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HABITAT AND HUMAN INFLUENCES ON LARVAL FISH ASSEMBLAGES IN NORTHERN LAKE HURON COASTAL MARSH BAYS

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Abstract: Great Lakes coastal marshes serve as spawning areas for adult and nurseries for young-of-year fishes, but the capacity of these habitats to facilitate fish reproduction is threatened due to their continued destruction and degradation. In order to appreciate the consequences of marsh loss and degradation, we collected fish larvae with icthyoplankton nets during the summers of 1997 and 1998 in three coastal marsh bays in Les Cheneaux, northern Lake Huron. In addition, we obtained several metrics of human activities and local habitat features (vegetation, water temperature, and substrate slope) and evaluated the importance of these metrics in structuring local larval fish assemblages. Our study indicated that local habitat features strongly and directly affected local larval fish assemblages in Les Cheneaux, while human activities did not. However, human activities may have altered local habitats in Les Cheneaux, thus indirectly impacting local larval fish assemblages.

Key Words: coastal marsh, human activities, Lake Huron, larval fish

INTRODUCTION

Coastal marshes in the Great Lakes facilitate fish reproduction by serving as spawning grounds for adult and nursery areas for young-of-year fishes (Jude and Pappas 1992). However, the capacity of these habitats to provide these services is threatened due to the continued human-induced loss and degradation of coastal marshes around the Great Lakes. The state of Michigan alone has lost between 60% and 70% of its coastal wetlands (Noss et al. 1995), and many remnant marshes have been degraded to some degree. Although ecological functions of degraded marshes may not be totally lost, degradation can greatly alter fish assemblages (Poe et al. 1986, Leslie and Timmins 1992, Brazner 1997). In view of the diminution and alteration of coastal marsh habitats in the Great Lakes, it is important to understand the ecological functions of coastal marshes and to be able to detect and appreciate the consequences of their degradation (Krieger et al. 1992).

Larval fishes appear to be an appropriate focal group in the study of coastal marshes. The presence of fish larvae in a coastal marsh represents the habitat's capacity to provide ecological services (spawning grounds and nursery areas), and thus, an adequately functioning coastal marsh should contain a high density and a large number of larval fish taxa. Further, numerous researchers have demonstrated that fish larvae are extremely sensitive to a variety of environmental factors (see Rose 2000), suggesting that fish larvae should be good indicators of the degree of degradation within a coastal marsh. Previous studies of fish larvae in coastal wetlands have focused upon the effects of local habitat features (Gregory and Powles 1985, Chubb and Liston 1986, Petering and Johnson 1991, Bryan and Scarnecchia 1992) and human impacts (Stephenson 1990, Bryan and Scarnecchia 1992, Leslie and Timmins 1992) in structuring local larval fish assemblages, suggesting that both may be important.

Although fish larvae are sensitive to numerous environmental factors, this sensitivity may render the larval stage of a particular fish species an inappropriate focus for assessment purposes. In a sense, fish larvae are hypersensitive. Annual abundances of fish larvae are highly variable, and within years, densities are spatially patchy. Thus, detecting differences among population means is difficult (Cyr et al. 1992). Further, larval fish assemblages are temporally dynamic, and the dates and lengths of time during which species of larvae are present in a system will vary. An implication of the spatial and temporal distributions of fish

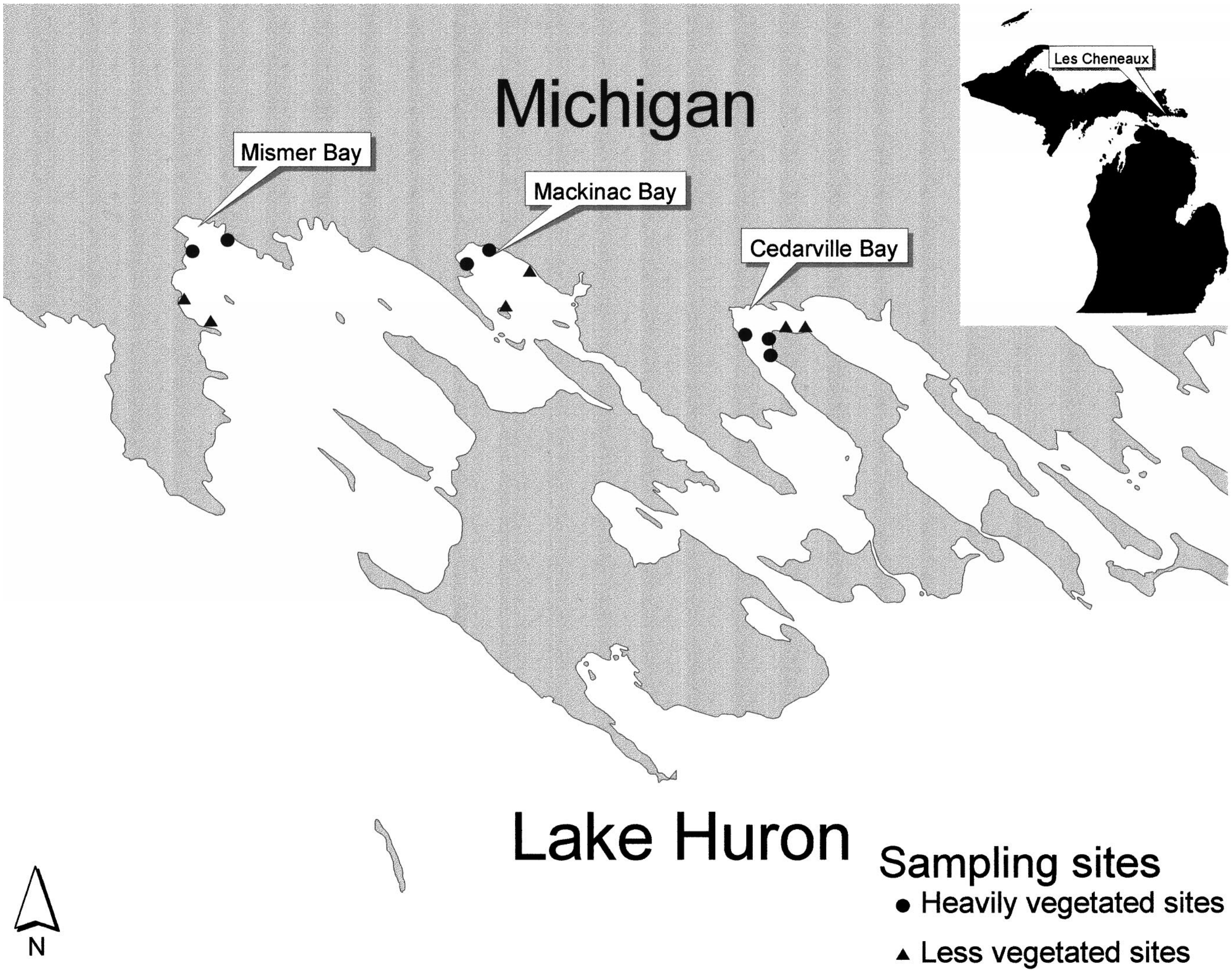

Figure 1. Study sites in three coastal marsh bays in Les Cheneaux, northern Lake Huron, 1997 and 1998.

larvae is that the quantitative assessment of larval fish assemblages may be inappropriate, and instead, as Jackson and Harvey (1997) suggested for adult fish communities, qualitative assessments (i.e., presence/absence, richness, etc.) should be used.

We sampled fish larvae during two summers in nearshore areas in three coastal marsh bays in Les Cheneaux of northern Lake Huron. Our three study bays differed in degree of bay-wide human activity, and all contained a variety of local habitats. We therefore sought to compare the relative importance of human impacts versus local habitat features in structuring local larval fish assemblages.

STUDY AREA

Les Cheneaux of northern Lake Huron is an area of islands and coastal marsh bays (Figure 1). Three such bays, Cedarville, Mackinac, and Mismer, were selected for this study. These bays were selected because they appeared to differ in degree of human impact, while being morphologically similar. Cedarville Bay was chosen because it is the most impacted bay in Les Cheneaux. It is bordered by the town of Cedarville, sewage settlement basins are emptied into it in the spring and fall, and a boat channel has been dredged through its center. Mackinac Bay has a less developed shoreline, but a paved highway passes close to its north side, and there is a dredged boat channel in its southeastern section. Mismer Bay is the least impacted bay. Its shoreline is relatively undeveloped, and no boat channels pass through the bay.

METHODS

Our basic study design involved relating larval fish assemblages to both bay and site-specific characteristics. Within each bay, four littoral sampling sites, two heavily vegetated and two less vegetated, were selected and delineated with markers. The former sites were considered permanent marsh, with dense vegetation year-round. The latter sites were sparsely vegetated in the spring, but vegetation grew in during summer. Nevertheless, densities of vegetation at these sites were never as great as at the heavily vegetated, permanent marsh sites during the period of study. The same sites were sampled in 1997 and 1998 with one exception; one of the heavily vegetated sites in Cedarville Bay sampled in 1997 was replaced by another in 1998. This change was made to more accurately represent the sum of all heavily vegetated habitat in the bay.

Bay Characterization

In order to quantify bay morphologies and human impacts, several measures were obtained. Bay boundaries were defined based upon perceived circulation patterns. Data on bay morphometrics were taken from NOAA chart 14885 and included mean and maximum depth and surface area. In addition, the length of the shoreline (both mainland and island) bordering each bay was measured.

There is no common standard for determining a relevant area of land that affects lentic water bodies. The recommendation of the bi-national State of the Lakes Ecosystem Conferences (SOLEC) was adopted, and land area and human activity were measured within 1 km of the shoreline of the bays and all tributary streams. Exceptions occurred when bays were separated from each other by narrow peninsulas. Here, it was assumed that terrestrial surface and subsurface flows occur equally in both directions. Therefore, peninsulas were bisected along their lengths, and human activity was considered for the half along the shoreline of a bay. The boundaries of the resulting land areas were traced on tared paper from 1:15840 (19.0 cm to 1.0 km) maps provided by the Clark Township Assessor's Office.

There are also no generally recognized indicator measures of human activity. Five measures were chosen to encompass a variety of human impacts: shoreline building density, boat dock and boat house densities, road density, impervious surface area, and boat traffic. A unit of development was defined as a building, its garage, whether attached or separate, and other outbuildings on a plat. Shoreline building density was defined as the number of developed plats per kilometer of shoreline (information regarding plat status was obtained from tax records in the Clark Township Assessor's Office). Boat dock and boat house densities were defined as the number of these structures per kilometer of shoreline. Shoreline boat structures were counted from 1997 1:4800 aerial photographs. Road density was defined as the ratio of road length to the land area within 1 km of the bay and its tributaries. Road lengths were measured using a cartographer's milometer from 1997 1:4800 aerial photographs. Impervious surface area was calculated as the sum of the footprints of roads, buildings, and other areas such as parking lots. Road area was calculated by multiplying the measured lengths of roads within 1 km of the shoreline by the average road width. Road width, measured from subsamples of roads, averaged 7 m for paved and 6 m for gravel roads. All buildings within the 1-km land area were identified from plat maps, and footprint areas were obtained from tax records. The surface area of parking lots, and other impermeable surfaces were determined from cutouts of tracings on tared paper from 1997 1:4800 aerial photographs. The number of boats per unit water area was determined from censuses on each bay taken between 0900 and 1500 when entering the bays to sample fishes from July 1–August 16, 1998. The area sampled was delineated by known landmarks and referenced to NOAA chart 14885.

Site Characterization

Two measures of potential local human impact were obtained: 1) distance from the shoreline at each sampling site to the nearest navigational boat channel, measured from NOAA chart 14885 (19^{th} edition) and 2) the number of developed plots which fell within 100 m of the nearest shoreline point, counted from Clark Township Tax Maps (Mackinac County, MI).

In addition to local human impacts, several site-specific habitat measurements were made. First, continuity of habitat was measured for heavily vegetated sampling sites as the area of continuous marsh habitat (measured from NOAA chart 14885; Eagan 1999). Second, the substrate slope at each sampling site was determined by measuring the distance from the shore to a depth of 1 m. Third, water temperatures ~0.5 m below the surface were recorded at each site for each sampling visit (from 6 May to 6 August during 1997, and from 3 May to 16 August during 1998). Finally, macrophytes were sampled three times at each site during 1998 (14 June, 19 July, and 13 August) in a 144-m^2 (12-m $\times$ 12-m) area.

To sample macrophytes, a ~5-min. wading survey was undertaken in the sampling area. All macrophytes detected were identified to genus and were classified as one of two submergent growth forms (rosette or flexous) or as emergent or floating growth forms (Fasset 1930). Then, to further quantify macrophyte cover, within each 12-m $\times$ 12-m sampling area, nine, equidistant, 1-m^2 sampling stations were established. There was one station in each corner of each 12-m $\times$ 12-m sampling area, one along the midpoint of each 12-m side, and one in the center of the area. At each of these 1-m^2 stations, the area of water surface covered by emergent and/or floating macrophytes and the area of substrate covered by submergent macrophytes were evaluated on scales from 0 to 3 where; 0= open water; 1= >0%-33% coverage; 2= 34%-67% coverage; 3= 68%-100% coverage.

These data were used to calculate an index of habitat complexity (IHC) similar to the macrophyte diversity index described by Brazner and Beals (1997). Here, IHC is given by:

$$IHC = \frac{\left(\frac{A_{sub}}{3} \times \frac{F_{sub}}{2}\right) + \left(\frac{A_{emg}}{3} \times \frac{F_{emg}}{2}\right)}{2}$$

where A_{sub} is the average ordinal ranking (0–3) of the nine subsamples of substrate area covered by submergent macrophytes, F_{sub} is the average number of submergent growth forms (0–2) detected (rosette and/or flexous), A_{emg} is the average ordinal ranking (0–3) of the nine subsamples of water surface area covered by emergent and/or floating macrophytes, and F_{emg} is the average number of emergent and/or floating growth forms (0–2) detected.

The IHC varies between 0 and 1. A score of zero represents a site with no area covered by vegetation and hence none of the macrophyte growth forms present, while a score of 1 represents a site with maximum coverage by both emergent and submergent vegetation, and all four classes of macrophyte growth forms present. The IHC equally weighs habitat complexity at the surface and near the substrate, and it also equally weighs area covered and form richness.

Correlation analysis showed that index values were significantly, positively correlated with all four variables upon which the index was built. Further, this analysis suggested that the weights of the four variables upon which the index was built were relatively equal. That is, no one variable was consistently the major component of IHC scores. The IHC was calculated at each site for each of the 3 sampling days and values were averaged.

Larval Fish Sampling

Larval fish were sampled approximately every other day. On a given sampling day, one of the heavily vegetated and one of the less vegetated sites were sampled in each bay between 0800 and 1800 (the time and order of sampling of individual bays varied). Thus, individual sites were sampled approximately once every 4 days. In 1998, all sites were sampled 26 times, from 3 May to 16 August. In 1997, half the sites were sampled 19 times and half the sites were sampled 15 times, from 29 April to 8 August.

Larvae were sampled using a seine and a tow net, both at water depths <1 m. One gear type was applied immediately to the right of the site marker (facing inshore) and the other immediately to the left. The seine consisted of a 365-μm-mesh net mounted upon a 0.22-m by 0.61-m metal frame to which two 1.63-m aluminum rods were attached. The seine was pulled by two investigators for approximately 30 m in a zigzag pattern (i.e., this method sampled an ~4-m^3 volume of water). The tow net consisted of a 365-μm-mesh plankton net mounted on a 0.5 m diameter metal hoop, which was attached to a 10-m rope. One investigator carried the net 10 m away from another investigator, who then hauled it in, taking care to ensure it was towed through undisturbed water (i.e., this method sampled an ~2-m^3 volume of water).

Fish larvae were preserved in 10% formaldehyde solution. Larval fish stages were defined on the basis of total length and morphology and identified to the lowest taxonomic level possible (Auer 1982). Most larvae (juvenile fish were excluded) were identified to species or genus, but others, including all cyprinids, were identified to family.

Abundance of a particular taxon at a site on a sampling day was calculated as catch-per-unit-effort (CPUE). The efficiencies of the two methods to sample different types of larval fish were similar, and thus, the aggregation of data generated from the application of the two different methods was deemed appropriate. Therefore, a unit of effort was defined as all larval sampling undertaken at a given site on a given day (i.e., one seine haul and one tow pull). The measures of CPUE at each site were averaged for each year. Although the number of sampling visits differed among years (15 or 19 in 1997 and 26 in 1998), the temporal range of sampling was similar for both years. Richness was defined in two ways: family richness (the number of fish families (the lowest common taxonomic group) detected at a site for each year) and taxa richness (the number of identifiable groups (family, genus, or species) detected at a site for each year).

Data Analyses

Initial analyses of the data from each of the sites in each bay suggested that categorical discrimination between high and low vegetation densities was inadequate because this habitat feature, along with other site characteristics, varied continuously. Thus, comparison among bays on the basis of these highly and less vegetated sites was replaced *a posteriori* by a correlation approach.

The bay-wide and site-specific characteristics, two sampling factors (year and number of sampling days), and larval fish assemblage measures (total CPUE, CPUE of the three most abundant taxa, family richness, and taxa richness) were related through Pearson correlation analysis. Resulting r-values were then evaluated using t-tests to determine if correlations were significantly different from 0 (α=0.05). All statistical analyses were carried out using SYSTAT version 5.0 (SYSTAT Inc. 1994).

RESULTS

Bay Characterization

The initial perception that bay morphologies were similar was justified by their morphometrics (Table 1). Likewise, the initial ordering of bays from most to least developed was justified. Cedarville and Mackinac Bays ranked first and second, respectively, in all five measures of bay-wide human impact (Table 1).

Site Characterization

Local human impact measures varied in the same way as bay-wide measures (Table 1). Distances to the nearest boat channel were smallest for sites in Cedarville Bay followed by those in Mackinac Bay and Mismer Bay, respectively. The number of developed plots within 100 m of a site ranged from 0 to 4, but nonetheless showed similar differences among the bays as distance to the nearest boat channel. Sites in Cedarville Bay averaged 1.8 developed plots within 100 m, while sites in Mackinac Bay and Mismer Bay averaged 0.8 and 0.3 developed plots within 100 m, respectively.

Some local measures of natural habitat revealed similar trends among the study bays. The area of continuous marsh habitat was smallest in Cedarville Bay, followed by Mackinac Bay, then Mismer Bay. Similarly, substrate slopes in Cedarville Bay were on average steeper than slopes in Mackinac Bay and Mismer Bay (Table 1).

In contrast, other measures of natural habitat did not differ among the bays. For example, there was no consistent spatial pattern in mean water temperatures in the three study bays. The average water temperature in 1997 was 18 °C (± 0.7; n = 144) and 20 °C (± 0.3; n = 306) in 1998 (Table 2). The higher average water temperature in 1998 was associated with a relatively early spring, with residents reporting an ice-off date of 5 April in 1998 compared with 30 April in 1997.

Index of habitat complexity scores for sites originally classified as heavily vegetated ranged from 0.21 to 0.61, while all less-vegetated sites had IHC scores ranging from 0.05 to 0.15. In spite of this categorization, vegetation levels measured by the IHC essentially varied continuously over the range from 0.05 to 0.61 (Table 2). The most common emergent and floating forms were *Scirpus* spp. and *Nuphar* spp., respectively, while the most common flexous and rosette forms were *Potamogeton* spp. and *Scirpus subterminalis* (Torrey), respectively.

Larval Fish Sampling

In total, 3,549 larval fish were collected (1,876 in 1997 and 1,673 in 1998) representing 12 families and 16 taxa. The three most abundant taxa, representing 86% of the total catch, were cyprinids (41%), yellow perch (*Perca flavescens* Mitchill) (25%), and sunfish (*Lepomis* spp.) (19%). In 1997, a large number (240) of whitefish (*Coregonus* spp.) was also collected. However, few were sampled in 1998, probably because water temperatures in the spring were high and the larval stage concluded prior to sampling.

There were only minor differences in larval fish assemblages among the three study bays. Half of the larval fish taxa were present in all three of the study bays (Figure 2 and 3), and those taxa that were only collected in one of the bays (*Umbra limi* Kirtland, *Alosa pseudoharengus* Wilson, *Micropterus dolomieui* Lacépède, and *Cottus* spp.) were each only collected on one occasion. The only taxon that was absent from one of the bays and collected frequently (>four times) during the 2 study years was banded killifish (*Fundulus diaphanus* Lesueur), which was never collected in Cedarville Bay.

The effect of temperature on larval fish in Les Cheneaux was dramatic. All fish taxa collected during both years were initially collected earlier in 1998, the warmer of the 2 years. Nonetheless, the general sequences in which fish larvae emerged were similar for both years (Figure 4). In addition, water temperatures during 1998 decreased rapidly over a short period in late May and early June. *Lepomis* spp. larvae were collected in Mackinac Bay (the on-average warmest of the three study bays) before temperatures decreased but then disappeared until 21 June, when they were once again collected in Mackinac Bay (Figure 4).

Correlations among Larval Fish Assemblages, Human Impacts, and Habitat

All measures of human impact (both bay-wide and site-specific) were significantly correlated with each other. These same measures, with the exception of the number of developed plots within 100 m, were also significantly correlated with marsh area and substrate slope at sampling sites (Table 3).

Significant correlations were also found among local

Table 1. Morphometrics and measures of human impact and habitat of three study bays in Les Cheneaux, northern Lake Huron, 1997 and 1998.

	Cedarville	Mackinac	Mismer
Bay morphometrics:			
Surface area (km^2)	2.07	1.63	1.87
Land area within 1 km (km^2)	13.11	7.77	9.54
Shoreline length (km)	8.69	5.65	5.19
Maximum depth (m)	4.6	2.7	3.4
Mean depth (m)	1.5	1.2	1.6
Bay-wide measures of human impact:			
Impervious surface area (%)	4.0%	1.1%	0.7%
Road density (km/km^2 land area)	1.06	0.89	0.88
Shoreline building density (#/km shoreline)	5.9	3.4	3.1
Shoreline boat structure (#/km shoreline)	14.8	4.4	2.7
Boat density (#/km^2 water area) (± 2 s.e.)	7.27 ± 1.19	0.80 ± 0.41	0.35 ± 0.27
Mean site-specific measures of natural habitat:			
Area of continuous marsh habitat (km^2)	0.02 & 0.01	0.15	0.29
Distance (m) from shore to 1 m isobath (± 2 s.e.)	46 ± 40	135 ± 111	147 ± 97
Mean site-specific measures of human impact:			
Distance (km) to nearest boat channel (± 2 s.e.)	0.18 ± 0.08	1.13 ± 0.61	2.11 ± 0.20
Developed properties within 100 m (± 2 s.e.)	1.8 ± 1.2	0.8 ± 1.5	0.3 ± 0.5

measures of natural habitat. In general, sites with denser and more structurally complex stands of macrophytes tended to be warmer and occur in areas where the substrate slope was more gradual (Table 3).

No measures of larval fish CPUE nor richness were significantly correlated with any measures of human impact. In contrast, some measures of the larval communities were correlated with local measures of habitat. The index of habitat complexity (IHC) was significantly, positively correlated with *Lepomis* spp. CPUE ($r=0.580$, $p=0.05$), family richness ($r=0.518$, $p=0.05$), and taxa richness ($r=0.549$, $p=0.05$, Figure 5). Furthermore, substrate slope was found to be significantly, negatively correlated with CPUE of *Lepomis* spp. ($r=-0.426$, $p=0.05$), and mean temperature was significantly, positively correlated with family ($r=0.431$, $p=0.05$) and taxa richness ($r=0.488$, $p=0.05$).

DISCUSSION

The Les Cheneaux coastal marsh complex seems to facilitate the reproduction of a number of fish species. Not only did we collect a large number of larval fish taxa, but we also collected different taxa during different periods of time. Fish larvae are small, gape-limited predators, and thus, their diet breadths are restricted and greatly overlap with each other. Keast (1980) suggested that fish larvae are able to minimize potential competition by temporally partitioning resources. Therefore, the sequential emergence of larval fish taxa in Les Cheneaux likely allows this system to yield more fish.

Effects of Local Habitat Features

Our study suggests that, in Les Cheneaux, local habitat factors (i.e., vegetation, temperature, and substrate slope), as compared to bay-wide factors, are more important in structuring local larval fish assemblages. Although all measures of larval fish assemblages were positively correlated with IHC, only three of these correlations were significant. That is, larval fish richness (both family and taxa) and CPUE of *Lepomis* spp. were significantly correlated with local habitat factors, while total CPUE and CPUE of cyprinids and *Perca flavescens* were not.

The absence of consistent patterns among species may relate to habitat preferences among various types of larval fish. *Perca flavescens* uses various spawning substrates (Scott and Crossman 1973, Auer 1982, Gregory and Powles 1985), and feeding migrations are undertaken by its larvae (Gregory and Powles 1985, Post et al. 1995). Thus, absence of strong habitat affinity by the larvae of this species is not surprising. *Lepomis* spp., however, has a strong preference for particular types of structural habitat (Crowder and Cooper 1982, Werner et al. 1983, Petering and Johnson 1991). *Lepomis* spp. is a nest builder (Scott and Crossman 1973), and larvae of this genus emerge in areas occupied by adults. Thus, the significant correlation between CPUE of *Lepomis* spp. and IHC may well be a result of strong adult habitat preferences.

Notwithstanding the species-specific habitat preferences, the majority of taxonomic groups seemed to favor more vegetated sites (Conrow et al. 1990, Petering and Johnson 1991, Bryan and Scarnecchia 1992,

Table 2. Site characteristics, including location, index of habitat complexity (IHC) scores, and temperatures (sites ordered by IHC scores) for all sites sampled during 1997 and 1998 in Les Cheneaux, northern Lake Huron.

Site	Location		IHC (mean ± 2 s.e.)	Mean temperature (°C ± 2 s.e.)	
	Latitude (N)	Longitude (W)	(1998; n = 3)	(1997; n = 12)	(1998; n = 26)
Heavily vegetated sites					
Mackinac M2	46° 00′ 14″	84° 24′ 57″	0.605 ± 0.014	20 ± 0.9	21 ± 0.4
Cedarville M2	45° 59′ 27″	84° 21′ 39″	0.562 ± 0.047	[a]	20 ± 0.3
Mackinac M1	46° 00′ 20″	84° 24′ 38″	0.549 ± 0.043	20 ± 0.7	22 ± 0.4
Mismer M2	46° 00′ 26″	84° 28′ 08″	0.475 ± 0.043	18 ± 0.7	19 ± 0.4
Mismer M1	46° 00′ 33″	84° 27′ 55″	0.364 ± 0.043	19 ± 0.6	20 ± 0.5[c]
Cedarville M1	45° 59′ 22″	84° 21′ 15″	0.207 ± 0.018	19 ± 0.8	19 ± 0.3
Cedarville M3	45° 59′ 28″	84° 21′ 17″	[b]	19 ± 0.9	[b]
Less vegetated sites					
Mackinac B1	46° 00′ 03″	84° 23′ 59″	0.151 ± 0.041	19 ± 0.6	21 ± 0.4
Cedarville B1	45° 59′ 32″	84° 20′ 59″	0.130 ± 0.037	18 ± 0.8	19 ± 0.6
Mackinac B2	45° 59′ 47″	84° 24′ 21″	0.117 ± 0.020	19 ± 0.8	20 ± 0.3
Cedarville B2	45° 59′ 33″	84° 21′ 10″	0.090 ± 0.025	18 ± 0.7	20 ± 0.3
Mismer S1	46° 00′ 07″	84° 28′ 14″	0.056 ± 0.006	16 ± 0.6	18 ± 0.4[c]
Mismer S2	45° 59′ 51″	84° 28′ 11″	0.046 ± 0.006	16 ± 0.7	18 ± 0.3

[a] Not sampled in 1997; [b] not sampled in 1998; [c] n = 23.

Leslie and Timmins 1992). This is supported both by the significant positive correlations between larval fish richness and IHC and absence of negative correlations (significant or non-significant) between any measures of larval fish assemblages and IHC.

In addition, significant positive correlations between CPUE of *Lepomis* spp. and substrate slope and between larval fish richness and mean temperature suggest that these two habitat features are also important. However, as both substrate slope and temperature were significantly correlated with IHC, it is difficult to evaluate the individual effects of these habitat characteristics on larval fish assemblages. In general, gradual slopes, relatively high temperatures, and low exposure to wind and boat-driven waves promote strong vegetation growth. Subsequently, macrophyte establishment reduces impacts of wave exposure and promotes accumulation of material, thus decreasing substrate slope, and possibly alters local temperatures by reducing water circulation and exchange. Thus, there may well be positive feedback mechanisms in place facilitating simultaneous macrophyte establishment, slope

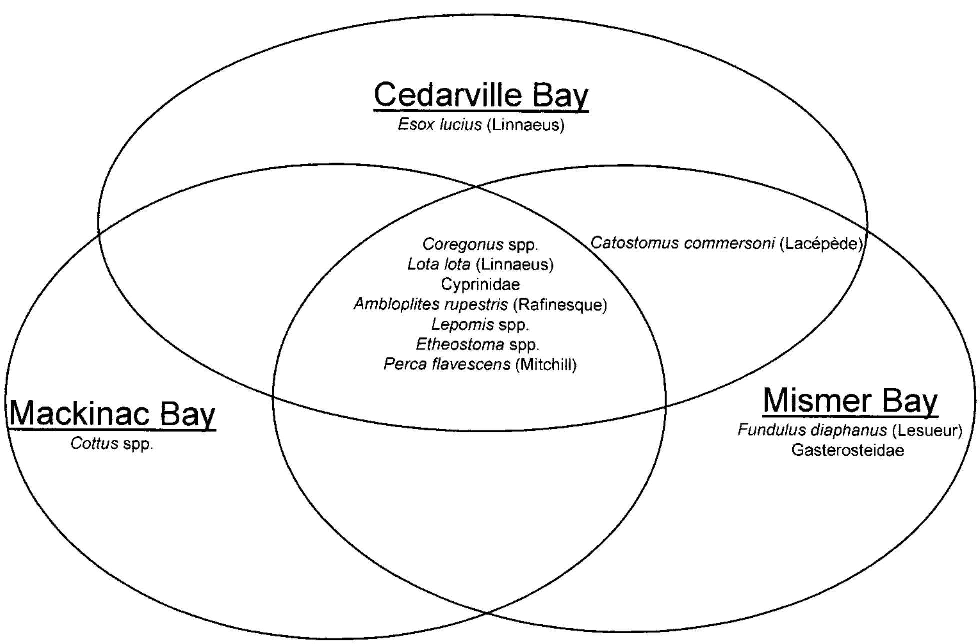

Figure 2. Shared and unique fish taxonomic groups among Les Cheneaux bays sampled during 1997.

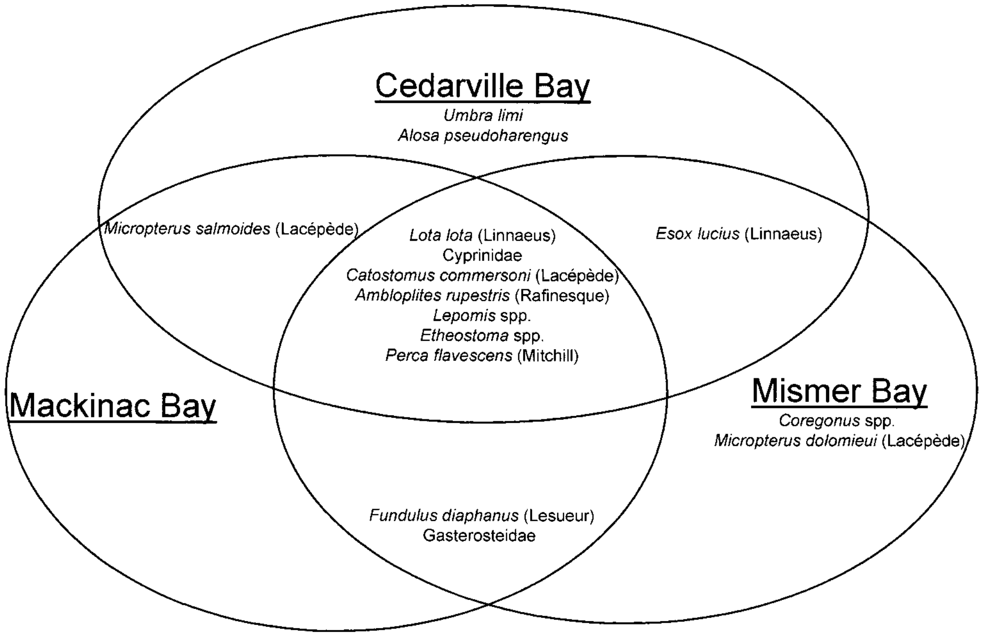

Figure 3. Shared and unique fish taxonomic groups among Les Cheneaux bays sampled during 1998.

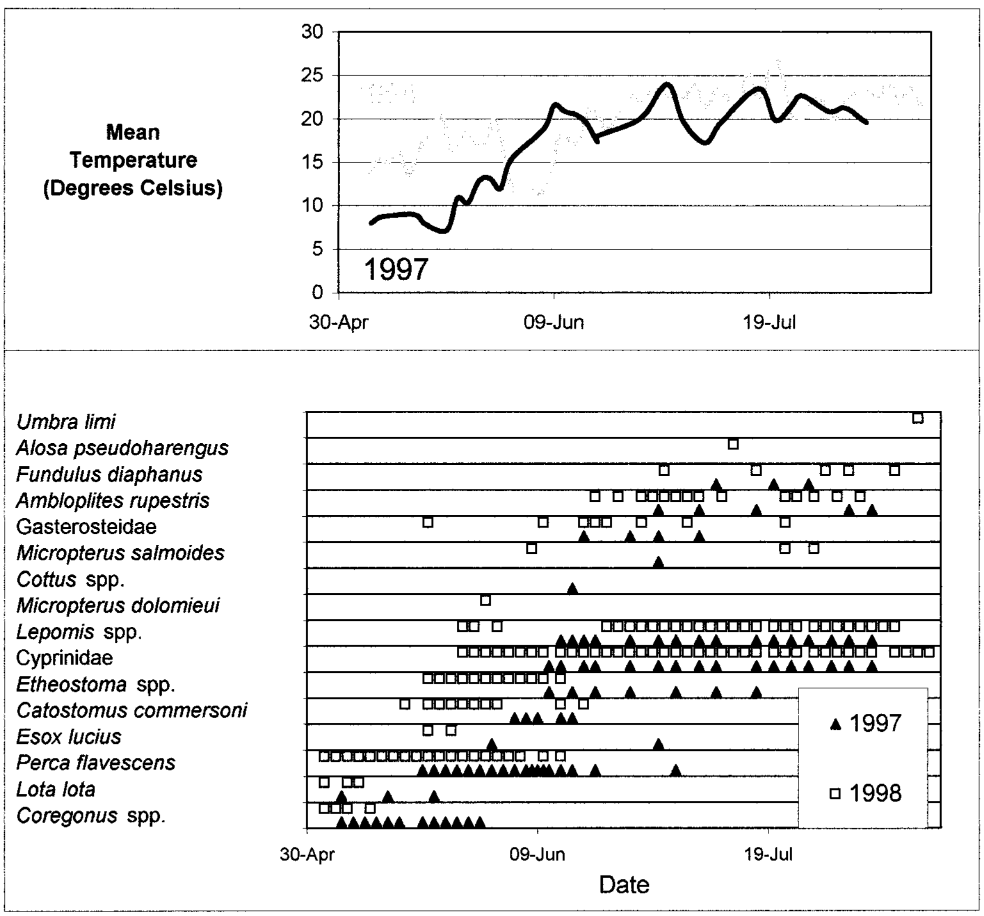

Figure 4. Mean water temperatures during summers 1997 and 1998 in the three study bays and presence of larval fish versus time. The top graph depicts mean temperatures in Les Cheneaux based upon temperatures recorded at all study sites. The bottom graph depicts days when larval fish taxa were detected in Les Cheneaux. A point on this graph represents a day when at least one fish larva of the corresponding taxa was sampled in any of the three study bays via either of the two methods.

Table 3. Pearson correlations (r-values) between measures of site characteristics describing 1997–1998 sampling locations in Les Cheneaux northern Lake Huron.

	IHC	Temp.	Slope	Marsh Area	Channel Distance	Plats
Habitat measures:						
IHC (Index of habitat complexity)	—	0.577*	−0.469*	0.224	0.342	−0.343
Mean temperature		—	−0.119	−0.053	−0.159	−0.006
Substrate slope			—	−0.390	−0.753*	0.721*
Area of continuous marsh habitat				—	0.963*	−0.405
Measures of human impact:						
Distance to nearest boat channel					—	−0.598*
Developed plats, within 100m						—
Impervious surface area	−0.182	0.046	0.766*	−0.915*	−0.847*	0.562*
Road density	−0.199	0.008	0.765*	−0.888*	−0.821*	0.555*
Shoreline building density	−0.186	0.036	0.766*	−0.909*	−0.841*	0.561*
Shoreline boat structures	−0.177	0.056	0.756*	−0.922*	−0.853*	0.564*
Boat density	−0.197	0.013	0.765*	−0.892*	−0.825*	0.566*

* Significant correlated ($p \leq 0.05$).

reduction, and temperature alteration. Ultimately, slope and temperature may have their effects upon the distribution of larval fish indirectly through their effects upon vegetation.

Past studies have suggested that local fish community and population parameters are related to vegetation cover (Eadie and Keast 1984, Weaver et al. 1997), vegetation growth form and species diversity (Brazner and Magnuson 1994, Weaver et al. 1997), submergent vegetation (Killgore et al. 1989, Randall et al. 1996), and emergent and floating vegetation (Conrow et al. 1990, Petering and Johnson 1991). We suggest that

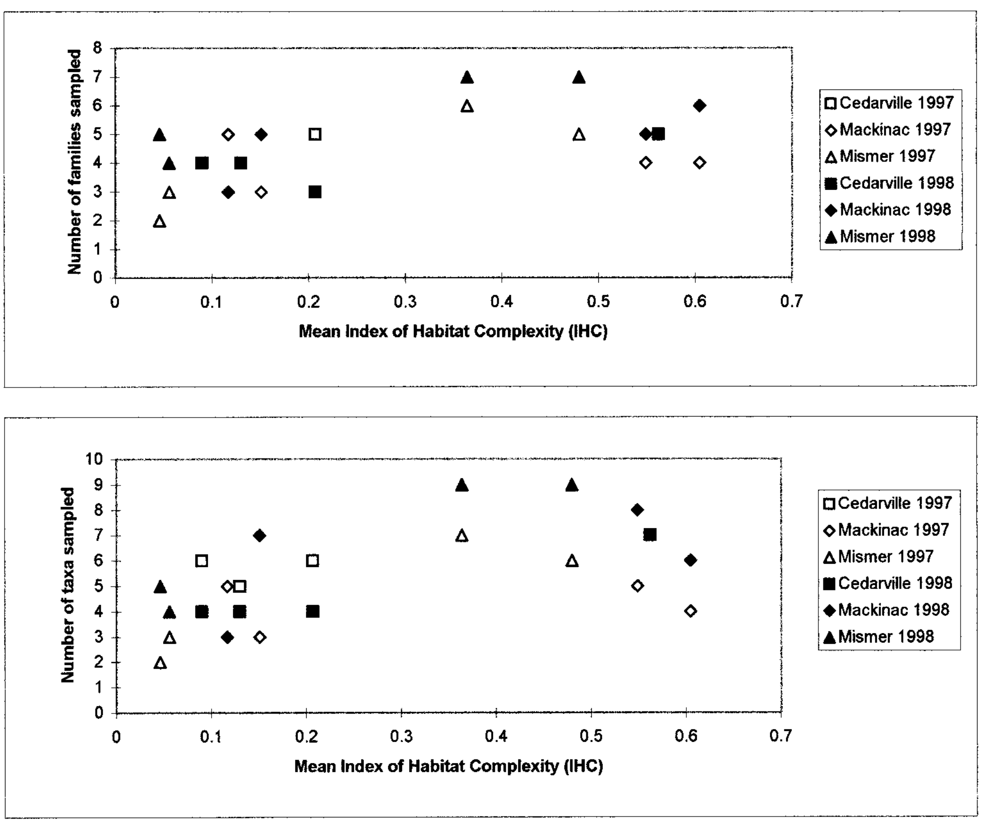

Figure 5. Larval fish richness (number of families sampled and number of taxonomic groups sampled) at individual sampling sites in Les Cheneaux coastal marshes versus mean index of habitat complexity (IHC) scores for 1997 and 1998.

emergent and floating macrophytes and submergent macrophytes probably play different roles in structuring larval fish distributions. The submerged portions of emergent and floating macrophytes tend to be structurally simple but sturdy, providing protection to fish larvae from wave action, sun, and avian predation (Petering and Johnson 1991). Submerged macrophytes, however, tend to be more structurally complex, but less sturdy, and would provide protection from aquatic predators and microhabitats promoting food production (Engel 1988, Jude and Pappas 1992).

On a coarser scale, relationships between larval fish assemblage measures and vegetation are probably not linear. At some point, densities of stems begin to physically limit habitat. Therefore, as suggested by the habitat diversity hypothesis, larval fish richness might asymptote and then decrease as vegetation increases (Petering and Johnson 1991, Jude and Pappas 1992). Our results for larval fish richness support this idea. Larval fish richness was greatest at vegetated sites with IHC scores of ~0.4, and fewer larval fish groups were found at sites with greater and lesser IHC scores. However, these data are equivocal, as the sites with intermediate IHC values and highest richness were located in Mismer Bay, the bay with the least human impact.

Human Impacts

We did not detect any direct, human-induced impacts on larval fish assemblages through correlation analysis. There are likely two reasons for this. First, all of Les Cheneaux is still relatively pristine compared to areas studied by other authors (Gregory and Powles 1985, Petering and Johnson 1991, Leslie and Timmins 1992). Thus, differences in larval fish communities among bays are likely small. Second, our study was designed to compare local larval fish assemblages, not to detect differences in bay-wide communities. We did not randomly select sampling sites but instead chose sites among bays that we deemed to be relatively similar. The area of marsh habitat in the three study bays differs greatly. Specifically, Cedarville Bay has much less marsh habitat compared with the other two bays due to intensive human activities in this bay. We found a positive correlation between vegetation (IHC) and larval fish richness. Thus, assuming that our sampling sites are representative of entire marshes, bay-wide differences in larval fish communities are likely more pronounced than suggested by site-specific differences alone.

Among human activities, we believe that boating activities may have particularly strong deleterious impacts upon marsh habitat in Les Cheneaux. Boat-channel dredging leads to steeper substrate slopes and hence less vegetation. Further, boat wakes are erosive and can hinder macrophyte establishment (Rich 1993, Asplund and Cook 1997).

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