COMPARISON OF SPECIES COMPOSITION AND RICHNESS OF FISH ASSEMBLAGES IN ALTERED AND UNALTERED LITTORAL HABITATS

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INTRODUCTION

A number of experimental pond and field studies have recently been conducted to investigate the influence of various components of the habitat (abiotic and biotic) on fish community structure. Several of these studies have been conducted with sunfishes in experimental ponds or pools in which the investigators were able to control habitat variables (e.g. Werner & Hall 1979, Mittlebach 1981, Werner et al. 1981, Crowder & Cooper 1982, and Savino & Stein 1982). These experiments have indicated that the structure and density of aquatic macrophytes are important components of the habitat that strongly influence the competitive interactions among fish, predator-prey relations, and consequently growth and abundance of fish. Recent field studies have also investigated the effect of environmental factors on the structure of natural assemblages of fish. These studies indicated that different habitat variables most strongly influenced fish community structure in different areas: littoral morphometries and vegetation structure in Michigan and Florida lakes (Werner et al. 1978); low oxygen in winter and vegetation diversity in 18 small Wisconsin lakes (Tonn & Magnuson 1982); and diversity of invertebrate prey in northern Ontario lakes and substrate diversity and vertical vegetation complexity in southern Ontario lakes (Eadie & Keast 1984).

In these studies the investigators examined the relationships between habitat factors and fish community structure in experimental ponds or in the natural environment, but few studies have evaluated the effect of human perturbations on these relationships. In a study of stream fish communities, Gorman & Karr (1978) found that man-made modifications of stream channels caused changes in species composition and relative abundance in fish communities. Recently, Livingston (1984) determined that water pollution disrupted the basic habitat structure and caused changes in the basic food web that led to the alteration of fish community structure in estuaries.

The primary purpose of the present study was to compare the species composition and species richness of fish assemblages in a natural littoral environment with those in a nearby littoral environment altered by human activities. We also examined the abiotic and biotic habitat factors that we believed might govern the relative abundance of fish and species richness in macrophyte beds in shallow littoral waters of Anchor Bay, Lake St. Clair.

METHODS AND MATERIALS

To compare fish community structure in altered and unaltered aquatic habitats, we selected sampling locations in two shallow embayments of Lake St. Clair -- Muscamoot Bay (including Big Muscamoot and Little Muscamoot Bays) in northern Anchor Bay and Belvidere Bay in western Anchor Bay (Fig. 1). Muscamoot Bay has a natural shoreline with almost no alteration due to dredging or bulkheading, high water quality, and a diverse community of emergent and submerged aquatic macrophytes. The area of the bay is about 500 hectares and average depth is 2 m. Three sampling locations (stations 1-3) were selected in mixed stands of submersed aquatic macrophytes that were representative of the major littoral habitats in the bay (Fig. 2). Belvidere

Bay has a bulkheaded shoreline and has been altered considerably by dredge-and-fill activities. Although major wetlands and stands of emergent aquatic vegetation once existed in Belvidere Bay, these areas were almost entirely lost to development (Jaworski & Raphael, 1976) . Water quality in Belvidere Bay is adversely affected by the nearby Clinton River, which carries high concentrations of nutrients and pollutants (Michigan Water Resources Commission, 1975); by other semi-polluted tributaries and canals; and by heavy boating use. The area of the bay is about 120 hectares and average depth is 2 m. Four sampling locations (stations 4-7) were established in mixed stands of submerged aquatic macrophytes that were representative of the major littoral habitats in the bay (Fig. 1).

Limnological measurements were made and water samples were collected at most stations in Little Muscamoot and Belvidere bays from June to November 1979, at 2-3 week intervals. At each station, duplicate 1-liter water samples were collected from 5 to 20 cm below the water surface in linear polyethylene bottles and refrigerated for later analysis of turbidity and suspended particulate matter (SPM). Light penetration was measured with a standard white Secchi disc 20 cm in diameter, and temperature and dissolved oxygen (DO) were measured throughout the water column with an oxygen meter (YSI, Model 54)[1/] which was calibrated weekly against a stem thermometer and the azide modification of the Winkler method (American Public Health Association et al., 1976).

[1/] Mention of a trade name does not constitute U.S. Government endorsement.

In the laboratory water samples were warmed to room temperature before SPM was measured (within 12 - 36 hours after collection); SPM was measured gravimetrically after filtration onto preweighed glass-fiber filters (Reeve Angle 984H, 0.3 μm porosity). Turbidity was measured with a nephelometric turbidimeter (HF Turbidimeter, Model DRT 1000) calibrated against standard reference suspensions of Formazin polymer (American Public Health Association et al., 1976).

Aquatic macrophytes and their associated invertebrate fauna (phytomacrofauna) were sampled at each of the seven stations at 2-3 week intervals from June to November 1979, according to the methods of Brown et al. (1985). In the laboratory invertebrates were removed from the macrophytes by placing the sample in a water-filled pan, and removing the plants stem by stem. Because the samples was fresh, the more motile invertebrates usually dislodged themselves from the plant material as it was being removed from the water. Visual inspection ensured that none were left attached to the plant. After the plants had been removed, the phytomacrofauna and detritus were placed in glass bottles and preserved in 10% formalin. The organisms were then separated from the detritus by the unaided eye, identified to the lowest practical taxon, and counted. Finally, the macrophytes were identified to genus or species, and the surface area of each plant was measured by the procedure of Brown and Manny (1985) and expressed as the number of square meters of plant structure within the water column above 1 m^2 of lake bottom.

Fish were collected with a 3.5 m otter trawl (2.5 cm mesh wing; 0.6 cm mesh cod end liner), which was towed in straight line transects at each station at a speed of 3-4 knots for 5 min. We selected the trawl as the sampling gear because it captured larger numbers of fish and more species in the dense stands of submerged aquatic macrophytes than did the other gears we tested (i.e. gillnets and electrofishing). All trawl collections were made near midday. At least three non-overlapping trawl tows were made at each station on each sampling date (the catch at each station on each date was the total number of fish captured in three trawl tows). Fish were identified to species, counted, and measured (total length). Immature centrarchids and shiners (usually $<$20 mm long) that we were unable to identify to species were categorized as unknown centrarchids and unknown shiners. Ages of yellow perch (Perca flavescens) were determined from their scales. The other most abundant species in the catch (rock bass, Ambloplites rupestris; pumpkinseed, Lepomis gibosus; bluegill, L. macrochirus; smallmouth bass, Micropterus dolomieui; largemouth bass, M. salmoides; and black crappie, Pomoxis nigromaculatus) were designated young-of-the-year (YOY), yearlings, or adults on the basis of length-frequency analysis.

We conducted simple linear correlation analyses between various habitat variables (water clarity, DO, water temperature, macrophyte surface area, macrophyte species richness, and density and species richness of phytomacrofauna; turbidity and SPM were deleted from the analyses because many values were missing) and fish species richness and fish abundance, to determine which variables were most closely related to fish community structure. We also used simple linear correlation analyses to compare surface area values of each macrophyte species and density of each taxon of phytomacrofauna with fish abundance, by species, for all stations and dates. In performing all analyses, we used the SAS statistical package (SAS Institute, Inc., 1982).

RESULTS

Water Quality

Overall water quality was higher in Muscamoot Bay than in Belvidere Bay. Water clarity as indicated by mean Secchi disk reading was consistently higher in Muscamoot Bay than in Belvidere Bay and SPM and turbidity were consistently lower in Muscamoot Bay (Table 1). Water temperature averaged slightly higher and dissolved oxygen slightly lower in Belvidere Bay.

Macrophytes

Aquatic macrophytes of 15 taxa were collected from Muscamoot and Belvidere bays (Table 2). The greatest number of taxa were collected at stations 1 and 3 in Muscamoot Bay, followed by station 5 in Belvidere Bay. Although there were mixed stands of macrophytes at all stations, only five taxa were dominant at any one station over all sampling periods (Table 2). Species dominance also changed with station even in the same bay. Greatest surface area was provided by Heteranthera dubia at stations 4 and 5, Chara spp. at stations 2 and 6, Najas flexilis at station 3, Elodea canadensis at station 1, and Myriophylum spicatum at station 7. Surface area values were higher in Belvidere Bay than in Muscamoot Bay, except at station 6. However, the total number of macrophyte species (species richness) was higher at stations 1 and 3 in Muscamoot Bay than at any in Belvidere Bay. Macrophyte abundance was thus highest in Belvidere Bay, but species richness was highest in Muscamoot Bay.

Phytomacrofauna

Species composition of phytomacrofauna differed within and between bays. A total of 49 taxa were collected in mixed stands of macrophytes at all stations from April 25 to November 29, 1979. Amphipods (Hyalella azteca and Gammarus), midge larvae (Chironomidae), and snails (primarily Amnicola, Gyraulus, and Physa) occurred most frequently in the samples and together accounted for over 85% by number of all phytomacrofauna collected during the study (Table 3). Leeches (Hirudinea) and isopods (Asellus and Lirceus) were much more abundant in Muscamoot Bay than in Belvidere Bay. The total density of phytomacrofauna was higher in Belvidere Bay than in Muscamoot Bay, at all stations except station 6 (Table 3). Species richness was very similar, however, in the two bays. Therefore, even though the species composition and density varied between bays, species richness remained fairly constant.

Fish

Fish of 29 species were collected with the trawl (Table 4); 10 species collected in Muscamoot Bay were not collected in Belvidere Bay and 4 were collected in Belvidere Bay were not collected in Muscamoot Bay. The catch was dominated by small fish (<150 mm long) that were mostly YOY or yearlings. Centrarchids constituted more than 84% of the fish community in Belvidere Bay, due primarily to the abundance of rock bass (Table 4). Although centrarchids were collected in Muscamoot Bay, they made up only 8.5% of the total catch; here yellow perch heavily dominated the catch (71% of the total). The next most abundant fishes in Muscamoot Bay were cyprinids and eastern banded killifish, which together composed over 20% of the total catch. The fish community of Muscamoot Bay can be characterized as a percid-cyprinid-cyprinodontid assemblage, and that of Belvidere Bay as a centrarchid assemblage .

The percid-cyprind-cyprinodontid assemblage dominated in Muscamoot Bay where Elodea canadensis, Najas flexilis, and Chara spp. were the dominant macrophytes and at station 6 in Belvidere Bay where Chara spp. were dominant (Tables 2 and 5). The centrarchid assemblage dominated at all other stations in Belvidere Bay, where Heteranthera dubia, Myriophyllum spicatum, and Vallisneria americana were the dominant macrophytes (Tables 2 and 5).

Statistical Analyses

Six significant correlations ($P \leq 0.05$) were obtained between fish species richness or fish abundance and habitat factors (Table 6). Fish species richness was highly correlated with macrophyte species richness and surface area and with phytomacrofauna species richness. Fish abundance was negatively correlated with dissolved oxygen concentration and positively correlated with macrophyte surface area and density of phytomacrofauna.

Of the 456 correlation analyses performed among the surface area values of each species of macrophyte and the abundance of each species of fish by station and date, 53 yielded significant correlation coefficients ($P \leq 0.05$;

Table 7). The abundance (surface area) of the macrophytes Heteranthera dubia, Vallisneria americana, and Ceratophyllum demersum was closely correlated with the abundance of centrarchids. Several other correlations were significant: yearling yellow perch with Najas flexilis and Potamogeton richardsonii; brook stickleback with Elodea canadensis, Myriophyllum exalbescens, Nitella spp., and Ranunculus spp.; golden shiner with Elodea canadensis, Nitella spp., and Ranunculus spp.; and banded killifish with Najas flexilis and Potamogeton richardsonii.

Correlation analyses performed between densities of phytomacrofauna taxa and fish (Table 8) showed that centrarchids had the highest number of significant ($P \leq 0.05$) relationships with taxa of phytomacrofauna that were found in highest densities in Belvidere Bay (Table 3). Included were Hyalella azteca (Amphipoda), Agraylea sp. (Trichoptera), Odonata, Chironomidae, and several genera of snails (Lymnea, Amnicola, Physa, and Bithynia). The percid-cyprinid-cyprinodontid assemblage had a high number of significant correlations with the phytomacrofauna that were most common in Muscamoot Bay (i.e. Gammarus, Asellus, Lirceus, and Hirudinea).

DISCUSSION

Fish assemblages in Muscamoot and Belvidere bays were distinctly different. The percid-cyprinid-cyprinodontid assemblage that dominated in Muscamoot Bay was typical of the historically dominant group of fish in Lake St. Clair (Krumholz & Carbine 1943, 1945, Johnston 1977), whereas the centrarchid assemblage that was so highly dominant in Belvidere Bay is not.

Differences in habitat structure between the two bays appear to be the main cause for the difference in fish assemblages. Human activities have had a major influence in altering the water quality and habitat structure in Belvidere Bay. Several of the species that were not caught in Belvidere Bay, such as the golden shiner, mimic shiner, brindled madtom, and brook stickleback all usually prefer quiet shallow waters bordered by stands of emergent vegetation (Scott and Crossman 1973). Such habitat is absent or extremely sparse in Belvidere Bay. Young and small fish dominated the community in the macrophyte beds in response to predatory fish that are present in Lake St. Clair. Small sunfishes and other young or small species of fish tend to prefer dense macrophyte beds as their habitat (Werner et al. 1977, Keast 1978, Laughlin & Werner 1980). These dense macrophyte beds provide cover from predatory fish (Crowder & Cooper 1979, Savino & Stein 1982) and provide an abundant source of invertebrate food (Gerking 1957, Brown et al. 1985). Water quality was lower in Belvidere Bay than in Muscamoot Bay. This difference was not surprising because water in Belvidere Bay is affected by the nearby Clinton River, which discharges high concentrations of nutrients and pollutants (Michigan Water Resources Commission, 1975); by other polluted tributaries and canals and by boaters.

Macrophyte species richness was also lower in Belvidere Bay, mainly due to physical alterations (i.e. dredging and bulkheading) in the nearshore zone that reduced the habitat complexity in the area, and reduced the species richness of the fish community. Eadie and Keast (1984) also reported that vegetation complexity (macrophyte species richness and diversity) was more important in influencing fish species diversity than the amount of vegetation per se. Macrophyte abundance (measured as surface area), however, was generally higher in Belvidere Bay than in Muscamoot Bay and was due to the different physical and chemical characteristics of the two areas. Nutrient levels were substantially higher in the Clinton River than in the St. Clair River (Michigan Water Resources Commission, 1975), and resulted in Belvidere Bay receiving a greater nutrient load than Muscamoot Bay. Substrate types also differed between these areas, organic rich muds being common in Belvidere Bay and sand and silt in Muscamoot Bay. The sediment types in Muscamoot Bay are the most common types found in Lake St. Clair (Thomas et al. 1975). The macrophyte assemblage in Belvidere Bay consisted mostly of rooted vascular macrophytes (such as H. dubia, M. spicatum, and V. americana) which grow faster and form a mosaic complex within the water column (Crowder et al. 1977); whereas, the types of macrophytes most common in Muscamoot Bay (E. canadensis, Chara and N. flexilis) have a more uniform growth pattern. Another factor that influenced the macrophyte assemblages was the amount of shoreline modification in each area. Bulkheading of the Belvidere Bay shoreline destroyed the littoral habitat provided by water less than 1 m deep. In Muscamoot Bay, where the natural shoreline still exists, the shallow littoral zone supported several macrophyte taxa that were not found in the deeper waters of the bay. As a result, macrophyte species richness was higher in Muscamoot Bay than in Belvidere Bay. The higher densities of phytomacrofauna in Belvidere Bay were most likely due to the greater macrophyte surface area in Belvidere Bay, which serves as cover from predation and a source of food and attachment for phytomacrofauna (Table 3). The density of the isopods, Asellus and Lirceus, however, was much higher in Muscamoot Bay than in Belvidere Bay, probably due to a preference of the isopods for species of macrophytes that were found almost exclusively in Muscamoot Bay, such as Elodea canadensis (Brown et al. 1985).

As previously mentioned, the abundance of fish, macrophytes, and phytomacrofauna was almost always higher in Belvidere Bay than in Muscamoot Bay. Although productivity appears high in Belvidere Bay, the loss of habitat diversity or complexity that occurred there has caused a reduction in species richness of macrophytes and fish. If further development and urbanization occurs in natural littoral areas such as those in Muscamoot Bay, the fish community there may be expected to shift from a percid-cyprinid-cyprinodontid assemblage to a centrarchid-dominated assemblage similar to that in Belvidere Bay.

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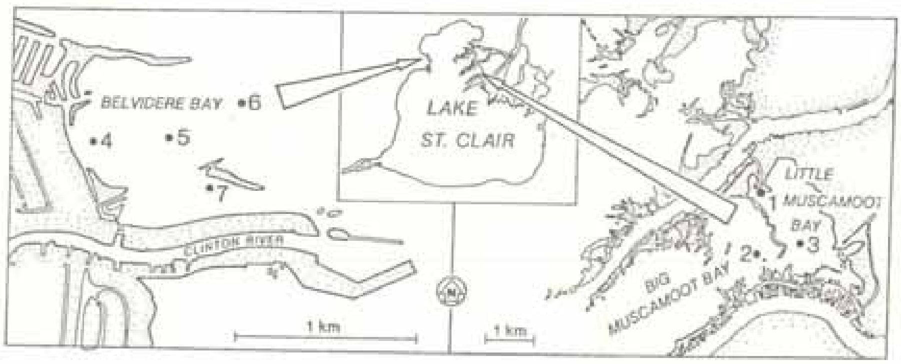
BELVIDERE BAY
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BAY
1
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BIG
MUSCAMOOT BAY

Figure 1

Table 1. Means (n = 9) and (in parentheses) ranges of limnological measurements taken in Anchor Bay, June-November in 1979.

Bay and Station[a/]	Secchi Disk (cm)	Dissolved oxygen (mg/L)	Water temp (°C)	Suspended particulate matter (mg/L)	Turbidity (NTU)
<u>Muscamoot</u>					
1	153.8 (60-200)	10.3 (9.1-12.4)	14.6 (1.6-21.6)	- -	- -
2	185.0 (80-200)	10.7 (9.7-11.9)	16.1 (2.5-22.5)	5.9 (3.0-10.3)	3.5 (2.2-7.0)
3	191.4 (140-200)	10.8 (9.6-12.4)	15.3 (1.6-23.0)	4.8 (2.0-13.3)	3.5 (1.7-9.4)
<u>Belvidere</u>					
4	98.6 (40-200)	9.8 (7.3-12.3)	15.9 (5.0-25.5)	- -	- -
5	83.8 (40-125)	8.9 (2.3-11.5)	16.3 (5.0-24.8)	12.0 (2.6-29.0)	8.8 (2.2-28.0)
6	110.0 (40-150)	10.3 (9.2-11.3)	17.2 (6.0-24.8)	10.3 (5.0-28.3)	10.3 (3.6-34.0)
7	128.6 (40-200)	10.4 (9.0-11.5)	16.2 (5.0-25.2)	- -	- -

[a/] See Fig. 1 for location of stations.

Table 2. Mean surface area values (SA), percent composition (%), and species richness (total no. of taxa) of macrophytes collected from Anchor Bay, June-November 1979 (n = 9).

	Muscamoot Bay Stations						Belvidere Bay Stations							
	1		2		3		4		5		6		7	
Taxon	SA	%	SA	%	SA	%	SA	%	SA	%	SA	%	SA	%
Heteranthera dubia	0.01	0.9			0.03	2.8	1.08	42.7	1.37	57.1			0.12	8.8
Myriophyllum spicatum	0.18	17.1			0.14	12.8	0.57	22.5	0.33	13.8	0.01	4.0	0.69	50.4
Vallisneria americana	0.01	0.9			0.14	12.8	0.28	11.1	0.53	22.1			0.42	30.7
Elodea canadensis	0.40	39.1			0.02	1.8	0.27	10.7	0.08	3.3			0.11	8.0
Najas flexilis	0.01	0.9	0.01	2.8	0.48	44.0	0.27	10.7	0.04	1.7	0.01	4.0	0.01	0.7
Chara spp.	0.14	13.3	0.32	88.9	0.07	6.4					0.23	92.0		
Nitella spp.	0.23	21.9												
Potamogeton richardsonii			0.01	2.8	0.19	17.4			0.01	0.4				
Ceratophyllum demersum							0.06	2.4	0.03	1.3			0.01	0.7
Ranunculus spp.	0.05	4.8							0.01	0.4			0.01	0.7
Myriophyllum exalbescens	0.02	1.9												
Potamogeton crispus					0.01	0.9								
Potamogeton-broad leaf			0.01	2.8										
Potamogeton-thin leaf					0.01	0.9								
Sagittaria cristata			0.01	2.8										
Total	1.05		0.36		1.09		2.53		2.40		0.25		1.37	
Total No. Taxa	10		5		9		7		8		3		7	

Table 3. Density (mean no./m²) and species richness (total no. of taxa) of dominant phytomacrofauna collected from macrophytes at Anchor Bay in June-November 1979 (n = 9).

Taxon	Muscamoot Bay Stations			Belvidere Bay Stations			
	1	2	3	4	5	6	7
Hirudinea	26.1	7.3	19.3	0.9	3.4	0.0	2.0
Gammarus sp.	270.6	75.3	96.6	119.7	90.9	313.9	176.1
Hyalella azteca	88.6	308.5	328.2	3158.1	2137.9	95.0	1158.9
Asellus sp.	352.0	51.2	166.8	10.4	4.1	0.2	12.9
Lirceus sp.	231.4	665.5	37.2	0.2	0.2	0.5	0.2
Chironomidae	343.6	441.5	276.1	1706.3	585.9	61.2	190.2
Physa spp.	63.7	9.1	19.3	303.7	198.1	14.3	71.9
Gyraulus spp.	35.1	0.7	62.8	107.0	366.1	15.9	235.7
Amnicola spp.	185.6	11.3	97.7	240.7	677.5	22.9	262.3
Others	265.0	51.2	122.9	177.3	131.5	74.1	178.2
Total density	1861.7	1621.6	1226.9	5824.4	4195.6	597.9	2288.4
Species richness	28	21	27	28	28	25	27

Table 4. Total catch of fish by species and location in Lake St. Clair, June-November 1979.

Species	Muscamoot Bay		Belvidere Bay	
	Total number	Percent of total	Total number	Percent of total
Yellow perch, Perca flavescens	2,438	71.1	570	11.7
Bluntnose minnow, Pimephales notatus	274	8.0	22	0.5
Rock bass, Ambloplites rupestris	130	3.8	1,368	28.0
Banded killifish, Fundulus diaphanus	127	3.7	0	0
Brook Stickleback, Culea inconstans	66	1.9	0	0
Pumpkinseed, Lepomis gibbosus	62	1.8	789	16.2
Spottail shiner, Notropis hudsonius	58	1.7	45	0.9
Johnny darter, Etheostoma nigrum	50	1.5	5	0.1
Unknown shiners (immature)	35	1.0	3	0.1
Smallmouth Bass, Micropterus dolomieui	33	1.0	75	1.5
Largemouth Bass, Micropterus salmoides	28	0.8	209	4.3
Black crappie, Pomoxis nigromaculatus	21	0.6	174	3.6
Alewife, Alosa pseudoharengus	19	0.6	0	0
Mimic shiner, Notropis volucellus	15	0.4	0	0
Brown bullhead, Ictalurus nebulosus	13	0.4	14	0.3
Yellow bullhead, Ictalurus natalis	11	0.3	0	0
Unknown centrarchids (immature)	10	0.3	1,179	24.2
Fantail darter, Etheostoma flabellare	7	0.2	0	0
Bluegill, Lepomis macrochirus	7	0.2	310	6.4
White sucker, Catostomus commersonii	5	0.1	1	0.1
Golden shiner, Notemigonus chrysoleucas	4	0.1	0	0
Northern pike, Esox lucius	4	0.1	1	0.1
Bowfin, Amia calva	3	0.1	0	0
Logperch, Percina caprodes	3	0.1	18	0.4
Mottled sculpin, Cottus bairdii	3	0.1	0	0
Common carp, Cyprinus carpio	1	0.1	6	0.1
Brindled madtom, Noturus minrus	1	0.1	0	0
Walleye, Stizostedion vitreum	1	0.1	4	0.1
Gizzard shad, Dorosoma cepedianum	0	0	1	0.1
Goldfish, Carassius auratus	0	0	1	0.1
Trout-perch, Percopsis omiscomaycus	0	0	77	1.6
Freshwater drum, Aplodinotus grunniens	0	0	6	0.1
Total	3,429		4,879	

Table 5. Total number of fish of different species and percent of total, collected at each station in Anchor Bay, 1979.

Species	Muscamoot Bay						Belvidere Bay							
	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Yellow perch	449	59.5	885	79.0	1104	71.0	105	6.3	194	8.5	182	52.2	89	15.9
Rock bass	41	5.4	34	3.0	55	3.5	289	17.2	824	36.0	14	4.0	241	43.0
Unknown centrarchids	6	0.8	0	0	4	0.3	648	38.6	469	20.5	0	0	62	11.1
Pumpkinseed	27	3.6	2	0.2	33	2.1	351	20.9	380	16.6	1	0.3	57	10.2
Bluegill	1	0.1	0	0	6	0.4	189	11.3	81	3.5	0	0	40	7.1
Bluntnose minnow	34	4.5	94	8.4	146	9.4	1	0.1	21	0.9	0	0	0	0
Largemouth bass	3	0.4	2	0.2	23	1.5	60	3.6	124	5.4	1	0.3	28	5.0
Black crappie	9	1.2	0	0	12	0.8	27	1.6	115	5.0	0	0	32	5.7
Banded killifish	1	0.1	30	2.7	96	6.2	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	26	2.3	7	0.5	2	0.1	32	1.4	36	10.3	5	0.9
Spottail shiner	42	5.6	3	0.3	13	0.8	0	0	29	1.3	15	4.3	1	0.2
Trout-perch	0	0	0	0	0	0	0	0	1	0.1	76	21.8	0	0
Brook stickleback	66	8.7	0	0	0	0	0	0	0	0	0	0	0	0
Johnny darter	30	3.9	15	1.3	5	0.3	0	0	4	0.2	1	0.3	0	0
Unknown shiners	13	1.7	22	2.0	0	0	0	0	2	0.1	0	0	1	0.2
Brown bullhead	5	0.7	1	0.1	7	0.5	5	0.3	7	0.3	0	0	2	0.4
Logperch	0	0	3	0.3	0	0	0	0	0	0	18	5.2	0	0
Alewife	3	0.4	0	0	16	1.0	0	0	0	0	0	0	0	0
Mimic shiner	6	0.8	0	0	9	0.6	0	0	0	0	0	0	0	0
Yellow bullhead	5	0.7	0	0	6	0.4	0	0	0	0	0	0	0	0
Others[a]	14	1.9	4	0.4	12	0.8	3	0.2	7	0.3	5	1.4	2	0.4
Total no. of individuals	755		1120		1554		1680		2290		349		560	
Species richness	24		14		22		12		18		11		15	

[a] Brook stickleback, common carp, mottled sculpin, brindled madtom, walleye, freshwater drum, northern pike, gizzard shad, goldfish, and fantail darter.

Table 6. Correlations between habitat variables and fish species richness and abundance for all stations and sampling periods (n = 63) in Muscamoot and Belvidere Bays in Lake St. Clair, 1979.

Habitat variable	Fish species richness	Fish abundance
Secchi disk	-0.1033	-0.1793
Dissolved oxygen	-0.2468	-0.2906*
Water temperature	-0.0420	-0.0513
Macrophytes		
Surface area	0.3801**	0.3582*
Species richness	0.5448***	0.2814
Phytomacrofauna		
Density	0.2350	0.2992*
Species richness	0.3085*	0.0784

$P \leq 0.05$ = *
$P \leq 0.01$ = **
$P \leq 0.001$ = ***

Table 9. Correlation coefficients of all significant ($P \leq 0.05$; n = 99) relationships among fish and macrophytes (fish or macrophyte species which had no significant relationships are not included).[1/]

Fish	Ceratophyllum	Chara	Elodea	Heteranthera	Myriophyllum exalbescens	Myriophyllum spicatum	Najas	Nitella	Potamogeton richardsonii	Potamogeton sp. A	Ranunculus	Vallisneria
Yellow perch (yearling)	...	...	...	...	...	...	0.4713	...	0.8292	...	...	...
Yellow perch	...	...	0.2237	...	...	...	...	...	...	...	...	...
Johnny darter	...	...	...	...	0.3621	...	...	...	...	...	...	...
Golden shiner	...	...	0.3136	...	...	...	...	0.7525	...	...	0.3868	...
Mimic shiner	...	...	...	...	...	...	...	...	...	0.2914	...	...
Bluntnose minnow	...	...	...	...	...	...	0.3629	...	0.4256	...	...	...
White sucker	...	0.2143	...	...	...	...	...	...	...	...	...	...
Banded killifish	...	...	...	...	...	...	0.4334	...	0.4707	...	...	...
Brook stickleback	...	...	0.3260	...	0.8766	...	...	0.5526	...	...	0.3713	...
Yellow bullhead	...	...	...	...	0.4363	...	...	...	...	...	...	...
Brown bullhead	...	...	...	0.3828	...	...	...	...	...	...	...	...
Northern pike	...	...	...	...	...	...	...	0.4287	...	...	...	...
Bowfin	...	...	...	...	0.4075	...	...	...	...	...	...	...
Alewife	...	...	...	...	...	0.4608	...	...	...	0.2823	...	...
Rainbow smelt	...	...	...	...	...	0.2115	...	...	...	0.3346	...	...
Common carp	...	...	...	...	...	...	...	...	...	...	...	0.3189
Unknown centrarchids	0.2719	...	...	0.3278	...	...	...	...	...	...	...	...
Rock bass (YOY)	0.2796	-0.2152	...	0.5076	...	...	...	...	...	...	...	0.4063
Rock bass (yearlings)	...	...	...	0.3854	...	...	...	...	...	...	...	0.3963
Pumpkinseed (YOY)	0.3912	-0.2283	...	0.4733	...	...	...	...	...	...	...	0.5076
Pumpkinseed (yearlings)	0.3867	...	...	...	...	...	...	...	...	...	...	...
Pumpkinseed	0.3023	-0.2083	...	...	...	...	...	...	...	...	...	0.2102
Bluegill (YOY)	...	...	...	...	...	...	...	...	...	...	...	0.2651
Bluegill (yearlings)	0.2827	...	...	...	...	...	...	...	...	...	...	...
Bluegill	0.3079	...	...	0.2698	...	...	...	...	...	...	...	0.3221
Smallmouth bass (YOY)	...	...	...	...	...	...	...	...	...	...	...	0.2743
Largemouth bass (YOY)	...	...	...	0.6877	...	...	...	...	...	...	...	0.2809
Largemouth bass	0.3329	...	...	...	...	...	...	...	...	...	...	...
Black crappie	...	...	...	0.3943	...	...	...	...	...	...	...	0.2838

1/ Dots indicate non-significance.

Table 8. Correlation coefficients for all significant (P≤0.05; n = 33) relationships among fish and [illegible].

Fish	Hirudinea	Gammarus	Hyalella azteca	[illegible]	[illegible]	[illegible]	PHYTOMACROFAUNA [illegible]	[illegible]	[illegible]	[illegible]	Chironomidae	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Yellow perch (YOY)	.3194	...[1]	...	.3868	...	.3508	...	...	...	...	...	...	...	...	...	...
Yellow perch (yearling)	...	...	...	...	...	...	.4733	...	...	...	...	...	...	...	...	...
Yellow perch	.3188	...	...	.3992	...	...	...	...	...	...	...	...	...	...	...	...
Walleye	...	.3110	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Johnny darter	...	...	...	...	...	.3976	...	...	...	...	...	...	...	...	...	...
Golden shiner	...	...	...	.3307	...	...	...	...	...	...	...	...	...	...	...	...
Mimic shiner	...	...	...	.3736	...	...	...	...	...	...	...	...	...	...	...	...
Bluntnose minnow	.3322	...	...	...	.4161	...	...	...	...	...	...	...	...	...	...	...
White sucker	...	...	...	...	.4007	.3238	...	...	...	...	...	...	...	...	...	...
Banded killifish	.3093	...	...	...	...	...	.4451	...	...	...	...	...	...	...	...	...
Brook stickleback	...	...	...	.3536	...	...	...	...	.3213	...	...	...	...	...	...	...
Yellow bullhead	.3568	...	...	.4008	...	...	...	...	.3418	...	...	...	...	...	...	...
Brown bullhead	...	...	...	...	...	...	...	...	...	...	...	...	.3187	.3002	...	.3838
Northern pike	...	.3140	...	.3992	...	...	...	...	...	...	...	...	...	...	...	...
Bowfin	.4419	...	...	.3320	...	...	...	...	.3896	...	...	...	...	...	...	...
Alewife	...	...	...	...	...	...	.3368	...	...	...	...	...	...	...	...	...
Freshwater drum	...	.3606	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Unknown centrarchids	...	...	.3378	...	...	...	...	...	...	...	...	.2556	.4178	.3167	.3444	...
Rock bass (YOY)	...	...	...	...	...	...	...	...	...	...	...	...	.3818	.5488	.3172	.3117
Rock bass (yearlings)	...	...	...	...	...	...	...	...	...	.4368	...	...	...	...	.4388	.3664
Pumpkinseed (yearlings)	...	...	.4773	...	...	...	...	...	...	.7263	.6115	...	...	...	...	...
Pumpkinseed	...	...	...	...	...	...	...	...	...	.8387	...	...	...	...	...	...
Bluegill (yearlings)	...	...	.4357	...	...	...	...	...	...	...	.8565	...	...	...	...	...
Bluegill	...	...	.3386	...	...	...	...	.2706	...	.7013	.3903	...	...	...	.3368	...
Largemouth bass (YOY)	...	...	...	...	...	...	...	...	...	.4373	...	...	.3668	...	...	...
Largemouth bass	...	...	.3163	...	...	...	...	...	...	...	.7318	.3548	...	...	...	...
Black crappie	...	...	.4383	...	...	...	...	...	...	.7838	...	...	...	...	.4554	.3176

[1] Dots indicate non-significance.