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Distribution Patterns of the Emerald Shiner,
Notropis atherinoides
In the St. Marys River, Michigan,
and Related Environmental and Behavioral Factors

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Michael V. Thomas

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Charles R. Liston
Major professor

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DISTRIBUTION PATTERNS OF THE EMERALD SHINER,

NOTROPIS ATHERINOIDES,

IN THE LOWER ST. MARYS RIVER, MICHIGAN,

AND RELATED ENVIRONMENTAL AND BEHAVIORAL FACTORS

By

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ABSTRACT

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Seasonal and diel distributions, and related environmental and behavioral factors of the emerald shiner, *Notropis atherinoides*, were investigated in the lower St. Marys River. A total of 2260 emerald shiners were collected in nearshore, mid-depth, and channel zones with trap nets, push nets, and trawls between 5 May and 7 November 1983. Emerald shiners schooled inshore during spring and early summer. Concurrently, horizontal diel migrations offshore at night and inshore during the day were noted. As summer progressed, inshore emerald shiner schools scattered into small groups throughout the nearshore and mid-depth zones. Vertical diel migrations to the surface at night and mid-water during the day were suspected, but not conclusively documented. By fall, emerald shiners were present in highest numbers in the mid-depth zone. During this time, diel movements were absent as emerald shiners remained in mid-water. Water temperature and food availability appeared to directly affect emerald shiner distributions. Relative importance and influences of these factors and several others were discussed.

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INTRODUCTION

The major piscivores in freshwater aquatic ecosystems are often economically important for commercial and sport fisheries, but maintenance of harvestable populations of these species is dependent upon the existence of a healthy forage base. Shifts in abundances or relative proportions of forage species can drastically affect production of preferred predator species. In fact, extensive salmonid introductions to the Great Lakes in the mid 1960s resulted primarily from a series of shifts and imbalances in the forage base and predator-prey system within the lakes (Smith 1968).

The modern history of the Great Lakes prior to the salmonid introductions of the mid-60s is a well documented case history of the perturbation of natural forage and predator/prey systems. Key factors included: 1) introduction of rainbow smelt (*Osmerus mordax*) in 1912; 2) invasion of sea lamprey (*Petromyzon marinus*) and alewife (*Alosa pseudoharengus*); 3) near extinction of the primary piscivore, the lake trout (*Salvelinus namaycush*), by sea lamprey and a size-selective commercial fishery; 4) explosive increases of the alewife; 5) and, extreme reduction or extinction of native forage species through suspected competition and predation by alewife and smelt (Smith 1970, Wells 1977, Crowder 1980, Stewart et al. 1981). One of the native forage species which suffered reduction in many areas of the Great Lakes was the emerald shiner. The purpose of this work is to document seasonal and diel movements of a forage species, the emerald shiner, _Notropis atherinoides_ Rafinesque, in a littoral zone of the lower St. Marys River, and behavioral and environmental factors affecting those movements.

Prior to alewife peak abundance, the emerald shiner was an abundant forage species in coastal areas throughout the Great Lakes. At times, this small cyprinid occurred so abundantly as to cause clogging of power plant intake screens (Flittner 1964). This abundance made the emerald shiner a major bait minnow species in many areas of the lakes. However, in most areas of the Upper Great Lakes, the species has become rare or remains at much depressed population levels (Wells 1970; Crowder 1980). The species has recently rebounded in some areas and maintains a relatively stable population in Lake Erie (Leach and Nepszy 1976; Flittner 1964). Recent field work on the St. Marys River, the connecting waterway between Lakes Superior and Huron, indicated that a substantial emerald shiner population existed in the lower river area.

N. atherinoides is a small cyprinid occurring exclusively on the North American continent where it is widely distributed from New York west to Montana and from Alabama and Texas north to the Northwest territories and Hudson Bay (Campbell and MacCrimmon 1970). The fish is most commonly found inhabiting large open lakes and rivers and exhibits the slender, elongate, laterally compressed body shape characteristic of a pelagic life habit. Past studies on this species have investigated taxonomic aspects, embryology, age and growth, fecundity, mortality, general food habits, and predator-prey interactions (Flittner 1964, Fuchs 1967, Campbell and MacCrimmon 1970, Parsons 1971, Barans and Tubb 1973, Mendelson 1975, Whitaker 1977, Courtney and Blokpoel 1980, Koburn 1982). However, lack of documentation centers upon seasonal distribution and diel movements. Considering this situation, this study focused on a single site in the lower St. Marys River, from navigation channel to nearshore waters, to investigate the seasonal and diel distributions, and related environmental or behavioral factors.

METHODS AND MATERIALS

Site Selection and Description

The St. Marys River is the only outflow of Lake Superior into the lower Great Lakes and serves as the major shipping link between the north central states and eastern portions of the United States (Figure 1). From Lake Superior headwaters in Whitefish Bay to its mouth on Lake Huron at DeTour, Michigan, the St. Marys River drops approximately 6.7m. Downstream of the Sault Ste. Marie area, the river is divided into a series of channels and shallow bays or lakes (Figure 2). Michigan State University, Department of Fisheries and Wildlife, under contract with the United States Fish and Wildlife Service and the United States Army Corps of Engineers, Detroit District, has conducted a baseline environmental study of the St. Marys River at various sites throughout the system since 1978 in anticipation of extension of the Great Lakes navigation season (Liston et al. 1981).

The site selected for this study was one of seven sites sampled extensively during 1982 and 1983 under the Michigan State University program. Station seven (VII) at Point Aux Frenes (Figure 3), near Raber Bay in the lower St. Marys River was selected as the study site. The selection was based on collections of large numbers of emerald shiners during 1982 and the characteristic nature of the site as being "typical" of lower reaches of the St. Marys River. Sampling occurred in a rectangular area approximately 1km by 2km spanning the river from shoreline littoral zone to

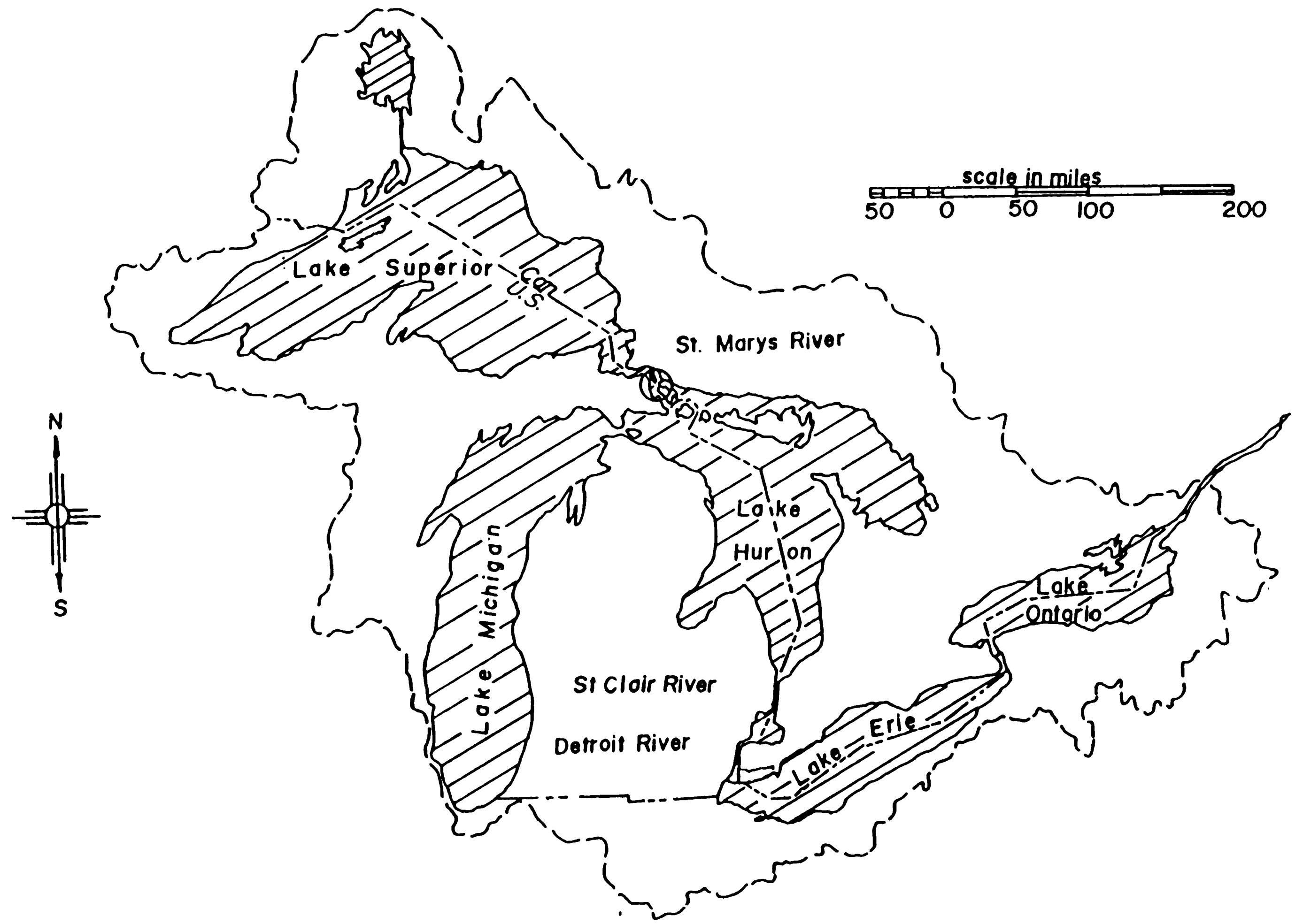

Figure 1. Map of the Great Lakes/St. Lawrence Seaway system including the St. Marys River.

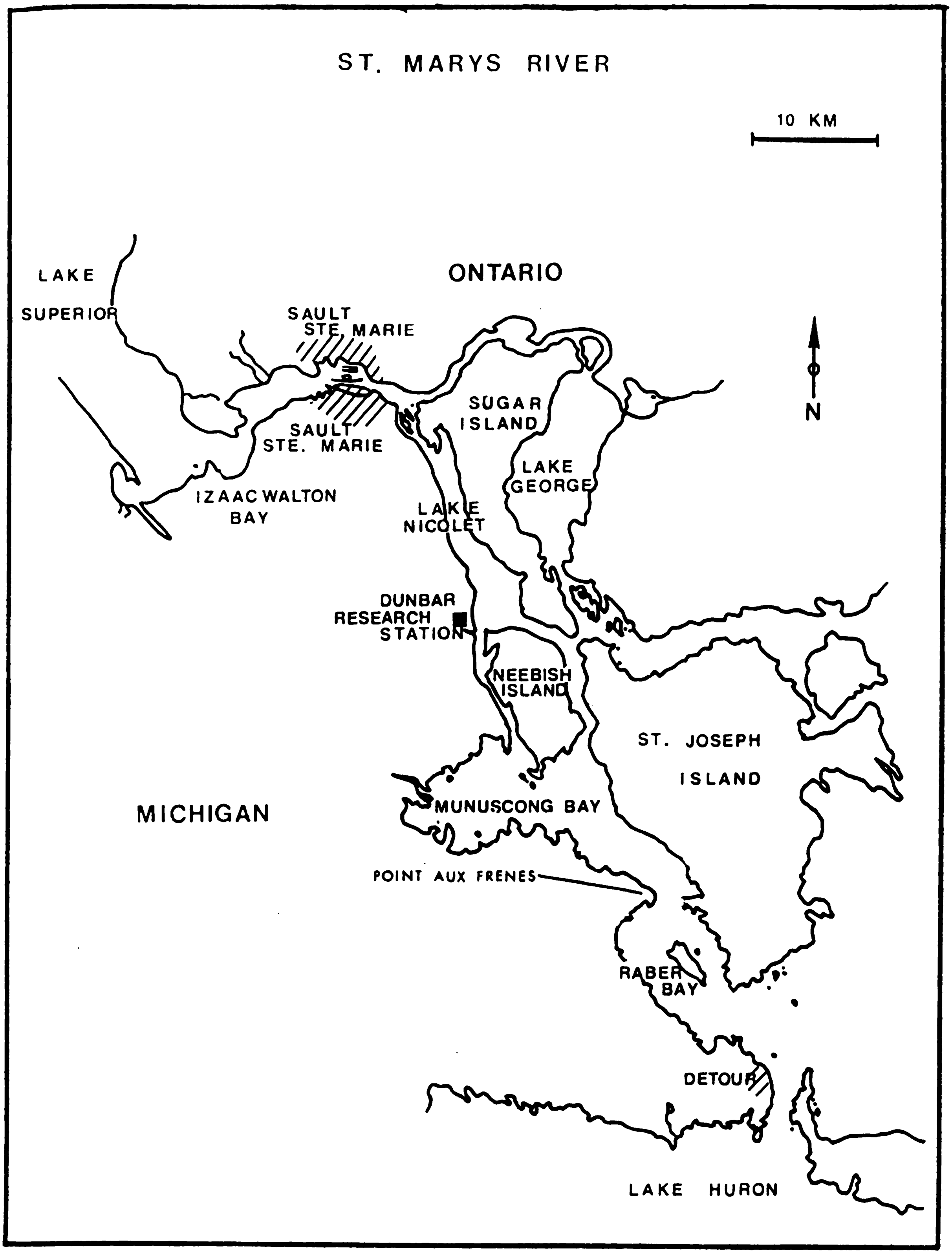

Figure 2. The St. Marys River system from Lake Superior to Lake Huron.

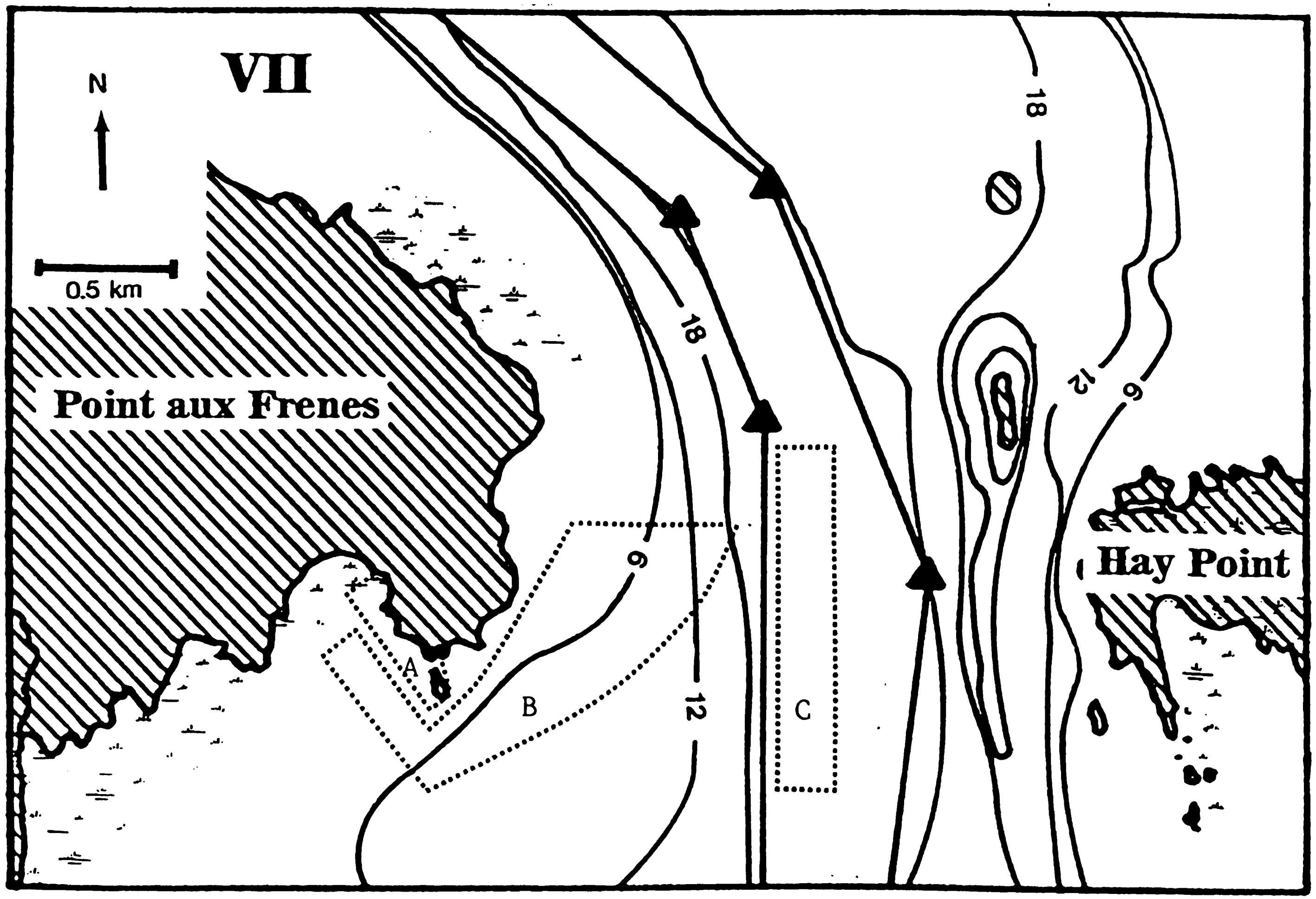

Figure 3. The Point Aux Frenes, Station VII, sampling site showing the nearshore (A), mid-depth (B), and channel (C) sampling zones.

commercial shipping channel. The shoreline was a mixture of exposed sand and rubble interspersed with emergent wetland. Primary emergent plant species at the site included *Scirpus acutus*, *Eleocharis smallii*, *Sparganium eurycarpum*, *Typha latifolia*, *Phragmites australis*, *Scripus americanus*, and *Sparganium chlorocarpum* extending outward to a depth of approximately 1.5m. Submergent species of charophytes and *Potamogeton* spp. were found to about 3.0m depth. Bottom substrate at the site was a continuum of sand, gravel, and clay near shore to pure clay in the shipping channel. For purposes of this study, the area was arbitrarily divided into three zones. The nearshore zone extended from the terrestrial environment to a depth of 1.5 m. The mid-depth zone included the area from the 1.5m depth contour to the edge of the navigation channel, with an aver- age depth of approximately 3.0m. The channel zone included the shipping channel itself, maintained to a depth of 8.3m.

Dissolved oxygen, temperature, and turbidity were measured for each sampling period. A standard YSI portable dissolved oxygen meter (Yellow Springs Instrument Company, Model 54) was calibrated just prior to use and used to measure midwater dissolved oxygen and temperature in the field. Surface water samples were collected in polyethylene bottles and returned to the laboratory and analyzed for turbidity within 24 hours with a Hach porta-LAB turbidimeter. All physical/chemical measurements and samples were taken immediately prior to sampling with the respective gear types.

Field and Laboratory Data Acquisition

Specific sampling schedules and methods were developed to investigate the seasonal distribution of the emerald shiner. All sampling took place between 5 May and 7 November 1983 (Table 1). The sampling schedule involved biweekly sampling in which all three horizontal zones were to be sampled at all depth strata on a given sampling date. Samples were collected over 24 hour periods including both day and night time periods. In the nearshore zone, 0.5m diameter push nets, (351 u mesh) as described by Tarplee et al. (1979), were mounted in tandem on the bow of a 5.2m Polar Craft boat powered by a 70 horsepower outboard motor and pushed at the 1.5m depth contour for five minutes. The nets were equipped with General Oceanics Digital flow meters (Model 2030) and the water volume filtered was recorded with each push sample. Estimates of emerald shiner densities were made based on the numbers of emerald shiners collected in a known volume of water (Appendix 1). Samples were collected on four dates with this method. The nearshore zone was also sampled with small mesh trap nets constructed of 6.35mm bar mesh nylon after Beamish (1972). The nets consisted of a 15.2 x 1m lead, 2.2 x 1m wings, a $1m^3$ pot, and a single heart (Figure 4). Trap nets were deployed with the lead perpendicular to the shoreline and completely extended from surface to bottom. Non-vegetated and vegetated sampling sites were established in the nearshore zone in water of less than 1.0m

Table 1. Sampling gear types and sample dates for the emerald shiner collections at Station VII, St. Marys River, 1983.

Date	.5m diameter push nets	Mod. small mesh trawl	Otter Trawl	Small mesh Trap Nets
5/5	X			X
5/18			X	
6/5	X			X
6/22			X	X
7/7	X			
7/9	X			X
7/22			X	
7/25		X		
7/26		X		
8/1				X
8/5		X		
8/15			X	
8/18		X		
8/24		X		
9/8				X
9/22			X	
10/4				X
10/17			X	
11/7			X	X

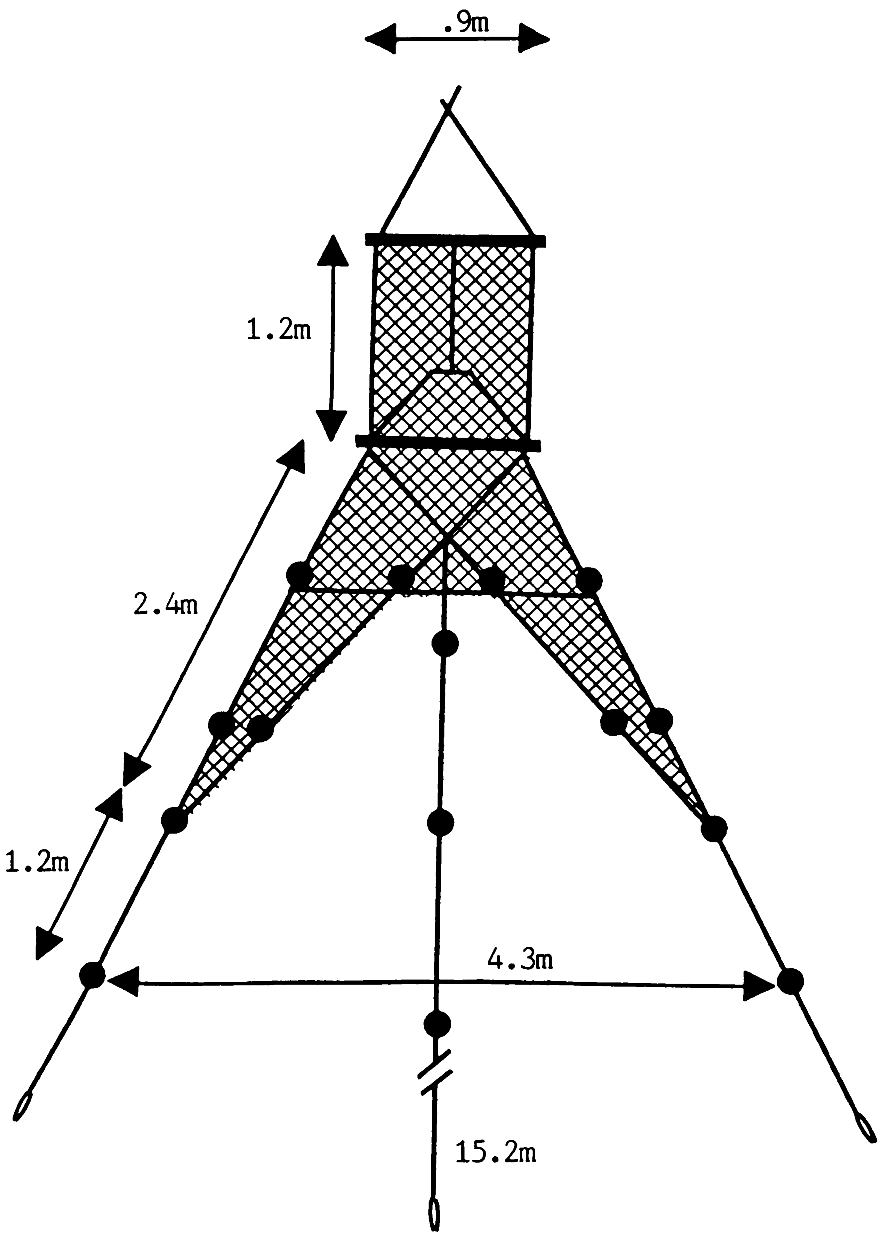

Figure 4. Top view of small mesh trap nets used in sampling at Station VII, St. Marys River, during 1983.

and used repeatedly during 1983. All trap nets were set for 24 hour periods, but catches were removed from the nets and recorded after day and night sampling periods. Semi-balloon otter trawls with 4.9m head rope, 38mm stretched mesh body, and 3mm bar mesh cod end liner were towed behind the boat at the 1.5m depth contour for day and night sampling. A modified shrimp trawl was also used in the nearshore zone. The apparatus consisted of a 0.6m by 0.9m PVC 51mm diameter pipe frame with a 1.2m long nylon 9.5mm mesh net attached to the frame (Figure 5). Weights attached to the lower frame crossbar caused the mouth of the net to remain upright during sampling. A bridle was attached to the four corners of the frame and connected by line to the stern of a 5.2m Polarcraft boat with 70 horsepower outboard motor. The modified shrimp trawl was towed for five minutes. In theory, manipulation of trawling speed, length of line to bridle, and amount of weight attached to the trawl frame allowed control over the vertical location of the trawl during sampling. A General Oceanics digital flowmeter (Model 2030) attached in the trawl mouth allowed determination of water volumes filtered and subsequently, densities of fish present (Appendix 1). Finally, an experimental 15.2m gill net was constructed of 12.7mm stretch mesh to facilitate bottom sampling at all depth zones for seasonal distribution. Additionally, 0.5m diameter push nets and the modified small mesh shrimp trawl were used for sampling of seasonal distribution at the mid-depth and channel zones. Otter trawls were used in the mid-depth zone. Also, on three dates small mesh trap

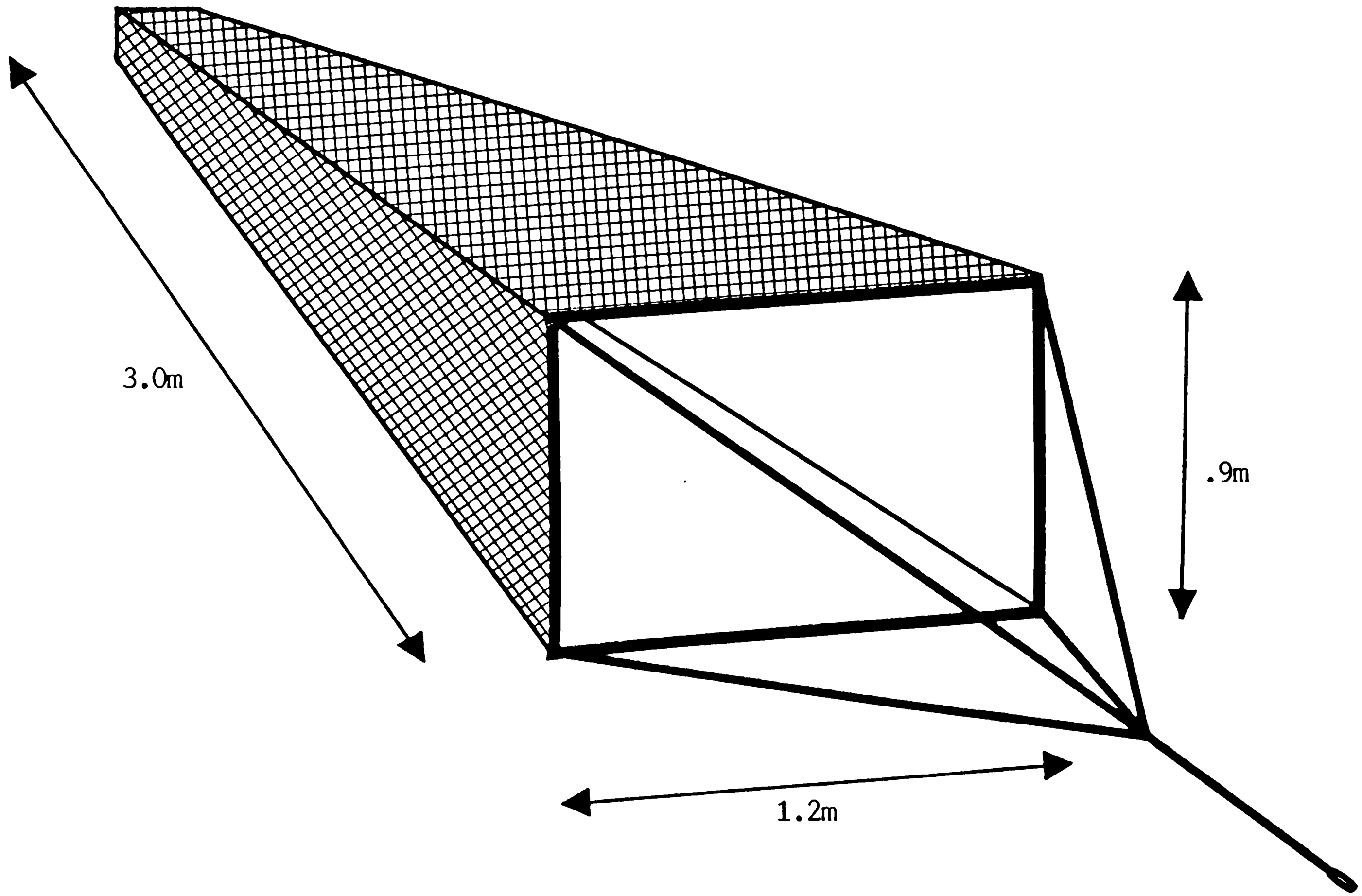

Figure 5. Front/side view of modified small mesh shrimp trawl with bridle used in sampling at Station VII, St. Marys River, 1983.

nets were deployed by boat in the mid-depth zone to sample the bottom 1.0m of water.

The spring, summer, and fall seasons of 1983 were arbitrarily designated as follows: spring extended from initial ice-free condition through 30 May; summer ranged from 1 June to 31 August; and, fall extended from 1 September through the end of open water sampling on 7 November.

Diel distribution patterns were investigated by collecting fish during both day and night periods, using all gear types. Initially, sampling was performed on a quarterly basis (dusk, night, dawn, day), but consistent absence of emerald shiners from the small mesh trap nets during dusk and dawn sampling periods dictated a shift to the day/night sampling. Sampling with all other gear types also occurred on a day/night basis.

Age structure of the emerald shiner population at Station VII was initially investigated by examination of scale annuli as discussed in Bagenal and Tesch (1978) and Flittner (1964). Examination of individual scales was aided by a microfiche projector. Later investigation of the age structure of the emerald shiner population focused on length frequency distributions (Ricker 1975).

Food habits of emerald shiners were investigated for the 1983 sampling season. Fish from collections with all gear types at all depth zones on selected sampling dates were immediately killed and preserved in 10% formalin in the field for later examination. Laboratory examination involved removal of digestive tracts, from esophagus to anus. Contents of digestive tracts were examined at 10x with a binocular microscope and all large organisms or particles identified to the lowest taxon possible and counted. The remaining portion of the contents were then examined microscopically at 20x to 450x and identified to the lowest taxon possible. Quantification of the gut contents was initially attempted, but later abandoned. Enumeration of both large insects and smaller organisms including zooplankton was not practical, as the majority of the identifiable food items in the gut contents exhibited evidence of phyrangeal mastication. Subsequently, all food habits data were recorded on a qualitative level with only subjective estimates of relative proportions of total gut volume held by each taxon present.

Rationale for Single Year Data Base

This work is based on samples collected during the ice-free period of 1983. Originally, the study was intended to include two years of field collections. During 1983, field work included the development of new sampling gear (e.g. small mesh gill nets, and small mesh modified shrimp trawl) specifically targeted for collection of emerald shiners. The second year was planned to reinforce the data using techniques developed the previous year. However, sampling during May and June 1984 failed to capture any emerald shiners. All methods previously used to collect shiners in large numbers, at the same locations and times, were ineffective. Emerald shiners were collected during the

MSU 1984 St. Marys River project in the Lake Munuscong portion of the river, using some of the gear types employed at the Raber Bay study location. Some suggestions to shift or broaden the focus of the original study to include Lake Munuscong were considered, but eventually rejected. The Lake Munuscong area differs physically and biologically from the Raber Bay location (Liston C.R., Personal Communication). Disappearance of the emerald shiner from the Raber Bay site will not be dismissed or ignored however, but will be addressed in the discussion.

Statistical Analysis

Non-parametric statistical tests were selected based on a number of conditions: 1) small sample size of data 2) qualitative nature of some of the data 3) lack of an a priori statistical design. Tests used included the Kruskal-Wallis one-way analysis of variance, Friedman two-way analysis of variance, and the Wilcoxon matched pairs signed rank non-parametric tests (Siegel 1956). Seasonal differences in small mesh trap net catches were evaluated with the Kruskal-Wallis one-way analysis of variance. Similarly, day and night small mesh trap net catches were compared across seasons with the Friedman two-way analysis of variance. Densities of emerald shiners in nearshore and mid-depth zones were compared using the Wilcoxon matched pairs signed rank test. In all cases, an alpha-level of 0.1 or less was considered significant.

RESULTS

Physical/Chemical Characteristics

Water temperature (°C), dissolved oxygen (ppm), and turbidity (NTU) were recorded for nineteen sampling dates. Diel fluctuations of these factors were not apparent in the mid-depth or channel zones. Within the nearshore zone, diel changes in temperature occurred sporadically. Calm, sunny days elevated day time temperatures several degrees over night temperatures within the nearshore zone. Other combinations of wind and sunlight did not produce diel fluctuations at the nearshore zone. For comparative purposes, the night period numbers will be reported here. Over the sampling season, water temperatures remained lower in the channel zone than nearshore or mid-depth zones (Figure 6). Temperatures in the nearshore zone ranged from 6.5 °C on 8 November to 22 °C on 25 July. The maximum temperature in the mid-depth zone was 23 °C on 24 August, while the minimal temperature of 6 °C occured on 8 November. The channel zone maximum and minimum temperatures were 20.0 °C on 25 July and 5 °C on 5 May respectively.

Turbidity levels varied widely in nearshore and mid-depth zones, but remained relatively low and stable in the channel zone (Figure 7). Nearshore zone turbidity ranged from 6.2 NTU on 26 July to 25.0 NTU on 5 May. High and low turbidity levels in the mid-depth zone were 30.0 NTU on 5 May and 6.0 NTU on 22 September, respectively. Channel zone turbidity levels were consistently lower, ranging from 2.5

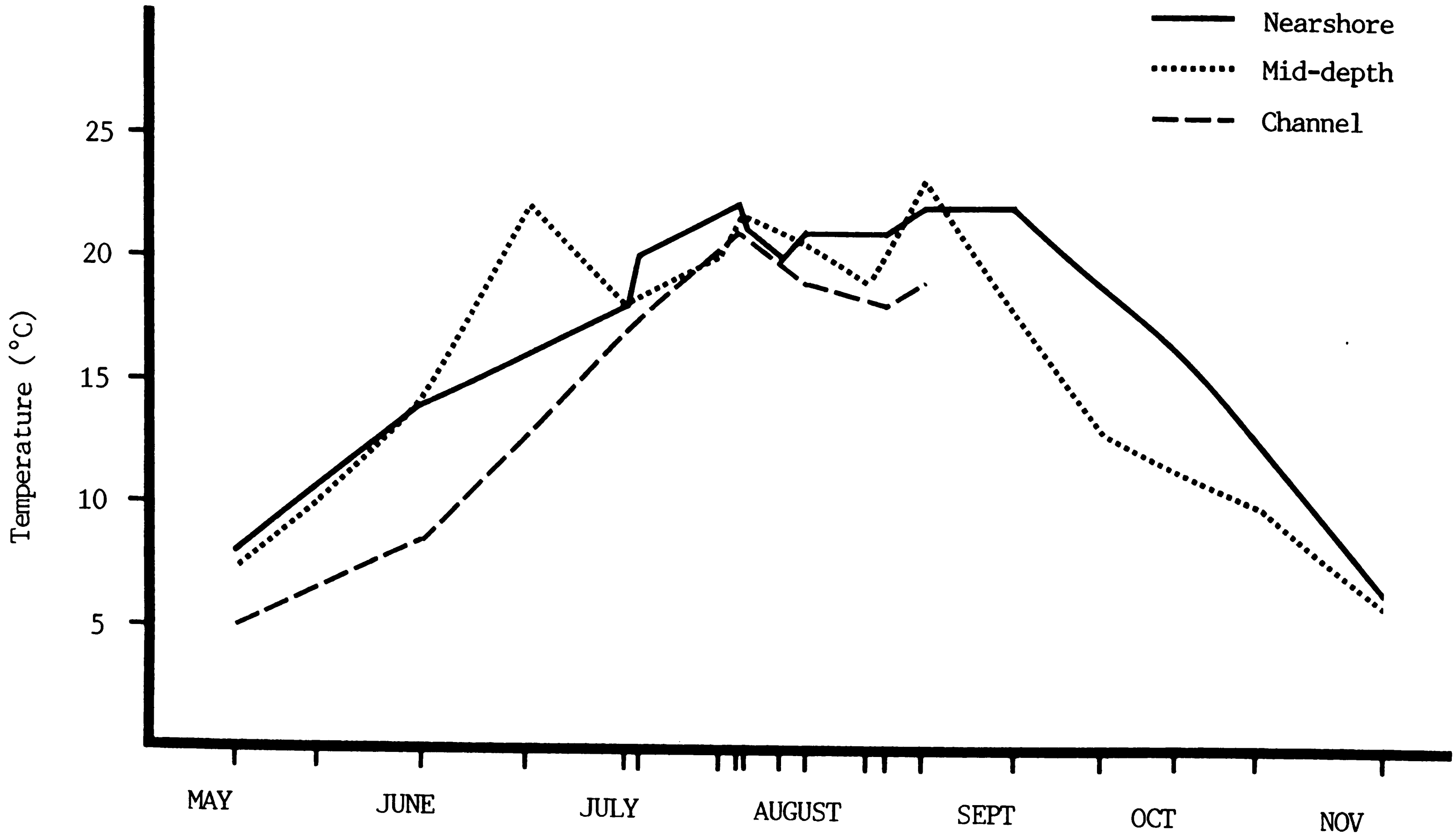

Figure 6. Water temperatures at the three Station VII, St. Marys River, sampling zones during 1983.

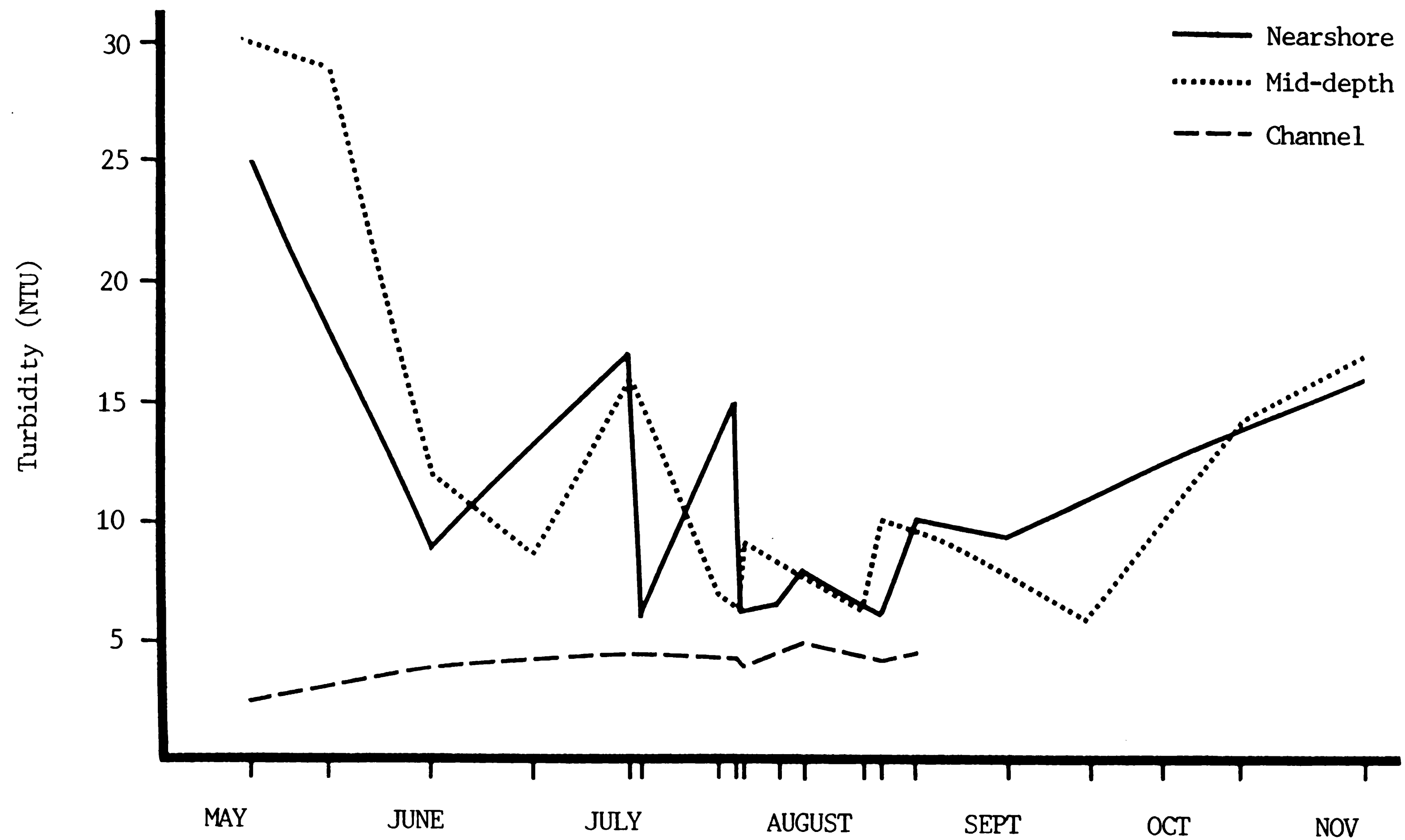

Figure 7. Turbidity levels at the three Station VII, St. Marys River, sampling zones during 1983.

NTU on 5 May to 5.0 NTU on 5 August. Overall, seasonal trends were apparent in turbidity levels of the nearshore and mid-depth zones. Higher turbidities characterized spring and fall, while relatively lower turbidities prevailed during the summer period.

Differences in concentrations of dissolved oxygen between zones were documented (Figure 8). On most sampling dates, lowest concentrations occurred in the nearshore zone, while highest concentrations were found in the channel zone. Dissolved oxygen levels in the nearshore zone ranged from 11.9 ppm on 4 May to 6.8 ppm on 5 August. Mid-depth zone concentrations ranged from 11.4 ppm on 7 November to 7.8 ppm on 15 August. Concentrations of dissolved oxygen in the channel zone peaked at 12.9 ppm on 5 June and were lowest on 8 July at 7.5 ppm. A general seasonal trend appeared to hold for all zones as dissolved oxygen concentrations were highest in spring and fall with lower levels encountered during the warmest summer periods.

Fish collections-- Overview

A total of 2260 emerald shiners were collected between 4 May 1983 and 7 November 1983. Approximately 69% of all fish captured were taken in small mesh trap nets (Table 2). The 0.5m diameter push nets accounted for 14.5% of the total catch. Only 4.7% of the emerald shiners were caught in otter trawls, while 12.0% were captured in the modified small mesh shrimp trawl. Emerald shiners were not collected with the experimental 12.7mm stretch 15.2m gill net, and gill net

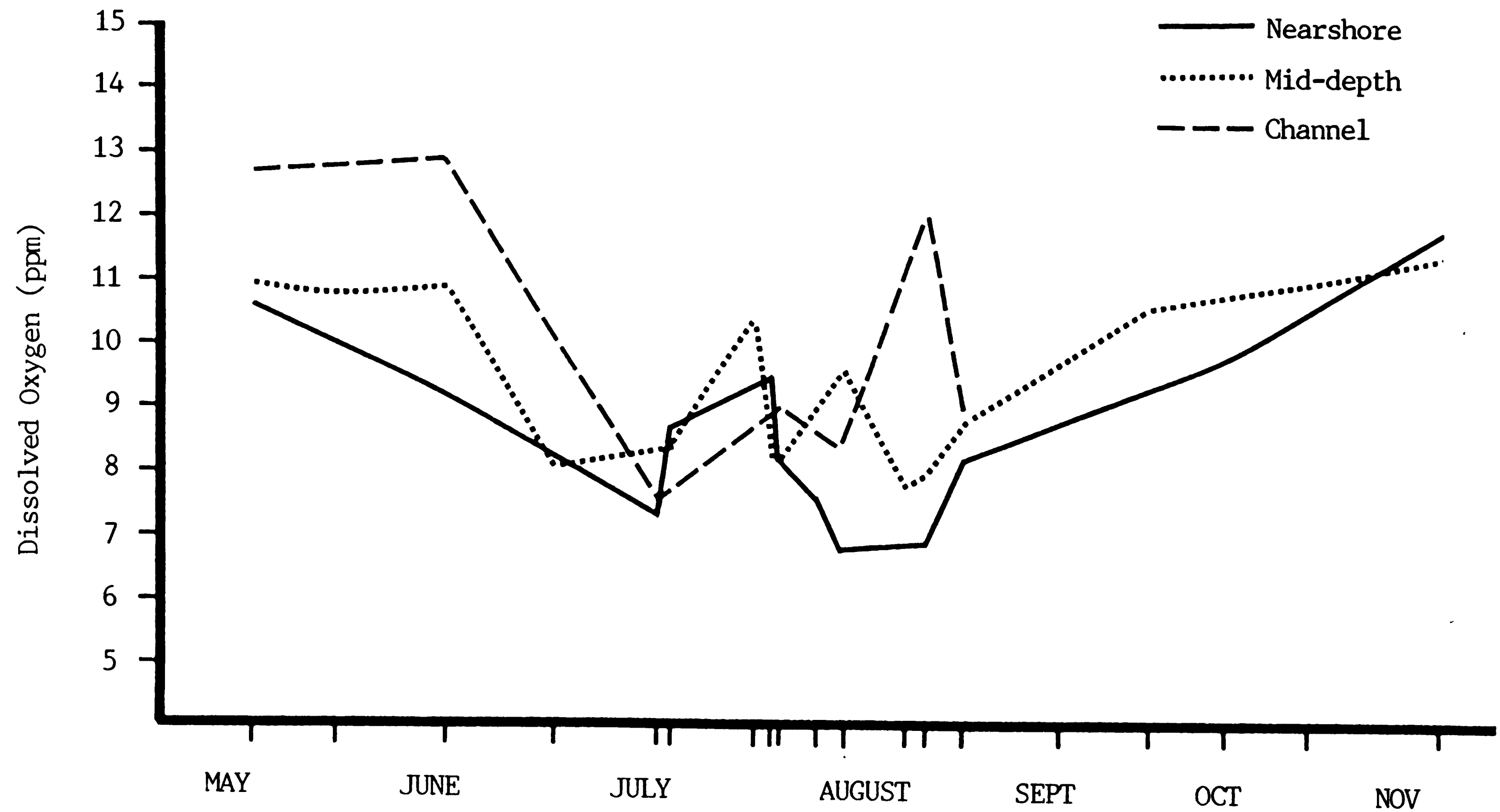

Figure 8. Dissolved oxygen levels (ppm) at the three Station VII, St. Marys River, sampling zones during 1983.

Table 2. Total numbers of emerald shiners collected with all gear types at Station VII, St. Marys River, during 1983.

Gear Type	# of Shiners Collected	% of Total
Small mesh trap nets	1554	68.8
0.5m diameter push nets	328	14.5
Modified small mesh trawl	272	12.0
Otter trawl	106	4.7
Totals	2260	100.0

sampling was discontinued after three unsuccessful 24 hour sets.

Seasonal distribution

All four gear types described previously were employed in the effort to document seasonal distribution of the emerald shiner. Small mesh trap nets captured a total of 1554 emerald shiners during 1983. Total catches of emerald shiners in small mesh trap nets over the 24 hour sampling periods declined dramatically from the highest catch of 766 on 4 May to zero on 4 October 1983 (Table 3). Overall, the catch of emerald shiners in small mesh trap nets varied significantly ($p<.1$) between spring, summer, and fall sampling dates within the nearshore zone. Experimental deployment of the small mesh trap nets in deeper water (2.0 to 3.0m) within the study zone resulted in no catches of emerald shiners.

Sampling with 0.5m diameter push nets and modified small mesh shrimp trawl collected a total of six hundred emerald shiners (Table 4). Densities of fish in the nearshore zone were significantly greater ($p<.025$) than those recorded for the mid-depth zone during 1983 (Figure 9). Nevertheless, it is noteworthy that density of emerald shiners in the mid-depth zone on the last date sampled was greater than that of the nearshore zone.

A total of 106 emerald shiners were captured during sampling with otter trawls (Table 5). Prior to 22 September, only 3 emerald shiners were captured in otter trawls. Trawls in September and October resulted in the two highest catches

Table 3. Emerald shiner collections with small mesh trap nets, Station VII, St. Marys River, 1983.

Date	Total Catch	Day Catch	Night Catch	Catch at Non-vegetated Site	Catch in Vegetation
5/4	766	756	10	127	639[1]
6/5	184	183	1	86	98
6/22	453	47	406	394	59
7/9	22	7	15	21	1
8/1	50	48	2	49	1
9/8	62	55	7	55	7
10/4	17	0	17	0	17
Totals	1554	1096	458	732	822

[1]During May, the site was not heavily vegetated, but contained sparse stands of dead emergent plants from the 1982 growing season.

Table 4. Estimated emerald shiner densities (#/100m³) at Station VII, St. Marys River, based on sampling with 0.5m diameter push nets and small mesh trawl during 1983.

Date	NSZ[1]	MDZ[2]	CZ[3]
5/5	132	40	0
6/5	28	6	0
7/8	50	6	0
7/13	0	0	0
7/25	16	1	0
7/26	6	3	0
8/5	10	4	0
8/18	22	5	0
8/24	7	18	--
Average	30	9	0

[1]NSZ = nearshore zone

[2]MDZ = mid-depth zone

[3]CZ = channel zone

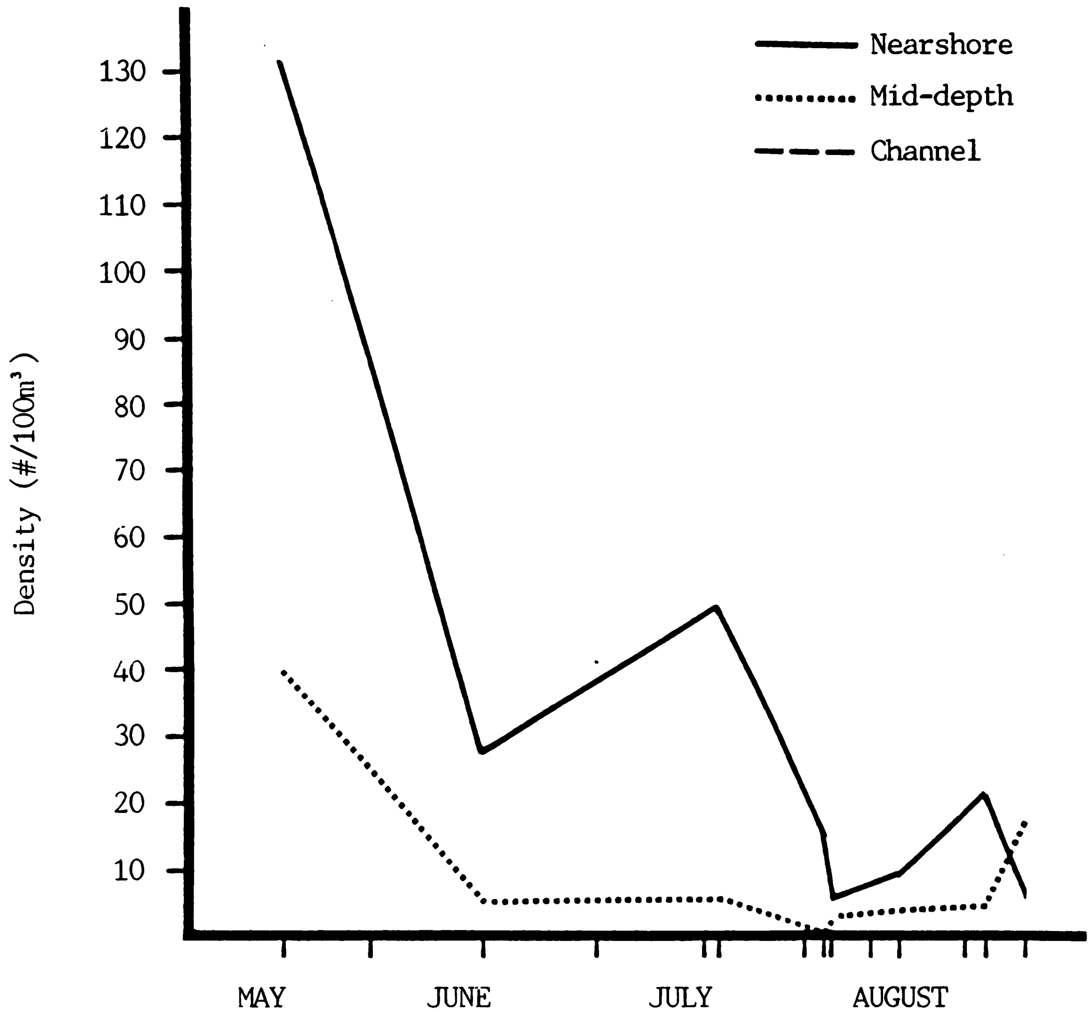

Figure 9. Estimated emerald shiner densities (#/100m³) at nearshore and mid-depth zones, based on night sampling and use of two gear types: 0.5m diameter push nets and small mesh trawls, at Station VII, St. Marys River, 1983.

Table 5. Emerald shiner collections with otter trawl at Station VII, St. Marys River, 1983.

Date	N[1]	NSZ[2]	MDZ[3]	CZ[4]	Day	Night
5/8	3	0	3	--	--	3
6/21	0	0	0	--	--	0
7/22	0	0	0	--	0	0
8/15	0	0	0	--	--	39
9/22	64	26	38	--	--	64
10/17	39	11	28	--	--	39
11/7	0	0	0	--	--	0
Totals	106	37	69	--	0	106
% of Total		35	65		0	100

[1]N = total number of emerald shiners collected on sampling date

[2]NSZ = nearshore zone

[3]MDZ = mid-depth zone

[4]CZ = channel zone

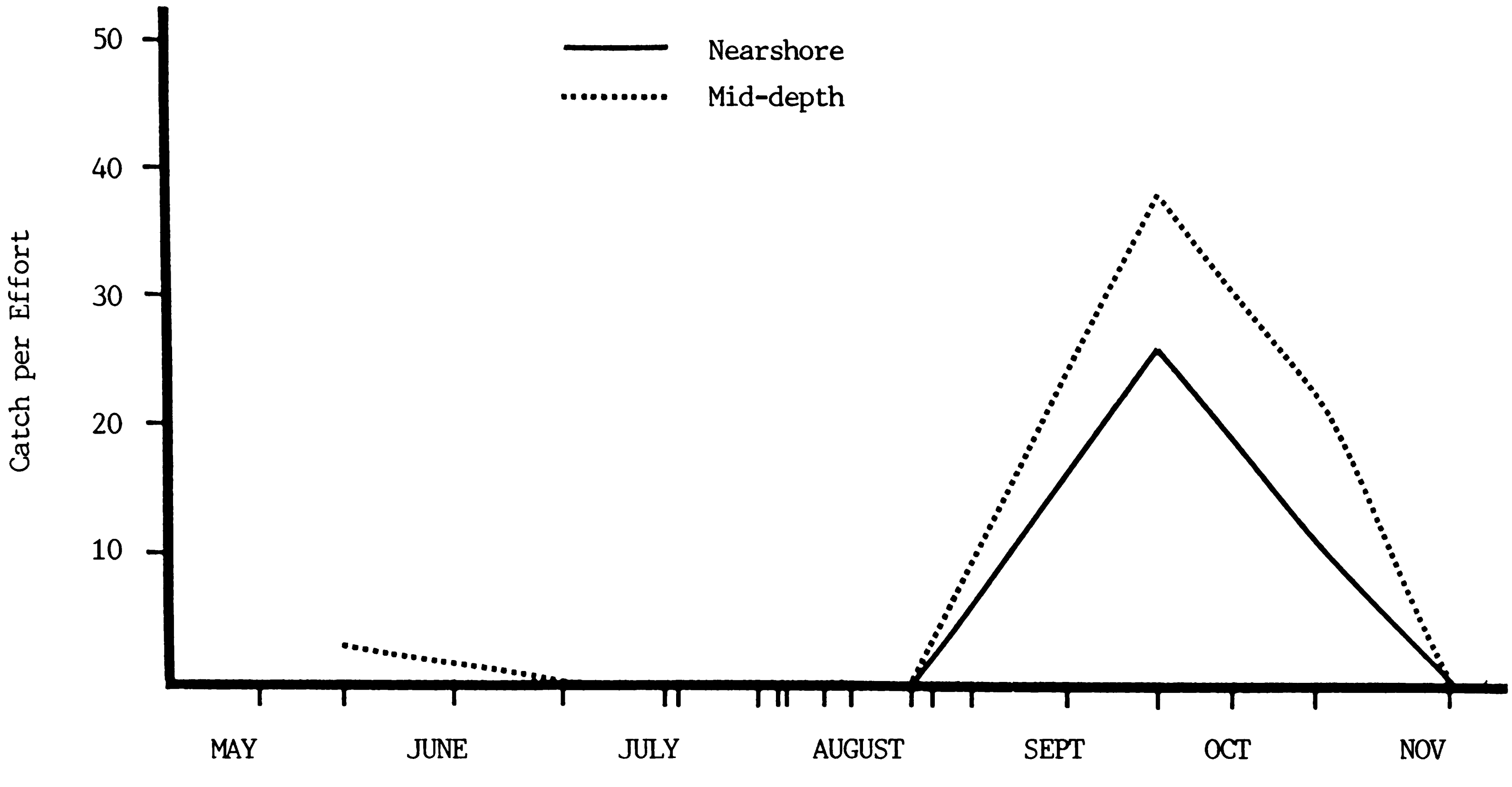

Figure 10. Otter trawl catches of emerald shiners at the nearshore and mid-depth zones, Station VII, St. Marys River, 1983.

with this gear type (Figure 10). Sampling occurred at both the nearshore zone and 3.0m contour or mid-depth zone. Approximately 65% of emerald shiners collected by this method were captured at the mid-depth zone on September and October dates mentioned above.

Diel distribution

Small mesh trawl and 0.5m diameter larval fish push nets were used in surface collections at all three zones. After five successive failures to collect emerald shiners during the day period of subsequent sampling dates, day sampling was discontinued for the two surface sampling gears. In an effort to discern the factors involved in the absence of emerald shiners from daylight surface samples collected with 0.5m diameter push nets and small mesh trawl, a series of five minute tows were performed at the 3.0m depth contour with the small mesh trawl. Tows were made each half hour from 1930 hr to 2130 hr; full darkness was noted at 2100 hr. A total of 50 emerald shiners were collected during the 5 tows. Although estimated densities of shiners increased after dark, the relative importance of visual gear avoidance and vertical distribution remained unclear.

Attempts were made to use the small mesh trawl in a mid-water and bottom sampling capacity without much success. Emerald shiners were not collected during these tows, and the actual location of the net in the water column was not easily discerned and could not be held constant. Further work on sampling mid-water and bottom strata focused on small mesh trap nets and otter trawls.

Small mesh trap nets sampled day and night distributions of emerald shiners at the nearshore zone. Day and night catches of emerald shiners in the nearshore zone did not differ significantly ($p<.7$). However, 70% of all emerald shiners collected in small mesh trap nets in the nearshore zone were captured during the daylight period (1096 out of 1554).

Small mesh trap nets were deployed by boat in the mid-depth zone to sample the bottom 1.0m of water. Although the nets fished successfully, no emerald shiners were collected during three 24 hour periods. Spottail shiners (*Notropis hudsonius*), rock bass (*Ambloplites rupestris*), yellow perch (*Perca flavescens*), and burbot (*Lota lota*) were collected during the sampling periods indicating the nets were properly deployed and fishing. In light of the gear ineffectiveness in sampling for emerald shiners, or conversely, the absence of emerald shiners from the lower 1.0m of water, sampling with small mesh trap nets at the mid-depth zone was discontinued.

Length Frequency Distribution

Three hundred and seventy-five emerald shiners collected on 22 June in small mesh trap nets were measured to provide a length frequency distribution (Figure 11). The plot revealed three peaks suggesting the presence of three age classes. Attempts to collaborate the age distribution by scale aging proved futile as the emerald shiner scales were not readily aged. The length frequency distribution plotted

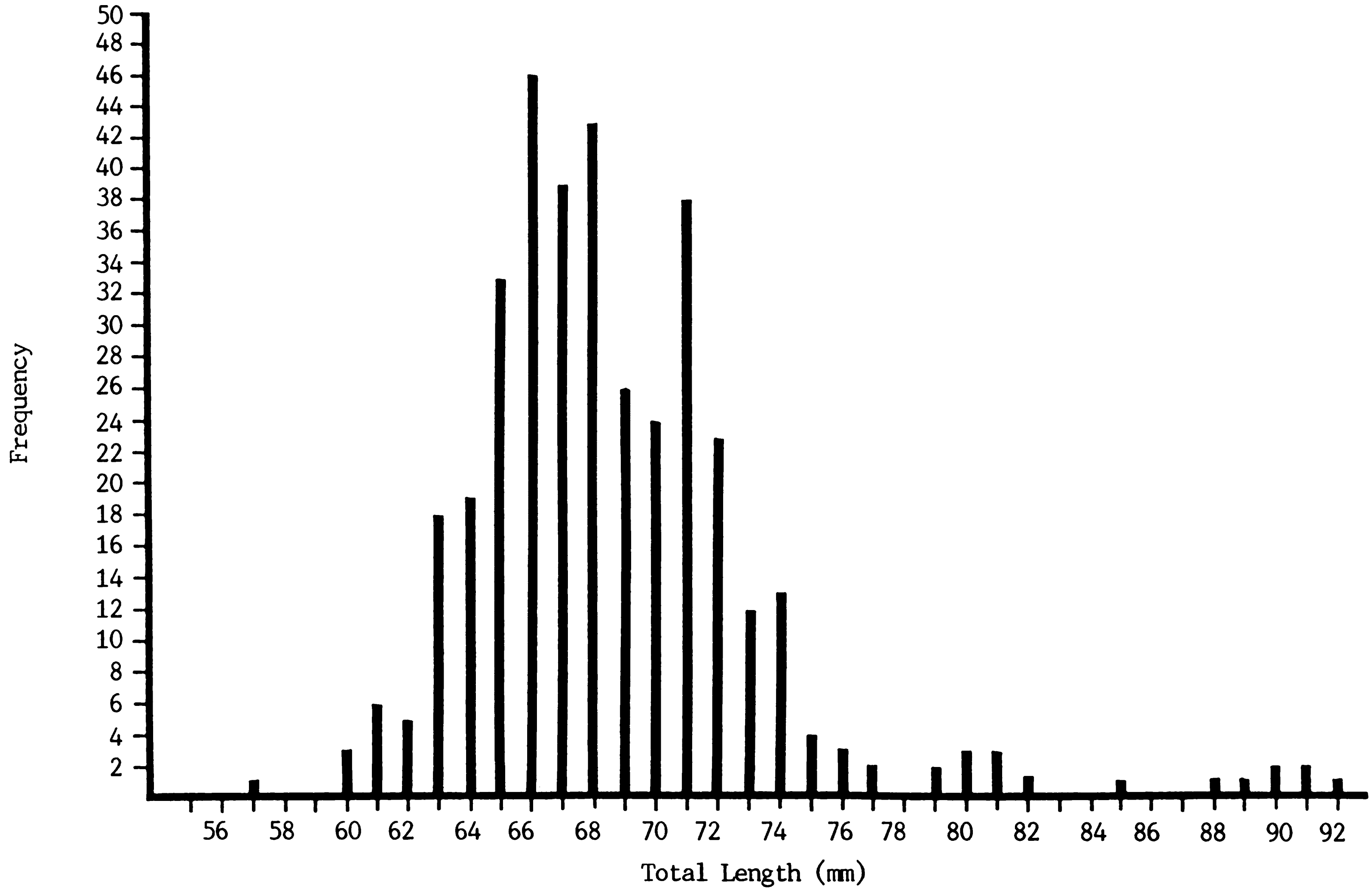

Figure 11. Length frequency distribution for 375 emerald shiners collected on 6/22/83 at Station VII, St. Marys River, with small mesh trap nets in the nearshore zone.

suggests a mean lenth of 68mm, 80mm, and 90mm, for age I, II, and III respectively, in June.

Food Habits

A total of 429 emerald shiners were examined for diet composition. Twenty-seven taxa of food items were identified in 301 non-empty guts (Table 6). Overall, zooplankton occurred in 42% of all fish examined, while insects were observed in 68% of fish examined. Frequency of occurrence of zooplankton and insects on individual sampling dates varied widely (Table 7, Figures 12 and 13). In the nearshore zone, zooplankton were frequently consumed in early spring and mid-July, while insects were heavily consumed in late June and again in late July and early August. In the mid-depth zone, trends were more stable. Zooplankton were heavily utilized in early spring, while insects dominated gut contents from mid-June through late August.

Zooplankton species most frequently occurring in gut contents included calanoid and cyclopoid copepods and cladocerans. Calanoid copepods with highest frequencies of occurrence were Limnocalanus and Diaptomus. Both genera occurred in highest frequencies on the first two sampling dates. Cyclops were the most frequently occurring cyclopoid copepods. Peak frequencies of Cyclops were recorded on 5 May and 8 July. The cladocerans most frequently observed were Bosmina, with peak frequency on the final sampling date, 24 August.

Ephemeroptera was the insect taxa with highest total frequency of occurrence over the sampling period. Mayflies

Table 6. List of food items and total frequencies of occurrence (%) in 301 emerald shiners with non-empty guts collected at Station VII, St. Marys River, 1983.

Food Item	Total Frequency of Occurrence
Zooplankton	42
Diaptomus	23
Limnocalanus	20
Cyclops	14
Bosmina	13
Mesocyclops	5
Sida	3
Daphnia	2
Leptodora	2
Epischura	1
Holopedium	1
Unidentified zooplankton	5
Insecta	68
Ephemeroptera (Adult)	30
Ephemeroptera (Immature)	11
Chironomidae (Adult)	24
Unidentified Dipteran	4
Corixidae	3
Ceratopogonidae	2
Coleoptera	2
Sialidae	2
Hymenoptera	1
Unidentified Insect	1

Table 7. Overall frequency of occurrence for zooplankton and insecta in the emerald shiner diet at Station Station VII, St. Marys River, for selected dates during 1983.

Date	N[1]	Frequency of Occurrence of Zooplankton	Frequency of Occurrence of Insecta	Nearshore Zone		Mid-depth Zone	
				Frequency of Occurrence of Zooplankton	Frequency of Occurrence of Insecta	Frequency of Occurrence of Zooplankton	Frequency of Occurrence of Insecta
5/5	79	98	26	100	35	95	29
6/7	62	86	14	58	0	100	18
6/22	113	10	90	10	93	--	--
6/25	31	0	100	0	100	0	100
7/8	26	69	69	100	56	0	100
7/26	28	12	100	0	100	22	100
8/5	30	4	100	0	100	7	100
8/24	60	59	67	44	83	68	58

[1]N = number of emerald shiner guts examined for sampling date

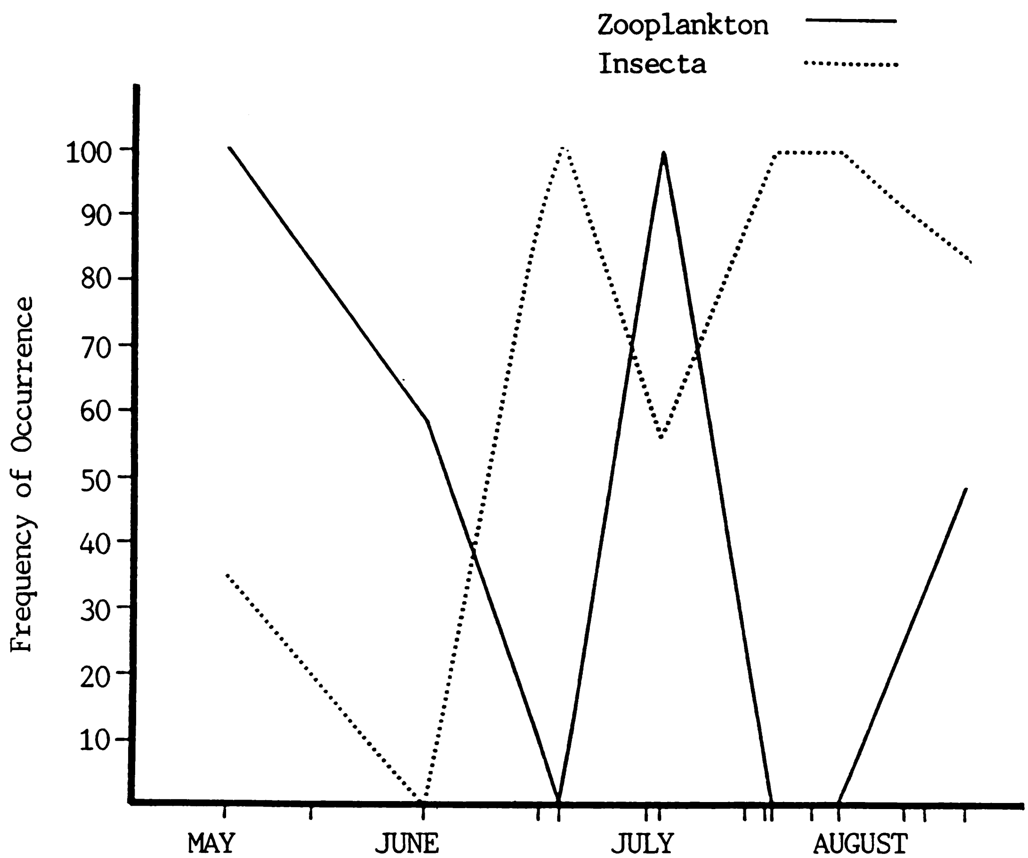

Figure 12. Zooplankton and Insecta frequency of occurrence (%) in the emerald shiner diet at the nearshore zone, Station VII, St. Marys River, 1983.

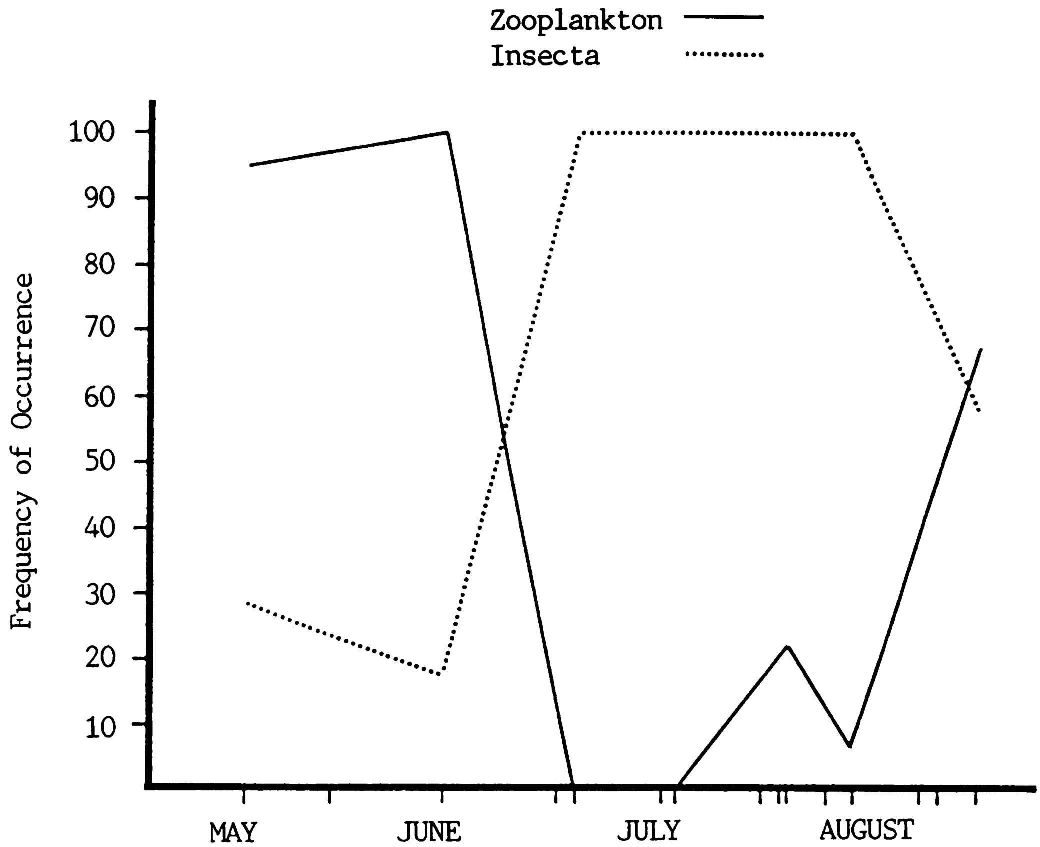

Figure 13. Zooplankton and Insecta frequency of occurrence (%) in the emerald shiner diet at the mid-depth zone, Station VII, St. Marys River, 1983.

were common in gut contents from mid-June through late July. Both immmature and adult stages were recognized in fish examined. The second most frequently observed insect taxon was the Chironomidae. Adult and immature chironomids were identified in 24% of all guts examined. In general, the taxon occurred at a stable level of abundance in fish collected throughout 1983, relative to the Ephemeroptera. No other taxon of insects was observed at frequencies of occurrence greater than 5%.

DISCUSSION

Physical/Chemical Characteristics of the Sampling Zones

Initially, three sampling zones at the Raber Bay site, nearshore, mid-depth, and channel, were designated based strictly on horizontal alignment with the shoreline and navigation channel. However, physical/chemical data collected over the sampling season suggest that there was also a physical and chemical basis for the designated zones. Channel zone waters resemble closest the cold, generally low productivity waters originating from Lake Superior. This zone was somewhat buffered from rapid atmospheric changes and was infrequently affected by conditions in the two shallower zones. Consequently, the channel zone warmed and cooled more slowly in spring and fall, respectively, than the nearshore or mid-depth zones. As might be expected, higher levels of dissolved oxygen and lower turbidities also were characteristic of the channel zone waters.

The mid-depth and nearshore zones more closely resembled each other relative to the channel zone. Conditions in the shallow nearshore zone responded quickly to atmospheric temperature changes. Dense stands of emergent vegetation reduced wave-action within the zone and thereby frequently maintained a turbidity level lower than that of the adjacent mid-depth zone. The mid-depth zone, on the other hand, was shallow enough to experience considerable wind induced turbidity, but deep enough to experience less atmospheric temperature effects and too deep to be afforded the protection of dense emergent macrophyte stands. It is not surprising that dissolved oxygen levels were highest in all zones during spring and fall, when temperatures are low and wind-induced, wave agitated, turbidities are highest.

Seasonal Distribution of the Emerald shiner

The assortment of sampling gear and sampling locations provided a detailed documentation of emerald shiner seasonal distribution at a littoral zone in the lower St. Marys River. During spring, emerald shiners formed large, dense, schools in nearshore zone waters. At this time they were most highly susceptible to small mesh trap nets deployed in water less than 1.0m deep. Dense nearshore aggregations of emerald shiners are not an unusual phenomenon during spring (Langlois 1954, Flittner 1964, Hubbs and Lagler 1964, Campbell and MacCrimmon 1970). As the water continued warming during summer, emerald shiner schools dispersed. Emerald shiners were captured in lower numbers by all gear types, but were still more abundant in the nearshore zone than in the other zones. Field observations indicated predominance of one year old fish in the nearshore zone, while fish taken in the mid-depth zone were often older adults. This continuing presence of relatively high numbers of emerald shiners within the nearshore zone was not noted in previous studies discussing emerald shiner seasonal movements.

Past studies indicate emerald shiners move offshore in large concentrations prior to spawning periods during July and August (Flittner 1964, Campbell and MacCrimmon 1970). No such offshore aggregations were observed during this study.

Furthermore, schools of spawning emerald shiners were not observed offshore as was documented in Lake Erie (Flittner 1964). It is likely that spawning occurred in the Raber Bay area however, as nearly ripe and spent adults as well as numerous emerald shiner larvae were collected during the summer of 1983 (Liston et al. 1983). Spawning may occur in smaller, dispersed groups of fish rather than in large schools.

As water temperatures cooled during fall, emerald shiners dispersed into the mid-depth zone from the nearshore zone. Small mesh trap net, small mesh trawl, and otter trawl catches indicated near abandonment of the nearshore zone and some aggregation of fish in the mid-depth zone. In contrast, Hubbs and Lagler (1964) described an inshore movement of fish during fall. Campbell and MacCrimmon (1970) documented this inshore movement of large schools of _N. atherinoides_ during fall at Lake Simcoe, Ontario. However, Flittner's (1964) Lake Erie observations of small groups of widely scattered fish closely approximate the fall distribution observed in the St. Marys River.

Emerald shiners were not found in the channel zone during the study. The coolness of the zone during the spring and the relatively low densities of zooplankton and insects during the summer apparently were not suitable habitat for emerald shiners. Additionally, the strong curents of the channel zone may have futher reduced the quality of the channel zone as emerald shiner habitat.

Diel Distribution

The emerald shiner has been described as a pelagic fish species by several researchers (Trautman 1981; Koburn 1982; Becker 1983). St. Marys River emerald shiners perhaps are more appropriately described as preferring open, surface waters. Surface, midwater and bottom sampling with various gear types indicated that during spring and summer emerald shiners were largely a surface and mid-depth species. Low numbers of emerald shiners were captured near bottom or with bottom sampling gear in water greater than 1.0m deep. Within this pelagic framework, N. atherinoides seemed to exhibit both horizontal and vertical diel movements. Small mesh trap net catches in the nearshore zone were 2.4 times greater during day periods than night periods over the course of the study. When dense schools of emerald shiners were present in the nearshore zone (during spring), a diel pattern of moving offshore at night and returning to the shallow nearshore zone during the day was apparent. This strategy may be an effort to take advantage of the warmer water of the nearshore zone during the day, and the abundant zooplankton of the mid-depth zone at night. Alternatively, this pattern may reflect a predator avoidance strategy, moving offshore at night as many predator species move inshore. This horizontal diel pattern has not been reported previously for emerald shiners. After spring, when schools of emerald shiners have dispersed and are distributed more evenly throughout the nearshore and mid-depth zone, this horizontal diel movement becomes undefined.

A strong vertical diel migration pattern for the emerald shiner during spring and summer may be indicated by day and night surface densities of shiners collected from nearshore and mid-depth zones with .5m diameter nets and small mesh trawl. Estimated surface densities at nearshore and mid-depth zones were 8.5 times greater during night than during the day. A diel vertical pattern of moving from mid-water to surface from day to night, as documented for many zooplankton species and fish species (Hasler and Barndach 1949, Crossman 1959a, Wells 1960, McNaught and Hasler 1961, Lane 1975, Janssen and Brandt 1980) is suggested. Unfortunately, attempts to verify the suspected mid-water, day distribution of emerald shiners were unsuccessful. Mid-water sampling was particularly problematic. Efforts centered on a mid-water trawling device which was sufficiently small in mesh size to ensure capture of emerald shiners, and which could be pulled fast enough to minimize gear avoidance. A satisfactory compromise was never achieved and the actual measurement of gear avoidance in the situation presented a Gordian problem. Bottom sampling was not a problem and reinforced the mid-water distribution pattern hypothesis by collecting very few emerald shiners during spring and summer. Additionally, observations and reports by other researchers support the possibility of vertical diel migrations. Langlois (1954) suspected that spring concentrations of emerald shiners in Lake Erie followed vertical diel migrations of zooplankton from near bottom during the day to the surface waters at night. Likewise, Flittner (1964) suspected a vertical diel migration by Lake Erie emerald shiners. Alternatively, Campbell and MacCrimmon (1970) noted no vertical diel migration of emerald shiners in Lake Simcoe, Ontario, Canada.

Age Classes

The observations of Age I, II, and III fish at the Raber Bay site indicated by the length-frequency distribution is consistent with reports of emerald shiner life histories at other locations (Flittner 1964, Fuchs 1967, Campbell and MacCrimmon 1975). Mean lengths observed in the Raber Bay emerald shiner age classes also closely approximated those previously reported. The St. Marys River emerald shiner is a short-lived fish rarely exceeding three years in age.

Food Habits

The St. Marys River emerald shiners consumed a varied diet composed primarily of zooplankton and insects. While 68% of all fish containing food held insects, zooplankton were extremely important in the diet during May and into early June. With the increasing emergence of ephemeropteran and dipteran species in June and July, insects became dominant in the diet, reaching a frequency of occurrence of 100% before insect levels diminished with the seasonal progression into autumn. Adult specimens of Ephemeroptera were observed frequently in the gut contents, but surface feeding of emerald shiners on emerging adult mayflies was never observed. Feeding of emerald shiners just below the surface, on the rising adults, is suggested. Interestingly, a peak of zooplankton occurrence in the gut contents of emerald shiners collected in the nearshore zone during mid July coincided with a peak in abundance of *Mesocyclops* and *Cyclops* in the nearshore zone (Thomas and Liston 1985). These temporal changes in diet composition have not previously been reported in emerald shiner populations.

Reports of food habits of adult emerald shiners vary widely. Langlois (1954) and Flittner (1964) report Lake Erie emerald shiners as primarily zooplanktivorous. Mendelson (1975) observed a combined diet of copepods and drifting insects, particularly Chironomidae, in a small stream situation. On the other extreme, Whitaker (1977) and Trautman (1981) describe the emerald shiner as an insectivorous fish species. In the St. Marys River, it is apparent the emerald shiner diet shifts seasonally as the fish feed opportunistically on populations of zooplankton or insects which are immediately most abundant.

Relative Influence of Environmental Factors on Distributions

The observed seasonal distribution and diel patterns of emerald shiners are products of a complex array of factors. One objective of this study was to determine the importance of several of these factors in the seasonal distribution. While the study actually may have been more effective in demonstrating the difficulty of making such determinations, some relative importance of temperature, food habits, dissolved oxygen and turbidity have been suggested through sampling results and field observations.

Temperature. The importance of temperature in determining fish distributions has been understood for many years.

Most recently, the concept of water of a given temperature as a resource itself, or thermal habitat, for fish species in the Great Lakes has been forwarded (Magnuson et al. 1979; Brandt et al. 1980). In the St. Marys River littoral and mid-depth zones, emerald shiner seasonal distribution seemed strongly influenced by water temperature. Nearshore aggregations in early spring, in the fastest warming waters, and the ensuing dispersion into the more offshore waters as the temperatures eventually rose in those areas are rather clear. The eventual abandonment of the nearshore zone in the fall, as the inshore waters quickly cooled added to the distinctness. Similarly, Campbell and MacCrimmon (1970) suggest that temperature was the major factor in the emerald shiner's seasonal distribution in Lake Simcoe.

Temperature does not appear to be a major factor in diel movement patterns over most of the open water season. Spring horizontal diel migrations of emerald shiners into the nearshore zone during daylight periods may be linked to direct heating of shallow inshore waters, but supporting evidence is lacking.

Phototaxicity. The observed vertical and horizontal diel movements in this study were possibly a function of negative phototaxis in the emerald shiner. Field methods of examining this possible factor were not apparent and laboratory experiments on phototaxic responses of adult *N. atherinoides* were not available. However, Flittner (1964) noted that artificial lights were used by bait dealers to attract emerald shiners into shallow waters to facilitate capture of the species with sienes. This positive phototaxic response would seem to indicate that phototaxis is not a factor in the diel movements of the emerald shiner suspected during this study.

Food Habits and Food Availability. Food availability and movements have been shown to influence the movements of fishes (Crossman 1959b, McNaught and Hasler 1961, Baumann and Kitchell 1974, Janssen and Brandt 1980). In the St. Marys River, emerald shiners fed opportunistically on zooplankton and insects. During the spring and early summer, zooplankton were distributed rather evenly between the nearshore zone and channel zone of the St. Marys River (Thomas unpublished data), while insects were emerging at low levels throughout the system. During summer and fall, highest concentrations of zooplankton and heaviest insect hatches appeared in the nearshore and mid-depth zones. While seasonal distribution of emerald shiners is not likely to be influenced by food availability to any great degree, diel vertical migrations suggested by this study seem to be impacted directly by local prey movements. Diel migrations of zooplankton have been observed and reported extensively. Further, night emergence en masse of many species of Ephemeroptera, the most important insect in the St. Marys emerald shiner diet, is a well documented phenomenon (Pennak 1978). Certainly, these nocturnal movements of prey towards the surface influence diel distribution patterns observed for the St. Marys emerald shiner population.

Dissolved Oxygen. Dissolved oxygen levels are often important determining factors in the seasonal and diel distributions of aquatic organisms in systems that exhibit temperature stratification. At the Raber Bay site, vertical temperature stratification was not observed during 1983. The shallow bay area and lotic central channel are readily mixed waters as a result of wind and current action. Consequently, vertical oxygen stratification was not observed at Raber Bay. Horizontal dissolved oxygen strata seemed evident on some sampling dates, but was not constant over the entire sampling period. Furthermore, major diel fluctuations of dissolved oxygen levels were not observed at any time during 1983. Emerald shiners are considered intolerant of low dissolved oxygen conditions (Mathews and Maness 1979). Such conditions were not measured during this study and it appears that dissolved oxygen levels play a minor role, if any, in seasonal or diel movements of emerald shiners in the lower St. Marys River.

Turbidity. Effects of turbidity on emerald shiner seasonal distribution or diel movements were negligible during this study. However, the importance of turbidity fluctuations in gear avoidance must be considered. It is suspected that visual contact and subsequent avoidance by the emerald shiner could be reduced in the relatively high turbid situations sometimes encountered in the lower St. Marys River.

Vegetative Considerations. Since the St. Marys River emerald shiner is primarily an open water, near-surface species, potential association with emergent aquatic plant beds is limited to spring and early summer when dense schools are located inshore. Trautman (1981) suggested that *N. atherinoides* actively avoids rooted aquatic vegetation. Alternatively, observations from lake and stream ecosystems in Wisconsin and Indiana indicate that vegetation has no influence on emerald shiner distributions (Whitaker and Wallace 1973, Becker 1983). Small mesh trap net catches in vegetated and non-vegetated areas of the Raber Bay site do not indicate a strong attraction or avoidance of emergent plant beds by the emerald shiners of the lower St. Marys River.

Other Possible Factors. Several other potential factors in the seasonal and diel patterns of emerald shiner distribution in the lower St. Marys River were considered. Trautman (1981) suggested that moderate to heavy wave action affected the diel movements of emerald shiner by inducing a mid-water distribution away from surface turbulence. Intuitively, this pattern seems likely, but efforts to investigate this possible effect were found to be impractical early in the study. Heavy wave action rendered mid-water sampling as well as surface sampling ineffective.

Reports of the emerald shiners' importance as a food item for many game fish species are numerous (Langlois 1954, Flittner 1964, Fuchs 1967, Campbell and MacCrimmon 1970, Parsons 1971). Walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieui*), and rock bass (*Ambloplites* *rupestris*) were game fish species commonly encountered in the sampling zones at Station VII during 1983. Field examination of gut contents of several hundred of these game fish species indicated that *N. atherinoides* was not an important food item in the diet of game fish of the lower St. Marys River. This may be a function of the emerald shiner's near-surface swimming behavior, since this behavior would reduce encounters with potential predators within the system. Inversely, this strategy increases likelihood of avian predation and this has been documented for emerald shiners in several locations (Langlois 1954, Courtney and Blokpoel 1980). Courtney and Blokpoel (1980) described the emerald shiner as a principal food item of the diet of *Sterna hirundo*, the common tern, on Lake Erie and Lake Michigan. In the St. Marys River, the emerald shiner may indeed be a very important component of the common and black tern, *Chlidonias niger*, diets. If game fish distributions and predation or potential predation are important influences in the emerald shiner seasonal and diel distributions, their effect remains unclear.

As mentioned previously, interspecific competition with the alewife is suspected to have been a factor in the decline of populations of emerald shiners in Lake Michigan. Flittner (1964) suggested that smelt as well as alewife may compete directly with emerald shiners for food. Alewife populations in the lower St. Marys River were minimal, while smelt were an important fish species only in early spring (Liston et al. 1982; Liston et al. 1983). Sampling did not provide indica- on of substantial overlap of distributions between the emerald shiner and any other fish species. Interspecific competition as a factor in the seasonal or diel movements of emerald shiners in the lower St. Marys River remains undetected.

Absence of Emerald Shiners in 1984

During 1982, Michigan State University field research documented high numbers of emerald shiners at the Raber Bay site of the lower St. Marys River. In 1983, substantial numbers of emerald shiners were again collected at Raber Bay. The following year, 1984, witnessed a nearly complete disappearance of emerald shiners from the sampling site at Raber Bay. Previously, Langlois (1954) observed similar patterns of high and low densities in Lake Erie's western basin. As a small, short-lived fish species, the emerald shiner closely fits the life mode of an r-selected species. As such, dramatic population abundance fluctuations from year to year are entirely likely, and rather probable.

Conclusions

Emerald shiners in the lower St. Marys river congregate in dense schools near the shoreline during the spring, and gradually disperse in small groups as offshore waters warm. Diel patterns seem to follow a vertical migration pattern similar to those observed in zooplankton, near the surface at night and in mid-water during daylight. Horizontal diel migrations occurred in spring as fish moved offshore during the night and returned inshore during the day. Temperature, food availability, and vegetation presence appear to be factors directly involved in the seasonal distribution and concurrent diel migrations. Influence of dissolved oxygen, turbidity, phototaxis, wind, predation, or competition was not discerned.

St. Marys River emerald shiners fed opportunistically on zooplankton and insects. Temporal diet shifts coincided with temporal shifts in abundance of zooplankton and insects documented and observed at the lower St. Marys River. Zooplankton occurred in 42% of all non-empty shiner guts examined, and were particularly important during spring and early summer. Sixty-eight percent of all non-empty guts contained insects, with Ephemeroptera the most frequently occurring insect taxa. Insects were observed with highest frequency during the summer period.

Absence of the emerald shiner from the sampling areas in 1984 is not disturbing. Subsequent seasons should exhibit a return of emerald shiners in comparable numbers to those of 1981-1983. Future considerations in work at Raber Bay should include continued documentation of emerald shiner population abundance shifts and investigation of winter distributions.

SUMMARY

Objectives of this study were to document the seasonal distribution and diel migration patterns of the emerald shiner, Notropis atherinoides, and to examine environmental and behavioral factors involved in those distributions. A total of 2260 emerald shiners were collected between 4 May 1983 and 7 November 1983 near Raber Bay on the lower St. Marys River. A variety of gear types were used including small mesh trap nets, small mesh trawls, larval fish push nets, and otter trawls, with varying degrees of success. Collections were taken in three horizontal zones designated nearshore, mid-depth, and channel zones. Environmental conditions at the site including water temperature, dissolved oxygen, and turbidity were monitored throughout the season. Food habits were investigated from fish collected over the course of the sampling season.

Emerald shiners tended to school in dense aggregations during spring and early summer in the nearshore zone. At this time, emerald shiners displayed a strong horizontal diel migration offshore at night and inshore during the day. Concurrently, a vertical diel migration towards the surface at night and to mid-water during the day period is suggested, but inconclusive in light of possible gear avoidance problems during the daylight period.

As summer progressed, dispersion of large schools into widely scattered smaller groups throughout the nearshore and mid-depth zones was apparent. Any horizontal diel migration

patterns became unclear, while the vertical diel migration pattern remained suspected, but not confimed.

With the onset of fall, emerald shiners had nearly disappeared from the nearshore zone and were present in highest numbers in the mid-depth zone. No horizontal or vertical diel migrations were observed during the period as shiners appeared to remain in mid-water or near bottom.

Food habits of emerald shiners reflected both seasonal distribution and availability of food items. Early spring abundances of zooplankton in the system coincided with a high frequency of occurrence of zooplankton in the diet. As summer progressed and levels of insect emergence increased, frequency of occurrence of zooplankton decreased and insect occurrence in the gut contents increased. Overall, 68% of all fish examined contained insects in their gut contents. In the lower St. Marys River, the emerald shiner appears to feed opportunistically on zooplankton and insects.

Water temperature was clearly associated with the seasonal distribution pattern of the emerald shiner. Dissolved oxygen and turbidity did not have well defined patterns of influence on seasonal distribution. Emerald shiners appeared to avoid the dense nearshore stands of emergent aquatic macrophytes which developed by mid-summer. Other possible influencing factors considered, but not documented, include predator-prey interactions, interspecific competition, and wind effects. No factors other than local food availability appeared related to diel movements.

Emerald shiners were absent from the sampling site during the 1984 season. While unexpected, similar population fluctuations are on record from other areas. Future field work at Raber Bay would determine if populations rebound to levels comparable to the 1982 and 1983 seasons. Furthermore, focus on the winter distribution of the emerald shiner, and other forage species, should be increased to allow detection of potential impacts due to proposed extension of the commercial winter navigation season.

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APPENDIX I

Calculation of Fish Densities from Collections with .5m diameter push nets and small mesh modified shrimp trawl:

I. Volume filtered calculations

A. Volume filtered by .5m diameter circular net

1. Distance of tow calculation

$$\text{Distance (m)} = \frac{\text{Difference in meter readings}}{999{,}999} \times \text{rotor constant}$$

where: rotor constant is 26,873

thereby: Distance (m) = (Difference in meter reading) x K^1

where: K^1 = .02687303

2. Volume filtered (m^3) = Area of net mouth x Distance (m)

Area of circle $= \pi r^2 \qquad r = \frac{d}{2} \qquad (\frac{d}{2})^2 = \frac{d^2}{4}$

where: r = radius of circular net mouth

d = diameter of circular net mouth

$\pi = 3.14$

thereby; $V\ (m^3) = \dfrac{d^2\ (\text{meter reading difference})\ K^1}{4}$

where: V = volume of water filtered

B. Volume filtered by modified shrimp trawl

1. Distance of tow (as above)

Distance (m) = (Difference in meter reading) x K^1

2. Volume of water filtered = area of net mouth x D

$V\ (m^3) = .557418\ m^2 \times (\text{difference in meter reading}) \times K^1$

II. Density Calculation

Estimates of densities of fish present in the system at time of sampling based on fish collected while straining a known volume of water were calculated as follows:

$$\text{Density} = \frac{\text{\# of fish collected during tow}}{\text{volume of water filtered}}$$

Low estimates of densities sometimes required the transformation of density estimates from $\#/m^3$ to $\#/100m^3$ by multiplying both numerator and denominator by 100.