Examining fish collection techniques and zooplankton community structure in coastal wetlands of Lake Erie and Ontario

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A STUDY OF FISH COLLECTION TECHNIQUES AND ZOOPLANKTON COMMUNITY STRUCTURE OF THE LAURENTIAN GREAT LAKE COASTAL WETLANDS

By

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GENERAL ABSTRACT

The Laurentian Great Lake wetlands are highly productive and complex systems. The net loss of wetlands since European settlement has been dramatic. The remaining coastal wetlands continue to be threatened with obliteration or severe environmental degradation. Therefore, the overall objective of this study was to provide information on the ecology of the remaining coastal wetlands within the lower Great Lakes.

This study describes a coastal wetland fish community along the north shore of Lake Erie within Long Point Marsh complex over a 24-h period and catch characteristics of three common fishing techniques. The fish community was sampled at two hour intervals over a 24-h period in June, and used three types of gear to determine possible sampling biases from the different collection techniques. A total of 497 fish encompassing 11 taxa were collected. A 2-h interval, four hours prior to sunset, netted the largest number of taxa (including 3 functional feeding groups: omnivores, planktivores, and piscivores), as well as highest abundance and biomass values. Seine netting demonstrated a biased towards sampling the smaller planktivores, while fyke nets were biased towards larger omnivorous fish, and boat electrofishing was biased towards the large piscivores. These results will assist scientists and lake managers to develop standardized fish sampling protocol in order to accurately assess differences in wetland fish communities.

Seven coastal wetlands within Lake Erie and Ontario along both the Canadian and United States shorelines were studied to verify predicted relationships from the literature and determine the relative influences of various habitat features on zooplankton community structure. Water quality, aquatic macrophyte, zooplankton, and fish community information were collected from the wetlands between July 4th and August 2nd of 2001. The predicted relationships from the literature concerning water quality and macrophyte species richness were verified by the results of this work. Water quality and macrophyte species richness were the most accurate predictors of wetland zooplankton community structure. Identifying the wetland characteristics that play primary roles in structuring zooplankton communities will also assist lake managers to make informed decisions of how to most effectively improve zooplankton habitat, to foster larger-bodied zooplankton populations, making the habitat more suitable for larger populations of larval and juvenile fish.

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GENERAL INTRODUCTION

Wetlands

Not land or water, but a fluid combination of both, wetlands are among the most productive habitats on earth. Wetlands are formed when water becomes trapped on land that is poorly drained or flooded periodically by natural or man-made coastal barriers such as sandbars or dikes. Many different types of wetlands are found throughout the world (freshwater coastal marshes, bogs, fens, arctic muskegs, wet meadows, swamps and salt marshes). They can be found everywhere in the world except in Antarctica. Wetlands all have common characteristics, yet each is unique in its hydrology and biodiversity. Wetlands are not easily defined, due in part to their diversity, but also to legal and political reasons. However, definitions do exist, and in Canada wetlands have been defined as:

> "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic (i.e. water-loving) vegetation, and various kinds of biological activity which are adapted to a wet environment (National Wetland Working Group 1988)."

There are many physical and biological differences between wetland and open water environments that make wetlands uniquely capable of performing the functions for which they are known. Fluctuating water levels in wetlands promote the interaction of aquatic and terrestrial systems, thereby resulting in higher quality habitat and increased productivity (Wilcox and Meeker 1992). Wetlands support lower rates of decomposition and higher rates of primary productivity. Wetlands are generally shallow environments that do not stratify and that freeze to the bottom in winter. In healthy wetlands, the dominance of primary productivity by aquatic macrophytes as opposed to algae provides an element of structural complexity to the habitat. Wetlands that have healthy plant communities provide areas of reduced water flow, allowing for water filtration and sediment attenuation. In addition, wetland plants protect zooplankton and juvenile fish from sight-feeding planktivorous and piscivorous fish. The aquatic vegetation and the often-complex shorelines also provide protection for juvenile fish from wind and wave action.

Wetland ecosystems are among the most productive ecosystems known (Wetzel 1990), approaching that observed in tropical forests and marine estuaries (Wittaker 1975). Wetlands provide habitats for many kinds of plants and animals, some of which are found nowhere else. They play an essential role in sustaining a productive fishery; many species of Great Lakes fish depend on coastal wetlands for successful reproduction. Reasons for the preferred utilization of marshes by fishes include the high primary productivity, which translates into a rich zooplankton and benthic food source (Jude and Pappas 1992). As well, for ducks, geese and other migratory birds, wetlands are the most important part of the migratory cycle, providing food, resting places and seasonal habitats. The concept of the nearshore zone acting as a center of organization (Steedman and Regier 1987) certainly applies to wetlands, since they have such a diversity of habitats, high productivity, and serve as important nurturing areas for young-of-the-year keystone predators (Jude and Pappas 1992).

Wetlands degradation

The importance of wetlands to humans, fish and wildlife is increasingly being recognized; however, there are many direct and indirect stresses that continue to threaten these unique habitats. Stresses can be classified as natural or human-induced. As they have for millennia, wetlands are able to recover from natural stresses, such as storms, ice damage and low water levels. Unfortunately, human-induced stresses often occur so quickly and drastically that wetlands either cease to exist or are unable to fully recover.

Human induced, direct stresses (those that occur within a wetland) include dredging, filling, draining, and invasive species. Aside from those activities such as dredging, filling and draining, which completely destroy the wetland habitat, invasive species can also have surprising detrimental effects. Invasive species of plants are often capable of reproducing so aggressively that they displace native plants in the area that they have become established. Common invasive wetland plants include Purple Loosestrife and Eurasian Water Milfoil. Aggressive fish and wildlife can also be a serious problem. The Common Carp, a fish introduced from Europe, damages wetland ecosystems while feeding and spawning by uprooting submerged vegetation and increasing suspended sediment in the water, which decreases light penetration required for plant growth.

There are also human-induced indirect stresses, which are often less pronounced, that result in changes to wetland function and vegetation communities over longer periods of time. Indirect stresses include runoff from upstream agricultural practices, sewage treatment plants and industrial sources, which can cause loading of nutrients, sediments and toxic chemicals in downstream wetlands. Due to the cumulative impacts and the large land areas involved, it is often difficult to remedy these problems. Fortunately, wetlands are able to assimilate some nutrients and toxic chemicals through plant uptake and the interaction of flowing water with microbial communities active in the wetland soils. Another indirect stress is lakewide water level regulation, which has been the case for Lake Ontario since 1958 and Lake Superior since 1921. Regulation is carried out to maintain water levels in these two lakes at a level appropriate for navigation, shipping, hydroelectric power and riparian landowners. However, this means less natural variability in water levels, a feature prevents establishment of monocultures in coastal wetlands and is a mechanism responsible for fostering high biodiversity in these ecosystems.

Thesis objectives

Coastal wetlands of the Great Lakes are believed to provide important ecological services to the lake biota (Krieger and Klarer 1991). However, the presence of accelerating coastal development increasingly threatens the existence of approximately 25% of the original coastal marshes remaining along the shores of the Great Lakes (Jude and Pappas 1992). Thus, it is urgent that their role in the Great Lakes ecosystem be understood and documented. Therefore, the overall objective of this study is to provide information on food webs in coastal wetlands of the Great Lakes, in particular the relationship between zooplankton and the aquatic environment, fish and aquatic plant communities.

It is important that we develop efficient/ reliable/ standardized sampling techniques to ensure that date sets within, as well as among studies, can be justifiably compared.

This is especially important where fish are concerned because of the number of different sampling methods that can be used. Chapter 1 identifies the biases associated with fishing techniques and the time of day when those techniques are deployed. The results of this study will allow a more complete understanding of how choice of fishing techniques, and time of deployment can bias survey results. Chapter 2 evaluates the habitat features that influence the zooplankton community structure within the Great Lake coastal wetlands. The primary goals of this study were to verify the relationships among water quality, aquatic macrophyte and fish communities with zooplankton community structure that have been reported in the literature, and to determine the relative influences of these habitat characteristics on the zooplankton community structure from seven Lake Erie and Ontario coastal wetlands. This information will assist lake managers to make informed decisions of how to improve zooplankton habitat to encourage larger-bodied zooplankton populations, thus make the habitat more suitable for larger populations of juvenile fish.

CHAPTER 1:

Comparison of sampling biases in three fishing techniques in Long Point Marsh Complex, a coastal wetland of Lake Erie

ABSTRACT

Diel changes in the fish community in a coastal wetland along the north shore of Lake Erie within the Long Point Bay wetland complex were examined. Fish were sampled with single seine hauls over a *Chara sp.* bed of uniform density every two hours over a 24-h period. A total of 497 fish encompassing 11 taxa were collected. A 2-h interval, four hours prior to sunset, netted the largest number of taxa (including 3 functional feeding groups: omnivores, planktivores, and piscivores), as well as highest abundance and biomass values. Among the most abundant were blacknose shiner (*Notropis heterolepis*), sunfish (*Lepomis sp.*), yellow perch (*Perca flavescens*), and rock bass (*Ambloplites rupestris*); among the rarest were spotted gar (*Lepisoteus oculatus*), grass pickerel (*Esox a. americanus*) and tadpole madtom (*Noturus gyrinus*), which occurred only once when all samples were pooled. Following the 24-h seine-net survey, the same area was sampled with paired fyke nets and an electrofishing boat. No single technique sampled all taxa, and only 5 species (blacknose shiner, sunfish, yellow perch, largemouth bass and rock bass) were common to all three fishing gear. Seine netting was biased towards sampling the smaller planktivores, while fyke nets were biased towards larger omnivorous fish, and boat electrofishing was biased towards the large piscivores.

INTRODUCTION

There are several factors that need to be considered when fish-community data in coastal wetlands of the Laurentian Great Lakes are to be compared across studies. First, the timing and frequency of sampling through the year must be standardized, because wetlands are habitat to both resident and migratory taxa, and there can be dramatic shifts in taxonomic composition through the season (Killgore et al. 1989; Stephenson 1990; Pope and Willis 1996; Scott and Crossman 1998; Tanner and Brazner, unpublished data). Secondly, diel changes in abundance and species composition have been noted (Reynolds 1989; Pope and Willis 1996), and therefore the hour of sampling must also be standardized. Thirdly, the type of sampling gear used may also lead to different results even when the two other factors are held constant (Hardin and Connor 1992).

There are two categories of fishing techniques: passive and active. Each category has advantages and disadvantages associated with their methods of gathering fish that require further explanation. Passive capture gears involve the capture of fish or other aquatic animals by entanglement or entrapment in devices that are not actively moved by man or machine (Hubert 1989). Examples of entanglement gear include gill and trammel nets. Examples of entrapment gear include: hoop nets, fyke nets, minnow traps, slat traps and weirs. There are many advantages to using passive capture techniques. Passive gears are generally easily handled, require little training to properly operate, are of simple design and construction and it has been shown that nets fished in a similar manner and time each year can give reasonable estimates of changes in stock density (Hubert 1989). However, there are also disadvantages to using passive fishing gears. Passive gears tend to be selective to some extent for certain species, sizes, or sexes of fish. Another drawback is that the process of capturing a fish involves numerous stages: the fish and gear must overlap in time and space, the fish must encounter the gear, the gear must catch the fish, and finally the gear must retain the fish until it is retrieved (Hubert 1989). With so many stages in the capture process, there is potential for selectivity to occur at any point of the capture sequence.

Active fish capture techniques include those that capture fish by sieving them from the water by means of mesh panels or bags (Hayes 1989). Examples of active capture techniques include: trawls (midwater, bottom, beam), seines (round haul, beach, purse), sled-tow net, lift net, cast net and electrofishing. There are certain advantages associated with using active fishing techniques. Active techniques tend to require less time from gear deployment to fish processing. They are more capable of enclosing or encompassing geometrically definable sampling spaces in which the target organisms are separated from the water by means of the sieving action of the gear (Hayes 1989). There are likewise disadvantages to using active techniques. Habitat characteristics, such as bottom type, water depth, vegetation, transparency, wave action and current may limit the usability of certain types of gear. The occurrence of boulders, rock outcrops, debris and stumps may also obstruct passage of gear along the bottom. Because gear are limited to ideal habitat where it functions properly, catches may be biased towards those fish that are prone to those habitat where the gear can be easily operated. Also, because active gear is deployed over a short time interval, catches may be biased towards those assemblages of fish that utilize the habitat during that particular period of the day when the sampling was conducted. Electrofishing, although an active fishing technique, is unique and therefore has it's own associated advantages and disadvantages. Electrofishing is the use of electricity to capture fish. There are two basic techniques for conducting electrofishing, using a backpack shocker (battery powered), or boat electrofishing units (generator powered). The rate of flow or intensity of the charge is the current and is measured in amperes. The electromotive force that moves the charge is voltage and is measured in volts. Electrical power is the rate at which electrical work is done and is measured in watts. High current will kill fish, moderate current will stun them, while low current will allow them to escape (Reynolds 1989). The advantages to using an electrofishing system include their ability to be used in a wide variety of habitat, irrespective of bottom types and morphology. Disadvantages include the fact that water conductivity has a strong influence on the effectiveness of electrofishing. At high conductivities, water is a better conductor for the electricity than are the fish, which causes the current to flow around them, thus having little to no influence on the fish (Reynolds 1989). At low conductivities, the water is more resistant than the fish, and since the electrical field is limited to the immediate vicinity of the probes, only a few fish are sampled (Reynolds 1989). Furthermore, a fish's vulnerability to capture by electrofishing varies according to physiological and behavioral differences (Reynolds 1989). Bony fish conduct current more readily than do cartilaginous fishes. Habitat preference among species will influence their vulnerability. Species that inhabit shallow littoral regions are more vulnerable than those that reside in open water environments.

Fish size is another factor that affects vulnerability because total body voltage increases with length, resulting in larger charge delivered to larger fish.

In previous comparison, no single sampling gear caught all species and sizes of fish, and each gear type presented only a partial view of the community (Weaver et al. 1993). Recent comparisons of fishing techniques within littoral zones, involving a variety of gears (fyke nets, gill nets, minnow traps, seine nets, electrofishing, etc.) have limited the scope of their comparisons to a single variable (species richness) or a combination of variables (species richness and fish sizes or abundances) (Hamley and Howley 1982; Kraft and Johnson 1992; Holland and Peters 1992; Weaver et al. 1993; Fago 1998). Yet, as fisheries management moves toward an ecosystem approach in managing aquatic systems, there is need for a more in-depth analysis of differences in fishing gears, that includes the traditional comparisons based on species richness and abundance, but that also takes into consideration functional feeding classes (omnivores, planktivores, benthivores, and piscivores).

In this paper, diel changes in the fish community of a coastal wetland along the north shore of Lake Erie within the Long Point Marsh complex were examined. The fish community was sampled at two hour intervals over a 24-h period in June, and used three types of gear to determine possible sampling biases from the different collection techniques. All comparisons were carried out in the same area because fish abundances and species richness can vary according to depth (Jeppesen et al. 1997) and macrophyte density (Tonn and Magnuson 1982; Killgore et al. 1989; Chick and McIvor 1994; Randall et al. 1996; Diehl and Kornijow 1997). Results from this study will allow a more complete understanding of differences among three commonly used fishing methods and permit informed decisions as to appropriate choice of technique to ensure comparable results across sampling sites.

METHODS

Study Site

Long Point Marsh Complex is located along the north side of Lake Erie, in the lee of a 35-km-long sandspit called Long Point (42°35'12"N, 80°23'16"W; Figure 1-1). The seine netting, fyke netting, and electrofishing were all conducted within Sturgeon Bay, located on the south shore of Inner Bay. The sampling site was a 30 m section of shoreline with uniform composition of muskgrass or stonewart (*Chara sp.*) that extended out to the 1.5 m contour.

Gear Descriptions

The seine net used during the 24-h fish survey was 12' x 5' with 1/8" nylon mesh. The fyke nets are of the same dimensions (10' long with 3' x 4' rectangular front openings and five 30" stainless steel rings behind, forming two throats that lead to a cod end). Mesh in one net was 3/16" nylon mesh (small mesh) while the other was 1/2" nylon mesh (large mesh). Two wings (3' x 25'; 3/16" mesh) were attached to sides of the net opening. The fyke nets were oriented toward each other with a 5 m gap between the ends of each set of wings, resulting in an enclosed area of 110 m^2. Nets were staked in place with six pieces of 10' steel tubing.

The electrofishing boat consisted of a Smith-Root SR-20 boat with GPP 7.5 Electrofisher. Dual anodes on booms extending 1.5 m from either side towards the bow supplied the current, with the boat hull operating as the cathode. The electrical control box was set for an output voltage of 400-500 Volts with a current of 10 Amps to produce a power output of approximately 4000-5000 Watts. Two people retrieved fish with 3 m long dip nets. Effort was limited to 1000 shock seconds, over two 30 x 5 m transects.

24-h Seine Net Survey

To assess the influence of time of day on the fish community, single seine hauls were conducted at 2-h intervals over a period of 24 hours. Sampling began at noon on June 25th and was completed by 10:00 the following day. Each seine haul was drawn from the 1 m depth contour to the 0.3 m depth contour (where the emergent macrophytes commenced) over an approximate distance of 5 m. The first six successive seine hauls were conducted parallel to each other with a 1 m buffer zone between each; the remaining six hauls took place in the same location as those sampled twelve hours earlier. No data were collected at 04:00 because of equipment failure.

Immediately following the end of the seine survey, fyke nets were deployed in the same vicinity. Frames and wings of the nets remained within the 1 m depth contour (± 10 cm). Deployment of the nets was completed by 11:30 on June 26th and removal commenced at 11:30 on June 27th, for a survey period of 24 hours. The following day on June 28th electrofishing was conducted between 10:50 and 11:10 within the immediate and surrounding area where fish were collected using seine netting and fyke nets. 1000 shock seconds were used to sample over the *Chara sp.* bed within the 0.7 to 1.2 m depth contours.

Fish Processing

All fish from the 24-h seine net survey were measured for total length to the nearest 1 mm, counted and identified to species using a Peterson Field Guide for Freshwater Fishes (Page and Burr, 1991) and Scott and Crossman (1998). The same variables were measured for those fish collected with fyke nets and electrofishing; however, only 20 specimens of each taxon were measured for total length, and the remaining fish were counted. The weights of fish were determined from published length-weight equations (Schneider et al. 2000; Table 1-1). Functional feeding classes were assigned to each fish based on diet information gathered from Scott and Crossman (1998). Table 1-2 summarizes the fish species, and their total abundance values for each species classed as omnivorous, planktivorous, benthivorous or piscivorous.

RESULTS

Comparison of fish caught over 24-h period

The 24-h sampling regime revealed that a wetland fish community can exhibit dramatic changes through the day with respect to species richness, abundance, biomass and composition of functional feeding groups. Choice of technique can influence species richness, abundance, biomass information, and bias data against different functional feeding groups.

Weather Conditions

The atmospheric conditions for the period from noon on June 25th to 10:00 on June 26th 2001 were consistent throughout. The daytime temperature high for this period reached 29 °C, with lows during the nights falling to 16 °C. Sunset on June 25th occurred at 21:03 and sunrise the following day occurred at 05:44. The sky was clear and the along-shore breeze from the east was light throughout the sampling period. Water temperature within the sheltered bay was 27.5 °C, with a dissolved oxygen concentration of 12.74 mg/L and a pH of 9.18. Water quality measurements were taken at 11:30 the morning of June 26th.

Weather conditions play an important role in the behavior of fish. Despite a lack of scientific published articles that deal with this phenomenon, observations conducted by fishermen over the centuries have described changes in fish behavior in association with changes in weather conditions. More specifically, increased fish activity (movement and feeding) is often associated with low-pressure conditions (cooler temperatures, overcast cloud conditions, and rain), and decreased fish activity with high-pressure conditions. Therefore, since weather conditions were consistent throughout the 24-h period, differences among the fish hauls at each interval cannot be attributed to changes in fish behaviour as a result of changes in weather conditions.

Fish Characteristics

A total of 497 fish were captured by seine netting within the 24-h period, representing 11 species. The common and scientific names of the fish species cited in this report are listed in Table 1-3, along with the numbers and biomass of each species captured during each sampling interval.

The highest fish abundances per interval were recorded during the afternoon period between 16:00-20:00, followed by a secondary peak at 02:00 (Figure 1-2). Blacknose shiner were the most numerous fish gathered (278 specimens), followed by sunfish (78), yellow perch (46), rock bass (31), banded killifish (18), largemouth bass (17), jonny darter (9), golden shiner (7), and single individuals of spotted gar, grass pickerel and tadpole madtom. The high biomass values at 16:00 and 02:00 can be attributed solely to a high abundance of blacknose shiners, whereas the 18:00 interval can be attributed to high abundance values for blacknose shiners, yellow perch and banded killifish and the 20:00 interval being attributed to high abundance values of blacknose shiner and yellow perch.

The total fish biomass calculated from species-specific length-weight regressions equaled 784 g for the 24-h period. Changes in total fish biomass per interval are similar to that of abundance, with peaks occurring at mid-late afternoon (14:00-18:00), and at 02:00 (Figure 1-3). Differences exist due to the presence of a few large fish that inflate the overall interval/species records. For example, the higher biomass values for 14:00 that were not related to high abundance values were a result of one large perch (30 g) and one large sunfish (27 g).

Species richness (total number of fish species) for each interval was not closely associated with either fish abundance or biomass. A total of 11 species were caught over the 24-h period. The maximum number of fish species was caught during the 02:00 interval with 8 species; the minimum number of species was represented by only 4 species caught at midnight (00:00)(Figure 1-4). The mean number of species per interval was 6. Of the 11 species caught, three of those species (spotted gar, grass pickerel and tadpole madtom) were only caught within a single haul/interval and were therefore considered as incidentals within the habitat and not expected to be resident to the area.

Therefore, of the 11 fish species, only 8 were common to more than one seine haul/interval and could be considered residents of the surveyed habitat. All 8 resident species were never caught together during a single sampling interval, although 7 of the 8 species were caught together on four of the 11 occasions (16:00, 18:00, 02:00 and 10:00).

Species richness, abundance, and biomass values all began to decline during the intervals leading up to sunset (21:03) with further declines in species richness and abundance following sunset, while biomass increased after sunset at 22:00. There were more species present close to sunrise (05:44) even though there was only moderate to low abundances and biomass.

Food Web Dynamics

Fish were divided into four feeding classifications: omnivorous, planktivorous, benthivorous and piscivorous. Planktivorous fish were by far the most abundant class; of the 497 total fish, 422 are classified as planktivores, 37 as omnivores, 35 as piscivores, and only 1 as a benthivore. Planktivore abundance represented a minimum of 70% the total fish abundance per interval (Figure 1-5). Planktivorous fish represented 94, 95, and 98% of the abundances sampled during the 16:00, 18:00 and 20:00 intervals respectively.

Biomass of planktivorous fish was highest (400 g), followed by piscivorous fish (213 g), omnivorous fish (160 g), and a single benthivore (11 g). The three common feeding classes (planktivores, omnivores and piscivores) were well represented at each sampling time, except during the late evening intervals (20:00 and 00:00) where piscivorous fish were absent (Figure 1-6). Planktivore biomass was highest during the evening intervals (16:00-18:00) and lowest for the 10:00 interval. Omnivore biomass was highest during the early and late evening intervals (14:00 and 22:00) and lowest during mid-evening (18:00-20:00). Piscivore biomass was highest for the early afternoon (12:00, 14:00, 16:00) and early morning intervals (02:00, 06:00, 08:00) and lowest during the period between mid-evening and midnight (18:00-00:00) and again at 10:00. Planktivore and piscivore biomass vary together over the intervals from early morning to early afternoon (02:00-14:00) with the biomass of each class remaining within a 10 g differential (Figure 1-7); whereas between early afternoon (16:00) and midnight (12:00) a more substantial decline in piscivore biomass (relative to the decline in planktivore biomass) resulted in higher planktivore biomass over each interval. Both planktivore and piscivore abundances began declining 3-hours prior to sunset, which continued over the following 3-hours. Sunrise was associated with a less pronounced decline in planktivore and piscivore abundance.

Comparison of fyke net, boat electrofishing and seining

Weather Conditions

Fair-weather conditions persisted throughout the 4-day period from June 25th to June 28th 2001 during which, each of the three fishing techniques were deployed. Therefore, any differences among the catches by each of the fishing techniques (which were deployed at different times) cannot be attributed to changes in fish behaviour as a result of changes in weather conditions.

Fish Characteristics

Seine netting, fyke netting and boat electrofishing caught a total of 855 fish including 17 species over a four-day period. Seine netting (all 11 intervals) was responsible for catching 497 fish/ 11 species, while fyke nets caught 201 fish/ 9 species, and electrofishing caught 157 fish/ 12 species (Figures 1-8, 1-9). The common and scientific names of the fish species cited in this section are listed in Table 1-4, along with the numbers of each species captured with each technique.

Different gear types demonstrated selectivity for particular fish species (Table 1-4). Seine netting caught primarily blacknose shiner and sunfish, fyke netting caught primarily sunfish and rock bass, while electrofishing caught primarily yellow perch and sunfish. Five fish species were common to all three techniques (blacknose shiner, sunfish, yellow perch, largemouth bass and rock bass), while tadpole madtom were common only to seine netting and the fyke net, grass pickerel and banded killifish were common to both the seine net and electrofishing, while brown bullhead and bowfin were common to both the fyke net and electrofishing. Other species were captured by only one of these techniques: jonny darter, golden shiner and spotted gar were only caught using seine netting, bluntnose minnow were caught within the fyke net, while northern pike, black crappie and black bullhead were only captured by electrofishing.

Each technique also demonstrated dissimilarity in the mean biomass of fish caught. The catch using the seine net had the lowest mean fish biomass at 1.6 g, while the fyke net fish had a mean biomass many times greater at 27.4 g and electrofishing caught a larger assemblage with a mean biomass of 45.2 g.

Seine netting, the fyke net and electrofishing each demonstrated a strong bias for a particular functional feeding group (Figure 1-10, 1-11). Seine netting, due to its selectivity for smaller fish, make it the most effective technique for catching planktivorous fish, with respect to both abundance and biomass. The fyke net caught high numbers and biomass of omnivorous fish. Boat electrofishing was the most effective technique for catching piscivorous fish in both numbers and biomass. None of the three techniques were successful at catching benthivorous fish in any substantial numbers; even though electrofishing did register a significant biomass of this class, it could only be attributed to a few large specimens. However, there is the possibility that there were very few benthivorous fish within the habitat available for capture.

DISCUSSION

Diel variation in a wetland fish community

The examination of changes in a wetland fish community over the course of 24 hours revealed diel periodicity with respect to species richness, abundance and biomass. The mid afternoon (16:00-18:00) and early morning (02:00) intervals have associations with fish catches that were twice as high in species richness, six times higher in fish abundance, and five times higher in fish biomass as compared to other intervals over the 24-h period, while all the common functional feeding groups (omnivorous, planktivorous and piscivorous), were also well represented. Mid afternoon (16:00-18:00), and during twilight hours (02:00), tended to get more fish with respect to species, abundance and biomass, and all three functional groups were well represented. By comparison, noon and midnight were probably the worst times.

Diel periodicity profoundly affects almost all life forms, wetland fish being no exception. During the sampling intervals leading up to, and after sunset (21:03), there were pronounced declines in species richness, fish abundance and biomass especially for piscivorous fish. Changes in the fish community before and after sunrise (5:44 A.M.) were less distinct; however, declines in species richness, abundance and biomass were recorded over the intervals preceding and following sunrise.

One explanation of how diel periodicity affects fish movement is that the fish are responding to horizontal migration of large zooplankton away from macrophyte beds into open water at night (Chow-Fraser et al. 1998; Lauridsen and Lodge 1996; Moss 1996). Experiments have demonstrated that the rates at which most fish species encounter and attack prey decrease with increasing density of macrophytes (Dionne and Folt 1991; Diehl and Kornijow 1997). Consequently, the same structurally complex environment that affords large zooplankton protection during the day also reduces the foraging efficiency of many planktivorous fish (Diehl 1992; Stanfield et al. 1997). Therefore, the declining numbers and species of planktivorous fish following the afternoon peaks could be linked to the changing ambient light levels associated with the pre-dusk period, whereby the fish are following the large zooplankton from the macrophytes in order to increase their own foraging efficiency under the approaching cover of darkness.

A closer examination of the graphs for fish abundance and biomass (Figures 1-2 and 1-3) over the intervals from early afternoon to dusk (14:00 to 20:00) reveals that there is a gradual shift in the size of fish composing the population. The average biomass of fish increased during early afternoon (14:00-16:00), but the average biomass decreased early evening (18:00-20:00). A recent diet study involving young of the year (YOY) largemouth bass demonstrated that during their earliest stages of development, largemouth bass primarily prey on the smaller size classes of zooplankton (copepod nauplii, small cladocerans and rotifers) before switching to larger zooplankton (*Daphnia sp.*) (Post et al.1997). It is speculated that the smaller planktivores remain in the macrophyte beds because small-bodied zooplankton do not apparently migrate, since horizontal migration for the fish would increase predation risk.

The large numbers and biomass of fish taxa during mid afternoon (16:00-18:00) may also be due to diel feeding of piscivores such as yellow perch (A. Dale, pers. comm.). Figure 1-6 shows an increasing representation of piscivore biomass from noon to mid afternoon (12:00-16:00), with large yellow perch having been caught at both the 14:00 (140mm-30g) and 16:00 (147mm-35g) intervals. Savino and Stein (1982) reported that selection of structurally complex habitat by prey fish, even in the face of poor foraging return, could be explained on the basis of higher survival in vegetation than in open water. Therefore, the existence of increased predation pressure on the predominantly planktivorous fish community could be causing these relatively vulnerable fish to seek refuge in high numbers within the dense near-shore macrophytes (Stephenson 1990).

Both explanations appear to have merit in explaining changes in the distribution of fish taxa in Long Point Marsh, and perhaps they are equally applicable. The migration of large herbivorous zooplankton into the open water as night falls appears to trigger the departure of larger planktivorous fish from the macrophyte beds, which are then pursued by the piscivores. Further detailed surveys and experimentation would be required to verify these speculations.

To conclude on this aspect of the study, the optimum times to collect representative members, sizes and species of fish in macrophyte beds in Long Point is in the late afternoon (16:00-18:00) and perhaps more generally stated as the period 4 hours prior to sunset.

Comparison of Fishing Techniques

The results indicate that a single technique is not adequate for catching all species, sizes and feeding classes in Long Point. Weaver et al. (1993) made similar observations when they compared seine netting, fyke netting and gill netting. Therefore, the use of a single sampling gear will inevitably bias the fish collection towards those fish, sizes and feeding classes associated with that specific technique.

A fish species' susceptibility to a gear depends on many things, including life stage, size in relation to the gear, habitat preferences, schooling and swimming behaviour, and feeding and activity levels of fish during the sampling period (Hayes 1983), which for most species varies considerably over the course of the season (Pope, 1996). Having constrained the sampling period to within four days, over uniform habitat (with respect to macrophyte species/ density, and depth), and spreading sampling effort over a 24-h period for two of the techniques, one can be confident that any differences that exist in the fish data are the result of collection techniques and not to seasonal or other environmental differences.

Fish Species

The seine net and electrofishing are active techniques and the fyke net is a passive technique. Sedentary fish, such as bullheads and madtoms are not as susceptible to passive gear, whereas more mobile fishes, such as sunfish and rock bass, are more susceptible to passive gear (Fago 1998). Fago's (1998) predicted relationship between active fish species and passive gear is precisely what was found with respect to the fyke net fish assemblage. Each of the active fishing techniques (seine netting and electrofishing) also demonstrated a bias towards specific fish species. Seine netting had a tendency to catch blacknose shiner and sunfish, while electrofishing had a tendency towards yellow perch and sunfish. However, sedentary fish remained under-sampled by both the active and passive fishing techniques.

Abundance

Abundances of fish caught by each fishing technique were quite similar. Following standard protocol, the fyke net caught 201 fish while electrofishing caught 157 fish. Since standard protocol when using a seine net does not require sampling to be conducted at 2-h intervals over 24 hours, an estimated 180 fish would be caught by seine netting during a typical effort of 4 seine hauls per habitat (average of 45 fish/haul*4 hauls). Due to the similarity in values, a comparison of fish abundances collected using different techniques would appear to by justified.

Size Classes

Each technique demonstrated strong inclinations towards fish of different size classes. Seine netting physically disrupts the macrophytes as it is drawn through the habitat. This disruption flushes out those small fish that are hiding in the dense macrophytes, seeking refuge from predators. As well, the smallest fish cannot evade the approaching seine net as capably as larger fish; therefore, seine netting is biased towards a smaller fish assemblage (mean fish weight = 1.6 g).

Fyke nets caught fish that were larger and heavier (mean fish weight = 27.4 g), which supports the contention that mobile fish are targeted by passive fishing gears (Fago 1998). This is because fish that are large, and therefore highly visible, must move swiftly to avoid being eaten (Laarman and Ryckman 1982). Larger mesh sizes have been shown to select for larger fish (Holland and Peters 1992; Kraft and Johnson, 1992); therefore, since the mesh covering both the fyke nets (3/16" and 1/2") is larger than that for the seine net (1/8") the fyke nets could simply be more effective in capturing larger fish.

Of the three techniques, boat electrofishing was the most efficient for large fish (mean fish weight = 45.2 g). As fish size increases, total body voltage also increases, and therefore the largest fish are most susceptible at a given voltage (Reynolds 1989). In general then electrofishing tends to bias against small fish because the voltage required to stun the smallest fish would ultimately cause undesirable mortality to the larger and coveted game fish. There are some exceptions however, as in the case of bluegills, which were found to be more susceptible when they were smaller (Pope, 1996). Pope (1996) found that electrofishing effectiveness decreased with increasing length of bluegill (*Lepomis macrochirus*). There is also the possibility that even after the small planktivorous fish are stunned they may remain unsampled because they are kept entangled in the macrophyte bed.

Feeding Classes

Seine netting, the fyke net and electrofishing each sampled a subset of the fish community that was strongly biased towards a specific functional feeding class. The fish attributes associated with the seine net catch (small and macrophyte dependent) are the same attributes that characterize planktivorous fish, making it the most effective technique for targeting this feeding guild. The attributes associated with the fyke net catch (larger mobile fish and sunfish) are the same attributes that make it an effective technique for targeting omnivorous fish. The increased effectiveness of electrofishing towards larger piscivores such as largemouth bass and ambush predators such as northern pike (which are not highly mobile) made it the most effective technique for sampling the piscivorous fish community. In contrast, none of the three techniques proved very effective at catching benthivorous fish. Even though electrofishing registered a significant biomass of benthivores, this is the result of only a few (7) large specimens. Perhaps the lack of benthivorous fish within the catches was the result of poor habitat characteristics for this feeding class of fish. The dense *Chara sp.* bed where sampling was conducted possibly made access to the sediment difficult for benthivorous fish, which would likely move elsewhere in search of more productive feeding locations.

Therefore, use of only one sampling gear will not guarantee that all available fish species will be successfully surveyed within a given habitat, and will likely bias towards a particular size class and feeding group. Since this study has been limited to one single comparison over a 24-h period in one embayment, the results should be cautiously extrapolated to other wetlands, especially when different times of year and different habitat characteristics are involved.

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Table 1-1: Length-weight regressions coefficients for Great Lake fishes. Values for the intercept are given in the metric system; metric equations are in g and mm. The standard equation is: $\log_{10}$ Weight = a + b *($\log_{10}$ Length).

Common Name	Species	Y intercept	Slope
Banded Killifish	*Fundulus diaphanous*	-5.57	3.33
Bowfin	*Amia calva*	-4.90	2.96
Bluntnose Minnow	*Pimephales notatus*	-5.71	3.39
Blacknose Shiner	*Notropis heterolepis*	-5.03	2.99
Black Crappie	*Pomoxis nigromaculatus*	-5.24	3.18
Black Bullhead	*Icalurus melas*	-4.61	2.88
Brown Bullhead	*Ameiurus mebulosus*	-4.61	2.88
Grass Pickerel	*Esox a. vermiculatus*	-5.29	3.01
Golden Shiner	*Notemigonus crysoleucas*	-5.25	3.08
Jonny Darter	*Etheostoma nigrum*	-5.40	3.20
Largemouth Bass	*Micropterus salmoides*	-5.17	3.13
Northern Pike	*Esox lucius*	-5.61	3.14
Rock Bass	*Ambloplites rupestris*	-4.18	3.05
Spotted Gar	*Lepisoteus oculatus*	-7.07	3.51
Sunfish	*Lepomis sp.*	-5.04	3.16
Tadpole Madtom	*Noturus gyrinus*	-5.04	3.10
Yellow Perch	*Perca flavescens*	-5.33	3.17

(Schneider et al. 2000)

Table 1-2: Numbers and species of fish caught by each fishing technique, sorted by functional feeding classification.

Seine Net	Abundance	Fyke Net	Abundance	Electrofishing	Abundance
Omnivorous Fish (> 50 mm)					
Sunfish *Lepomis sp.*	37	Sunfish *Lepomis sp.*	133	Sunfish *Lepomis sp.*	34
Planktivorous Fish (< 50 mm)					
Blacknose shiner *Notropis heterolepis*	278	Sunfish *Lepomis sp.*	7	Blacknose shiner *Notropis heterolepis*	20
Yellow Perch *Perca flavescens*	43	Blacknose shiner *Notropis heterolepis*	6	Sunfish *Lepomis sp.*	7
Sunfish *Lepomis sp.*	41	Largemouth Bass *Micropterus salmoides*	6	Banded Killifish *Fundulus diaphanus*	1
Banded Killifish *Fundulus diaphanus*	18				
Largemouth Bass *Micropterus salmoides*	17				
Jonny Darter *Etheostoma nigrum*	9				
Golden Shiner *Notemigonus crysoleucas*	7				
Spotted Gar *Lepisoteus oculatus*	1				
Benthivorous Fish (> 50 mm)					
Tadpole Madtom *Noturus gyrinus*	1	Brown Bullhead *Ameiurus nebulosus*	4	Brown Bullhead *Ameiurus nebulosus*	6
		Bluntnose Minnow *Pimephales notatus*	3	Black Bullhead *Icalurus melas*	1
		Tadpole Madtom *Noturus gyrinus*	2		
Piscivorous Fish (> 50 mm)					
Rock Bass *Ambloplites rupestris*	31	Rock Bass *Ambloplites rupestris*	36	Yellow Perch *Perca flavescens*	65
Yellow Perch *Perca flavescens*	3	Yellow Perch *Perca flavescens*	2	Rock Bass *Ambloplites rupestris*	15
Grass Pickerel *Esox a. americanus*	1	Bowfin *Amia calva*	1	Grass Pickerel *Esox a. americanus*	2
				Largemouth Bass *Micropterus salmoides*	2
				Northern Pike *Esox lucius*	2
				Bowfin *Amia calva*	1
				Black Crappie *Pomoxis nigromaculatus*	1

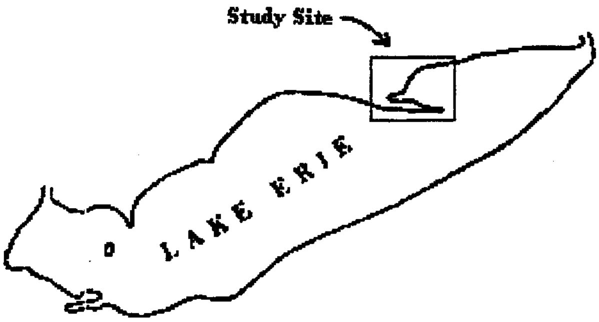
Table 1-3: Summary of fish species, abundance and calculated biomass (*in italics*) corresponding to 2-h sampling intervals from noon June 25th to 10:00 June 26th, 2001. Larval fish were excluded. Sampling was inadvertently omitted at 04:00.

Time / Species	12:00	14:00	16:00	18:00	20:00	22:00	00:00	02:00	06:00	08:00	10:00	Total
Blacknose shiner *Netropis heterolepis*	12 *12.76*	23 *23.15*	73 *82.57*	66 *61.57*	24 *19.27*	13 *7.16*	13 *13.30*	26 *25.16*	10 *11.88*	15 *18.79*	3 *4.66*	278 *280*
Sunfish *Lepomis sp.*	9 *17.12*	8 *50.72*	6 *11.55*	6 *10.23*	1 *2.41*	15 *58.90*	10 *20.88*	9 *25.17*	5 *8.91*	5 *13.97*	4 *9.19*	78 *225*
Yellow Perch *Perca flavescens*		3 *30.29*	2 *34.80*	8 *1.92*	20 *5.50*	4 *1.43*	2 *0.17*	1 *11.94*	2 *0.33*	2 *0.58*	2 *0.50*	46 *88*
Rock Bass *Ambloplites rupestris*	6 *24.58*		2 *9.56*	4 *15.49*		2 *7.47*		7 *31.31*	5 *21.67*	4 *18.15*	1 *5.24*	31 *134*
Banded Killifish *Fundulus diaphanus*		1 *1.68*		11 *17.61*	2 *2.06*					3 *5.68*	1 *0.63*	18 *28*
Largemouth Bass *Micropterus salmonides*			1 *0.46*	1 *0.65*	3 *1.08*	1 *0.08*	1 *0.26*	1 *0.38*	3 *0.81*	2 *1.24*	4 *1.49*	17 *7*
Larval Fish *Netropis sp.*				4 *0.24*	6 *0.23*							10 *0.4*
Jonny Darter *Etheostoma nigrum*		1 *0.06*	1 *0.04*	2 *0.20*			2 *0.16*	1 *0.04*			2 *0.26*	9 *0.8*
Golden shiner *Notemigonus crysoleucas*			2 *3.92*		1 *0.29*			3 *2.47*	1 *3.78*			7 *11*
Spotted Gar *Lepisoteus osseus*	1 *0.07*											1 *0.1*
Grass Pickerel *Esox a. americanus*									1 *3.07*			1 *3.1*
Tadpole Madtom *Moturus gyrinus*								1 *11.16*				11 *11.2*
Species Richness	**4**	**5**	**7**	**7**	**6**	**5**	**5**	**8**	**7**	**6**	**7**	**11**
Abundance	**28**	**36**	**87**	**102**	**57**	**35**	**28**	**49**	**27**	**31**	**17**	**497**
Biomass	*54.53*	*105.9*	*142.91*	*107.90*	*30.85*	*72.90*	*34.77*	*107.64*	*50.44*	*58.42*	*21.97*	*784*

Table 1-4: Summary of the number of species caught with each fishing technique.

Seine Net	Abundance	**Fyke Net**	Abundance	**Electrofishing**	Abundance
Blacknose shiner *Notropis heterolepis*	278	Blacknose shiner *Notropis heterolepis*	6	Blacknose shiner *Notropis heterolepis*	20
Sunfish *Lepomis sp.*	78	Sunfish *Lepomis sp.*	141	Sunfish *Lepomis sp.*	41
Yellow Perch *Perca flavescens*	46	Yellow Perch *Perca flavescens*	2	Yellow Perch *Perca flavescens*	65
Largemouth Bass *Micropterus salmoides*	17	Largemouth Bass *Micropterus salmoides*	6	Largemouth Bass *Micropterus salmoides*	2
Rock Bass *Ambloplites rupestris*	31	Rock Bass *Ambloplites rupestris*	36	Rock Bass *Ambloplites rupestris*	15
Tadpole Madtom *Noturus gyrinus*	1	Tadpole Madtom *Noturus gyrinus*	2		
Grass Pickerel *Esox a. americanus*	1			Grass Pickerel *Esox a. americanus*	2
Banded Killifish *Fundulus diaphanus*	18			Banded Killifish *Fundulus diaphanus*	1
		Brown Bullhead *Ameiurus nebulosus*	4	Brown Bullhead *Ameiurus nebulosus*	6
		Bowfin *Amia calva*	1	Bowfin *Amia calva*	1
Jonny Darter *Etheostoma nigrum*	9				
Golden Shiner *Notemigonus crysoleucas*	7				
Spotted Gar *Lepisoteus oculatus*	1				
		Bluntnose Minnow *Pimephales notatus*	3		
				Northern Pike *Esox lucius*	2
				Black Crappie *Pomoxis nigromaculatus*	1
				Black Bullhead *Icalurus melas*	1
# of Species = 11	487	# of Species = 9	201	# of Species = 12	157

Figure 1-1: Long Point Bay showing sampling site within Inner Bay, Lake Erie, Ontario, Canada.


Study Site
LAKE ERIE

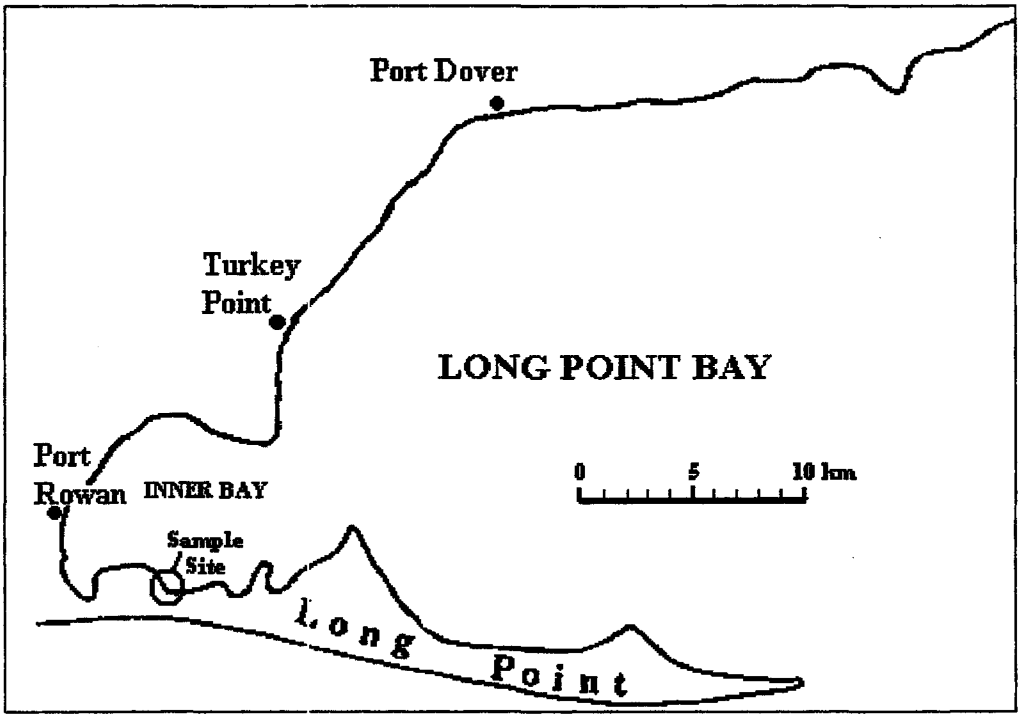

Port Dover
Turkey Point
LONG POINT BAY
Port Rowan
INNER BAY
0 5 10 km
Sample Site
Long Point

Figure 1-2: Abundance of fish species by sampling interval from noon on June 25th to 10:00 June 26th, 2001. Rare species included species represented by fewer than 5 individuals (refer to Table 1-3).

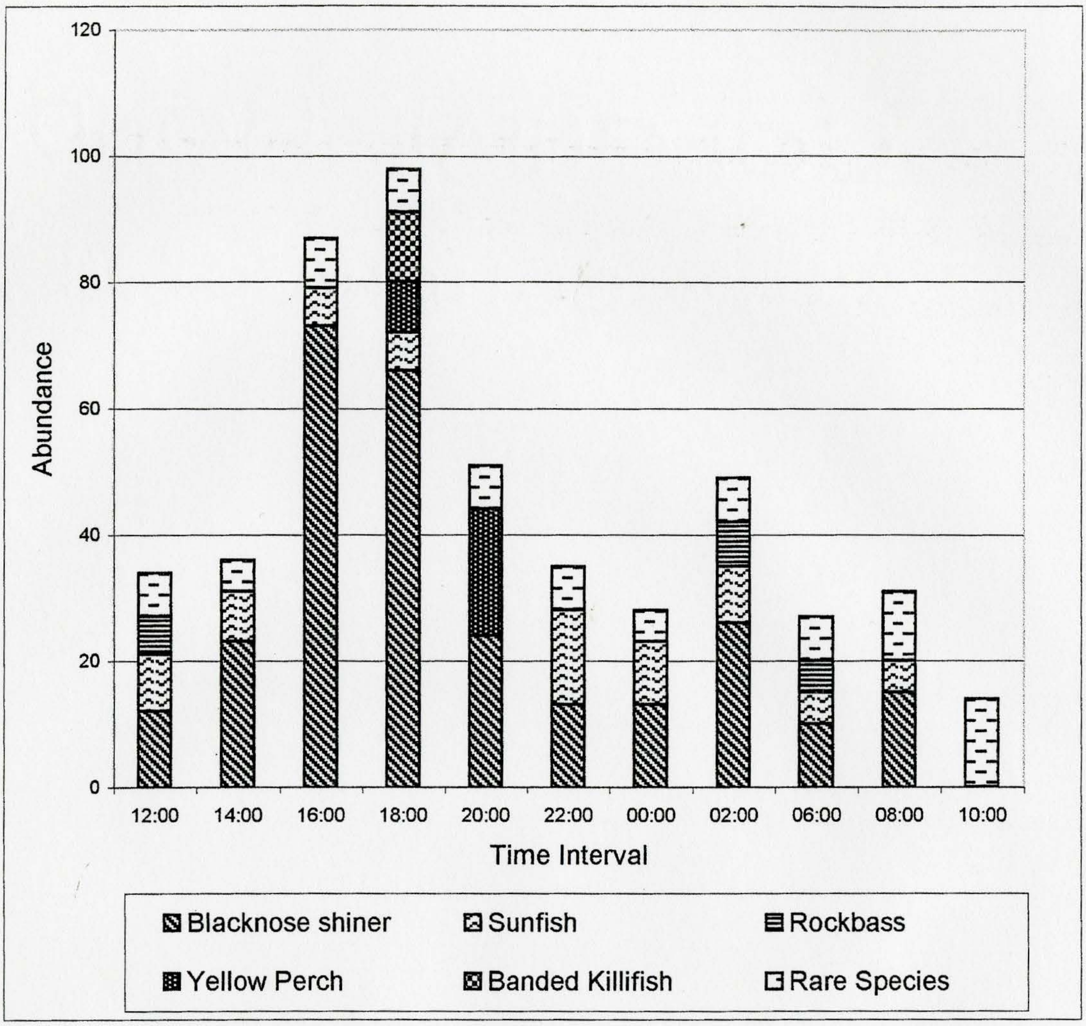

120
100
80
60
40
20
0
Abundance
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Blacknose shiner
Sunfish
Rockbass
Yellow Perch
Banded Killifish
Rare Species

Figure 1-3: Biomass of fish species by sampling interval from noon on June 25th to 10:00 June 26th, 2001. Rare species included species represented by fewer than 10 g (refer to Table 1-3).

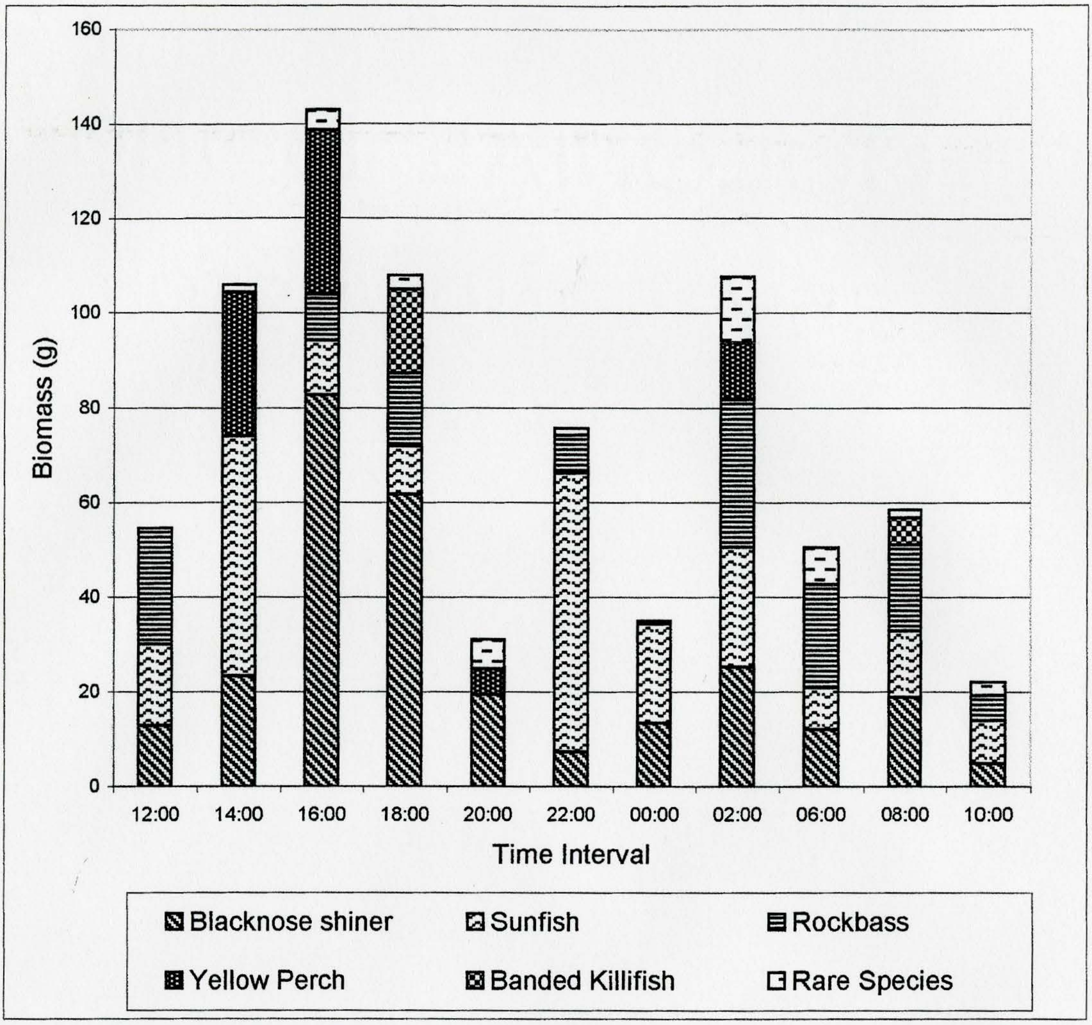
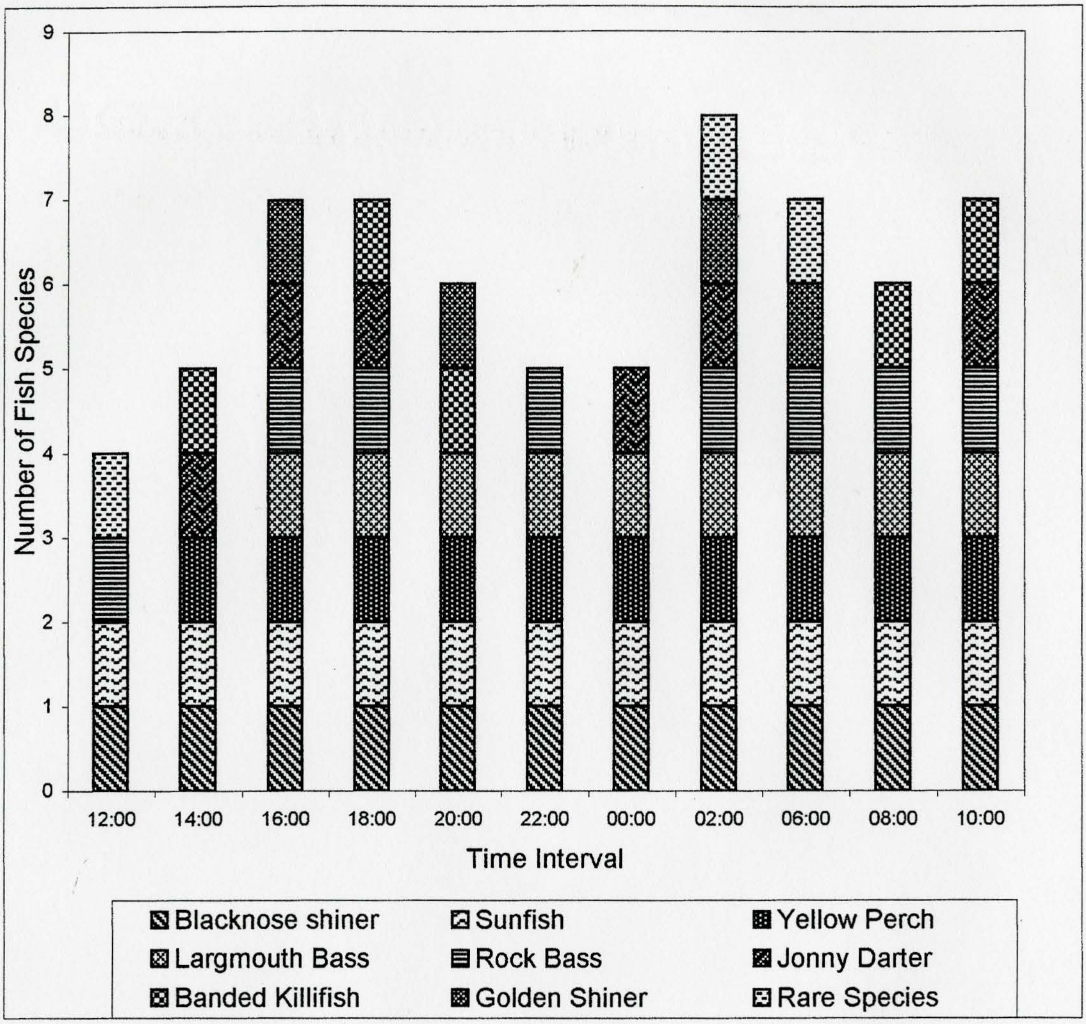
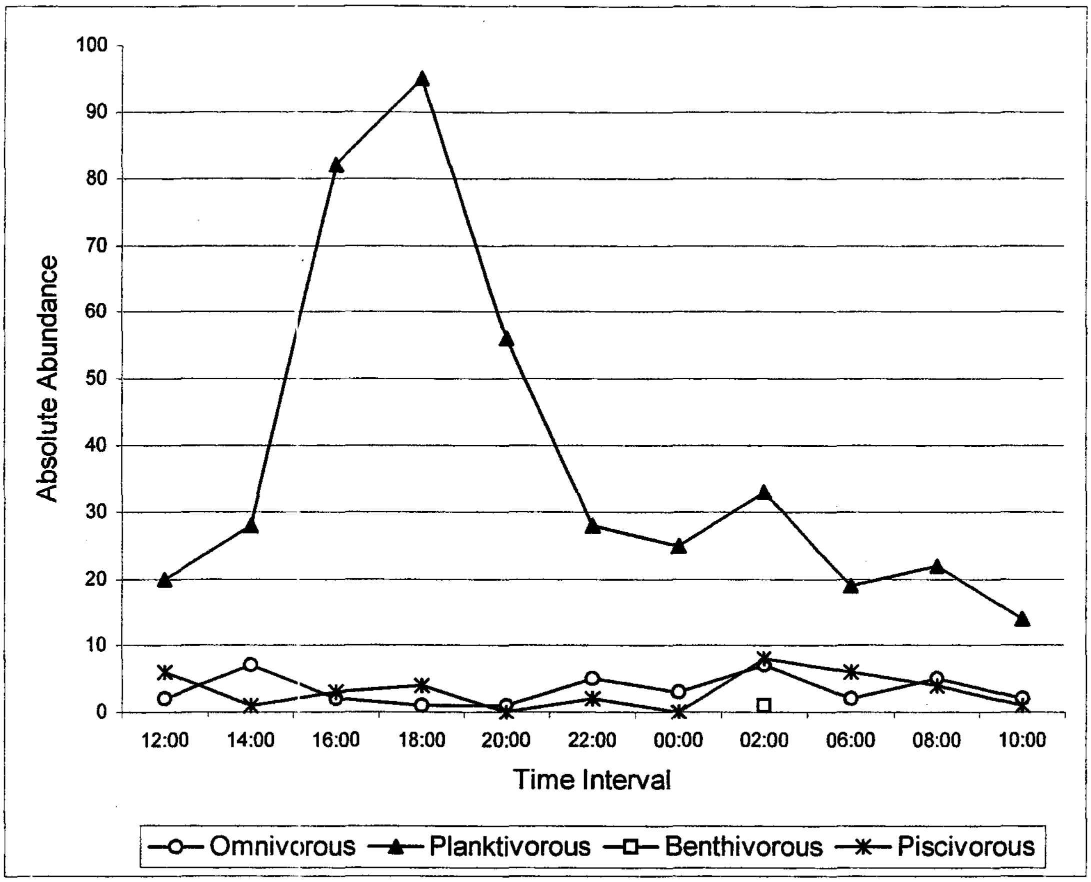

160
140
120
100
80
60
40
20
0
Biomass (g)
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Blacknose shiner
Sunfish
Rockbass
Yellow Perch
Banded Killifish
Rare Species

Figure 1-4: Fish species caught by sampling interval from noon on June 25th to 10:00 June 26th, 2001. Rare species included species represented by 1 individual (refer to Table 1-3).



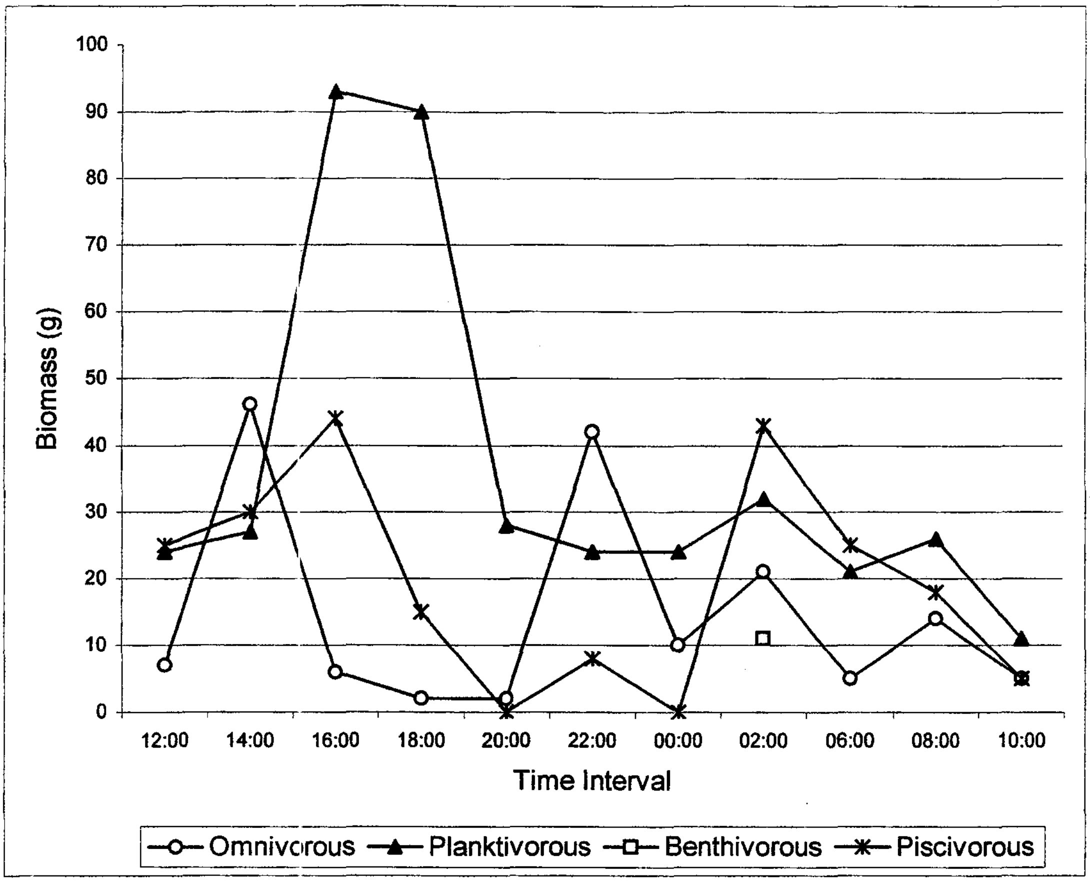
9
8
7
6
5
4
3
2
1
0
Number of Fish Species
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Blacknose shiner
Sunfish
Yellow Perch
Largmouth Bass
Rock Bass
Jonny Darter
Banded Killifish
Golden Shiner
Rare Species

Figure 1-5: Absolute abundance of fish sampled over a 24-h period from noon June 25th to 10:00 June 26th, 2001. Data are sorted by feeding categories.



100
90
80
70
60
50
40
30
20
10
0
Absolute Abundance
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Omnivorous
Planktivorous
Benthivorous
Piscivorous

Figure 1-6: Absolute biomass of fish sampled over a 24-h period from noon June 25th to 10:00 June 26th, 2001. Data are sorted by feeding categories.



100
90
80
70
60
50
40
30
20
10
0
Biomass (g)
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Omnivorous
Planktivorous
Benthivorous
Piscivorous

Figure 1-7: Total biomass of planktivorous and piscivorous fish sampled over a 24-h period from noon June 25th to 10:00 June 26th, 2001.

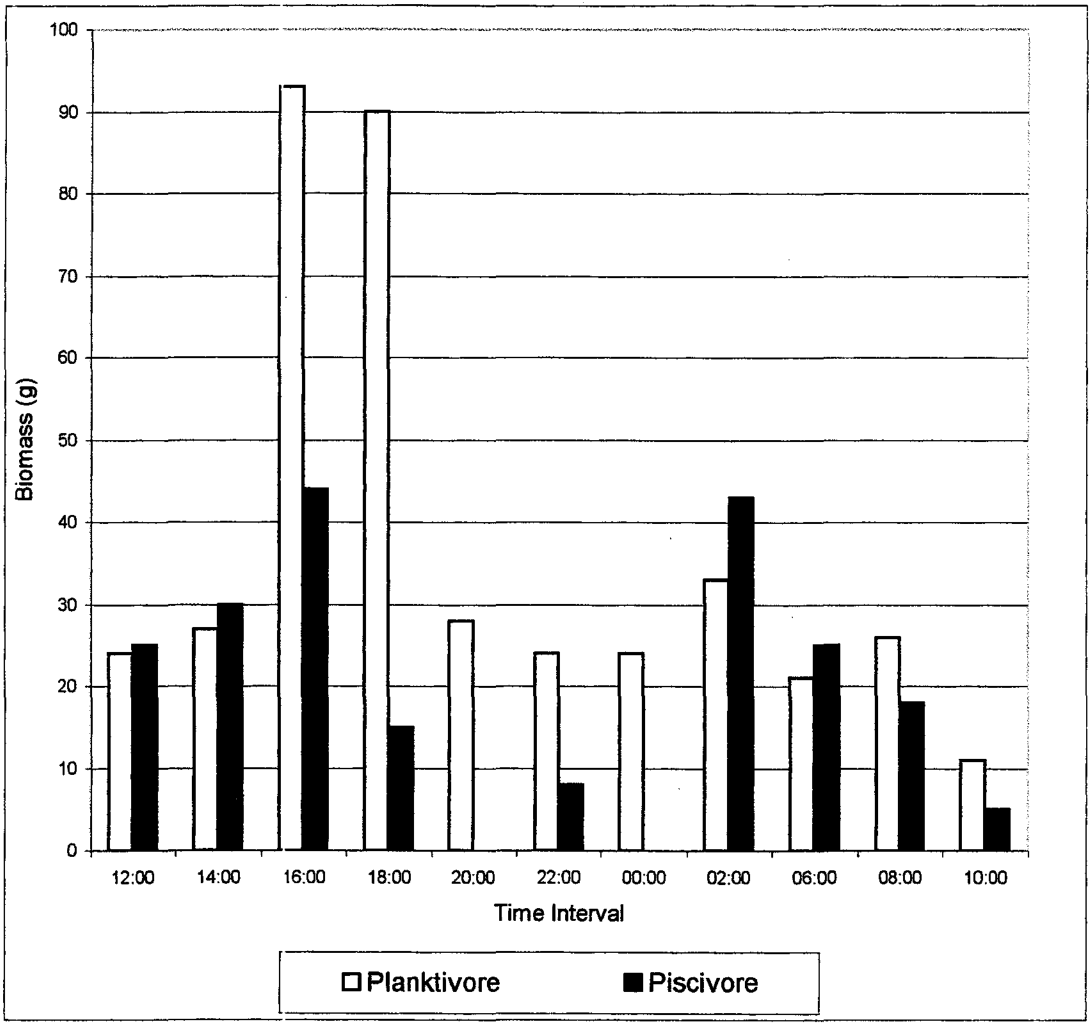
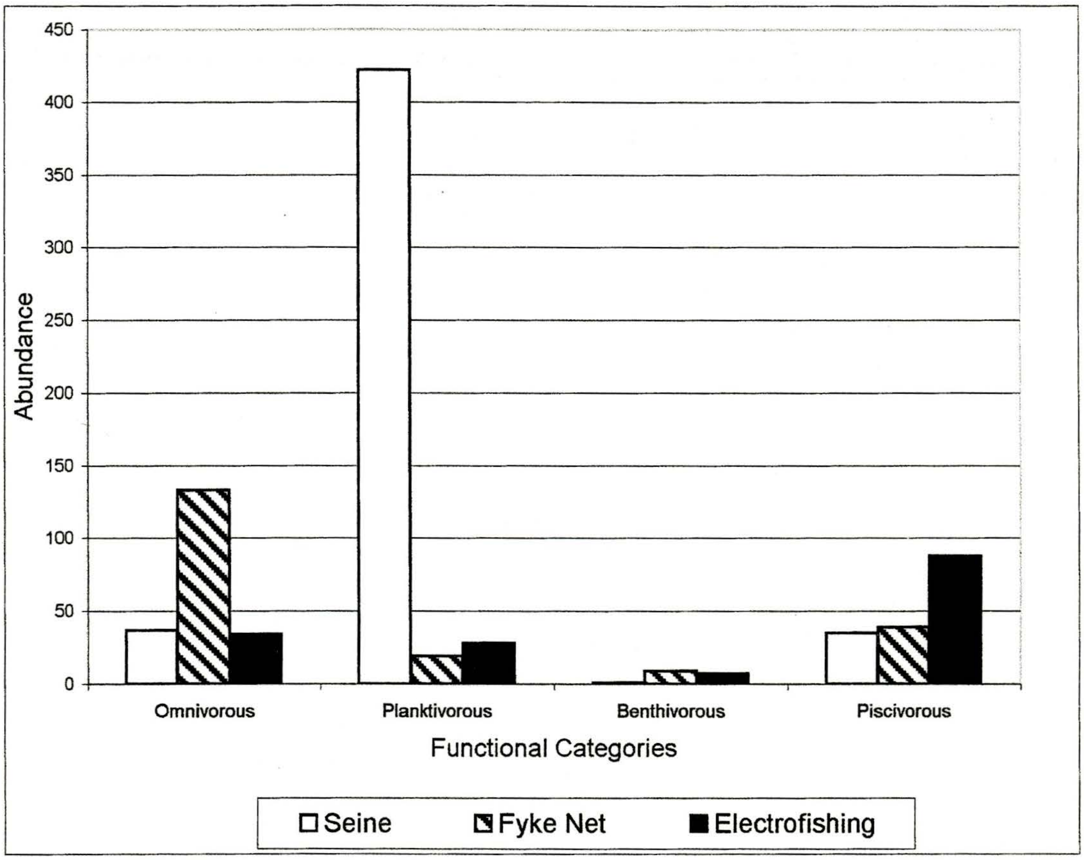
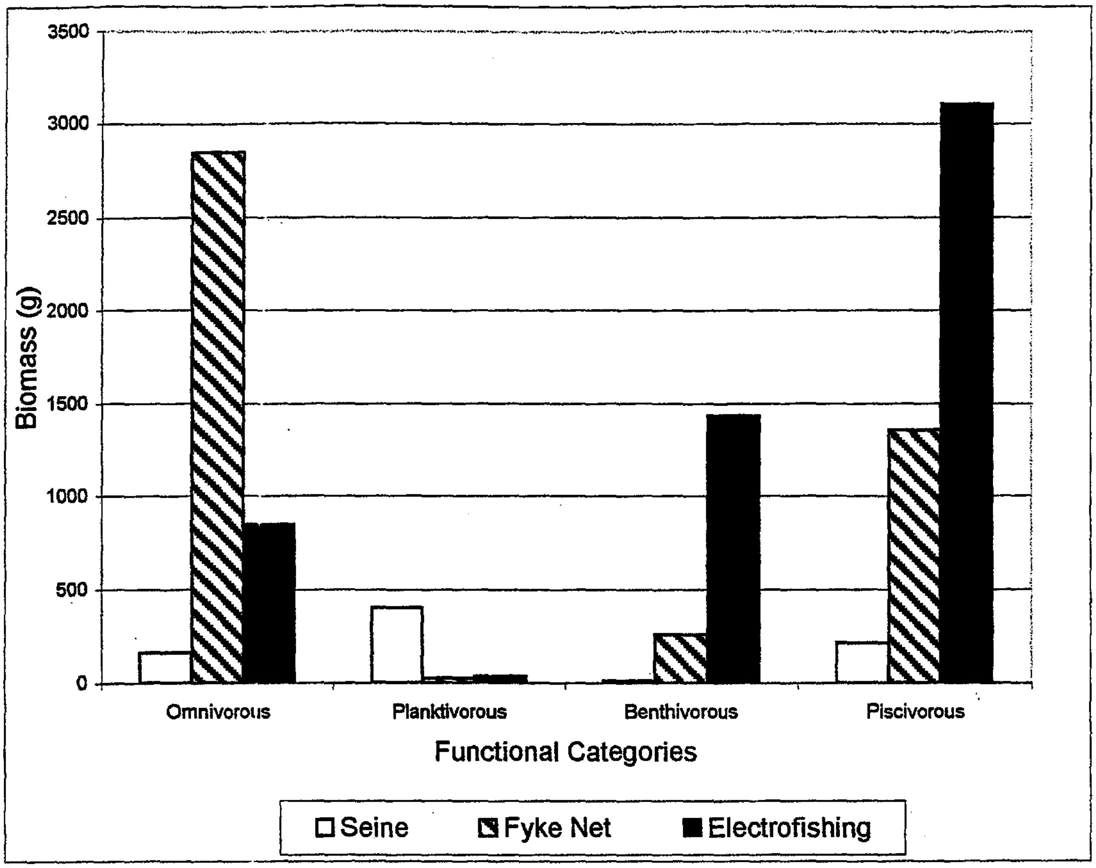

100
90
80
70
60
50
40
30
20
10
0
Biomass (g)
12:00
14:00
16:00
18:00
20:00
22:00
00:00
02:00
06:00
08:00
10:00
Time Interval
Planktivore
Piscivore

Figure 1-8: Total abundance of fish sorted by functional feeding categories sampled with 3 fishing gears in Long Point from noon June 25th to 10:00 June 26th, 2001.



450
400
350
300
250
200
150
100
50
0
Abundance
Omnivorous
Planktivorous
Benthivorous
Piscivorous
Functional Categories
Seine
Fyke Net
Electrofishing

Figure 1-9: Total biomass of fish sorted by functional feeding categories sampled with 3 fishing gears in Long Point from noon June 25th to 10:00 June 26th, 2001.



3500
3000
2500
2000
1500
1000
500
0
Biomass (g)
Omnivorous
Planktivorous
Benthivorous
Piscivorous
Functional Categories
Seine
Fyke Net
Electrofishing

CHAPTER 2:

The impact of water quality, aquatic macrophyte and fish communities on zooplankton community structure in seven lower Great Lake coastal wetlands.

ABSTRACT

Seven coastal wetlands within Lake Erie and Ontario along both the Canadian and United States shorelines were studied to verify predicted relationships from the literature and determine the relative influences of various habitat features on zooplankton community structure. Water quality, aquatic macrophyte, zooplankton, and fish community information was collected from the wetlands between July 4th and August 2nd of 2001. Wetlands were selected along a gradient of degradation to ensure variability with respect to water quality variables. Individual least-square regressions, as well as stepwise multiple regression analyses were run to verify relationships and determine the relative influence each independent variable had on the zooplankton communities. A close agreement was revealed among the published material and the results of this study. It was also determined that zooplankton community structure was primarily a function of differences in water quality characteristics and the presence of macrophytes among the wetlands. High concentrations of nutrients, suspended solids, ions (conductivity) and chlorophyll were correlated with higher micrograzer biomass, total zooplankton abundance and biomass values. Macrophyte species richness however, was inversely correlated with micrograzer biomass, total zooplankton abundance and biomass values. These relationships represented a shift in the zooplankton community structure towards a dominance of micrograzers (small cladocerans and rotifers). Macrophyte species richness showed indirect correlations with aspects of the zooplankton communities. Very few of the differences in the fish communities were associated with any of the differences in the zooplankton communities across the seven wetlands.

INTRODUCTION

Coastal wetlands are highly productive and complex systems. They link both the watershed and open water and provide diverse habitats to a variety of resident and migratory aquatic life, such as fish and waterfowl (Lougheed and Chow-Fraser 1998). The net loss of wetlands within the Laurentian Great Lake basin since European settlement has been dramatic, and is mainly a result of agriculture, land filling, and port development (Jude and Pappus 1992). The remaining coastal wetlands in the Great Lakes are increasingly threatened with obliteration or severe environmental degradation unless measures are taken to protect them (Stephenson 1990).

The extensive use of coastal wetlands for spawning and nursery habitat by several Great Lake fish species has been attributed to warmer water temperatures, relief from waves and currents, higher productivity and more food for young fish in the wetland setting (Stephenson 1990; Jude and Pappas 1992). A study of the reproductive utilization of coastal wetlands of Lake Ontario determined that at least 75% of the species sampled were juveniles, and that 86% of all fish encountered were using the wetland for nursery habitat (Stephenson 1990). A recent study has shown that factors affecting growth and diet during the first few months of life are critical to determining piscivore success, and that differences in growth rate were the result of variations during the periods when the fish are feeding on invertebrate prey (Mittelbach and Persson 1998). Therefore, a healthy aquatic invertebrate community is imperative to the larval fish population that utilizes the habitat during their vulnerable first year of life.

The scientific communities' appreciation for the importance of coastal wetlands as fish spawning and nursery habitat has only developed within the last couple of decades. Consequently, our understanding of the elements that affect zooplankton, the primary food source of larval and juvenile fish, remains limited. The majority of the studies that have been conducted on zooplankton dynamics in open water, shallow lake and wetland ecosystems have limited their scope to individual aspects of the habitat that influence zooplankton community structure. These studies have examined the effects of biotic influences such as macrophytes (Timms and Moss 1984; Schriver et al. 1995; Diehl and Kornijow 1997; Lougheed and Chow-Fraser 1998; 2001), fish predation (Northcote 1988; Evans 1990; Hanson and Butler 1990; Christoffersen et al. 1993; Jeppesen et al. 1997; Stanfield et al. 1997; Romare 1999), food supply (Hart 1990; Lougheed and Chow-Fraser 1998), the abiotic influences such as turbidity (Zettler and Carter 1986; Hart 1988, 1990; Kirk 1991; Lougheed et al. 1998; Lougheed and Chow-Fraser 1998; 2001; 2002), nutrient levels (Bays and Crisman 1983; Pace 1986; Lougheed et al. 1998; Lougheed and Chow-Fraser 1998; 2001; 2002), and temperature (Zettler and Carter 1986; Hart 1988, 1990; Lougheed and Chow-Fraser1998) on the zooplankton community structure.

For this project, seven wetlands along the shorelines of Lake Erie and Ontario were visited between July 4th and August 2nd of 2001. Wetlands were selected along a continuum of water quality characteristics ranging from nutrient rich, highly turbid wetlands, to relatively pristine wetlands with low nutrient and turbidity levels. Within each wetland, observations and collections were made pertaining to all of those variables that have been separately implicated as influential on zooplankton community structure within lake and wetland systems.

A change in zooplankton community structure along the degradation gradient is expected for a variety of reasons. First, poor water quality conditions have been shown to reverse the usual competitive dominance of larger zooplankton (macrograzers) over smaller zooplankton (micrograzers)(Kirk 1991), thereby directly favoring proliferation of smaller zooplankton. Second, poor water quality conditions reduce the numbers of macrophyte species able to persist in wetlands (Lougheed et al. 2001), and since macrograzers are normally found among plants, the absence of plants within degraded wetlands permit micrograzers to dominate the system. Lastly, increased nutrient and suspended sediment concentrations have been linked to the disappearance of top-predatory fish and their replacement by planktivorous, cyprinid populations (Grimm and Backx 1990). As the production of planktivorous cyprinids takes over the fish community, they will selectively consume the largest component of the zooplankton populations, thereby eliminating macrograzers (Hart 1988; Evans 1990; Hanson and Butler 1990; Chrirstoffersen et al. 1993; Stanfield et al. 1997; Romare 1999).

Accurately identifying the primary stressors, followed by reducing their impact over a sustained period of time is key to any successful, stable restoration (Moss et al. 1996). Previous studies have already revealed that trophic state, macrophyte diversity and planktivorous fish abundance levels can independently have significant impacts on zooplankton community structure. However, none of these studies have examined these factors simultaneously to determine the relative impact of each on the zooplankton community structure. Therefore, the objectives were to verify the predicted relationships from the literature, and determine the relative association of each of these aspects with differences in zooplankton community structure within wetland ecosystems. Identifying the variables that play primary roles in structuring zooplankton communities will allow lake managers to make informed decisions on how to most effectively improve zooplankton habitat, by encouraging larger-bodied zooplankton populations, and thus make the habitat more suitable for larger populations of larval and juvenile fish.

METHODS

Study Sites

Seven wetlands within Lake Erie and Ontario were visited over the summer of 2001. Each wetland was processed for water quality, zooplankton, macrophyte and fish community information. Wetlands were distributed along both the US and Canadian sides of each lake from Sandy Creek at the eastern end of Lake Ontario (north of Syracuse) to Rondeau Provincial Park along the western portions of Lake Erie (south of Chatham) (Figure 2-1). All wetlands were visited once during mid-summer (4th July to August 2nd). Originally, an additional wetlands located along the shore of Grand River was surveyed for this study. The site however, could not be considered a 'coastal' wetland since it was situated approximately 8-kilometers from the Lake Erie coast. The coarse rocky sediment at this location was also unlike wetland systems, which are typically composed of fine-grained sediment, high in organic content. As a result of the coarse sediment, fyke nets could not be properly secured. This resulted in the collapse of one of the nets, which would have influencing the fish haul. The water quality measurements from this location were also a minimum of two times, up to a maximum of five times the mean values for the group of wetlands. It is for these various reasons that the Grand River wetland was omitted from subsequent analyses. The locations of all wetlands were determined using a Magellan 300 handheld GPS unit with a reported accuracy of 15 m.

Water Quality Methods

Sampling protocol from Lougheed and Chow-Fraser (2002) were followed for all of the water quality variables to make results directly comparable. All water samples were collected from mid-depth at an open water site (3 m from vegetation) using a 1 L Van Dorn bottle. Water samples were analyzed according to standard methods (APHA 1992) for total phosphorus (TP), total nitrogen (TN)(sum of total kjeldahl nitrogen (TKN) and total nitrate nitrogen (TNN)) and total suspended solids (TSS). Following digestion by potassium persulfate, TP was analyzed according to Murphy and Riley (1962) and measured on a Milton Roy spectrophotometer (Thermo Spectronic, Rochester, New York, USA). Nitrogen analyses (TKN and TNN) were performed using Hach protocols and Hach reagents (Hach Company 1989) and measured on a Hach DR2000 spectrophotometer (Hach, Loveland, Colorado, USA). Suspended solids were filtered onto pre-weighed Whatman GF/C filters (Whatman, Clifton, New Jersey, USA) dried and re-weighted to calculate the weight of additional material on the filter. Planktonic chlorophyll-a (Chl-a) was filtered onto a Whatman GF/C filter and extracted using 90% acetone over a 1 h extraction period. Absorbance measurements were made with a

Milton Roy spectrophotometer and results were corrected for phaeopigments by acidification. Temperature and conductivity were determined using a Minisonde Hydrolab multiprobe and Surveyor 4a monitor.

Macrophyte Methods

All submergent, emergent and floating-leaf plant species encountered within the enclosed area of the fyke net wings were identified. A Wetland Plants of Ontario field guide (Harris et al. 1996) was used to identify the macrophyte specimens to species where possible. Since many wetlands were visited only once, and because certain species are difficult to identify accurately without flowering parts, some taxa were identified to genus only. The objective of the plant survey was not meant to create a complete inventory of plant species within each wetland, but rather to obtain information on species residing in the immediate vicinity where fish and zooplankton samples were collected. This approach therefore likely excluded some species that were present elsewhere within the wetland.

Large areas of each wetland were surveyed in an effort to represent the greatest number of macrophyte species possible by setting each fyke set within unique macrophyte stands. Due to the proximity of the large fyke nets along the 1 m depth contour and the inability of most emergent macrophytes to grow at these depths, the majority of macrophytes species identified within the winged region of each net were submergent and floating-leaf varieties. However, emergent plants species were represented to a lesser extent by the small fyke nets. Since the small fyke nets were situated along the 40 cm depth contour, the wings (the borders of the survey region) typically extended into the emergent stands.

Fish Methods

Fyke nets were chosen as the fish sampling technique for this study despite their bias for catching omnivorous fish (Chapter 1), rather due to the facts that they are easily deployed regardless of sediment conditions and the straightforward set and retrieve design ensured that effort among wetlands would be highly standardized. One to three pairs of fyke nets were installed in each wetland for a 24-h period to sample the fish community. A complete set of fyke nets consisted of 6 nets (4 large, 2 small). The two small fyke nets had 1.5' x 3.0' rectangular front openings, with 5, 12" stainless steel rings behind creating two throats before reaching the cod end. All small nets were covered in 3/16" mesh and were 8 ½' in length. The four large nets were all of the same design, with two 3' x 4' rectangular front openings, and 5, 30" stainless steel rings behind forming the throats and cod end. Total length for large nets was 10'. Two of the large nets were covered in 3/16" nylon mesh and two were covered in 1/2" nylon mesh. Wings and leads made of 3/16" mesh with a float line on top and a leadline on bottom were attached to each net. Two wings were attached to the sides of the openings to each net (1.5' x 10' for small nets, 3' x 10' for large nets) and one 25' lead was attached to the center opening for each net pair (1.5' tall for small nets, 3' tall for large nets). Fyke nets were coupled according to size. Small nets were staked into place along a 40 cm depth contours using 4' pvc tubing. Large net were staked further out along a 1 m depth contour using 10' steel tubing. Large nets were paired with one 1/2" mesh net and one 3/16" mesh net.

All fish were identified to species using Peterson Field Guide for Freshwater Fishes (Page and Burr, 1991) and Scott and Crossman (1998). The first 20 representative of each species were measured for total length (to the nearest 1 mm) with the remaining fish being counted. Since fish weight was not measured in the field and the fish were released after processing, published species-specific length-weight regressions were used to calculate biomass from the length of the fish (Schneider et al. 2000). For a summary of the intercept and slope for each fish species refer to Table 2-1. A functional feeding guild classification was assigned to each fish based on diet information gathered from Scott and Crossman (1998). Table 2-2 summarizes the fish species, and their total abundance values for each species classed as omnivorous, planktivorous, benthivorous or piscivorous.

Zooplankton Methods

All zooplankton samples were collected from the middle of the water column at a central location midway between the openings of each pair of fyke nets, following protocol of Lougheed and Chow-Fraser (2002). Since mid-depth for the large fyke nets was a maximum of 50 cm and the nets were most often situated within vegetation, collections were made using a 2.75 L beaker inverted twice into adjacent areas in the vegetation for a total sample of 5.5 L. All samples were filtered through 63-μm-mesh Nitex screen, backwashed into 60 mL bottles and preserved in 4% sugar-formalin. Samples were thoroughly mixed and sub-sampled to obtain at least 100 animals. A complete count of all animals and a sub-set of 10 individuals of each species were measured for length (estimates based on field of view of 110 μm). Biomass was then calculated based on published length-weight relationships and dry-weight estimates from Dumont et al. (1975) and Malley et al. (1989). For statistical and graphical analyses, zooplankton biomass values were divided into the following categories: micrograzers (<400 μm), medium grazers (400-600 μm) and macrograzers (>600 μm).

Crustacean identification was based on Pennak (1989), while rotifer identification was based on Stemberger (1979). Identification was to the level of species for all common organisms except *Asplanchna*, *Polyarthra*, *Hexarthra*, and *Filinia*, which were to genus. Copepods were identified to sub-order only (i.e., cyclopoids, calanoids, harpacticoids), with all immature forms being classed as nauplii.

Statistical analysis

All water quality, fish and zooplankton measures were $\log_{10}$-transformend (log (x + 1)) to normalize the data and reduce sample variance. The plant species data required no transformation. The term 'species richness' identifies the total number of plant, fish or zooplankton species counted within each sampling site. The individual relationships among the independent variables (water quality, macrophyte and fish communities) and the dependent zooplankton variables were determined using least-square regression analysis. All regression analyses resulting in p values less than 0.05 were reported.

To address the relative impact of the biotic and abiotic factors on the zooplankton communities stepwise multiple regression analyses were performed. This type of analysis incorporates all of the independent variables as possible predictor variables for each of the zooplankton variables. With the selection of each independent variable the effects of co-linearity with the remaining variables is removed; subsequently, their partial correlation values decline, therefore, highlighting those variables that offer unique information apart from the variables that preceded them. 'R square adjusted' values are reported to make models containing varying number of variables more comparable, since R square has been 'adjusted' by using the degrees of freedom in its computation.

A measure of wetland quality recently developed by Lougheed and Chow-Fraser (2002), entitled wetlands zooplankton index (WZI) was calculated for each wetland to determine their consistency with the predicted wetlands rankings. The index was calculated using the following equation:

$$\mathrm{WZI} = \frac{\sum_{i=1}^{n} Y_i T_i U_i}{\sum_{i=1}^{n} Y_i T_i}$$

where Y_i is the abundance of species i,T_i is the tolerance (1-3), and U_i is the optimum (1-5). The index ranges from one (indicative of low-quality) to five (indicative of high-quality wetland). For species-specific tolerance and optimum vales refer to Lougheed and Chow-Fraser (2002).

Co-linearity within the independent and the dependent variables were separately determined using least-squares regression analysis. All regression analyses resulting in p values less than 0.05 were reported. All calculations and statistical analyses were preformed using JMPIN Statistical Discovery Software (SAS Institute Inc. 1992).

RESULTS

Environmental and Community Gradients

Water Quality – Water collections and probe measurements were conducted within a central, well-mixed region of each wetland, and were therefore considered to be representative of those areas where information on macrophyte, fish and zooplankton communities were gathered. Wetlands in this study represented a wide range of environmental conditions (Table 2-3). Water quality values from the wetlands show substantial range in their values: total phosphorus (17 – 142 μg/L), total nitrogen (0.51 – 5.10 mg/L), total suspended solids (2 – 19 mg/L), chlorophyll-a (1 – 9 μg/L) and conductivity (228 – 939 mS/cm). Since all the sampling was conducted during mid-summer (July 4th to August 2nd) water temperature did not vary tremendously among wetlands. All but one site (Rondeau at 32 °C) had a water temperature within the range of 21 to 25 °C. Overall, the water quality values from Cootes Paradise represented the highest values for each of the variables, with the exception of the Frenchman's Bay, which had the highest concentration of chlorophyll-a. Spicer Creek represented the opposite end of the spectrum with the lowest concentration of nutrients and chlorophyll-a among the wetlands. Sandy Creek and Rondeau possessed the lowest concentrations of total suspended solids and ions (conductivity) respectively.

Significant regressions among the water quality variables can only be reported for total phosphorus and total nitrogen (r^2=0.84, p=<0.0001), as well as total suspended solids and conductivity (r^2=0.57, p=0.0003-Figure 2-2). All the remaining weaker, but significant regressions among the water quality variables are listed in Table 2-4.

Macrophyte Community -- A total of 21 macrophyte species were identified among all the wetlands. Of the macrophyte species identified, there were 12 submergent varieties, 6 emergent varieties and 3 floating-leaf varieties. Even though some of the macrophyte species identified were likely present within all of the wetlands, none were common to any one of the fyke sets within all of the wetlands. Only three submergent macrophyte species (*Potamogeton zosteriformis, Myrophyllum sp.* and *Vallisneria americana*) were common to fyke nets within five of the wetlands. Two submergent and one floating-leaf variety (*Potamogeton pectinatus, Elodea canadensis* and *Nymphaea ordorata*) were common to nets in four of the wetlands. The remaining 15 macrophyte species were isolated to three or fewer of the fyke net sets within each wetland.

Turkey Point possessed the greatest number of total plant species with 17, followed by Sandy Creek (13), Spicer Creek (9), Little Sodus Bay (7), Rondeau (7), Frenchman's Bay (3) and Cootes Paradise with only a single species. The number of macrophyte species identified within each fyke set ranged from 0 (for two of the fyke sets at Frenchman's Bay), to 12 species for one of the fyke sets at Turkey Point (Table 2-5).

Macrophyte species richness values from the nets in each of the wetlands were regressed against the other independent water quality and fish variables to check for significant regressions (Table 2-4). Macrophyte species richness was inversely related with the water quality variables: total suspended solids (r^2= 0.36, p=0.0085), conductivity (r^2= 0.32, p=0.0148), total phosphorus (r^2= 0.30, p=0.0196) and chlorophyll-a (r^2= 0.27, p=0.0266). Macrophyte species richness demonstrated no relationships with any of the fish variables.

Fish Community – A total of 2296 fish of 34 species (Tables 2-1 and 2-5) were caught using fyke nets in seven wetlands. The fish communities from the seven wetlands were dissimilar. Only four fish species (bluegill, pumpkinseed, largemouth bass and brown bullhead) were common to all seven wetlands. Yellow perch and carp were common to six and five of the wetlands respectively. The remaining 28 fish species were caught in only three (5 species), two (9 species) or a single wetland (14 species). Frenchman's Bay harbored the greatest number of fish species with 17, followed by Rondeau (14 species), Turkey Point (13 species), Cootes Paradise (11 species), Little Sodus (11 species), Spicer Creek (11 species), while Sandy Creek exhibited only 8 fish species.

Significant regressions were prevalent among the fish variables (Table 2-4). The most notable examples exist between piscivore abundance and total fish abundance (r^2=0.54, p=0.0005), total fish biomass (r^2=0.47, p=0.0018), and fish species richness (r^2=0.47, p=0.0018). The remaining significant regressions among fish variables all have lower R-square values and are reported in Table 2-4. Significant regressions also existed between planktivore abundance and conductivity (r^2=0.39, p=0.0053), and total suspended solids (r^2=0.36, p=0.0084). None of the regressions between the fish variables and macrophyte species richness were significant.

Zooplankton Community – A total of 22 210 zooplankton of 48 species were collected and identified in this study; including 15 species of cladocerans, 3 copepod, and 31 rotifers. For a complete inventory of abundance and biomass of individual zooplankton species from each wetland refer to Table 2-6a and 6b. The zooplankton communities collected from the fyke sets within the seven wetlands were dissimilar. Only three zooplankton species (*Bosmina longirostris, Keratella cochlearis* and *Polyarthra sp.*), *Nauplii* and a single copepod genus (*Cyclopoida*) were common to all seven wetlands. None of the zooplankton species were common to six of the wetlands. Only a single cladocera (*Chydorus sphaericus*) was common to five of the wetlands. Seven species (*Ceriodaphnia reticulata, Diaphanosoma brachyurum, Monostyla quadridentata, Monostyla lunaris, Mytilinidae sp., Platyias patulus, and Trichocera longiseta*) were common to four of the wetlands. The remaining 34 zooplankton species were only common to three (6 species), two (12 species) or a single wetland (18 species). Little Sodus Bay supported the greatest number of zooplankton species with 26, followed by Rondeau (24 species), Turkey Point (23 species), Sandy Creek (17 species), Spicer Creek (14 species), Frenchman's Bay (13 species), while Cootes Paradise only had 8 species.

Wetlands in this study represented a broad range of zooplankton community characteristics (Table 2-6a). The number of zooplankton species identified from each fyke net among all the wetlands ranged from 5 to 20 species per sample. Total abundance of zooplankton ranged from 39 to 8221 individuals/L, while biomass ranged from 15 to 3946 µg/L. Mean zooplankton length ranged from 0.2 mm to 0.39 mm among wetlands. Micrograzer (5 – 3054 µg/L), medium grazer (0 – 542 µg/L) and macrograzer (0 – 810 µg/L) biomass also each demonstrated substantial variation among wetlands. The high values pertaining to total zooplankton abundance, biomass, micrograzer and macrograzer biomass could all be attributed to a sample collected from Frenchman's Bay. Otherwise, there were no associations among high or low values for each of the variables among the wetlands.

The WZI values calculated for each wetland (Table 2-6a) followed the predicted wetland rankings with a few exceptions. Cootes Paradise and Frenchman's Bay, the most degraded wetlands with the highest total phosphorus levels were ranked the poorest quality (2.05 and 2.87 respectively). Likewise, Spicer Creek, which had the lowest total phosphorus concentrations, was ranked the highest (3.96). Those wetlands with intermediate phosphorus levels did not have corresponding WZI values. Although, it is noteworthy that differences in total phosphorus levels in those wetlands were not pronounced and the WZI values were likewise very similar.

Three of the zooplankton variables in this study were highly related with each other (Table 2-8). Micrograzer biomass was directly related with total zooplankton abundance (r^2=0.89, p=<0.0001-Figure 2-3), and total biomass (r^2=0.75, p=<0.0001-Figure 2-4). Zooplankton abundance and biomass were also directly related with each other (r^2=0.89, p=<0.0001). It would appear from this that total zooplankton abundance and biomass are functions of micrograzer biomass indicating that total zooplankton abundance and biomass are redundant measures of zooplankton community characteristics within these wetland systems.

Least-Squared Regression Analyses

Individual least-square regression analyses were performed between all of the independent variables to determine the direction and strength of their relationship with the zooplankton communities from the seven Lake Erie and Ontario coastal wetlands.

Water Quality – With 14 individually significant regressions, water quality variables were most correlated with characteristics of the zooplankton communities (Table 2-9). Due to cross-correlations among total zooplankton abundance, biomass and micrograzer biomass, many of the water quality variables yielded similar results. Total phosphorus (r^2=0.58, p=0.0003-Figure 2-5) and total suspended solids (r^2=0.51, p=0.0009), were the best predictors of total zooplankton abundance. Similarly, differences in micrograzer biomass were related with concentrations of total phosphorus (r^2=0.51, p=0.0008-Figure 2-6), total suspended solids (r^2=0.47, p=0.0018), and chlorophyll-a (r^2=0.47, p=0.0016). Zooplankton biomass was also directly related to total suspended solids (r^2=0.44, p=0.0027-Figure 2-7) and total phosphorus (r^2=0.36, p=0.0089). Conductivity was inversely related with mean zooplankton length (r^2=0.49, p=0.0013-Figure 2-8) while water temperature was directly related to mean length (r^2=0.30, p=0.0198). None of the variation in zooplankton species richness, medium grazer, and macrograzer biomass among the wetlands was explained by any of the water quality variables.

Macrophyte Species Richness – Macrophyte species richness also demonstrated relationships with zooplankton abundance, biomass and micrograzer biomass (Table 2-9). In contrast to the direct relationships among the zooplankton and water quality variables, macrophyte species richness was inversely related with micrograzer biomass (r^2=0.54, p=0.0006-Figure 2-9), zooplankton abundance (r^2=0.48, p=0.0015) and biomass (r^2=0.32, p=0.0140).

Fish Community Characteristics – Among the 7 independent fish, and the 7 dependent zooplankton variables 49 individual linear regression analyses were performed (Table 2-

9). Only three of the regressions analyses achieved levels of significance (which could be expected based on chance alone). The strongest of the three relationships between benthivore abundance and mean zooplankton length (r^2=0.31, p=0.0164), shows a substantial amount of scatter about the line of best fit (Figure 2-10), due primarily to small sample size.

Stepwise Multiple Regression Analyses

Mean Zooplankton Length – Variations in mean zooplankton length were most completely explained by the independent water quality variables (Table 2-10). The combined influence of conductivity, total suspended solids, total phosphorus and water temperature (all water quality variables) explained 98% of the variation in mean zooplankton length. Many of these variables did not have individually significant correlations with mean zooplankton length. However, when their partial correlation values were considered, their combined contributions resulted in an almost complete explanation of variations in zooplankton length.

Micrograzer Biomass – A model including the plant species richness, total phosphorus, chlorophyll-a and total suspended solids variables explained 77% of the variation in micrograzer biomass (Table 2-10).

Zooplankton Abundance – In this case, far fewer variables were incorporated into the model than had significant individual correlations. Of the six variables, which individually showed significant correlations with zooplankton abundance (Table 2-9), only total phosphorus and total suspended solids were incorporated into the stepwise multiple regression model (Table 2-10). The combination of the two water quality variables accounted for 70% of the variation in zooplankton abundance.

Zooplankton Biomass – Only total suspended solids could be included without the model being forced out of the range of significance (Table 2-10). Therefore, only 41% of the variation in zooplankton abundance was explained by the independent variables.

Zooplankton Species Richness –Total fish abundance explained 20% of the variation in zooplankton species richness, representing only the second stepwise multiple regression model where an independent fish variable was included as an explanatory variables.

Medium and Macrograzer Biomass – None of the variation in these variables was explained by the independent water quality, plant or fish variables.

According to the individual least-square regression coefficients (Table 2-8) as well as the stepwise multiple regression models (Table 2-10), any differences in the water quality variables among the seven Lake Erie and Ontario wetlands were closely associated with differences in the zooplankton communities. Varying numbers of plant species in each wetland were also associated with differences in the zooplankton communities. Variations in the fish communities were poorly related with differences in the zooplankton communities from the wetlands.

DISCUSSION

The zooplankton communities within the coastal wetlands of the Laurentian Great Lakes were structurally diverse. This diversity was well reflected by the range of WZI values (2.05-3.96) for the seven wetlands. As expected, the most degraded wetlands (i.e.

Cootes Paradise and Frenchman's Bay) harbored a micrograzer dominated zooplankton community structure (85 and 99 percent composition respectively – Table 2-7). Also as predicted, the relatively pristine wetlands (i.e. Turkey Point and Spicer Creek) supported a medium and macrograzer dominated zooplankton community structure (59 and 66 percent composition respectively – Table 2-7). The task was then to verify the predicted relationships from the literature, and determine their relative influence on the zooplankton community structure.

As predicted by numerous existing studies (Bays and Crisman 1983; Pace 1986; Zettler and Carter 1986; Hart 1988, 1990; Kirk 1991; Lougheed et al. 1998; Lougheed and Chow-Fraser 1998; 2001; 2002) the degree of water quality degradation proved to be an influential aspect on zooplankton community structure in the lower Great Lake wetlands. Elevated total phosphorus, suspended sediment, conductivity, and chlorophyll-a concentrations, which are typically associated with degraded coastal wetlands, were all associated with increased micrograzer biomass, total zooplankton abundance and biomass levels.

The relationship described between nutrient levels and changes in the zooplankton communities is precisely what has been described within the literature on lake and wetland systems. Bays and Crisman (1983) found that total zooplankton biomass (and abundance) generally increases with increasing trophic state (nutrient concentration) and was accompanied both by species and group replacements within cladocera and copepods, the macrograzers, and an increased importance of micrograzers, including the rotifers, copepod nauplii, and large bodied cladocerans (*Eubosmina, Daphnia*) are replaced by smaller bodied taxa (*Bosmina longirostris*). Likewise, Pace (1986) found a direct correlation between total zooplankton biomass and total phosphorus levels. More recently, Lougheed and Chow-Frazer (2002) reported that total phosphorus levels were one of the most important predictors of zooplankton distribution among 70 coastal and inland Great Lake wetlands.

The effects of suspended sediment on zooplankton have been described by various researches to have opposing outcomes. Zettler and Carter (1986) looking at a zooplankton community along a turbidity gradient describe a situation where the more turbid zones harbour larger bodied zooplankton, reasoning that the turbidity would reduce the reactive distance of planktivorous fish, and thereby protect them from predation. On the other hand, Kirk (1991) determined experimentally that the presence of inorganic suspended sediment particles reversed the usual competitive dominance of cladocerans over rotifers. This shift in dominance was attributed to the fact that rotifers are raptorial and capable of capturing individual prey item that are outside the size range of particles typical of suspended sediments, whereas cladocerans are non-selective feeders that ingest particles in proportion to their abundance in the environment. The results from this study favor the latter explanation where high suspended sediment concentrations favor increased abundance of smaller cladocerans and rotifers (micrograzers).

Increased chlorophyll concentrations in wetlands would be expected to favor the medium and macrograzer communities. However, elevated chlorophyll levels were instead associated with an increase in micrograzer biomass and zooplankton abundance levels. A study conducted recently within Cootes Paradise, showed that the phytoplankton biomass associated with high nutrient and suspended sediment conditions mostly consisted of large, flagellated phytoplankton (>30μm), which were inedible to those smaller zooplankton able to withstand the high levels of turbidity typical of these sites (Lougheed and Chow-Fraser 1998). Therefore, the high chlorophyll levels within the degraded wetlands do not appear to be directly contributing to the increase in microzooplankton biomass and zooplankton abundance levels; but instead simply represents an unused resource resulting from the absence of medium and macrograzers that would be capable of exploiting it.

The number of macrophyte species identified within the winged region of each fykenet pair was inversely correlated with micrograzer biomass, zooplankton abundance and biomass values, precisely the same three zooplankton variables that were associated with differences in nutrient, suspended sediment, conductivity and chlorophyll concentrations. There are two explanations for the correlations between macrophyte species richness and the zooplankton communities. First, differences in macrophyte species richness among the wetlands have a direct impact on zooplankton community structure. Second, the effects of water quality independently influence both the number of plant species and zooplankton community structure.

Macrophytes are known to be an important structuring element in zooplankton communities within littoral lake regions and wetland environments. There are well-documented plant-associated taxa whose presence in a system is highly dependent on the presence of submergent macrophytes (Lougheed and Chow-Fraser 2002). Increased submergent macrophyte diversity has also been associated with an increased diversity of zooplankton species (Lougheed and Chow-Fraser 2001). Zooplankton size structure is also directly influenced by the presence of submerged macrophytes. Studies in a shallow, eutrophic Danish lake showed that an increase in macrophyte cover shifted the zooplankton community from rotifers to larger cladocerans (Jeppesen et al. 1992). Another study found that with increased fish density, the structure of the zooplankton community changed from one in which daphnids dominated to one dominated by small cladocera, and that the threshold at which this occurred depended on macrophyte density (Shriver et al. 1995). Researchers attribute the observed preference of larger-bodied zooplankton for macrophytes to fish predation in shallow lakes and wetlands where vertical migration is restricted (Timms and Moss 1984; Schriver et al. 1995; Lauridsen et al 1996; Jeppesen et al. 1997; Stanfield et al. 1997; Lougheed and Chow-Fraser 1998). Lauridsen (1996) has shown experimentally that *Daphnia magna* (a cladoceran) in the presence of predation pressure (a fish or fish odor) increases their occupation of macrophytes. Horizontal migratory behaviour of zooplankton has also been tracked on a diel basis, which found relatively higher zooplankton abundance and biomass levels within vegetation during daylight hours, when predation pressure was at its highest (Lauridsen et al 1996). Therefore, the reduced proportions of micrograzer biomass within wetlands of high macrophyte diversity suggest that, in the presence of aquatic macrophytes, micrograzers are outcompeted by larger medium and macrograzers.

As previously discussed, differences in nutrients, suspended sediments, conductivity and chlorophyll concentrations among the wetlands have direct impacts on the zooplankton communities. However, differences in water quality are at the same time influencing growth of aquatic plants. Linear regressions among the water quality and macrophyte variables revealed that as nutrient, suspended sediment, conductivity and chlorophyll levels increased, the numbers of macrophyte species declined (Table 2-4). High quality sites (with low nutrient, suspended sediment, ion and chlorophyll content) generally supported numerous macrophyte species, while degraded sites (high in nutrient, suspended sediment, ion and chlorophyll content) were capable of supporting only a few species (Lachavanne et al. 1991; Lougheed et al. 2001). Researching the effects of trophic status on aquatic vegetation, Srivastava et al. (1995) showed that nutrient enriched water has direct effects on macrophyte growth and community structure. It appears that degraded water quality conditions favor the proliferation of micrograzer taxa in two ways. First, fewer macrophytes are capable of growing within degraded conditions, thereby reducing available refuge for medium and macrograzers. Second, the increased suspended sediment within the water column limits the food collection capabilities of medium and macrograzers, thereby favoring proliferation of micrograzers.

To date, several connections demonstrating how fish communities influence zooplankton community structure in lakes have been documented. Research has shown that the taxonomic and size structures of zooplankton communities are strongly influenced by planktivorous fish (Evans 1990; Hanson and Butler 1990; Christoffersen et al. 1993; Schriver et al. 1995; Romare 1999). It has also been shown that zooplankton abundance and community structure can be influenced through a cascading effect initiated by increased predation pressure by piscivores on the planktivorous fish community (Timms and Moss 1984; Hanson and Butler 1990; Christoffersen et al. 1993;

Schriver et al. 1995; Romare 1999). It needs to be noted however, that the reported changes in zooplankton community structure within these studies were largely based on experiments where the planktivorous or piscivorous fish communities within enclosures, or on a whole-lake scale, were artificially controlled or manipulated.

The least-squared and stepwise multiple regression analyses performed on the data collected from the seven lake Erie/Ontario wetlands demonstrate no clear relationships between the fish community and zooplankton community structure and were unable to confirm the relationships reported in the literature dealing with shallow lakes. There are some noteworthy findings however, that justify further discussion.

Studies have shown that the removal of benthivorous fish communities has caused an increase in zooplankton biomass (Lougheed and Chow-Fraser 1998) and mean body size (Hanson and Butler 1990; Havens 1993). The inverse correlation between benthivorous fish abundance and mean zooplankton length agrees with this prediction. The mechanism of this outcome is thought to be that as benthivore abundance increases so does turbidity (due to their feeding and spawning activities that stir up the sediment).

The direct correlation between planktivore abundance and zooplankton biomass could be the result of two possibilities and requires further discussion. First, there is the possibility that the planktivorous fish were selectively consuming the largest component of zooplankton communities resulting in a shift in community structure towards dominance by smaller taxa (high total biomass)(Hart 1988; Evans 1990). Another possibility could be that the fish are merely present as a result of the high zooplankton abundance values that resulted from poor water quality conditions. Unfortunately, it is impossible to distinguish between the two possible explanations without further study.

The weak inverse correlation between total fish abundance and zooplankton species richness has no ecological explanation and no such relationship has been reported in the literature. Aside from the possibility that relationships 'just do not exist'; there may be another explanation for the lack of significant findings between the fish and zooplankton communities within wetland habitats. The migratory and mobile nature of fish may itself make it next to impossible to devise significant relationships without the use of enclosures. As well, fish assemblages based solely on catches made using fyke nets are biased towards omnivorous fish communities (Chapter 1); therefore, our data may under represent planktivorous fish populations that potentially have a significant impact on zooplankton community structure.

One of the objectives was to compare the relative influence of each habitat characteristic (water quality, macrophyte and fish communities) on zooplankton community structure. Variations in water quality and macrophyte species richness among the seven wetlands clearly had the greatest relative impact on zooplankton community structure. The water quality variables had the greatest number of significant correlations with characteristics of the zooplankton communities (Table 2-9), which also figured prominently in the stepwise multiple regression models developed for each of the zooplankton variables (Table 2-10). Regressions with macrophyte species richness also demonstrated predictive capabilities of zooplankton community structure. The fish variables however, only produced a few, weak correlations with the zooplankton communities from the seven wetlands.

Instead of judging the relative impact of the habitat characteristics solely from the numbers and strengths of their individual regressions with zooplankton community structure, stepwise multiple regression analyses were also conducted. The general purpose of stepwise multiple regression analysis is to learn about the relationship among several independent or predictor variables and a dependent or criterion variable. Stepwise multiple regression analysis determines the proportion of the dependent variable that can be attributed to the combined effects of all the independent variables acting together. As well, this analysis allows the researchers to address the question of which among the independent variables is the best predictor of the dependent variable under study. Therefore, since all of the independent variables are considered together, the strengths of their associations will be measured against one another. The output from each model for the zooplankton characteristics revealed that differences in water quality are the primary factors influencing zooplankton community structure. Plant species richness was a notable exception to the dominance of water quality variables, since it was the primary explanatory variable of micrograzer biomass.

Therefore, lake managers faced with decisions of how to improve wetland zooplankton habitat would be advised to consider the relative association each of the habitat characteristics has with zooplankton community structure before investing time and resources toward remediation efforts. Artificially manipulating the piscivorous fish community, in an attempt to increase predation pressure on the planktivorous fish, and thereby reducing predation pressure on the larger zooplankton would not be a recommended strategy. Unless the habitat is naturally barricaded from other bodies of water, measures will need to be taken to prevent the stocked fish from exiting the habitat. If successful in keeping the fish in the habitat, there is also the distinct possibility that they will eventually perish since the visual feeding strategy of most piscivorous is not well adapted for poor quality wetlands. Even though increased macrophyte species richness would undoubtedly have beneficial impacts on the zooplankton community structure, by providing refuge for larger medium and macrograzers, manually installing plants would not be a recommended strategy for the beginning phases of habitat restoration. Since the plants were unable to survive under the water quality conditions in the first place, it is unlikely that they would survive in the long term after the initial planting. Therefore, macrophyte-planting initiatives remain a recommended strategy following improvements to existing water quality conditions. Unfortunately, water quality, which is probably the most difficult aspect of wetland habitat to alter, is the only one that would appear to lead to long-term improvements. The shear size of the watersheds, which feed the tributaries that carry most of the nutrients and suspended sediment into the wetlands, poses many management difficulties. The necessary involvement of all by those living in the watershed, makes planning and executing various strategies cumbersome. As well, the behavioral changes required by the inhabitants of the watershed would also be met with opposition. Examples of behavioral changes include: altering agricultural practices to reduce the amounts of fertilizers applied to the land (which would reduce crop yield), change land-till methods to reduce surface sediment run-off, banning the use of herbicides for both agriculture and lawn applications, just to name a few.

The challenge faced by ecologists is to convey the importance of wetlands and the role they play in healthy, functioning ecosystems to the public in order to achieve even just some of the behavioral changes necessary to save our existing wetlands.

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Table 2-1: Length-weight regressions coefficients for Great Lake fishes. Values for the intercept are given in the metric system; metric equations are in g and mm. The standard equation is: $\log_{10}$ Weight = a + b *($\log_{10}$ Length).

Common Name	**Species**	**Y intercept** (a)	**Slope** (b)
Alewife	*Alosa pseudoharengus*	-5.29	3.06
Banded Killifish	*Fundulus diaphanous*	-5.57	3.33
Blackchin Shiner	*Notropis heterondon*	-5.03	2.99
Blacknose Shiner	*Notropis heterolepis*	-5.03	2.99
Black Crappie	*Pomoxis nigromaculatus*	-5.24	3.18
Black Bullhead	*Icalurus melas*	-4.61	2.88
Bluegill	*Lepomis macrochirus*	-5.10	3.17
Bowfin	*Amia calva*	-4.90	2.96
Brook Silverside	*Labissthes sicculus*	-5.12	2.96
Brown Bullhead	*Ameiurus mebulosus*	-4.61	2.88
Bullhead	*Icalurus sp.*	-4.61	2.88
Carp	*Cyprinus carpio*	-4.44	2.84
Central Mudminnow	*Umbra limi*	-4.85	2.92
Emerald Shiner	*Notropis atherinoides*	-4.71	2.73
Fathead Minnow	*Pimephales promelas*	-5.03	3.08
Freshwater Drum	*Apoldinotus grunniens*	-5.44	3.20
Gizzard Shad	*Dorosoma cepedianum*	-5.08	3.04
Golden Shiner	*Notemigonus crysoleucas*	-5.25	3.08
Grass Pickerel	*Esox a. vermiculatus*	-5.29	3.01
Green Sunfish	*Lepomis cyanellus*	-5.07	3.21
Jonny Darter	*Etheostoma nigrum*	-5.40	3.20
Largemouth Bass	*Micropterus salmoides*	-5.17	3.13
Longnose Gar	*Lepisoteus osseus*	-7.07	3.51
Mimic Shiner	*Notropis volucellus*	-5.03	2.99
Muskellunge	*Esox masquinongy*	-6.44	3.44
Northern Pike	*Esox lucius*	-5.61	3.14
Pumpkinseed	*Lepomis gibbonus*	-5.11	3.21
Redfin Pickerel	*Esox a. americanus*	-5.29	3.01
Rock Bass	*Ambloplites rupestris*	-4.18	3.05
Spottail Shiner	*Notropis hudsonius*	-5.03	2.99
Sunfish	*Lepomis sp.*	-5.04	3.16
Tadpole Madtom	*Noturus gyrinus*	-5.04	3.10
White Crappie	*Pomoxis annularis*	-5.82	3.38
White Perch	*Morone americana*	-5.38	3.22
White Sucker	*Catostomus catostomus*	-5.05	3.06
Yellow Perch	*Perca flavescens*	-5.33	3.17

(Schneider et al. 2000)

Table 2-2: The total abundance and fish species that correspond to each feeding class of fish from all 7 wetlands sampled.

Common Name	Latin Name	Abund.	Common Name	Latin Name	Abund.
***Omnivorous Fish* (< 50mm)**					
Bluegill	*Lepomis macrochirus*	461	Gizzard Shad	*Dorosoma cepedianum*	10
Pumpkinseed	*Lepomis gibbonus*	432	Mimic Shiner	*Notropis volucellus*	4
Sunfish	*Lepomis sp.*	10	Green Sunfish	*Lepomis cyanellus*	1
***Planktivorous Fish* (< 50mm)**					
Sunfish	*Lepomis sp.*	353	Jonny Darter	*Etheostoma nigrum*	4
Largemouth Bass	*Micropterus salmoides*	162	White Sucker	*Catostomus catostomus*	3
Black Bullhead	*Icalurus melas*	62	Banded Killifish	*Fundulus diaphanous*	3
Spottail Shiner	*Notropis hudsonius*	48	Gizzard Shad	*Dorosoma cepedianum*	2
Golden Shiner	*Notemigonus crysoleucas*	39	Pumpkinseed	*Lepomis gibbonus*	2
Yellow Perch	*Perca flavescens*	27	Emerald Shiner	*Notropis atherinoides*	2
Blacknose Shiner	*Notropis heterolepis*	14	Tadpole Madtom	*Noturus gyrinus*	2
Alewife	*Alosa pseudoharengus*	14	Bluegill	*Lepomis macrochirus*	1
Brown Bullhead	*Ameiurus mebulosus*	11	Blackchin Shiner	*Notropis heterondon*	1
Bullhead	*Icalurus sp.*	9	White Crappie	*Pomoxis annularis*	1
Rock Bass	*Ambloplites rupestris*	8	Black Crappie	*Pomoxis nigromaculatus*	1
Fathead Minnow	*Pimephales promelas*	7	Central Mudminnow	*Umbra limi*	1
Carp	*Cyprinus carpio*	6			
Benthivorous Fish (> 50mm)					
Brown Bullhead	*Ameiurus mebulosus*	81	Black Bullhead	*Icalurus melas*	4
Carp	*Cyprinus carpio*	27	Bullhead	*Icalurus sp.*	3
***Piscivorous Fish* (> 50mm)**					
Largemouth Bass	*Micropterus salmoides*	334	Freshwater Drum	*Apoldinotus grunniens*	3
Yellow Perch	*Perca flavescens*	98	White Crappie	*Pomoxis annularis*	2
Rock Bass	**Ambloplites rupestris**	13	White Perch	*Morone americana*	1
Bowfin	*Amia calva*	9	Grass Pickerel	*Esox a. vermiculatus*	1
Black Crappie	*Pomoxis nigromaculatus*	8	Redfin Pickerel	*Esox a. americanus*	1
Muskellunge	*Esox masquinongy*	4	Longnose Gar	*Lepisoteus osseus*	1
Northern Pike	*Esox lucius*	4			

Table 2-3: Water quality values for 7 wetlands from Lake Erie and Ontario over the summer of 2001. Wetlands are arranged in order of decreasing total phosphorus levels.

Wetland	Lake	Lat. N	Long. W	Temp (°C)	TP (μg/L)	TN (mg/L)	TSS (mg/L)	Chl-a (μg/L)	Cond. (mS/cm)
Cootes Paradise	Ont.	43°16'14.3"	79°55'52.6"	24	142	5.10	19	6	939
Frenchman's Bay	Ont.	43°49'00"	79°05'00"	25	66	1.35	14	9	395
Little Sodus Bay	Ont.	43°20'21.9"	76°41'40.1"	25	65	1.84	4	5	363
Rondeau PP	Erie	42°17'16.8"	81°52'1.2"	32	48	1.35	5	2	228
Turkey Point	Erie	42°38'55.8"	79°05'40.8"	21	47	1.58	8	2	303
Sandy Creek	Ont.	43°42'3.2"	76°11'47.3"	24	42	1.26	2	5	232
Spicer Creek	Ont.	43°20'4.2"	76°41'21.6"	25	17	0.51	5	1	287

Table 2-4: Linear regressions among the independent variables. Coefficients represented in italics signify negative correlations.

Independent Variables	Water Temperature	Total Phosphorus	Total Nitrogen	Conductivity	Total Suspended Solids	Chlorophyll-a
Water Temperature						
Total Phosphorus						
Total Nitrogen		r^2= 0.84 p= <0.0001				
Conductivity		r^2= 0.42 p= 0.0036				
Total Suspended Solids		r^2= 0.23 p= 0.0449		r^2= 0.57 p= 0.0003		
Chlorophyll a		r^2= 0.28 p= 0.0243				
Macrophyte Richness		*r^2= 0.30 p= 0.0196*		*r^2= 0.32 p= 0.0148*	*R^2= 0.36 p= 0.0085*	*r^2= 0.27 p= 0.0266*
Fish Species Richness				r^2= 0.27 p= 0.0282		
Abundance						
Biomass						
Omnivores						
Planktivores				r^2= 0.39 p= 0.0053	r^2= 0.36 p= 0.0084	
Benthivores						
Piscivores						

	Fish Species Richness	Abundance	Biomass	Omnivorous	Planktivorous	Benthivorous
Fish Species Richness						
Abundance	r^2= 0.40 p= 0.0047					
Biomass	r^2= 0.24 p= 0.0374	r^2= 0.27 p= 0.0279				
Omnivores		r^2= 0.36 p= 0.0090	r^2= 0.42 p= 0.0037			
Planktivores				*r^2= 0.28 p= 0.0202*		
Benthivores	r^2= 0.22 p= 0.0487				r^2= 0.27 p= 0.0277	
Piscivores	r^2= 0.35 p= 0.0099	r^2= 0.54 p= 0.0005	r^2= 0.47 p= 0.0018	r^2= 0.33 p= 0.0127		
Macrophyte Richness						

Table 2-5: Summary of plant and fish variables for each fyke set at each wetland. Arranged in order of decreasing total phosphorus levels. Wetland abbreviations: CP-Cootes Paradise, FB-Frenchman's Bay, LS-Little Sodus Bay, RN-Rondeau Provincial Park, SC-Sandy Creek, SP-Spicer Creek and TP-Turkey Point.

Wetland	**Set #**	**Plant Species Richness**	**Fish Species Richness**	**Abundance** (# of fish)	**Biomass** (g)	**Omniv.** (abundance / *biomass*)	**Plank.** (abundance / *biomass*)	**Benth.** (abundance / *biomass*)	**Pisc.** (abundance / *biomass*)
CP	1	1	18	418	2843	36	362	7	12
						933	*423*	*346*	*250*
FB	1	0	10	163	2330	2	96	54	11
	2	3	3	30	26	1	29	0	0
	3	1	5	37	225	7	25	4	1
						245	*383*	*1157*	*795*
LS	1	3	7	196	6640	54	17	8	117
	2	5	8	50	2338	4	30	6	10
	3	6	9	42	7164	21	6	10	5
						2409	*51*	*4760*	*8923*
RN	1	6	5	61	272	12	45	0	4
	2	3	6	23	1885	18	1	0	4
	3	5	12	342	4205	118	34	1	189
						3265	*71*	*364*	*2661*
SC	1	8	5	73	3469	57	5	5	6
	2	8	6	290	13243	269	0	0	21
	3	11	4	26	901	22	1	1	2
						13443	*4*	*1241*	*2926*
SP	1	9	7	89	124	1	76	7	5
	2	6	8	49	10789	1	25	8	15
						74	*88*	*10584*	*168*
TP	1	7	7	280	11344	241	3	3	33
	2	12	7	37	122	2	27	2	7
	3	8	8	90	3941	52	1	0	37
						9188	*38*	*789*	*1452*

Table 2-6a: Summary of mean abundances (ind./L) of zooplankton species per wetland.

		CP	FB	LS	RN	TP	SC	SP
Number of Samples		1	3	3	3	3	3	2
WZI values		2.05	2.87	3.46	3.43	3.71	3.39	3.96
CLADOCERA	**ABREV.**							
Acroperus harpae	*A.harp.*				30	1	4	
Allonella exisa	*A.exis*						1	
Bosmina longirostris	*B.long*	7	2509	7	129	4	294	1
Camptocercus macrurus	*C.macru*			1	4	1		
Ceriodaphnia reticulata	*C.reti*		27	9	36	96		
Chaoborus instar	*C.inst*			1	1	1	1	
Chydorus sphaericu	*C.spha*			5	4	1	1	1
Diapanosoma brachyurum	*D.brach*		6	1	12	35	2	
Echinisca rosea	*E.rosea*				4			
Macrothrix sp.	*Macr.*		15					
Moina micrura	*M.mic*		86					
Pleuroxus procurvatus	*P.proc*			1				1
Polyphemus pediculus	*P.pedi*					29		
Scapholeberis sp.	*Scaph*		5				15	15
Sida crystallina	*S.crys*					1		
Simocephalus exspinosus	*S.exsp*			2				
COPEPODA								
Nauplii	*Naup*	301	153	72	42	76	72	11
Cyclopodia	*Cyclo*	12	47	17	38	23	17	12
Calanoida	*Calan*				1			
Harpacticoida	*Harpa*							4
ROTIFERA								
Asplanchna sp.	*Aspl*	3				1		
Branchionus angularis	*B.angul*	3133	199					
Branchionus caudatus	*B.caud*	1	7					
Branchionus rubens	*B.rub*						1	
Branchionus urceolaris	*B.urceo*	1				11		
Euchlanis calpidia	*E.calp*			1		2		
Euchlanis triquetra	*E.triq*					7		
Filinia sp.	*Filin*		17		1			
Gastropus sp.	*Gast*			6				
Hexarthra sp.	*Hexa*		58					
Keratella cochlearis	*K.coch*	1	40	74	22	2	1	2
Keratella quadrata	*K.quad*				1			
Lecane leontina	*L.leon*			1				
Lecane luna	*L.luna*			4	1			
Lecane mira	*L.mira*							
Lecane tudicola	*L.tudi*			1				1
Lepedella ovalis	*L.oval*			8				
Monostyla bulla	*M.bulla*			1		4	1	
Monostyla crenata	*M.cren*				1		1	
Monostyla lunaris	*M.luna*			1	1	1	2	
Monostyla quadridentata	*M.quad*			1	1	6	5	
Mytilinidae sp.	*Mytil*			1	4	13	3	1
Northolca acuminata	*N.acum*							
Platyias patulus	*P.patu*			20	1	4		1
Polyarthra sp.	*Polyar*	160	213	25	16	3	9	1
Testudinella sp.	*Testu*			1	1			1
Tricocerca elongata	*T.elon*					1		
Tricocerca lata	*T.lata*			1				1
Tricocerca longiseta	*T.long*			1	1	1		1
Tricocerca multicrinis	*T.mult*				1			
Trichotria pouillum	*T.poui*			1			1	
	Total Abundance	3620	3382	264	356	324	177	52
	Species Richness	8	13	26	24	23	17	14

Table 2-6b: Summary of mean biomass (µg/L) of zooplankton species per wetland.

		CP	FB	LS	RN	TP	SC	SP
CLADOCERA	**ABREV.**							
Acroperus harpae	*A.harp.*				60	2	1	
Allonella exisa	*A.exis*						<1	
Bosmina longirostris	*B.long*	3	1716	4	46	2	21	<1
Camptocercus macrurus	*C.macru*			1	10	3		
Ceriodaphnia reticulata	*C.reti*		26	11	54	73		
Chaoborus instar	*C.inst*			3	3	3	3	
Chydorus sphaericu	*C.spha*			2	1	<1	1	1
Diapanosoma brachyurum	*D.brach*		5	<1	12	40	7	
Echinisca rosea	*E.rosea*				<1			
Macrothrix sp.	*Macr.*		53					
Moina micrura	*M.mic*		234					
Scapholeberis sp.	*Scaph*		10				41	10
Sida crystallina	*S.crys*					109		
Simocephalus exspinosus	*S.exsp*			2				
Pleuroxus procurvatus	*P.proc*			<1				1
Polyphemus pediculus	*P.pedi*					45		
COPEPODA								
Nauplii	*Naup*	28	14	10	11	8	10	1
Cyclopodia	*Cyclo*	15	85	23	73	107	19	22
Calanoida	*Calan*				7			
Harpacticoida	*Harpa*							1
ROTIFERA								
Asplanchna sp.	*Aspl*	1				<1		
Branchionus angularis	*B.angul*	1567	100					
Branchionus caudatus	*B.caud*	<1	2					
Branchionus rubens	*B.rub*						<1	
Branchionus urceolaris	*B.urceo*	<1				2		
Euchlanis calpidia	*E.calp*			1		1		
Euchlanis triquetra	*E.triq*					2		
Filinia sp.	*Filin*		8		<1			
Gastropus sp.	*Gast*			1				
Hexarthra sp.	*Hexa*		45					
Keratella cochlearis	*K.coch*	<1	4	8	2	<1	<1	<1
Keratella quadrata	*K.quad*				<1			
Lecane leontina	*L.leon*			<1				
Lecane luna	*L.luna*			1	<1			
Lecane mira	*L.mira*				<1			
Lecane tudicola	*L.tudi*			<1				<1
Lepedella ovalis	*L.oval*			3			2	
Monostyla bulla	*M.bulla*			<1		1	<1	
Monostyla crenata	*M.cren*				<1		1	
Monostyla lunaris	*M.luna*			<1	<1	<1	1	
Monostyla quadridentata	*M.quad*			<1	1	2	<1	
Mytilinidae sp.	*Mytil*			<1	2	7		<1
Northolca acuminata	*N.acum*							
Platyias patulus	*P.patu*			7	<1	2		<1
Polyarthra sp.	*Polyar*	118	158	19	12	2	6	1
Testudinella sp.	*Testu*			1	2			1
Tricocerca elongata	*T.elon*					1		
Tricocerca lata	*T.lata*			<1				<1
Tricocerca longiseta	*T.long*			1	1	<1		<1
Tricocerca multicrinis	*T.mult*				1			
Trichotria pouillum	*T.poui*			<1			<1	
	Total Biomass	1732	2460	100	300	512	120	40

Table 2-7: Summary of zooplankton variables for each fyke set at each wetland. Arranged in order of decreasing total phosphorus levels. Bracketed values within each size class of zooplankton represent percent composition of each class. Wetland abbreviations: CP-Cootes Paradise, FB-Frenchman's Bay, LS-Little Sodus Bay, RN-Rondeau Provincial Park, SC-Sandy Creek, SP-Spicer Creek and TP-Turkey Point.

Wetland	**Set #**	**Species Richness**	**Abundance** (#/L)	**Biomass** (µg/L)	**Mean Length** (mm)	**Micro-Graz.** (µg/L)	**Medium Graz.** (µg/L)	**Macro-Graz.** (µg/L)
CP	1	9	4978	1732	0.2	1717	15	0
						(99)	(1)	(0)
FB	1	10	8221	3946	0.32	3054	82	810
	2	11	3128	1832		1777	55	0
	3	11	2037	1217		1120	7	90
						(85)	(2)	(13)
LS	1	20	380	90	0.27	54	36	0
	2	12	140	45		33	11	1
	3	18	470	127		87	0	40
						(67)	(18)	(16)
RN	1	15	242	156	0.39	52	1	102
	2	17	668	356		81	256	18
	3	10	344	192		76	33	83
						(30)	(41)	(29)
SC	1	7	182	41	0.31	24	17	0
	2	8	184	50		50	0	0
	3	16	245	122		67	49	7
						(66)	(31)	(3)
SP	1	11	39	15	0.26	14	1	0
	2	9	73	50		5	2	43
						(29)	(5)	(66)
TP	1	5	135	17	0.32	17	0	0
	2	15	622	997		27	542	317
	3	15	124	18		13	0	5
						(6)	(59)	(35)

Table 2-8: Linear regressions among the dependent zooplankton variables. Coefficients represented in italics signify negative relationships.

Zooplankton Variables	Species Richness	Total Abundance	Total Biomass	Mean Length	Micrograz.	Medium Grazers	Macrograz.
Species Richness							
Total Abundance							
Total Biomass		r^2= 0.89 p= <0.0001					
Mean Length							
Micrograzers		r^2= 0.89 p= <0.0001	r^2= 0.75 p= <0.0001				
Medium Grazers		r^2= 0.27 p= 0.0287	r^2= 0.41 p= 0.0041				
Macrograzers			r^2= 0.24 p= 0.0402				

Table 2-9: Correlation coefficients relating the independent water quality, plant and fish variables to the dependent zooplankton variables. Coefficients represented in italics signify negative relationships.

Zoop. / Indep. Var.	**Richness**	**Abundance**	**Biomass**	**Mean Length**	**Micro.**	**Med.**	**Macro**
Water Temperature				R^2= 0.30 p= 0.0198			
Total Phosphorus		r^2= 0.58 p= 0.0003	r^2= 0.36 p= 0.0089		r^2= 0.51 p= 0.0008		
Total Nitrogen		r^2= 0.30 p= 0.0194			r^2= 0.22 p= 0.0485		
Conductivity		r^2= 0.38 p= 0.0069	r^2= 0.24 p= 0.0381	*r^2= 0.49 p= 0.0013*	r^2= 0.37 p= 0.0075		
Total Suspended Solids		r^2= 0.51 p= 0.0009	r^2= 0.44 p= 0.0027		r^2= 0.47 p= 0.0018		
Chlorophyll a		r^2= 0.22 p= 0.0125			r^2= 0.47 p= 0.0016		
Macrophyte Richness		*r^2= 0.48 p= 0.0015*	*r^2= 0.32 p= 0.0140*		*r^2= 0.54 p= 0.0006*		
Fish Species Richness							
Abundance	*r^2= 0.24 p= 0.0371*						
Biomass							
Omnivores							
Planktivores			r^2= 0.24 p= 0.0402				
Benthivores				*r^2= 0.31 p= 0.0164*			
Piscivores							

Table 2-10: Summary stepwise multiple regression outputs for the zooplankton variables.

Dependent Zooplankton Variables Independent Variables (Water Quality, Plants and Fish)			
Zooplankton Species Richness		(R square adjusted = 0.20, n=18)	
Fish Abundance			
R^2=0.24			
p=0.0371			
Zooplankton Abundance		(R square adjusted = 0.70, n=18)	
TP →	TSS		
R^2=0.58	R^2=0.74		
p=0.0003	p=0.0087		
Zooplankton Biomass		(R square adjusted = 0.41, n=18)	
TSS			
R^2=0.44			
p=0.0027			
Mean Zooplankton Length		(R square adjusted = 0.98, n=18)	
Cond. →	TSS →	TP →	Temp.
R^2=0.49	R^2=0.74	R^2=0.95	R^2=0.99
p=0.0013	p=0.0018	p=<0.0001	p=0.0001
Micrograzer Biomass		(R square adjusted = 0.77, n=18)	
Plant Sp. →	TP →	Chla →	TSS
R^2=0.54	R^2=0.68	R^2=0.74	R^2=0.82
p=0.0006	P=0.0201	p=0.0900	P=0.0287
Medium Grazer Biomass		(R square adjusted = 0.00, n=18)	
None			
Micrograzer Biomass		(R square adjusted = 0.00, n=18)	
None			

Figure 2-1: Map of lower Great Lake sampling sites.

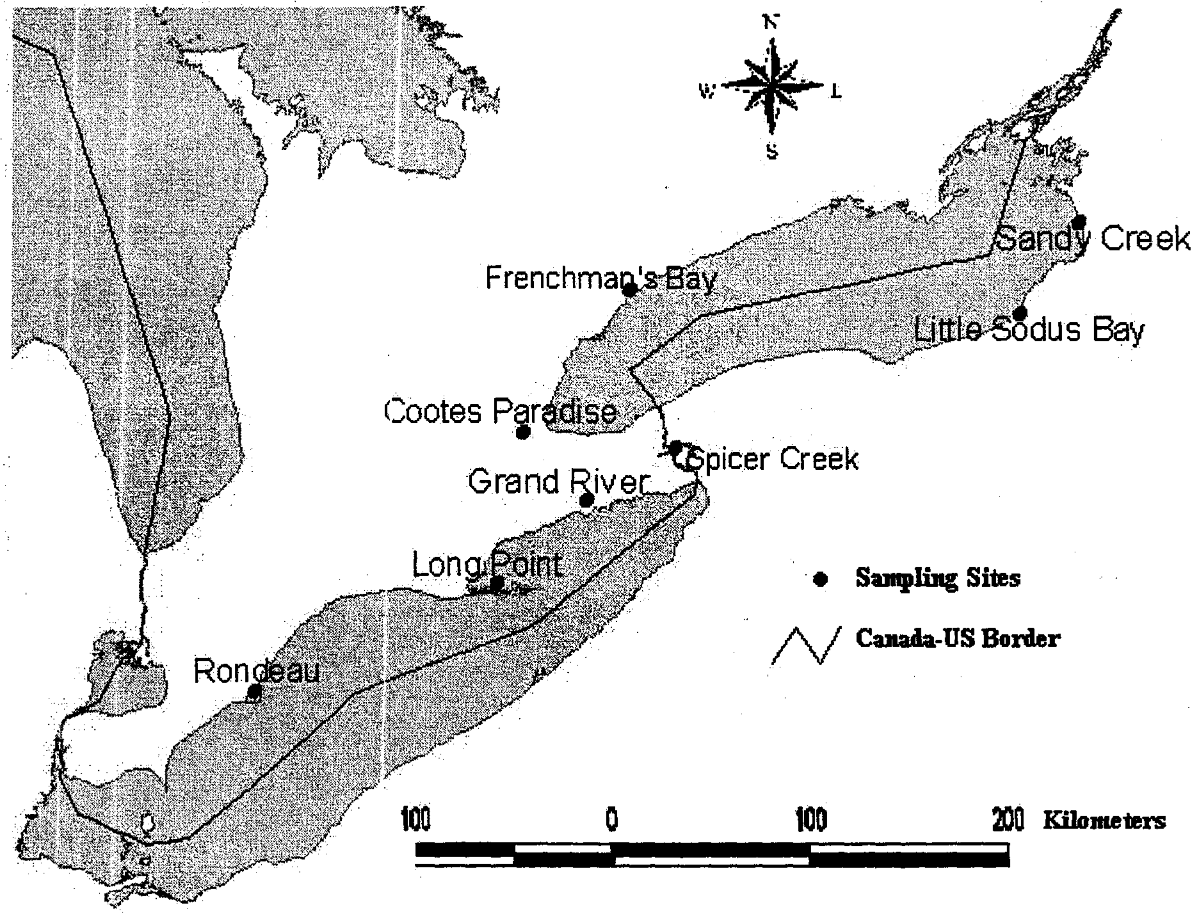

N
W
E
S
Sandy Creek
Frenchman's Bay
Little Sodus Bay
Cootes Paradise
Spicer Creek
Grand River
Long Point
Sampling Sites
Canada-US Border
Rondeau
100
0
100
200
Kilometers

Figure 2-2: Linear regression demonstrating co-linearity between total suspended solids and conductivity (Equation of the line, Log TSS = -2.156866 + 1.2005738 Log Cond., $r^2 = 0.57$, $p=0.0003$).

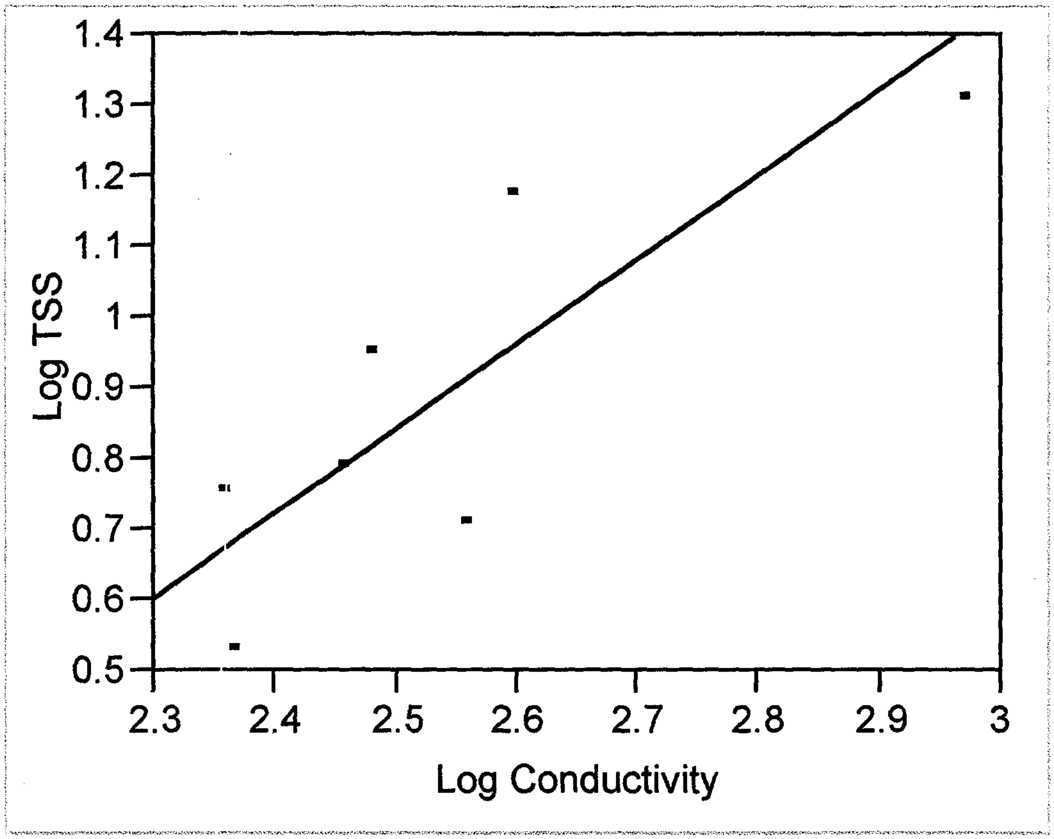
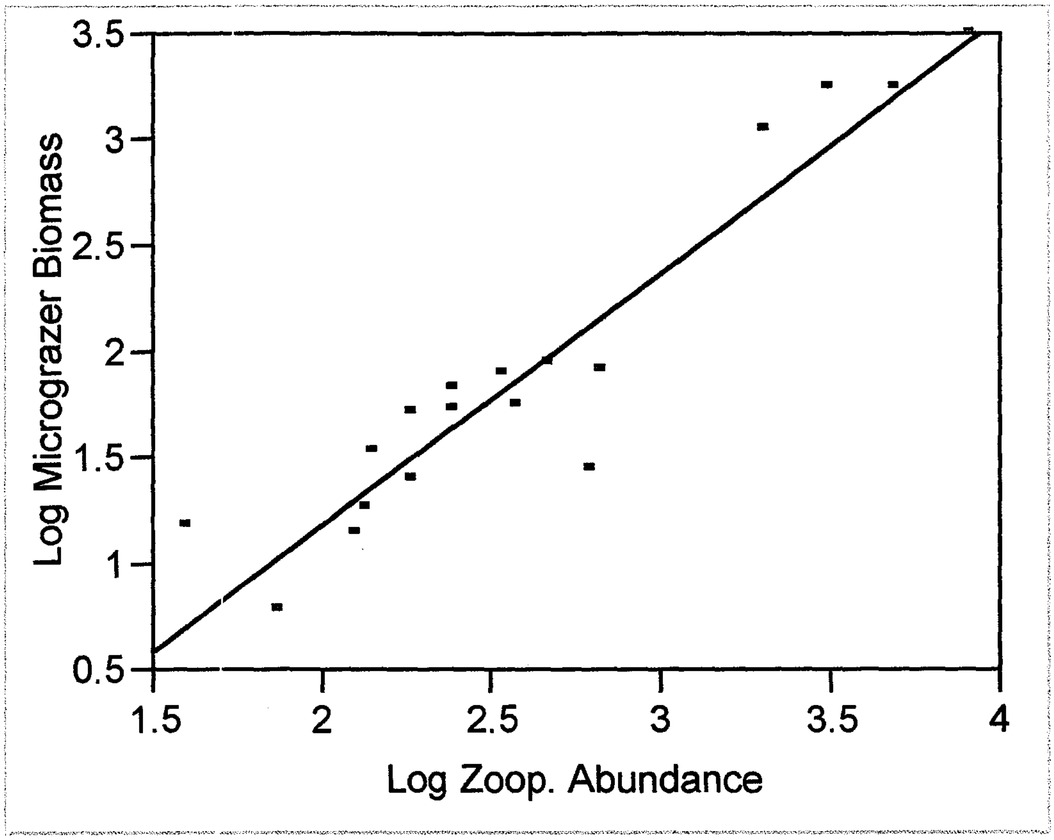

1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
Log TSS
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Log Conductivity

Figure 2-3: Linear regression demonstrating co-linearity between micrograzer biomass and total zooplankton abundance (Equation of the line, Log Micro = -1.194004 + 1.1917153 Log Zoop Abund., r^2= 0.89, p=<0.0001).



3.5
3
2.5
2
1.5
1
0.5
Log Micrograzer Biomass
1.5
2
2.5
3
3.5
4
Log Zoop. Abundance

Figure 2-4: Linear regression demonstrating co-linearity between micrograzer biomass and total zooplankton biomass (Equation of the line, Log Micro = -0.126038 + 0.9235768 Log Zoop Biomass, r^2= 0.75, p=<0.0001).

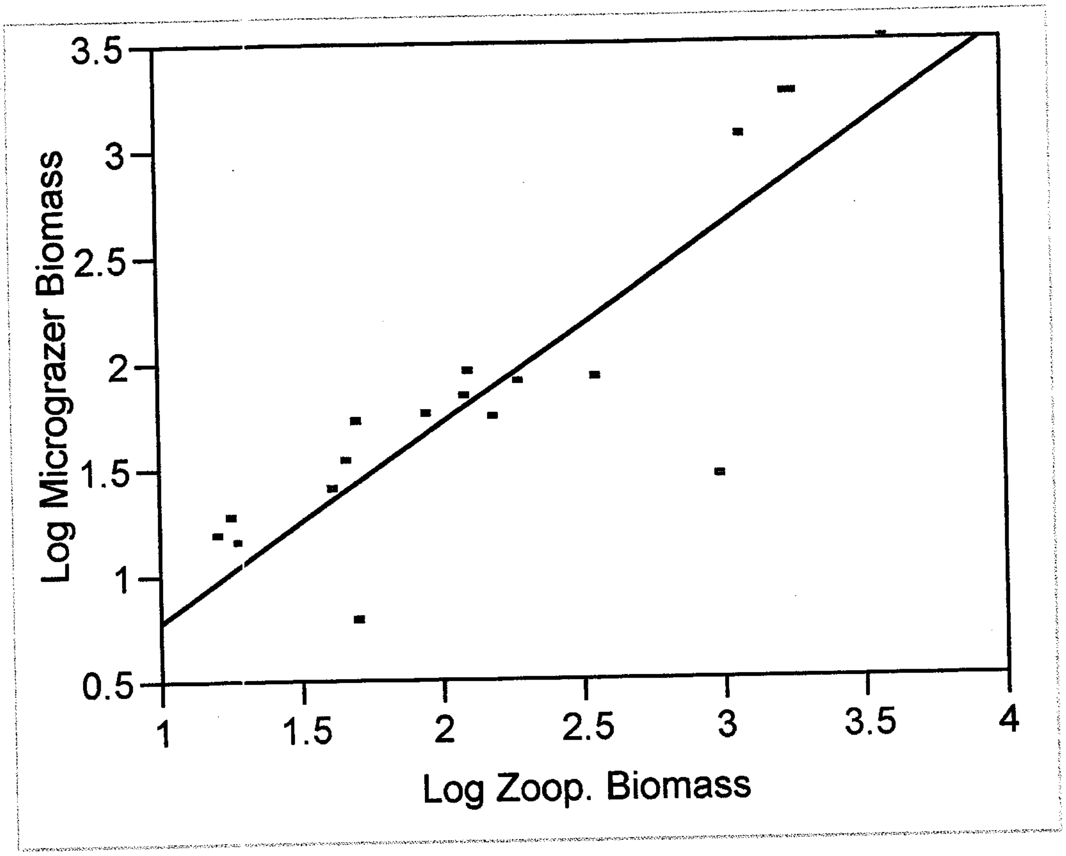

3.5
3
2.5
2
1.5
1
0.5
Log Micrograzer Biomass
1
1.5
2
2.5
3
3.5
4
Log Zoop. Biomass

Figure 2-5: Linear regression demonstrating a direct correlation between total zooplankton abundance and total phosphorus (Equation of the line, Log Zoop Abund = -1.371824 + 2.3424236 Log TP, $r^2 = 0.58$, p=0.0003).

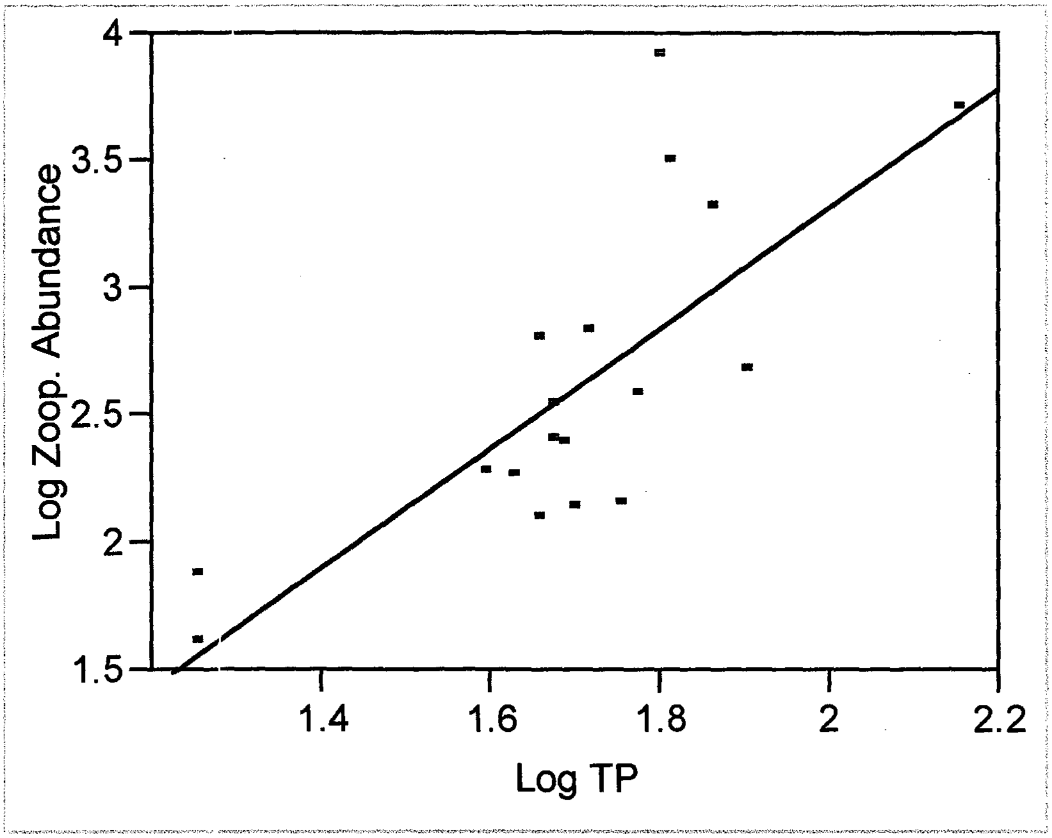

Log Zoop. Abundance
4
3.5
3
2.5
2
1.5
1.4
1.6
1.8
2
2.2
Log TP

Figure 2-6: Linear regression demonstrating a direct correlation between micrograzer biomass and total phosphorus (Equation of the line, Log Micrograzer Biomass = -2.825538 + 2.789567 Log TP, $r^2 = 0.51$, $p=0.0008$).

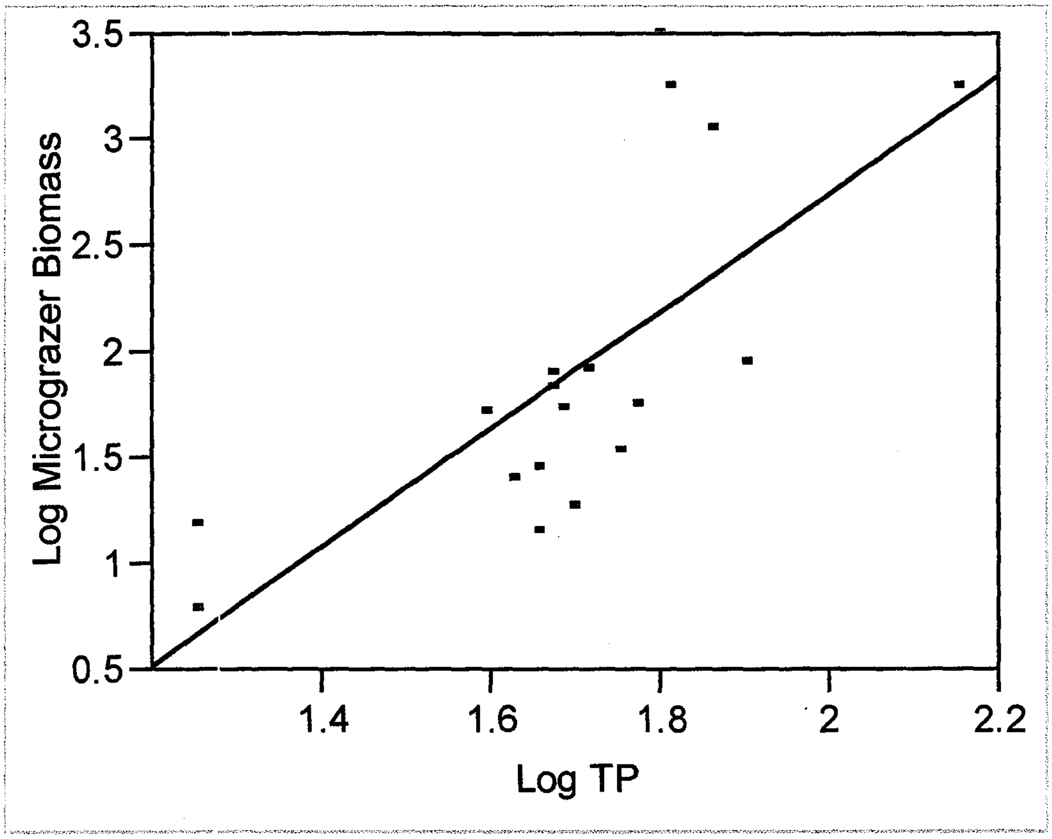

Log Micrograzer Biomass
3.5
3
2.5
2
1.5
1
0.5
1.4
1.6
1.8
2
2.2
Log TP

Figure 2-7: Linear regression demonstrating a direct correlation between total zooplankton biomass and total suspended solids (Equation of the line, Log Zoop. Biomass = 0.4409264 + 2.0965145 Log TSS, $r^2 = 0.44$, $p=0.0027$).

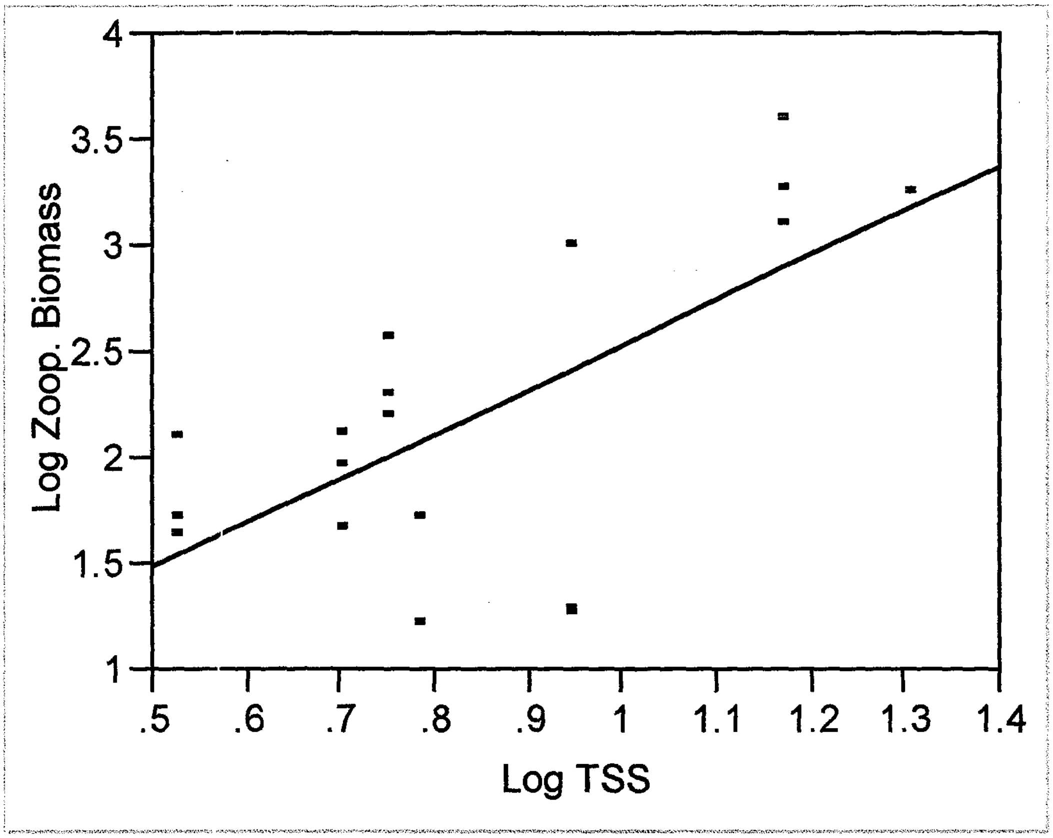

Log Zoop. Biomass
4
3.5
3
2.5
2
1.5
1
.5
.6
.7
.8
.9
1
1.1
1.2
1.3
1.4
Log TSS

Figure 2-8: Linear regression demonstrating an indirect correlation between mean zooplankton length and conductivity (Equation of the line, Log Mean Zoop. Length = 0.308549 - 0.0768471 Log Conductivity, $r^2 = 0.49$, $p=0.0013$).

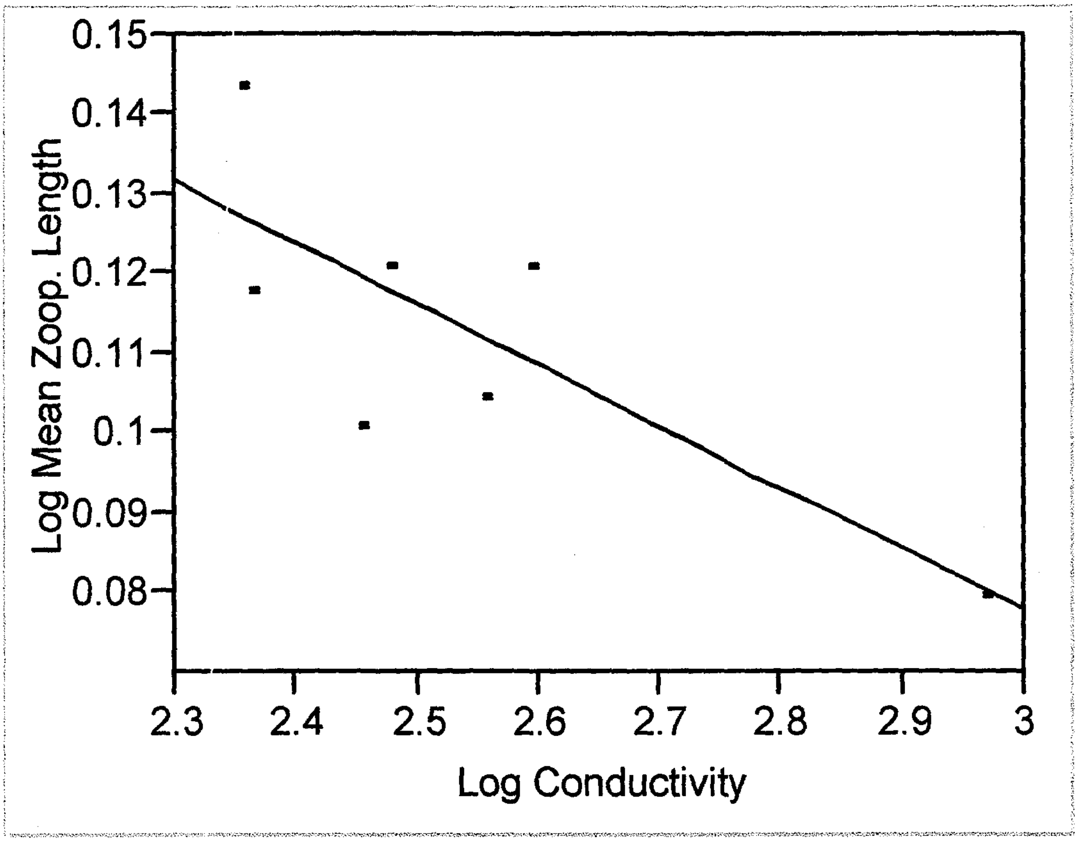
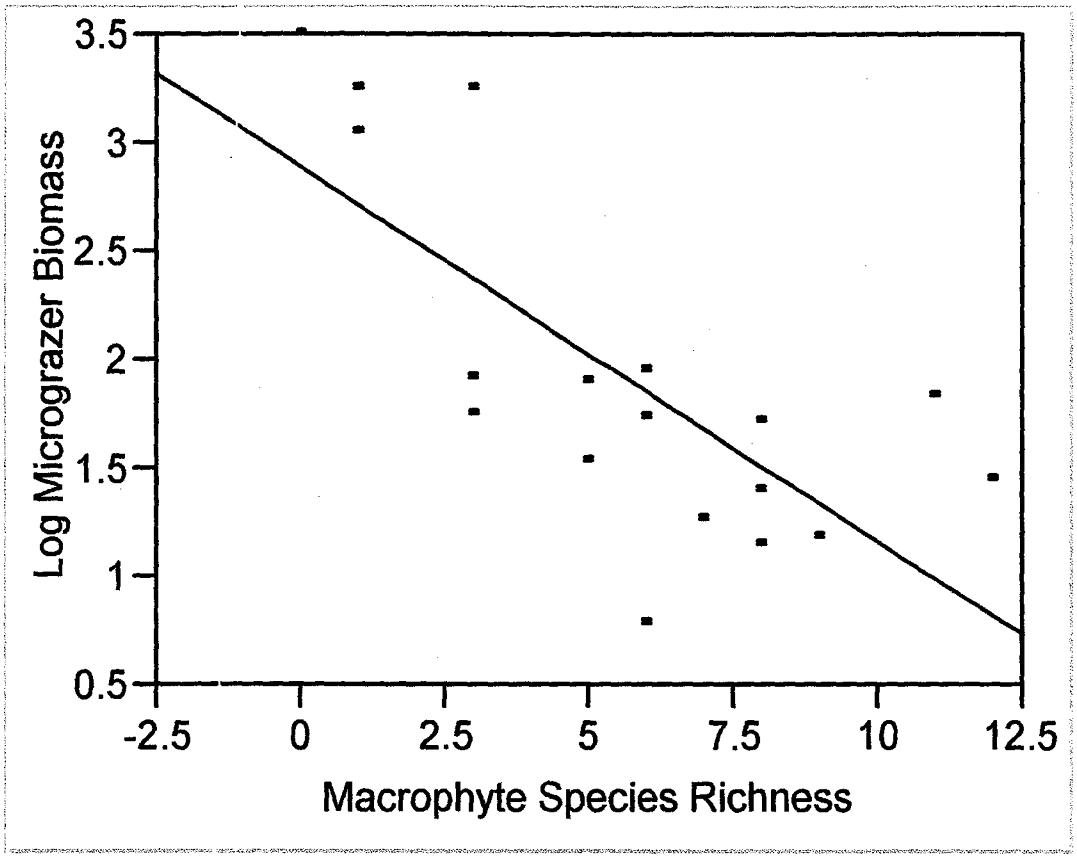
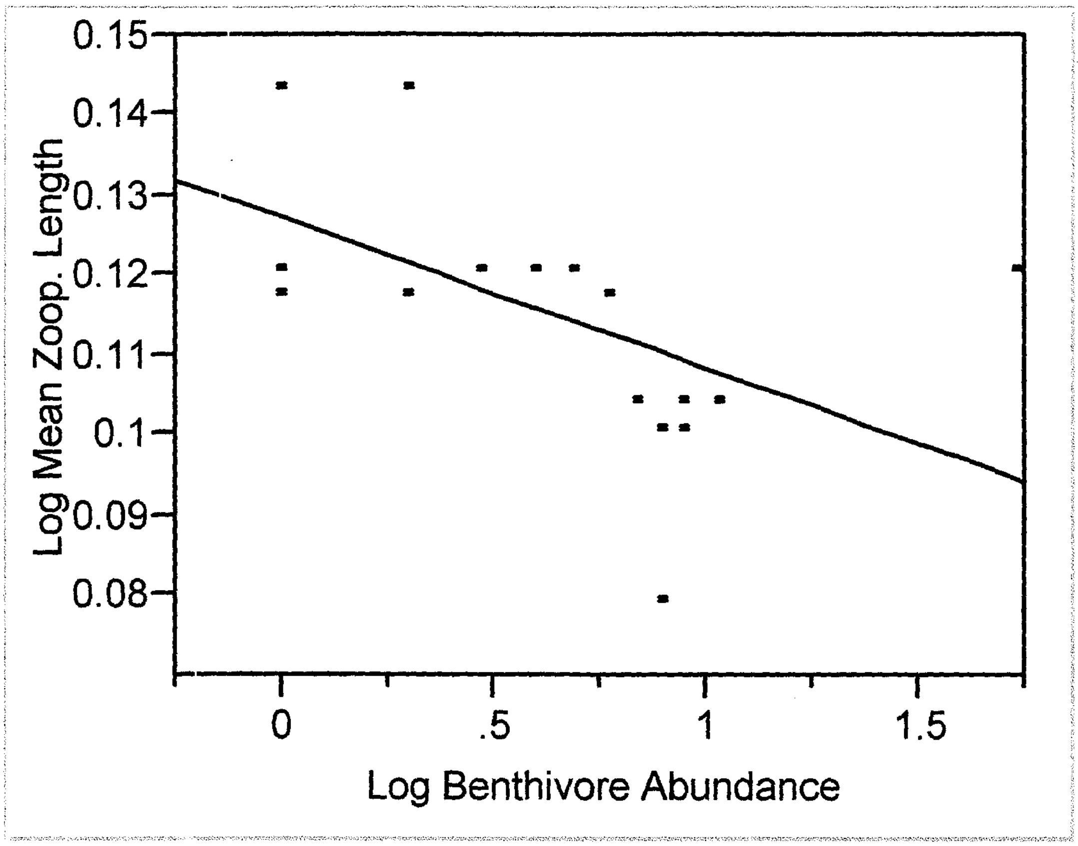

0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
Log Mean Zoop. Length
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Log Conductivity

Figure 2-9: Linear regression demonstrating an indirect correlation between micrograzer biomass and macrophyte species richness (Equation of the line, Log Micrograzer Biomass = 2.8948388 - 0.1726059 Macrophyte Species Richness, $r^2 = 0.54$, $p=0.0006$).



Log Micrograzer Biomass
3.5
3
2.5
2
1.5
1
0.5
-2.5
0
2.5
5
7.5
10
12.5
Macrophyte Species Richness

Figure 2-10: Linear regression demonstrating an indirect correlation between mean zooplankton length and benthivore abundance (Equation of the line, Log Mean Zoop. Length = 0.1274195 - 0.0188493 Log Benthivore Abundance, $r^2 = 0.31$, $p=0.0164$).


Log Mean Zoop. Length
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0
.5
1
1.5
Log Benthivore Abundance

GENERAL CONCLUSION

Summary

The overall objective of this study was to address the need for information on coastal wetland ecology in the Great Lakes. In particular, the aim was to address our current methods of sampling and techniques for sampling fish, as well as, verify and assess the effects of various habitat characteristics on the structure of the zooplankton communities.

Chapter 1 demonstrated that both when, and how, fish are collected affects the composition of the fish community that is sampled. Sampling conducted every 2 hours over a 24-hour period revealed that wetlands fish communities vary tremendously over the course of a day. Particular intervals caught twice as many fish species as others. Abundances and biomass of fish caught were 5 to 6 times higher over the values of other intervals. The composition of fish according to feeding classes also changed over the course of a day. Overall, a period of time 4 hours pre-sunset was determined as ideal for sampling wetland fish communities, to achieve high values for species richness, abundance and biomass, as well as representing all of the common feeding classes. Chapter 1 also revealed that the fish communities represented by different fishing techniques caught different abundance and biomass values, and were biased towards particular species, sizes and feeding classes of fish.

The results from Chapter 1 imply that future work conducted on fish communities within wetlands needs to be standardized with respect to both when, and how the fish are collected. Despite the recommendation that a period 4 hours pre-sunset is ideal for sampling wetland fish communities, the specific objectives of future projects will dictate whether this is indeed a suitable sampling interval. Since there were other periods of the day when the fish yields resulted in high values for specific variables, those times might be equally suitable. However, due to the magnitude of the changes and the short intervals over which they took place, it is highly recommended that future surveys of wetland fish communities be standardized according to when the sampling is carried out to ensure comparable data.

Variations in species, sizes, behaviour, and distribution of fish preclude the use of any single gear or technique for all scientific sampling within wetlands. Therefore, it is not recommended that all future wetland research should use any *one* of the methods tested in this study. The specific limitations and biases of each fishing gear must be fully considered before beginning a sampling program, in order to properly select the most appropriate gear to meet the scientific objectives for sampling. As well, once a particular fishing gear has been selected for a study, that gear should be used exclusively for the duration of the study, in order to ensure comparable data.

Chapter 2 confirms finding from other studies that zooplankton community structure is most strongly associated with differences in the water quality and submergent macrophyte characteristics of wetland ecosystems. Specifically, the nutrient and sediment burden, as well as the number of macrophytes species within the wetlands are the best predictors of dominant size of grazers in a wetland. Unfortunately, we were unable to determine the necessary wetland characteristics that foster a healthy zooplankton population, where medium, and macrograzers dominate the ecosystem.

Fyke nets were selected as the sampling gear for chapter 2 despite their bias towards catching omnivorous fish. Fyke nets were chosen based on their ease of deployment and their ability to catch fish within a variety of habitat and substrate types.

The findings from Chapter 2 have important management implications that need to be considered when making decisions concerning the remediation of wetland habitat. The results indicate that reducing the nutrient and sediment load entering into a wetland will have a negative impact on the micrograzer community abundance and biomass levels, and a positive influence on macrophyte growth. These effects would inevitably reduce the dominance of micrograzers over larger zooplankton assemblages, by reestablishing competitive superiority of the larger medium and macrograzers over micrograzers. There are indications that reducing the nutrient and sediment load will lead to larger zooplankton, since conductivity was inversely correlated with mean zooplankton length. However, despite indications, there were no direct relationships among the medium and macrograzer assemblages and the independent variables. Expanding the scope of this study to include a greater number of sampled wetlands, with a greater representation of those considered high quality wetlands (where medium and macrograzers were observed in higher abundances), would allow researchers to determine with certainty if significant relationships exist. These results would enable lake managers to focus their time and resources with confidence, and more effectively towards the modification of very specific components of the wetland habitat in order to establish healthy, larger-bodied zooplankton communities.

Concluding Statements

As the functions and values of wetlands became increasingly clear to scientists, the political and economic sectors of society also became increasingly aware of the overall importance of wetland habitat. As this awareness came about, the field of wetland ecology came into existence as an independent group of scientists devoted to learning more about these unique ecosystems. In contrast, even though the government continues to fund research in the area of wetland ecology, they have yet to introduce more appropriate legislation to ensure the protection of the remaining wetlands. Historically, within the economic sector, the most common way of demonstrating the value of something was to quote a price. But people started to ask questions such as; what is the price of a wetland? Fortunately, there is an entire branch of economics emerging that is devoted to the assessment of ecological value.

However, the real difficulty faced by these institutions is how to communicate these functions and values in a way that will be understood by landowners and the general public. We need to succeed in the objective if we are ever to achieve a substantial reduction in the human-induced, indirect stressors such as nutrient and sediment loading entering into the remaining wetlands. It is the landowners and the general public who are required to alter their behaviour for any true improvements to the wetlands to take place.

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