Les Cheneaux Coastal Wetland Project: A Synthesis

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1. Overview

The Great Lakes coastal wetland project was designed to identify factors important to the protection of the unique wetlands in the Les Cheneaux area. Many studies, by several researchers, were implemented to describe the plant and animal communities in the area and to begin to develop an understanding of the natural and human-created factors affecting them.

The importance of water level fluctuations was observed over the study period as Lake Huron water levels changed dramatically. Plant communities in the marshes responded to multi-year variation in the water levels while invertebrates and fish were able to respond more rapidly to seasonal and short-term fluctuations.

Impacts of human development in the area were also investigated. Of special interest was the potential impact of nutrient enrichment in Cedarville Bay from the local wastewater treatment facility, residential septic systems and fertilizer run-off. While degradation was indicated by the biota, there was less impact on overall water chemistry. Also, measures of human development such as road construction and building density were correlated with differences in flora and fauna among bays.

Overall, the communities found in the Les Cheneaux area marshes were very diverse. Plant communities were generally very well developed and showed the characteristic vegetation gradation from wet meadow to deep emergent marsh. Invertebrates were abundant and diverse in general, but showed a high amount of variation in and among bays which made distinct patterns difficult to determine. Fish communities were diverse and showed consistent differences among bays. The marshes were found to be important nursery areas for some fish species.

Analyses of trophic interactions in the marshes, focusing on fish feeding preferences, showed some dietary separation among species, although most fish in the marshes were generalist feeders. The data also indicate that the food resources in the marshes are not limiting to fish growth.

The marshes seem to be quite healthy and yet the impacts on them continue to increase. Our research suggests several methods that could be used to monitor the marshes so that potential impacts are identified before damage begins. Among these are certain indicator taxa such as *Hexagenia* mayflies which are still quite abundant in nearshore areas. Reduced numbers are found in the Cedarville area indicating potential problems with nutrient enrichment there. Other methods to detect changes incorporated multiple groups into an Index of Biotic Integrity. Our data suggest that indices using invertebrates and fish communities may be useful.

A component of our research was devoted to yellow perch, an economically important fish in the Les Cheneaux region. Continued studies focusing on various aspects of yellow perch life history could be useful, not only to further understand population declines, but also as a general focal point to promote community interest and understanding of coastal wetlands.

2. Introduction

2.1 Goals

The Great Lakes coastal wetland project is an important component of the community-based northern Lake Huron project, initiated by The Nature Conservancy-Michigan chapter. The project is largely focused on nearshore waters and the adjacent shoreline between St. Ignace and Drummond Island, MI . The immediate goal is to identify ecological and economic factors that can result in protection of habitat and healthy ecosystems for ten globally rare terrestrial species, four globally rare fish, eight federally threatened or endangered species, and over sixty state threatened or special concern plants and animals. Results from the Great Lakes marsh studies are being integrated with other activities to protect complementary ecological and economic systems in this ecologically-rich region of Michigan. Ultimately, we expect this project to provide a model for shoreline protection in the Great Lakes basin.

Specific goals of the Great Lakes marsh project were:

1. Identify the biota of the marshes so that the protection of natural processes is integrated with protection of natural communities and their component species.
2. Develop an ecological model describing the processes that maintain Great Lakes marshes, so that protection and conservation strategies ensure their long-term viability.
3. Integrate and develop both scientists' and local people's knowledge and understanding of the relationship of the Great Lakes to the local economy, water quality, and biodiversity protection issues.
4. Create a narrative and GIS description of the local marshes and how they function, suitable for local planning and education as well as professional publication.

Most individual research projects were designed as descriptive surveys of flora and fauna in relation to selected environmental factors (Figure 1A) because no detailed studies had been undertaken previously. As initial results were obtained many of the studies became more focused on more detailed study of some of the marshes, while certain others were expanded to new sites. These projects have generated many hypotheses about ecological mechanisms (Figure 1B), but our efforts were focused on refining monitoring procedures rather than rigorously exploring ecological mechanisms.

2.2 Importance of Les Cheneaux Coastal Wetlands

Over 50% of pre-settlement wetlands of the Great Lakes have been lost to human uses such as agriculture. Wet meadows, lake-plain prairie wetlands, and adjacent swamps have been especially vulnerable, with losses approaching 100% in certain areas (Brazner 1997, Comer et al. 1995, Jaworski and Raphael 1978). The Les Cheneaux Islands area is one of the few remaining Great Lakes shoreline regions with a wealth of coastal wetland acreage that has been left mostly intact. These wetlands support rich flora and fauna, and contribute to the general attractiveness of the region to tourists and residents alike. Coastal wetlands are also important feeding, spawning, and nursery habitats for some game fish species. These systems, then, are important for both their biological value and their economic value to local residents.

2.3 Distinguishing Characteristics of Great Lakes Coastal Wetlands

Great Lakes coastal wetlands have received relatively little research attention. This may be because they "fall between the cracks", not fitting into the traditional definitions of wetland or lake habitats. However, a special symposium (Prince and D'Itri 1985) and a 1992 special issue of the Journal of Great Lakes Research each focused on Great Lakes coastal wetlands, indicating a growing recognition of the need for more research on these systems. Further, coastal wetlands of the Great Lakes have been surveyed and described according to their vegetation and hydrologic characteristics by Albert et al. (1987, 1989) and Minc (1996, 1997a-d), but other than this recent body of work, no formal studies including Les Cheneaux coastal wetlands have been published.

Great Lakes coastal wetlands are like other wetlands in many respects, but their position at the interface between uplands and large lakes gives them certain distinct hydrologic characteristics that are the ultimate causes of most of the features that are typical of these systems.

2.3.1 Hydrologic forces. Coastal wetlands are exposed to hydrologic influences from adjacent open-lake waters. The degree of exposure to these influences is the basis for a coastal wetland classification scheme suggested by Maynard and Wilcox (1997). These influences and the resulting unique suite of hydrologic phenomena common to Great Lakes wetlands is one of the most distinguishing features of these systems, as well as one of the strongest influences on the biota. These phenomena include the exposure of wetlands to multi-annual and annual water level fluctuations, which create a constantly changing hydrologic environment at the shoreline. They also include the short-term horizontal water movements in and out of wetlands caused by seiches, and the more forceful movements of waves, storm surges, and ice.

Water levels vary by as much as 150 cm or more over periods of 7 to 15 years in response to variation in precipitation and evapotranspiration within the watershed. Superimposed on these long-term lake level fluctuations are annual fluctuations with amplitudes of 20 to 40 cm from low winter water levels to high mid-summer levels. These water-level changes lag behind precipitation events. For example, the time required for snowmelt water from the entire upper Great Lakes basin to accumulate delays high lake levels until July. These vertical changes in lake level translate into horizontal changes in the areal extent of shoreline flooding as the water's edge advances and retreats.

Seiches are bay-wide to basin-wide oscillations of lake water that are initiated by steady winds blowing in one direction for a period of time. They are similar to the way water "sloshes" back and forth in a bath tub, but extend over scales of minutes to hours (see Bedford 1992). These oscillations commonly have amplitudes in the 10-20 cm range and periods that vary from less than an hour to as much as 14 hours (Bedford 1992). Seiches vary because wind is variable in direction, duration, and intensity. A seiche, once begun, continues to "bounce" from shore to shore until its energy is dissipated. As a result, many overlapping seiches with different periods, amplitudes, and directions combine to create a chaotic series of water level changes in coastal wetlands.

Wave energy is a constant force that affects the deeper portions of coastal wetlands most, diminishing as waves move inshore and encounter shallower depths and dense plant growth. Wave action varies among coastal wetlands depending on the interaction of shoreline morphology and prevailing wind directions. Watercraft-created waves are also important in some regions where human activity is high. The Great Lakes are partly distinguished from inland lakes by the waves created by commercial shipping, which is common near some coastal wetlands.

Storm surges, unlike seiches, cause major short-term fluctuations in water level of as much as 90 cm or more (Whitt 1996) over periods of 24 hours or less. These surges can be very forceful, carrying highly destructive energy into coastal wetlands. Storm surges on one side of a lake or bay can also create comparable dewatering of wetlands on the opposite shore.

Coastal wetlands can freeze to depths of 50 cm or more during most winters. In spring, ice and its entrained detritus and other substrate material are loosened and moved by waves and water level changes. Moving ice can scour material from the substrate, creating bare areas in wetlands.

2.3.2 Effects of hydrologic forces on biota. The effects of coastal hydrology on wetlands are most evident in plant community zonation, composition, and density. Long-term water level fluctuations, combined with annual changes, determine plant community distributions because aquatic plants are sensitive to duration of inundation and to water depth. As a result, wetland plants are sorted into sub-communities based on their level of flood-tolerance. These sub-communities occur in strips that are roughly parallel to each other and to the elevation contours of the substate. A person walking a path from upland to deep water would pass successively through all the zones as they passed from saturated soil conditions into lower elevation zones of increasing flood depth and duration, finally reaching permanently-flooded deep water.

Viewing this path through the zones in the opposite direction, Minc (1996) reported that a transect extending from deep water to the shoreline in coastal wetlands, would encounter most or all of the following vegetation zones: (1) a submergent marsh zone, (2) an emergent marsh zone, (3) a narrow but diverse shoreline zone, (4) a sedge and grass dominated herbaceous zone (wet meadow) of variable width, (5) a shrub-dominated zone, and (6) a swamp forest. In Les Cheneaux wetlands, the submergent marsh zone can extend lakeward to depths of up to 12 feet, though in wave-exposed areas the submergent zone usually does not extend as far as the emergent plants. In the latter situation, submergent plants may appear again at even greater depths where wave energy is not as disruptive. The "shoreline" zones in the Les Cheneaux also deviate from Minc's description, frequently being occupied by a narrow band of cattails (*Typha* spp.) and a mixture of species commonly found in adjacent zones. This zone, which we refer to as the "transition zone", occurs at the long-term average water's edge.

The areal extent of wetlands at a given time depends primarily on the slope of the substrate. Shallow slopes allow for a much greater substrate area to be flooded, while steep slopes result in deep water occurring relatively close to shore. The species richness and density of plants decrease with depth, so the extent of wetlands is relatively low where slopes are steep and the nearshore band of shallow water is thin.

Over time, wetland areal extent is determined by water-level changes. High water levels cause flooding of broad shoreline areas, especially where substrate slope is shallow. Conversely, dewatering occurs when water levels drop. When water rises or falls steadily over several years, vegetation zones respond by "migrating" up or down the slope in the direction of the water movement (Burton 1985).

Seiches and waves cause open-lake water to mix into coastal wetlands, although mixing diminishes in the shoreward zones because plants absorb much of the incoming energy (Suzuki et al. 1995). The result of this inshore mixing is a gradient in water quality characteristics from open water to shore, which appears to affect attached algae and associated invertebrates (Cardinale et al. 1997).

Storm surges and ice movements are notable for their destructive effects above the water line and at the substrate, respectively. Storm surges can shear the tops off emergent plants and destroy bird nests, while the movement of ice can damage and destroy plant propagules and rhizomes as it scrapes the substrate.

3. Terminology

It is important to establish terminology and definitions that are appropriate for coastal wetlands monitoring. Coastal wetlands fall into the limnological definition of littoral zones, but this term includes all habitats in the shoreline euphotic zone and is inadequate for describing coastal wetlands. The standard definition of "wetland", as it applies to coastal wetlands, would include vegetated areas up to two meters deep. This is not a very useful definition for the Les Cheneaux sites, because vegetation can extend well beyond these depths, and because depth can change so much from year to year. Instead, we make a distinction between inshore and nearshore zones based on sampling methodology, and we distinguish separate plant zones within the inshore zone. Further, for the purposes of fish sampling, we distinguish between "permanent" and "seasonal" marsh based on whether standing dead plant stems in a given area persist above the water line through the winter. We also use the standard distinction between macrobenthos and meiobenthos, though the distinction is often blurred because of different sampling methods in different zones.

"Nearshore" is variously, and often loosely, defined in the literature. It generally refers to areas in relatively shallow water, but deep enough for researchers' boats to navigate. We define "nearshore" as the areas at the lower edges of the vegetated wetlands from one to four meters deep, where a small boat can operate.

We use the term "inshore" to refer to all wetland areas shallower than the "nearshore" samples described above. We subdivide the inshore zone into vegetation-based habitat zones. The deepest of these habitats is referred to as the "emergent marsh", characterized by greater emergent and submergent plant density and diversity, and siltier substrates, than the sparse *Scirpus*-dominated, sandy-bottomed nearshore zone.

Just up the elevation gradient from the emergent marsh, which can be very wide, is a narrow "transition zone". This zone is often dominated by cattails, but where cattails are scarce, a mixture of other plants occurs. These include representatives from the adjacent zones on either side, as well as species that thrive in this narrow range.

Wet meadows occur up-slope from the transition zone. The Les Cheneux wet meadows are divided into two sub-zones based on elevation. The "low" meadow is visually identifiable during the mid-summer by the lack of shrubs and flowering grasses. It is dominated by the sedges *Carex lasiocarpa* and *C. aquatilis*, and is also occupied by relatively high densities of several broadleaf species, notably *Campanula aparanoides* and *Lysimachia thyrsiflora*. The "high" wet meadow is distinguished from the "low" wet meadow by the conspicuous dominance of the hummock-forming sedge *Carex stricta* ("tussock sedge"), and the common occurence of shrubs (including *Salix* spp. and *Myrica gale*) and grasses (especially *Calamogrostis canadensis*).

"Macrobenthos" (e.g. most insects, amphipods, isopods) are those animals retained by a 500μm (0.5 millimeter) sieve when the sample is washed through a series of progressively-finer-meshed sieves. "Meiobenthos" (e.g. copepods, nematodes) are those animals that pass through a 500μm sieve, but are retained by a 63μm sieve in the same type of washing procedure.

Fish-related terms that could be confused are "larvae" and "young-of-year (YOY)". While "YOY" could refer to larvae and post-larval juveniles in their first year of life, we use "YOY" to refer only to post-larval juveniles, thus distinguishing between these two age groups of zero-year-cohort fish.

4. Principal Investigators and Projects

4.1 **Dr. Dennis Albert** of the Michigan Natural Features Inventory, East Lansing, MI was the primary plant specialist on the project. He led the plant sampling surveys conducted in late July and confirmed all plant identifications.

4.2 **Dr. Thomas Burton** of the Departments of Zoology and Fisheries and Wildlife, Michigan State University, East Lansing, MI coordinated a number of studies over the duration of the project.

4.2.1 Plants. Along with Albert, the plant sampling surveys were conducted during the last week of July 1996, 1997, 1998 at six marshes: Cedarville, Duck, Mackinac, Mismer, Prentiss, and St. Martin's Bays. Plants were sampled every 20 m along a transect from the shallow wet meadow to deep emergent marsh. At each point, three 0.25 m^2 quadrats were randomly placed and emergent plants identified and counted. Submergent plants were identified and the percent cover recorded.

4.2.2 Invertebrates. In June and August 1996, extensive surveys of the communities were made in the six bays as above. Samples were collected using dip nets in the field along a transect, preserved and then sorted and identified in the laboratory. In June and August 1997, invertebrates were sampled in Cedarville, Duck, Mackinac and Mismer using a Rapid Bioassessment Protocol (RBP) in plant zones to reduce the time needed to process samples. A comparison of the RBP method with the 1996 sampling method was conducted in September 1997 to assess potential differences in techniques. The transect in Mackinac Bay was sampled in June and August 1998 using the RBP method and supplemented using activity traps to ensure more motile organisms were collected. Additionally, in August 1998, a more quantitative survey using the RBP method was conducted to assess among-site variability and within-site variability in eight bays (the above six plus Peck and Voight Bays) within a single plant zone.

4.2.3 Fish. In 1996, fish communities in the shallow marsh habitat were sampled using fyke nets in each of the six bays. The nets were set in three plant zones for 24 hours in each bay during June and August. Sampling in 1997 was conducted in Duck and Mackinac Bays during June and August. Traps were set in each bay for three consecutive days and checked every 24 hours to examine daily variability in catches.

4.2.4 Water chemistry. Water chemistry was documented at Cedarville, Duck, Mackinac, Mismer, Prentiss, St. Martin and Voight Bays in July 1998. Samples were taken along a transect from the shallow marsh to open water. Dissolved oxygen (mg/L), conductivity (µs), depth, and temperature (^{O}C) were recorded in the field. Turbidity (NTU), pH, nitrate and phosphate (mg/L), and total alkalinity (mg $CaCO_3$/L) were determined upon return to the laboratory.

4.3 **Patrick Hudson** of the U.S. Geological Survey, Biological Resources Division, Great Lakes Science Center, Ann Arbor, MI investigated invertebrate communities and trophic interactions.

4.3.1 Nearshore macrobenthos. The macrobenthos of two impacted bays, Cedarville and McKay, and two similar but less impacted sites, Mackinac Bay and Moscoe Channel, were sampled in May and September 1996 using a Ponar grab sampler. Samples were collected at three depth strata: 1-2, 2-3, 3-4 m. In 1997, grabs were made in September at Cedarville and Mackinac Bays. Additional samples were taken in June, 1997 at 1.5 m intervals to a depth of 12 m in Search and St. Martin's Bays.

4.3.2 Nearshore meiobenthos. The meiobenthos in shallow (<1 m) water was sampled in Cedarville, Duck, Mackinac, Mismer, St. Martin and Prentiss Bays in May, July and September 1996 in the sedge/hummock and silt substrate habitats using a 5 cm corer. Additional samples were collected in Prentiss Bay from four other habitats (bulrush, cattail, sedge, sedge/shrub). Sampling in each of the six bays was repeated in July 1997 with additional samples taken near the M-134 highway to assess its impact on the fauna.

4.3.3 Fish stomach analyses. Contents of fish stomachs were examined to define fish habitat use and community structure, and to begin constructing an aquatic food web for the marsh study area. Samples of fish were collected by the various research participants and local fishermen during 1996-1999 from a variety of habitats. These fish were collected using a range of sampling gear to ensure capture of representatives from all age-classes. They were dissected and the stomach contents examined and identified. Special emphasis was placed on examining the stomachs from yellow perch, *Perca flavescens*.

4.3.4 Burrowing mayfly life history. The presence and abundance of burrowing mayflies (*Hexagenia limbata* and *Ephemera simulans*) was documented using Ponar grabs as above (4.3.1). SCUBA was used in June 1997 in Mackinac and Hessel Bays to evaluate burrow configurations (epoxy resin casts), relative nymphal abundance without destructive sampling and sampling bias, and performance of several sampling devices in different substrates. In addition, the effect of mayfly burrowing on the sediment was examined by measuring the compactness of sediments containing varying densities and sizes of nymphs.

4.3.5 Yellow Perch. Yellow perch populations and their associations with various habitats were investigated using electrofishing during May, June, July and September 1997. Fish were collected from a rock reef lacking aquatic vegetation in Hessel Bay, a channel in Mackinac Bay with late-emerging vegetation and the shoreline of Mackinac Bay which had both submergent and emergent vegetation. Collections were made during both daylight and dark with the greater emphasis on night sampling. Analysis of perch stomach contents was performed as above (4.3.3).

4.3.6 Warbler-Chironomid interactions. The importance of adult midges (Chironomidae) emerging from wetlands as a food source for migrating warblers was investigated at Search and Dudley Bays. Adults were collected at inland points along a transect perpendicular to shore using Tanglefoot adhesive and a fine mesh net. Sampling was conducted four times from late April to early June, 1997.

4.3.7 Invertebrate taxonomy. Hudson coordinated identification of invertebrates to the lowest possible taxonomic resolution. Samples were sent to recognized experts when necessary.

4.4 **Dr. Richard Merritt** of the Department of Entomology, Michigan State University, East Lansing, MI, examined the invertebrate communities at erosional (rocky) and depositional (silt/organic) habitats in Prentiss Bay in 1996. Dip-net and vegetation samples were collected along transects, and invertebrates were preserved and identified in the laboratory.

4.5 **Drs. Paul Webb, James Diana and James Teeri** of the University of Michigan Biological Station and School of Natural Resources and Environment, Department of Biology, The University of Michigan, Ann Arbor, MI, examined the fish communities in the marshes and the impacts of human development.

4.5.1 Fish. Fish communities were sampled six times in Cedarville, Mackinac, Mismer and St. Martin's Bays from May to November 1996. Additional samples for larval fish were made in June and July. Inshore fish were collected in shallow water (<1 m) using beach seines, larval seines, and backpack shocking. Nearshore fish in deeper waters (1-3 m) were sampled using gill nets, a boat shocker, and a towed larval net. In 1997 and 1998, inshore permanent and seasonal marsh larval fish communities were sampled extensively with seines and hand tow nets in Mackinac, Mismer, and Cedarville Bays from spring to the onset of ice in winter. Intensive trap-netting was used to sample marsh fishes during July and August, the periods of peak richness and abundance, while a June and a July gill-net sample were also obtained. Analyses of fish data emphasized phenological changes between ice-off and ice-on, and correlations of community parameters with vegetation and human development

4.5.2 Age structure of fish populations. The age structure of populations of larger-bodied species found in Cedarville, Mackinac and Mismer bays (rock bass, *Ambloplites rupestris*, yellow perch, and white sucker, *Catostomus commersoni*) was determined from scale annuli. Comparable data were sought for small-bodied abundant species, largely cyprinids and larvae from size-frequency distributions (Petersen methods). Growth rates were determined from resulting length-at-age data.

4.5.3 Diet. Stomachs were analyzed for rock bass, pumpkinseed (*Lepomis gibbosus*), yellow perch and smallmouth bass (*Micropterus dolomieui*) from the same three bays. All specimens were taken in July from fyke-net catches.

4.5.4 Water chemistry. The following chemical parameters were measured from monthly water samples from ice-off in the spring to ice-on in the winter: nitrate nitrogen, ammonium-nitrogen, phosphate phosphorus, silicate, chlorophyll-a, pH, turbidity, alkalinity, conductivity, temperature and dissolved oxygen. Samples were taken from the beach in Mismer Bay, permanent and seasonal marshes in Cedarville, Mackinac and Mismer Bays, and from Pearson Creek draining into Cedarville Bay.

4.5.5 Plants. Growth forms and densities of permanent and seasonal plants were measured in 1998 in larval fish habitat, and combined into an index of habitat complexity.

4.5.6 Land use and development. The impact of human development on the fish communities in Cedarville, Mackinac, McKay, Mismer and Prentiss Bays was assessed in 1998. Several measures of development were calculated in the area one kilometer around the bay shoreline and tributary streams. Shoreline plot development was measured by counting the number of developed plots using Clark Township records. Road density was calculated as the ratio of road length to land area based on 1997 aerial photography. Road area, total impervious surface area (roads, buildings and other paved surfaces), and the number of boat houses and docks also were calculated from the 1997 aerial photographs. Boat use in the bays was measured between 9:00 A.M. and 3:00 P.M. when entering the bays to sample fishes.

5. Site Descriptions

The following descriptions focus on the initial study sites selected in 1996 (Figure 2). Only one wetland site in each bay was selected for inshore invertebrate and plant studies, though some bays have more than one wetland area. Nearshore benthic sampling, burrowing mayfly studies, and some fish sampling were carried out more broadly because they focused on deeper areas at the edges of the emergent marshes.

In general, these sites exhibit typical wetland vegetation zonation, with wet meadow vegetation at the higher elevations separated from deeper emergent marsh by *Typha*-dominated transitional communities. The emergent marshes are comprised of emergents such as *Scirpus*, *Pontedaria*, and *Eleocharis*, interspersed with floating-leaved plants and patches of often-dense submergents. The outer, deeper regions of the emergent marshes are comprised primarily of wave-swept *Scirpus* with sandier bottoms than inner regions. Exceptions to this general pattern are noted below.

5.1 Cedarville Bay

Cedarville Bay is generally considered to be the most human-impacted area in the Les Cheneaux islands complex. A very large island occupies the middle of the bay, so the bay actually resembles an "n"-shaped channel, which receives very high boat traffic. The town of Cedarville, a marina, and a public boat launch occupy the northwestern shore of the bay, and many private residences, businesses, and docks (private and commercial) line the mainland and island shores.

The main wetland surrounds the stream mouth, public launch, and several docks, but the emergent marsh is cut off from its historic wet meadow by a paved road and a lumberyard built on fill. The only remaining aquatic connection between wet meadow and marsh is the stream, which runs through a culvert under the road and carries discharges from an upstream sewage treatment plant twice each year. Possibly as a result of the discharge, the emergent marsh in this area has unusually dense growths of submergent plants and filamentous algae. Another marsh area is located on the island shore across the channel from the main study site. This site consists of a narrow band of *Scirpus* with a sedge-dominated wet meadow area just up-slope. Several other stretches of Cedarville Bay shoreline have narrow bands of *Scirpus*-dominated emergent marsh.

5.2 Duck Bay

Duck Bay is located on the east side of Marquette Island. The bay is well protected, but the study site on the southern shore has a very sparse submergent plant community, a relatively less dense and less diverse emergent marsh community, and a steeper slope to deep water than most other sites. The transition zone consists of a dense *Typha* band. The wet meadow is not very expansive because of the relatively steep slope to the upland forest. There is one private dock on the bay shore, and boat traffic appears to be relatively low.

5.3 Mackinac Bay

The Mackinac Bay site is typical of the wetlands in the area. It is in an island-protected bay, has a low-gradient stream running through it and out into the open bay, and has the vegetation zonation described above, although the emergent marsh zone is very extensive, with *Scirpus* occurring farther out into the bay than in most of the other bays that we studied. To the north, the embankment of a paved two-lane highway truncates the upper end of the wet meadow. The stream was diverted in the past to make way for an expansion of the embankment to accommodate a public viewing platform and small gravel parking lot. Several residences with private docks and boathouses line the shores of the bay to the south and east of the site. Boat traffic in the bay is relatively low, but the main dredged channel through the Les Cheneaux Islands crosses the southern end at the mouth of the bay. Fringing *Scirpus* marsh lines much of the shoreline.

5.4 McKay Bay

The combination of a large limestone quarrying operation on adjacent land and the exposure of the bay to Lake Huron proper cause this bay to be rather unique in the study. The overall bay is of a greater depth than the other bays studied and experiences much boat traffic, including that of large freighters that access Port Dolomite. Wetlands are not extensive in the bay as a result of its open exposure to the lake; they are found primarily in the more-protected northwest end of this long and narrow bay. The substrate is predominantly sandy due to the open exposure to the lake. Within the marsh areas, the sandy substrate has some organic material, but not to the degree found in more protected bays such as Duck. Several residences line the shores of this bay.

5.5 Mismer Bay

Mismer Bay is divided into two main wetlands. The main study site, to the north and east, is more wave-swept than Mackinac Bay, having only partial protection from open-lake waves. The result is a sandier bottom and the lack of a *Typha* stand, although the wet meadow is well developed. A wide stream runs through the site in a southerly direction. Two residences, without docks, abut the site, and a dirt road borders the wet meadow to the east. The other wetland, to the west, was not studied as intensely, though some invertebrate and fish sampling was conducted there. It has a stream running in a generally easterly direction, and the wetland surrounds the stream for a longer distance than is the case in the more eastward wetland. The stream flows through culverts under a dirt road that bounds the site to the west, while a paved road (highway M-134) forms the westernmost portion of the northern boundary.

5.6 Moscoe Channel

This channel is also long and narrow, like McKay Bay, however it is much more protected from the winds and wave action than is McKay and has a softer substrate in general and a much more established marsh. Many residences line the channel along Hill Island as well as along the mainland shore. A wet meadow area is found along the very northern section of the channel, while there is emergent marsh found around most of the channel's perimeter. Despite its name, it is not a passageway for boats approaching Cedarville, although its proximity to the town and accessibility via roads provides for higher human use of the land around the channel as compared to some of the other research sites.

5.7 Peck Bay

Peck Bay is located on the same island as Duck Bay and shares that bay's general orientation. However, Peck Bay is located further lakeward (south) on Marquette Island, and has a narrow mouth that opens directly toward the open lake. Human impacts are apparently very low, there being only one residence located along the shore of the bay and no roads. The main study site is in the north-northwest end of the bay, furthest from the narrow bay mouth. It is a relatively low-slope site, with a broader wet meadow than is found in the Duck Bay site.

5.8 Prentiss Bay

Prentiss Bay is divided by a road, like some other sites, but is distinct from most others in that highway M-134 was built through the wetland, completely separating the wet meadow from the emergent marsh, and supplanting most of the transition zone. Two culverts connect the remaining wetland zones, resulting in a more restricted water flow than would occur had the wetland been left intact. Because of the proximity of the road to deeper water, anglers often put boats in near the culvert and fish at the edge of the deep marsh. The dense emergent zone is narrow, giving way to a deeper, sparser, and patchier emergent zone fairly near the road. The only dwellings are located on the outer edges of the bay and are not very near the wetland area.

5.9 St. Martin's Bay

The St. Martin's Bay site differs from the typical vegetational and morphological pattern seen in the other sites. The wetland site is on an unprotected shoreline in this large bay. The site is characterized by two parallel sandbars, giving the protection necessary for wetland development. The inner sandbar is continuous and separates a wet meadow from the remainder of the site. The outer sandbar has a single inlet that connects it to the open bay. The resulting wetland zone between the sandbars is a typical dense emergent zone, though the bottom is relatively sandy and submergent plants are sparse because of the exposure to bay waves. Because there is no direct wet meadow/emergent interface, the only *Typha* occurs at the inner edge of the outer sandbar, at the protected transitions from aquatic to upland vegetation. Outside the outer sandbar lies a very sparse *Scirpus* patch. The number of sandbars and inlets may vary with varying water levels among years.

5.10 Voight Bay

Voight Bay differs from the others in that it is on the south side of Marquette Island with direct exposure to open-lake waves. The wetland area is partially protected from wave action by low sandbar islands. The emergent marsh is somewhat sparsely vegetated and has a sandier bottom than many sites. The wetland is well protected from wave action and probably receives very little human impact relative to its large size. There are two residences and one dock on the bay shore, but the bay's distance from the main boating areas and exposure to the open lake suggest that recreational boating in the bay is not very common.

6. Project Results: Abiotic Factors in the Marshes

6.1 Water Movements

Because of the importance of water level fluctuations in coastal wetlands, we placed a water-level recorder in Mackinac Bay from May to September in 1997 and 1998. The main intent was to monitor short-term changes in water level, supplementing long-term data from other sources. We obtained monthly mean water level data collected at Detour Village by the NOAA, and found these data to correspond well with our recordings. Because the NOAA data comprise a record of decades of data, we present these in the discussion below.

6.1.1 Long-term variation. We observed year-to-year changes in water level that caused dramatic changes in wetland flooding among years. When field sampling began in May, 1996, the water's edge was near the upper bound of the transition zone in our study sites (Figure 3). By the following May (1997), the water level was over 25 cm higher, so that even the high wet meadow was flooded through the ice-free season. Water levels peaked in July, 1997, and declined for the rest of the year. In 1998 the high wet meadow was not flooded, but the low meadow remained flooded throughout the summer season, though it was becoming shallower as the water level dropped. By August the water was clearly receding, which continued into 1999 when water levels reached very low levels, so that much of the wetland areas previously sampled were not even flooded that year.

While neither the high nor the low level observed during the study were outside the historical range of variation, such a large change in such a short period is quite unusual in the 100-year record, part of which is included in Figure 4. It appears, then, that we were fortunate to observe this unusual occurrence.

6.1.2 Seasonal fluctuation. Our initial expectation of seasonal water-level changes was based on literature-reported average patterns. However, our observations over the three-year study period suggested a very dynamic hydrologic pattern not evident in averages. While it is true that, on average, Lake Huron experiences an annual oscillation from low winter water levels to high mid-summer levels, we found that year-to-year changes influenced the way that seasonal variation was manifested in coastal wetlands. During the first year of the project (1996), water levels rose over 40 cm, rather than the multi-year average of approximately 25 cm (Figure 5). During the fall, the expected water level decline was muted, resulting in a net increase over the year and continued flooding of coastal wet meadows, which we had expected to drain as part of the normal decline. During the following year, the annual rise and fall occurred as expected, but again the magnitude of the variation was greater than the average. In 1998, the opposite of the 1996 pattern was observed: low initial rise followed by a precipitous decline to early 1996 levels.

6.1.3 Seiches and storm surges.

Our understanding of seiches in the Les Cheneaux area is based on anecdotal evidence and our water-level recordings. We frequently observed water level changes of approximately 10 cm in one-to-two hours. Seiches manifest themselves in the marsh as surface water movements either into or out of the wetland. These movements are often quite rapid and readily observable as floating debris is carried along. Movement is more rapid along well-established trails through the vegetation, whereas it is apparently slowed by dense, undisturbed plant stands. The whole phenomenon can be viewed as large-scale, periodically-reversing sheet flow across the entire wetland surface, with local variations in speed determined by vegetation resistance.

Storm surges are movements of water associated with the strong winds of a passing storm front. They can be voluminous and violent, causing damage to plants, animals, and research equipment. We only observed one such surge, which occurred in 1997. The water was already high that year, so when the surge began it was building on a base of water that was at least 10 to 20 cm deep throughout the wet meadows. The surge was so severe that waves were observed spraying onto the highway at Prentiss Bay, which we estimate to be at least one meter above the usual water level at that time. However, our data suggest that such extreme surges are unusual.

6.2 Water Chemistry

Water quality parameters along marsh transects were within the "normal" range for freshwaters, and differences among study sites were not apparent. However, samples taken at different times from Mismer Beach, and permanent and seasonal marshes in Cedarville, Mackinac and Mismer bays from spring to fall, show considerable temporal variation in several chemical measures (Figure 6).

Within sites, however, variation along the elevation gradient was apparent. As we proceeded from deep water into the densely vegetated shallow water areas, conductivity increased strongly, and both temperature and dissolved oxygen decreased. On the other hand, measures such as nitrate, ammonium, and phosphate varied but did not show consistent rising or falling trends along the gradient.

Twice each year the Cedarville wastewater treatment facility releases treated water into Pearson Creek, which empties into Cedarville Bay. Not surprisingly, we found elevated nutrient levels in the creek at times. Also, we specifically analyzed wetland water from near the creek mouth and found elevated nutrient levels immediately following the two annual discharge events. These high nutrient concentrations apparently are diluted or taken out of the water column quickly because we did not detect high concentrations at sampling points farther (beyond ~150 m) from the creek mouth. Similarly, concentrations returned to the usual lower levels shortly after the discharge events.

6.3 Substrate quality

Though we did not quantitatively analyze soil constituents, we can describe them as follows. Deep wave-exposed emergent marsh sediments are mostly sandy, because wave action prevents accumulation of fine particulate organic matter (FPOM) and silt. Shallow emergent zones are much more mucky and silty, both because reduced water movement allows settlement of fine particles, and because the higher biotic production leads to higher detritus production. Coarse particulate organic matter (CPOM) also accumulates seasonally in these zones, but CPOM is an especially abundant substrate component in the transition zones, because cattails often dominate these areas in the Les Cheneaux. Cattails produce dense growths of recalcitrant leaf and stalk material that is bulky and slow to decompose. By contrast, the emergent marsh has many more soft-tissued submergent plants, although dead bulrush stems can be a persistent and substantial component of the sediments. In the wet meadow, although large quantities of sedge and grass tissue are produced, CPOM does not appear to accumulate over the long term. The wet, seasonally-oxygenated conditions of the soils are ideal for decomposition, so the substrate is generally composed of FPOM within a dense root matrix, overlain by the previous year's CPOM. In the upper wet meadow, hummock-forming sedges create a matrix of hummocks consisting of rich soil held in place by the root system of the sedges.

6.4 Physical and Landscape Attributes

Each site is unique in its shoreline morphometry, fetch, and aspect, which affect the degree of exposure to wind and wave energy. Waves affect sediment quality and vegetation, so sites such as Mismer Bay, Voight Bay, and St. Martin's Bay have sandier substrates and/or sparse *Scirpus* zones with little or no submergent vegetation. By contrast Mackinac Bay and Cedarville Bay are among the most protected areas so their vegetation is dense and bottoms consist primarily of silt and muck. We believe that factors related to wave exposure are among the most influential on coastal wetland biota and this hypothesis should now be directly tested.

It also appears that bays vary in temperature, which depends on their exposure to the colder open-lake water, and the relative amount of colder groundwater inputs. Prentiss Bay is notably cold, probably due to groundwater influx, while St. Martin's Bay water is strongly influenced by open Lake Huron water. Most other sites studied are warmer, though we have observed that even in warm Mackinac Bay, upper wet meadow water at the sediment/water interface can be up to ten degrees colder than *Scirpus* zone water. This suggests that groundwater inputs as well as shading by the dense vegetation are important in the wet meadow.

6.5 Human Impacts

6.5.1 Nutrient enrichment. Suspected sources of nutrient enrichment in the Les Cheneaux area are sewage effluent from the wastewater treatment facility in Cedarville, leaking septic systems, and the application of fertilizers to lawns adjacent to the shoreline. We only attempted to study the wastewater discharge into Cedarville Bay because it is the main potential point source of nutrients in the area. While water chemistry in Cedarville Bay is not detectably different from that in other bays, the broad stretch of wetland located along the west shore, southward from the creek mouth and boat ramp, shows other signs of nutrient enrichment. These include dense growths of floating filamentous algae, dense submergent plant growth, especially of species that thrive in high-nutrient conditions (e.g. *Elodea*), and a very mucky bottom.

6.5.2 Building development. A number of different measures of the degree of building development around several of the bays were developed to examine their potential impacts. The number of developed properties per decade (Figure 7) and the total number of developed properties (Figure 7) has increased slowly but steadily over the last century with the largest growth around Cedarville Bay. While the number of developed properties has continued to increase, the size of the buildings being constructed (building "footprint") has remained relatively constant (Figure 7). The 1998 shoreline building density, including homes, boat houses and docks, was greatest in Cedarville Bay and very low in Prentiss Bay (Figure 8). This trend was also seen in the amount of boat use in the bays (Figure 8).

6.5.3 Roads. Roads around the bay shoreline may have significant ecological effects on the wetlands, causing altered hydrological regimes or introducing pollutants (e.g. road salt, automobile fluids). The road density (length of roads/land area) of the five bays studied was greatest around Prentiss Bay (Figure 9). Cedarville, Mackinac and Mismer Bays had intermediate densities and McKay Bay had the lowest road density.

6.5.4 Impervious surface area. Impervious surface area (roads, buildings, paved areas) was the greatest around McKay and Cedarville Bays (Figure 9) The mining activity in Port Dolomite on McKay Bay and the town of Cedarville on Cedarville Bay contributed to the large area of impervious surface at these sites. Around the other bays, roads were the primary impervious surface.

7. Project Results: Patterns in Community Composition

7.1 Plants

The vegetation zonation pattern we found in the Les Cheneaux coastal wetlands was typical of wetlands with a continuous gradient of conditions from upland down to deep water. Figure 5 is a schematic view of the zonation common to the sites.

7.1.1 Wet meadow zone. The wet meadow zone was characterized by plants that cannot survive extended flooding, or are outcompeted after long periods of flooding. Despite occasional years of high water, such as 1997, wet meadows occurred at elevations above the long-term average water level, but still low enough to be seasonally flooded or at least experience soil saturation through most of the year. The Les Cheneaux wet meadows can generally be sub-categorized as "sedge meadows" because they were dominated by sedge species in the genus *Carex*. In addition, a great variety of plants occurred in wet meadows, making these zones the most diverse parts of coastal wetland complexes.

The "high" wet meadow was dominated by the presence of the hummock-forming sedge *Carex stricta* and the common occurence of shrubs and grasses. The common shrubs included several species of willow (*Salix* spp.), sweet gale (*Myrica gale*), shrubby cinquefoil (*Potentilla fruticosa*), and others. The only very common grass was Canada bluejoint (*Calamogrostis canadensis*) but cutgrass (*Leersia oryzoides*) and reed canary grass (*Phalaris arundinacea*) were sparsely distributed in several sites.

The "low" meadow was dominated by the sedges *Carex lasiocarpa* and *C. aquatilis*, although several other species were found in most sites. We also found a relatively high density of several broadleaf species such as bellflower (*Campanula aparanoides*), tufted loosestrife (*Lysimachia thyrsiflora*), and more conspicuous, but sparse, plants such as blue flag (*Iris versicolor*), rushes (*Juncus* spp.), and twig rush (*Cladium mariscoides*).

The sedges were important to the overall physical structure of the wetlands because their dead stems and leaves persisted through winter. This dead material layed down over the soil to varying degrees, creating substantial shading and ultimately becoming part of the coarse detritus base overlying the soil. Coarse detritus is an important food and refuge source for many invertebrates and is likely an important source of carbon to the aquatic community.

7.1.2 Transition zone. The transition zone was very important because it indicated the approximate average water level and delineated the division between permanent emergent marsh and temporarily-flooded meadow. The transition zone was aptly named because the upper elevations of the zone were characterized by mixtures of wet meadow plants with transition zone specialists, while emergent marsh plants mixed with these specialists in the lower elevations. Given this, the transition zone can be seen as a gradual thinning of wet meadow vegetation giving way to emergent marsh plants, with the entire transition bridged by cattails and a few other species. In general the transition zone was where cattails (*Typha angustifolia* and *T. latifolia*) dominated, but they were not common in all sites, so many other plants were able to specialize in the varying conditions of the transition zone. Spike rush (*Eleocharis smallii*) and water smartweed (*Polygonum amphibium*) were intermixed with bulrushes (*Scirpus acutus*) where cattails were not dominant.

7.1.3 Emergent marsh zone. The emergent marsh zone was dominated by bulrush all the way out to its deep-water fringe. In the more protected inner emergent marsh with its siltier substrate, diversity was high. Common emergent plants in this zone were arrowhead (*Sagittaria* spp.), pickerelweed (*Pontedaria* spp.), and bur-reed (*Sparganium* spp.). The floating-leaved spatterdock (*Nuphar variegata*) was very common, as was floating pondweed, *Potamogeton natans*. A variety of submergent plants co-occurred in the protected shallows: *Myriophyllum excalbescens*, *Ceratophyllum demersumi*, *Utricularia* spp., *Hippurus* spp., *Najas flexilis*, *Ranunculus longirostris*, *Megalodonta* spp., *Vallisneria americanus*, etc. In many areas a lawn-like covering of the short, rooted *Scirpus subterminalis* was obvious. All of these plants were more sparse further away from shore until only bulrushes were found in the more wave-swept, sandy-bottomed outer edges of the emergent marsh.

Open water patches, where the bottom was cleared of rooted vegetation, were common within the emergent marsh. These bare areas persisted from year to year, but the mechanisms of their creation and maintenance were unclear. We observed signs of high muskrat and beaver activity in some sites, including networks of trails through wet meadow and transition zones, floating mats of chewed-off plant stems, lodges and dams, and recently-cleared areas in the vegetation. We suspected that these mammals may have been responsible for some of the vegetation-cleared areas.

7.2 Meiofauna

From core samples taken in the wet meadow and emergent marsh areas of six wetlands, we identified 86 taxa ranging from the very small (62-93 µm) copepod nauplii (immature stages), *Difflugia* (a cased, amoeboid protozoan), and rotifers, to oligochaetes up to 25 mm in length. Overall densities ranged from 0.6-3.6 million invertebrates m^{-2} with densities highest in the silt habitat at Duck and Prentiss bays and in the sedge/hummock habitat at Mismer Bay. Benthic cladocerans ("water fleas") were quite common in samples with individual taxa densities ranging from 39,000 to 137,000 m^{-2} with areal distribution and habitat unique to each group. For example, *Acroperus* was only common in Mismer Bay in the sedge/hummock habitat, *Alona* was widely distributed but densities were always highest in the silt habitat, and *Chydorus* was widely distributed and commonly found in both habitats. Cyclopoid and harpacticoid copepod densities ranged from 78,000 to 332,000 m^{-2} with both groups widely distributed but with harpacticoids more common in the sedge/hummock habitat. *Difflugia* was widely distributed in space and habitat with densities ranging from 39,000 to 1.7 million m^{-2}. *Hexagenia* eggs were found only at Prentiss Bay in the silt habitat with estimated densities ranging from 78,000 to 332,000 m^{-2}. Chironomids, ceratopogonids, and fingernail clams were common macrobenthic taxa found in the core samples.

In addition, microcrustaceans were collected, but not quantified, in activity traps that were placed in select emergent marshes. Common genera of cladocerans found in these samples included the large-bodied *Sida* and *Simocephalus*. Members of the families Macrothricidae and Chydoridae were also very common. Harpacticoid copepods, being more associated with sediments, were not as common as cyclopoid copepods in these water-column samples. Many ostracods and occasional calanoid copepods were also taken in these samples.

7.3 Inshore Macroinvertebrates.

Invertebrate communities in the inshore wetland zones were dense and diverse. Of the insects, we identified eight families of Hemiptera, and seven families of Coleoptera. We sampled Odonata in the families Aeschnidae, Coenagrionidae, Libellulidae, and Lestidae, with Coenagrionidae being the most abundant. No Macromiidae or Gomphidae larvae were collected in our sampling, although adults of both of these dragonfly families were observed ovipositing in the marshes. Four families of mayflies were collected, however, over 99% of the individuals were members of the family

Caenidae. Few Ephemeridae (burrowing mayflies) larvae were collected, though large numbers of their exuviae were observed. These mayflies reside in the nearshore zone and outer marsh fringe. The large number of shed exuviae observed floating in the wetlands were presumed to have been blown inshore by the wind.

In general the aquatic insects followed a univoltine life-history, with reproduction occurring during the summer. Most insect species appeared to emerge during the summer, but some segregation of emergence times was apparent. For example, Aeschnidae dragonflies seemed to emerge mostly in early summer, *Libellula quadrimaculata* in June/July, and the assemblage of *Sympetrum* species in August. *Sympetrum* is a genus of small-bodies species, so they may have synchronized their emergence with the mass emergences of the very small *Caenis* mayflies, a likely prey species. Most insects overwintered as intermediate-instar larvae, though a few species were very mature during winter and emerged as soon as the ice thawed. One such example is an unidentified wet meadow Limnephilidae caddisfly species, whose empty cases we collected in large numbers in May, but only rarely did we capture a larva.

Among non-insects, the Gastropoda (snails) assemblage was especially diverse, consisting of eight families and many more species. Macrocrustaceans (Amphipoda, Isopoda, Decapoda) were not diverse, but were very dense. Amphipods and isopods were two of the most common invertebrate groups, found in densities similar to those of Chironomidae and Caenidae, the dominant insects. Crayfish (Decapoda) were apparently very abundant, but we did not study them formally because our sampling methods were biased against them. Our observations of crayfish were based primarily on incidental catches in fish-trapping gear.

7.3.1 Invertebrate community composition by plant zone. There were marked trends in invertebrate community composition across vegetation zones as indicated in correspondance analysis displays (Figures 10-12). It was difficult to ascertain whether this is caused by a water depth gradient, a vegetational gradient, or both because both the water depth and vegetational composition changed with increasing distance from the shoreline.

We conducted a correspondence analysis (CA) for each bay and date separately. In most cases, the four vegetational zones separated in sequence, producing a "gradient" describing the invertebrate communities. Two-dimensional CA displays accounted for approximated 70 - 90% of the variation; thus, they were accurate depictions of the community structure. For Duck and Mackinac Bays, the first dimension of the CA display separated Zone 1 (wet meadow) from the other three, and the second dimension separated Zones 2, 3, and 4. Very marked and consistent species associations were present around these Zones. As indicated in Figure 10, for example, Ceratapogonidae and Dytiscidae were seen to be very strongly associated with Zone 1 while Bithynidae, Chrysomelidae and Baetidae were very strongly associated with the other end of the gradient, Zone 4, plotting farther from the center than even the Zone 4 points. Physidae, Gerridae, and other taxa displayed mid-way between Zones 1 and 2 while Caenidae occurred mid-way between Zones 2 and 3. These taxa were strongly associated with more than one zone. Chironomidae were displayed midway between Zones 1 and 4 reflecting high abundance in both zones but relatively little association with Zones 2 and 3.

In general, associations among taxa and among zones were relatively constant among bays and dates. While very few taxa were restricted to only one vegetation zone, it was possible to identify three distributional patterns with respect to the depth/vegetation gradient through analysis of the CA displays and the relative abundances of taxa in each vegetational zone.

7.3.1.1 Wet meadow or shallow water-associated taxa. These organisms displayed either remarkably higher relative abundance in or tight association with Zone 1, or a distinctly decreasing abundance with increasing depth. Many taxa exhibited this distribution including: five families of Coleoptera; three families of Hemiptera (Hydrometridae, Gerridae, and Nepidae), Libellulidae dragonfly larvae; Sphaeriidae; and most gastropods (Physidae, Planorbidae, Bithynidae,and Lymnaidae).

7.3.1.2 Transition zone. These taxa displayed either tight associations with or markedly higher relative abundances in Zone 2, Zone 3, or both. Most of these taxa were present in the other zones as well, but occurred in lower abundances there. This distributional pattern was observed for Gyrinidae, Sciomyzidae, Tipulidae, Caenidae mayflies, Belastomatidae, Mesoveliidae, Lepidoptera, Aeschidae and Coenagrionidae (Odonata), and Phryganeidae and Polycentropodidae (Trichoptera).

7.3.1.3 Offshore emergent or deep water-associated taxa. Either a markedly higher relative abundance in Zone 4 or an obviously increasing trend in relative abundance with increasing water depth characterized distributional patterns of these taxa. These taxa included three mayfly families (Baetidae, Ephemerellidae, and Ephemeridae), Corixidae, Leptoceridae caddisflies, Hydrobiidae, Ancylidae, and mites.

7.3.2 Difference between sampling dates. Community composition was similar on different sampling dates. Shifts that were apparent can be attributed to either increased water levels from the June sampling dates to the August dates or changes in abundance/species composition due to the phenology of adult emergence, oviposition and larval maturation. For instance, a comparison of June vs. August data reveals that Libellulidae dragonfly larvae were strongly associated with the wet meadow (Zone 1) in June but were associated with deeper zones in August. A likely explanation is that the species composition of the Libellulidae changed over the summer. *Sympetrum* larvae were numerous in wet meadow areas, but began emerging in August whereas adults of *Libellula* and *Leuchorrinia* genera oviposited early in the summer in deeper areas.

7.4 Nearshore Macroinvertebrates

7.4.1 General community. Nearshore benthic macroinvertebrates were compared among depth ranges and dates. The benthic macroinvertebrate densities in the nearshore areas ranged from 9,440-25,740 m^{-2}. Densities in the fall (~21,000 m^{-2}) were significantly larger than densities in the spring (~15,000 m^{-2}). Taxa richness (the average number of taxa per sample) was variable with no differences among dates or depths. However, diversity measures showed differences among depth zones. The 2-3 m depth was the most diverse, except for Cedarville Bay where the most diverse community was in the 3-4 m depth. The least diverse area was the 1-2 m depth in Cedarville Bay.

7.4.2 Burrowing mayflies. Particular attention was paid to burrowing mayflies of the family Ephemeridae because of their known sensitivity to pollution. Two species of burrowing mayflies were found in the Ponar grab samples, *Hexagenia limbata* and *Ephemera simulans*.

Hexagenia limbata was found in 85% of the samples with a mean density of 210 m^{-2}. Nymph lengths ranged from 2-35 mm and the length frequency distribution suggests two cohorts in each sampling period. Densities were the highest at McKay Bay in May (260 m^{-2}) and Mackinac Bay in September (730 m^{-2}). Otherwise, densities were fairly uniform over the four sites, except for the complete absence of nymphs from the 1-2 m strata in Cedarville Bay. Differences in nymph densities in various substrates were also noted: 130 m^{-2} in sand, 230 m^{-2}in sandy silt, 210 m^{-2} in silty sand, and 240 m^{-2} in silt.

Ephemera simulans was found in 31% of the samples with a mean density of 40 m^{-2}. It was absent in Cedarville Bay and only two individuals were found in Moscoe Channel. The nymphs were found almost exclusively in sand substrate(170 m^{-2}) with 0-40 m^{-2} in silty substrates. Samples from Search and St. Martin's Bays supported this conclusion. In the mostly sand substrates of Search Bay, the nymphal abundances of *H. limbata* and *E. simulans* were about equal. In the silty substrates of St. Martin's Bay, *H. limbata* accounted for 99% of the burrowing mayflies.

Both species were absent or at very low densities along the shoreline (0-2.3 m), depending on the exposure to wave action. Densities peaked at 3.8-6.9 m then declined. In water greater than 12 m depth, nymphs were rarely found. Densities of both species in Search Bay at the 3.8-6.0 m depth interval varied from 250-420 m^{-2} and *H. limbata* in St. Martin's Bay varied from 310-500 m^{-2}.

Hexagenia and *Ephemera* are known to disturb soft sediments in the process of excavating the burrows that they inhabit (called bioturbation). This observation led to a study of this phenomenon in the Les Cheneaux Club region of Mackinac Bay. It was found that the degree of bioturbation corresponds to the average size of the mayflies present. Early in the summer, before the larval mayflies emerge, there was a higher degree of bioturbation than immediately after emergence and in the fall when only the younger and smaller cohorts remain. The bioturbation may help to maintain an oxygenated zone on the floor of the bay which may help to ensure their continued presence in the substrate. It may also enable colonization of this area by other aquatic invertebrates which would otherwise be excluded by anoxic conditions. This would be likely to occur until such a point in time that the bioturbation and aeration could not keep up with the demand for oxygen placed on the system by an increased amount of pollutants and stimulated plant growth.

7.5 Fish

7.5.1 Wet meadow zone. We collected fish in the wet meadow zone using activity traps in all three years at Mackinac Bay. In "average" water level conditions, we measured lower dissolved oxygen levels in the wet meadow than in the more exposed water of the emergent marsh. Thus, tolerant fish species such as mudminnows (*Umbra limi*) and bowfin (*Amia calva*) which can gulp air during low-oxygen conditions are expected to be more common. In fact, we found mudminnows to be the most common fish in the wet meadow. Bowfin and the relatively tolerant largemouth bass (*Micropterus salmoides*) were also fairly abundant.

Less abundant, but still relatively frequent visitors to the wet meadow were YOY yellow perch, and Iowa darters (*Etheostoma exile*). It is likely that these oxygen-sensitive fish make temporary forays into the wet meadow, either to feed or to avoid predators. We frequently observed fish swimming into the meadows and out again repeatedly during the day. It appears, then, that flooded wet meadows are important habitat, even for some fish that cannot occupy them for long periods of time.

In 1997 the wet meadows were flooded to a much greater depth than the previous year, and dissolved oxygen was presumably higher in these waters. Mudminnows were less abundant in traps, and bass and bowfin were not only abundant, but were larger in size than those measured during the same sampling times the previous year. Also, YOY bullhead and pumpkinseed, which had only been present in the *Scirpus* zone previously, were abundant in the meadow. This suggests that fish shifted their distributions in response to the higher water. Larger fish may also have been present, as a single fyke net sample suggests, but the activity traps were size-limited, so only small fish were collected.

7.5.2 Transition zone and emergent marsh. From the transition zone out to the inner emergent marsh (*Scirpus*) zone, the icthyofauna was dominated by many of the same species mentioned in the previous section: bullhead, bass, perch, pumpkinseed, bowfin, occasional mudminnows, darters, and various other species. Also, cyprinids (minnows) were abundant, but not in all bays, as discussed in the "human impacts" discussion below. Communities differed somewhat between seasonal and permanent marsh areas (Figures 13 &14).

Larvae were found in all three bays sampled from spring to the onset of winter. Ten families of larval fishes were found. Larvae from different taxa appeared at different times of year, starting with the winter-spawning coregonids and ending with the often iteroparous sunfishes and cyprinids. Thus larvae partition the time resource, presumably to minimize competition among life-stages with very similar initial food requirements. Larvae were most abundant and speciose in permanent marshes, but some taxa were found only in seasonal marsh and open water. Differences in larval fish communities among bays were small.

Permanent marshes appeared to be more valuable as nursery habitats, in that diversity and abundance of fish larvae were higher in these areas than in seasonal marshes. However, it is important to note that seasonal marshes, open water, and beaches are possibly irreplacable nursery habitat as well, because certain larval taxa were found only in these areas. The same statements can be made about post-larval juveniles and adult fish.

The value of permanent marshes as nursery areas may have been related to the more dense and diverse plant communities found there. The number of larval taxa and larval abundance were compared with an index of plant density and complexity in the larval habitats. These measures of larval community were more strongly affected by this habitat diversity due to macrophyte composition than human impacts due to development. It appears that complexity in the macrophyte composition provides areas of protection from predators and varied feeding areas that are beneficial to fish breeding and/or larval survival.

7.6 Bay-to-Bay Variation

In general, biotic differences among the Les Cheneaux sites were not large. Some bay-to-bay differences were detected in plant and invertebrate data, but they were: 1. not usually very strong differences, and/or 2. not always consistent among years, and/or 3. did not suggest strong patterns of environmental characteristics that affect the biota. The exception was Cedarville Bay, which is discussed below. More noticeable differences were found in the fish communities among bays and there was evidence that some of this resulted from human development pressures on the bays (see Section 9.1).

Plant zonation is similar among bays, although some sites have a cattail-dominated transition zone, while others do not. However, high-density cattail monocultures, as found in many other wetlands, are not found in the study sites. The only vegetation differences among sites seem to reflect wave-energy exposure: the least protected sites, and sample stations within sites, are notable for their lack of rich submergent communities. Emergent plants can also be less dense and less diverse in such areas.

Inshore invertebrate communities did not differ strongly among bays either (but, again, Cedarville is an exception as discussed below). As an example, Mismer, Mackinac, and Duck Bays were similar in the total number of invertebrate taxa present, but the relative abundances of the most dominant taxa varied among the bays. However, from year to year the dominant taxa appeared to change from site to site, so fluctuations in the individual populations of the dominant groups (isopods, amphipods, chironomids, Caenidae mayflies) appear to be independent of each other or of site-specific environmental characteristics. However, among-year differences in sampling methodology and concerns about data "noise" from spatial variation masking true differences preclude our making an absolute statement about bay-to-bay distinctions.

To partly address the sampling concerns mentioned above, we carried out a one-time multi-bay comparison of inshore invertebrate communities using the same method at all bays. As in earlier efforts, we found differences among sites in the dominant taxa, but they did not correspond well with earlier data sets, suggesting no consistent pattern of dominance within sites, hence no consistent differences among sites. It was clear, however, that differences in some taxa among some sites could be detected over the noise of within-site variability (Figure 15).

Nearshore benthic macroinvertebrate densities at Cedarville Bay and Moscoe Channel (~25,000 m^{-2}) were significantly larger than those at McKay and Mackinac bays (~11,000 m^{-2}). On average, Mackinac Bay, with 26.2 taxa, had significantly more than the 21.5 taxa at McKay Bay. Moscoe Channel and Cedarville Bay were not significantly different from Mackinac and McKay Bays. Using clustering techniques, the overall community makeup was most similar in Mackinac and McKay Bays and most dissimilar in Cedarville Bay. When the data set was reduced to include taxa that represent a single species or taxon with a distinctive habitat, Mackinac and McKay Bays were again most similar, but Moscoe Channel was the most dissimilar.

The initial year's data on juvenile and adult fish in the nearshore zone and the most open beach-like areas of marsh showed little difference between Cedarville and Mackinac Bays, and between St. Martin's and Mismer Bays. However, significant differences were found between the pairs of bays (Figures 13 & 14). Subsequent intensive sampling of the inshore marsh habitats showed significant differences between Cedarville, Mackinac and Mismer bays in terms of richness, numbers of cyprinid species and the proportion of individuals from more tolerant species. These differences were most marked for juveniles, but the same trends were apparent among larvae. In general, richness decreased, cyprinids became rare (or disappeared in Cedarville), and the proportion of tolerant individuals increased as human development increased. Some of the resulting correlations were significant, and significant relationships were found when an Index of Biotic Integrity based on these measures was regressed against an index combining major development measures. In addition, although Mackinac Bay appeared very much less developed than Cedarville Bay, its fish community may have deteriorated more than would be expected on the basis of that development. Thus, some of the bay-to-bay variation in the fish community can be explained by human impacts, but the role of other environmental characteristics remains less clear.

8. Discussion: Environmental Influences on Marsh Communities

8.1 Effects of Water Level Fluctuation on Plant Communities

8.1.1 Long-term. The long-term variation in Lake Huron water level is possibly the most important ecological influence on the biota of coastal wetlands. Its direct effects are on plant community zonation and on the distribution of biota through water depth effects. It's most powerful impacts, however, result from its interaction with plants to create gradients that affect animals, and even feed back to affect plants.

The literature suggests that plant communities respond to long-term water-level changes by gradually migrating shoreward during rising water periods and lakeward during declines. It is unclear, however, how quickly such changes occur. Because we observed a relatively rapid rise and fall of water levels, we are able to draw some conclusions about the immediate effects of multi-year water level changes. In general the plant community responded conservatively over the three-year period.

Periodic high-water periods serve the purpose of excluding shrubs from lower wet meadow areas in coastal wetlands. Also, we observed decreased emergent stem density and lower plant diversity during and after a high-water period. At the same time, diversity in the deeper emergent marsh increased slightly, and the submergent bladderworts (*Utricularia* spp.) spread into the wet meadow. The dominance of three *Carex* species unexpectedly increased, even in the emergent marsh zone, and many rare species declined or disappeared from the wet meadows of the area, although they presumably remained on-site in the soil seed bank.

Low-water periods appear to have opposite effects on plant zones from the high water effects. We observed a partial recovery of plant species diversity and stem density in 1998, and several species that declined in 1997 showed some recovery in 1998, although this was not true for all plants (e.g. *Juncus* spp., *Phalaris arundinacea*).

8.1.2 Seasonal. The seasonal water-level fluctuation seen in most years most likely affects animal communities more than plants. Because high water is not generally reached until mid- to late summer, wet meadow plants that are depth-limited have already had a chance to attain shoot lengths that can make them less vulnerable to inundation. Nonetheless, the temporary flooding of wet meadows probably contributes to the exclusion of flood-sensitive plants from these zones. At the other end of the gradient, the increased water depth in the summer may hinder light-limited plants at the deep fringe of the wetland. However, the clarity of Les Cheneaux water suggests that the additional depth (about 20 cm) is probably far less influential than the light attenuation caused by the already-deep water and the exposure to wave energy that is common in such deeper water.

8.1.3 Seiches and storm surges. While seiches cause water levels to fluctuate continuously on an hourly and daily basis, we can only speculate on their effects on the coastal wetland biota because we did not study these effects directly. Probably the most significant effects of short-term water movements are caused by the occasional storm surges that can raise water levels a meter or more and can batter the wetlands with strong waves. The disturbances caused by these surges, and the subsequent recoveries of the biota are an interesting area for future study.

8.2 Effects of Water Level Fluctuation on Animal Communities

Multi-year water-level changes are as influential on animal communities as they are on plants, though perhaps the effects are not as persistent. High water creates broad expanses of new aquatic habitat, and even higher water is likely to make this habitat more desirable to oxygen-limited animals as greater horizontal mixing brings dissolved oxygen into upper wetland areas. This is probably why we observed fish invading wet meadows when they were most flooded in 1997. Simultaneous changes in invertebrate communities suggest that invertebrates, too, respond to water level changes, though the effect may be indirect as invertebrates are likely affected by changing fish predation pressures.

By contrast, low-water periods dewater the densely-vegetated upper wetlands, forcing animals into lower areas where protection from plants is lower (although submergent plants may make up for the lower emergent density). Only animals with resistant stages can survive the de-watered period in the upper wetland, so some animals that are "stranded" in the wet meadow when the water recedes will not survive. Our data suggest that this may be an important control on the total productivity of invertebrates in the Les Cheneaux wetlands.

9. Discussion: Human Impacts on Marshes

9.1 Landuse

9.1.1 Roads. Road development in the Les Cheneaux area can impact the marshes in a variety of ways. The road is an impervious surface that increases precipitation runoff and erosion as well as introducing contaminants (road salt, automobile fluids) to the marshes. In some locations, road construction has reduced the size of marshes, fragmented them, or altered their hydrology.

Prentiss Bay has the greatest road density (road length/ land area) surrounding the bay primarily as a result of the small area on the surrounding peninsulas. M-134, the main highway along the coastline, runs directly through the bay, separating the shallow wet meadow from the deeper, bulrush marsh. The wet meadow is connected via culverts but the hydrology is greatly altered. The effects of the roads cannot be separated greatly from other effects, but the invertebrate and fish communities are somewhat less diverse than other bays. It appears that the disconnection of the wet meadow from the deeper emergent marsh in this bay and others significantly alters the communities using them.

Of the bays for which road density was calculated (this does not include the bays on Marquette Island), Mackinac Bay has the lowest road density within 1 km of the water, but it is also impacted by M-134, which separates the bay from a large wetland to the north. However, unlike Prentiss Bay, there is still an extensive wet meadow zone that may help to buffer the deeper parts of the marsh from the effects of the road. The plant, invertebrate, and fish communities of Mackinac Bay are relatively diverse, even with the presence of the road.

Cedarville Bay has a relatively high road density, and the flora and fauna are the most impacted in the area. Again, there are multiple impacts, but the roads along with the building development has reduced the amount of wet meadow adjacent to the deeper marsh. There is an intact wet meadow on LaSalle Island, and a wet meadow west of the Taylor Lumber Co. and Meridian Road that is connected to the deeper marsh only via Pearson Creek. For much of the shoreline around Cedarville Bay, the marsh is absent or drops off immediately to deeper emergent marsh vegetation (cattail, bulrush and submergent plants).

9.1.2 Urban development. Urban development is most pronounced around Cedarville Bay as the town of Cedarville continues to grow. However the entire area continues to show increased development of shoreline properties. The building of homes, driveways, roads, parking lots and small businesses eliminates wetland habitat and increases the effects of runoff and other impacts.

Not surprisingly, the impervious surface area surrounding the marshes is greatest in McKay and Cedarville Bays. McKay Bay is bordered by Port Dolomite on the east side and numerous residences along the west and southwest. It is subject to wave action and marsh development is not extensive. The water quality seems to be good since there are large numbers of burrowing mayflies in the nearshore sediments.

Cedarville is impacted by development as well as by roads (see 9.1.1). It has the highest number of shoreline buildings (including docks and homes). In many cases, home owners have cleared the marsh vegetation from a portion of their shoreline or have cleared a path for their boats. The resulting fragmentation of the emergent marsh may have a significant impact although it has not been studied specifically. Fragmentation increases the ratio of edge to marsh area (edge effect) compounding the effects of wave action from boats as well as wind. This seems to be especially important since Cedarville Bay has the greatest boat density confined to a relatively small area. Other effects of fragmentation may have equal or greater impacts and deserve to be studied.

9.2 Nutrient Enrichment

As noted above, the water of Cedarville Bay did not have elevated nutrient levels during much of the year, yet the biota indicated probable organic enrichment. This condition of eutrophic biotic conditions without high nutrient levels in the water column is not surprising. Water-column nutrients are quickly taken up by the biota, especially when organism density is already high before the nutrient introduction. Also, nutrients, especially phosphates, quickly sorb to substrate particles if not first intercepted by biota. As a result of these mechanisms, nutrients have low residence times in the water column and, unless constantly replenished, their levels will not remain high.

9.3 Introduction of Exotic Species

The introduction of exotic species into the marshes of the Les Cheneaux area has the potential to change them substantially. Several exotic species are present; five established species are described below.

9.3.1 Eurasian Milfoil. Eurasian Milfoil is a submerged plant that can outcompete many native species. Currently, it is found in high density in Cedarville Bay around the public boat dock.

9.3.2 Zebra mussels. Zebra mussels have been increasing in number in the Great Lakes for over a decade, and can have dramatic effects on resident organisms and the structure of food webs. At present, zebra mussels are most abundant in the Les Cheneaux area in nearshore areas, especially on rocky substrates. They only rarely are recovered in the shallow marsh habitat but are relatively abundant at the deep marsh edge and casual observations suggest that they are increasing in number.

9.3.3 Rusty crayfish. Rusty crayfish is an aggressive species that tends to displace native species of crayfish as well as alter the habitat by cutting and consuming plants. While the majority of our sampling methods do not collect many crayfish, recent work using baited minnow traps has increased the number of individuals sampled. The majority of rusty crayfish are found in Mismer Bay where they could seemingly cause serious impacts. One individual has also been found in Cedarville Bay. This species of crayfish has not been collected in the other bays yet.

9.3.4 Carp. Carp have been a part of the marshes for a long time and many people may not realize that they are an exotic species. Some aspects of the marsh dynamics are probably affected by the carp, but the carp are a well incorporated part of the current marsh communities. They are most common in the marshes during spawning in early summer, when their aggressive swimming uproots vegetation and perturbs the substrates. These disturbances increase the heterogeneity of the habitat in the marshes and probably to some extent contributes to the overall diversity.

9.3.5 Alewife. Alewife is an exotic species that is an important food source for some large game fish. While abundant in offshore regions of Lake Huron, we find them infrequently in the coastal marshes, and it is unlikely that they have much of an impact there.

10. Discussion: Trophic Interactions

10.1 Food Webs

Food webs can be inferred from known feeding habits of many animals, but the only data we collected related to feeding were from stomach contents of fish.

Cluster analysis was used to search for feeding groups among the 51 species of fish analyzed. Five to nine groups were formed depending on the clustering method used. An insectivorous group included some of the more common species collected along the northern Lake Huron shoreline such as pumpkinseed, banded killifish (*Fundulus diaphanous*), brook stickleback (*Culaea inconstans*), and Iowa darter. Banded killifish also consumed many ostracods, and brook sticklebacks were more generalist feeders than the rest in the group, consuming many seeds and microcrustaceans. Juveniles of some species, such as the sand shiner (*Notropis* stramineus)and adults of northern redbelly dace (*Phoxinus eos*) formed a second group feeding primarily on algae. A third group included juveniles of many species plus a few adults, such as ninespine stickleback (*Pungitius pungitius*), which are planktivores. Johnny darters (*Etheostoma* nigrum) fell into this group but we found them to feed mainly on chironomid larvae. A piscivorous group included bowfin, bass, northern pike (*Esox lucius*), and burbot (*Lota lota*). Yellow perch was in this group but our studies indicate that their piscivory depends on locality of capture.

Special attention was given to yellow perch feeding because of their importance to the local economy. Larval yellow perch were treated separately from the other age classes in an attempt to see whether there was any difference in feeding habits of the larvae between bays. Larval yellow perch appear to be very opportunistic in their food selection. The larval yellow perch collected in Flower Bay primarily ate *Bosmina* (a small cladoceran) while those from Sheppard Bay ate more biofilm (Figure 16). Biofilm is a collective grouping of food items which includes algae, protozoans, rotifers, and unidentifiable material growing on the surface of aquatic plants, logs, rocks, etc.

The post-larval yellow perch were grouped using a k-means statistical analysis which groups individual fish into clusters based upon similar type and quantity of prey eaten. A breakdown of fish into 11 clusters, grouped by size, provided the best illustration of their feeding habits (Figure 17). The first three clusters represented a few slow-growing one-year-old perch and the young-of-the-year perch. The cluster representing the smallest perch ate primarily small cladocerans (Table 1). The next clustered grouping ate mainly copepods and medium-sized cladocerans while the larger fish in this grouping ate larger cladocerans, such as *Sida*, and chironomid larvae. The prey eaten by perch in these three clusters may be planktonic, plant-associated, or benthic. Even though they did not show the variation in food consumed that the next four clusters did, there was still a fair amount of variability in prey eaten.

The middle four clusters were those yellow perch that fall into the young-of-the-year and one-year-old size range. They had a much more varied diet than the other sets of clusters. Their preferred foods were a variety of small- to medium-sized insect larvae, amphipods, isopods, and larger copepods and cladocerans (Table 1). The prey consumed by these perch were more typically plant-associated, but some also fell into the benthic and planktonic categories. There was a trend in decreasing prey item size with a decrease in fish length. These clusters were very similar in their composition. Seasonal changes influenced the composition of these clusters.

The final four clusters represented large perch which ate other fish (mainly 9-spine stickleback and sculpins), larger aquatic insect larvae, and crayfish (Table 1). These prey were most commonly found in open-water situations or on the bottom, although some were plant-associated. There was no direct link between prey consumed and season or the sex of the perch. These perch ate fewer different food items as compared to the previous group of clusters. Again, a trend in the relationship between fish size and prey length was apparent. Although these larger fish were capable of eating prey more typical of the smaller fish, and on occasion did so, they most often ate the larger-bodied prey. This suggests that food resources are not limiting for the older perch.

Comparisons of food consumption among Cedarville, Mackinac and Mismer Bay fish was made difficult because different species were most abundant in different bays. Of the species found in these three bays in sufficient numbers to obtain multiple stomachs, food habits were typical of those described above, and no differences were found among bays.

In spite of some dietary separation among groups of fishes, most of the marsh fish were opportunistic omnivores. Overall, food is not seen as being a limiting factor at this time. Certainly we have no evidence of different limiting production of fish prey in comparing growth rates of fish in Cedarville, Mackinac and Mismer bays. Thus growth rates measured from scales, although somewhat variable, did not differ for large-bodied species. The record in the scales begins before the start of our studies, with some fish being seven years old, so that the lack of differences in growth rates of these fish from different bays suggests our observations for three years are not atypical. Measuring growth rate for small-bodied fish and larvae was not judged useful for comparing among bays. This was because dominant species differed among bays, negating comparisons among more than a pair of bays at most. Nevertheless, although these data are not strong, there were no indications of differences in growth rates of similar fish in different bays. Other factors may alter the trophic patterns in the future. Zebra mussels, not common in the marshes but abundant in offshore waters, could impact deeper-water populations of yellow perch which we have not studied as well as inshore fishes as they spread further into the system. Colonization of the area by round goby could also upset the predator-prey balance within the islands.

10.2 Chironomids as Bird Prey

The potential role of the marshes as a source of adult midges eaten by migrating warblers was investigated at Search and Dudley Bays. Migration is a stressful part of a songbird's life history and stopover sites that provide feeding opportunities along the migration route are vital. Observations of migrating songbirds along the coastline of the eastern Upper Peninsula have found songbirds to be feeding on adult midges. Interactions between the aquatic and terrestrial environment are an often overlooked function of the coastal wetland. Differences in abundances of midges were found between the two bays as well as various substrate/tree types. It remains to be seen whether the birds are able to cue in on these differences during their stopover.

11. Potential Tools for Monitoring Wetland Integrity

11.1 Indicator taxa

The use of indicator taxa or groups of taxa to assess the integrity or environmental health of various habitats can be helpful. The diversity of taxa present in the Les Cheneaux area indicates the integrity of most of the marshes at the current time. However, with the increase in population and associated development, it is likely that impacts to the marshes will continue to grow. The ability to assess the effect of the impacts of the marsh flora and fauna will become critical since early detection of degradation is important when implementing protective measures. The following are several types of indicators that could be used in the Les Cheneaux area for this purpose.

11.1.1 Mayflies. Mayflies, especially of the genera, *Hexagenia* and *Ephemera*, are well documented as sensitive species to human impacts such as organic pollution. These mayflies burrow in the sediments in the nearshore region and require clean, well-oxygenated water. Organic pollution generally increases the production of algal and macrophyte densities. As these decompose, oxygen is depleted in the substrate which makes such substrates unsuitable for the mayflies.

As mentioned above, mayflies are absent in shallower regions of Cedarville Bay and their densities are somewhat reduced in Moscoe Channel. In these two locations, organic pollution from the wastewater treatment lagoons and from septic system leakage appears to have the greatest effect. Continued monitoring of the mayflies in these regions may be able to document any drastic changes in the nutrient loads to the bays. In other bays, monitoring of the mayflies may indicate the increase of nutrients to damaging levels.

11.1.2 Rare species. Rare species in the area can be used as indicators of the water quality. Often, the rare species require very specific conditions that only a pristine, unimpacted marsh can provide. Perhaps even the slightest perturbation of the habitat can be enough to eliminate or modify the environment so that these species cannot survive. In these cases, the monitoring of rare species can be a very sensitive indicator. However, in order to fully understand the extent or nature of the impact, the ecology of the rare species must be known in a fair amount of detail. Unfortunately, this is not always the case.

We discovered two rare species of copepod in the wet meadow interstitial meiofauna. This is an interesting find, but it is probably more an indication of how little these habitats have been studied than of the environmental quality of the Les Cheneaux wet meadows. Because the Les Cheneaux biota has not been studied in detail before, it is likely that other rare, or even new, species will be found in the area.

11.1.3 Index of Biotic Integrity. 1997 and 1998 invertebrate data were used as part of a project to develop an index of biotic integrity for Great Lakes coastal wetlands. Several invertebrate metrics were found to be useful in distinguishing levels of human impact on wetlands, so further development of the index should lead to a usable monitoring tool. This and other wetland IBI systems may add to our understanding of wetland communities, because several of the metrics that proved useful do not use animal taxa that are generally considered to be indicators of disturbance.

The invertebrate IBI results indicate, not surprisingly, that Cedarville Bay is the most impacted of the wetlands tested. It is not as degraded as some sites in Saginaw Bay which were used for comparison, but one relatively high-quality Saginaw Bay site ranks above Cedarville in biotic integrity. No other sites in the Les Cheneaux ranked very low except, surprisingly, Voight Bay. We cannot fully explain this result, though we believe it is because Voight Bay is the most exposed (to the open lake) of all the sites. Unfortunately the IBI at present cannot clearly distinguish between human impact and wave exposure effects.

As noted above, an IBI based on juvenile-adult fish species richness, cyprinid representation and the proportions of tolerant individuals correlates with independent measures of human impact. The methods used in 1996-1998 involved technical gear, numerous person-hours, and expertise that are not readily available. A more general use of fish-IBI approaches is therefore contingent on testing of simpler protocols. Preliminary results in 1998 and 1999 suggested that marshes were accessible from land and could be effectively sampled using minnow traps. In spite of their importance, larvae proved not suitable for long-term monitoring.

11.1.4 Exotic species. Exotic species are of concern not only in the Les Cheneaux area, but to the Great Lakes in general. The exotic species currently present should be monitored and possibly studied more closely, and management strategies may need to be considered in the future. At the very least, public education should be undertaken. It would also be prudent to inform the public of other exotic species that may invade the Les Cheneaux. These efforts will help support the basin-wide effort to monitor and reduce range expansions of these organisms.

11.2 Focus species - Yellow Perch

Yellow perch are an important species historically and economically to the Les Cheneaux community. Although it may not be a good biological indicator in the strictest sense, we feel that it could be used as a focus species. In this sense, it is a focus species because it is recognizable to the community and can serve to increase interest in the research of coastal marsh dynamics and conservation. Also, the concern about declining perch populations suggests that research into some of the many different sources of mortality at different perch life stages (Figure 18) would be welcome and useful. Also, investigations of various aspects of yellow perch life history may be a useful method of understanding the changes occurring over time in the marshes.

We engaged in special study of perch egg deposition in an effort to learn what factors are important for successful perch reproduction and to design a monitoring program. This study focused on the deposition locations of egg skeins, the gelatinous strings of eggs that perch deposit on the marsh bottom. During the egg stage, yellow perch undergo substantial metabolic changes and are vulnerable to mortality induced by environmental factors that include water level fluctuation, availability of spawning habitat, strong winds or currents, and extreme temperature changes. Where the skeins are deposited is important since the entire annual reproductive potential will be affected by microenvironmental conditions found at that location. Other studies of the yellow perch spawning process have shown the fishes' affinity for submerged vegetation, rough substrates, and other forms of structure (wood debris, docks, etc.) that are believed to prevent the egg masses from becoming dislodged and transported to other areas.

The methods used to find skeins included wading the shallows, snorkeling, SCUBA diving, and searching from a boat. In 1999, a group of local volunteers was assembled to assist in the survey process. These volunteers were able to cover a greater area over a longer period of time and assisted the project greatly.

The combined search efforts led to the following observations regarding the spawning habits of yellow perch in the Les Cheneaux area. Most of the skeins were found in water less than three feet deep. The majority of skeins were entwined in *Scirpus* stems, however, some skeins were deposited on other vegetation and a few were left on the bare substrate. Students from the local high school who surveyed Flower Bay over a two week period found that strong winds blew ashore several of the skeins they had counted the previous week in very shallow marsh. The bays where skeins have been found thus far include Mackinac, Duck, Cedarville, and Flower Bays. However, larvae have been collected in a greater number of the bays, including: Mackinac, Duck, Cedarville, Mismer, St. Martins, Flower, Hessel, Sheppard, Peck, and Government Bays and Snows, Moscoe, and Hill Island Channels. The locations yielding the highest numbers of larvae were Sheppard Bay (204 larvae caught per unit of effort), Flower Bay (180 larvae caught per unit of effort), and Cedarville Bay behind the TerHaar residence (74 larvae caught per unit of effort).

12. Conclusions and Recommendations

12.1 Conceptual Model of Les Cheneaux Coastal Wetland Development and Function

At this point we have completed enough work to propose a general conceptual model of coastal wetland establishment and function. The model focuses on the physical forces and their broad effects, but the biota are only generally treated. Much more work is needed to determine the specific roles of specific groups of biota.

12.1.1 Physical requirements for coastal wetland development. The first necessary conditions for coastal wetland development depend on landforms and their relation to lake hydrology. Wetlands form where shoreline morphology creates coastal areas that are protected from waves to some degree. The other necessary condition is that the protected area must have a substrate that can support plants: relatively shallow sediments as opposed to rock.

12.1.2 Physical structure. While plants are biological entities, their biotic activity creates the physical structure that guides development of coastal wetland substrates and fauna, while reinforcing their own distributions. Thus, given the appropriate physical "template", as described above, plant communities provide the most important system-structuring forces.

12.1.2.1 Plant zones. Where the prerequisite conditions are met, aquatic plant communities will develop. The interaction of substrate slope and fluctuating water levels is the key factor determining plant distributions. Plants segregate along the elevation gradient between deep water and uplands so that relatively distinct communities form, allowing the wetland to be viewed as an assemblage of zones occurring in predictable order. At the outer edge, adjacent to open water, lies the deep emergent marsh characterized by low plant density and diversity as a result of relatively high exposure to waves. Adjacent to this zone is the shallow emergent marsh, where the wave-damping influence of deep marsh plants allows a greater density and diversity of plants to develop. At the inland edge of this zone lies a transition zone, so named because it occurs at the long-term average water level, so it is a transition from the usually-flooded to the usually-not-flooded areas of the wetland. This zone is dominated by plants that thrive in temporally-heterogeneous environmental conditions. Just upland is the lower wet meadow, which is an area that is seasonally flooded during many years, so shrubs and many other flood-intolerant plants are excluded much of the time. Finally, at the upland end of the gradient, the upper wet meadow only rarely is flooded, but remains wet much of the time so only wetland-adapted plant thrive, including many shrubs and grasses.

12.1.2.2 Substrates. Substrate composition within wetlands is largely determined by water movement intensity and organic production. Where wave energy is high, lightweight fine material is continually swept away, leaving the heavier sand and rock particles. Where substrates are relatively protected by shoreline form and, secondarily, by vegetation, fine organic material and silt can accumulate. Areas of high biotic production tend to have soils with high organic content because of detritus accumulation; but the form (relative coarseness or fineness) of the detritus is also important, and is determined by the plant species contributing the detritus, and the conditions for decomposition. The transition zone appears to be important because it is dominated by cattails, which produce recalcitrant detrital material. As a result, particulate matter is coarser and probably accumulates over time in this zone. This accumulation results in soil building which may counteract the erosive forces of water flow, trap and preserve organic material, and maintain the zonation structure of the wetland.

12.1.3 Water-plant interaction and water quality gradients. The physical interaction of water movements with plants appears to be one of the key structuring forces in coastal wetlands. As waves and seiches move shoreward through wetlands, plants absorb much of their energy. The result is that the outer portions of the wetland are well-mixed with nearshore pelagic water, but inner portions are not. This creates gradients in water quality measures such as dissolved oxygen, temperature, conductivity, and many others. Here, again, cattails may play a role greater than their representation in the wetland suggests. Being stiff and dense, cattail stems offer strong resistance to waves, protecting the relatively stagnant nature of the wet meadow water. It must be noted, however, that coastal wet meadow waters are not very stagnant because oscillating seiche flow constantly changes the depth and water quality of the water.

12.1.4 Animal distributions

12.1.4.1 Invertebrates. Invertebrate community composition varies along the elevation gradient, but also exhibits considerable unexplained spatial variation. Given the great diversity of animals in this category, there are probably many variables responsible for their distributions. Many variables co-vary with the elevation gradient, making them candidates as invertebrate influences. Detrital, algal, and plant food base quantity and quality are likely important. The availability of refuges from predators should be important and they take two forms: physical structure (plant and detritus-matrix), and dissolved oxygen restrictions on fish, which increase up-gradient. Flooding duration is also very important, because only some invertebrate taxa can survive the non-flooded periods by burrowing or aestivating in drought-resistant stages, and those that can't are limited by their ability to migrate back into newly flooded areas.

12.1.4.2 Fish. As mentioned above, fish generally are limited in distribution by their higher oxygen requirements than many invertebrates. This prevents most fish species from spending much time in the low-oxygen wet meadow zones, except during high water years. Other than oxygen, predation avoidance is probably the most important factor determining fish species distributions at early post-larval life stages. Food availability may also be important, but there does not appear to be a shortage of invertebrates anywhere in the wetlands, except in the wave-swept deep emergent zone. However, preferred food items change with life stage, so fish are likely to shift distributions as they seek greatest abundances of their preferred food items.

12.1.5 Variations. Above we present a "template", or simplified view of Les Cheneaux coastal wetland structure and dynamics, but many factors can cause variations on that theme. The following list is not exhaustive, but it includes the most apparent influences. We do not cover these in detail because we have not studied them well enough to draw conclusions about their effects on coastal wetlands.

12.1.5.1 Larger vertebrates. Carp, muskrats, and beaver can cause destruction of plant patches and/or alter water flow through the wetland with their activities. These disturbances may be important to maintaining wetland diversity, like canopy openings in forests, but we have not studied this issue. What is clear, however, is that some spatial variation in biota is attributable to these animals. Beaver can be particularly influential because they damage vegetation; they create networks of paths through the wetlands; and they can dam streams that flow through wetlands.

12.1.5.2 Human activity. As discussed elsewhere in this report, human activities are diverse and increasing. They can cause wetland fragmentation and channelization, loss of habitat area, organic and contaminant pollution, and introduction of exotic species.

12.1.5.3 Differences among sites. Wetlands can vary depending on the relative amount of groundwater inputs, local bedrock, which affects soil composition and water chemistry, the surrounding land types, and the degree of exposure to winds and wave action.

12.1.5.4 Streams. Streams run through most Les Cheneaux wetlands. These certainly alter water quality, plant communities (through-flow effects), and animal communities in localized wetland areas adjacent to the streams and near the stream mouths. They also may provide a source of invertebrates to recolonize dewatered nearshore areas.

12.2 Monitoring Recommendations

12.2.1 Monitoring approaches. Ongoing monitoring of the Les Cheneaux wetlands is important for two reasons: it will provide data that will help us better understand the biotic dynamics in these systems, and it will allow for detection of any new wetland degradation that may occur as a result of the projected increasing human activity in the area.

Monitoring should incorporate IBIs and surveillance for more obvious signs of degradation: filamentous algae accumulation, habitat loss (especially wet meadows), invasive species and changes in indicator species. Development of the invertebrate IBI has progressed relatively rapidly, and we anticipate that it will be available for use after the current testing is complete. We believe volunteers can use it if they are trained and overseen by a trained professional. An IBI based on fishes has also been shown to correlate with development (Figure 19), and is expected to be available for use by volunteers by 2000. Data for both these IBIs should ideally be collected on an annual basis because these fauna change from year to year to some extent. A plant-based IBI is being developed, but until this is completed and tested we do not recommend using plants as indicators. In any case, their conservative responses to the recent water level changes also suggest that they need not be sampled every year.

In addition to the obvious signs of a degrading system, such as accumulation of unwanted algae, some species could be monitored individually to provide earlier indications of habitat change. Mayflies, amphipods, isopods, and certain molluscs are suitable indicators.

12.2.2 Monitoring protocols. One goal of the project was to establish practical sampling methods for long-term monitoring of the Les Cheneaux coastal wetlands. This necessitated a trial-and-error approach, but we have settled on definitions and sampling methods that work, and we have ruled out several alternatives. The plant sampling method is the only protocol that has not changed since the first year of fieldwork. We have refined invertebrate and fish sampling methods as described below and have settled on those that seem to provide representative data with the least amount of effort and a relatively low level of technical expertise.

For invertebrates, nearshore benthic sampling is effectively accomplished with Ponar grab sampling, though the assistance of a SCUBA diver can increase its effectiveness. Burrowing mayflies are taken in these samples so they do not require a separate sampling method. The invertebrate IBI is based on a Rapid Bioassessment Protocol sampling procedure using D-frame dipnets. We recommend taking three samples per plant zone, but it is probably unnecessary to pick 150 invertebrates from the samples, as we have done. 100 individuals should be sufficient to provide a representative sample. We strongly recommend that technicians use hand counters when field picking the samples to ensure accurate counts. We also recommend that more than one site be sampled each year of monitoring. Time constraints will determine how many sites are monitored, but at least three would be desirable.

Several fish-collection methods have worked well, though each is best used in certain habitats. Fyke nets and minnow traps are effective samplers in shallow, densely-vegetated marshes. Sets of five commercially-available minnow traps equally spaced along a 10 m transect traversing submerged plant and *Scirpus* patches can obtain a representative sample of the permanent marsh fish most affected by development. Minnow traps should be checked and data recorded for a week in mid June/July, the period of maximum richness and abundance. Any IBI will require field training of volunteers and a central collection center to accumulate and further analyze data.

12.3 Management Recommendations

12.3.1 Nutrient Enrichment Prevention. Currently the marshes in Cedarville Bay and the surrounding area (e.g. Moscoe Channel) appear only moderately impacted by nutrient enrichment originating from the waste water treatment lagoon discharge and from septic system leakage and residential fertilizer runoff. Dense growths of cattails and high amounts of organic muck are characteristic of the nutrient enrichment in these areas. However, these effects are localized. The greater future threat of enrichment may be increased use of lawn fertilizers and residential septic systems if population density continues to grow in shoreline areas. Civilian monitors should be trained to watch for the appearance of filamentous algae mats, fish kills, and nutrient-loving macrophytes (*Elodea*, *Typha*) in areas other than the Cedarville boat ramp.

12.3.2 Development Regulation. Development along the waterfront has the potential to disrupt many of the natural processes in the marshes. Obviously increased development in the area can pose a significant threat to the overall marsh ecosytem.

Roads built near the waterfront may impact the marshes in a number of ways. Leaking automobile fluids and road salt used in the winter have the potential to impact the marshes although currently, there is no evidence to suggest that this is occurring widely in the area. Probably the most obvious effect of roads to the marshes is when they are constructed through the wet meadow regions. Besides directly destroying parts of the wet meadow, this can disconnect the wet meadow and deeper emergent portions of the marsh. Bays where this is obvious include Prentiss and Cedarville Bays. In the case of Prentiss, the wet meadow is still intact, whereas in Cedarville much of the wet meadow is no longer present. The direct effect of this division of the marsh is difficult to measure and to separate from other human impacts (especially in Cedarville Bay) and has not been targeted extensively in our sampling, but constructing roads to minimize the hydrologic interruption would be prudent.

The building of docks and the clearing of vegetation to provide access for boats create fragmentation in the marsh plants, especially the outer bulrush zone. This increase in the amount of edge exposed to open water may affect the substrates and the plants that are able to root by increasing the wave action entering the marsh. This may also decrease those species of invertebrates and fishes in the marsh that are more adapted to lentic, still-water conditions and promote those adapted to lotic conditions.

12.3.3 Marine Traffic Control. Boat and jet ski wakes increase the wave action in the marshes and may produce similar effects to those mentioned above by the fragmentation. Waves produced by wakes contain more energy that wind-produced waves and therefore have more potential for perturbing the substrates and increasing turbidity. Of course, boat and jet ski motors are also a source of water-borne contaminants. It would be prudent to consider regulating motorized watercraft in and around well-developed coastal wetland areas.

12.3.4 *Development patterns.* Our expertise is limited to assessment of the organism communities of the Les Cheneaux bays, including those activities of humans that impact the land and water. As such, we cannot address many issues of development approaches that achieve minimal impact or sacrifice some areas for the good of others (e.g. cluster housing). However, inclusion of such options into a full management plan for Les Cheneaux would be wise.

12.4 Areas Requiring further study

12.4.1 Algae. Algae are important components of aquatic systems, being the foremost source of primary production that is directly consumed (most macrophyte biomass senesces before being consumed). Algae are also known to be good indicators of environmental conditions, including some human impacts.

12.4.2 Seiche and storm surge effects. Our hydrological efforts focused on annual and multi-annual changes, yet seiches are constant occurrences in coastal wetlands. Storm surges, though not common, are powerful and have potentially very influential destructive force.

12.4.3 Water chemistry. Our analyses of water chemistry were helpful, but they were minimal. While we do not think that water chemistry would provide efficient monitoring tools, a full understanding of the ecology of the marshes would require much more intensive chemical analyses.

12.4.4 Food webs. We have only begun this work by studying fish stomachs. However, a large proportion of Les Cheneaux wetland animals are generalist feeders, so intensive food web work might be relatively unproductive. More interesting would be models of energy/material flows within and across wetland boundaries.

In examining trophic interactions, some areas that we did not include in our study would need to be addressed. In particular bacterial communities, epiphytic algae with associated invertebrates, and plankton are key links in energy and material fluxes, and would need major attention.

12.4.5 Human impacts and fragmentation. It would be desirable to study the most common human impacts on Les Cheneaux wetlands: habitat destruction and fragmentation. Nutrient enrichment is an important concern, but much more is known of the effects of this sort of disturbance.

13. Acknowledgements

We greatly appreciate funding from the Michigan Coastal Management Program, Great Lakes Protection Fund, Islands Association, University of Michigan Biological Station, Les Cheneaux Economic Forum, The Nature Conservancy, University of Michigan, Michigan State University, U.S. Geological Survey and two anonymous donors. Many local residents contributed to the project by providing background information on the marshes, providing access to land for sampling purposes, by organizing and participating in a public meeting that focused on results of the research, and by providing housing. We especially thank: Nadine Cain, Mark Engle, Wayne Honnila, Linda Hudson, Dave Murray, Phil and Margaret Pittman, Randy Schaedig, Frank and Barbara Taylor, Carl and Kate Ter Haar, and Greg Wright.

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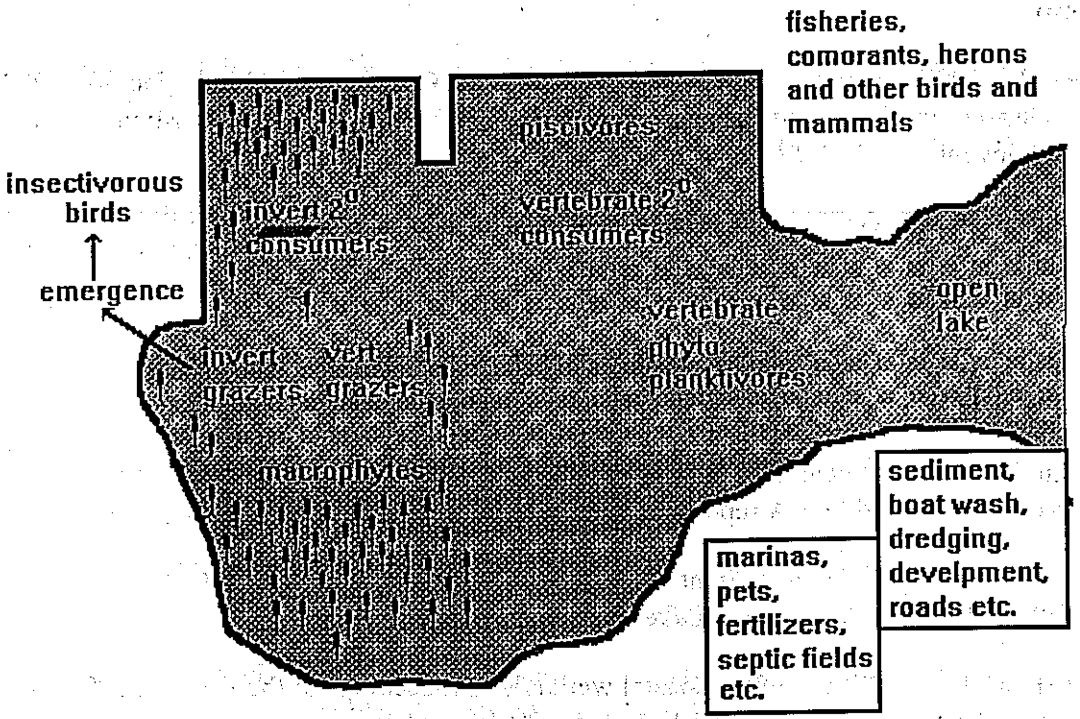


Figure 1a. The North Lake Huron Project focuses initially on certain major floral and faunal components of marshes and wetlands. This figure shows the aquatic groups studied.

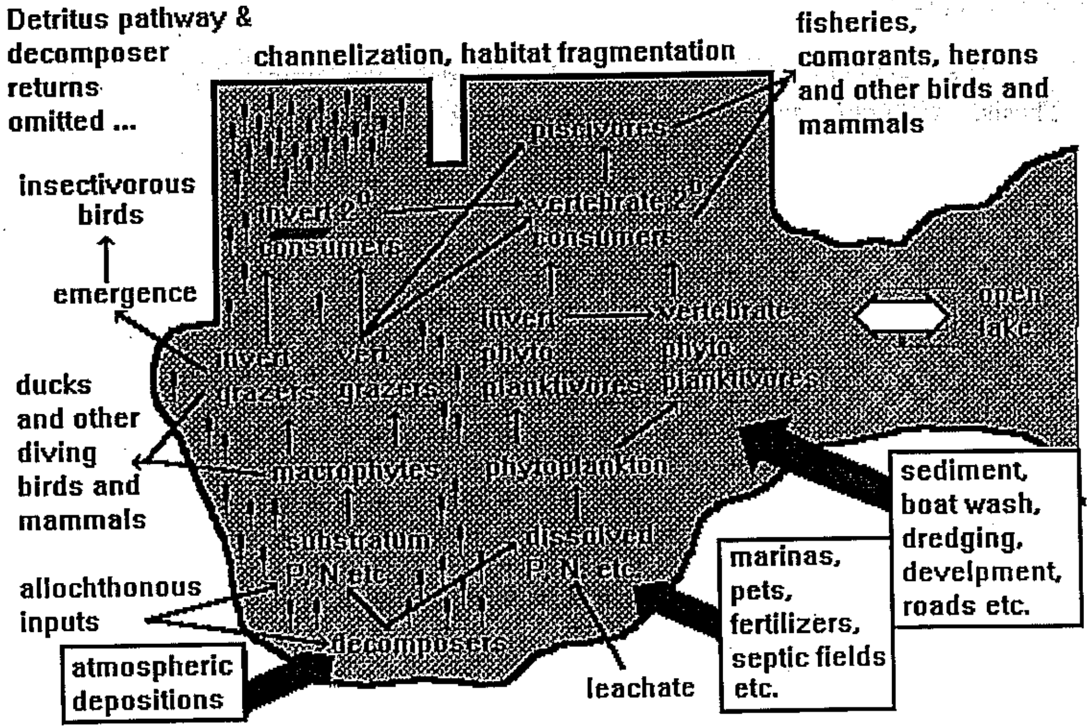


Figure 1b. Full understanding of the marsh ecosystem will require analysis of linkages among organisms and terrestrial inputs as suggested here for the aquatic components of marshes.

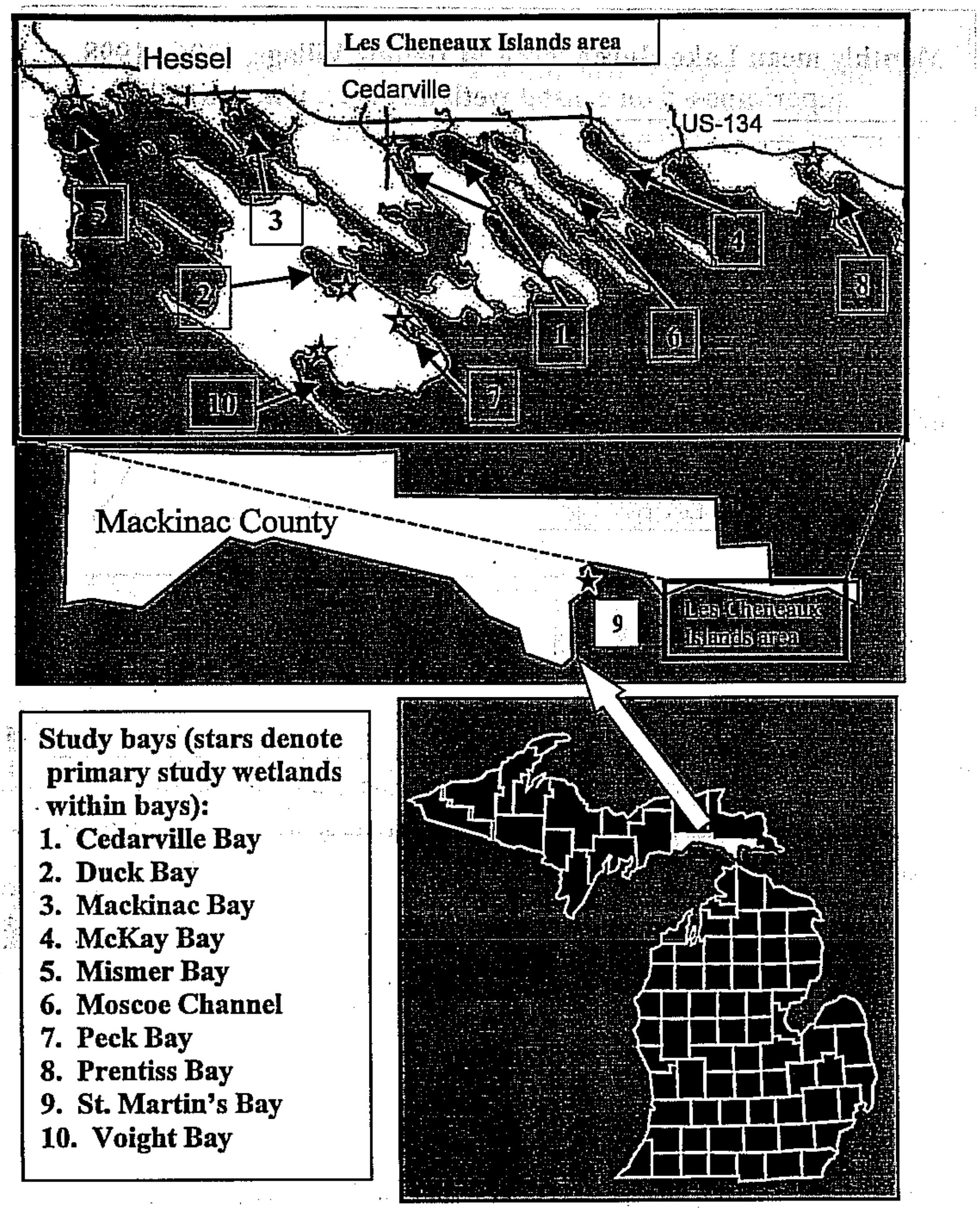


Figure 2. Locations of study area, study bays, and focus wetlands.

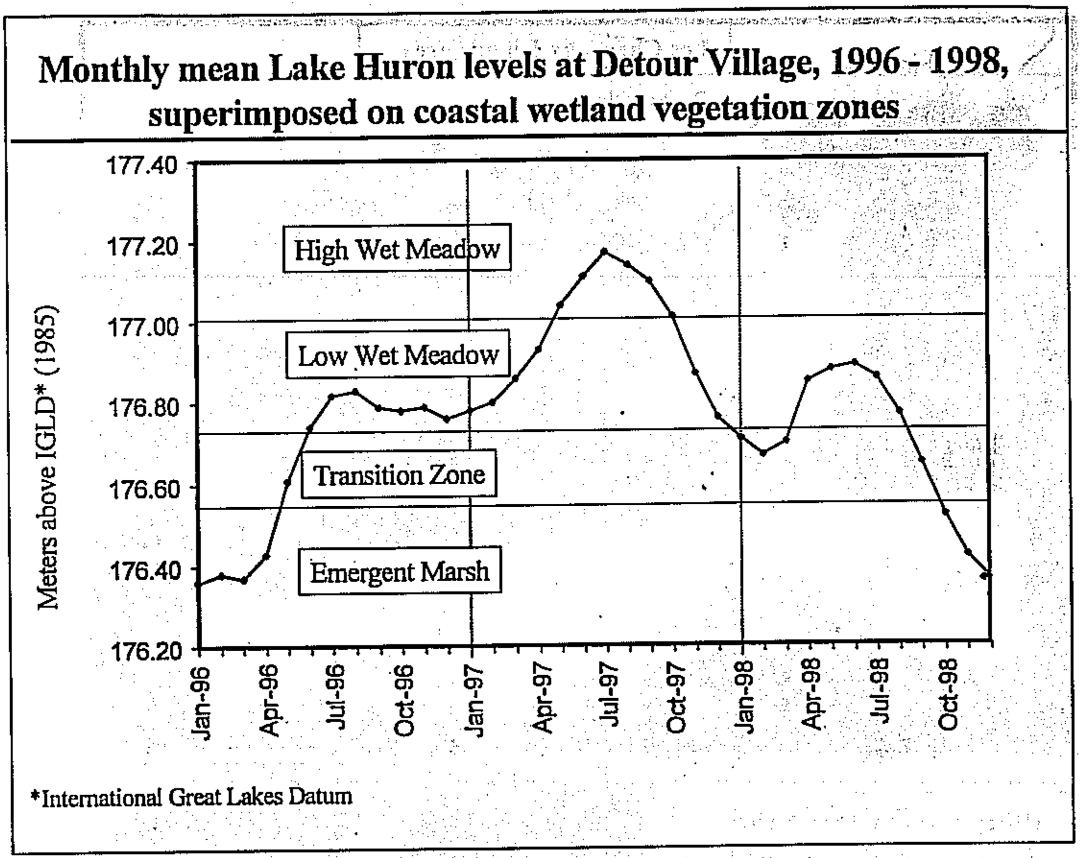


Figure 3. Les Cheneaux coastal wetland vegetation zones superimposed on Lake Huron monthly mean water levels during Coastal Marsh Project duration (Data source: U.S. Department of Commerce, NOAA/NOS, Silver Spring, MD).

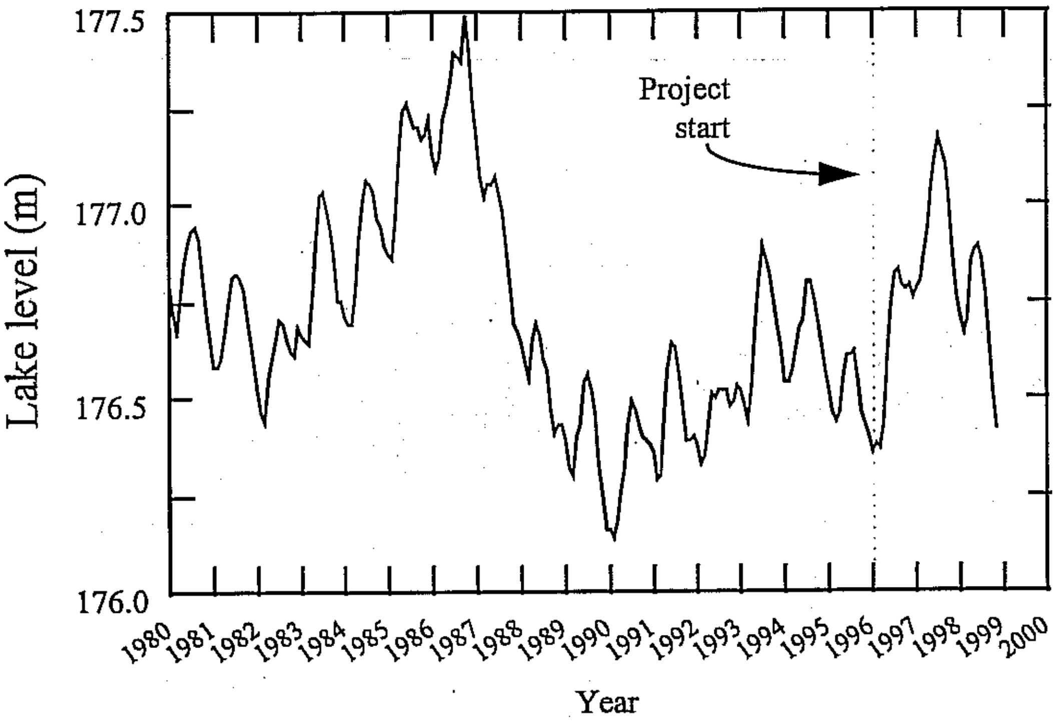


Figure 1.

Figure 4. Lake Huron monthly average water levels in meters above International Great Lakes Datum, measured at DeTour Village, MI, 1980 through 1998 (Data source: U.S. Department of Commerce, NOAA/NOS, Silver Spring, MD).

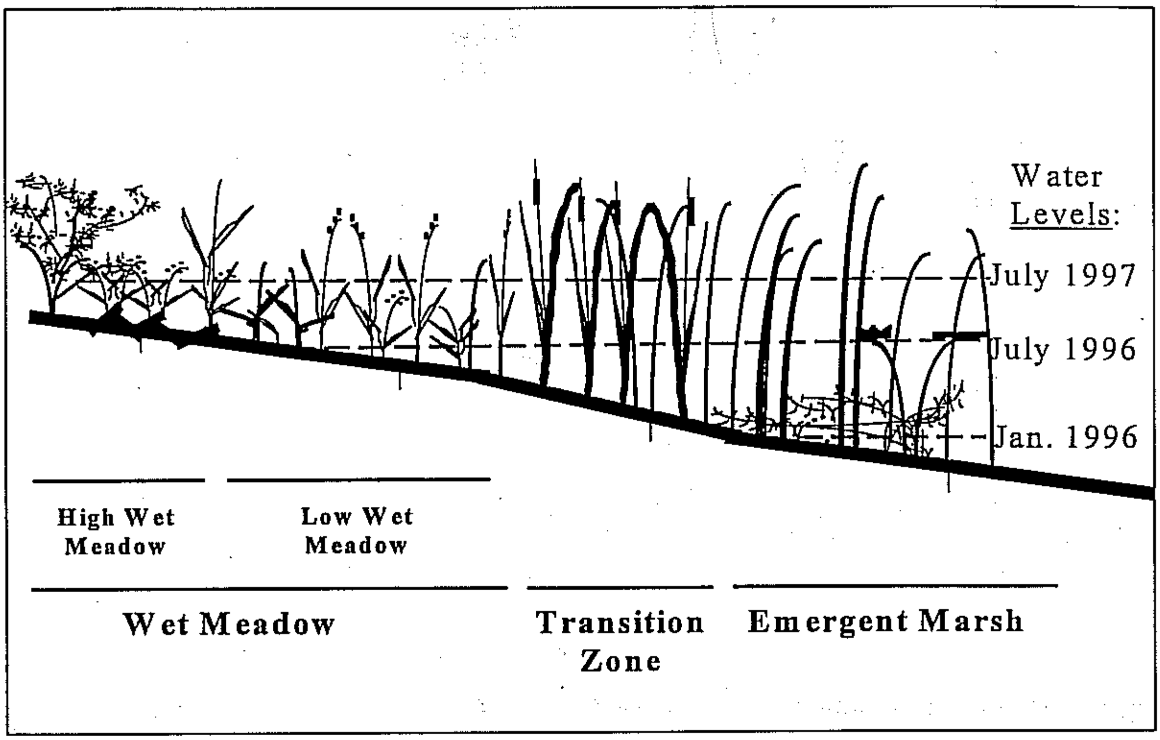


Figure 5. Representative cross-section through Les Cheneaux coastal wetland vegetation zones, with approximate high and low water levels during Coastal Marsh Project duration.

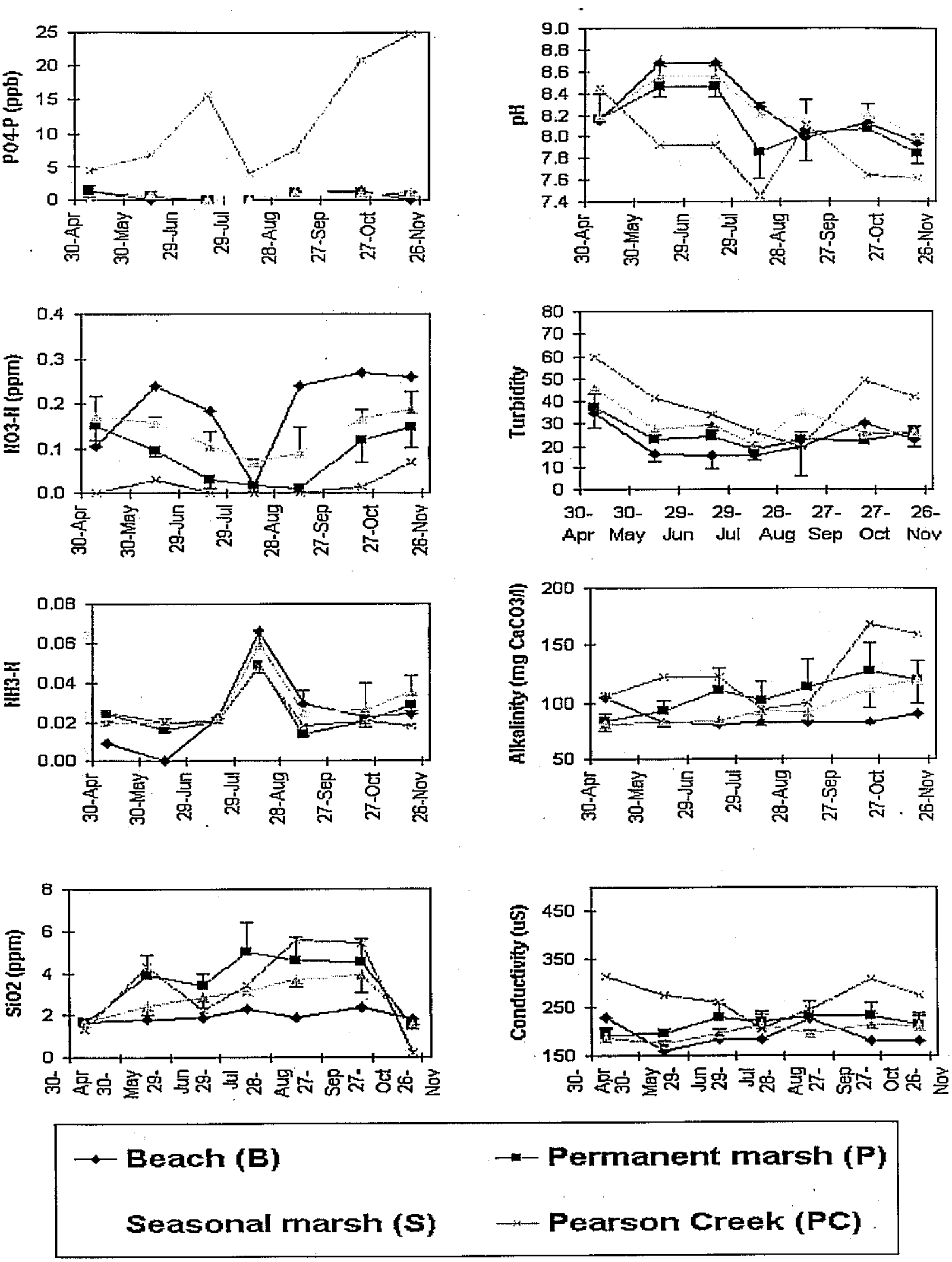


Figure 6. Water quality measures taken in four Les Cheneaux habitats during summer, 1996.

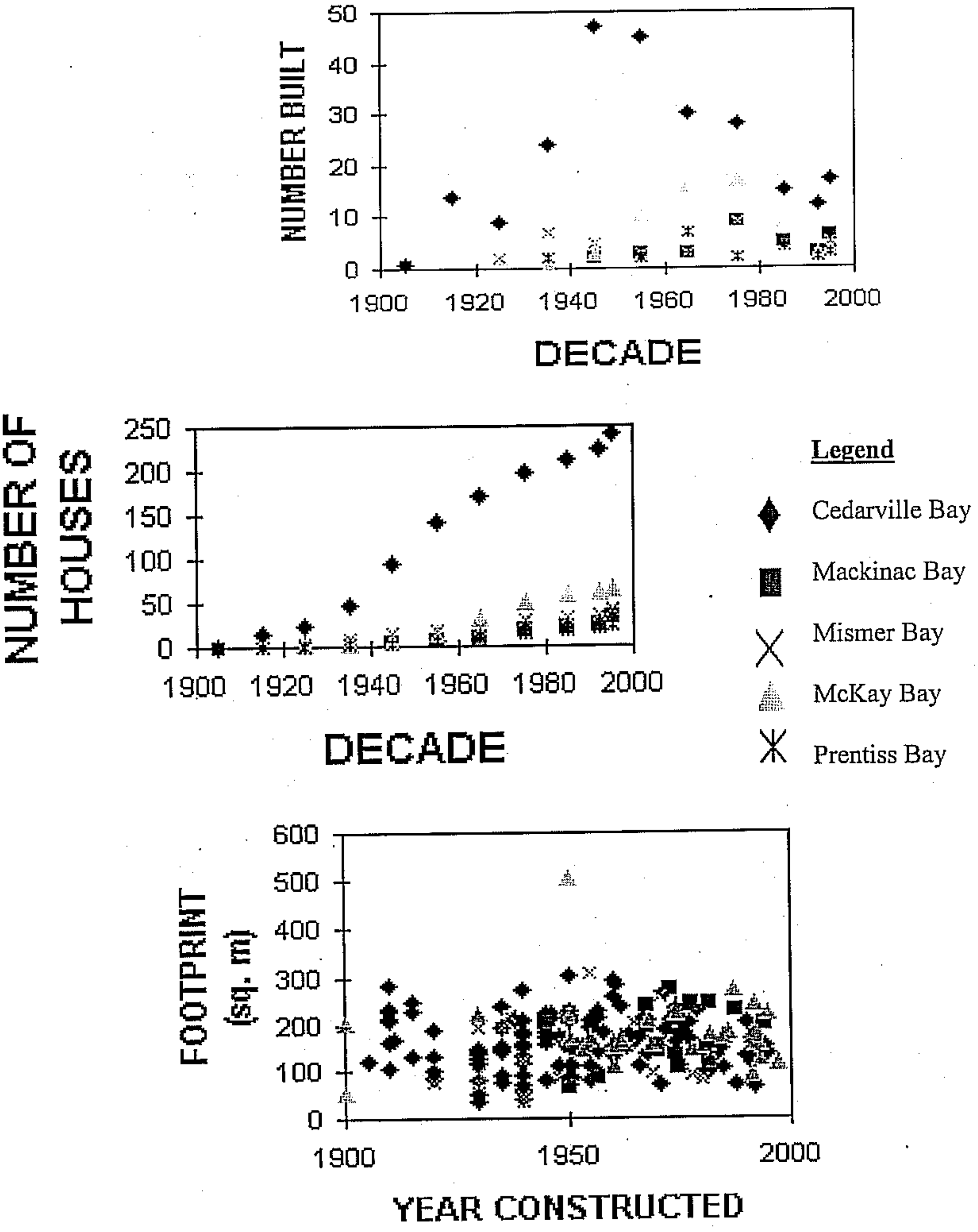
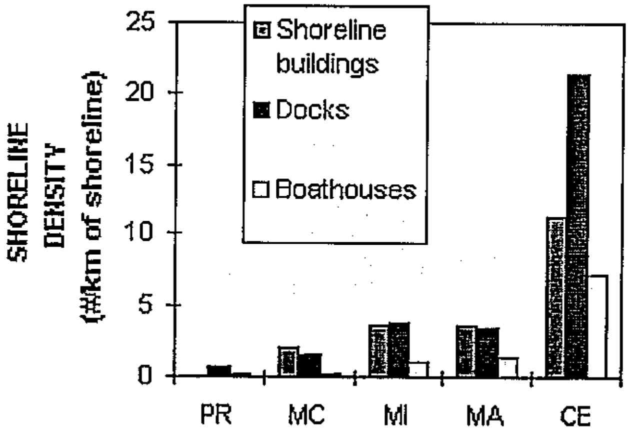


Figure 7. Houses built per year, cumulative number of houses, and foundation size (footprint) of new houses on shores of five Les Cheneaux bays, 1900 to present.



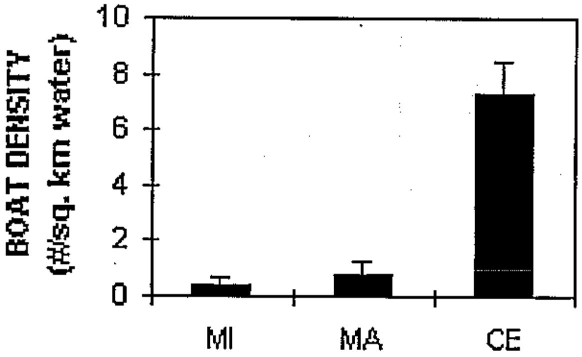


Figure 8. Shoreline building density and boat density in Les Cheneaux bays, 1998 (CE=Cedarville Bay; MA=Mackinac Bay; MC=McKay Bay; MI=Mismer Bay; PR=Prentiss Bay).

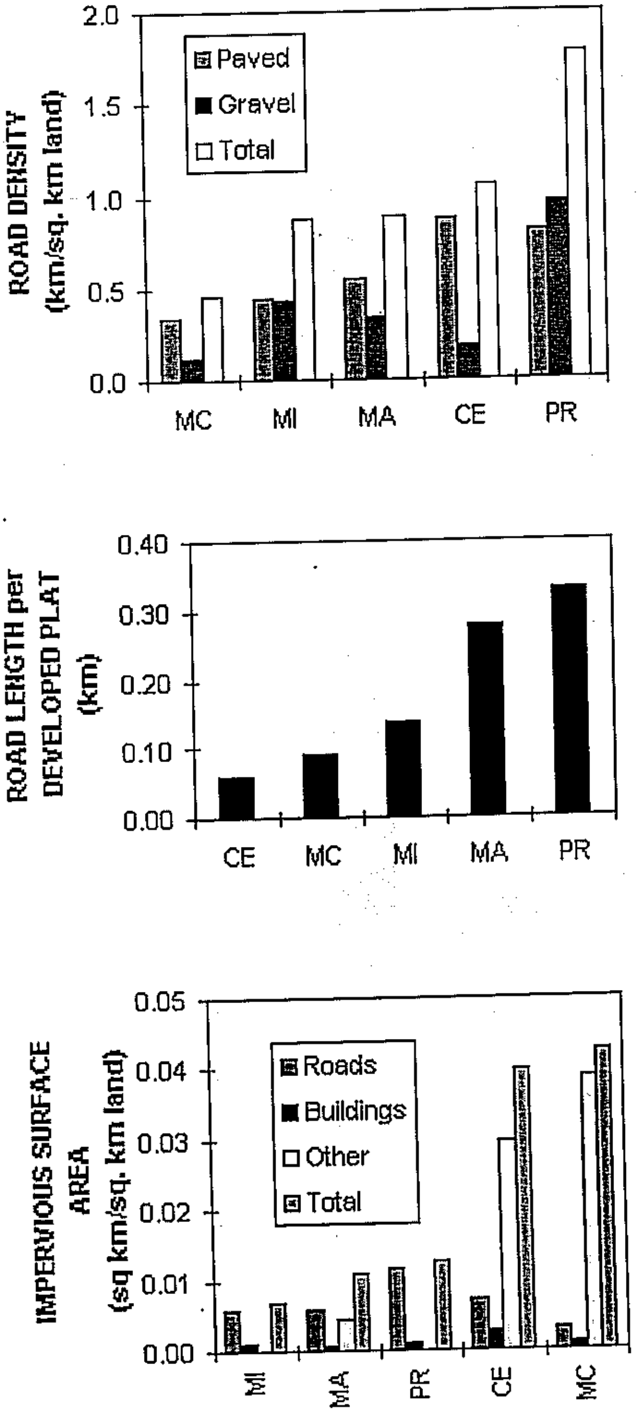


Figure 9. Road density, length of roads per plat, and impervious surface area surrounding five Les Cheneaux bays (CE=Cedarville Bay; MA=Mackinac Bay; MC=McKay Bay; MI=Mismer Bay; PR=Prentiss Bay).

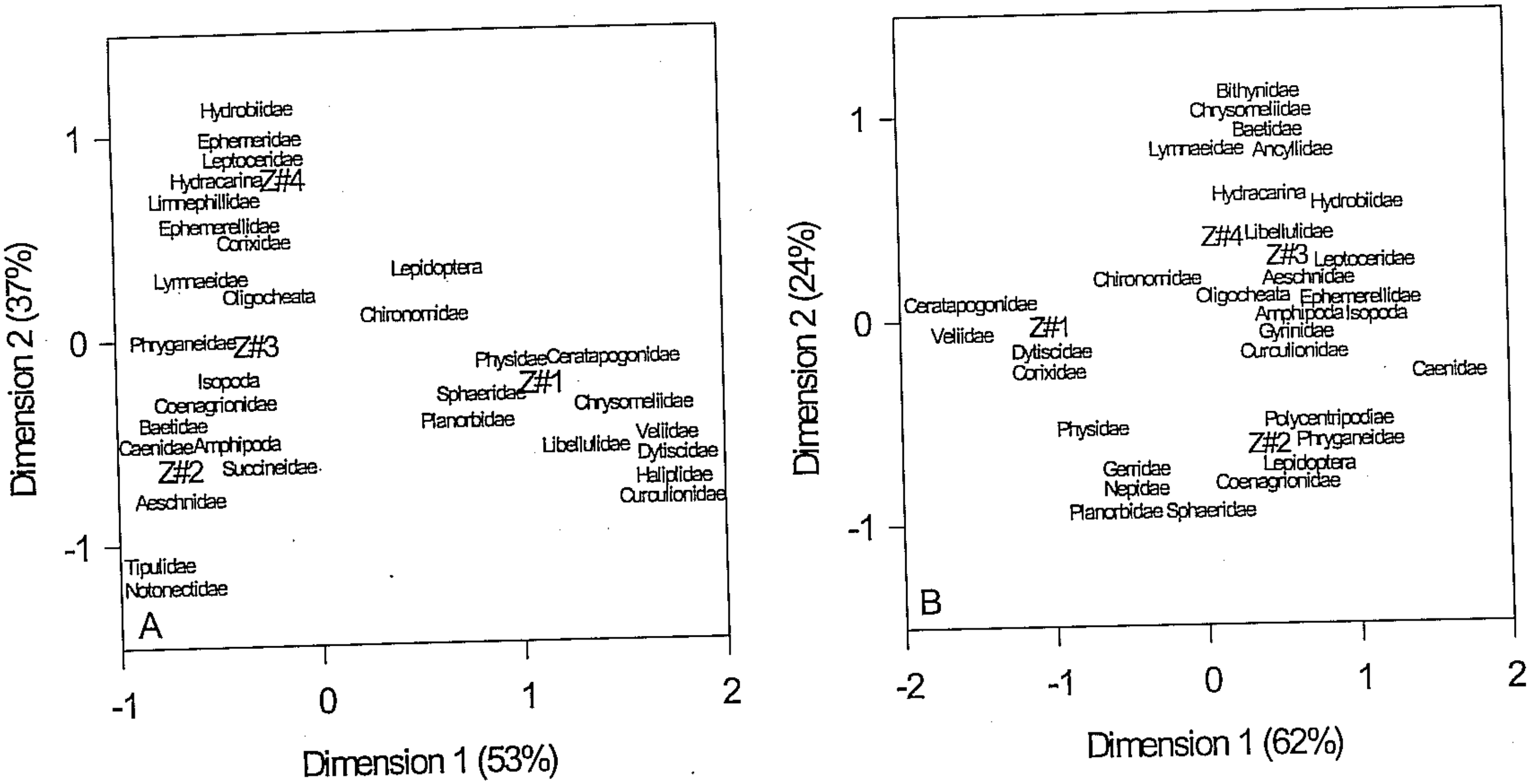


Figure 10. Correspondance analysis of invertebrate communities in Duck Bay during June (A) and August (B), 1997.

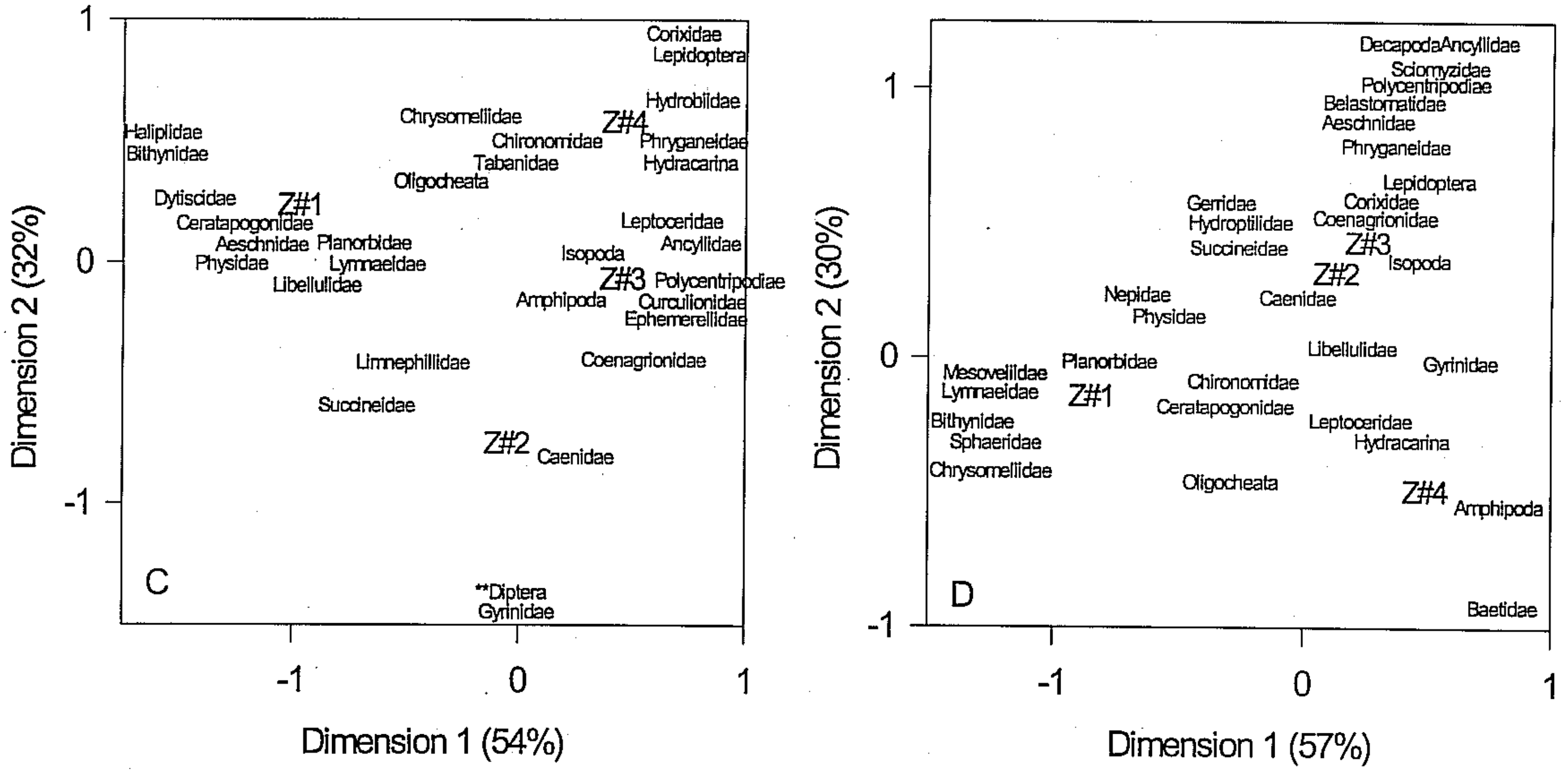


Figure 11. Correspondance analysis of invertebrate communities in Mackinac Bay during June (C) and August (D) in 1997.
** "Diptera" represents Psychodidae, Sciomyzidae, and Tipulidae which shared identical coordinates.

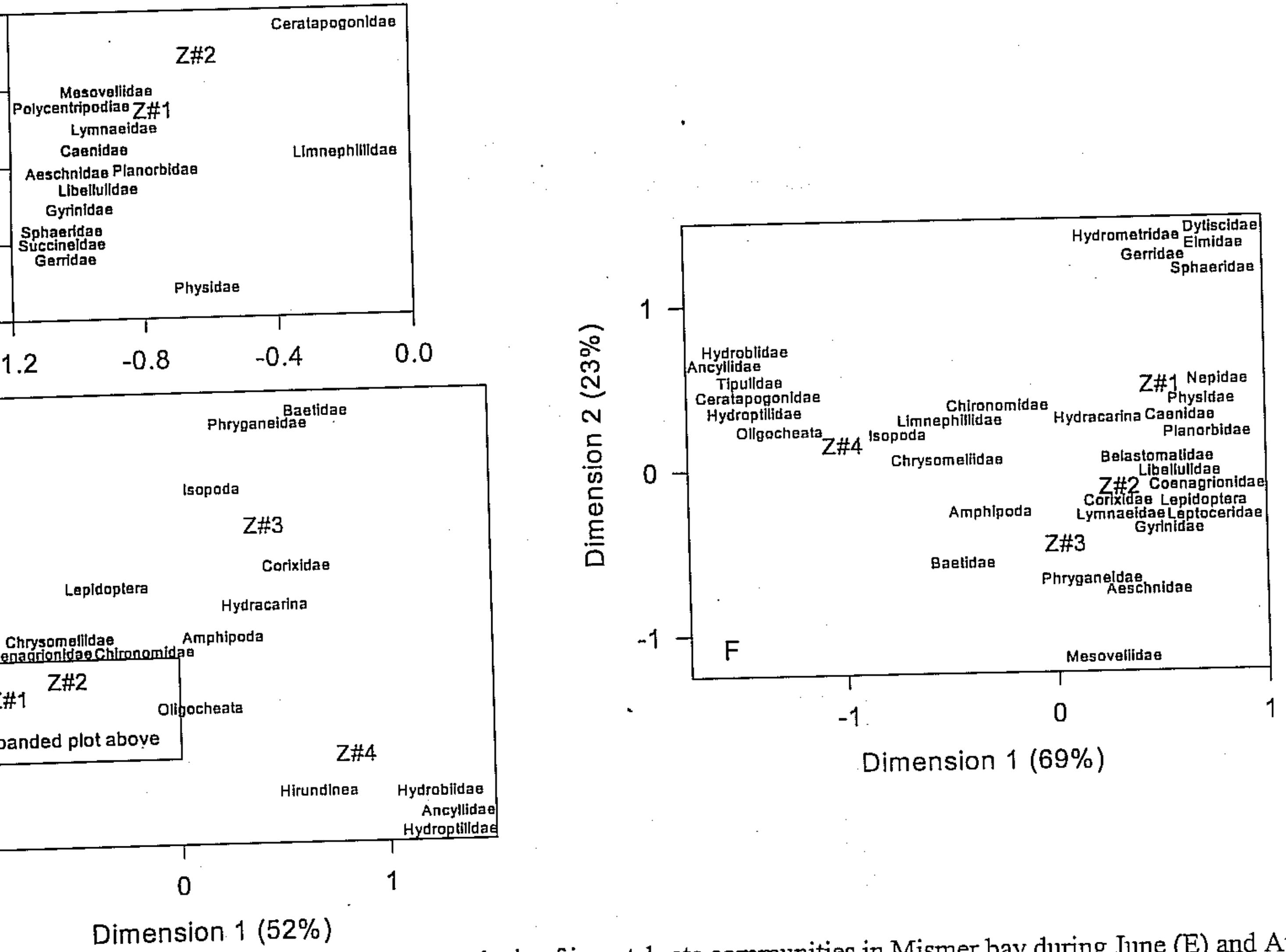


Figure 12. Correspondance analysis of invertebrate communities in Mismer bay during June (E) and August (F) of 1997.

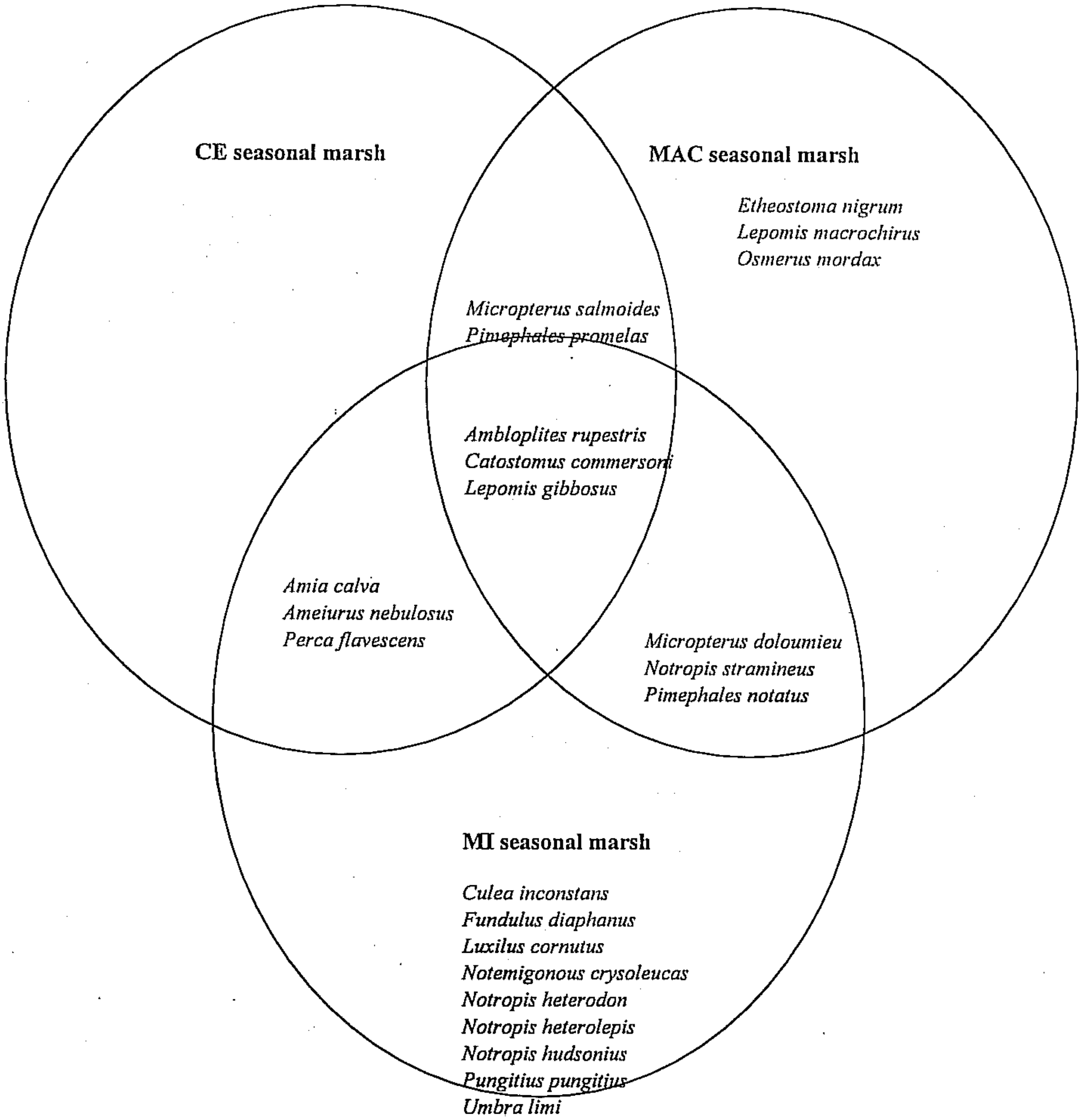


Figure 13. Venn diagram of species composition in seasonal marshes in Les Cheneaux.

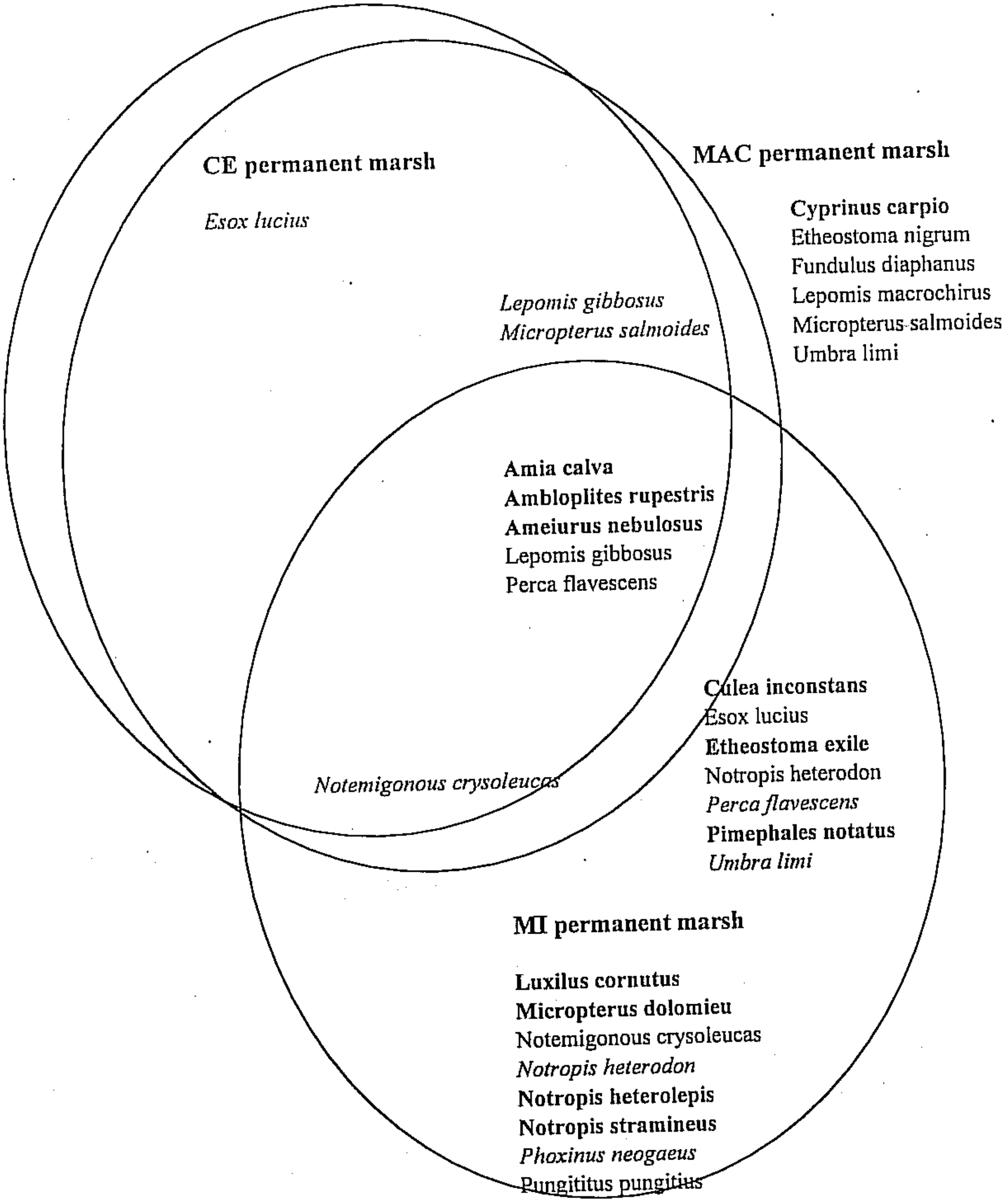


Figure 14. Venn diagram of species composition in permanent marshes in Les Cheneaux. Species present in both years are in bold, those present in 1998 are in italics, and those found only in 1997 are in normal type.

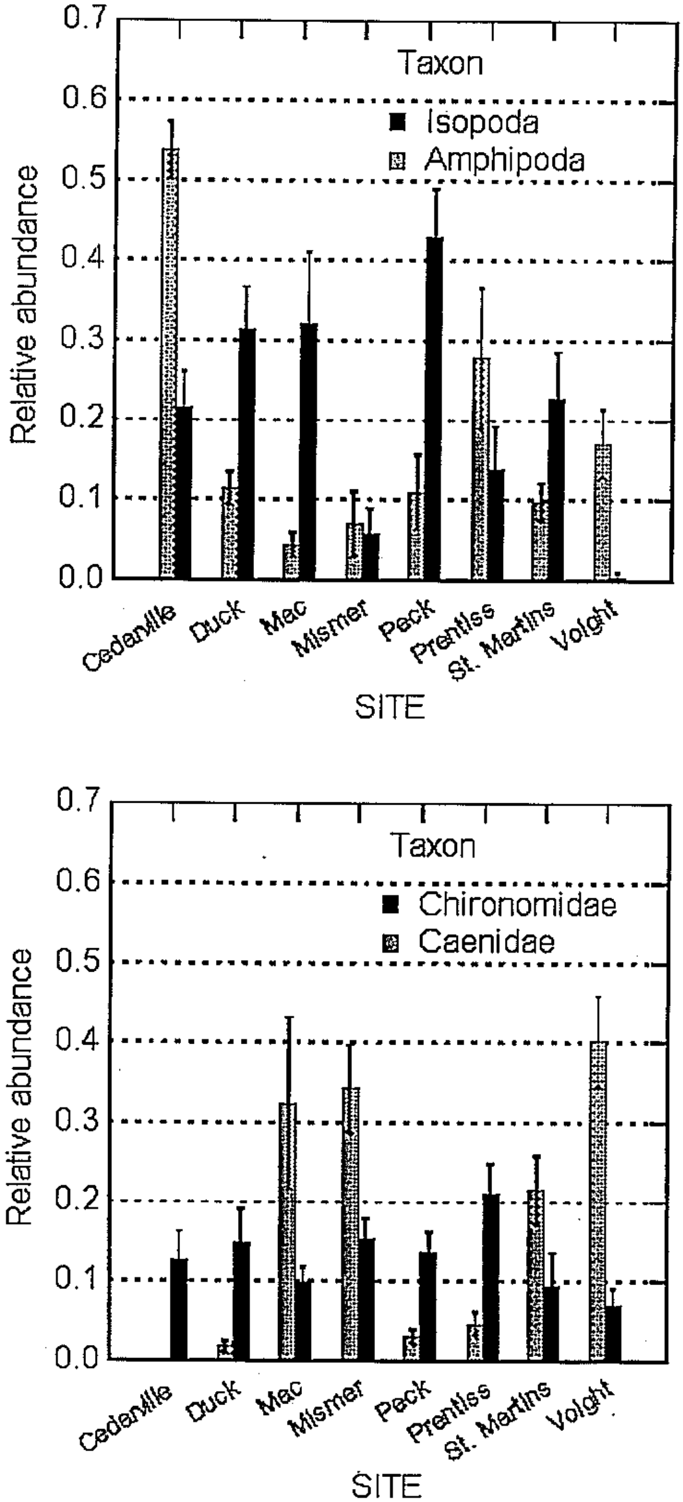


Figure 15. Relative abundances of the four dominant invertebrate taxa in wetlands of eight Les Cheneaux bays (non-insects above, insects below; error bars indicate standard errors).

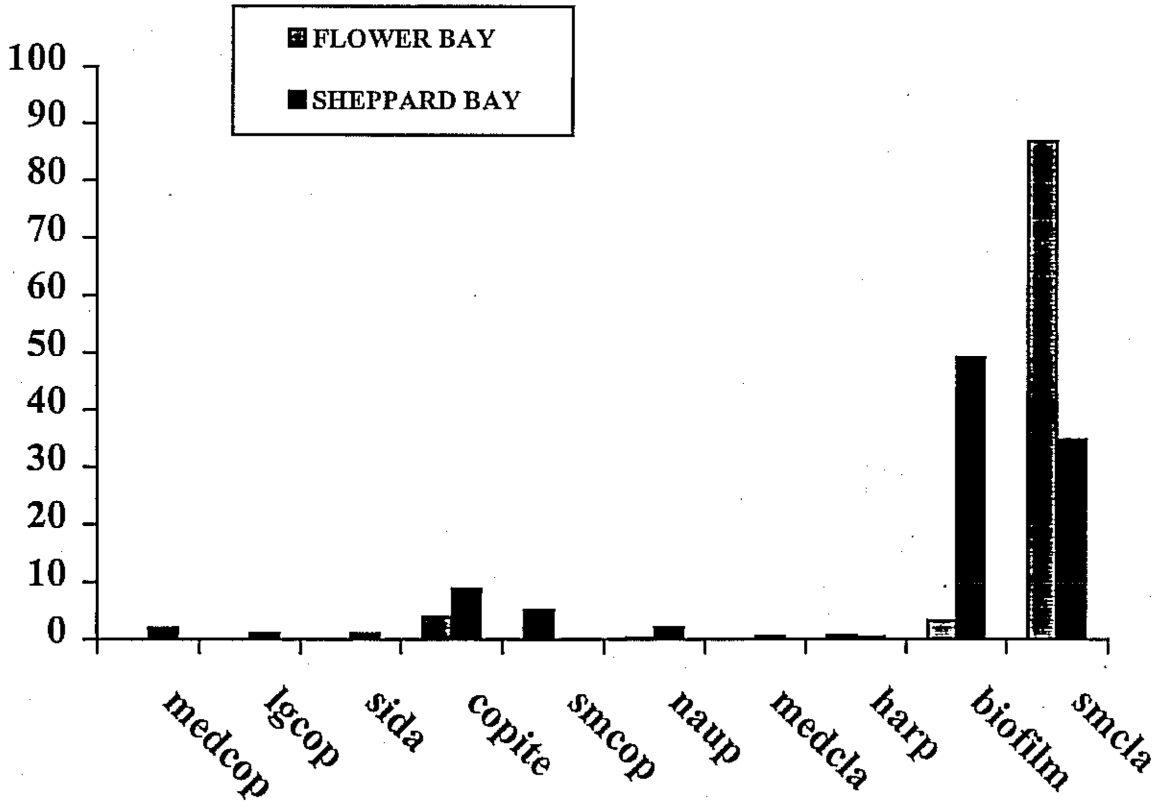


Figure 16. Relative abundances (%) of food items in yellow perch guts taken from Flower Bay and Sheppard Bay (medcop=medium copepods; lgcop=large copepods; sida=*Sida*, a large cladoceran; copite=copepodites; smcop=small copepods; naup=cladocera nauplii; medcla= medium cladocera; harp=harpacticoid copepods; smcla=small cladocera).

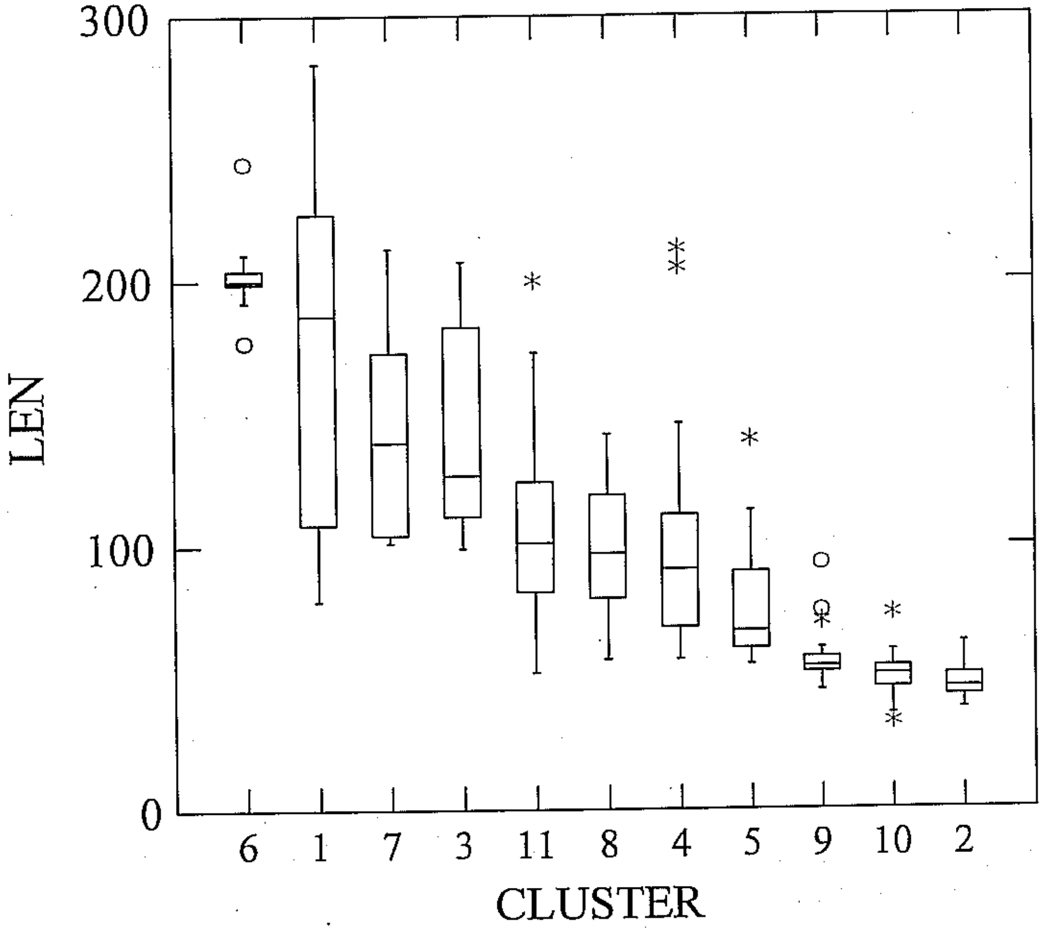


Figure 17. Length distributions of yellow perch (mm) in eleven feeding clusters determined by K-means clustering of gut contents data.

Table 1. Size and food preference data for clusters of yellow perch based on K-means clustering of gut content data.

Size Class	Cluster	Sample size	Median length (range) mm	Food items	# of taxa
> 30 mm	9	24	54 (45-93)	*Sida*, chironomidae	24
	10	25	51 (33-74)	copepodites, copepods, cladocerans	35
	2	11	46 (38-63)	small cladocerans	10
> 50 mm	11	19	101 (52-200)	bryozoa, assorted insect larvae, isopods	30
	8	13	97 (57-142)	*Caenis* & damselfly larvae, isopods	29
	4	27	91 (57-212)	isopods, *Caenis*	30
	5	18	68 (55-140)	damselfly larvae, *Eurylophella*, isopods, *Sida*	31
> 75 mm	6	9	200 (177-244)	fish, *Hexagenia* larvae, crayfish	8
	1	17	187 (79-282)	crayfish	17
	7	10	139 (101-212)	dragonfly & *Hexagenia* larvae	19
	3	12	127 (99-207)	*Hexagenia*, bryozoa	15

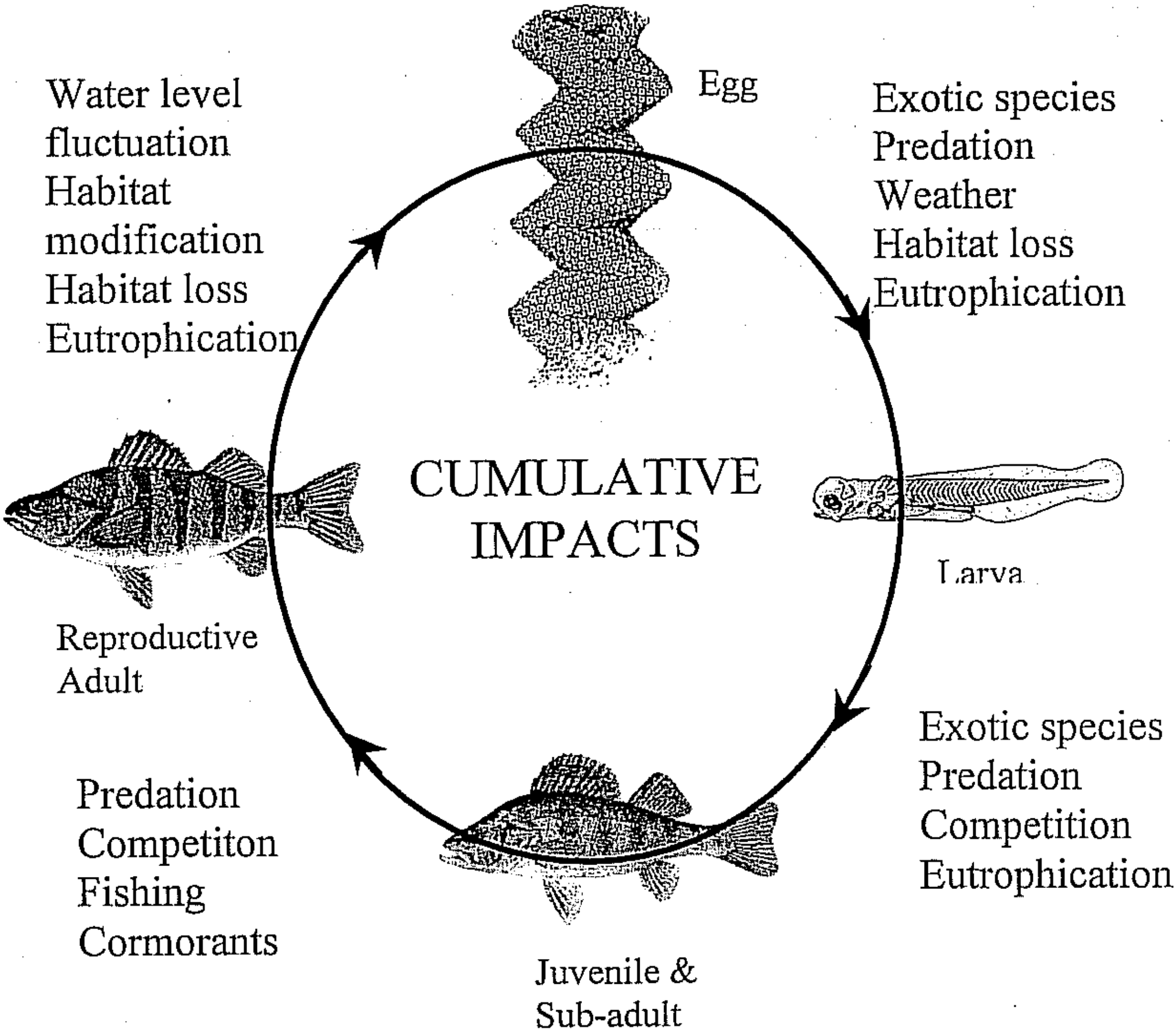


Figure 18. Life cycle of yellow perch, including major sources of mortality at each life stage

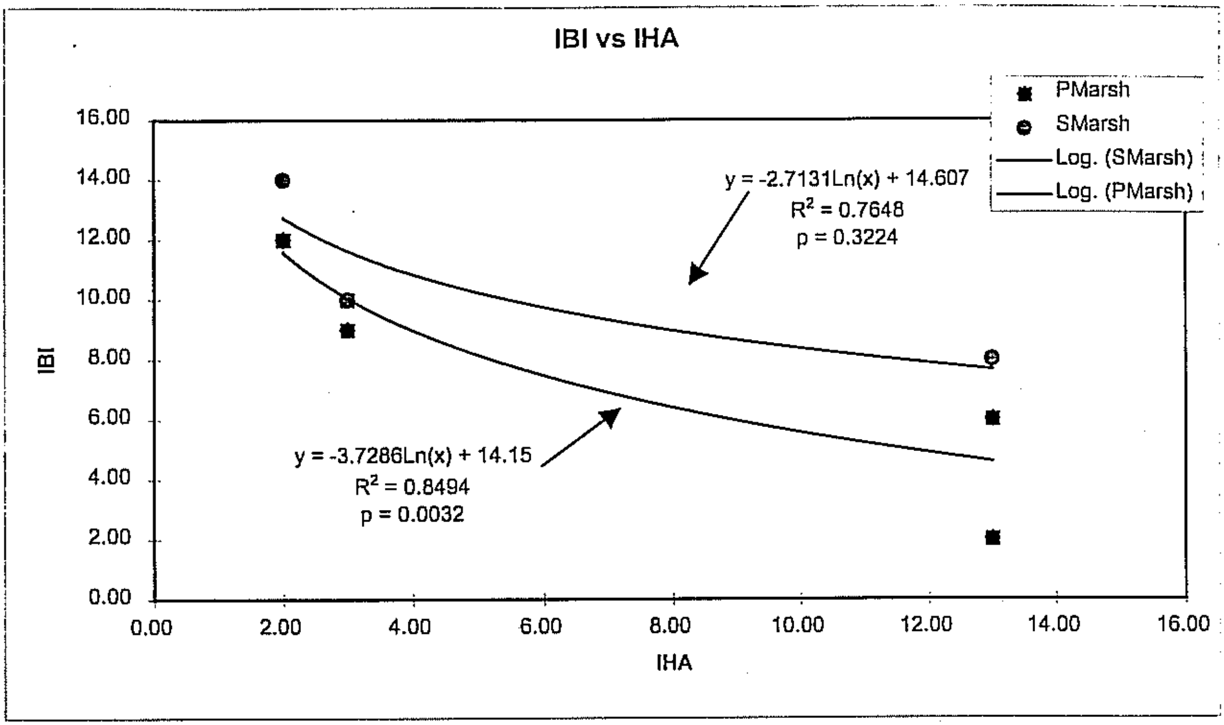


Figure 19. Relationship of fish community integrity, measured as an Index of Biotic Integrity (IBI), to human activity in bays and surrounding landscapes, measured as an Index of Human Activity (IHA), in permanent marshes (PMarsh) and seasonal marshes (SMarsh) in three Les Cheneaux bays.