p<0.001). The relative abundance of cyclopoids was not significantly different between shoreline types in WLM (F=2.7, p>0.10), but it was higher for the MB site in SLE (F=7.8, p<0.01) and higher for the UQ site in ELM (F=5.2,p<0.03) (Table 15).

Harpacticoid densities and mean relative abundance were not significantly different between shoreline types (F=0.6, p>0.40 and F=2.1, p>0.10, respectively) or lake areas (F=1.6,p>0.20 and F=2.9, p>0.06, respectively) (Tables 14 and 15). There was no significant interaction between shoreline type and lake area for either harpacticoid analysis (F=2.1, p>0.10 and F=1.6, p>0.20, respectively).

Nauplii densities were higher for the UQ shoreline type (F=48.0, p<0.001) and were greatest in the SLE lake area (F=23.4, p<0.001) (Table 14), likely due to the earlier season sampling of this lake area compared to the others. A significant interaction between shoreline type and lake area indicated that the degree to which nauplii densities were higher at UQ sites varied among the lake areas sampled (F=25.8,p<0.001). The mean relative abundance of nauplii was higher for the UQ shoreline type (F=64.5, p<0.001) and was highest for the WLM lake area (F= 96.7, p<0.001) (Table 15). The interaction between shoreline type and lake area was marginally significant (F=3.6, p>0.03), suggesting that the degree to which the relative abundance of nauplii in zooplankton communities varied between shoreline types was dependent upon the lake area sampled.

Shallow Water Fish Communities

Overall SW fish CPUE was higher for the UQ shoreline type (F=7.7, p<0.01) and was also higher in WLM compared to ELM (SLE shallow water fish densities were not significantly different from WLM or ELM, F=4.6, p<0.02) (Figure 3). There was no interaction between shoreline type and lake area for the overall shallow water fish community analysis (F=2.8, p>0.10).

Shallow water piscivorous fish CPUE was not significantly different between shoreline types (F=3.3, p>0.09) or among lake areas (F=3.6, p>0.06) (Figure 4), primarily due to high variability in data among the unique sites. There was no significant interaction between shoreline type and lake areas for the piscivore density analysis (F=2.5, p>0.12) (Figure 4). The relative abundance of piscivores in shallow water fish communities was not different between shoreline types (F=2.1, p>0.18), but was different among lake areas (F=6.9, p=0.01), where SLE had greater shallow water piscivore relative abundance than other lake areas (Figure 5). There was no interaction between shoreline type and lake area for this analysis (F=3.0, p>0.09). Shallow water benthivorous fish CPUE was not different between shoreline types (F=0.1, p>0.71), although benthivore CPUE was far greater for the WLM lake area (F=7.1, p=0.01) (Figure 6). There was no significant interaction between the main effects for this analysis (0.7, p>0.51). The mean relative abundance of benthivores in shallow water fish communities was not different between shoreline types (F=2.7, p>0.12), although it was significantly greater for the WLM lake area (F=28.6, p<0.001) (Figure 7). There was no interaction between shoreline type and lake area for the shallow water benthivore relative abundance analysis (F=0.7, p>0.54). Shallow water planktivorous fish CPUE was not different between shoreline types (F=1.7, p>0.21) or among lake areas (F=2.2, p>0.15) (Figure 8). There was no significant interaction between shoreline type and lake area for this analysis (F=0.48, p>0.63) (Figure 8). The relative abundance of planktivores in shallow water fish communities was not different between shoreline types (F=0.88, p>0.36), although it was higher for the SLE and ELM lake areas compared to WLM (F=16.7, p<0.001) (Figure 9). There was no evidence to suggest a significant interaction between the main effects for this analysis (F=0.9, p>0.42).

Shallow water native fish CPUE was not different between shoreline types (F=1.7, p>0.21) or among lake areas sampled (F=1.4, p>0.29) (Figure 10). There was no interaction between shoreline type or lake area for the shallow water native fish CPUE analysis (F=0.1, p>0.89). The relative abundance of native shallow water fish was not different between shoreline types (F=3.2, p>0.1), although it was higher for the WLM lake area compared to the ELM lake area (F=7.5, p<0.01) (Figure 11). No significant interaction was detected between shoreline type and lake area (F=2.7, p>0.11) (Figure 11). Shallow water non-native fish CPUE was not different among shoreline type (F=2.1, p>0.17) or lake area (F=1.2, p>0.33) (Figure 12), and no significant interaction was detected between the main effects (F=0.6, p>0.58) (Figure 12). The relative abundance of non-native fish in shallow water communities was not different between shoreline types (F=3.6, p>0.08), although it was statistically higher for the ELM lake area (F=7.5, p<0.01) (Figure 13). There was no significant interaction between the main effects in this analysis (F=3.1, p>0.08).

Nearshore Fish Communities

Overall nearshore fish CPUE was not significantly different between shoreline types (F=0.05, p>0.80), but was significantly greater for the SLE lake area (F=14.1, p<0.002) (Figure 14). There was no evidence to suggest an interaction between shoreline type and lake area (F=3.5, p>0.065). Nearshore planktivorous fish CPUE was not different between shoreline types (F=0.3, P>0.6), although the relative abundance of nearshore planktivorous fish was greater at MB sites (F=5.9, p<0.04) (Figures 15 and 18). Nearshore planktivore CPUE was significantly lower for WLM compared to the other lake areas (F=5.1,p<0.03, Figure 15), and nearshore planktivore relative abundance was higher at ELM compared to WLM and was also greater at SLE compared to WLM (F=19.2, p<0.001, Figure 18). A significant interaction between shoreline type and lake area for both analyses indicated that patterns of planktivore CPUE and relative abundance were inconsistent between shoreline types for the lake areas surveyed (F=11.4, p=0.002 and F=25.1, p<0.001, respectively) (Figures 15 and 18). Nearshore piscivorous fish CPUE was not different between shoreline types (F=1.1, p>031), but it was significantly greater for the SLE lake area (F=15.9, p=0.001) (Figure 16). There was no evidence to suggest an interaction between shoreline type and lake area for this analysis (F=1.8, p>0.21). The relative abundance of piscivores in nearshore fish communities was not different between shoreline types (F=0.2, p>0.62) or lake areas (F=1.1, p>0.36), and there was no interaction between the main effects for the nearshore piscivore relative abundance analysis (F=0.1, p>0.94) (Figure 20). Nearshore benthivorous fish CPUE and the relative abundance of benthivores in nearshore fish communities were not different between the shoreline types (F=2.9, p>0.11 and F=0.3, p>0.61, respectively) (Figures 17 and 19). Benthivore CPUE and relative abundance in nearshore communities was not different among the lake areas sampled (F=3.7, p>0.05 and F=0.1, p>0.87, respectively) (Figures 17 and 19). There was no evidence of an interaction between shoreline type and lake area for nearshore benthivore CPUE or relative abundance analyses (F=1.8, p>0.20 and F=2.2, p>0.16, respectively).

Nearshore native fish CPUE and the relative abundance of native fish in nearshore fish communities were not significantly different between shoreline types (F=0.9, p>0.36 and F=0.01, p>0.91, respectively) (Figures 21 and 23). Native fish CPUE was higher for the SLE compared to the ELM and WLM lake areas (F=20.1, p<0.001, Figure 21). Non-native fish CPUE was not different between shoreline types (F=2.0, p>0.18), although it was marginally higher for SLE compared to ELM and WLM (F=4.2, p<0.05, Figure 22). However, the relative abundance of nearshore native and non-native fish was not different among lake areas (F= 2.9, p>0.09 and F=0.4, p>0.69, respectively) (Figures 23 and 24). There was no interaction indicated for nearshore native fish CPUE (F=0.9, p>0.44), although there was a significant interaction for the relative abundance of nearshore native fish (F=7.9, p<0.01). An interaction existed between shoreline type and lake area for non-native fish CPUE, indicating that differences between non-native CPUE values between shoreline types were not consistent among the lake areas sampled (F=11.5, p<0.002). There was no interaction indicated for the non-native fish relative abundance analysis (F=1.2, p>0.34).

Substrate Stability Effects

Benthic Invertebrate Communities

Total mean benthic invertebrate densities were not significantly different between high and low substrate stability regimes (F=2.2, p>0.13, Table 12). Larval aquatic insect and oligochaete mean densities were higher at sites characterized by higher substrate stability (F=20.7, p<0.001 and F=6.7, p<0.012, respectively, Table 12). Mean relative abundance measures for both larval aquatic insects and oligochaetes were also higher for sites classified as having high substrate stability (F=81.3, p<0.001 and F=11.4, p<0.002, respectively, Table 13). Amphipod/isopod and gastropod densities were higher at sites with lower substrate stability (F=25.9. p<0.001 and F=8.4, p<0.005, respectively, Table 12). The relative abundance values for amphipods/isopods and gastropods were also higher for sites classified as having lower substrate stability (F=83.3, p<0.001 and F=14.8,p<0.001, respectively, Table 13). Sphaerid clam densities and relative abundance measures were not significantly different between low and high substrate stability regimes of the Great Lakes nearshore areas surveyed (F=1.3, p>0.24 and F=1.2, p>0.25, respectively, Tables 12 and 13).

Zooplankton Communities

Total zooplankton densities were higher for sites

Table 16. Shallow water and nearshore fish community mean (±1S.E.) catch per unit effort (CPUE) and relative abundance (RA) values calculated for trophic classes, species origin and total fish communities (CPUE only) characteristic of selected Great Lakes nearshore high and low substrate stability regimes.

Fish Community Measure	Substrate Stability	Tropic Classification			Species Origin		Total
		Piscivores	Planktivores	Benthivores	Native	Non-Native	
Shallow Water Fish CPUE	High	0.08±0.05	1.10±0.45	0.23±0.13	0.79±0.20	0.62±0.27	1.86±0.35
	Low	0.01±0.01	0.06±0.03	0.32±0.16	0.36±0.15	0.04±0.03	0.43±0.58
Shallow Water Fish RA	High	0.07±0.04	0.61±0.11	0.32±0.12	0.67±0.08	0.33±0.08	N/A
	Low	0.03±0.03	0.33±0.19	0.64±0.20	0.87±0.09	0.12±0.09	N/A
Nearshore Fish CPUE	High	3.37±1.49	1.77±0.62	1.12±0.30	3.14±1.05	3.49±1.16	6.63±2.00
	Low	3.10±1.40	0.08±0.05	1.42±1.12	3.92±2.48	0.72±0.57	4.64±3.10
Nearshore Fish RA	High	0.42±0.11	0.19±0.06	0.28±0.10	0.39±0.24	0.44±0.08	N/A
	Low	0.46±0.20	0.06±0.01	0.13±0.09	0.45±0.09	0.21±0.20	N/A

characterized by higher substrate stability (F=30.3, p<0.001, Table 14). Daphnia, calanoids, nauplii and exotic zooplankter densities were also higher at sites with higher substrate stability (F=9.4, p<0.002, F=7.5, p<0.008, F=18.9, p<0.003, F=8.1, p<0.006, respectively, Table 14). However, densities of cladocerans, cyclopoids and harpacticoids were not significantly different between substrate stability regimes (F=0.4, p>0.50, F<0.1, p>0.88, F<0.1, p>0.75, respectively, Table 14). Relative abundance measures for cladocerans, calanoids and cyclopoids were higher under low substrate stability regimes (F=5.2, p<0.03, F=9.3, p<0.002, F=15.0, p<0.001, respectively, Table 15). The relative abundance of exotic zooplankters was higher under the high substrate stability regime (F=14.4, p<0.001, Table 15). Relative abundance values for daphnia, nauplii and harpacticoids were not significantly different between high and low substrate stability regimes (F=2.3, p>0.12, F=0.7, p>0.38, F=0.1, p>0.79, respectively, Table 15).

Shallow Water Fish Communities

Total shallow water fish CPUE was marginally higher for nearshore areas characterized by higher substrate stability regimes (F=4.4, p<0.05, Table 16). Shallow water planktivore CPUE was not different between substrate stability regimes (F=2.2, p>0.16, Table 16). CPUE values for shallow water piscivorous and benthivorous fish were not significantly different between low and high substrate stability regimes (F=0.9, p>0.37 and F=0.2, p>0.69, respectively, Table 16). Shallow water native and non-native fish CPUE was not significantly different between high and low substrate stability regimes (F=1.7, p>0.20 and F=1.9, p>0.19, respectively) (Table 16). The relative abundance of shallow water planktivores, benthivores, and piscivores were not significantly different between high and low substrate stability regimes (F=1.7, p>0.21, F=2.1, p>0.16 and F=0.5, p>0.47, respectively) (Table 16). The relative abundance measures for native and non-native shallow water fish were both not significantly different between substrate stability regimes (F=2.3, p>0.14 and F=2.5, p>0.13, respectively, Table 16).

Nearshore Fish Communities

Total nearshore fish CPUE was not significantly different between nearshore areas with low vs. high substrate stability (F=0.3, p>0.59, Table 16). CPUE measures for nearshore fish tropic classes were also not significantly different between substrate stability regimes, including piscivores (F<0.1, p>0.90), planktivores (F=3.0, p>0.10) and benthivores (F=0.1, p>0.71) (Table 16). CPUE measures for native and non-native nearshore fish were not significantly different between high and low substrate stability regimes (F=0.1, p>0.73 and F=2.2, p>0.16, respectively, Table 16). Similarly, relative abundance measures for nearshore fish grouped according to trophic class and origin were not different between substrate regimes, including piscivores (F<0.1, p>0.85), planktivores (F=3.2, p>0.09), benthivores (F=0.9, p>0.36), native fish (F=0.2, p>0.64) and non-native fish (F=1.4, p>0.24) (Table 16).

DISCUSSION

Study Design and Statistics

Ecological properties of the Great Lakes nearshore areas surveyed during 1999 and 2000 varied greatly within and among sites. Site descriptions are provided within this text with some comparisons of ecological properties among sites. These site descriptions demonstrate the high variability in community properties (e.g., taxonomic composition and biological productivity) among sites, although the intent of the sampling effort was not necessarily to compare individual sites. Rather, it was to detect ecological patterns related to nearshore physical properties and associated shorelines. Discussion points related to these site descriptions will be limited to instances in which data from particular sites were remarkably different from other sites within shoreline type, lake area or substrate stability classes.

On the coarsest level, differences in biological productivity and fish community structure between Lake Erie and Lake Michigan are considerable. Based on the results of this study, considerable differences in biological community structure appear to exist even between the eastern and western shores of Lake Michigan, although this may have also been an artifact of differences in the seasonality of data collection among the Lake Michigan sites. The initial statistical design focus for the ecological component of the larger study was to determine whether aquatic community measures were similar between MB and UQ shoreline types identified by the research team. The lumping of the unique sites was largely artificial and not very ecologically meaningful given that the UQ sites had little in common other than the fact that they were unique shoreline types for each of the three lake areas surveyed. In addition, the study design precluded the replication of sites identified as unique to each lake area, so analyses using data from individual unique shoreline types were not feasible. Even though the MB group was replicated among lake areas (but not within lake areas), individual bluff characteristics appeared to vary widely in terms of the active contribution of materials to the nearshore area as well as the physical structures of the bluff themselves (e.g., bluff height, sloughing characteristics).

The tested null hypotheses for analyses based on this shoreline type classifications essentially revolved around the premise that ecological attributes of nearshore areas adjacent to UQ shorelines were similar to ecological attributes of nearshore areas adjacent to MB shorelines. This classification of sites for statistical analysis did not result in particularly homogenous or meaningful groupings of data for analysis. Hence, analyses based on these classifications were hampered by high variability within the classes as well as interactions between the main effects for most statistical tests. These interactions made the results of these statistical analyses difficult to interpret, particularly because the reverse pattern of response to shoreline type occurred consistently in one of the three lake areas compared to the other two (i.e., SLE compared to ELM and WLM). Also, the magnitude of the response was also often quite different among the lake areas, leading to interactions between the main effects. Increased replication within and among lake areas for each of the shoreline types of interest, or for a subset of these shoreline types, would greatly enhance the statistical power of future studies. It would also likely lead to more significant findings regarding patterns of response by nearshore communities to varied shoreline types or characteristics.

Much more intuitive and successfully homogenous groupings of the nearshore community data were obtained using a classification based on the substrate stability regime of the sites. This classification was based on the combined substrate characteristics of the nearshore areas estimated from interpretations of site specific side-scan sonar mosaics. Substrate stability reflects both nearshore and shoreline processes in combination. Estimations of more specific measures of nearshore and shoreline-nearshore substrate transport for all sites were beyond the scope of this study. Additionally, the rate and magnitude of change in substrates observed was for a very discrete time period, and patterns measured over a longer time period would be more reliable for classifying sites based on substrate stability regime. Regardless, the substrate stability analysis provided perhaps the most useful insight into the relationships between Great Lakes nearshore communities and nearshore/shoreline properties in this study.

Benthic Invertebrates

It was not surprising that overall non-dreissenid benthic invertebrate densities and individual taxonomic group densities were not different between shoreline types due to the inconsistent (and highly variable) ecological properties among the sites comprising the two shoreline classes. Lake area analyses revealed significant differences in benthic taxonomic group densities that contributed to the high variability observed within the shoreline classes. Despite these differences in specific taxonomic group densities among lake areas, overall non-dreissenid benthic densities were similar among lake areas. We expected the higher overall productivity of Lake Erie compared to Lake Michigan to be reflected in the non-dreissenid benthic community, although this was not the case. These results may have been influenced by the temporally incongruent samples used for analysis. Weather conditions, logistical issues related to travel to disparate sites and boat mechanical problems necessitated the use of temporally discontinuous samples for the benthic invertebrate analyses in this study. Seasonal changes in benthic community structure may have therefore contributed to the non-significant statistical tests for the lake area analysis.

The extensive colonization of the PV site by non-native aquatic species may have also contributed to the unexpected similarity in overall non-dreissenid benthic densities among lake areas. The colonization of hard substrates by dreissenids increases local habitat complexity, creating additional habitat for local non-dreissenid benthos (Dermott et al. 1993, Griffiths 1993, Stewart and Haynes 1994, Wisenden and Bailey 1995, Botts et al. 1996, Stewart et al. 1998a and b). The increased substrate complexity provided by the dreissenid shells and the higher rate of organic matter deposition in the form of dreissenid fecal and pseudofecal material can contribute to increased abundances of non-dreissenid benthic taxa (Izvekova and Lvova-Katchanova 1992, Thayer et al. 1997). Certain taxa, including amphipods, isopods, hydroptilid caddisfly larvae, small gastropods, oligochaetes and chironomids, have been reported to be more abundant under higher zebra mussel colonization regimes (Dermott et al. 1993, Griffiths 1993, Ricciardi et al. 1997, Kuhns and Berg 1999). However, non-dreissenid invertebrates were highly underrepresented at the PV site, especially given that macrobenthic invertebrate populations have been observed to increase following zebra mussel colonization (Griffiths 1993, Dermott et al. 1993, Stewart and Haynes 1994, Ricciardi et al. 1997, Stewart et al 1998a and b). These low benthic densities may have been the result of the large numbers of *N. melanostomus* at the site. Manipulative studies have demonstrated that benthic invertebrates decline significantly in the presence of *N. melanostomus* (Kuhns and Berg 1999). This non-native benthivore has been reported to rely heavily on native benthic taxa as food sources, primarily during the juvenile stages (Jude et al. 1995), despite its primary reliance upon dreissenids as a food source. Densities of *N. melanostomus* based on SCUBA observations were estimated to be about 16 individuals/m^2. These densities were extremely high compared to SCUBA observations and beach seine hauls at other sites, so it is highly likely that the high densities of *N. melanostomus* at the PV site contributed greatly to the sparse non-dreissenid benthic communities observed.

Benthic productivity at the PV site appears to have shifted to favor the non-native *N. melanostomus* and *D. polymorpha*. The PV shoreline has been heavily manipulated, and the nearshore areas were generally sand starved with extensive exposed hard-pack clays and glacially deposited hard substrates (e.g., cobbles, boulders and bedrock). These large, hard substrates are ideal habitat for both *N. melanostomus* and *D. polymorpha*, so shoreline changes and associated changes in nearshore substrates (compared to historic times) have facilitated the dominance of non-native benthos at the PV site. Based on SCUBA observations in 2000, the TR site appears to be following a similar pattern. Based on this study, the physical characteristics of the TR nearshore area are most similar to PV, and although no zebra mussels were observed at the site in 1999, all hard substrates present at the site were heavily colonized by small zebra mussels in 2000. A similar change in benthic community properties may be expected at TR based on observations at PV. However, there will likely be a lag time between the zebra mussel colonization and *N. melanostomus* invasion during which benthic communities will remain relatively intact.

We expected overall non-dreissenid benthic densities to be higher for sites with greater substrate stability than sites with lower substrate stability, but this was not the case. While overall densities were not different, densities of specific taxonomic groups were different between the substrate regimes. This suggests that benthic taxa are differentially adapted to substrate stability regimes within the context of Great Lakes nearshore ecosystems. While these results were not expected, they were also not especially surprising given that taxa are variably adapted to a wide range of conditions across most ecosystem types and that densities are likely to be driven more by biological productivity rather than environmental stability. Additionally, inclusion of zebra mussels in benthic density and productivity calculations may alter these results significantly given that dreissenids dominated substrates at the PV site. However, such measures can be deceiving given that they express non-native density/productivity as a prevalent component of nearshore productivity, which is arguably not a favorable ecosystem indicator. Rather, keeping dreissenid numbers separate from nearshore benthic community measures is more likely to identify communities that have been altered due to environmental, anthropogenic or non-native species impacts.

Larval aquatic insect and oligochaete density patterns were inconsistent between shoreline types for the lake areas sampled. While mean density measures for both groups were lower for MB sites in SLE and WLM, they were considerably higher for the MB site in ELM. These inconsistencies may have been due, in part, to the temporal discontinuity among sites for benthic samples. Although PV benthic samples were collected within a comparable seasonal period to most sites, they were collected a year earlier, and conditions may have been sufficiently different during 1999 that the benthic data were not comparable for the site in 2000. The influences of non-native benthic organisms as discussed previously also likely contributed to the inconsistent results from the PV site. Benthic samples were collected considerably later in the season at TR compared to the other nearshore sites, which may have contributed to the comparably lower aquatic insect and oligochaete densities at the site. However, if substrate stability of sites is considered, both TR and PV emerged as having lower overall substrate stability compared to all other sites, including SJ, the other MB site. Larval aquatic insect and oligochaete densities at SJ were generally more similar to other higher substrate stability sites, and the MB and UQ classification of sites was a much more artificial and inconsistent classification than substrate stability. Given these considerations, it is reasonable to conclude that larval aquatic insect density measures were meaningful for all sites despite the temporal discontinuity of the data and that aquatic insect and oligochaete densities were lower for sites with lower substrate stability regimes. Sands were prominent substrate features of sites with higher substrate stability regimes, and chironomid larvae were found to occur in higher densities and in high relative abundance within the aquatic insect communities at these sites. Oligochaetes are also associated with organic rich sands and other fine substrates, and the abundance of sands at the higher substrate stability sites likely contributed to higher densities of these taxa in comparison with nearshore areas characterized by lower substrate stability regimes. Larval aquatic insects overall appear to be better adapted to Great Lakes nearshore areas with comparably higher substrate stability regimes. However, given that the data used to come to this conclusion are derived from a short-term study (i.e., two years or less), additional study over a larger time frame is needed to confirm this conclusion.

Sites with lower substrate stability regimes (TR and PV) were characterized by comparably larger proportions of hard substrates such as glacially deposited boulders and cobbles. The presence of these larger substrate particles can contribute to the higher densities and relative abundance measures for the amphipod/isopod and gastropod taxonomic groups. Amphipods and isopods of the Great Lakes are often associated with higher water quality conditions, but they also require larger substrate particles among which they seek cover and feed on a wide variety of materials. Although some gastropods are adapted to feeding on materials associated with substrates of small particle size, gastropods are generally adapted for scraping off and feeding on materials attached to larger substrates. The significantly higher densities and relative abundance of amphipods/isopods and gastropods under lower substrate stability regimes was largely due to data from the TR site. In fact, WLM sites had far greater densities and relative abundance measures for amphipods/ isopods compared to other lake areas/sites. This was likely due to the comparably high proportion of large substrates in the nearshore waters of these sites. The comparatively high species richness, density and relative abundance for gastropods at the TR site exemplified the importance of large substrates for diverse, productive gastropod communities in the Great Lakes.

Sphaerid clam densities and relative abundance measures were not different between shoreline types, among lake areas or between substrate stability regimes. These results are largely mediated by the comparatively high sphaerid community measures at the SM site compared to all other sites and the high variability in sphaerid community measures within sites. Sphaerids appeared to be very patchily distributed when they were present at a site, accounting for the high variability in density and relative abundance measures for this group. Ecologically, they are more likely to occur in sandy and other fine substrates, especially in the presence of higher organic loads. Only the SM site fit these criteria well, although even within the site they were disparately distributed.

Zooplankton Communities

Criteria for distinguishing sites based on zooplankton community characteristics are not nearly as well defined or studied as benthic macroinvertebrates and fish. In addition, zooplankton are highly susceptible to water currents, prevailing winds, etc., and may respond to much larger scale phenomena than ecological properties of specific nearshore areas and associated shorelines. Nonetheless, zooplankton serve as an essential food web component for nearshore ecosystems, and were considered an appropriate focus in this study. Nearshore zooplankton samples were dominated by small crustaceans, including members of the Cladoceran group (including *Daphnia spp.*) and the Class Copepoda (including the Orders Calanoida, Cyclopoida and Harpacticoida). It was clear that there were differences in the taxonomic composition and density/relative abundance measures for zooplankton between shoreline types, among lake areas and between substrate stability regimes. However, it was not clear whether these differences were in response to the various environmental factors of interest or the temporal discontinuity of the samples among sites. Zooplankton communities vary widely among seasons, and seasonal differences in zooplankton community structure may have been responsible for the observed patterns. In order to more effectively compare zooplankton community characteristics among sites, it is essential that the samples be collected within a tighter timeframe. Unfortunately, for reasons described previously, temporally comparable samples could not be collected during this study.

Lake Erie's higher overall productivity compared to Lake Michigan is reflected in the zooplankton data collected during this study. Densities of cladocerans, including *Daphnia* sp., calanoids, cyclopoids, nauplii and overall zooplankton densities were higher in Lake Erie compared to Lake Michigan by as much as one to two orders of magnitude. Lake Erie zooplankton data appeared to drive the statistically significant results of most zooplankton analyses between shoreline types, among lake areas and between substrate stability regimes. These differences in zooplankton densities among the lake areas emphasize the need for replication within lake areas for more robust statistical analyses of multi-lake studies within the Great Lakes Basin. Additionally, identification of zooplankton taxa to lower taxonomic levels, while beyond the scope of this study, will be essential for future zooplankton studies in Great Lakes nearshore areas.

One particularly notable result related to the zooplankton communities was the dominance of non-native zooplankters at the SJ site. Most sites had very low occurrences of non-native zooplankters, and there was no clear factor that would explain the predominance of non-native zooplankters at the SJ site other than seasonality of the samples. Significant patterns for exotic zooplankters between shoreline types, among lake areas and between substrate stability regimes were solely the result of the samples collected at the SJ site. Additional study of the distribution and association of non-native zooplankters in the Great Lakes is needed to better understand the dynamics of these populations. This has significant implications for fisheries and ecosystem management given that the dominant exotic zooplankters, *B. cederstroemi* and *C. pengoi*, can dramatically influence Great Lakes ecosystems by both competing with native fish larvae for food and, in some cases, preying on larval fish. The results of this study suggest that there may be factors related to nearshore/shoreline properties that influence the distribution and predominance of non-native zooplankters in the Great Lakes and indicates that further research of these phenomena is warranted.

Shallow Water Fish Communities

Shallow water fish communities were comprised principally of species that serve as forage for larger piscivores, typically recreationally and commercially important game fish, in Great Lakes nearshore areas. These communities have been seldom studied (Brazner and Beals 1997) and described historically (e.g., Jude and Tezar 1985, Jude and Pappas 1992) despite their important role in Great Lakes ecosystems. Accordingly, methods development for sampling these communities has been limited. Beach seining techniques were judged to be largely successful for collecting representative samples of shallow water fish communities, although seining efficiency was highly dependent upon substrate structural complexity and wave action. Seine hauls were generally conducted under calm water conditions, although some variability in site specific wave conditions may have compromised the comparability of fish sample data among sites. Additionally, shallow water fish communities were sampled under two distinct water temperature regimes even though actual sampling dates were within a 6-week time period. Samples were collected at TR, PW and PV much later in the field season when water temperatures were ~10°C cooler than earlier season surveys at LD, SJ and SM. In streams, fish typically move downstream into larger, deeper waters as water temperatures fall in order to seek the comparatively greater thermal stability of large river reaches. Shallow water fish in the Great Lakes may also move to deeper waters as temperatures fall in order to overwinter in more thermally stable areas. If this is the case, temporal changes in fish community structure may have confounded shallow water fish analyses. Additional study of shallow water fish movements in the Great Lakes is needed to verify this hypothesis, although this is a likely scenario. Given the limitations in sampling efficiency and the temporally discontinuous data collection, interpretations of shallow water fish community data must be tempered by caution.

Shallow water fish community composition varied among both lake areas and study sites surveyed. WLM and SLE had very few shallow water fish species in common, while ELM shallow water fish communities were comprised of species present in both WLM and SLE samples. Additionally, few Great Lakes shallow water fish species considered to be intolerant of degraded environmental conditions were encountered during the study (tolerance classifications based on Minns et al. 1994 and Thoma 1999). *N. hudsonius* and *Labidesthes sicculus* were particularly abundant within shallow water fish communities of ELM, while *R. cataractae* were very abundant in WLM. Very few intolerant fish species were observed in SLE, and the species pool observed was very small in comparison to the potential suite of species described by Thoma (1999). In ELM, shallow water fish community composition was similar to historical communities (Smith 1970, Wells and McLain 1972, Christie 1974, Jude and Tesar 1985), including species such as *N. atherinoides*, *P. omiscomaycus*, *P. flavescens* and the intolerant *N. hudsonius* and *L. sicculus*. *A. pseudoharengus*, an essentially naturalized non-native species, continues to contribute large numbers of individuals to ELM populations where it preys on larval *N. atherinoides* and competes with other native planktivores. WLM samples were dominated by the intolerant *R. cataractae* with very few non-native species present in shallow water fish samples. Despite the continued presence of the non-native *A. pseudoharengus* and *O. mordax*, these results suggest that WLM and ELM sites generally reflect higher levels of biological integrity and environmental quality compared to SLE. Given Lake Erie's history (Regier and Hartman 1973), it is not surprising that shallow water fish communities in the SLE lake area reflected overall higher tolerance to degraded environmental conditions.

It was not surprising that overall shallow water fish CPUE was higher for UQ shorelines given the high productivity of SM and comparatively species rich community at LD. Differences in CPUE between UQ and MB sites may have been due, in part, to greater seining success in the sandy shallow water substrates generally associated with the unique sites (except PW, where substrates were more variable and estimates were comparably lower than other UQ sites). The structurally complex substrates characteristic of the MB sites can decrease seining efficiency and skew CPUE estimates. The high variability in catch rates among seine hauls further suggests that shallow water fish are patchily distributed or that variable substrate and/or wave conditions influenced sampling efforts both among site specific seine hauls and among study sites. However, the generally consistent higher CPUE and species richness of shallow water fish along sandy shorelines suggests that these are highly significant habitats within the context of the Great Lakes Basin. This is contrary to popular beliefs that sandy nearshore areas of the Great Lakes are generally species poor and characterized by low productivity. It also suggests that anthropogenic activities that modify substrate transport and composition in nearshore areas can potentially lead to decreased fish species richness and abundance in shallow water habitats.

Shallow water fish community trophic classes varied somewhat unpredictably between shoreline types. Shallow water piscivores were generally rare in shallow water samples and high variability in piscivore numbers among samples yielded no significant differences between shoreline types or among lake areas. This may have been partially due to the temporal discontinuity in samples among sites or changes in temperature regime over the sampling period. Two of the MB sites were sampled during the later part of the field season, and it is possible that more juvenile piscivores were present within shallow waters and susceptible to the sampling gear (beach seines) at that time. This may reflect a habitat preference shift for juvenile game fish during late summer/early fall, although definitive evidence for this hypothesis was beyond the scope of this study.

It was relatively surprising that shallow water benthivorous fish CPUE and relative abundance measures were not different between shoreline types. We expected greater densities and abundance of benthivores in shallow waters characterized by higher substrate diversity such as those associated with MB sites. However, benthivores were generally uncommon in shallow water fish communities with the exception of WLM where both CPUE and relative abundance measures were significantly greater than other lake areas. Large numbers of the intolerant *R. cataractae* in WLM beach seine samples were the principal benthivores present, although a few *C. bairdi* were also present in TR samples. *C. bairdi* and darter species (Percidae) likely comprised significant portions of shallow water and nearshore fish communities historically, although only a few *C. bairdi* were collected at one site and no darter species were observed during the study. Because benthivores are generally associated with habitats characterized by high structural diversity, they are inherently more difficult to sample and may have been underrepresented in our samples as a result. However, despite the sampling difficulties we expected to see greater abundance and species richness of benthivores across most sites. The absence of native benthivores in SLE samples, and the high density of *N. melanostomus* observed during SCUBA surveys at PV, suggested that this species has successfully replaced native benthivores in these nearshore areas.

Although we expected shallow water planktivore CPUE and relative abundance measures to be higher for UQ shoreline types and in SLE, CPUE was not significantly different between shoreline types or lake areas, largely due to the great variability in catches among samples for most sites. However, while the relative abundance of shallow water planktivores was not different between shoreline types (again due to the great variability in data among samples collected from different lake areas), it was higher for ELM and SLE compared to WLM. Shallow water planktivores were nearly absent from WLM shallow water fish communities, although they were significantly more abundant in ELM and SLE, where they comprised the bulk of shallow water fish communities. This pattern followed the general trophic status of the lake areas surveyed. Shallow water planktivores were more prevalent in the eutrophic SLE and mesotrophic ELM, while they were nearly absent in the more oligotrophic WLM. However, this pattern may have also reflected the temporal discontinuity of and associated changes in water temperature regime between site surveys. Behavioral responses of planktivorous fish to lower water temperatures characteristic during the later season surveys may have been reflected in these analyses as previously discussed.

The relative abundance measures for native shallow water fish were not different between shoreline types, although the relative abundance of native shallow water fish was higher for WLM compared to ELM. This primarily reflected the greater shallow water planktivore CPUE and abundance at ELM and the fact that the planktivores comprising that community were primarily *A. pseudoharengus*. Seasonal differences in the presence/absence of *A. pseudoharengus* in WLM may have accounted for this pattern. Reconnaissance visits to WLM at earlier times during the summer season in 1999 yielded anecdotal observations of *A .pseudoharengus* that were not present in later season beach seine samples in 2000. So, it is difficult to attribute the differences in the relative abundance of native shallow water fish to any factor other than varied seasonality/water temperature regime.

It was surprising that fish community measures were largely similar between substrate stability regimes. Only total shallow water fish CPUE was marginally significant, with higher CPUE measures under higher substrate stability regimes. We expected that the changes in habitat character and availability at low substrate stability sites would yield lower measures for most fish community attributes, especially given that one of the two sites identified as having low substrate stability was characterized by significant shoreline and nearshore anthropogenic manipulations (i.e., PV). We also expected non-native shallow water fish CPUE and relative abundance to be higher under lower substrate stability regimes given that invasive exotics tend to be habitat generalists that successfully exploit a wide range of habitats, although this was not the case. The great variability in samples from sites, the low number of replicate sites (especially for the low substrate stability regime) may have contributed to our inability to detect differences in shallow water fish community attributes. Additional study with greater replication within lake areas is needed to explore this issue more thoroughly.

Nearshore Fish Communities

Nearshore fish CPUE values were not different between shoreline types, although they did reflect the trophic state of each lake area sampled. Lake Erie, well known for its high productivity (Regier and Hartman 1973), had the greatest nearshore fish CPUE of all lake areas surveyed. Nearshore fish community composition followed a pattern similar to shallow water fish. ELM nearshore fish communities shared species with both WLM and SLE, although only one fish species (*P. flavascens*) was present in both WLM and SLE nearshore communities. SLE was dominated by fish generally associated with more productive lake ecosystems (e.g., *S. vitreum*, *I. punctatus*, *A. grunniens*, *C. carpio* and *D. cepediaum*), while salmonids were much more common and even dominated WLM and LD gillnet samples.

The significantly greater relative abundance of nearshore planktivorous fish largely reflected the higher productivity of the SJ and PV sites compared to almost all other sites (excepting SM). This was likely a product of the locations of the sites (in SLE and southeastern Lake Michigan) rather than reflecting significant responses to different shoreline types. The high productivity of SLE was also reflected in the nearshore piscivore CPUE analysis, although the relative abundance of piscivores among the lake areas was similar. Both the nearshore planktivore and piscivore analyses suggested that nearshore fish abundance and trophic composition are probably largely determined by lake productivity rather than physical properties related to adjacent shorelines. This was also reflected in the substrate stability analyses, in which no differences in fish community attributes were detected between high and low substrate stability regimes.

SUMMARY

Analyses of nearshore community data collected from this study yielded little conclusive evidence of relationships between Great Lakes nearshore communities and shoreline properties. This was likely due to the limited duration of the study, disparate seasonality of sample collection and limited replication within shoreline classes and lake areas. One important factor to consider is that the alteration of littoral transport processes and transformation of Great Lakes nearshore substrates from sand to larger, harder substrates likely influences community composition with respect to native fish and benthic invertebrates. Long-term exposure of these larger substrates increases the likelihood of invasions by non-native species such as zebra mussels and round gobies. The longer term consequences of these invasions may far outweigh the short-term effects. Zebra mussel colonization has the potential to shift productivity of nearshore areas from primarily pelagic (i.e., plankton) to benthic. As food sources are converted over time, the ability of nearshore ecosystems to support planktivores and the game fish species that prey on them will likely decrease. Changes in game fish community composition may not be immediately evident, although declining stocks will result. With the primary productivity shifted to benthic habitats, round gobies will thrive once they enter the system and will likely come to dominate fish biomass over time.

This conceptual model for nearshore ecosystem change is rooted in recent and current research findings based on fine scale manipulative experiments. Our study, though limited in scope, suggests that identifying shifts in nearshore ecosystems related to local shoreline environmental properties may not be sufficient for detecting these changes. In truth, the sites comprising this study likely represented somewhat subtle gradations in environmental perturbation that confounded statistical analysis in the absence of more specific criteria for classification and replication of appropriate classes. Changes in littoral transport, plankton distribution, fish movements and migrations, etc., are linked to, if not dependent upon, larger scale processes not considered in this study. In order to more effectively identify community and habitat changes related to anthropogenic manipulations within the Great Lakes Basin, future studies must consider multiple spatial and temporal scales that influence nearshore ecosystems. Once we have a better idea of the factors and scales to which nearshore communities and ecosystems are responsive, we can begin studying them more effectively to identify management and protection priorities to enhance the long-term viability of the Great Lakes Basin ecosystem.

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APPENDICES

Appendix A. Macrobenthic taxa identified in samples collected from hard and soft substrates of Great Lakes nearshore study sites.

Taxonomic Group		Shoreline Type		Lake Area			Unique Sites			Midbluff Sites		
Class	**Order, Family, Genus**	**Unique**	**Mid Bluff**	**Erie**	**East Michigan**	**West Michigan**	**Sheldon Marsh**	**Luding-ton**	**Port Washing-ton**	**Paines-ville**	**St. Joseph**	**Two Rivers**
Insecta (Aquatic Larvae and Nymphs)	**Ephmereroptera, Heptageniidae, *Stenonema sp.***	X	X	X		X	X			X		X
	Trichoptera, Leptoceridae, *Oecetis sp.*	X				X			X			
	Diptera, Chironomidae (Larvae)	X	X	X	X	X	X	X	X	X	X	X
	Diptera, Ceratopogonidae		X		X						X	
	Diptera, Ephydridae	X				X			X			
Gastropoda (Snails)	***Bithynia sp.***		X			X						X
	Limnophila, Physidae, *Physa sp.*	X	X	X		X	X		X			X
	Mesogastropoda, Valvatidae, *Valvata sp.*	X	X		X	X		X				X
	Mesogastropoda, Pleuroceridae, *Elimia sp.*	X	X			X			X			X
Annelida (Segmented Worms)	**Hirudinea (Leeches)**	X		X		X	X		X			
	Oligochaeta	X	X	X	X	X	X	X	X		X	X
Peracarida	**Amphipoda (Scuds)**	X	X	X		X	X		X	X		X
	Isopoda (Sow Bugs)	X	X			X			X			X
Turbellaria (Flatworms)		X				X			X			
Decapoda (Crayfish)		X				X			X			
Hydrachnida (Water Mites)			X		X	X					X	X
Dreissenidae (Zebra Mussels)	***Dreissena polymorpha***	X	X	X	X	X	X		X	X	X	X
Sphaeriidae (Fingernail Clams)		X	X	X	X	X	X	X	X		X	
Total number of morphospecies:		**18**	**17**	**10**	**11**	**20**	**10**	**7**	**15**	**4**	**10**	**13**

Appendix B. Fish species observed in beach seines (S) and gill nets (G) fished in nearshore waters of six Great Lakes shoreline areas. Functional groups were used to describe the ecological disposition of each species, including specialist, generalist, exotic, and introduced. Feeding guild designations are also provided, including planktivore (plank), benthivore (benth), and predator (pred).

			Functional Groups		**Shoreline Type**		**Lake Area**			**Unique Sites**			**Midbluff Sites**		
Family	**Common Name**	**Scientific Name**	**Ecological Designation**	**Feeding Guild**	**Unique**	**Midbluff**	**Erie**	**East Michigan**	**West Michigan**	**SM**	**LU**	**PW**	**PV**	**SJ**	**TR**
Atherinidae (Silversides)	**Brook Silverside**	***Labidesthes sicculus***	**Generalist**	**Plank**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**		**S**	
Catostomidae (Suckers)	**Golden Redhorse**	***Moxostoma erythrurum***	**Specialist**	**Benth**		**SG**		**SG**						**SG**	
	Longnose Sucker	***Catostomus catostomus***	**Specialist**	**Benth**	**G**				**G**			**G**			
	White Sucker	***Catostomus commersoni***	**Generalist**	**Benth**	**G**			**G**	**G**		**G**	**G**			
Centrarchidae (Sunfishes and Black Basses)	**Smallmoth Bass**	***Micropterus dolomieu***	**Generalist**	**Pred**		**SG**		**SG**						**SG**	
Clupeidae (Herrings)	**Alewife**	***Alosa pseudoharengus***	**Exotic**	**Plank**	**S**	**S**		**S**	**S**		**S**	**S**		**S**	**S**
	Gizzard Shad	***Dorosoma cepedianum***	**Generalist**	**Plank**	**SG**	**G**	**SG**	**SG**		**SG**	**SG**		**G**	**G**	
Cottidae (Sculpins)	**Mottled Sculpin**	***Cottus bairdi***	**Specialist**	**Benth**		**S**			**S**						**S**
Cyprinidae (Carps and Minnows)	**Emerald Shiner**	***Notropis atherinoides***	**Generalist**	**Plank**	**S**	**S**	**S**	**S**		**S**	**S**		**S**	**S**	
	Longnose Dace	***Rhinichthys cataractae***	**Specialist**	**Benth**	**S**	**S**		**S**	**S**		**S**	**S**		**S**	**S**
	Spottail Shiner	***Notropis hudsonius***	**Generalist**	**Plank**	**S**	**S**	**S**	**S**	**S**	**S**	**S**		**S**	**S**	**S**
	Carp	***Cyprinus carpio***	**Generalist**	**Benth**	**G**	**G**	**G**			**G**			**G**		
Cyprinodontidae (Killifish)	**Banded Killifish**	***Fundulus diaphanus***	**Specialist**	**Plank**		**S**		**S**						**S**	
Gobiidae (Gobies)	**Round Goby**	***Neogobius melanostomus***	**Exotic**	**Benth**	**S**	**S**	**S**			**S**			**S**		
Ictaluridae (Catfish and Bullheads)	**Channel Catfish**	***Ictalurus punctatus***	**Generalist**	**Pred**	**G**	**G**	**G**			**G**			**G**		
Osmeridae (Smelts)	**Rainbow Smelt**	***Osmerus mordax***	**Generalist**	**Pred**	**S**	**S**	**S**	**S**			**S**		**S**		
Percichthyidae (Temperate Basses)	**White Bass**	***Morone chrysops***	**Generalist**	**Plank**	**SG**	**SG**	**SG**			**SG**			**SG**		
	White Perch	***Morone americana***	**Exotic**	**Plank**	**SG**	**S**	**SG**			**SG**			**S**		
Percidae (Perches and Darters)	**Walleye**	***Stizostedion vitreum***	**Generalist**	**Pred**	**G**	**G**	**G**	**G**		**G**			**G**	**G**	
	Yellow Perch	***Perca flavescens***	**Specialist**	**Pred**	**SG**	**SG**	**G**	**SG**	**G**	**G**	**S**	**G**	**G**	**SG**	
Percopsidae (Trout-perches)	**Trout-perch**	***Percopsis omiscomaycus***	**Specialist**	**Benth**	**S**	**S**		**S**			**S**			**S**	
Salmonidae (Salmon and Trout)	**Brown Trout**	***Salmo trutta***	**Stocked**	**Pred**	**G**				**G**			**G**			
	Chinook Salmon	***Onchorhynchus tshawytscha***	**Stocked**	**Pred**	**G**	**G**		**G**	**G**		**G**	**G**		**G**	**G**
	Coho Salmon	***Onchorhynchus kisutch***	**Stocked**	**Pred**	**G**	**G**		**G**	**G**		**G**				**G**
	Lake Trout	***Salvelinus namaycush***	**Specialist**	**Pred**	**G**				**G**			**G**			
	Rainbow Trout	***Onchorynchus mykiss***	**Stocked**	**Pred**		**S**	**S**						**S**		
Sciaenidae (Drums)	**Freshwater Drum**	***Aplodinotus grunniens***	**Generalist**	**Benth**	**G**	**G**	**G**	**G**		**G**			**G**	**G**	
Total Number of Species					**22**	**23**	**14**	**17**	**12**	**12**	**12**	**9**	**13**	**14**	**6**

Appendix C. Zooplankton taxa observed in vertical plankton tows (i.e., 1m, 3m and 6m depths) in nearshore waters of six Great Lakes shoreline areas.

		Shoreline Type		**Lake Area**			**Unique Sites**			**Mid-Bluff Sites**		
Taxonomic Grouping	**Morphospecies/Genus**	**Unique**	**Midbluff**	**Erie**	**East Michigan**	**West Michigan**	**SM**	**LD**	**PW**	**PV**	**SJ**	**TR**
Exotics	***Cercopagis pengoi***	X	X		X	X		X	X		X	X
	Bythotrephes cederstroemi	X	X	X	X		X	X		X		
Cladocerans	***Leptodora sp.***	X	X	X	X	X	X	X	X	X		
	Polyphemus sp.	X	X		X			X			X	
	Diaphanosoma sp.	X	X	X	X		X	X		X	X	
	Eubosmina sp.	X	X	X	X		X				X	
	Bosmina sp.	X	X	X	X	X		X	X	X	X	X
	Chydorus sp.	X	X	X	X	X	X				X	X
	Daphnia retrocurva	X	X	X		X	X		X	X		X
	Daphnia galeata	X	X	X	X	X	X	X	X	X	X	X
	Daphnia longiremis											
Diaptomidae	***Limnocalanus sp.***	X		X		X	X		X			
	Skistodiaptomus sp.	X	X		X	X		X			X	X
	Leptodiaptomus sp.	X	X	X		X			X	X		
Cyclopoidae	***Diacyclops sp.***	X	X	X	X	X	X	X	X	X	X	X
Harpacticoid		X	X	X		X			X	X		X
Nauplii		X	X	X	X	X	X	X	X	X	X	X