MEASURING FISH ASSEMBLAGES IN GREAT LAKES COASTAL WETLANDS, LES CHENEAUX, MICHIGAN: A PROGRAM ASSESSMENT

by

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Abstract

Les Cheneaux Islands constitute an archipelago along the shoreline of Michigan's eastern upper peninsula, containing coastal wetlands that provide key supports for fishes in the Laurentian Great Lakes. This thesis reports unpublished 1996 survey data used to evaluate fish assemblages in Les Cheneaux coastal wetlands. It is also a program assessment of fish survey methods in Les Cheneaux marshes from 1996-2004, growing from the 1996 survey recommendations. In 1996, I sampled larval and adult fish assemblages from ice-off to ice-on in four bays: Cedarville, Mackinac, Mismer, and St. Martin. From 1997-2004, larval and adult fishes were sampled in Cedarville, Mackinac, Mismer, McKay, and Prentiss bays. The 1996 survey focused on open water and what proved to be seasonal marsh areas. Visual surveys identified more diverse zonations, from permanent marsh through seasonal marsh to open water. Subsequent years focused on the seasonal and permanent marsh. I found that electroshocking and seining were ineffective for sampling these marsh habitats. Gill nets were highly effective but only accurate when nets with variable mesh sizes were used. Fyke nets and minnow traps proved most useful, accurately sampling fishes in densely vegetated marsh. The key for effectively sampling all areas of the marsh is to deploy multiple methods with good overlap across zones, testing and validating methods. Fish assemblages were typical of lacustrine habitats and varied among methods, habitats, bays and with time. Results of the 1996 survey showed July and August were key sampling times because richness and abundance were highest. Subsequent surveys demonstrated that extended sampling protocols are preferable to short surveys when evaluating habitat utilization of marsh fishes. Overall, this thesis and subsequent research in Les Cheneaux Islands support

studies showing that conservation of Great Lakes shoreline habitats will be important for the success of fish populations that depend on them.

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I. Introduction

Located at the intersection of terrestrial and aquatic ecosystems, coastal wetlands play an important role in supporting fish populations in the Laurentian Great Lakes (Jude and Pappas 1992, Wei et al. 2004). The shoreline of Michigan's eastern Upper Peninsula in northern Lake Huron includes several globally unique habitats including Great Lakes coastal wetland ecosystems with rich biodiversity (Ashworth 1987, Jaworski & Raphael 1992). The region is largely pristine and undisturbed, but the shoreline is beginning to show signs of stress from development and overuse. In the mid-1990s, The Nature Conservancy began to take steps to preserve this ecologically diverse and important ecosystem, to identify the region's native species and ecology and to work to form community partnerships. The program included a multi-gear fish survey initiated in 1996, as described here, which subsequently continued for a decade.

Recent work on fish communities in Great Lakes coastal wetlands has used fish survey data to develop rapid survey-based indicators of ecosystem health (Uzarski et al. 2005, Seilheimer and Chow-Fraser 2006). When using such indicators, methods and survey protocols depend on effective sampling, which in turn should be based on multi-method assays. The results of the program in Les Cheneaux therefore provide a basis to assess sampling designs and methodologies for evaluating ecosystem health.

This thesis reports unpublished 1996 survey data used to evaluate fish assemblages primarily in the coastal wetlands of Les Cheneaux Islands, together with the adjacent St. Martin Bay that is indicative of more exposed northern Lake Huron coastline. Les Cheneaux is an archipelago located in the middle of a stretch of northern Lake Huron shoreline that The Nature Conservancy is working to preserve; St Martin

Bay is to the west of this region. The 1996 survey was performed for The Nature Conservancy to evaluate northern Lake Huron fish assemblages to assist in the identification of future conservation areas. It was also intended to provide focus for subsequent surveys (1997-2004), which refined assemblage descriptors, methods, and evaluated the factors affecting fish assemblages in the various marsh areas. I describe the 1996 survey in detail, and report in aggregate subsequent years' data collected by others, focusing on the following questions: What is the composition of the fish assemblage of a relatively pristine Great Lakes coastal wetland? How effective are typical methodologies and effort for sampling wetlands across life history stages of fish communities? When is the most effective time to sample?

II. 1996 Study Area

Les Cheneaux area of northern Lake Huron is located along the southern shore of Michigan's eastern upper peninsula (Figure 1). Larvae, and juvenile and adult fishes were sampled in four bays, Cedarville Bay, Mackinac Bay, Mismer Bay, and St. Martin Bay (Figures 2 A-D), from ice-off on 4 May to ice-on on 12 November 1996 (Table 1). St. Martin Bay is the largest bay, with a water area of roughly 90 km^2, followed by Cedarville Bay (2.07 km^2), Mismer Bay (1.87 km^2), and Mackinac Bay (1.63 km^2). All four bays are bordered in part by Great Lakes marshes. Coastal wetlands are an intermediate zone linking the open waters of the Great Lakes with their watersheds and containing plant species of variable composition and density (Krieger et al. 1992). Vegetation tends to be most dense near the shoreline and less dense towards open water.

In 1996, preliminary surveys were conducted to estimate fish diversity in representative shoreline habitats to depths of approximately 3 m. Fish populations are known to be affected by latitude and climate (Brazner and Magnuson 1994, Brazner 1997, Brazner and Beals 1997, Latta et al. 2008); I selected survey sites in the same geographic area and watershed.

A. Bays

Cedarville, Mackinac, and Mismer bays are classified as protected lacustrine embayment wetlands (Albert et al. 2003). These lake-based wetlands are characterized by protection from large lake processes, resulting in increased sediment accumulation and more extensive vegetation development than open lacustrine systems. Cedarville and Mackinac bays are most sheltered, and similar in marsh development. By November, growth of hardstem bulrush (*Schoenoplectus arcutus*) filled much of these bays, and beaches exposed in the spring were overgrown. Cedarville Bay has the town of Cedarville on its shores. Historical photographs (Les Cheneaux Historical Society) indicate that much of the original mainland shoreline marsh in Cedarville Bay has been reduced by residential development, light industry, and by dredging a channel. In addition, sewage from municipal settling ponds is released into Cedarville Bay from the mainland in spring and fall via Pearson Creek.

Mismer Bay is more exposed than Cedarville and Mackinac bays, but less than St Martin Bay. Mismer Bay opens to the West Entrance to Lake Huron, but is somewhat sheltered by Marquette Island and other smaller islands. It contains the most extensive marshes, particularly in the northwest part of the bay. The southwest Mismer Bay shoreline is dominated by shallow, sandy beach with few bulrushes throughout the season.

St. Martin Bay is most exposed to Lake Huron, with limited shelter from St. Martin and Big St. Martin islands. It is classified as an open lacustrine embayment wetland, directly exposed to large lake processes with little physical protection by geomorphic features (Albert et al. 2003). This exposure results in little accumulation of organic sediment, limiting vegetation development to relatively narrow nearshore bands. While all the bays receive stream inputs, St. Martin Bay is fed by two rivers, the Pine and Carp rivers. Although I observed sediment plumes into the bay from these rivers, possibly bringing added nutrients, I did not observe substantial marsh formation near these river mouths. However, the smaller Nunn's Creek enters the bay in its northeast corner and I observed a localized marsh area that was more developed than the rest of St. Martin Bay. Although atypical for St. Martin Bay, the Nunn's Creek area was similar to the marshes in the other three, more protected bays and therefore was included in my survey.

The substratum in Mismer and St. Martin bays was similar, primarily sand and accumulations of organic material with substantial cobble further offshore. The Nunn's Creek area of St. Martin Bay created a patch with large amounts of organic material from river sediment and emergent macrophytes were abundant. Cedarville and Mackinac bays had substrate of mixed sand and muck, with substantial amounts of detritus. Overall, these characteristics of the bays indicated that Cedarville and Mackinac bays were more eutrophic, and Mismer and St. Martin bays were more oligotrophic.

In summary, the four bays selected were representative of Great Lakes marshes and open-water fish habitat along the northern Lake Huron shoreline, varying in exposure to the open lake, vegetation patterns, and shoreline development.

B. Habitats

During the 1996 survey, I sampled on-shore and near-shore zones. The on-shore zone (water depth < 1m) was comprised of sandy beach with substantial areas of marsh characterized by emergent plants, primarily hardstem bulrush and scattered floating-leafed plants (*Nuphar* spp. and *Potamogeton* spp.) (Jacobus and Ivan 2005, Webb 2008). The emergent macrophytes were incised at water level by winter ice, followed by summer re-growth. Therefore, I described the marsh as seasonal marsh.

The near-shore zone (water depth > 1m) was characterized by open water with little to no emergent vegetation and submerged plants (primarily *Utricularia* spp. and algal species) covering less than 25% of the bottom area.

During the course of the study, a further marsh zone became apparent, inshore from the seasonal marsh. This was characterized by absence of ice-incision of bulrush stems, such that emergent stems were always present. The macrophytes were also more abundant. I called this permanent marsh. Following my identification of greater heterogeneity in marsh structure than originally thought, the permanent marsh zone was surveyed extensively in subsequent field seasons (1997-2004).

In permanent marsh, the water was typically warmer, more shallow (< 0.5 m), and better buffered against wave action than the seasonal marsh (Conlon et al., 2000, Jacobus and Ivan 2005). Permanent marsh was characterized by more speciose macrophyte communities, including emergent, floating-leaved, and submerged vegetation. The permanent marsh habitat has also been described as “inner” marsh (Burton et al. 2002) and inner “*Scirpus*” (renamed *Schoenoplectus*) zone (Uzarski et al. 2005).

III. Methods

A. 1996 Sampling methods

Bays in Les Cheneaux were sampled for larvae, and juvenile and adult fishes between ice-off and ice-on (Table 1). Sampling was more frequent at the beginning of the season in expectation of rapid population changes characteristic of spring. The three sampling periods in May and early June were biweekly. The sampling interval was decreased to monthly in July and August. Samples were also collected during one final period in November, just before ice-on. Two additional larval collections were made in June and July. Although all methods were planned for each site at every sampling period, some data were not collected each sampling time due to variable weather, field equipment failure, boat traffic, and conditions in the bays (Table 2).

Species composition and abundance were determined using multiple gears (Tables 3 A-B). A larval seine was used to sample the larval component of the fish assemblage in the onshore zone. The seine consisted of a 365 µm mesh net mounted upon a 0.22 m by 0.61 m metal frame to which two 1.63 m aluminum rods were attached. The seine was pulled horizontally through ~4 m^3 of water in a zigzag pattern for 2 minutes. Off-shore, larvae were sampled with a 0.5 m diameter, 365 µm mesh net towed for 6 minutes from a boat traveling at 3-5 knots through ~60 m^3 of water.

The juvenile and adult portions of the fish assemblage were sampled at on-shore sites using beach seines in beach areas throughout the season and in marsh areas through early June before bulrushes became dense. For the beach seines, a unit of effort was defined as 5 hauls per site, each haul starting approximately 9 meters from shore and ending at the shoreline (~70 m^3 swept). Backpack electroshocking was used later in June where macrophyte densities became too high for seining. A volume of water equivalent to that sampled by the beach seine was swept with the backpack electroshocker.

Juvenile and adult fishes in the near-shore zone were sampled with two 30 m gill nets, one with 51 mm (2 inch) mesh and one with 76 mm (3 inch) mesh. A unit of effort was defined as the duration of the set, averaging approximately 17 hours overnight including dawn/dusk. The line of water sampled by the gill nets was sampled with a 110 VAC boat electroshocker and I considered these efforts equivalent. The boat electroshocker was used sporadically due to equipment failures and the inability of the boat to penetrate the macrophytes that emerged later in the season.

Fish communities were described in terms of species composition, richness, relative abundance (CPUE), and the Shannon-Weiner Diversity Index (H):

$$H = \sum(\log f/t)(f/t)$$

where f is the number of species caught and t is the total number of individuals caught. This widely-used measure of diversity uses log transformed data that weighs rare groups more heavily than other indices. Larger values of H are associated with greater richness or with greater evenness (Magurran 2004).

Water and air temperatures were recorded at each site at the time of sampling with exceptions due to equipment failure in May and weather problems later in the year.

B. 1997-2004 Sampling methods

After the 1996 survey, Les Cheneaux bays were sampled during the 1997-2004 field seasons using additional methods, as well as those found to be most effective during 1996 (Tables 3 A-B). Effort initially focused on Cedarville, Mackinac, and Mismer bays, and later Prentiss and McKay bays were added.

During 1997 and 1998, a hand-held larval seine and hand-towed larval net were used to sample larval fish assemblages in the seasonal and permanent marsh areas (Hook et al. 2001). As in 1996, the larval seine sampled a volume of water equivalent to that of the beach seines. Larval seining consisted of a horizontal hand tow through a 10 m stretch of water (~2 m^3 volume). The larval tow net consisted of a 365 μm-mesh plankton net mounted on a 0.5 m diameter metal hoop attached to a 10 m rope and sampled ~2 m^3 volume of water. Larval fish sampling was concentrated in summer months (May-August) and sites were sampled more intensively (every 4 days) than in 1996.

In 1997, beach seines, experimental gill nets, and 0.5 cm fyke nets were deployed to survey juvenile and adult fish in seasonal and permanent marsh (Conlon et al. 2000). Beach zones were again sampled using beach seines. The near-shore zone with depth >2 m was again sampled with gill nets, but the single-mesh size nets were replaced with two experimental gill nets. One experimental gill net was 36 m long and 2 m deep with five 7.2 m long panels and mesh sizes of 2 cm, 4 cm, 5 cm, 7 cm, 8 cm and 10 cm. A second gill net was 45 m long and 2.25 m deep with six 7.2 m long panels and mesh sizes of 4 cm, 5 cm, 7 cm, 8 cm and 10 cm.

A passive method was introduced to sample both permanent and seasonal marsh in order to avoid the problems of pursuit sampling in dense vegetation (Conlon et al. 2000). Seven-hoop, 95 cm diameter fyke nets with 5 mm mesh and a single 16.4 m lead were set in permanent marsh in 1997 and 1998 and in seasonal marsh in 1998. Nets were set in <0.5 m of water with the throats always immersed. Fyke net leads are commonly set either parallel to shore to catch fish moving on and off-shore or perpendicular to the shore to catch fish moving along the shoreline. In this case, it was judged most important that leads crossed habitats, here the different macrophyte patches. Traps remained *in situ* through June and July. They were visited every 2 to 6 days and fishes were released back to the marsh. Catch rate was defined as the number of fishes caught per day.

The 1998 and 1999 field seasons targeted mid-summer sampling when richness and diversity were found to be highest in the 1996 survey. Experimental gill nets and fyke nets were used again; beach seines were abandoned but baited minnow traps were added to the sampling methods. GEE minnow traps were baited with dog food and set in gangs of five traps deployed equidistant along a 30 m line in shallow marsh areas (Conlon et al. 2000). One gang was set in each of three marshes: Cedarville, Mackinac, and Mismer. Water depth was 15 to 30 cm, although weather and seiches increased this to about 40 cm on some occasions. The interval between traps ensured a trap was located in at least one hardstem bulrush, floating-leaved, and submerged vegetation patch. Traps were checked every 1 to 2 days for 10 days.

Between 2000 and 2004, McKay and Prentiss bays were added to the field survey and all five bays were sampled (Cedarville, Mackinac, Mismer, McKay, and Prentiss) using minnow traps, which were found most effective in assessing the fish assemblage in permanent marsh habitat. McKay Bay has a dolomite plant along the NE shore and Prentiss Bay has vacation camps. These bays provided additional data for the later studies, which focused on the effects of human development on Les Cheneaux bays. Fish were sampled in late July and early August (Webb 2008).

C. Comparisons among assemblages

A resampling, or bootstrap, program was written to determine if differences between Cedarville, Mackinac, Mismer, and St. Martin bays were statistically significant, using 1996 survey data. The assumption was that all bays were the same, with assemblages arising at random from a common regional pool of species. The bootstrap program randomly assigned species from the observed Les Cheneaux assemblage to bays and actual differences between species abundances between pairs of bays were compared with the simulated differences. One thousand replicates of these random species assemblages were created and estimates of means and variances were obtained for expected differences. The observed differences in species frequencies in assemblage that were outside the 95% confidence intervals for the replicated simulated assemblages were considered significant.

IV. Results

A. Water temperature

Summer water temperatures increased in 1996 from 12°C 19 days after ice-off (23 May) to a maximum of 16-25°C in July and August before declining to 4-8°C on 9 November, just before ice-on (Figure 3). St. Martin Bay took longer to warm than the other bays, but reached similar maximum temperatures (24.5°C) by early August. Mackinac Bay was usually the warmest bay, but reached the same maximum temperature of 25°C.

After 1996, sampling periods were limited to the summer months and water temperatures did not differ among marshes within a field year, nor were they related to water levels. Water temperatures did, however, differ among years. 1996, 1997, and

2003 were coolest, differing significantly from the warmest years: 1999, 2000, 2001, 2002 and 2004 (Webb 2008). Thus, water temperature is unlikely to be a factor explaining variation in marsh fishes during a single year. Comparisons of marsh fish assemblages across years, however, should consider water temperatures as a factor.

B. Marsh macrophyte phenology

General growth patterns of marsh vegetation were assessed qualitatively in this study. Macrophyte densities in the seasonal marsh, primarily hardstem bulrush, differed among bays throughout the field season. In early May, bulrushes in the seasonal marsh that had been cut back by the ice were, at most, just starting to grow back in all four bays. Although emergent stems persisted in permanent marsh over winter, die-back reduced the density of macrophytes. Grow-back followed the same pattern as in seasonal marsh, but macrophytes were always more dense in permanent marsh. Some grow-back occurred between late May and early June, but bulrush stems remained sparse in the seasonal marsh. Grow-back accelerated between July and early August, culminating in early November by which time all bays showed areas of at least moderately well–developed marsh. These patterns were typical of the marshes as a whole, with the exception of beaches in Mismer Bay, which remained largely free of macrophytes throughout the summer and fall. Due to these observations on bulrush growth and marsh zonation in 1996, in subsequent years fishes were sampled in both seasonal and permanent marsh zones in all bays (Hook et al. 2001, Jacobus and Ivan 2005; Jacobus and Webb 2005).

C. Fish assemblages: 1996 survey

Thirteen taxa of larval fish from 7 families were collected in larval seines and towed larval nets (Table 4). Several larvae could not be identified to species due to lack of specific field characters for several cyprinid and catostomid larvae (Auer 1982). I could not identify a few percid and centrarchid larvae to species due to ambiguous field characters and/or mutilation. As with the juvenile and adult fishes, the larval species were typical for lake habitats (Hubbs and Lagler 1958, Scott and Crossman 1973). The only larval species not observed in both the juvenile and adult populations was burbot.

For larval fishes, no taxon was common to all bays (Figure 4). Lake herring larvae were found in three bays, and sucker and yellow perch larvae were found in two bays. St. Martin Bay had five unique larval taxa, including longnose and white suckers, longnose dace, burbot, and rock bass. Mackinac Bay had two unique groups, spottail shiner and bass, while Mismer Bay had one unique group, banded killifish. Cedarville Bay did not have any unique larval groups.

Thirty-four species of juvenile and adult fish from 13 families were collected in the beach seine and gill net samples from on-shore and near-shore sites in the four bays (Table 5). Some *Catostomus* juveniles for which field characters are lacking could not be identified to species (Auer, 1982). Fishes were generally typical of lacustrine habitats (Hubbs & Lagler 1958, Scott & Crossman 1973, Weinstein 1979, Cosentino 1983, Brazner & Magnuson 1992, Jude & Pappas 1992). An exception was the riverine longnose dace that was collected in St. Martin Bay, perhaps because of on-shore flows associated with greater exposure or the two large rivers, the Pine and the Carp, opening into the bay.

As in other lakes (Hubbs & Lagler 1958, Scott & Crossman 1973, Weinstein 1979, Cosentino 1983, Brazner & Magnuson 1992, Jude & Pappas 1992), the fishes caught in beach seines were primarily minnows and shiners with some benthic darters and sculpins. Some fishes typical of marshes were also found, for example, top minnows and stickleback. Larger bass and sunfish, some perch and pelagic soft-rayed fishes such as trout, lake herring, whitefish, larger suckers, bullheads, and pike were commonly caught in gill nets.

For juvenile and adult fishes, six species were common to all bays: pike, spottail shiner, bluntnose minnow, banded killifish, johnny darter, and rock bass (Figure 5). St. Martin Bay had eight unique species, including three cyprinid species, logperch, longnose sucker, threespine stickleback, and rainbow trout. Mackinac Bay had one unique species, the longnose gar. Neither Mismer nor Cedarville bays had species unique to these bays.

The 1996 juvenile and adult fish data suggest an almost complete separation between on-shore and near-shore zones. In all four bays, small-bodied minnow species such as spottail shiner, bluntnose minnow, and sand shiner dominated the on-shore zone and larger-bodied species such as brown bullhead, lake herring, and white sucker dominated the near-shore zone (Table 6). The percentage overlap for number of fish taxa in the two zones was also quite low (Table 7). In Cedarville Bay, the two zones had taxa in common and St. Martin Bay showed the highest overlap, with 13% of taxa in common.

Since the beach seines capture smaller-bodied fishes and gill nets capture larger-bodied fishes, I suspected that this difference between on-shore and near-shore zones was due to different gear types being used in each zone, rather than to real differences in species composition of the two zones. This possibility was further supported by the high abundance of juvenile suckers in the on-shore zone of St. Martin Bay (Table 6). Adult suckers were found throughout the near-shore zones of Cedarville, Mismer, and St.

Martin bays, indicating that sucker species thrived in both the on-shore and near-shore zones of Les Cheneaux.

In addition to better defining sampling sites, the results of the 1996 field season determined sites and methods for subsequent field surveys (Webb et al. 1997). The 1996 data showed that St. Martin Bay was not characteristic of Great Lakes marsh habitat and I recommended that it be excluded from further sampling. Subsequent Les Cheneaux marsh surveys did not include St. Martin Bay.

D. Assemblage descriptors

I used species richness, abundance (as measured by CPUE and total fish caught), and diversity (the Shannon Diversity Index) to describe the juvenile and adult fish assemblages in the four bays. All three descriptors varied among Cedarville, Mackinac, Mismer, and St. Martin bays, as well as with time from ice-off to ice-on.

1. Richness

Richness of larval fish varied among the four bays (Table 5). St. Martin Bay had the highest richness (10 taxa), followed by Mackinac Bay (5 taxa), Mismer Bay (4 taxa), and Cedarville Bay (1 taxon).

Presence of larval fish taxa varied throughout the field season (Figure 6). In early May, the larval assemblage was dominated by lake herring and burbot, with yellow perch emerging in late May and early June. Catostomid species, including longnose and white sucker were observed throughout June. In July, minnow larvae emerged, along with rock bass, banded killifish, and longnose dace larvae.

In the beach seine samples, St. Martin Bay had the greatest overall juvenile and adult species richness, with 21 total species, followed by Mismer and Mackinac bays, with 13 and 10 species, respectively. Cedarville Bay had the smallest overall species richness, with a total of 7 species (Table 4).

In the gill net samples, Mismer Bay had the greatest overall juvenile and adult species richness, with 13 species, followed by Cedarville and Mackinac bays, with 9 and 10 species, respectively (Table 4). St. Martin Bay had the smallest overall species richness, with a total of 7 species (Table 4). All four bays exhibited similar seasonal trends: numbers of juvenile and adult species generally increased from 5-12 species in early May, to a maximum of 10-19 species in July (58 days from ice-off). Richness then declined to 3-8 species by ice-on in November (Figure 7).

2. Abundance

Larval fish abundance varied among the four bays (Table 5). St. Martin Bay had the highest abundance (CPUE=57 fish/tow), followed by Mackinac Bay (10 fish/tow), Mismer Bay (6 fish/tow), and Cedarville Bay (1 fish/tow).

Initially, total fish caught was used to compare bays, combining all sampling sources in on-shore and near-shore zones. In Mackinac, Mismer, and St. Martin bays, total fish caught generally increased from ice-off to a maximum, and then declined until ice-on in November (Figure 7). Cedarville Bay deviated from this trend, decreasing in abundance from early to late May, then increasing in early June and remaining at that level for the duration of the season.

CPUE was used as an abundance measure when comparing data within a zone (on-shore or near-shore) where efforts were equivalent. In the on-shore zone, sampled by beach seines, Mismer Bay had the greatest total juvenile and adult abundance, with a CPUE of 138 fish/tow, followed by St. Martin and Mackinac bays, with catches of 91 and

41 fish/tow respectively. Cedarville Bay had the smallest total abundance, with a CPUE of 21 fish/tow (Table 8).

In the near-shore zone, sampled by the gill nets, Cedarville Bay had the greatest total juvenile and adult abundance, with a CPUE of 17 fish/set, followed by Mackinac and Mismer bays, with catches of 10 and 5 fish/set, respectively (Table 8). St. Martin Bay had the smallest total abundance, with a CPUE of 2 fish/set.

Dominant species varied among bays for both near-shore (gill net) samples and on-shore (beach seine) samples (Figures 8 A-B). For beach seines, Cedarville and Mackinac bays were dominated by spottail shiner and bluntnose minnow. Mismer Bay was dominated by the sand shiner, while St. Martin Bay had a more diverse constituency of juvenile suckers, spottail shiner, longnose dace, and sand shiner. For gill net samples, Cedarville Bay had nearly equal representation of brown bullhead, lake herring, and rock bass. Brown bullhead was the dominant species present in Mackinac Bay, lake herring was the dominant near-shore species in Mismer Bay, and white sucker dominated St. Martin Bay.

3. Diversity

Diversity indices combine both richness and abundance and were calculated for juvenile and adult fishes. Small numbers of larval fish were caught and the frequency of sampling appeared too low to fully characterize the larval fishes, so diversity indices were not calculated for this component of the fish assemblage.

For juvenile and adult fishes, diversity fluctuated among bays and across the field season for both beach seine and gill net samples (Figure 7). Since richness and abundance showed similar seasonal trends, I expected diversity indices to be similar.

However, no clear overall trends were found. Cedarville Bay was most consistent, with a diversity value starting at 0.45 in May, gradually increasing to 0.73 in July and then decreasing to a low of 0.03 in November. In both Mismer and St. Martin bays, large numbers of a few species caught in early summer contributed to a drop in diversity during early June. Mackinac Bay showed the least variation, with a starting value of 0.74, increasing to a high of 0.78 and ending with 0.51 in November.

4. Resampling (Bootstrap)

As with diversity indices, the resampling method considered both diversity and abundance, but provided detailed comparisons of species and their abundances between bays at any time, or between times for any bay. An example of results from this method shows differences between bays summed for 26 June-4 July (Table 9). These results showed that the five most numerous species, representing about 80% of the total abundance, generally differed significantly among bays. At the other extreme, no significant differences were found among the seven least abundant species, which represented 0.25% of the total abundance. However, rare species may be under-sampled, so that re-sampling, like other methods, cannot be used with confidence to quantitatively evaluate differences in distribution of rare species.

Distribution of remaining species, approximately 20% of the total abundance, varied among bays. Cedarville and Mackinac bays had fewest significant differences in species composition, and St. Martin Bay the most, verifying the patterns shown in Tables 4 and 6. Notable differences between the onshore communities of Cedarville and Mackinac bays are shown for common shiner, larval perch, and bass. The bootstrap analysis indicated that overall differences in fish assemblages between bays appeared to be real and not due to chance.

E. Fish assemblages: 1997-2004

Subsequent field surveys yielded a more detailed picture of Les Cheneaux marsh fish assemblages (Conlon et al. 2000, Hook et al. 2001, Jacobus and Ivan 2005, Jacobus and Webb 2005, Webb 2008). These surveys focused on the permanent and seasonal marsh. Forty-two fish species were observed in sampling from 1996 to 2004 (Webb 2008). Of these, 12 species were found in all marshes. Overall, Cedarville marsh had the lowest species richness (17 species) and Mismer marsh had the highest (34 species), with Mackinac, McKay, and Prentiss marshes having 26-28 species (Webb 2008).

V. Discussion

The objective of the 1996 field survey was to evaluate fish assemblages in Les Cheneaux and St. Martin Bay, as well as to provide focus for subsequent Les Cheneaux marsh fish surveys. In addition to describing composition of the larval, juvenile, and adult fish assemblages in 1996, I evaluated the effectiveness of typical methodologies, effort, and timing for sampling these wetlands.

A. Habitat description

In the on-shore zone, I focused on the open, beach areas that initially appeared typical of Les Cheneaux bays. However, extensive growth of macrophytes occurred, resulting in macrophyte dominance even in these beaches. A broad extent of permanent marsh appeared to be the major marsh zone. Recognition of the different zones, on-shore (seasonal marsh), near-shore (open water), and permanent marsh refined sampling site selections and survey methods for subsequent years, and is the basis for some of the differences between sampling in 1996 and subsequent years (Conlon et al. 2000, Hook et al. 2001, Jacobus and Ivan 2005, Jacobus and Webb 2005, Webb 2008). For example, in 1996 I caught species typically found on sandy beaches such as the common shiner and sand shiner. In later years, yellow perch and bluntnose minnows were caught in Mismer marsh but the shiners were not, due to switching the focus of the survey away from beach to permanent marsh.

By the end of the 1996 field season, it was apparent that vegetation in the sampled areas in Mismer and St. Martin bays differed substantially from vegetation in Cedarville and Mackinac bays. In the former, there was relatively little development of marsh, while Cedarville and Mackinac both showed growth of macrophytes that came to dominate the sampled area. With the seasonal grow-in of the marshes in Mismer Bay, more complete marsh, comparable to the diversity in Cedarville and Mackinac bays, became apparent and was sampled in subsequent years.

Based on 1996 survey results, I judged St. Martin Bay to be an outlier compared with the Les Cheneaux bays. St. Martin Bay exhibited a number of unique larval species, including longnose dace, burbot, and rock bass (Figure 4). Larval richness and abundance in St. Martin Bay was higher than in the other three bays. Ten of the 13 larval taxa observed in 1996 were found in St. Martin Bay, while no other bay had more than 5 of the 13 taxa observed across all bays (Table 4). Total CPUE for St. Martin Bay was 57, while Mackinac Bay had the second largest abundance with a CPUE of 10 (Table 4).

I observed a similar trend with the juvenile and adult fishes. St. Martin Bay showed the highest richness, with a peak of 21 species observed in early August, and the highest abundance, with a high of 861 total fish caught in July (Figure 7). It also had a large number of unique species, including riverine species such as rainbow trout, creek chub, and brassy minnow (Figure 5). The larger size of St. Martin Bay, together with its contiguity with Lake Huron and inputs from the Pine and Carp rivers, is probably the basis for higher species richness and abundance. This is consistent with well-known species area relationships (Jacobus and Webb 2005).

Comparisons with other fish surveys, both in northern Lake Huron and in other Great Lakes bays, show that Les Cheneaux has been fairly undisturbed by non-native species and has a representative fish assemblage of historical Great Lakes coastal wetlands. Fish observed in Les Cheneaux, such as lake herring and yellow perch, as well as catostomid and cyprinid species are typical species in Great Lakes wetland communities (Scott and Crossman 1973, Chubb and Liston 1986). A fish survey conducted in St. Martin Bay from 1991-1993 also observed that these native species dominated the littoral zone (<1m depth) but found that non-native species such as rainbow smelt and alewife were abundant (up to 83% in midwater trawl samples) in nearshore areas (5-20 m) (Brown et al. 1995). I did not observe high levels of non-native species during the 1996 survey, nor did subsequent Les Cheneaux surveys observe them.

A comparison with a fish survey in Green Bay during 1990 and 1991 shows that restricting sample sites to a limited geographic area is advantageous for effectively describing fish assemblages. Brazner (1997) found that the large geographic range covered by Green Bay resulted in distinct environmental differences (e.g. temperature and turbidity) among regions of the bay. This regional variation complicated comparisons among marshes from different localities since observed differences may be due to the geographic range. Despite minor variations among Les Cheneaux bays, larger regional differences due to latitude and climate were not a factor when comparing fish survey data among bays. Thus, geographic range can be excluded as a source of the observed differences among bays.

B. Assessment of methods

Throughout the nine-year Les Cheneaux survey, a variety of methods were tested and refined. To successfully survey fish populations, it is necessary to employ multiple gears across different habitats because each gear differs in its biases, such as capture effectiveness for different sizes and species of fishes (Murphy and Willis 1996).

1. Evaluation of 1996 sampling methods

Hand-held larval seines worked well throughout the season, even in presence of dense macrophyte growth. The metal frame to which the net was attached was easily maneuvered through bulrush stands and there was no lead line to keep down.

The boat-towed larval net sampled the water column effectively, but few larval fish were caught in the near-shore zone. I recommended that future larval sampling efforts focus on the seasonal and permanent marsh habitats to better capture the larval fish assemblages and phenology, as was done (Hook et al. 2001).

Growth of macrophytes in the seasonal marsh required shifting from beach seines to electroshocking in late summer when bulrushes became so dense that they lifted the lead line of the seines. Seines proved to be useful only on sandy beach areas and on the edge of the seasonal marsh where macrophyte densities were low. I was able to seine until mid-June in Cedarville, Mackinac, and St. Martin bays, but throughout the year in Mismer Bay. Unfortunately, I found that electroshocking was ineffective for sampling the marsh habitats as well. Variable water depths, macrophyte density, and soft substratum hindered mobility and effectiveness.

Gill nets were highly effective. The nets with uniform mesh sizes of 51 and 76 mm only captured the larger fish species whereas other methods showed smaller fishes were more abundant. Therefore, I recommended experimental gill nets for subsequent use, with panels of various mesh sizes to sample the bulk of the range of juveniles and adults.

Although samples were occasionally missed due to equipment failure or field conditions, I do not believe that incomplete sampling can explain observed differences among Les Cheneaux bays. Missed fish samples were not common and sampling was most complete over the high richness and abundance periods of late spring and summer (Table 2). In addition, trends in richness and abundance were consistent among bays over time and no irregularities were apparent that might result from missed sampling (Figure 7).

The 1996 season was unique in that it was the only year where fish were sampled from ice-on to ice-off (Table 1). This initial, long field season was critical to understanding the phenology of Les Cheneaux fish assemblages and highlighting July and August as the times when richness is highest. Subsequent field seasons moved to an approach of intensive sampling at few sites during this time period, increasing the likelihood of showing differences among bays. Jacobus and Ivan (2005), Jacobus and Webb (2005), and Webb (2008) found that an intensive 10-day sampling period at single sites per bay was more effective at capturing all species throughout the season than less intense sampling at many sites per bay.

2. Evaluation of 1997-2004 sampling methods

Based on 1996 results, St. Martin Bay was not sampled and efforts were focused on the seasonal and permanent marsh habitats of Cedarville, Mackinac, Mismer, and later, Prentiss and McKay bays. Larval sampling was confined to the on-shore zone and larval boat tows in the near-shore zone were not used.

Identification of the permanent marsh and failure of both beach seines and electroshocking to successfully sample even seasonal marsh as the summer progressed led to recommendations to refine sampling methods for future Les Cheneaux surveys. Fyke nets and minnow traps were deployed in 1998 and 1999 as passive methods that were not negatively affected by vegetation and substratum. These successfully captured a variety of fish species across marsh zones comparable to the experimental gill nets, with the added benefit that fish were not killed.

My recommendation for using experimental gill nets with variable mesh size lead to capturing a variety of fishes, both small and large-bodied species, across marsh zones, supporting the observation from 1996 that the apparent on-shore versus off-shore differences were due to gear bias.

Overall, sampling from 1996 to 1998 showed that differences between marshes and zones within marshes were largely associated with the small-bodied portion of the fish assemblage. Baited minnow traps were added and proved most useful for sampling these fishes, especially in shallow, densely vegetated water of the diverse inner marsh zone (Jacobus and Ivan 2005). Passive methods therefore replaced typical pursuit methods (electroshocking and seining).

The 1996 survey used methods that were most common at that time for sampling on-shore habitat. They proved effective in sampling the near-shore zone and less dense seasonal marsh and beach. Following 1996, interest in conservation focused on marsh habitat and greater effort was required with the addition of passive methods. Fyke nets and baited minnow traps proved most successful in surveys; fyke nets were also recommended as a primary survey tool by the 2008 Great Lakes Coastal Wetlands Monitoring Plan (Burton et al., eds. 2008). The fyke nets captured small and intermediate-sized fish, while the minnow traps sampled small, vagile fishes.

The assessment of methods over several years also showed that long-term sampling with fyke and trap nets (10 days or more/site) was necessary to adequately sample fish assemblages. This differed from the currently adopted approach of rapidly sampling many sites (Wilcox et al. 2002, Uzarski et al. 2005). The rapid sampling approach can be useful for monitoring but increases the chance of bias due to variable, chance capture of rare species (Uzarski et al. 2005).

There is disagreement over the efficacy of electrofishing in marsh habitats. My survey found both the boat and backpack shockers ineffective in shallow water and dense vegetation, as did Wilcox et al. (2002). Others have found boat electrofishing successful when the boat can penetrate vegetation, primarily in seasonal marsh with less dense vegetation. This has lead to the endorsement of electrofishing as a primary survey tool by the 2008 Great Lakes Coastal Wetlands Monitoring Plan (Burton et al. 2008). However Burton et al. (2008), qualified their recommendation as depending on specific study goals and boat access.

C. Phenology

Larval survey data from 1996 show change in the larval fish assemblage over time, but because changes among larval fishes were rapid, I suspected that the twice-monthly sampling schedule might not have captured the complete larval phenology. I recommended an increase in larval sampling frequency to a 4-day period and this protocol was used successfully to determine larval phenology in subsequent years (Hook et al. 2001).

The chronology I recorded in 1996 demonstrated that Les Cheneaux fish assemblages changed from ice-off to ice-on, and especially in the spring and early summer. Rapid sampling of many sites typically sampled different sites at different seasonal times. Such a protocol risks claiming false differences among sites actually due to differences in sampling time rather than differences in assemblages.

In addition, there are latitudinal differences in fish assemblages as well as differences in the timing of reproduction and fish movements (Latta et al. 2008). Combined latitudinal and chronological effects have yet to be accounted for in rapid assessment protocols (Wilcox 2002).

Although the measures of assemblage composition I used—species richness, abundance, and diversity—showed differences among bays over time, they did not capture all the differences and provided little explanatory basis for them. The resampling method, using species composition and abundance, provided a complementary approach for quantifying differences. The bays chosen for sampling differed in size, exposure, and presence of a town; the resampling method using these 1996 survey data showed that differences in fish assemblages among bays were largely significant. Data collected in subsequent years refined such analysis and showed that the largest factor correlating with differences in marshes in different bays was associated with human activity (Hook et al. 2001, Webb 2008).

D. Relevance to current research questions

The results over the nine-year span from 1996 to 2004 validate the importance of Great Lakes coastal wetlands as critical fish habitat (Jude & Pappas 1992, Wilcox 1995, Wei et al. 2004). As transition zones between land and water, wetland habitats are among the first impacted by development and pollution (Mayer et al. 2004). Therefore, marsh preservation is desirable, although administrative changes in TNC to a regional structure appears to have diminished interest in creating a marsh preserve along the northern Lake Huron shoreline.

Fishes historically have been used as indicators of biotic integrity in streams (Karr et al. 1986, Lyons and Wang 1996), lakes (Fabrizio et al. 1995, Whittier 1999), and estuaries (Jordan et al. 1991, Deegan et al. 1997), and there has been considerable interest in using fish species as indicators of wetland ecosystem health, including for Great Lakes coastal wetlands (Uzarski et al. 2005, Seilheimer and Chow-Fraser 2006). Authors cite concerns about gear bias (Seilheimer and Chow-Fraser 2007), water levels (Wilcox 2002, Webb 2008), turbidity (Trebitz et al. 2007), and latitudinal effects (Latta et al. 2008). Not as frequently discussed are sampling times and duration. A rapid sampling approach (1-2 days) has been used to survey the greatest number of coastal wetlands in the shortest amount of time. The chronology of Les Cheneaux fish data, especially the 1996 results, suggests that this rapid sampling approach could miss key changes in the fish population. For monitoring, rapid sampling is advantageous because it allows scientists to sample a large number of wetlands during a field year. As an assessment tool, and for effective characterization of wetland fish populations over time, rapid sampling is inadequate. I suggest a longer sampling period (10 days or more) in each wetland as the most effective method for assessing coastal wetland fish assemblages (Jacobus and Ivan 2005, Jacobus and Webb 2005, Webb 2008).

In addition to selecting an effective sampling schedule, it is important to choose effective gear types and compare them carefully. Bias associated with different fishing gear can influence comparisons of aquatic habitats, especially when looking for meaningful assemblage data (Jackson and Harvey 1997). The false separation of on-shore and near-shore zones in 1996 is exemplary of such bias. Les Cheneaux results showed that passive capture methods (fyke nets, minnow traps) were most effective and they have been used with success in other surveys (Seilheimer and Chow-Fraser 2007, Trebitz et al. 2007). For best results, consistency of sampling gear and effort is essential for monitoring and comparing fish assemblages among marshes.

VII. Literature Cited

Albert, D.A., J. Ingram, T. Thompson, and D. Wilcox. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. J. Great Lakes Res. Vol. 31, suppl. 1, pp. 129-146.

Ashworth, W. 1987. *The Late Great Lakes*. Wayne State University Press, Detroit, MI.

Auer, N.A. (ed.). 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission, Ann Arbor, MI 48105. Special Publication. 82-3:744

Brazner, J.C., and J. J. Magnuson. 1992. Patterns of fish species richness and abundance in coastal marshes and other nearshore habitats in Green Bay, Lake Michigan. Verh. Internat. Verein. Limnol. 25:2098-2104

Brazner, J.C. 1997. Regional, habitat and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. J. Great Lakes Res. 23:36-51

Brazner, J.C. and E.W. Beals. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Can. J. Fish. Aquat. Sci. 54:1743-1761.

Brown, R. W., M. P. Ebener, T. J. Sledge and W. W. Taylor. 1995. Forage fish assemblage structure in the littoral and nearshore areas of St. Martins Bay, Lake Huron. In *The Lake Huron Ecosystem: Ecology, Fisheries and Management*, pp. 207-222. M. Munawar, T. Edsall, and J. Leach (Eds.). University of Chicago Press.

Burton, T.M., J.C. Brazner, J.H. Ciborowski, G.P. Grabas, J. Hummer, J. Schneider, D.G. Uzarski (eds.). 2008. Great Lakes Coastal Wetlands Monitoring Plan. Great Lakes Coastal Wetlands Consortium, project of the Great Lakes Commission, Ann Arbor, MI.

Chubb, S.L. and C.R. Liston. 1986. Density and distribution of larval fishes in Pentwater Marsh, a coastal wetland on Lake Michigan. J. Great Lakes Res. 12:332-343.

Conlon, M.R., P.W. Webb and J.A. Teeri. 2000. Fish assemblages in Great Lakes marshes and human disturbance in Les Cheneaux, northern Lake Huron. Unpublished report. University of Michigan, Ann Arbor, MI.

Cosentino, P. M. 1983. Fish community structure and the utilization of Harsens Island marsh-bay complex, Lake St. Clair. Michigan Department of Natural Resources, Fisheries Research Report 1913, Ann Arbor

Deegan, L.A., J.T. Finn, S.G. Ayvasian, C.A. Ryder-Kieffer, and J. Buonaccorsi. 1997. Development and validation of an estuarine biotic integrity index. Estuaries 20: 601-617.

Fabrizio, M.C., C.P. Ferreri, and M.J. Hanson. 1995. Prey fish communities as indicators of ecosystem health in Lake Michigan. National Biological Service, Project Completion Report, Great Lakes Science Center, Ann Arbor, MI.

Hook, T.O., N.M. Eagan, and P.W. Webb. 2001. Habitat and human influences on larval fish assemblages in northern Lake Huron coastal marsh bays. Wetlands 21:281-291

Hubbs, C. L. and Lagler, K. F. 1958. *Fishes of the Great Lakes Region.* University Michigan Press, Ann Arbor, MI.

Jackson, D.A. and H.H. Harvey. 1997. Qualitative and quantitative sampling of lake fish communities. Can. J. Fish. Aquat. Sci. 54:2807-2813

Jacobus, J. and L.N. Ivan. 2005. Evaluating the effects of habitat patchiness on small fish assemblages in a Great Lakes coastal marsh. J. Great Lakes Res. 31:466-481

Jacobus, J. and P.W. Webb. 2005. Using fish distributions and behavior in patchy habitats to evaluate potential effects of fragmentation on small marsh fishes: a case study. J. Great Lakes Res. 31 (Supplement 1): 197-211.

Jaworski, E., and C. N. Raphael. 1978. Coastal wetlands value study in Michigan: Phase I and II. Great Lakes Shorelands Section, Division of Land Resources, Michigan Department of Natural Resources, Lansing.

Jordan, S.J., P.A. Vass, and J. Uphoff. 1991. Fish assemblages as indicators of environmental quality in Chesapeake Bay. Proceedings of Biological Criteria: Research and Regulation Symposium. EPA-440/5-91-005. U.S. Environmental Protection Agency, Washington, D.C.

Jude, D. J., and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. J. Great Lakes Res. 18:651-672.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessment of biological integrity in running waters. A method and its rationale. Illinois Natural History Survey, Special Publication No. 5. Chicago, IL.

Krieger, K.A., D.M. Klarer, R.T. Heath, and C.E. Herdendorf. 1992. Special issue of the Journal of Great Lakes Research, Coastal Wetlands of the Laurentian Great Lakes: Current Knowledge and Research Needs. Preface: A call for research on Great Lakes Coastal Wetlands. J. Great Lakes Res. 18(4):525-528.

Latta, W.C., J.E. Breck, and E.R. Marshall Duchon. 2008. Species-area and latitudinal patterns for Michigan fishes. Am. Midl. Nat. 159:349-363

Lyons, J. and L. Wang. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. N. Am. J. Fish. Mang. 16: 241-256.

Magurran, A.E. 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, NJ.

Mayer, T., T. Edsal and M. Munawar. 2004. Factors affecting the evolution of coastal wetlands of the Laurentian Great Lakes: an overview. Aquat. Ecosys. Health Manage. 7(2):171 -178.

Murphy, B.R. and D.W. Willis. 1996. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, MD.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Bd Canada 184:1-966.

Seilheimer, T.S. and P. Chow-Fraser. 2006. Development and use of the Wetland Fish Index to assess the quality of coastal wetlands in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 63:354-366.

Seilheimer, T.S. and P. Chow-Fraser. 2007. Application of the Wetland Fish Index to northern Great Lakes marshes with an emphasis on Georgian Bay coastal wetlands. J. Great Lakes Res. 33 (Special Issue 3):154-171.

Trebitz, A.S., J.C. Brazner, V. J. Brady, R. Axler, and D.K Tanner. 2007. Turbidity tolerances of Great Lakes coastal wetland fishes. N. Am. J. Fish. Mang. 27:619-633.

Uzarski, D.G., T.M. Burton, M.J. Cooper, J.W. Ingram, and S.T.A. Timmermans. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish-based index of biotic integrity. J. Great Lakes Res. 31(1):171-187.

Webb, P.W., L.E. Welsh, J.S. Diana, and J.S. Teeri. 1997. Report on the open water fishery survey for the northern Lake Huron project. Annual report to The Nature Conservancy, East Lansing, MI.

Webb, P.W. 2008. The impact of changes in water level and human development on forage fish assemblages in Great Lakes coastal marshes. J. Great Lakes Res. 34:615-630

Wei, A., P. Chow-Fraser, and D. Albert. 2004. Influence of shoreline features on fish distribution in the Laurentian Great Lakes. Can. J. Fish. Aquat. Sci. 61:1113-1123

Weinstein, M. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish. Bull. 77:339-357.

Whittier, T.H. 1999. Development of IBI metrics for lakes in southern New England. In: Simon, T.P. (ed.), Assessing the sustainability and biological integrity of water resources using fish communities. Lewis Publishers, Boca Raton, FL, pp. 563-582.

Wilcox, D.A. 1995. The role of wetlands as nearshore habitat in Lake Huron. In *The Lake Huron Ecosystem: Ecology, Fisheries and Management*, M. Munawar, T. Edsall, and J. Leach (Eds.), pp. 223-245. University of Chicago Press.

Wilcox, D.A., J.E. Meeker, P.L. Hudson, B.J. Armitage, M.G. Black, and D.G. Uzarski. 2002. Hydrologic variability and the application of Index of Biotic Integrity metrics to wetlands: a Great Lakes evaluation. Wetlands 22:588-615.

Table 1. Schedule of field collections for the 1996 open water season.

Date	Days from ice-off (4 May)	Average days from ice-off for sampling period	Sampling	
			Adults & Juveniles	Larvae
7-13 May	3-9	6	X	X
20-24 May	16-20	18	X	X
3-9 June	30-36	34	X	X
20 June	47	47		X
26 June- 4 July	53-61	58	X	X
19 July	76	76		X
31 July- 4 Aug	88-92	90	X	X
7-12 Nov	187-192	189	X	
12 Nov (Ice-on)	192	192		

Table 2. Summary of gear use and temperature measurement at each sample site during the 1996 survey. Variations are due to changing marsh conditions (inception of backpack shocker, limited use of boat shocker), weather (wind, storms, ice inhibiting boat use) and technical difficulties. Key: CE= Cedarville Bay, MA= Mackinac Bay, MI= Mismer Bay, SM= St. Martin Bay

Sampling dates	Gill nets	Beach seines	Boat electro-shocker	Larval boat tow	Larval seine	Backpack electro-shocker	Water temp. (^{o}C)
7-13 May	CE, MA, MI, SM	CE, MA, MI, SM	CE, MI	MA, MI, SM	CE, MI		
20-24 May	CE, MA, MI, SM	CE, MA, MI, SM		CE, SM	MA, MI, SM		MA, MI, SM
3-9 June	CE, MA, MI, SM	CE, MA, MI, SM		CE, MA, MI, SM	MA, MI, SM		CE, MA, SM
20 June				CE, MA, MI, SM	CE, MA, MI, SM		SM
26 June- 4 July	CE, MA, MI, SM	CE, MI, SM (Carp River site only)	CE, MA, MI	CE, MA, MI, SM	CE, MA, MI, SM	SM (Nunn's Creek site only)	CE, MA, MI, SM
19 July					CE, MA, MI, SM		CE, MA, MI, SM
31 July- 4 Aug	CE, MA, MI, SM	CE, MI, SM (Carp River site only)		CE, MA, MI, SM	CE, MA, MI, SM	MA, SM (Nunn's Creek site only)	MA, MI, SM
7-12 Nov	CE, MA, MI	CE, MI, SM (Carp River site only)				MA, SM (Nunn's Creek site only)	MI, SM

Table 3A. Summary of gear specifications, methods and effort used to sample larval fish assemblages in coastal marshes in Les Cheneaux, MI.

Gear	Year	Specifications	Sampling	Catch per effort
Larval seine	1996-1998	365 µm mesh net mounted upon a 0.22 m by 0.61m metal frame to which two 1.63 m aluminum rods were attached	Swept ~4 m^3 volume of water	Fish caught per trip
Larval boat tow	1996	365 µm mesh net mounted on a 0.5 m diameter metal hoop and towed at 3 knots for 6 minutes	Swept ~60 m^3 volume of water	Fish caught per trip
Larval tow net	1997, 1998	365 µm mesh net mounted on a 0.5 m diameter metal hoop, attached to a 10 m rope and towed through the water by hand	Swept ~2 m^3 volume of water	Fish caught per trip

Table 3B. Summary of gear specifications, methods, and effort used to sample juvenile and adult fish assemblages in Great Lakes coastal marshes in Les Cheneaux, MI.

Gear	Year	Specifications	Sampling	Catch per effort
Backpack electroshocker	1996	110 VAC	Swept ~70 m^3 volume of water	Fish caught per trip
Boat electroshocker	1996	110 VAC, probes extending in front of 13 ft. aluminum boat	Swept ~60 m^3 volume of water	Fish caught per trip
Beach seine	1996, 1997	25 ft (7.6 m) long, 4 ft. (1.2 m) deep, ¼-3/8 inch (6.4-9.5 mm) mesh, with bag	5 hauls per site, from 9 m off-shore to beach at right angles to shore, swept ~60 m^3 volume of water	Fish caught per trip of 5 hauls
Gill nets (uniform mesh)	1996	2 x 100 ft (30 m) long and 4 ft (1.2 m) deep, one with 2 inch (51 mm) and one with 3 inch (76 mm) mesh.	Overnight set averaging 17 hours	Fish caught per hour
Gill nets (experimental)	1997, 1998	1 x 36 m long and 2 m deep with five 7.2 m long panels with mesh sizes of 2 cm, 4 cm, 5 cm, 6 cm and 7.5 cm 1 x 45 m long and 2.25 m deep with six 7.2 m mesh sizes of 4 cm, 5 cm, 7 cm, 8 cm and 10 cm.	Overnight set averaging 17 hours	Fish caught per hour
Fyke nets	1998-2004	1 x 0.95 m seven-hoop, 0.5 cm mesh, 16.4 m leaders	Continuous from June through July, checked every 2-6 days	Fish caught per day
Minnow traps	1998-2004	5 nets at equal 7.6 m distant intervals along a 30.4 m transect. Each trap baited with 5 ml of dog chow	Continuous from June through July, checked every 1 to 2 days	Fish caught per day

Table 4. CPUE for each taxon of larval fishes collected by larval seine and larval boat tow in four Great Lakes marsh bays in Les Cheneaux in 1996.

Taxa	Common Name	Cedarville	Mackinac	Mismer	St. Martin
Salmonidae					
Coregonus artedii	lake herring	0.00	0.80	0.40	15.00
Catostomidae					
Catostomus spp.	sucker	0.00	0.00	2.60	26.29
Catostomus commersoni	white sucker	0.00	0.00	0.00	4.07
Catostomus catostomus	longnose sucker	0.00	0.00	0.00	1.60
Cyprinidae					
Rhinichthys cataractae	longnose dace	0.00	0.00	0.00	3.33
Notropis hudsonius	spottail shiner	0.00	0.10	0.00	0.00
Cyprinidae	minnow	0.00	8.90	0.40	1.26
Cyprinodontidae					
Fundulus diaphanus	banded killifish	0.00	0.00	2.40	0.00
Gadidae					
Lota lota	burbot	0.00	0.00	0.00	5.00
Percidae					
Perca flavescens	yellow perch	0.80	0.30	0.00	1.60
Percidae	percid	0.00	0.00	0.00	0.18
Centrarchidae					
Ambloplites rupestris	rock bass	0.00	0.00	0.00	0.03
Micropterus spp.	bass	0.00	0.10	0.00	0.00
TOTAL CPUE (Larval seines and larval boat tows)		0.80	10.20	5.80	56.58

Table 5. Juvenile and adult fish species collected in four bays in Les Cheneaux, 1996 (presence indicated by xxx). "SN" fish were collected in water less than 1 m in depth by beach seines and electroshocking. "GN" fish were collected from water of 1 to 5 m in depth using gill nets.

Taxon	Common Name	Cedarville		Mackinac		Mismer		St. Martin	
		SN	GN	SN	GN	SN	GN	SN	GN
Lepidosteidae									
Lepisosteus osseus	longnose gar	-	-	-	xxx	-	xxx	-	-
Osmeridae									
Osmerus mordax	rainbow smelt	-	-	-	-	xxx	-	xxx	-
Esocidae									
Esox lucius	northern pike	-	xxx	-	xxx	-	xxx	-	xxx
Clupeidae									
Dorosoma cepedianum	gizzard shad	-	-	-	xxx	-	xxx	-	-
Salmonidae									
Coregonus artedii	lake herring	-	xxx	-	-	-	xxx	xxx	xxx
Prosopium cylindraceum	round whitefish	-	-	-	-	-	xxx	-	xxx
Oncorhynchys mykiss	rainbow trout	-	-	-	-	-	-	-	xxx
Salvelinus fontinalis x S. namaycush	splake	-	-	-	xxx	-	xxx	-	-
Catostomidae									
Catostomus catostomus	longnose sucker	-	-	-	-	-	-	xxx	xxx
Catostomus commersoni	white sucker	-	xxx	-	-	-	xxx	xxx	xxx
Catostomus spp.	sucker	-	-	-	-	xxx	-	xxx	-
Cyprinidae									
Cyprinus carpio	carp	-	xxx	-	xxx	-	xxx	-	-
Rhinichthys cataractae	longnose dace	-	-	-	-	-	-	xxx	-
Semotilus atromaculatus	creek chub	-	-	-	-	-	-	xxx	-
Notropis cornutus	common shiner	-	-	xxx	-	xxx	-	xxx	-
Notropis hudsonius	spottail shiner	xxx	-	xxx	-	xxx	-	xxx	-
Notropis stramineus	sand shiner	-	-	xxx	-	xxx	-	xxx	-
	Unidentified shiner	xxx	-	-	-	xxx	-	xxx	-
Hybognathus hankinsoni	brassy minnow	-	-	-	-	-	-	xxx	-
Pimephales notatus	bluntnose minnow	xxx	-	xxx	-	xxx	-	xxx	-
Pimephales promelas	fathead minnow	xxx	-	-	-	-	-	xxx	-
Ictaluridae									
Ictalurus nebulosus	brown bullhead	-	xxx	-	xxx	-	xxx	-	-
Cyprinodontidae									
Fundulus diaphanus	banded killifish	xxx	-	xxx	-	xxx	-	xxx	-

Table 5 (continued)

Taxon	Common Name	Cedarville SN	Cedarville GN	Mackinac SN	Mackinac GN	Mismer SN	Mismer GN	St. Martin SN	St. Martin GN
Gasterosteidae									
Culaea inconstans	brook stickleback	-	-	xxx	-	xxx	-	-	-
Gasterosteus aculeatus	threespine stickleback	-	-	-	-	-	-	xxx	-
Pungitius pungitius	ninespine stickleback	-	-	-	-	xxx	-	xxx	-
Percidae - Percinae									
Morone americana	white perch	-	xxx	-	xxx	-	xxx	-	-
Perca flavescens	yellow perch	-	xxx	-	xxx	-	xxx	-	-
Percidae - Etheostomatinae									
Percina caprodes	logperch	-	-	-	-	-	-	xxx	-
Etheostoma exile	iowa darter	xxx	-	xxx	-	xxx	-	-	-
Etheostoma nigrum	johnny darter	xxx	-	xxx	-	xxx	-	xxx	-
Centrarchidae									
Micropterus dolomieui	smallmouth bass	-	xxx	xxx	-	-	-	xxx	xxx
Ambloplites rupestris	rock bass	-	xxx	xxx	xxx	-	xxx	-	-
Lepomis gibbosus	pumpkinseed	-	-	-	xxx	-	xxx	-	-
Cottidae									
Cottus bairdii	mottled sculpin	-	-	-	-	xxx	-	xxx	-
TOTAL SPECIES		7	9	10	10	13	13	21	7

Table 6. CPUE of fish taxa in on-shore (depth < 1 m) and near-shore (depth > 1 m) zones from each of four bays in Les Cheneaux, 1996. Species are listed in order of catch per unit effort in each habitat.

Taxa	Cedarville	
	on-shore	near-shore
Notropis hudsonius	17.00	
Pimephales notatus	4.20	
Etheostoma nigrum	0.53	
Unidentifiable shiner	0.33	
Etheostoma exile	0.20	
Pimephales promelas	0.10	
Fundulus diaphanus	0.07	
Ictalurus nebulosus		5.21
Coregonus artedii		5.13
Ambloplites rupestris		2.98
Perca flavescens		1.19
Esox lucius		1.14
Catostomus commersoni		0.59
Micropterus dolomieui		0.18
Cyprinus carpio		0.03
Morone americana		0.03

Taxa	Mackinac	
	on-shore	near-shore
Pimephales notatus	27.80	
Notropis hudsonius	8.80	
Cyprinidae	7.80	
Notropis stramineus	4.80	
Notropis cornutus	3.10	
Etheostoma nigrum	1.60	
Micropterus dolomieui	0.70	
Fundulus diaphanus	0.40	
Perca flavescens	0.30	0.18
Etheostoma exile	0.30	
Ambloplites rupestris	0.20	0.73
Culaea inconstans	0.10	
Micropterus spp.	0.10	
Ictalurus nebulosus		7.08
Esox lucius		0.63
Cyprinus carpio		0.43
Lepomis gibbosus		0.11
Lepisosteus osseus		0.08
Dorosoma cepedianum		0.05
Morone americana		0.03
Salvelinus fontinalis x S. namaycush		0.03

Table 6 (continued)

Taxa	Mismer on-shore	Mismer near-shore
Notropis stramineus	144.20	
Etheostoma nigrum	10.20	
Catostomus spp.	5.70	
Notropis hudsonius	3.80	
Pimephales notatus	1.20	
Etheostoma exile	0.60	
Notropis cornutus	0.40	
Culaea inconstans	0.40	
Coregonus artedii	0.20	2.09
Unidentifiable shiner	0.20	
Fundulus diaphanus	0.20	
Pungitius pungitius	0.20	
Osmerus mordax	0.20	
Cottus bairdii	0.20	
Ictalurus nebulosus		7.26
Esox lucius		1.23
Perca flavescens		0.98
Ambloplites rupestris		0.97
Cyprinus carpio		0.52
Salvelinus fontinalis x S. namaycush		0.41
Catostomus commersoni		0.31
Lepomis gibbosus		0.11
Lepisosteus osseus		0.08
Prosopium cylindraceum		0.06
Dorosoma cepedianum		0.05
Morone americana		0.03

Taxa	St. Martins on-shore	St. Martins near-shore
Catostomus spp.	46.06	
Notropis stramineus	22.93	
Rhinichthys cataractae	15.83	
Notropis hudsonius	14.23	
Catostomus commersoni	7.82	1.05
Pimephales notatus	5.68	
Etheostoma nigrum	4.02	
Notropis cornutus	3.07	
Coregonus artedii	2.90	0.40
Pungitius pungitius	2.78	
Catostomus catostomus	1.95	0.38
Semotilus atromaculatus	1.75	
Cyprinidae	1.68	
Cottus bairdii	1.17	
Percidae	0.60	
Percina caprodes	0.60	
Osmerus mordax	0.27	
Fundulus diaphanus	0.25	
Unidentifiable larva	0.25	
Unidentifiable shiner	0.15	
Gasterosteidae	0.10	
Pimephales promelas	0.07	
Ambloplites rupestris	0.07	
Micropterus dolomieui	0.05	0.05
Hybognathus hankinsoni	0.05	
Gasterosteus aculeatus	0.05	
Prosopium cylindraceum		0.20
Esox lucius		0.19
Oncorhynchys mykiss		0.03

Table 7. Summary of overlap of fish taxa for on-shore and near-shore zones of four Great Lakes marsh bays in Les Cheneaux, Michigan, 1996.

	Total number of taxa	Number of taxa in on-shore zone	Number of taxa in nearshore zone	Number of taxa in common between on-shore and near-shore zones	Percentage of taxa found in both on-shore and near-shore zones
Cedarville	16	7	9	0	0
Mackinac	21	13	10	2	10
Mismer	25	14	13	1	4
St. Martin	29	26	4	4	13

Table 8. CPUE of fishes at each sampling period in four bays of Les Cheneaux, MI, 1996. SN=beach seine samples, GN=gill net samples

Date	Days from ice off	Cedarville		Mackinac		Mismer		St. Martin	
		SN	GN	SN	GN	SN	GN	SN	GN
10-May	6	0.50	1.44	2.90	0.83	1.83	0.50	6.80	0.33
22-May	18	0.27	0.25	14.42	0.38	41.00	0.25	1.45	1.00
7-Jun	34	12.40	2.46	12.83	3.42	58.33	0.41	24.67	0.43
1-Jul	58	7.67	3.44	4.75	3.98	34.33	2.03	21.12	0.18
2-Aug	90	0.00	3.69	1.42	1.24	1.83	0.97	36.08	0.37
12-Nov	189	0.00	5.18	4.90	0.18	0.20	0.59	0.40	No data
Total CPUE		21	17	41	10	138	5	91	2

Table 9. Results from the resampling method analyzing differences in species composition and abundance among bays for the 26 June-4 July sampling period, a time during early summer when differences among bays might be expected to be least. The table shows the probability that observed abundances for each species compared between bays are due to chance. Differences are considered significant for values of less than 0.05. These cells are shaded.

On-shore fish - all times	% Total Abundance	Cedarville versus Mackinac	Cedarville versus Mismer	Cedarville versus St. Martin	Mackinac versus Mismer	Mackinac versus St. Martin	Mismer versus St. Martin
Notropis stramineus	45.18	0.026	0.000	0.000	0.000	0.000	0.000
Notropis hudsonius	11.51	0.000	0.000	0.055	0.000	0.000	0.000
Pimephales notatus	10.22	0.000	0.028	0.260	0.000	0.000	0.002
Catostomus spp. (larvae)	8.02	1.000	0.043	0.000	0.039	0.000	0.000
Catostomus spp.	5.60	1.000	0.001	0.000	0.000	0.000	0.000
Etheostoma nigrum	4.28	0.231	0.000	0.000	0.000	0.003	0.000
Rhinichthys cataractae	4.15	1.000	1.000	0.000	1.000	0.000	0.000
Cyprinidae (larvae)	2.29	0.000	1.000	0.181	0.000	0.000	0.197
Catostomus commersoni	1.94	1.000	1.000	0.000	1.000	0.000	0.000
Notropis cornutus	1.73	0.000	0.561	0.000	0.000	1.000	0.000
Pungitius pungitius	0.79	1.000	0.705	0.000	0.710	0.000	0.000
Coregonus artedii (larvae)	0.58	1.000	0.626	0.000	0.651	0.000	0.000

Table 9 (continued).

On-shore fish - all times	% Total Abundance	Cedarville versus Mackinac	Cedarville versus Mismer	Cedarville versus St. Martin	Mackinac versus Mismer	Mackinac versus St. Martin	Mismer versus St. Martin
Semotilus atromaculatus	0.47	1.000	1.000	0.000	1.000	0.000	0.000
Catostomus catostomus (larvae)	0.42	1.000	1.000	0.000	1.000	0.000	0.000
Cottus bairdii	0.37	1.000	0.571	0.000	0.571	0.000	0.000
Etheostoma exile	0.29	0.811	0.138	0.517	0.276	0.258	0.022
Fundulus diaphanus	0.26	0.257	0.813	0.475	0.475	0.824	0.817
Coregonus artedii	0.24	1.000	1.000	0.000	1.000	0.001	0.001
Cyprinidae	0.21	1.000	1.000	0.000	1.000	0.000	0.001
Micropterus dolomieui	0.21	0.000	1.000	0.796	0.001	0.003	0.772
Unidentified cyprinid larvae	0.18	0.162	0.768	0.775	0.423	0.400	1.000
Percina caprodes	0.16	1.000	1.000	0.002	1.000	0.002	0.002
Catostomus commersoni (larvae)	0.13	1.000	1.000	0.007	1.000	0.006	0.009
Culaea inconstans	0.13	0.729	0.027	1.000	0.101	0.733	0.022
Osmerus mordax	0.13	1.000	0.330	0.109	0.314	0.100	0.734
Catostomus catostomus	0.11	1.000	1.000	0.022	1.000	0.017	0.023
Perca flavescens	0.08	0.048	1.000	1.000	0.033	0.040	1.000
Unidentified larvae	0.08	1.000	1.000	0.030	1.000	0.037	0.034
Ambloplites rupestris	0.05	0.137	1.000	1.000	0.126	0.117	1.000
Pimephales promelas	0.05	0.533	0.532	1.000	1.000	0.560	0.540
Ambloplites rupestris (larvae)	0.03	1.000	1.000	0.464	1.000	0.457	0.462
Micropterus spp. (larvae)	0.03	0.374	1.000	1.000	0.375	0.371	1.000
Gasterosteidae	0.03	1.000	1.000	0.337	1.000	0.335	0.343
Gasterosteus aculeatus	0.03	1.000	1.000	0.363	1.000	0.353	0.347
Hybognathus hankinsoni	0.03	1.000	1.000	0.333	1.000	0.360	0.374

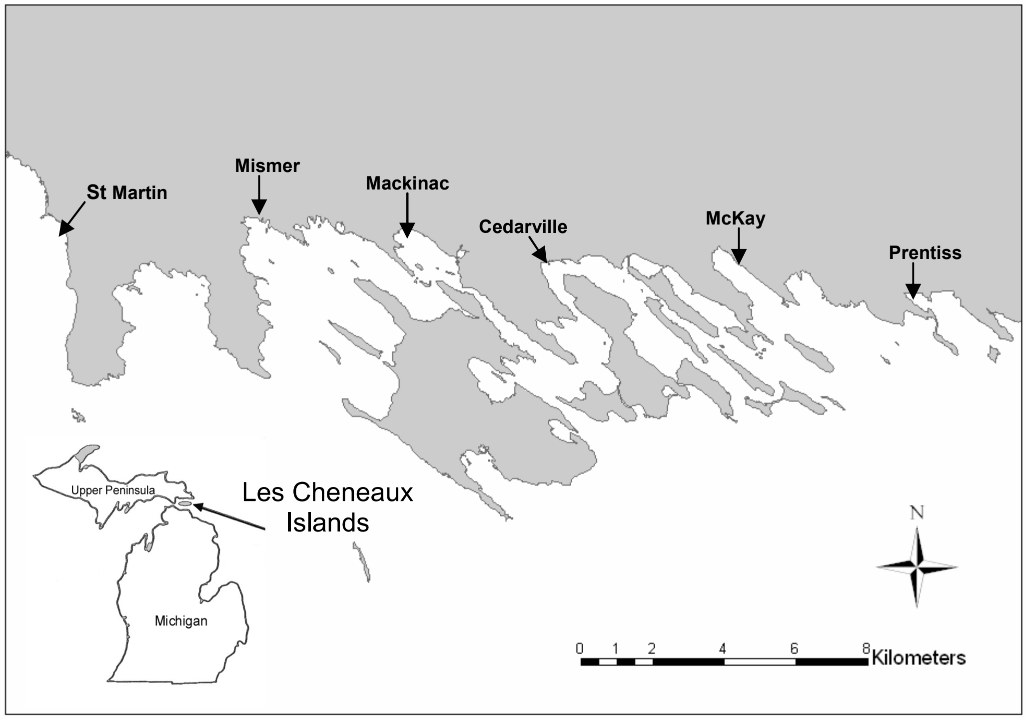

Figure 1. Les Cheneaux bays sampled in northern Lake Huron, 1996-2004

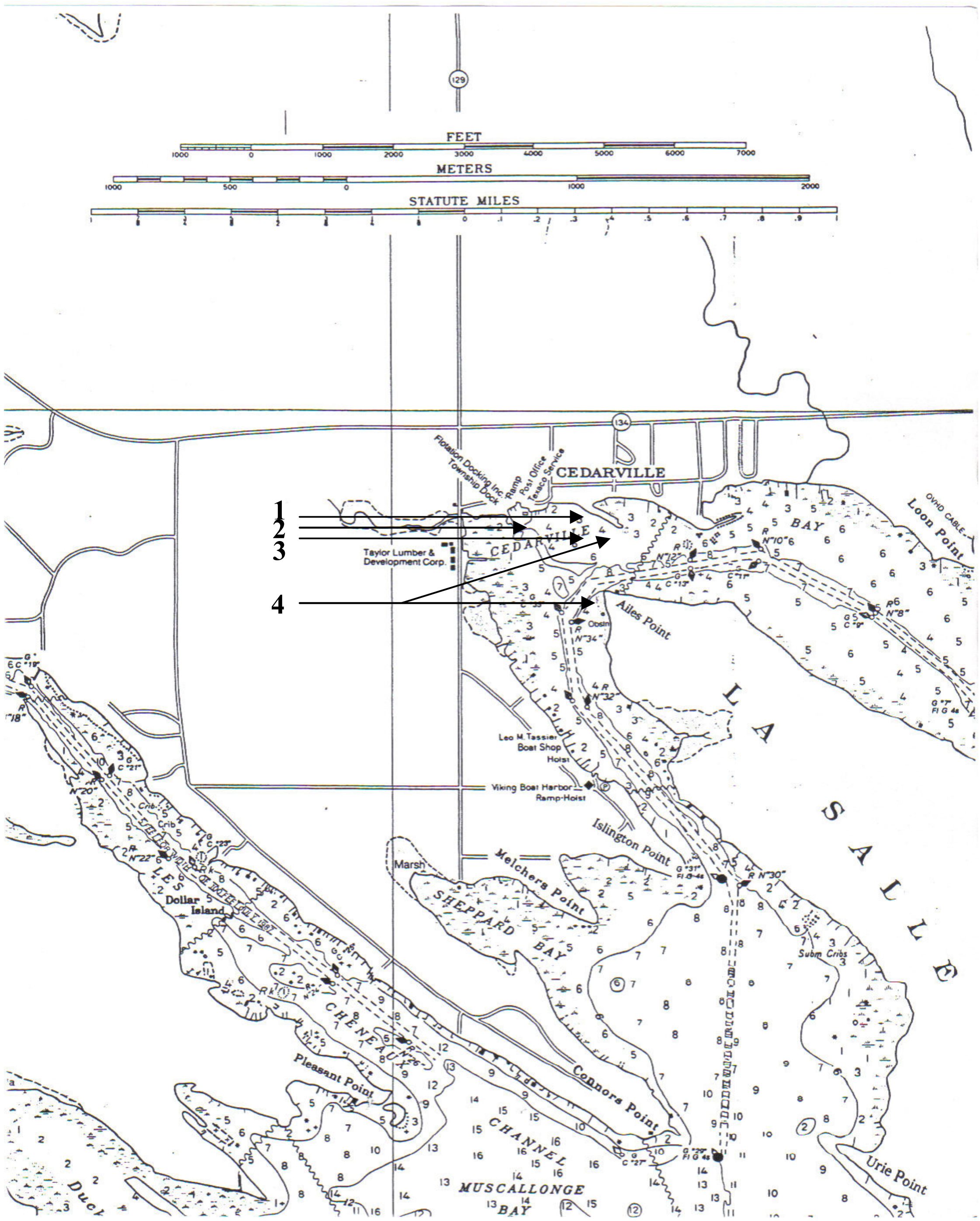

Figure 2A. Cedarville Bay, sampling sites indicated

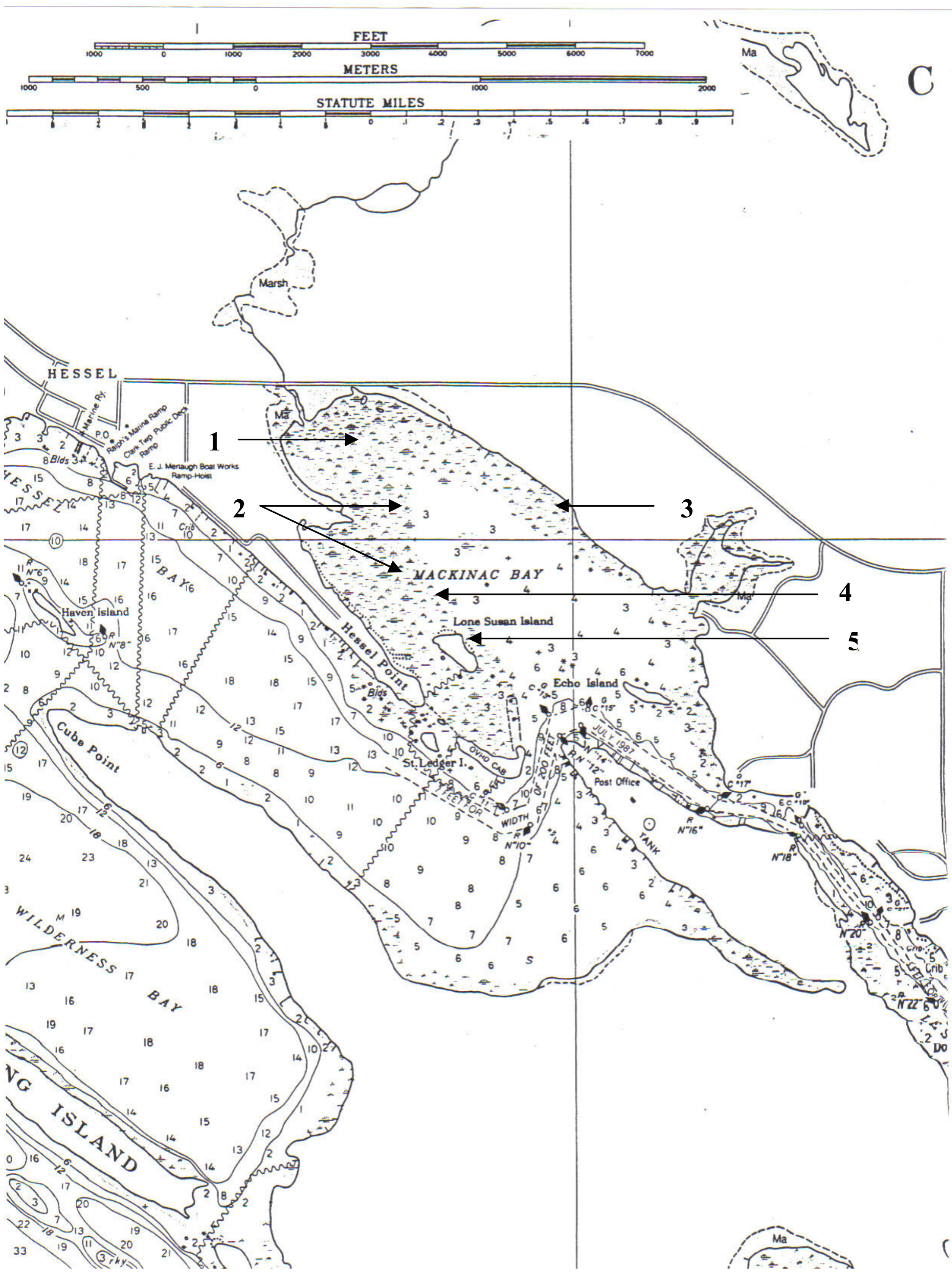

Figure 2B. Mackinac Bay, sampling sites indicated

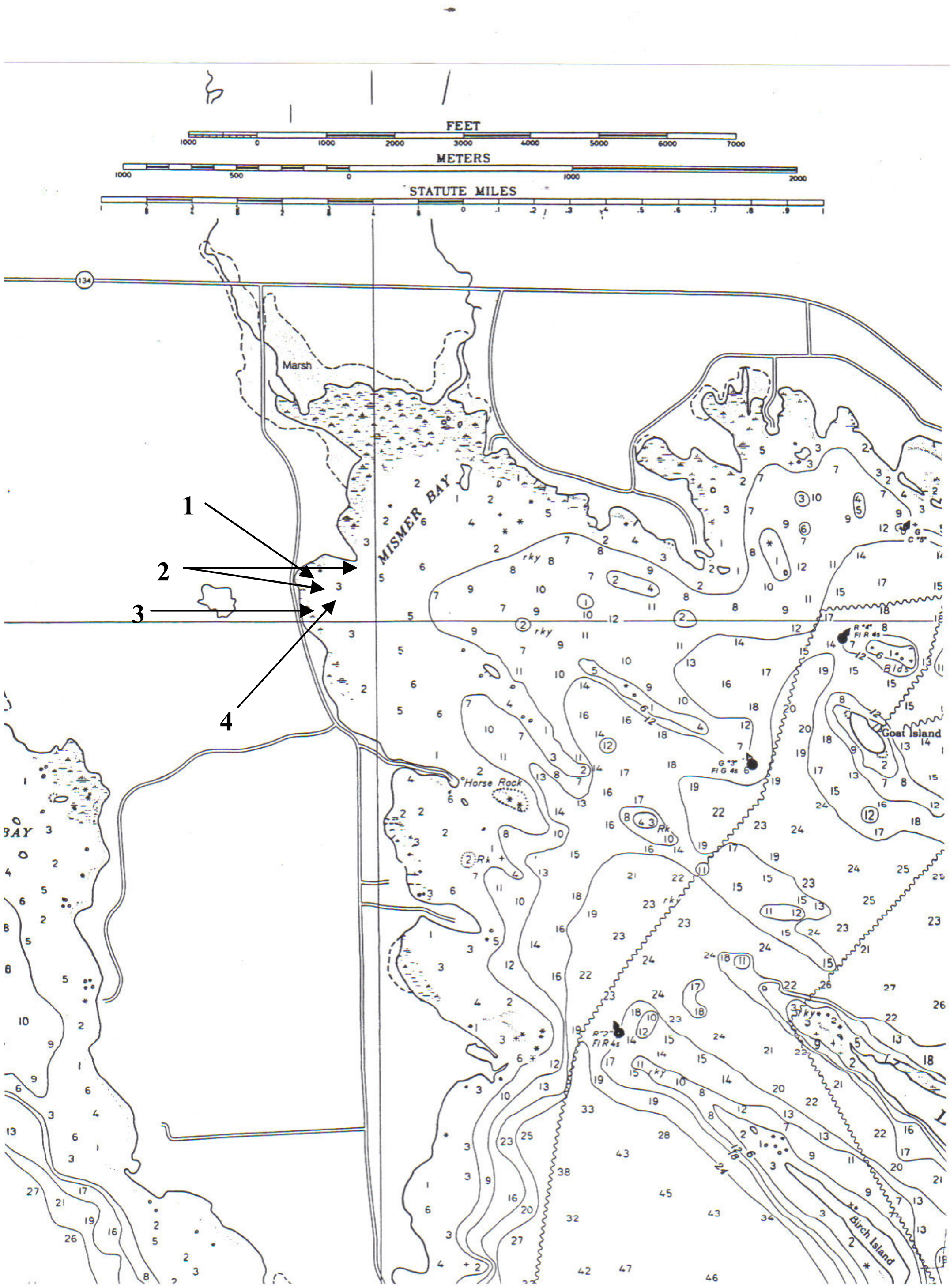

Figure 2C. Mismer Bay, sampling sites indicated

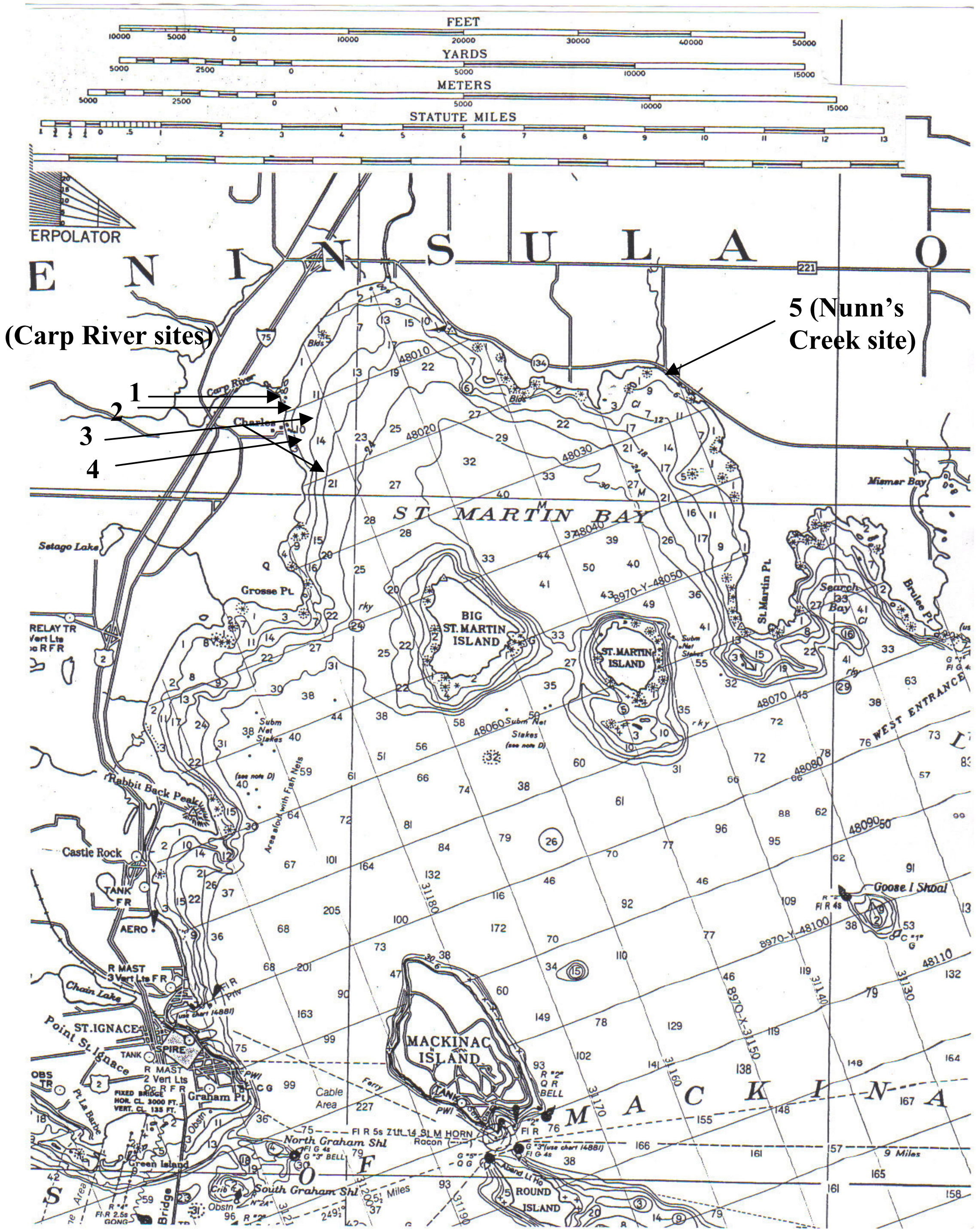

Figure 2D. St. Martin Bay, sampling sites indicated

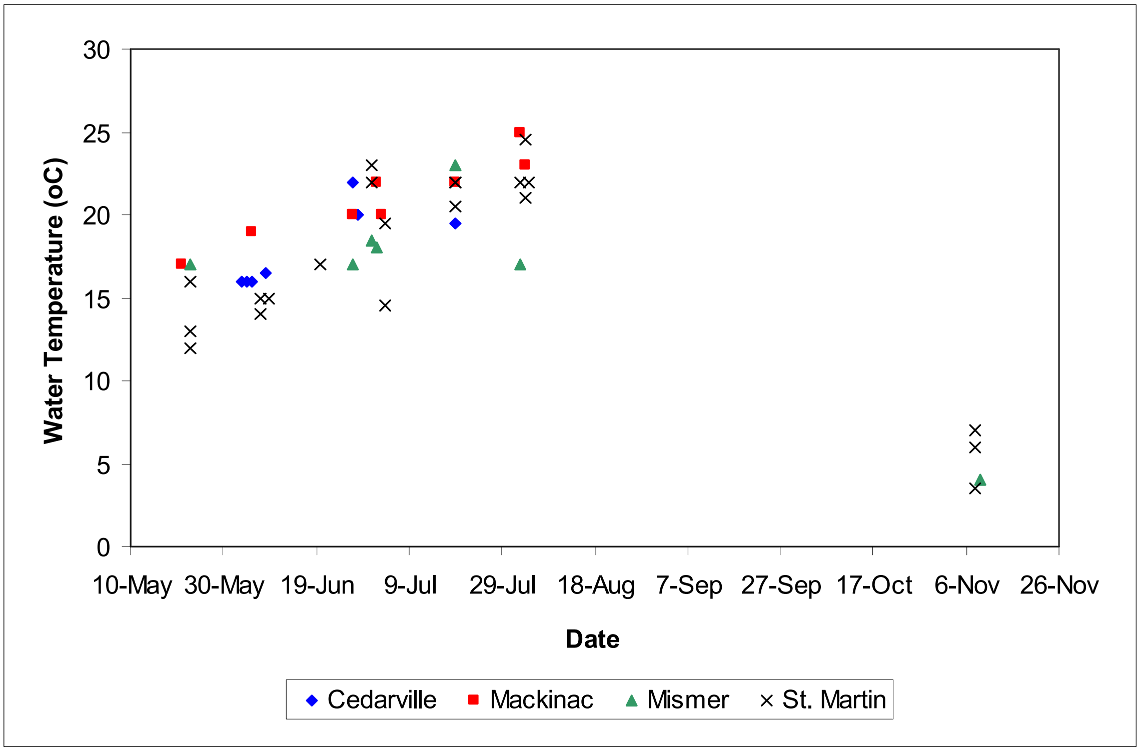

Figure 3. Water temperatures in Cedarville, Mackinac, Mismer, and St. Martin bays during the 1996 field season

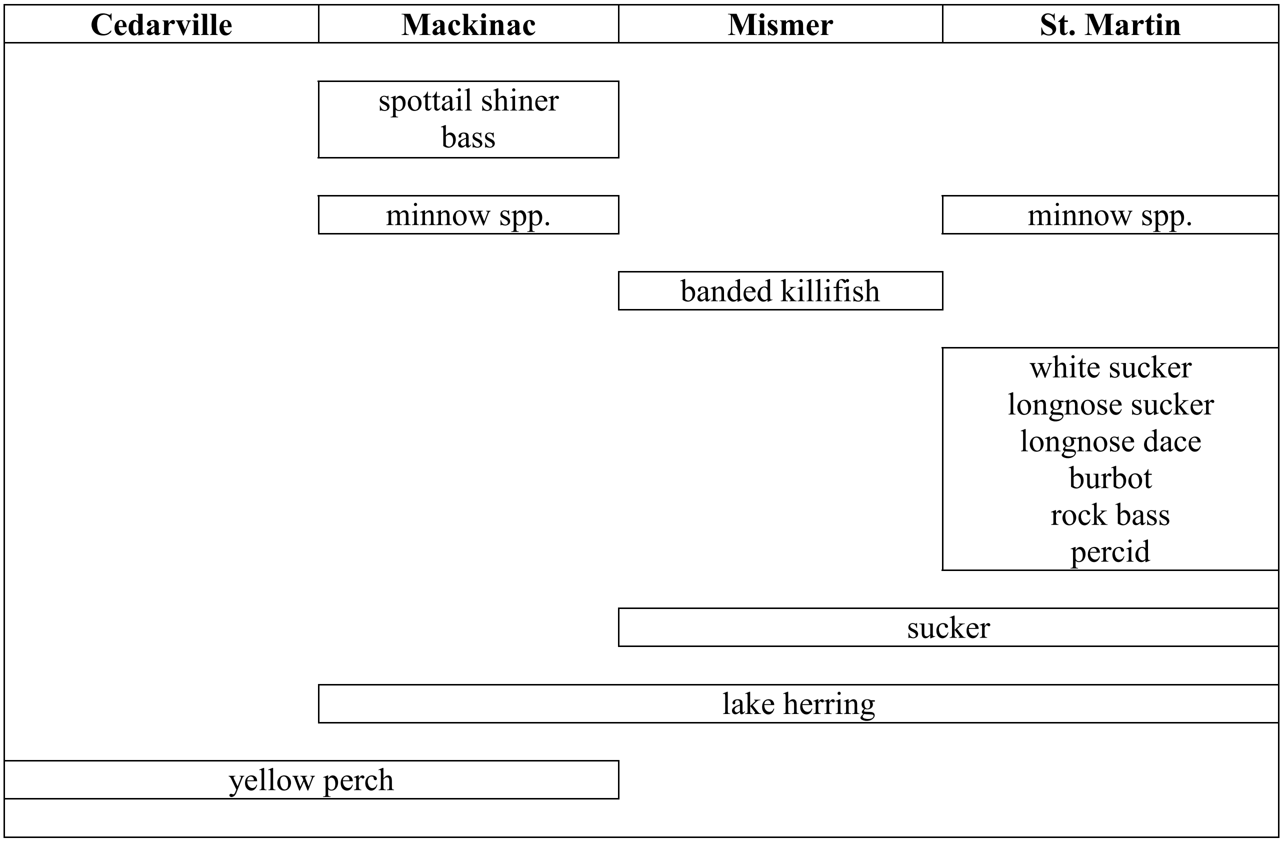

Figure 4. Distribution of larval fish taxa in seasonal marshes, 1996.

<table>
<tr><th>Cedarville</th><th>Mackinac</th><th>Mismer</th><th>St. Martin</th></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">pike, spottail shiner, bluntnose minnow, banded killifish, johnny darter, rock bass</td></tr>
<tr><td></td><td>longnose gar</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>rainbow trout
longnose sucker
longnose dace
creek chub
brassy minnow
threespine stickleback
burbot
logperch</td></tr>
<tr><td></td><td></td><td colspan="2">rainbow smelt
round whitefish
ninespine stickleback
mottled sculpin</td></tr>
<tr><td></td><td colspan="2">gizzard shad
splake
brook stickleback
pumpkinseed</td><td></td></tr>
<tr><td>lake herring
white sucker</td><td></td><td colspan="2">lake herring
white sucker</td></tr>
<tr><td colspan="3">carp
brown bullhead
yellow perch
iowa darter
white perch</td><td></td></tr>
<tr><td></td><td colspan="3">common shiner
sand shiner</td></tr>
<tr><td>fathead minnow
smallmouth bass</td><td></td><td></td><td>fathead minnow
smallmouth bass</td></tr>
</table>

Figure 5. Distribution of juvenile and adult fish species in seasonal marsh, 1996

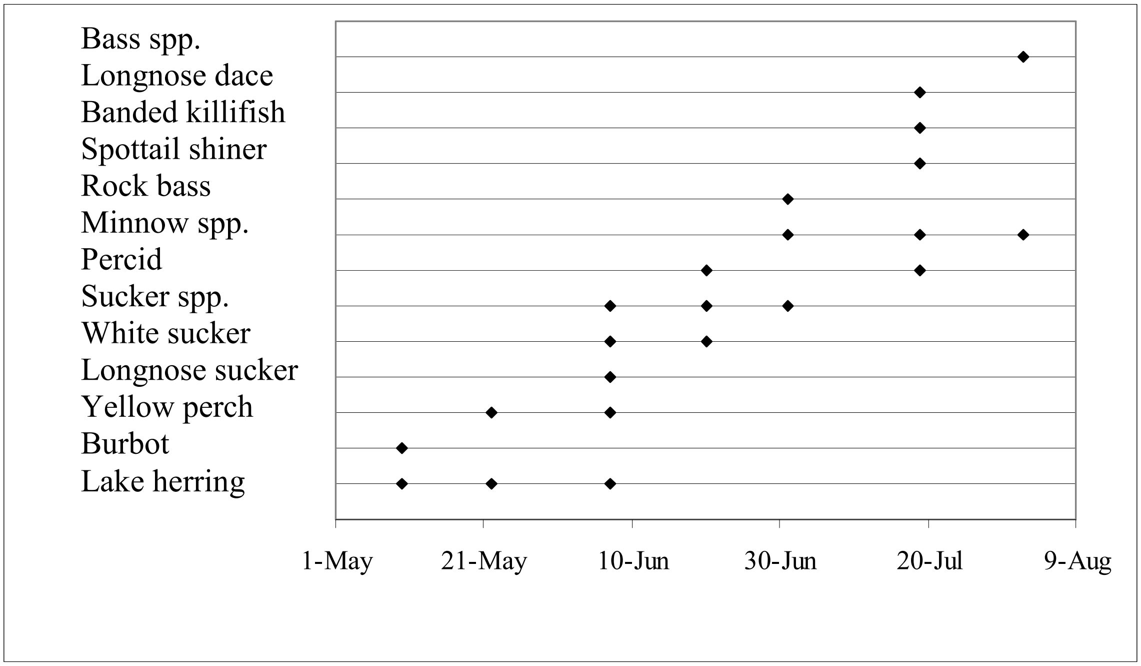

Figure 6. Larval phenology showing occurrence of larval taxa during the 1996 field season. A point on this graph represents a day when at least one fish larva of the corresponding taxa was sampled in any of the bays. Data indicate presence and absence across all habitats, as determined by all methods.

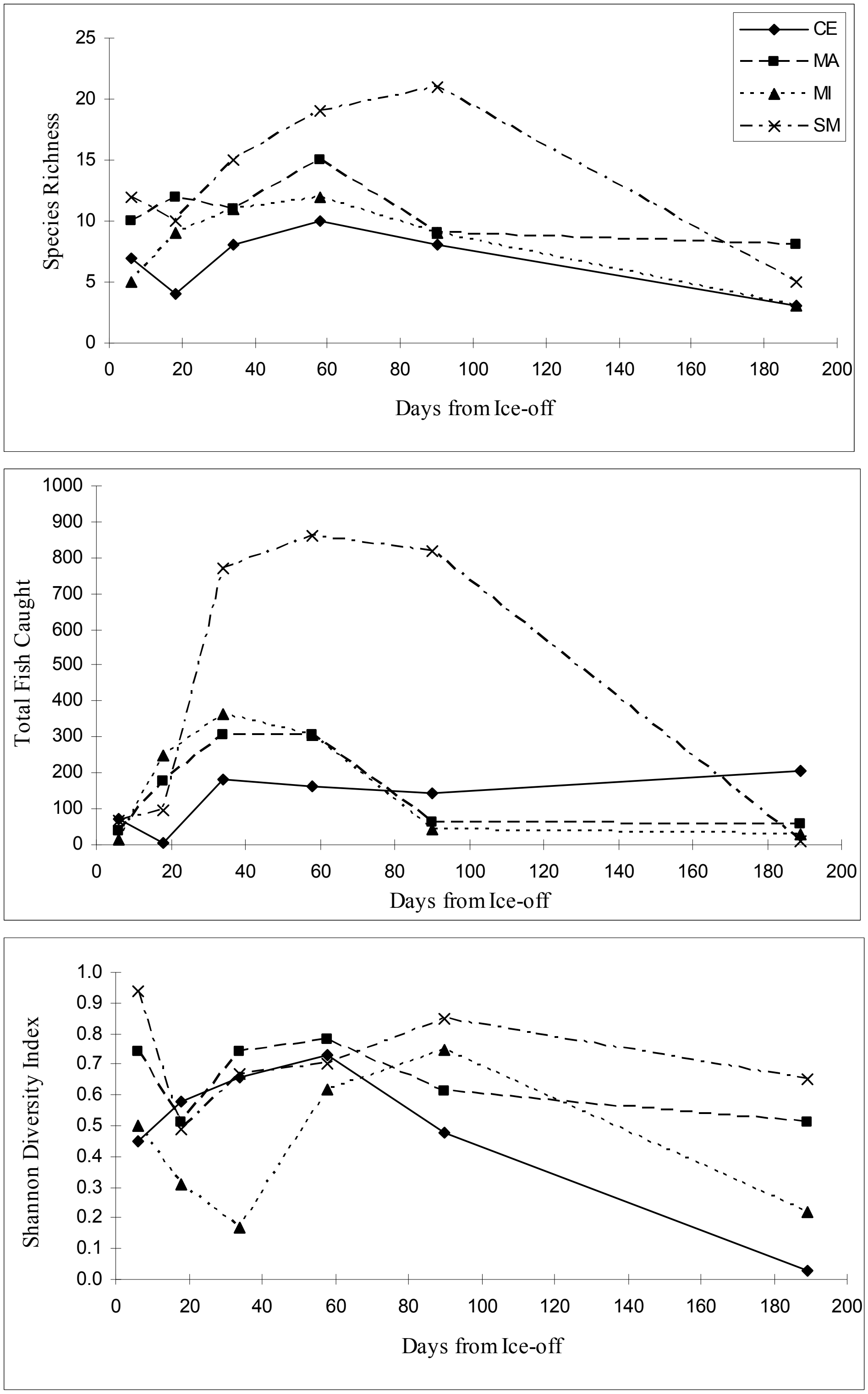

Figure 7. Relationships between A) species richness, B) abundance (as measured by total fish caught) and C) diversity of Cedarville, Mackinac, Mismer, and St. Martin bays across time for near-shore and on-shore zones, 1996 field survey.

Key: CE - Cedarville Bay; MA - Mackinac Bay; MI - Mismer Bay; SM - St. Martin Bay.

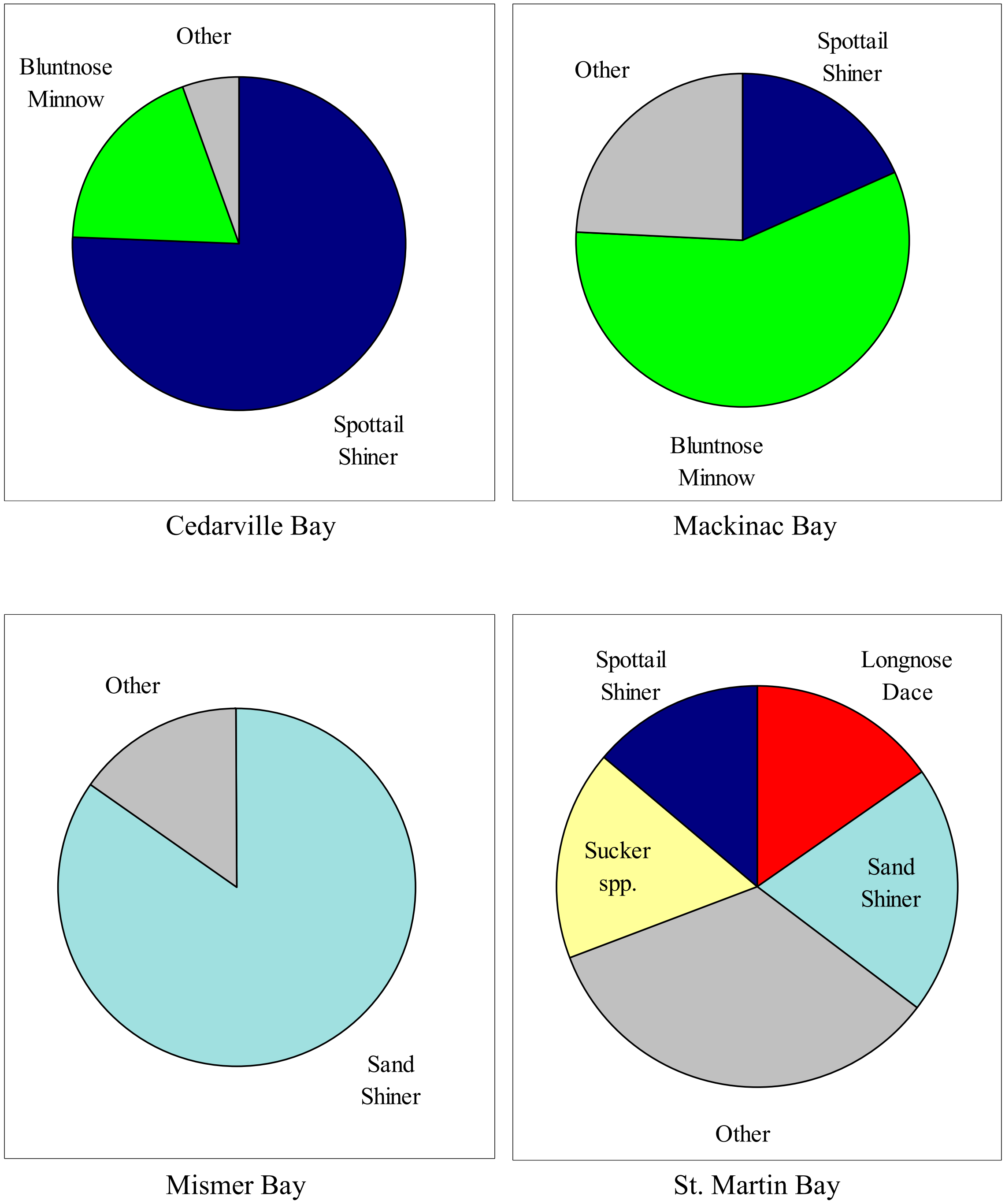

Figure 8A. CPUE by species in seasonal marsh, 1996, for beach seine samples. Species shown represent > 10% of the CPUE.

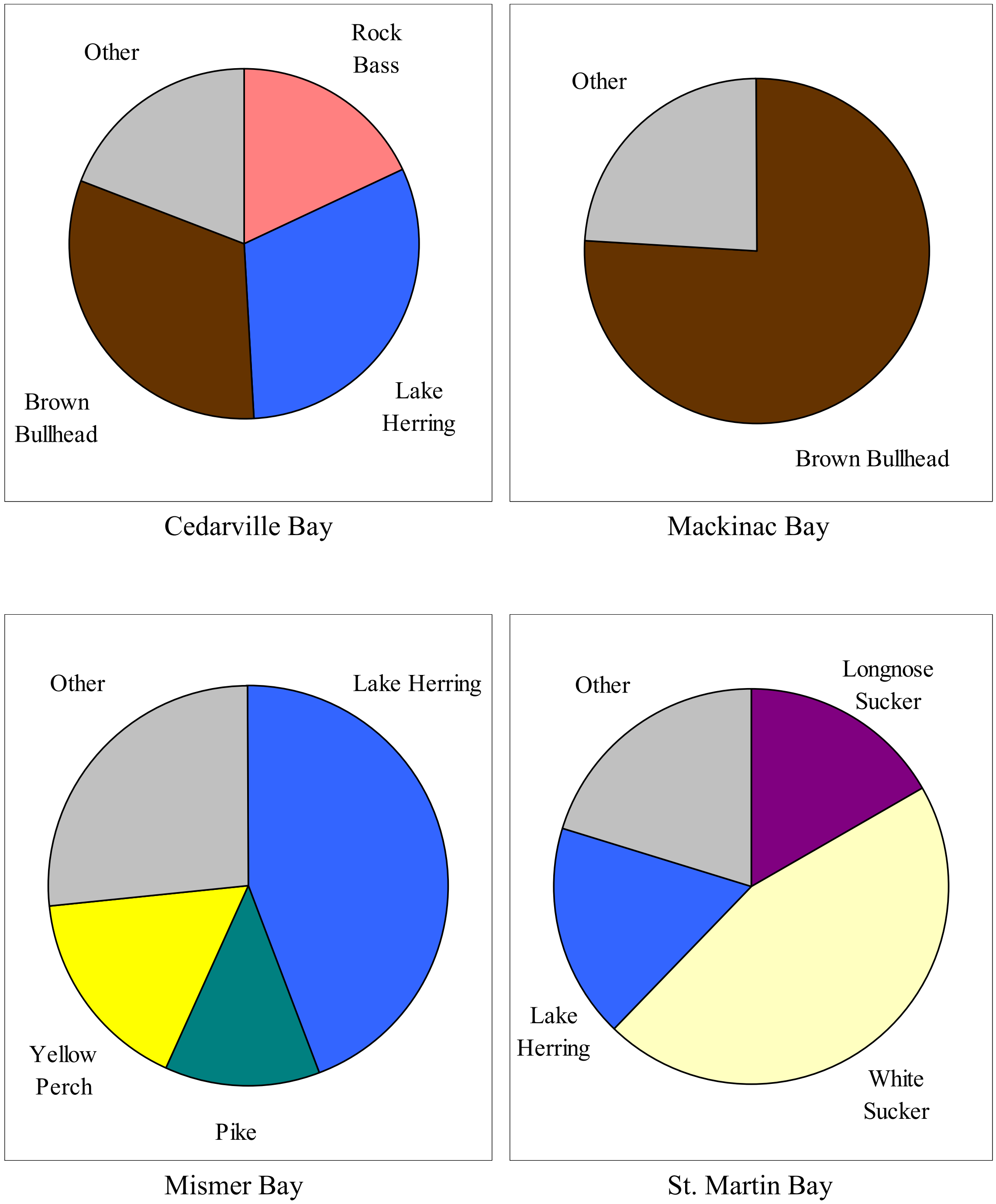

Figure 8B. CPUE by species in seasonal marsh, 1996, for gill net samples. Species shown represent > 10% of the CPUE.