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DISTRIBUTION AND ABUNDANCE OF LARVAL FISH IN WESTERN LAKE ERIE

by

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PREFACE

The following report was prepared by Michael R. Heniken for a Master of Science Degree in the Department of Zoology, The Ohio State University. Research conducted for this thesis was part of a project coordinated by the Center for Lake Erie Area Research and was sponsored by the U.S. Environmental Protection Agency, Grant No. R-804612-02-0. Dr. Charles E. Herdendorf, Department of Zoology, served as advisor; Drs. Bernard Griswald and Roy Stein served as members of the reading and examination committee.

On behalf of the Center for Lake Erie Area Research, I am pleased that we are able to reproduce copies of this research effort and make them available to other scientists.

Charles E. Herdendorf
Director

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INTRODUCTION

Purpose and Objectives

The western basin of Lake Erie has long been considered important in the reproduction of many fishes, due to its shallow nature and many reefs and shoals (Hartman 1970). This basin is also being increasingly utilized by man for numerous industrial purposes such as dredging and dumping of dredge spoils, and the removal of water for cooling and other industrial purposes.

These uses of the lake not only threaten the spawning grounds of fishes, but also represent a hazard to eggs and larvae. Embryonic and larval stages of fishes cannot actively avoid these pollutants and processes; therefore, these life stages are particularly succeptible to these pollutants. Consequently, this study was designed to determine distribution and abundance of larval fishes in the western basin of Lake Erie.

This research was part of a larger study designed to evaluate the impact of power plants on fish populations in Lake Erie. Sampling was done in the Ohio and Canadian waters in association with other research being done in the Maumee and Sandusky rivers, Michigan waters, onsite studies at a power plant at Monroe Michigan, and a modeling effort concerning entrainment and its effect on fish populations in the western basin. The purpose of this survey was to (1) identify the common species of larval fishes found in the western basin, (2) estimate the abundance of these species, and (3) locate spawning and nursery grounds.

Previous Investigations

Studies of larval fishes in fresh water are not extensive. Individual life history studies of various species have been done, but little work has been done on a qualitative or quantitative basis concerning larval fish populations. In Lake Erie, few studies have examined larval fishes and these studies were often only small portions of larger research efforts.

The first major study of larval fishes in Lake Erie was a joint project of several Ohio, New York, Ontario, and federal conservation and game authorities (Fish 1932). Sampling was done throughout much of Lake Erie with most of the sampling being done in the central and eastern basins. This study was basically of a qualitative nature in which a total of 62 species of larval fish were described and illustrated. Twenty-four species were collected in the open lake and the remaining species were collected from hatcheries, streams, and alongshore. Wickliff (1931), discussing this research effort, pointed out that more species and greater numbers of each species were captured inshore than were found in the open lake around the islands of the western basin.

In another study, the Ohio Division of Wildlife surveyed the fishery resources of Sandusky Bay (Chapman 1955). Shore seining in the bay collected young-of-year fish. Gamefish species (yellow perch, crappies, bullheads, white bass, sunfish, and catfish) represented 23 percent of the fish captured (see Table 1 for scientific names of fishes). Eight species of forage minnows, primarily emerald shiners, represented 61 percent of the catch. The remaining 16 percent was made up of rough species, including gizzard shad, carp, goldfish, and freshwater drum.

The Ohio Division of Wildlife also undertook a study to locate and describe areas of walleye spawning in the western basin (Kellar et al. unpublished). Fish eggs were sampled at numerous stations with a suction pump to remove the eggs from the bottom. Walleye eggs were found most abundantly over rocky bottoms off Locust Point and the Bass Islands area.

Fish larvae were also sampled in the same areas as the egg sampling. The few walleye larvae collected with also collected primarily in the rocky areas off Locust Point. Large numbers of yellow perch larvae were collected throughout the study area. Perch larvae were found concentrated near the bottom and in the nearshore area. Other larvae collected in the western basin were rainbow smelt, sunfish, lake whitefish, gizzard shad, emerald and spottail shiners, logperch, and additional unknown species.

The remaining studies of larval fish have been associated with siting and preoperational studies of power generating plants. Investigations at the Locust Point area, as part of a preoperational study of the Davis-Besse nuclear power plant, collected seven species of fish larvae (Reutter and Herdendorf 1975). The most abundant species were gizzard shad, yellow perch, and emerald shiners. The remaining species were walleye, smallmouth bass, goldfish, and brook silversides.

TABLE 1. - Common and scientific names of fishes reported in this paper. Names are according to Bailey et al. (1970).

Common Name	Scientific Name
Alewife	- *Alosa pseudoharengus* *
Gizzard shad	- *Dorosoma cepedianum* * !
Rainbow smelt	- *Osmerus mordax* * !
Emerald shiner	- *Notropis atherinoides* * !
Spottail shiner	- *Notropis hudsonius* * !
Carp	- *Cyprinus carpio* * !
Goldfish	- *Carassius auratus*
White sucker	- *Catostomus commersonii* *
Quillback	- *Carpiodes cyprinus* *
Freshwater drum	- *Aplodinotus grunniens* * !
White bass	- *Morone chrysops* * !
Sunfish	- *Lepomis sp.* *
Crappie	- *Pomoxis sp.* *
Smallmouth bass	- *Micropterus dolomieu* *
Yellow perch	- *Perca flavescens* * !
Walleye	- *Stizostedion v. vitreum* * !
Logperch	- *Percina caprodes* *
Brook silversides	- *Labidesthes sicculus*
Sculpin	- *Cottus sp.* *
Troutperch	- *Percopsis omiscomaycus* *
Lake whitefish	- *Coregonus clupeaformes* *
Mooneye	- *Hiodon tergesius* *
Catfish	- *Ictalurus sp.*
Bullhead	- *Ictalurus sp.*

* Species of larval fish captured in the western basin during this study.

! Common species

Another study of a possible power plant site on Sandusky Bay collected seven species of larval fish (Hartley 1975). The most abundant species was the gizzard shad. Other larvae collected were white bass, emerald shiner, freshwater drum, yellow perch, carp-goldfish, and smallmouth bass.

METHODS

Study Area

The study area consisted of approximately 1740 km^2 in Ohio and Canadian waters of the western basin of Lake Erie (Figure 1). The western basin is separated from the rest of Lake Erie by a line drawn from Pelee Point, Ontario to Cedar Point, Ohio.

The study area was divided into seven geographically identifiable sectors (A-G). These sectors were established because different areas of the basin are quite dissimilar in depth, amount of shoreline, and bottom substrate. All of these factors could affect the suitability of these different areas for spawning purposes and are discussed below for each sector.

Each sector was further divided into depth zones, with reference to National Oceanic and Atmospheric Administration (NOAA) navigation chart number 39 of Lake Erie. A 2 m contour interval was used to delineate six depth zones in the western basin (Table 2 and Figure 2) with a depth zone being the vertical column of water bounded by two depth contours.

TABLE 2. - Depth zones and corresponding depths of the western basin of Lake Erie.

Zone	Depth (m)
1	0 - 2
2	2 - 4
3	4 - 6
4	6 - 8
5	8 - 10
6	> 10

Sampling stations were generally established in a stratified random pattern in the depth zones within each sector (Figure 1, 2 and Appendix A). A minimum of two stations were placed in each depth zone in nearly all sectors, exceptions being sectors B and F which will be discussed later. Some stations were established in areas of interest such as reefs (26, 27, 34, 58, 49, 52), dredging areas (6, 10), industrial intake, and effluent areas (22, 23, 68). A total of 56 stations were sampled during the spawning season of 1975 and 60 stations during 1976. In the 1976 sampling, stations 22 and 23 were transferred to an onsite study and stations 54, 66, 67, 68, 69, 70, and 71 were added in the Sandusky Bay area.

Sector A - Maumee Bay. Maumee Bay proper lies at the western end of Lake Erie, separated from the lake by two spits, Woodtick penninsula extending southerly from the Michigan shoreline and Little Cedar Point extending northwesterly from the Ohio shore. (Figure 1) For this study, the northeastern boundary of sector A includes the water off the mouth of Maumee Bay out to the 6-m contour.

Maumee Bay is a broad shallow shelf sloping gently lakeward toward the northeast. Four stations were sampled in depth zone 1 and

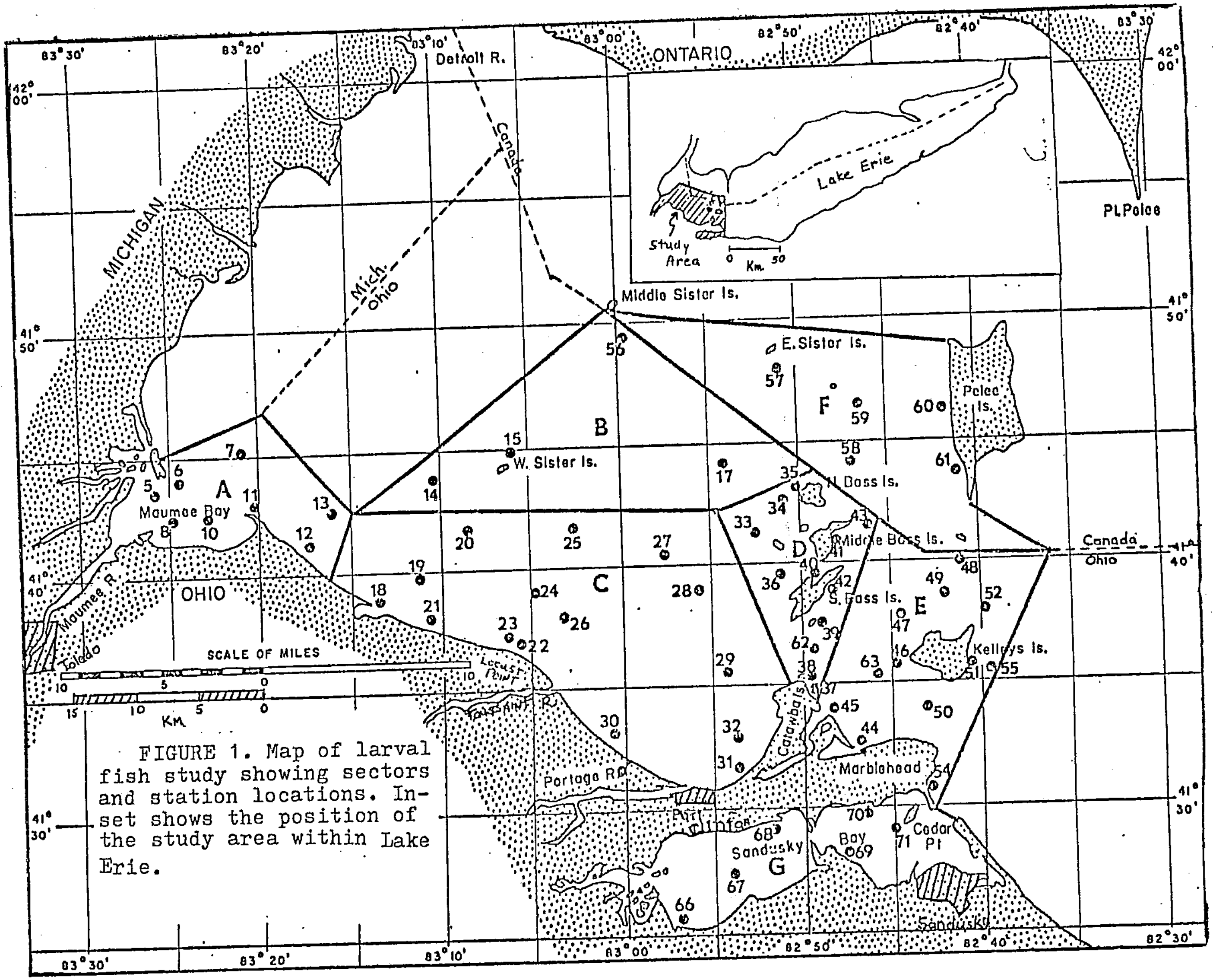

FIGURE 1. Map of larval fish study showing sectors and station locations. Inset shows the position of the study area within Lake Erie.

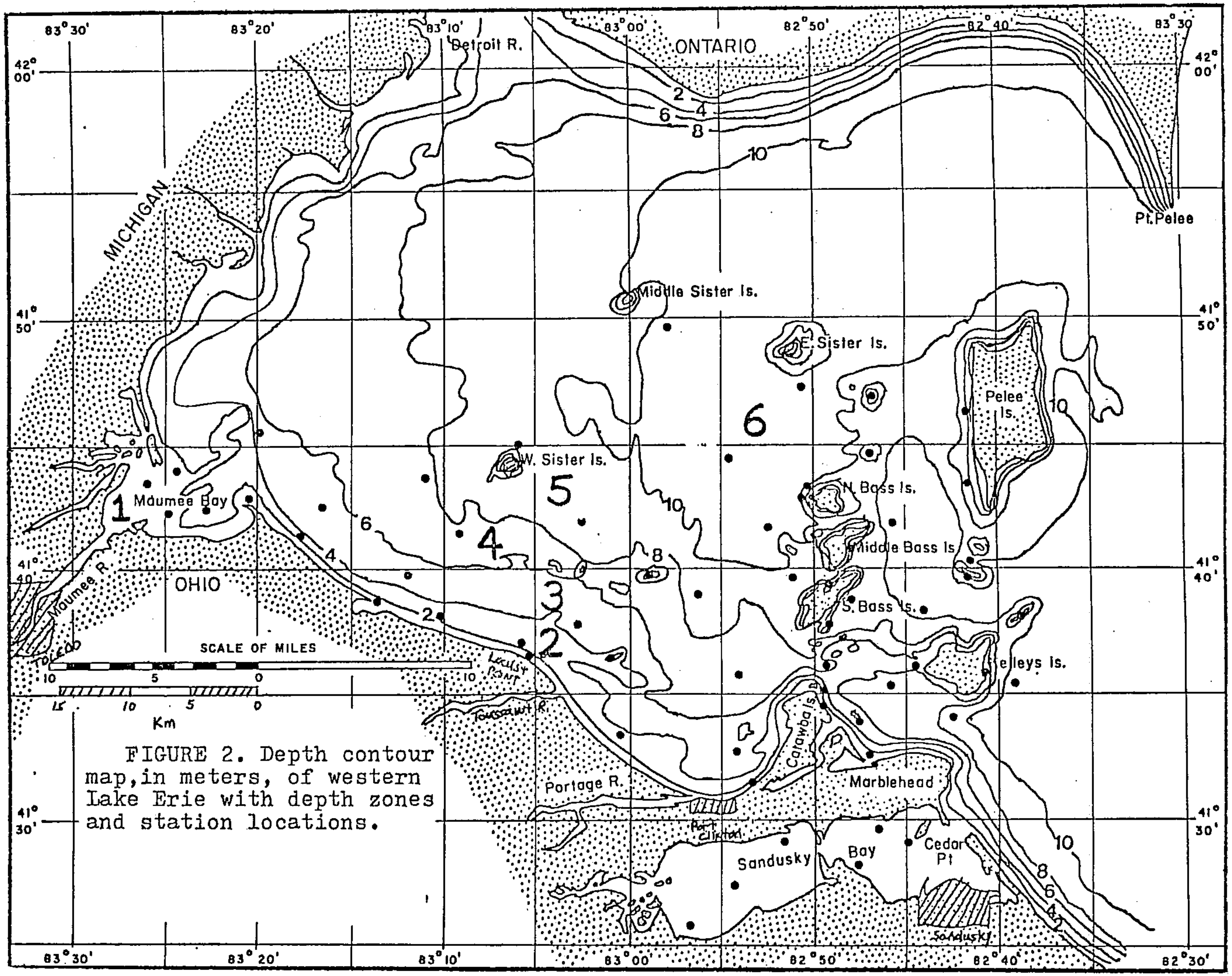

FIGURE 2. Depth contour map, in meters, of western Lake Erie with depth zones and station locations.

two stations each in depth zones 2 and 3 (Figure 2). Maximum depth is approximately 6 m, except in the navigation channel which crosses the bay and is dredged to a depth of 28 feet (9 m) below low water datum.

The Maumee River is a major inlet into the bay. The lower 15 miles (24 km) of the river are considered a freshwater estuary because its flow is affected by the lake water mass (Herdendorf et al. 1977).

The shoreline of Maumee Bay is composed mainly of clay with small areas of sand on the side of the bay near Little Cedar Point (Figure 3). Offshore material is lacustrine clay overlain by silt except for sand deposits located off Little Cedar Point (Verber 1957). The sand deposits, lying in a modified spit northward from Little Cedar Point, were deposited by littoral currents coming from the southeast (Herdendorf et al. 1977). On either side of the shipping channel are a series of linearly arranged shoals, sandy at the surface, which were formed from spoil banks when the channel was dredged to 25 feet (8 m) in the 1930's.

Maumee Bay was suspected to be a potential spawning area because of its generally shallow nature and the various sand deposits located in the bay. The bay could also act as a catch basin for larvae produced upriver and therefore could be a nursery ground.

Sector B - West Sister Island. This sector is entirely open water with only the small shoreline area of West Sister Island (Figure 1). The sector is bounded by the international boundary to the northeast, the Toledo shipping to the northwest, and sectors A, C, and D to the south.

The bottom gently slopes to the east and this sector contains only three depth zones, 4, 5, and 6. There are no reefs and the shallow areas are only those immediately adjacent to West Sister Island.

The shoreline of West Sister Island is composed of bedrock from the Tymochtee Dolomite formation (Herdendorf 1970). Bottom sediments in this sector are composed of mud (silt and clay size particles, Figure 3). A small area to the west of the island is composed of sand, gravel, and shells (Verber 1957).

Because of the deep water and the primarily mud bottom, this sector was not suspected to be a spawning area. Therefore only one station each was sampled in depth zones 4 and 6 and two stations in depth zone 5 (Figure 2).

<u>Sector C - Locust Point</u>. Sector C is bounded to the west by sector A, to the north by sector B, and to the east by sector D. The Ohio shoreline from the edge of sector A to Catawba Point forms the southern boundary (Figure 1).

Five depth zones (1-5) are present in this sector. A total of 15 stations were sampled. Five stations were sampled in depth zone 1, with two of these stations (26, 27) being placed on Toussaint and Niagra Reefs respectively. Three stations each were sampled in depth zones 2 and 3 and two stations each in depth zones 4 and 5 (Figure 2).

The shoreline, proceeding from the west towards Locust Point, is clay covered with rip-rap becoming sand (Figure 3). From Locust Point towards Port Clinton the shoreline is clay with intermittent areas of sand. A large sand beach proceeds from Port Clinton eastward

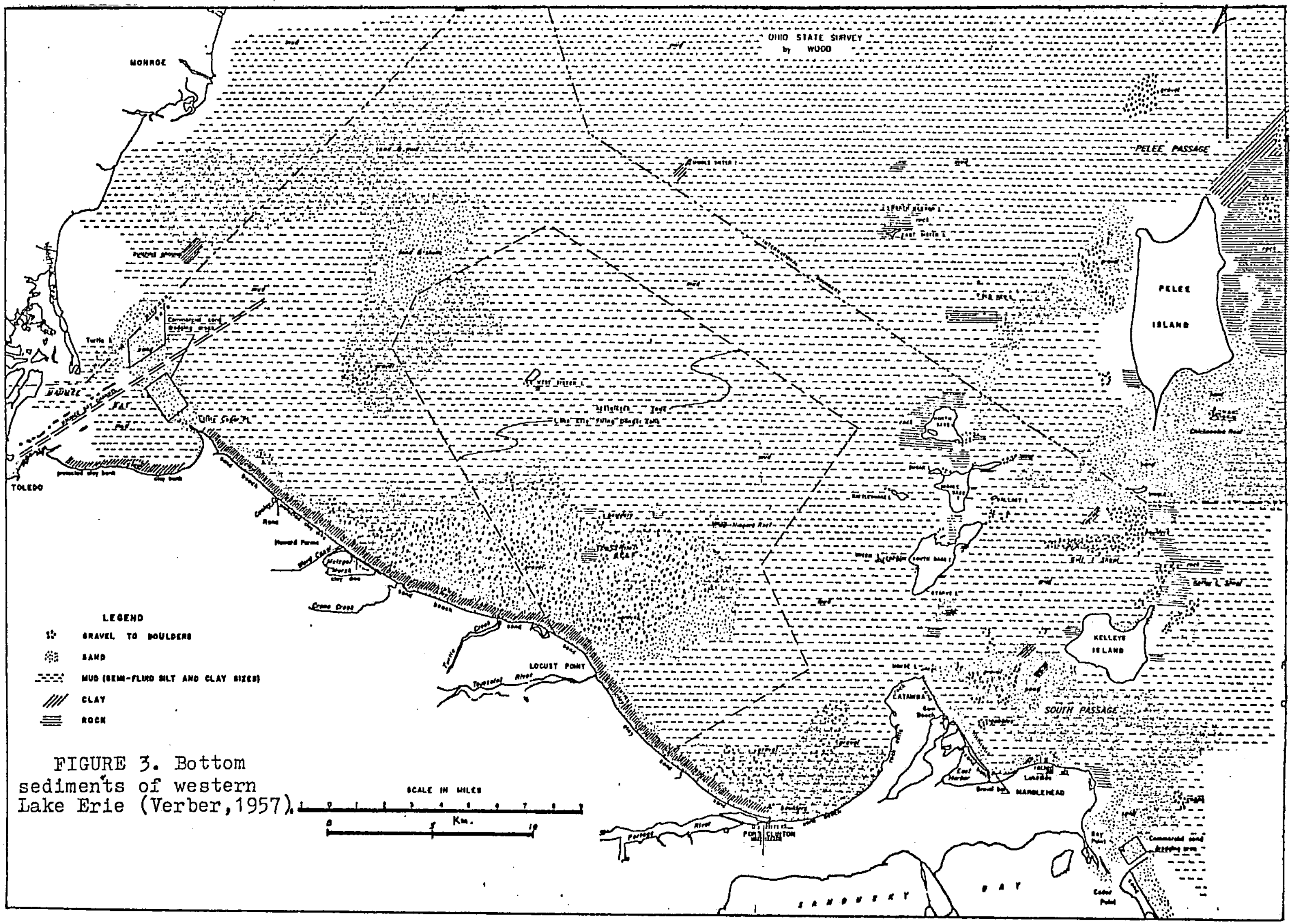

FIGURE 3. Bottom sediments of western Lake Erie (Verber,1957).

where the shoreline changes to bedrock cliffs and headlands (Verber 1957).

The bottom sediments of this sector are composed of numerous areas of sand, gravel, bedrock, and mud (Figure 3). The numerous reefs (reefs or shoals being elevations of rock or gravel above the bottom) in this area are composed of the Tymochtee Dolomite formation. These reefs are composed of exposed bedrock and gravel with occasional glacial erratics (Herdendorf 1970).

There are numerous creeks entering the lake in this sector; however, there are only two large rivers, Toussaint and Portage. There are two large marsh areas adjacent to the lake, Metzger Marsh and Magee Marsh which is a state game preserve.

This sector was a suspected spawning area because of its numerous reefs and wide variety of bottom types. The numerous streams and marshes also allow for many different habitats which could be used for spawning.

Sector D - Bass Islands. Sector D is bounded to the northeast by the international boundary and to the other sides by sectors B, C, and E, and Catawba Point to the south (Figure 1).

All depth zones (1-6) are present in this sector and two stations were sampled in each depth zone (Figure 2). Stations 34 and 62 were located on West Reef and Starve Island Reef respectively.

This sector is characterized by many islands and reefs. The larger islands in this sector are South, Middle, and North Bass, Rattlesnake, and Green Islands. The islands and reefs are composed of the Put-in-Bay and River Raisin Dolomite formations (Herdendorf 1970).

The island shorelines and Catawba Point are composed of bedrock, steep to the west but with a gradual shelf to the east. The reefs are also composed of bedrock and rubble. There are areas of sand and gravel deposits to the west of the Bass Island sand in the South Passage between the islands and the mainland. The majority of the sediments are composed of mud (Figure 3; Herdendorf 1970; Verber 1957).

This sector was also a suspected spawning area do to the many reefs and the large amount of shoreline that is bedrock. The sand and gravel deposits are primarily located in the deeper waters and probably would not be utilized for spawning.

<u>Sector E - Kelleys Island</u>. Sector E is bounded by the international boundary to the north, sector D to the west, Marblehead Penninsula to the south, and the central basin to the east (Figure 1).

All six depth zones (1-6) are present in this sector with two sampling stations located in each depth zone (Figure 2). Station 49 was located on Gull Island Shoal and station 52 was located on Kelleys Island Shoal.

Kelleys Island is the only island present in this sector along with several reefs. The majority of the bedrock is Columbus Limestone with small areas composed of Lucas Dolomite.

The shoreline of Catawba and Marblehead Penninsulas is composed of bedrock with areas of sand and gravel. The area to the south of the Marblehead, at the mouth of Sandusky Bay is composed of sand. The Kelleys Island shoreline is bedrock (Verber 1957). Areas of sand and gravel are located primarily in South Passage and in the vicinity of Kelleys Island and Gull Island Shoals (Figure 3). There is a large bedrock shelf to the east of Kelleys Island. The remainder of the bottom is composed of mud and mixtures of mud and sand.

This sector was also a suspected spawning area because of the reefs and large bedrock areas along with the sandy deposits in the nearshore areas.

Sector F - Pelee Island. Sector F is located entirely in Canadian waters. It lies above the international boundary, west of Pelee Island, and below a line drawn approximately from Middle Sister Island to Sheridan Point on the northwest of Pelee Island (Figure 1).

Only four depth zones (1, 3, 4, 6) were sampled in this sector. These were depth zones which were present in large enough areas to sample easily. Intermediate depths were present in only small areas. One station was sampled in each depth zone (Figure 2).

There are several islands present in this sector. The largest island is Pelee Island with several smaller islands, Middle and East Sister as well as Middle Island. Chicken Island Reef is the main reef located in this sector.

Pelee Island is composed of Columbus Limestone with its shoreline being composed of clay, bedrock, and to the south by sand (Verber 1957). The reefs and islands to the west are composed of River Raisin Dolomite (Herdendorf 1970). The remainder of the bottom is composed of mud (Figure 3).

This sector was not suspected to be a primary spawning area because of its generally deep nature and primarily mud bottom. The reef and shoreline areas are possible spawning areas because of their sand and gravel areas.

Sector G - Sandusky Bay. This sector is composed entirely of Sandusky Bay. The bay is separated from the lake by two sand points, Bay Point and Cedar Point (Figure 1). The bay is approximately 24 km long and 6 km wide.

The shoreline is composed mainly of clay with the bottom being composed entirely of mud. The bay is extremely shallow and all stations were of depth zone 1. A total of six stations were sampled.

The Sandusky River is the main inflow into the bay, and like the Maumee River, the lower portions are considered a freshwater estuary. There are also numerous marshy areas around Sandusky Bay.

Sandusky Bay was considered important for larval fish because of its shallow nature, the marshy areas surrounding the bay, and the possibility that the bay could act like a catch basin for larvae carried in by the river.

In addition to factors such as sediments and depth other factors may influence distribution and abundance of larvae in the western portion of Lake Erie.

Food base. The distribution of food in the western basin affects both adult and larval fishes. Primary production is higher in the western basin than in the other basins of Lake Erie, as indicated by chlorophyll concentrations (Fay 1976). High chlorophyll concentrations are present in the area near Maumee Bay, this progressively decreases towards the central basin. Chlorophyll concentrations in Maumee Bay are low near the river mouth and increase toward the open lake (Herdendorf et al. 1977). This is attributed to the high turbidity of the river water entering the bay. Sandusky Bay probably behaves similarly because of its highly turbid nature.

This uneven distribution of plankton could affect the distribution of larvae because larvae require the appropriate kind of food, concentration of food, and size of food organisms (Lasker 1975). Areas of higher plankton concentrations could allow for different rates of survival for larvae spawned in different areas.

The benthic community of the western basin and Sandusky Bay can be described as being pollution tolerant. Wright and Tidd (1933) described the benthos as having large numbers of mayflies (*Hexagenia sp.*) in the open waters of the lake. However in the nearshore area the benthos consisted of large numbers of pollution tolerant tubificid worms. More recent studies found the benthic community consisted mainly of oligachaete worms of the family Tubificidae and the dipteran midge larvae of the family Chironomidae (Britt et al. 1973; Cones 1976; Herdendorf 1970; Lindsay 1976). Areas of sand and gravel were found to have fewer organisms than mud bottoms. Studies in the reef areas found that on the rocky substrate, amphipods and isopods were the most abundant organisms with trichopterans and ephemeropterans also being fairly abundant (Kellar et al. unpublished).

This distribution of more macroscopic food could affect the larvae as they grow older and their food requirements change and they become capable of swimming. In order to find the desired food, the young fish might have to move to quite different localities.

Hydrologic factors. Patterns of flow in the western basin could be a factor in the distribution of larvae. Larvae spawned in one area could be transported from the spawning grounds into areas that might be more or less beneficial to larval survival.

The western basin receives greater than 95 percent of its inflow from the Detroit River (Chandler 1945). The remainder of the inflow comes from the Maumee, Huron, Portage, Sandusky, and Raisin rivers. Part of the Detroit River water proceeds south to the Ohio shore then east along the Ohio shore, while the other portion of the flow proceeds along the north (Canadian) shore and passes into the central basin between Pelee Point and Pelee Island (Herdendorf 1970). There is a gyre of water that flows back into the western basin around the Kelleys and Bass Islands. During peak flow, the Maumee River produces a plume of water which leaves Maumee Bay and proceeds eastward along the Ohio shoreline carrying highly turbid water (Herdendorf 1977). Under normal and low flow conditions, the Maumee River flow is thought to provide a flow northward along the Michigan shoreline as a compensatory flow for the large southeasterly flow of the Detroit River (C. E. Herdendorf, Ohio State Univ. personal communicator).

The shallow nature of the western basin also allows the wind to generate seiche and current activity. There are surface currents which are normally driven downwind while subsurface currents are often opposed to the wind direction in the form of a compensating return flow (Herdendorf 1970). Wind and wave activity on shore can also produce longshore currents which are capable of sediment transport.

Wind direction, bottom topography, and shoreline configuration are major factors in the formation of current patterns along with the generalized flow patterns of river inflows. Therefore, the aquatic communities are subjected to currents from many different directions which could move waters of varying quality from place to place as well as transporting sediments and organisms.

Temperature and Oxygen. The shallow nature of the western basin allows for complete mixing of the water colum (Chandler 1940). This fact causes a nearly uniform distribution of temperature and oxygen from surface to bottom and also can cause rapid changes in turbidity of the water. Extended periods of hot calm weather can cause temporary stratification by heating surface waters without mixing. Temporary stratification of sufficient length can cause oxygen depletion in the hypolimnion. These periods of temporary oxygen depletion are responsible for the inhibition of more desirable benthic communities, such as mayflies (Britt et al. 1973).

Temperature is an important factor to fishes because it not only determines the approximate times of spawning but also determines development times of the eggs as well as playing a part in the makeup of the plankton community. These factors can play a role in the survival of fish larvae. The depletion of oxygen would quite obviously be detrimental to larvae if they were not capable of avoiding the areas. In general, the rather uniform distribution of temperature and oxygen would tend to be beneficial to larvae that were transported from place to place by currents because they probably would not be subjected to as many stresses.

Sampling

Sampling took place during the spawning seasons of 1975 and 1976. Sampling at 10 day intervals (such that a different hatch of larvae would be sampled on each cruise) began in May of 1975 and in

April of 1976. A total of nine cruises were made during the first season and 14 cruises during the second (Table 3). The survey of 1975 was comprised of sectors A-F. The second year sector G was added to the previous six sectors.

Sampling was done using a metered 0.75 m oceanographic plankton net with a mesh size of 760 micron. The net was towed using a 21 foot (6 m) Boston Whaler outboard motor boat at a speed of approximately 2-3 knots. Surface and bottom tows were made at each station except at stations where the depth was less than 1 m (stations 18, 31, 44), where only one tow was made. Stations were located through the use of landmarks and navigation marker bouys.

In addition to the larvae sampling several water quality parameters were measured. These included surface and bottom temperature, dissolved oxygen, conductance, and turbidity.

Variability is a crucial sampling problem when sampling for any type of zooplankton. Sampling errors can arise from three sources: active avoidance of sampling equipment, mechanical problems inherent to the equipment, and nonrandom distribution of the organisms.

Studies of net avoidance by organisms have shown that larger diameter net sizes decrease the possibility of avoidance by the organism (Fleminger and Clutter 1965; Sameoto 1975; Wiebe and Holland 1968). Night sampling was also recommended to decrease avoidance behavior; however, other nonvisual cues can also trigger avoidance behavior.

The equipment itself can affect the catch. Minor changes in towing speed caused by engine speed, wind waves, and currents can result in significant changes in the composition of catch (Aron and

TABLE 3.- Schedule of cruises, with dates of sampling and number of stations sampled for larval fish in western Lake Erie.

Year	Cruise no.	Dates	No. stations
1975	1	May 12-14	25
	2	May 21-25	55
	3	June 1-4	55
	4	June 12-17	56
	5	June 21-23	56
	6	June 30-July 3	56
	7	July 11-15	56
	8	July 31-Aug. 4	51
	9	Aug. 24-Sept. 3	51
1976	1	April 12-16	56
	2	April 21-23	18
	3	April 28-May 1	55
	4	May 8-11	57
	5	May 20-23	60
	6	May 30	27
	7	June 7-9	60
	8	June 19-25	60
	9	June 30-July 7	58
	10	July 11-16	54
	11	July 21-28	59
	12	Aug. 2-5	58
	13	Aug. 16	12
	14	Aug. 25-Sept. 3	58

Collard 1969). Different types of nets also behave quite differently even when other factors such as boat speed and depth of tow are constant (Aron et al. 1965).

Error caused by patchy nonrandom distribution of organisms is not easily overcome. The size and distribution of patches will affect the accuracy and precision of abundance estimates (Wiebe 1971). Even using large nets, the species composition of an area can still be under-estimates (McGowan and Fraundorf 1966).

The use of replicate tows to overcome patchy distribution is not entirely without problems. To detect a change in five species from day to night or location to location would require at least seven replicates. To detect a 10 percent difference in numbers of individuals would require 10 replicates in a densely populated area and 15 or more tows in a sparsely populated area (Roessler 1965). Replicate tows may even provide erroneous results caused by the disturbance of the area by the passage of the boat, motor, and net (Brown and Langford 1975).

A summary of 13 previous studies, showed that 95 percent confidence limits for a single net tow exceeded one half to two times the observed value (Wiebe and Holland 1968). These findings were regardless of the type of net, method of towing, or organisms involved.

In this study, the use of a 0.75 m net was the largest size net that was practicable to use under the many conditions encountered on Lake Erie. The use of replicate tows and night sampling, also were not practical due to the large size of the study area and the time constraints for sampling all stations. Engine speed was held constant for all tows, but the actual towing speed was affected by wind and waves.

Preservation and Identification

Samples were preserved in the field with 5 percent formaldehyde. Fish larvae were sorted from other plankton and debris in the laboratory. Larvae from each sample were then identified to species, length range measured (to the nearest 0.5 mm), and counted. Identification of larvae was done using the keys of Nelson (1975), Norden (unpublished), and the descriptions and illustrations of Fish (1932). Developmental stages were identified according to the definitions of Hubbs (1943):

Embryo - Developmental stages to the moment of hatching or birth.

Larvae - Developmental stages well differentiated from the juvenile and intervening between the times of hatching and transformation.

Prolarvae - Larvae still bearing yolk.

Postlarvae - Larvae following the time of absorption of yolk; applied only when the structure and form continues to be strikingly unlike that of the juvenile (formation of all vertical fin rays).

Juvenile - Young essentially similar to adult. Larvae were finally preserved in a solution of one part glycerin to one part 70 percent alcohol.

Population Estimates and Statistical Treatment

Initially, the area of each depth zone in each sector was determined using a planimeter and the NOAA chart number 39 of the western basin. Each area was then multiplied by the average depth of that depth zone to obtain a volume estimate for each depth zone (Appendix B).

Concentrations of larvae were calculated at each station based on the number of larvae collected in the tow and the volume of water filtered, as measured by the flowmeter in the net. An average concentration of larvae was calculated for each depth zone of each sector by averaging all stations within a depth zone. The average concentration of larvae was then multiplied by the volume of the depth zone to provide an abundance estimate. This procedure was done for each depth zone of each cruise. These estimates were then summed through all depth zones on each cruise. Population estimates were made by summing all abundance estimates, calculated for each cruise, throughout the season.

Yellow perch, being of commercial importance, were selected for statistical analysis to see if areas of high concentrations could be located. These areas could represent spawning or nursery grounds which could be adversely affected by man's activities. The non-parametric statistical tests were taken from Hollander and Wolfe (1973).

Preliminary data handling suggested a tendency for perch larvae to concentrate near the bottom. To test this hypothesis, surface/bottom concentrations were compared using a Wilcoxon signed rank test. Differences in surface/bottom concentrations were tested between sectors as well as for the cruise as a whole.

To determine if significant differences in yellow perch concentrations between sectors occurred, a Kruskall-Wallis test was used. When differences were found, a multiple comparison technique (Dunn modification) was used to locate the sectors which had significant differences in concentrations.

A Wilcoxon rank sum test was used to determine if there was a difference between concentrations of larvae observed at reef stations (stations 26, 27, 34, 58, 49, 52) with other areas. The designated reef stations were compared to nearshore stations of equal depth, depth zones 1 and 2. The same nearshore stations were also compared with remaining deeperwater stations, depth zones 3-6, to determine if there was a tendency for perch to concentrate nearshore.

RESULTS

Collections

A total of 20 species of larval fish were collected in this survey (Table 1). Of the species collected, only nine were collected routinely and in large enough numbers to be considered common. Several species, which are morhologically similar, could not be efficiently separated. The species complex of gizzard shad-alewife, carp-goldfish and their hybrids, black-white crappies, and the sunfish were not separated. The gizzard shad and alewife were grouped as gizzard shad. At larger sizes (> 18 mm), alewife could be distinguished from shad and were reported separately in the abundance estimates. For the final population estimates these two species were grouped as gizzard shad. Carp-goldfish species were grouped as carp and black-white crappies and sunfish were grouped simply as crappies and sunfish respectively.

Some morphologically similar species, such as emerald-spot-tail shiners, gizzard shad-smelt, and walleye-yellow perch, presented identification problems at first because it was not certain if these similar species were present at the same time. In each case however, one of the species in each pair was abundant earlier than the other species (Figure 4). This fact allowed familiarization with the identification of one species before the other species became prevalent.

Each species captured in this survey appeared to have a characteristic developmental stage and size (Table 4). Some species, such as gizzard shad and emerald shiners, were collected in more than one stage and over a rather large size range. Other species, such as freshwater drum, carp, and walleye, were collected in only one developmental stage and in a very small size range.

Sampling in 1975 began in May which was not early enough to collect walleye larvae. For this reason, sampling was started in April of 1976. This was sufficiently early to see the beginning of the walleye hatch.

A series of tows was made to compare the effectiveness of paired surface/bottom tows with one oblique tow. A surface/bottom tow was followed by an oblique tow so that conditions during the tows would be as identical as possible for comparison purposes. Five sets of tows were made.

Only emerald shiners were collected in the series of tows (Appendix C). Surface/bottom tows varied by as much as 3.4 and the oblique tows varied by as much as 5.3. In each set of tows, the number of larvae as determined by the average of a surface/bottom tow was higher than the number of larvae in one oblique tow.

A comparison of daylight sampling with night sampling was made at two stations (34, 36). The two stations were sampled at approximately 1100 hours and again at 2300 hours. Sampling at night collected more species, larger numbers of larvae, and larger larvae than were collected during the day (Appendix D).

Population Estimates

Abundance estimates were made for all species collected in each cruise (Appendix E). Population estimate for each species were also calculated (Appendix F). The raw data, consisting of the number of larvae at each station for each sampling can be found in Herdendorf et al. (1977).

Whereas standard deviations were calculated for all the abundance and population estimates, they were not included. In general, standard deviations ranged from 50 percent to 100 percent of abundance estimates; more usually, approximately 100 percent.

Graphical presentations of abundance estimates through time were made for the nine common species (Figure 5). These graphs illustrate the abundance of the species for the two years of the survey. Species such as gizzard shad, emerald shiner, and freshwater drum were abundant and were collected throughout much of the season. Other species, rainbow smelt and walleye, were only collected for short periods of time. Abundance of these species reached a sharp peak and then dropped off rapidly.

The time of first capture, last capture, period of peak abundance, relative abundance, and population estimates have been summarized for the nine common species (Table 5).

The population estimates for many of the species did not appear to change much between the 2 years. However, the relative abundance of species did change markedly. The largest change was in the percentage of emerald shiners. The emerald shiners changed from 16 percent of the larvae in 1975 to 62 percent in 1976. This dramatic

TABLE 4.- Characteristic developmental stages and lengths of nine common species collected in western Lake Erie with a 0.75 m (760 μ mesh) plankton net.

Species	Developmental Stage	Length (mm)
Gizzard shad	postlarvae	7-8
	early juvenile	18-25
Rainbow smelt	postlarvae	8-20
Emerald shiner	postlarvae	5-15
	juvenile	15-25
Spottail shiner	postlarvae	5-8
Carp	prolarvae	5-7
Freshwater drum	prolarvae	4-6
White bass	prolarvae	5-7
	postlarvae	7-10
Yellow perch	prolarvae	5-7
	postlarvae	7-10
Walleye	prolarvae	5-10

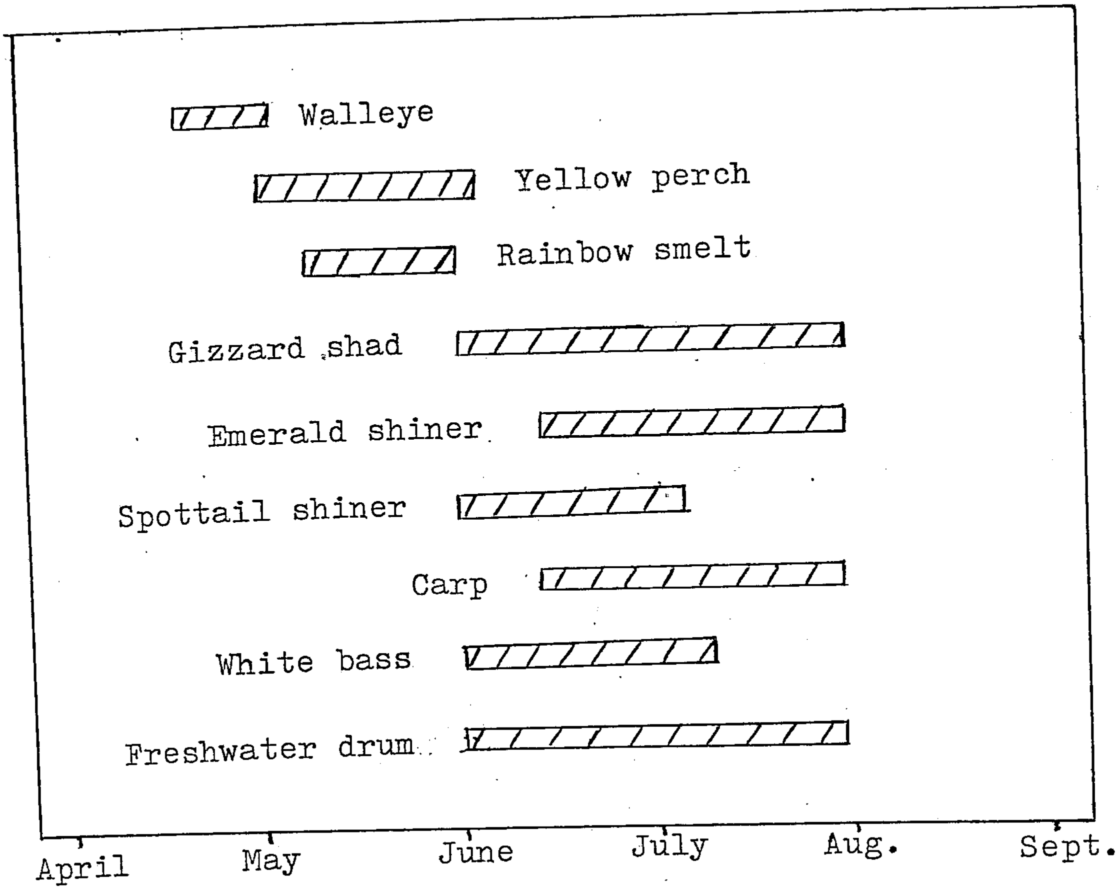

FIGURE 4. Periods of abundance of nine common larval fish in western Lake Erie, derived from surveys in 1975 and 1976.

FIGURE 5 Abundance and density of common larval fish species in western Lake Erie.

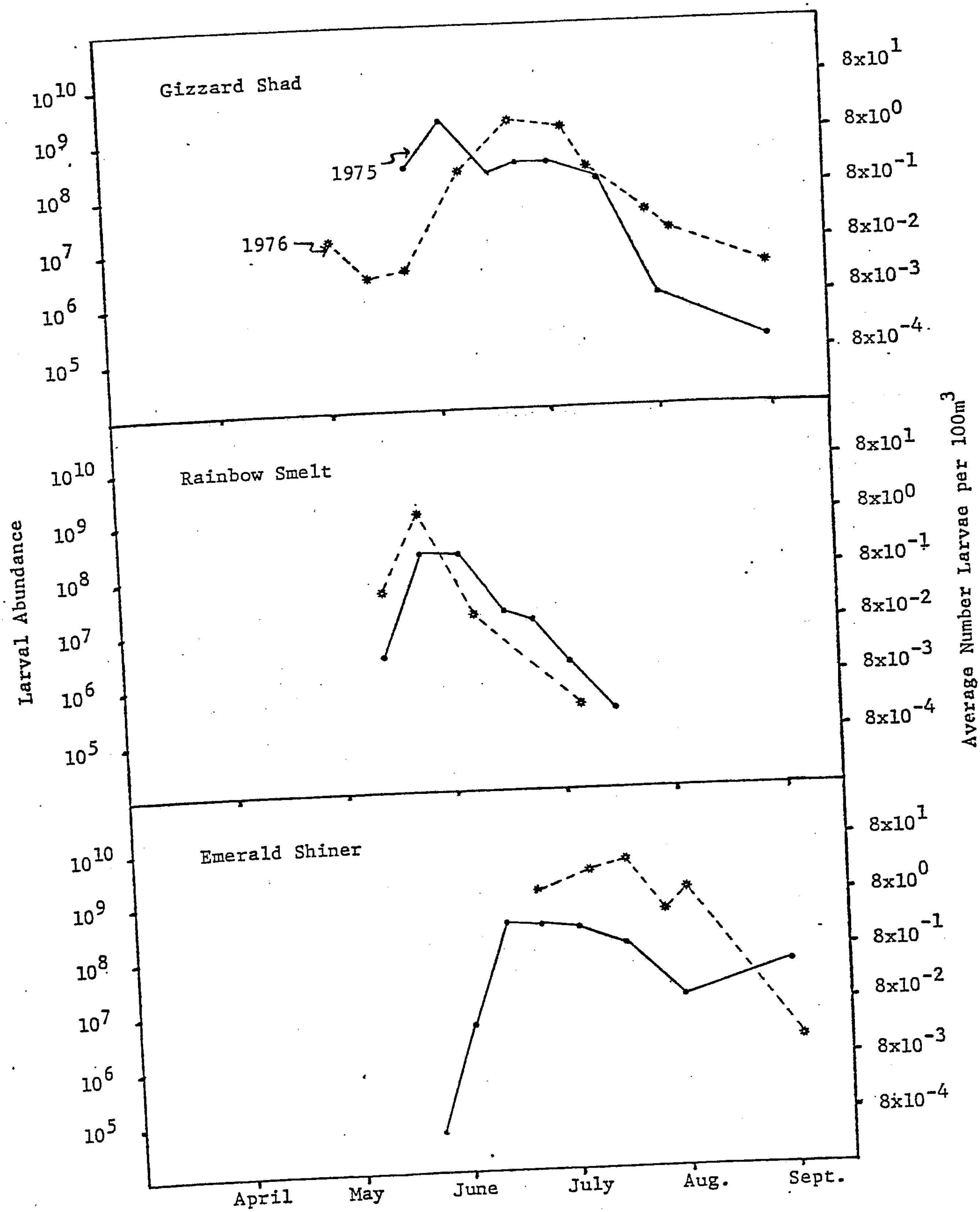

FIGURE 5. (cont'd) Abundance and density of common larval fish species in western Lake Erie.

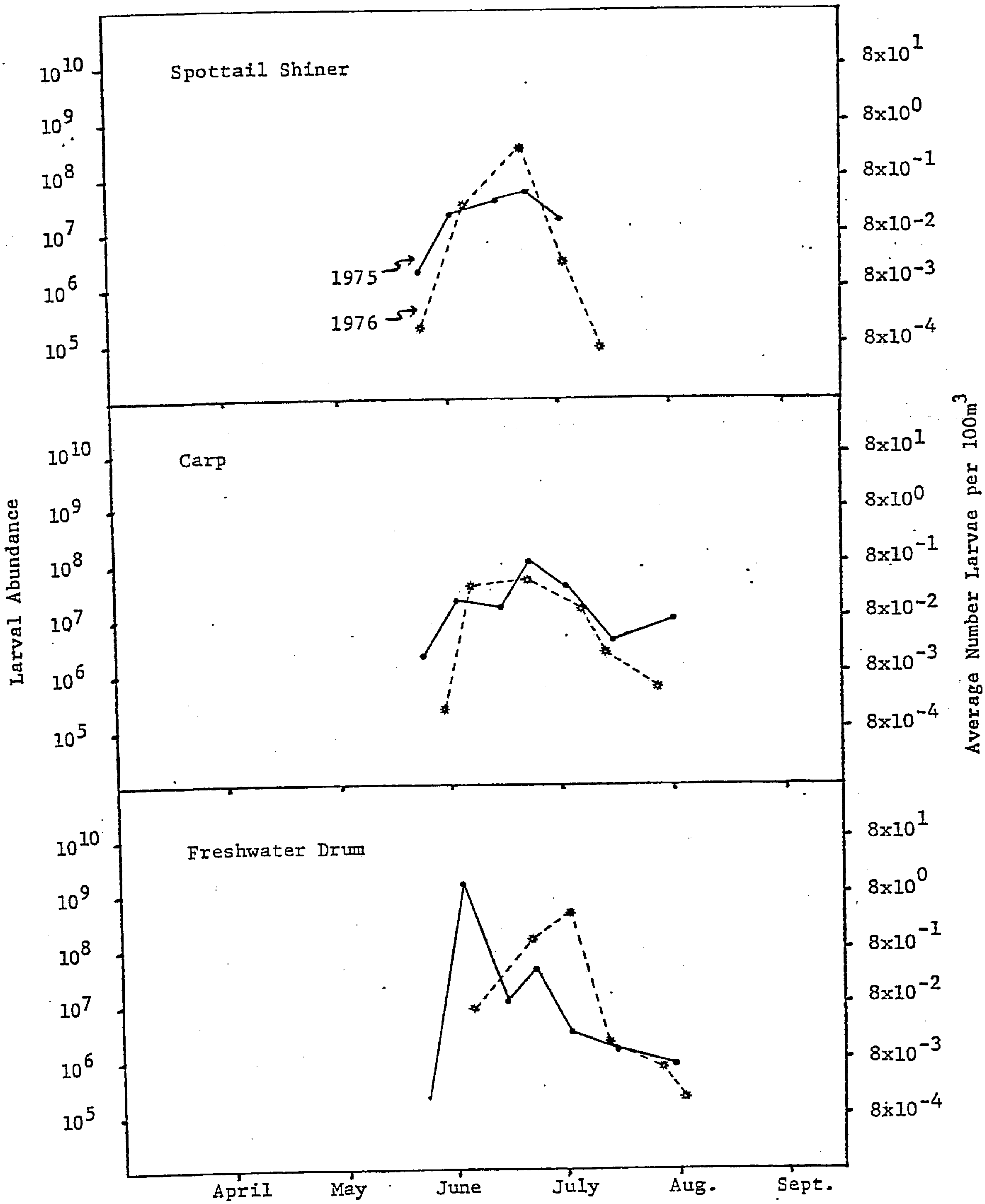

FIGURE 5(cont'd) Abundance and density of common larval fish species in western Lake Erie.

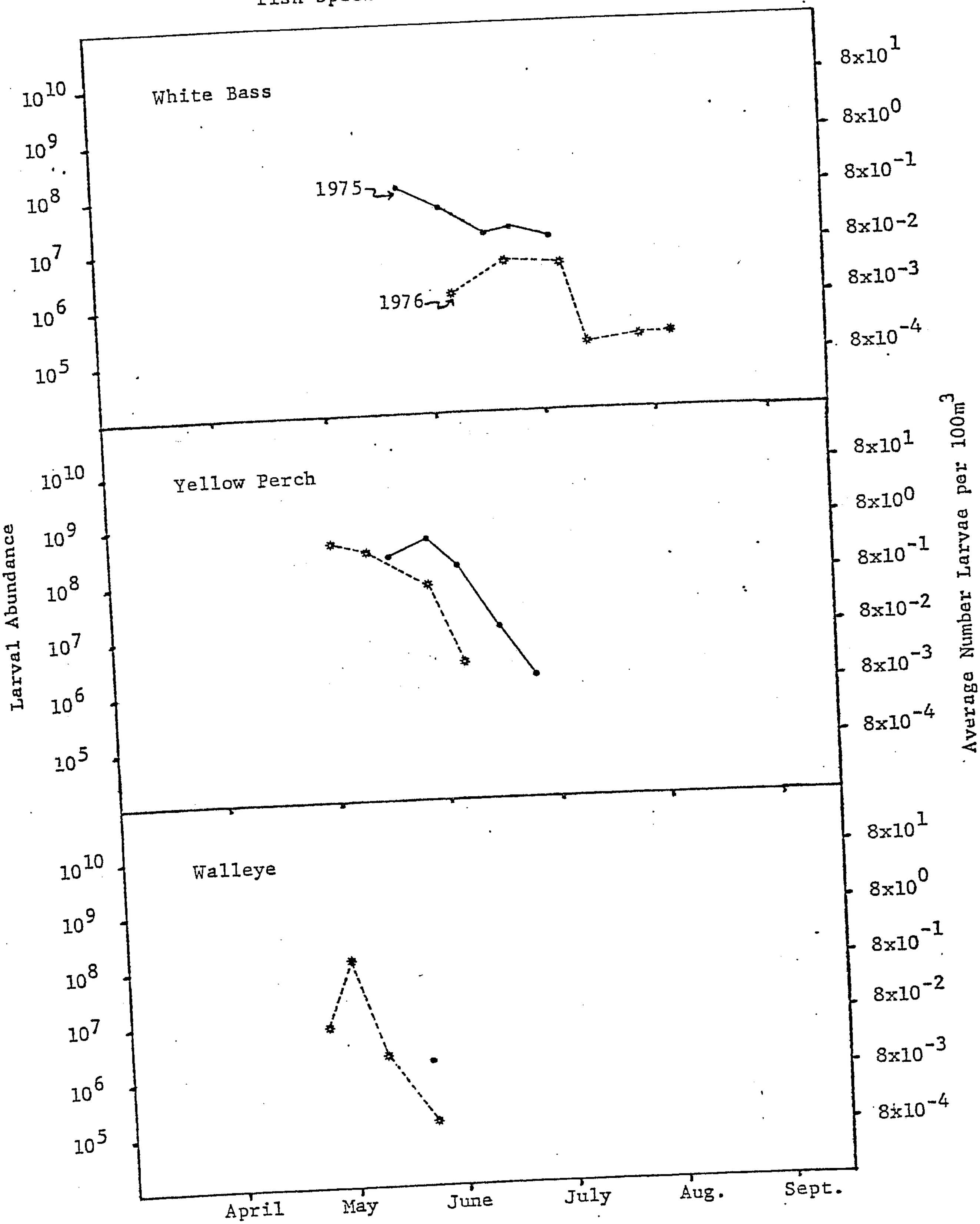

TABLE 5. Summary of capture data for nine common species of larval fish in western Lake Erie.

Species	First Capture 1975	First Capture 1976	Last Capture 1975	Last Capture 1976	Peak Abundance	Relative Abundance[a] 1975	Relative Abundance[a] 1976	Pop. Estimate 1975	Pop. Estimate 1976
Gizzard shad	24 May	30 April	3 Sept.	3 Sept.	June - mid July	40%(1)	17%(2)	$4.6x10^9$	$4.2x10^9$
Rainbow Smelt	13 May	10 May	13 July	21 June	mid - late May	7%(5)	7%(3)	$7.5x10^8$	$1.6x10^9$
Emerald Shiner	22 May	22 June	3 Sept.	3 Sept.	mid June - early Aug.	16%(3)	62%(1)	$1.8x10^9$	$1.5x10^{10}$
Spottail Shiner	22 May	23 May	2 July	2 July	early - mid June	2%(8)	2.7%(6)	$2.0x10^8$	$6.4x10^8$
Carp	23 May	30 May	4 Aug.	28 July	mid - late June	2%(7)	0.6%(8)	$2.1x10^8$	$1.5x10^8$
Freshwater Drum	22 May	7 June	4 Aug.	5 Aug.	early - late June	19%(2)	4%(5)	$2.2x10^9$	$9.8x10^8$
White Bass	22 May	23 April	15 July	4 Aug.	early - mid June	2%(6)	0.1%(9)	$2.7x10^8$	$1.6x10^7$
Yellow Perch	12 May	23 April	23 June	9 July	early May - early June	12%(4)	5.8%(4)	$1.4x10^9$	$1.4x10^9$
Walleye	22 May	21 April	-	22 May	late April - early May	- (9)	0.8%(7)	$2.2x10^6$	$2.0x10^8$

a Numbers in parenthesis indicate relative rank.

change is probably responsible for the decreases in the relative abundances of gizzard shad, freshwater drum, and yellow perch since their population estimates did not change much between the two years. Increases in population estimates were seen in the rainbow smelt, spottail shiner, and walleye in addition to the emerald shiner.

Distribution of Yellow Perch

Yellow perch larvae exhibited a strong tendency to concentrate near the bottom. Larvae were found to be in higher concentrations (number/100 m^3) near the bottom in three of four cruises during 1975 (cruises 1, 2, 3) and two of four cruises during 1976 (cruises 3, 4; Wilcoxon signed rank test, $p < 0.05$). A comparison of bottom concentrations with surface concentrations in each sector, showed the Locust Point, Bass Islands, and Kelleys Island sectors had perch larvae concentrated near the bottom in most cruises, while other sectors did not have this distribution.

A comparison of average perch concentrations in each sector did not show any cruises in 1975 in which there were significant differences (Kruskall-Wallis test, $p < 0.05$). In 1976, cruises 4 and 5 had significant differences in average concentrations of perch larvae between sectors. The Kelleys Island sector was found to have a higher average concentration of perch than did other sectors in cruise 4. Sandusky Bay was significantly higher than other sectors in cruise 5.

Yellow perch larvae showed significantly higher average concentrations in shallow inshore areas than in the shallow reef areas (Wilcoxon rank sum test, $p < 0.05$). Cruises 2 and 3 of 1975 and cruise

3 of 1976 had higher average concentrations inshore. These cruises are representative of the time when perch larvae are newly hatched, based on size, and would probably be closest to the spawning grounds. When the same inshore stations were compared with the remaining off-shore-deeper stations, cruises 3 of 1975 and 3 and 5 of 1976 had higher average concentrations inshore. However, if the significance level is changed to $p < 0.20$, then all cruises had higher average concentrations inshore except cruise 1 of 1975 and cruise 6 of 1976.

DISCUSSION

The purpose of this study was to survey a portion of the western basin of Lake Erie and determine (1) those larval fishes present, (2) their abundance, and (3) their distribution.

Sampling during the 2 years of the study collected a total of 20 species of larval fishes. Of these 20, only nine were collected frequently in large enough numbers to be considered common. In this survey, no sampling was done in the tributaries of the western basin nor in any of the large marshes which border the lake. Some fish species may use these areas for spawning; larvae of these species may have been overlooked.

Routine sampling of stations was done with the hypothesis that sampling every 10 days throughout the season would sample a different hatch on each cruise. This was further enhanced by the fact that the sampling gear was apparently size selective for each species. This meant that larvae sampled at one time were not sampled again when they were larger. The routine sampling of a given size larvae throughout the season should provide a representative picture of the larval population.

Beyond a certain size, larvae were no longer susceptible to the sampling gear. This fact may result from any of several factors. Upon reaching a certain length or developmental stage, larval fish may be capable of sensing and avoiding the net. In support of this hypothesis, greater numbers of individuals and species as well as larger larvae were collected at night compared to the day. Larvae may see the net during daylight and avoid it. Secondly, larvae after reaching a locomotive stage, may move to nursery areas that are local or specific enough that they were no longer sampled. Finally, natural mortality may be high enough to reduce populations to low levels and routine sampling effort might not be sufficient to collect larvae.

The use of night sampling and replicate tows at each station are probably the best techniques to be used for accurate sampling of larval fish. These techniques were impractical because of the size and time constraints of this study. The use of a surface and bottom tow at each station appears to give larger numbers of larvae than would be collected by one oblique tow from surface to bottom. Which of these towing techniques is the most representative of the larval concentrations at a given station is not known. However, the use of a bottom tow is more likely to sample larvae which remain near the bottom during the day. The use of a surface/bottom tow might not represent the larval makeup of a station as accurately as night sampling but is probably more representative than oblique tows.

Abundance and population estimates of larval fish were estimated by multiplying average concentration by volume. Numbers of larvae collected at each station were averaged for each depth zone and then multiplied by the volume of that depth zone. Standard deviations surrounding these population estimates were quite large and reflected variation in catch from station to station. Once again the use of replicate tows would help to reduce this variation in catch, or at the very least more precisely estimate the magnitude of this variability.

The population estimates for some species did not change appreciably between 1975 and 1976. Population estimates for walleye, rainbow smelt, and spottail shiner did increase somewhat but is probably due to the fact that these species tend to spawn early in the season, and in 1976 sampling was begun earlier. The only species which appeared to decline in abundance from 1975 to 1976 was the white bass. The emerald shiner exhibited a large change in the population estimates from 1975 to 1976. This change is not due to earlier sampling because emerald shiners were not collected until mid June 1976.

Based on the population estimates, the nine common species were ranked according to their relative abundance. Emerald shiners changed from 16 percent of larvae in 1975 to 62 percent in 1976. This large increase in relative abundance served to decrease the relative abundance of other species even though their population estimates did not change appreciably. No reason for this increase in emerald shiners is apparent. This change could be part of a natural cycle from year to year. Chapman (1955) also reported shiners making up 61 percent of catch in the Sandusky Bay.

One drawback in ranking larvae according to population estimates is that survival of most fish populations decreases exponentially with time. Not all larvae were collected in the same age or developmental stage. Therefore, the larvae could be at different places along a typical exponential curve. A species with a large population of prolarvae could have a larger population estimate than a species which was caught in the postlarval stage simply because the second species had lived longer and natural mortalities had reduced the population. The two species in actuality could have had the same abundance if prolarval stages had been compared.

Mortality and age factors could affect the relative rankings of the species collected in this study. In general, emerald shiners and gizzard shad were the most abundant larvae and were also collected in the later developmental stages. If these larvae were compared to other larvae while in the prolarval stage, their relative abundances might be even higher.

Cultural eutrophication of Lake Erie has had several effects on fish populations. Wright and Tidd (1933) noted that pollution in the western basin had adversely affected Hexagenia populations, increased Tubifex populations, and may have harmed spawning grounds because of siltation. They hypothesized that all these factors may have been offset by the increase in primary production due to nutrient inputs into the western basin.

Fish larvae must pass through a critical period following absorption of yolk until first feeding. As previously stated, larvae require the correct type of food, correct concentration of food, and the correct size of food for successful feeding.

Along with an increase in algaes such as the blue-greens, there has also been an increase in the gizzard shad. Part of the reason for the increase in shad may be because gizzard shad utilize blue-green algae as a food source during larval stages (Kutkuhn 1957). Blue-green algae are abundant and blooms are common in the western basin during the summer months.

Food studies of larval walleye have shown that the primary food of postlarval walleye are diatoms (Hohn 1966). Larger larvae consumed zooplankton as well as diatoms. Diatoms are the predominant plankton during the spring when walleye larvae would be hatching out.

Food studies of cohabiting larval species showed that each species tended to have a specific food organism and that there was little overlap, thus minimizing competition (Bulkley et al. 1976). The abundance of the diatoms, blue-green algae, and zooplankton was such that the collection net was often clogged with these plankton.

The increased primary production caused by eutrophication has probably eliminated or decreased the factor of food concentration as an inhibitor to larval feeding. Eutrophication has most likely shifted the plankton community to more pollution tolerant species. Thus the change in species, or types of food, and possibly size of the plankton has affected survival of larvae so that fish populations have changed through time by selection of species which are capable of utilizing the plankton present for food.

Areas of high turbidity can also affect larval fish populations. Primary production can be limited and also plankton tend to concentrate near the surface to maintain optimum light levels. This concentration of plankton could allow easier feeding for larvae but a net decrease in primary production may also limit larval populations. Concentration of plankton near the surface could also cause larvae to concentrate near the surface. Although turbid water might tend to protect larvae, the concentration of larvae feeding near the surface could also make them easier prey for predators.

In addition to trophic and other natural factors, industrial uses of a lake can also affect larvae. Power generating stations can affect fish populations in several ways. The first and most obvious way is through entrainment mortality. Larval fish can be killed through any combination of temperature shocks, mechanical damage, or chemical poisoning.

Power plants can also affect fish populations by altering spawning habitats. Power plants can alter local temperature regimes which may enhance or inhibit spawning of various species of fish (Nelson 1975). Provided that food supplies were adequate to support larvae, this alteration of temperature regimes could seriously alter diversity.

Power plants can also affect primary production in the area of their outfalls (Brook and Baker 1972; Hamilton et al. 1970). The use of chlorine in the plants for defouling purposes can inhibit primary production which could have a negative impact on larval fishes as well as other plankton consumers.

To develop an understanding of larval distribution in the study area, the numbers of larvae at each station were plotted for various cruises and then contoured. The cruises chosen were the ones on which peak abundance of a species was observed. This was done assuming that during peak hatching the larvae were closest to where they were spawned. This mapping was done for each of the nine common species.

The gizzard shad appear to be centered mainly in Maumee and Sandusky bays (Figure 6); concentrations of larvae often exceeded 1000 per 100 m^3. These two bays are the areas which would be considered to have the poorest water quality. Secchi disc readings seldom exceeded 0.3 m and conductance was often twice that in the open lake. The area along the Ohio shoreline and off Locust Point also appears to be utilized for spawning. Numerous small streams and marshy areas enter the lake here, along with a plume of turbid water from the Maumee River. Gizzard shad appear to utilize the turbid areas of the lake for spawning.

Rainbow smelt favor gravelly areas for spawning (Scott and Crossman 1973); however, smelt larvae appear to be more closely associated with mud bottoms in this study (Figure 7). The shape of the contours suggests that the flow of the Detroit River may be influencing smelt distribution. Because no gravel substrate exists to the northwest of the study area, it appears that smelt larvae are being carried into this area by the Detroit River. Larvae found in the area of Kelleys and Bass islands may result from local spawning in these areas. Large numbers of adult smelt found in these areas tends to support this suggestion. Smelt larvae were seldom collected nearshore or in the bays where turbidity was high.

Emerald shiners were also caught in highest numbers in open and less turbid portions of the study area, especially in the vicinity of rocky reefs. Shiners were not necessarily caught on the reef itself but often in the deeper waters adjacent to the reef. These larvae were captured in a very large size range and large numbers of postlarvae to

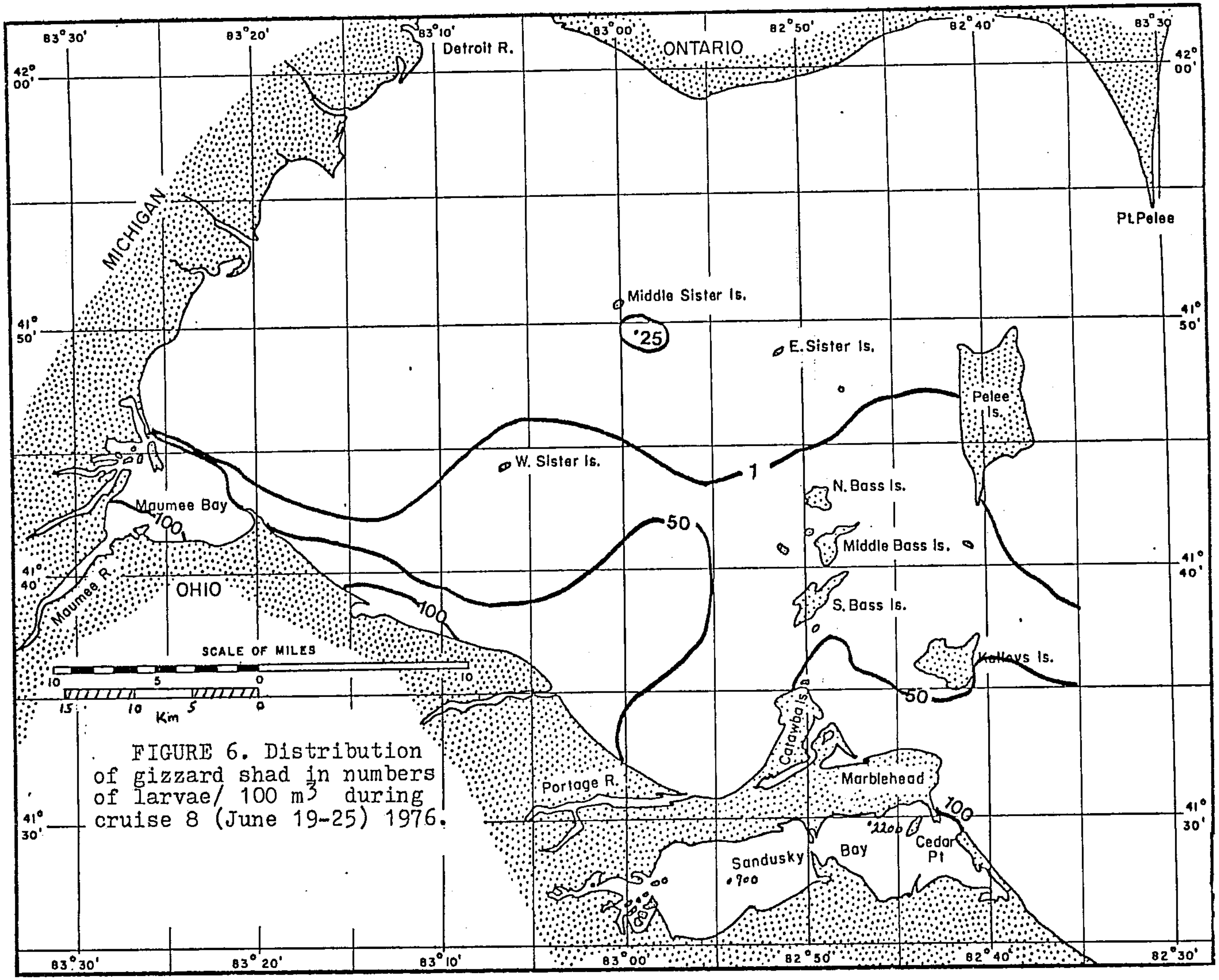

FIGURE 6. Distribution of gizzard shad in numbers of larvae/ 100 m^3 during cruise 8 (June 19-25) 1976.

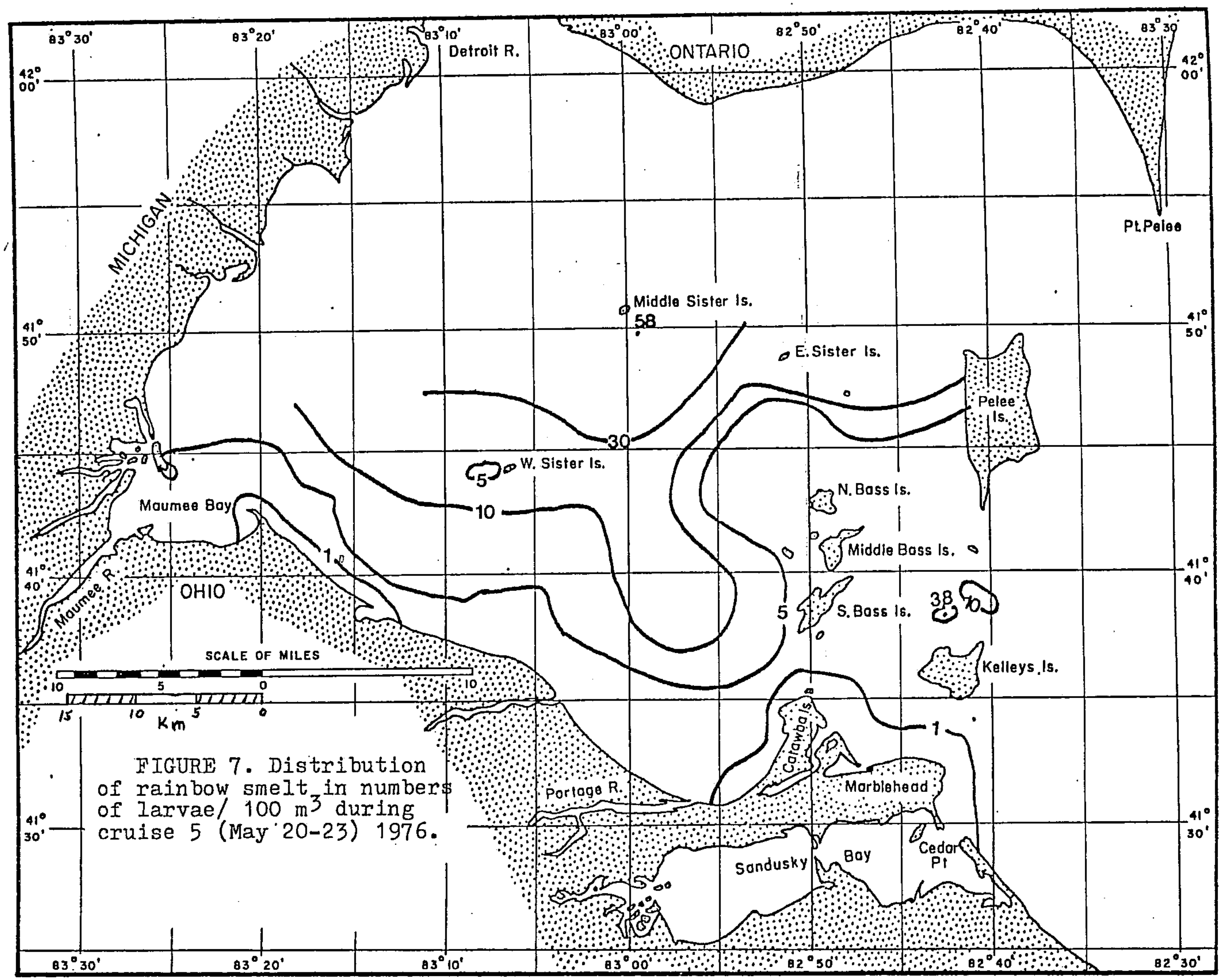

FIGURE 7. Distribution of rainbow smelt in numbers of larvae/ 100 m^3 during cruise 5 (May 20-23) 1976.

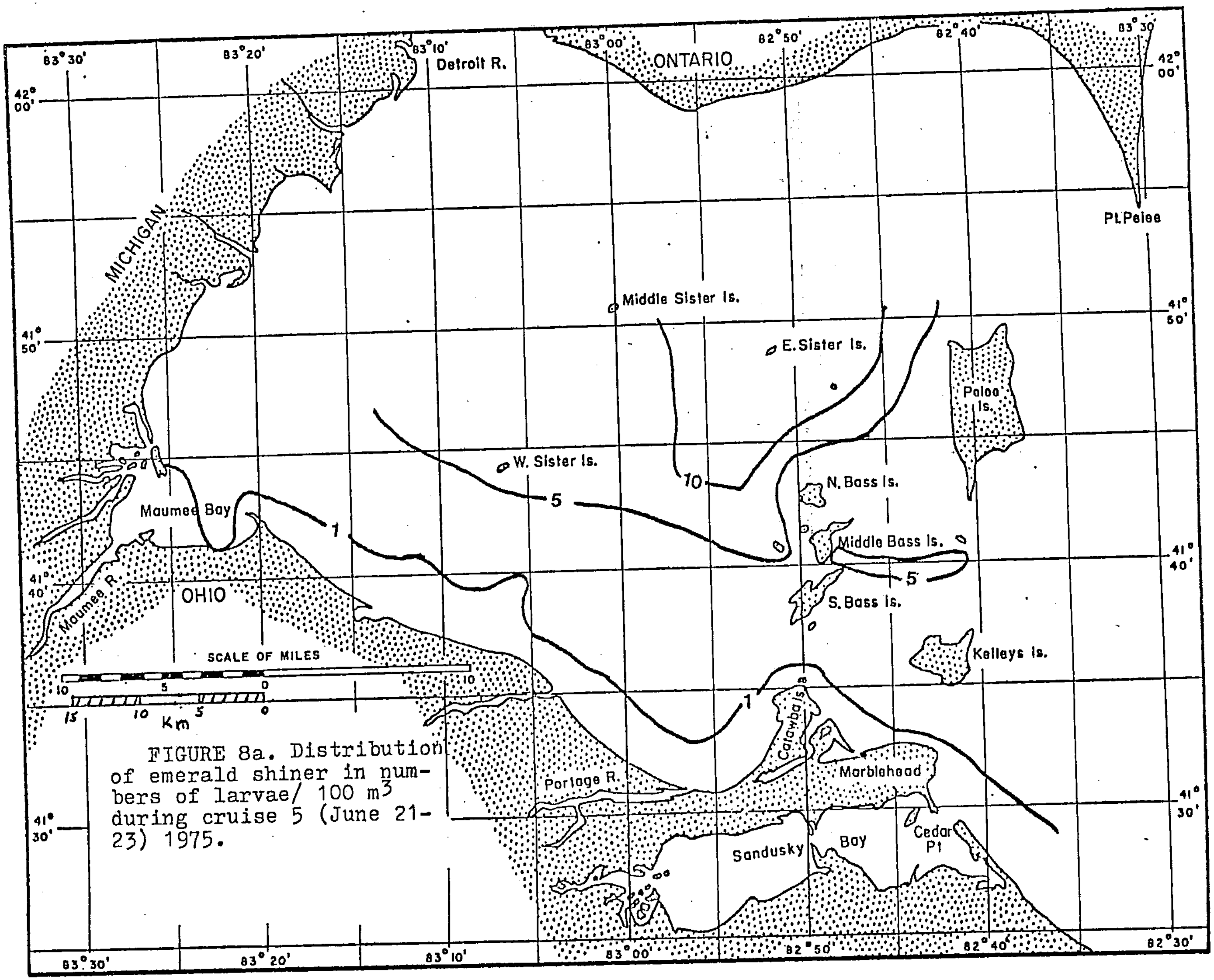

FIGURE 8a. Distribution of emerald shiner in numbers of larvae/ 100 m^3 during cruise 5 (June 21-23) 1975.

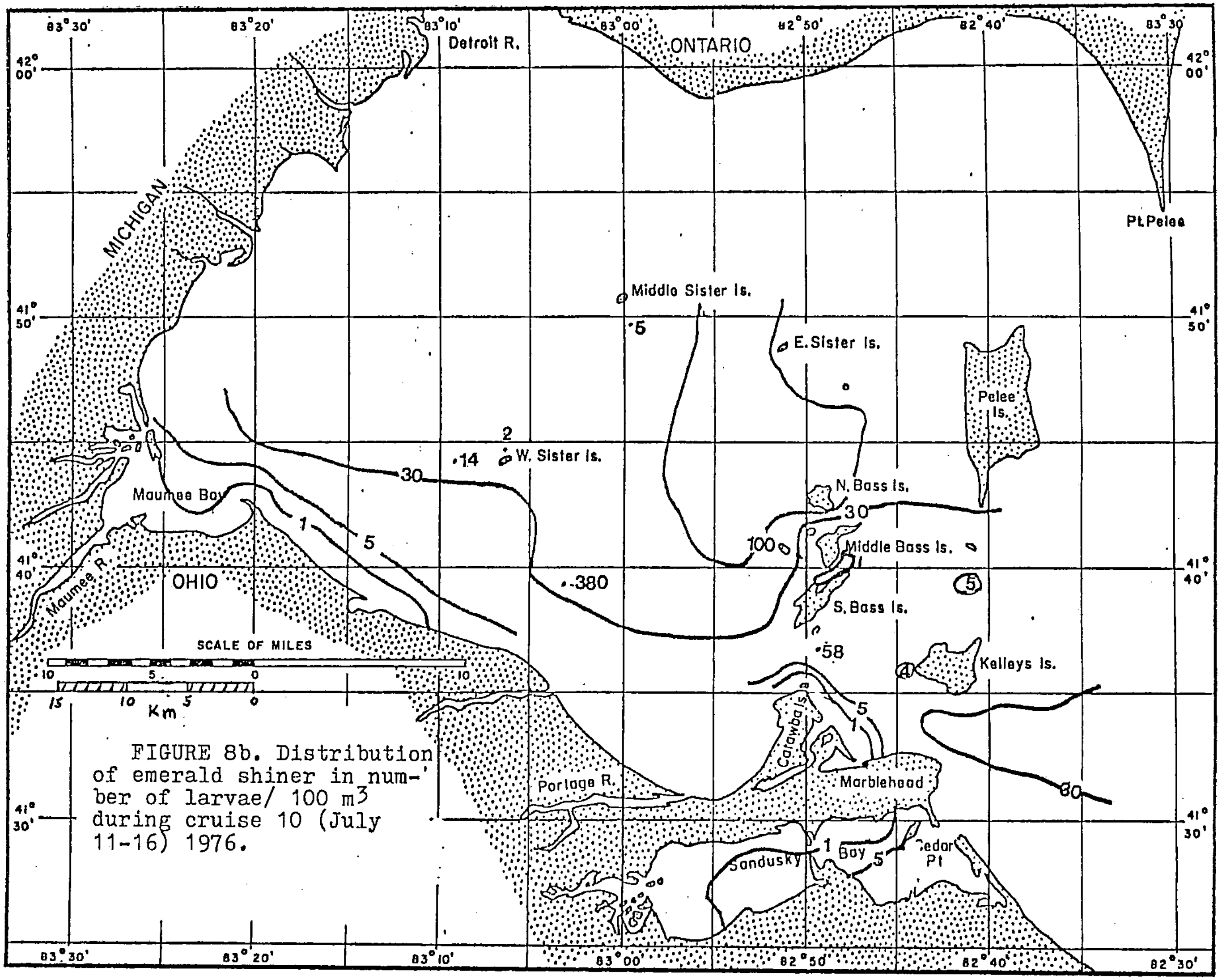

FIGURE 8b. Distribution of emerald shiner in number of larvae/ 100 m^3 during cruise 10 (July 11-16) 1976.

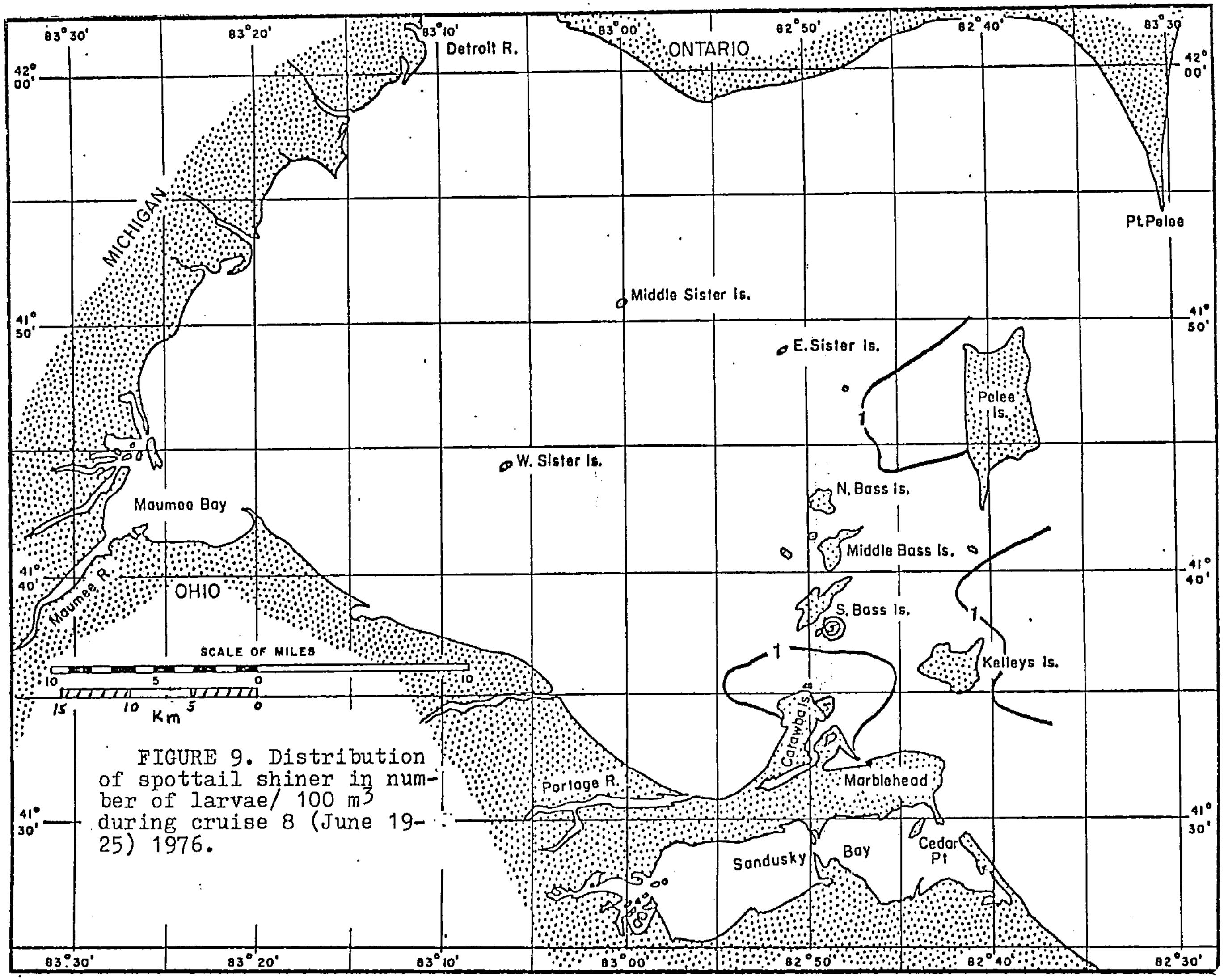

FIGURE 9. Distribution of spottail shiner in number of larvae/ 100 m^3 during cruise 8 (June 19-25) 1976.

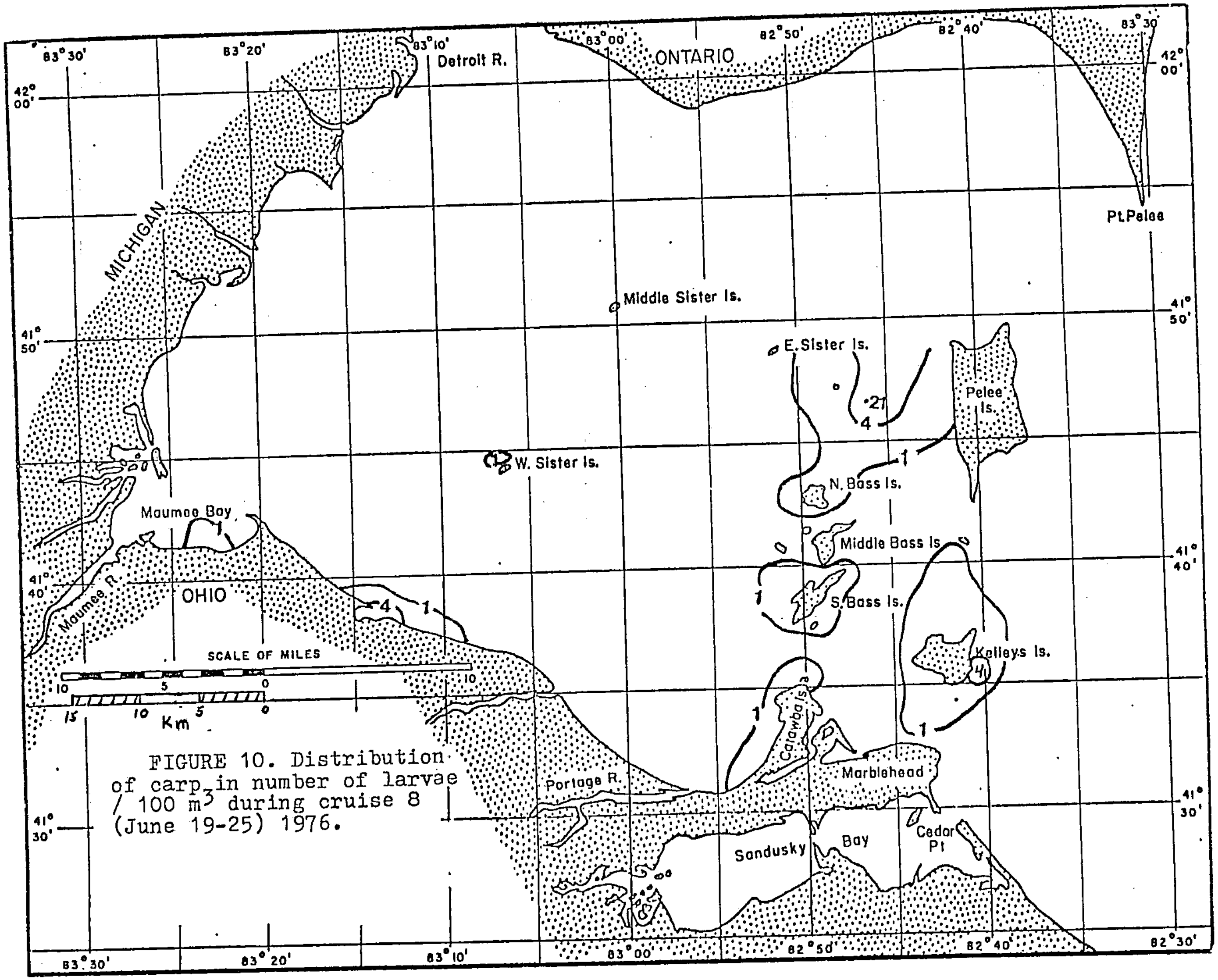

FIGURE 10. Distribution of carp in number of larvae / 100 m^3 during cruise 8 (June 19-25) 1976.

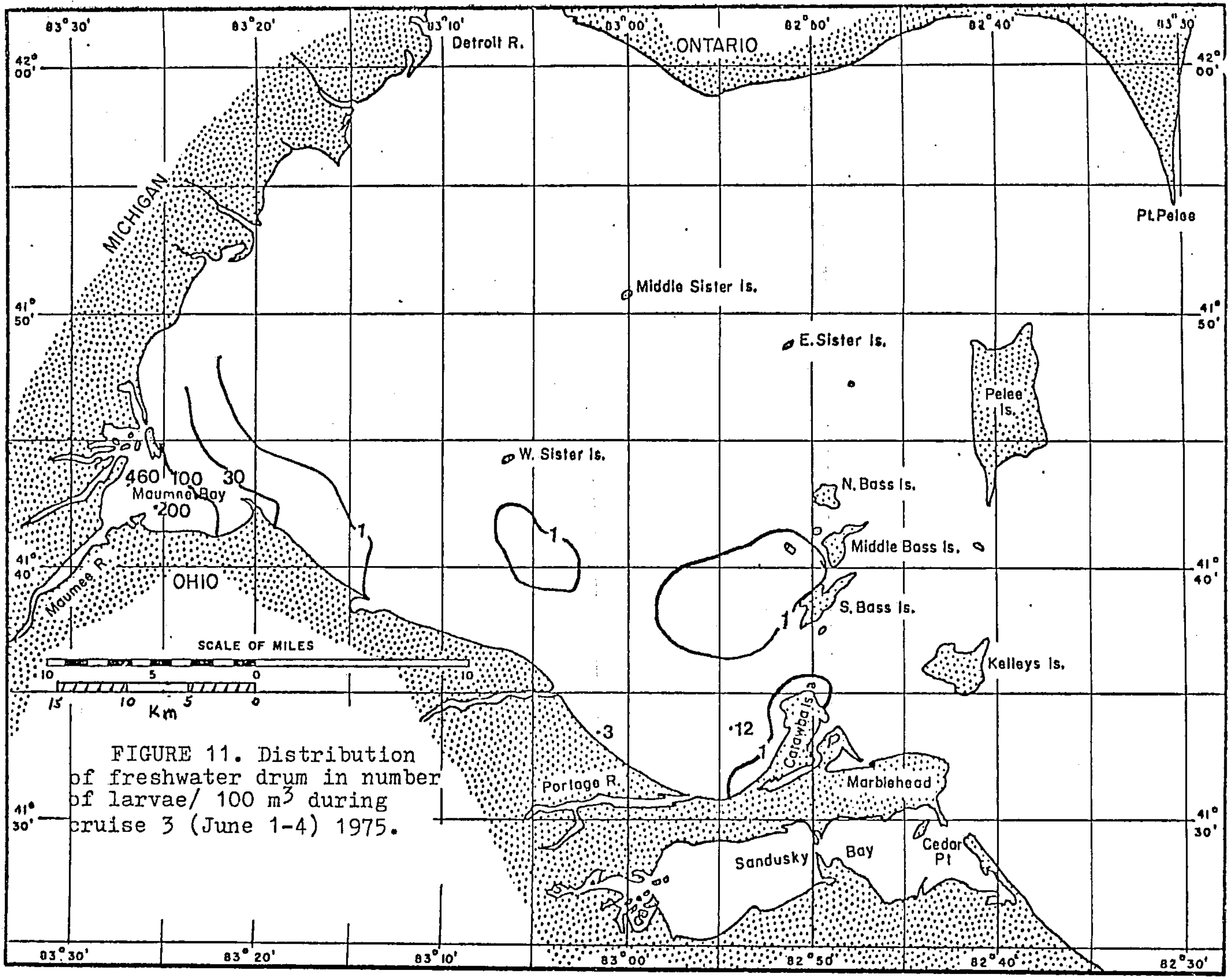

FIGURE 11. Distribution of freshwater drum in number of larvae/ 100 m^3 during cruise 3 (June 1-4) 1975.

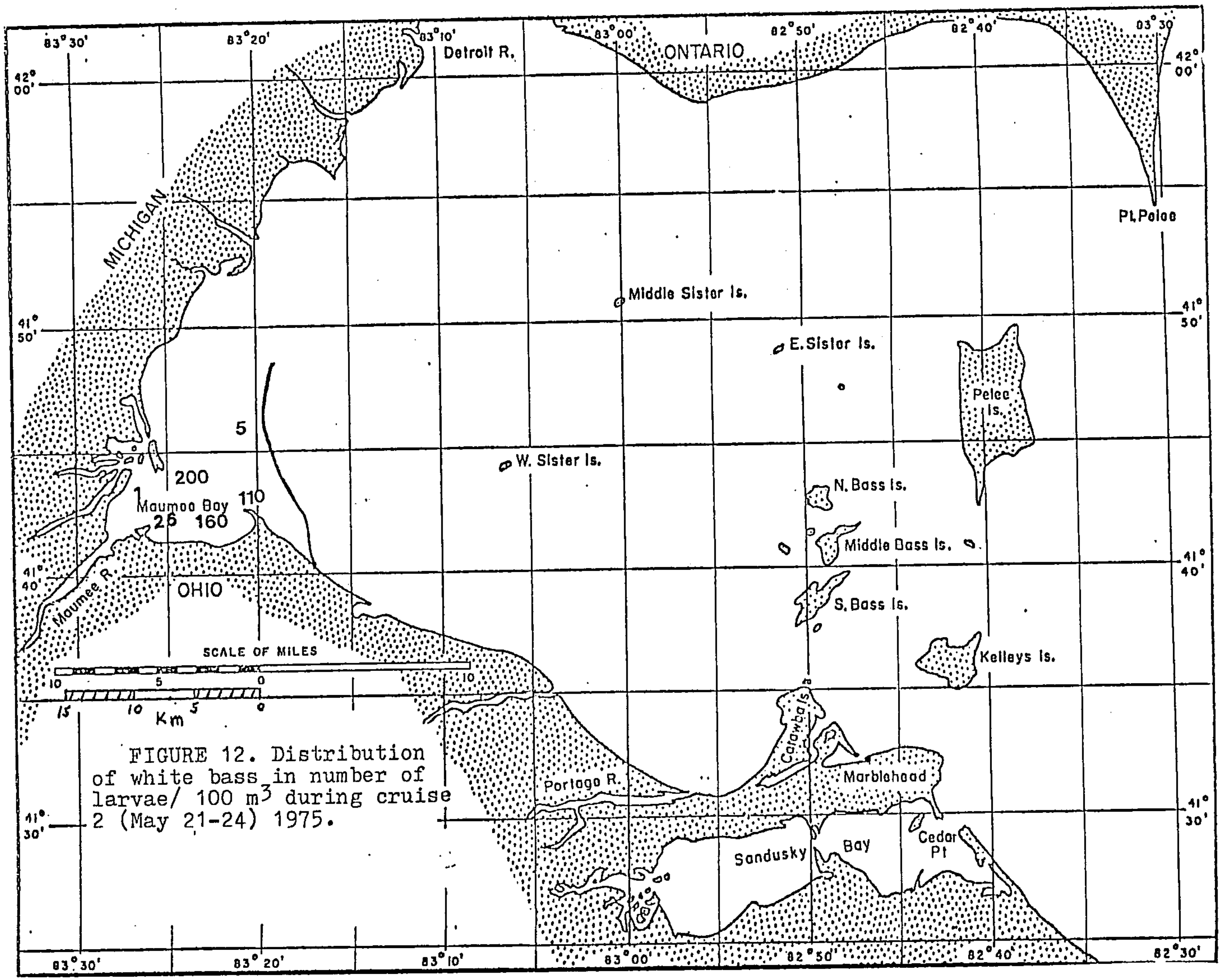

FIGURE 12. Distribution of white bass in number of larvae/ 100 m^3 during cruise 2 (May 21-24) 1975.

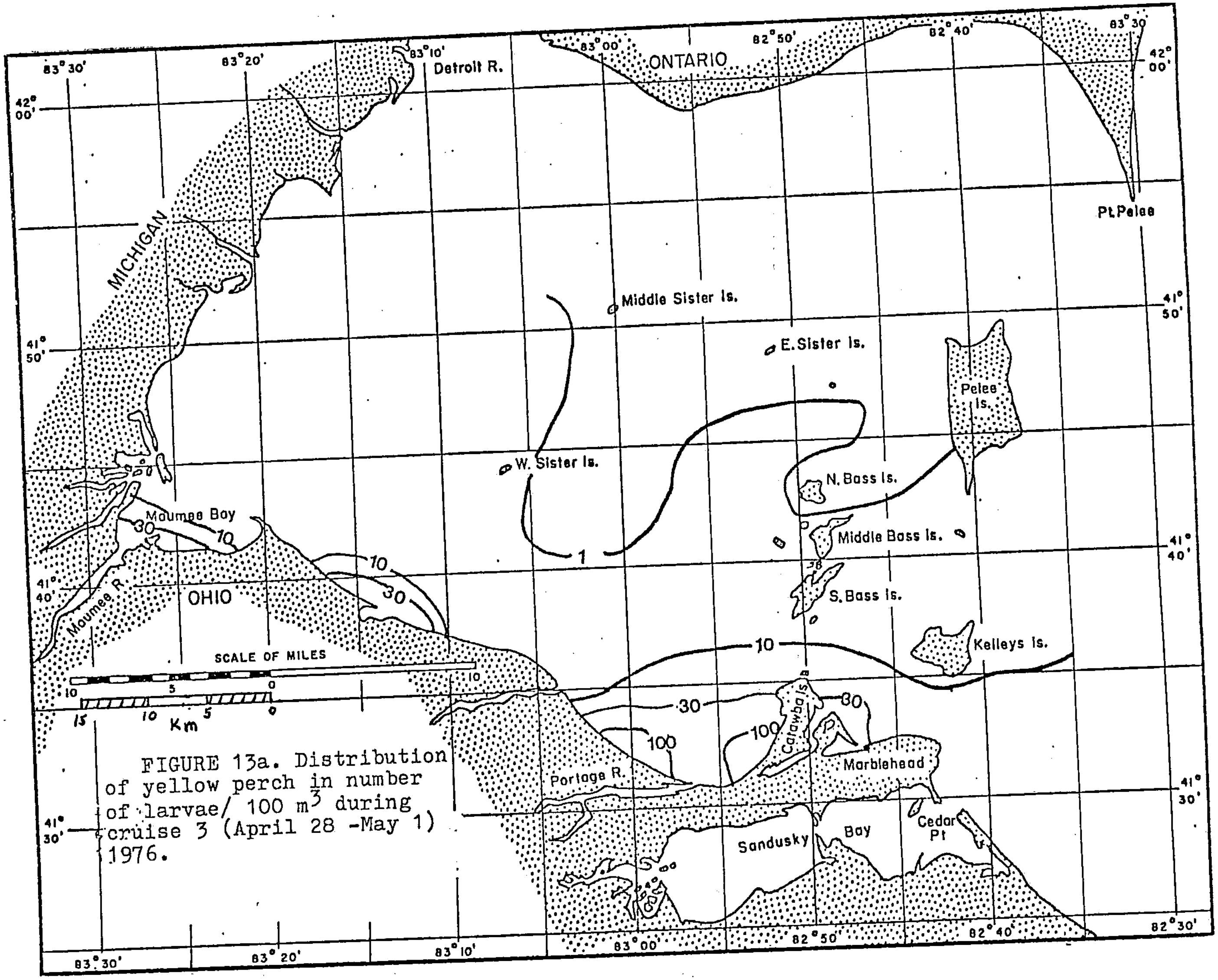

FIGURE 13a. Distribution of yellow perch in number of larvae/ 100 m^3 during cruise 3 (April 28 -May 1) 1976.

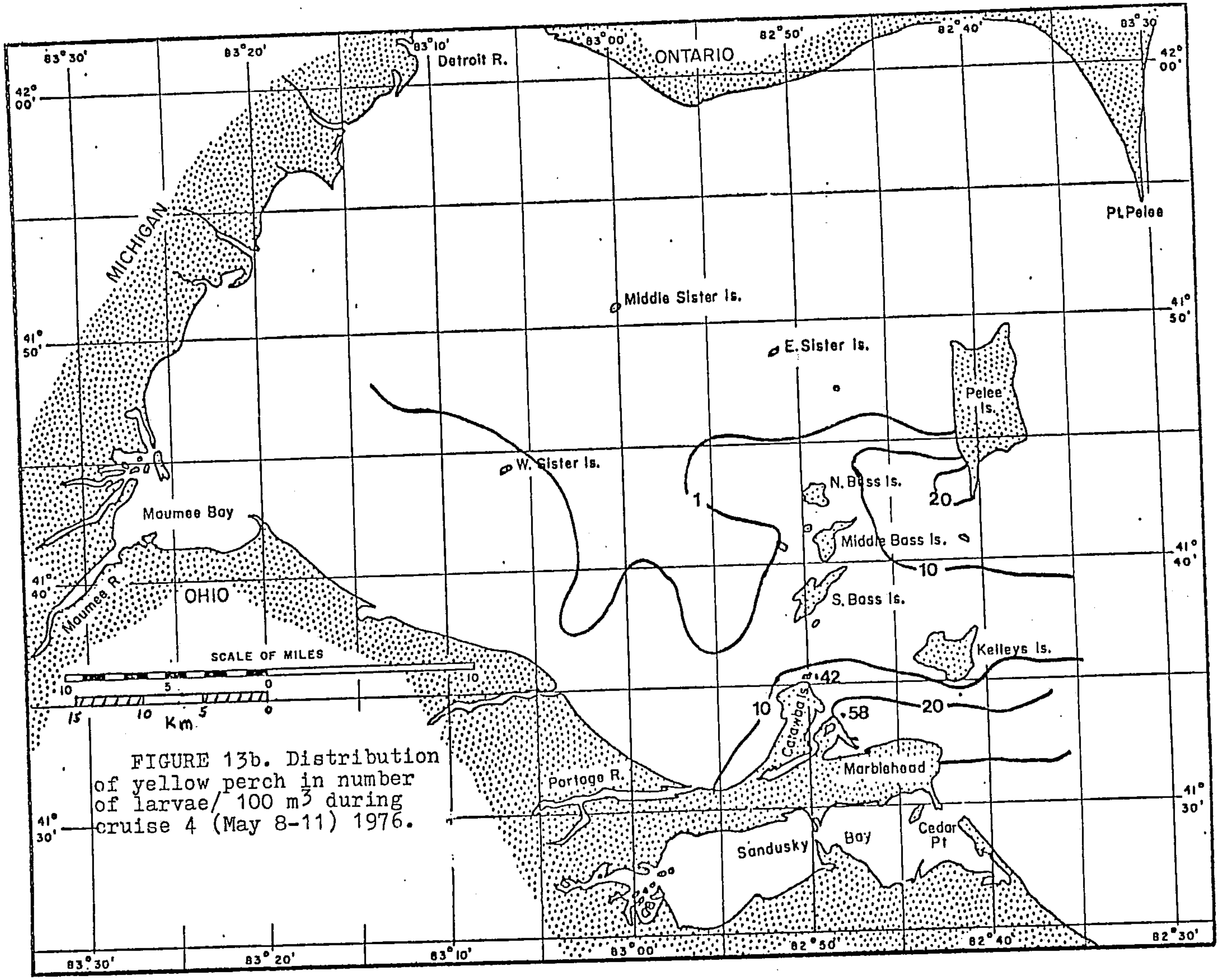

FIGURE 13b. Distribution of yellow perch in number of larvae/ 100 m^3 during cruise 4 (May 8-11) 1976.

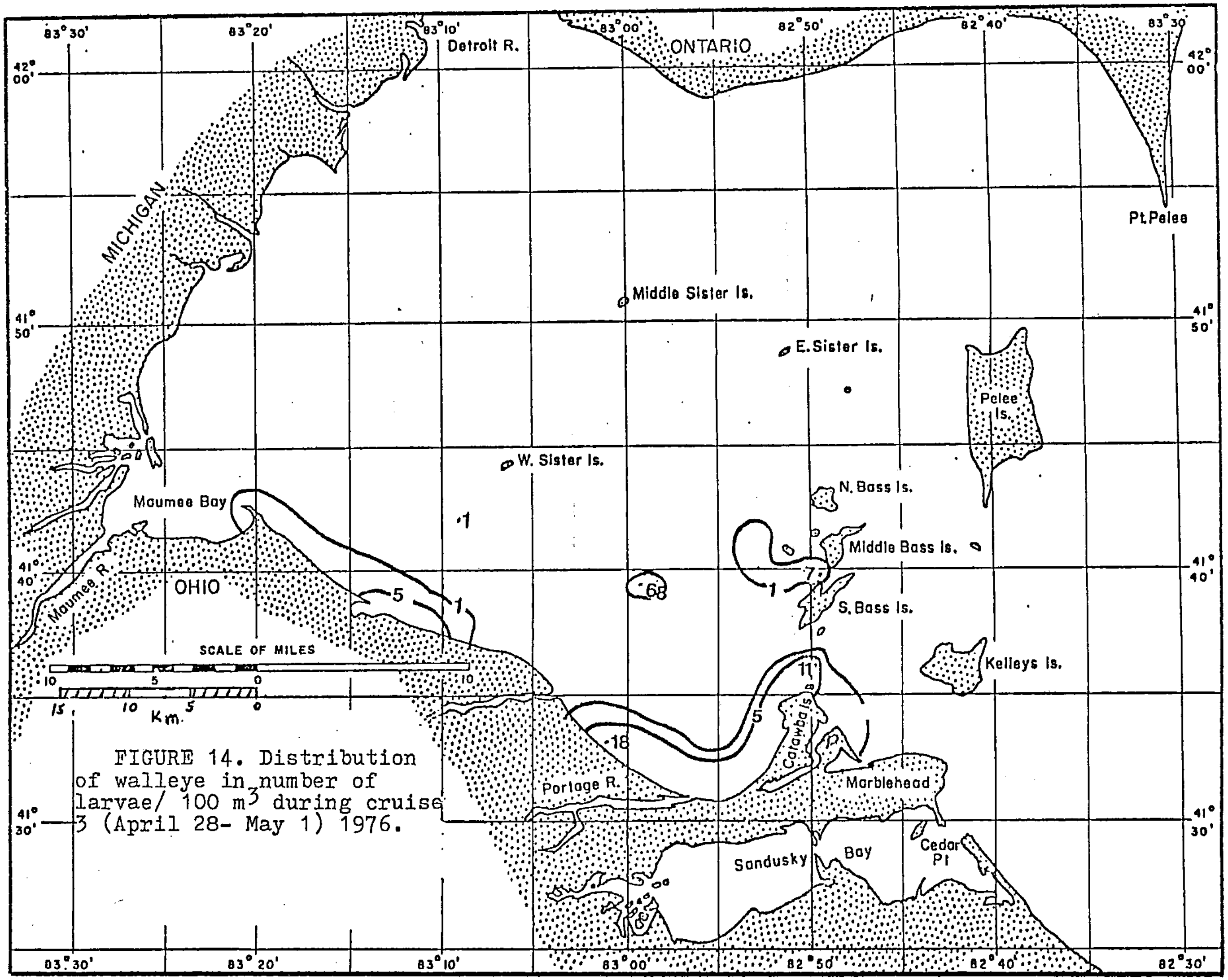

FIGURE 14. Distribution of walleye in number of larvae/ 100 m^3 during cruise 3 (April 28- May 1) 1976.

early juvenile stages were collected. These larvae either do not sense the collection net or are incapable of avoiding it. If the latter situation is the case, the emerald shiner larvae are probably not capable of moving off the reef and island areas under their own locomotion. Strong currents over the reef areas have been thought to be responsible for sweeping the reefs clean of sediments (Herdendorf 1970). These same currents could be responsible for movements of shiner larvae into deeper waters. The other alternative is that emerald shiners do in fact spawn in the deeper waters.

Neither spottail shiners nor carp were ever collected in large numbers. Both species appear centered in the Bass and Kelleys islands areas (Figure 9 and 10). These species apparently favor the rocky areas around the islands. At times, cladophora was scraped loose during bottom tows over the reefs. Carp eggs were often found in this algae.

Freshwater drum is another species found almost exclusively in the highly turbid areas (Figure 11). Drum eggs and prolarvae contain a large oil globule which causes them to float near the surface. Eggs were often seen and collected on the surface. This characteristic of drum larvae would permit them to remain in areas where oxygen tensions would be low deeper in the water. This characteristic may also place the drum larvae in the surface waters where plankton may be concentrated because of high turbidity. The increase in drum populations in Lake Erie may be in part due to this characteristic.

The white bass is also found almost exclusively in the bay areas of the lake (Figure 12). Similar studies done in the Maumee and

Sandusky rivers, found both white bass and freshwater drum to be very abundant in the rivers (Fred Snyder, Ohio State Univ. personal communication). Many larvae found in the respective bays could have been carried downstream and into the bays by the river currents. The primary spawning grounds may not be in the bays but in the rivers. The bays may be nursery grounds however.

Yellow perch larvae were found mostly in the nearshore areas and to be concentrated near the bottom (Figure 13). The tendency for perch to be near the bottom may be a reaction to light levels because in the more turbid areas of the lake the perch were not found to be stratified as they were in the clearer waters. Perch prefer to spawn in sandy areas with vegetation (Scott and Crossman 1973). The inshore areas where the larvae were found were sandy to gravelly with cladophora being the main vegetation. However, southerly flow of the Detroit River passes over the reef areas off Locust Point. This flow could carry larvae from the reefs into the area between Locust Point and Catawba Island (Figure 13a). On a later cruise (Figure 13b), perch larvae are found a little further east than the previous figure, but are still found predominantly in the inshore areas. Finding perch larvae mainly inshore and concentrated near the bottom is similar to the findings previously discussed in the Ohio Division of Wildlife studies (Keller et al. unpublished).

Walleye larvae were not collected in large enough numbers to really characterize their spawning areas; however, the walleye larvae were found similarly to the yellow perch (Figure 14). The walleye larvae were found inshore in sandy to rocky substrates. Once again the presence of larvae inshore between Locust and Catawba points could be a result of the southerly flow of Detroit River across the reefs and depositing larvae in this area. The fact that a large number of larvae were found on Niagra Reef (68 larvae/100 m^3) indicates that the reefs probably are also being utilized for spawning.

The distributions of larvae presented here were distributions observed during the 2 years of the study. Based only on numbers of larvae collected, Sandusky and Maumee bays produce the most larvae though not of desirable species. The nearshore areas also produce large numbers of larvae of both desirable species, walleye and yellow perch, as well as undesirable species such as gizzard shad.

These same nearshore areas are also areas where industrial intakes and outfalls are likely to be located. The first and most important question to be answered is whether or not entrainment is a serious problem to fish populations. However, this question may never be adequately answered. The next step would be to evaluate what areas of the lake do not appear to be utilized for spawning. From this study, nearly all areas of the nearshore appear to be used by one species or another for spawning. Therefore an evaluation of the relative worth of fish species would be necessary. Obviously walleye and yellow perch spawning areas would be the first to be protected in lieu of species such as gizzard shad, freshwater drum, or carp. This approach may not be entirely valid because ecological relationships not presently known could be disturbed if certain species were inhibited through entrainment.

The task therefore becomes to find areas where the smallest amount of spawning and/or nursery activities are taking place and to place intakes as far from shore as economically possible. From the distribution diagrams, the most likely area in the study area is the area to the west of Locust Point to the mouth of Maumee Bay. The offshore area is deep with mud bottoms where fewest larvae were collected. Other offshore areas would not be suitable because of their proximity to reefs, or they are downcurrent from reefs and therefore still could entrain larvae swept from the reefs.

In the future, this area may not be suitable for development. Therefore, any of several decisions will be made; does entrainment significantly affect fish populations, what is the relative worth of different species, and should closed cooling systems being employed for power plants? Much of the problem will come down to the value of fish and other aquatic organisms weighed against the costs of future industrial construction.

CONCLUSIONS

1. Replicate tows at each station and sampling at night are recommended for more accurate results in larval sampling. These methods were not feasible for this study. The use of a surface/bottom tow gave larger values of larval concentration than did an oblique tow from surface to bottom.

2. A total of 20 species were collected in this study. Gizzard shad, rainbow smelt, emerald and spottail shiners, carp, freshwater drum, white bass, yellow perch, and walleye were the species commonly collected.

3. Estimates of larval population were made for the 2 years of the study. Based on these estimates, the larvae were ranked from most to least abundant. These relative abundances changed considerably between the 2 years. The most dramatic change was the emerald shiner which represented 16 percent of the larvae in 1975 to 62 percent in the 1976 sampling. The relative ranking of larvae according to abundance is not entirely accurate because of natural mortality factors which could influence population estimates for larvae of different ages (developmental stages). Generally, the more abundant species were also those collected in more developed stages.

4. Larval gizzard shad, freshwater drum, and white bass were found most abundantly in Maumee and Sandusky bays. These were areas of high turbidity and lower water quality. The presence of large numbers of larvae in the bays may result from spawning in the bay and larvae being carried into the bay by river currents. Emerald shiners and rainbow smelt were found predominantly in the open and deeper waters. Smelt larvae appear to originate in the Detroit River. Emerald shiners may spawn on the rocky reefs and larvae are carried into deeper water by currents. Spottail shiners and carp were found in the islands area associated with the reef and sandy areas. Yellow perch were found primarily in the nearshore area associated with sandy and gravelly substrate. Perch were also found concentrated near the bottom. Walleye larvae appeared to be collected in the same areas as the yellow perch although the reefs probably are important to walleye spawning.

5. Many species of larval fish are found in nearshore areas, both desirable and undesirable species. These same areas are also likely areas for industrial intakes. It would not be wise to single out certain species that could be entrained because trophic relationships are often complex. One area where the least impact on larvae would probably be observed is the area west of Locust Point to the mouth of Maumee Bay and as far from shore as possible. This area appears to be the least utilized for spawning or nursery grounds in the study area.

APPENDIX A

APPENDIX A

Geographic Coordinates and Depth Zones of Stations Sampled for Larval Fish in Western Lake Erie.

Sector	Station No.	Field Notation	Latitude	Longitude	Depth Zone
A	5	A 1/1	N41°43.7'	W83°25.7'	1
	6	A 1/3	N41°45.0'	W83°22.8'	1
	7	A 3/1	N41°46.3'	W83°20.2'	3
	8	A 1/2	N41°42.2'	W83°24.6'	1
	10	A 2/1	N41°43.5'	W83°21.8'	2
	11	A 1/4	N41°43.1'	W83°20.8'	1
	12	A 2/2	N41°42.4'	W83°18.5'	2
	13	A 3/2	N41°43.4'	W83°17.4'	3
B	9	B 4/1	N41°47.5'	W83°18.1'	4
	14	B 4/2	N41°44.4'	W83°12.7'	4
	15	B 5/1	N41°44.7'	W83°05.9'	5
	16	B 6/1	N41°45.5'	W82°57.2'	6
	17	B 6/2	N41°45.0'	W82°51.8'	6
	56	B 5/2	N41°49.2'	W82°59.0'	5
C	18	C 1/1	N41°39.1'	W83°14.0'	1
	19	C 3/1	N41°40.0'	W83°11.7'	3
	20	C 4/1	N41°41.5'	W83°08.7'	4
	21	C 2/1	N41°37.8'	W83°07.4'	2
	22	C 1/2	N41°36.0'	W83°04.0'	2
	23	C 2/2	N41°36.4'	W83°03.8'	2
	24	C 3/2	N41°36.4'	W83°02.2'	3
	25	C 5/1	N41°41.5'	W83°02.1'	5
	26	C 1/3	N41°37.9'	W83°00.9'	1
	27	C 1/4	N41°39.8'	W82°58.4'	1
	28	C 5/2	N41°38.8'	W82°56.5'	5
	29	C 4/2	N41°35.7'	W82°54.4'	4
	30	C 2/3	N41°32.2'	W82°57.7'	2
	31	C 1/5	N41°31.6'	W82°53.0'	1
	32	C 3/3	N41°33.2'	W82°53.2'	3
	64	C 2/4	N41°36.4'	W83°04.5'	2
	65	C 2/5	N41°36.0'	W83°03.5'	2

Sector	Station No.	Field Notation	Latitude	Longitude	Depth Zone
D	33	D 6/1	N41°42.0'	W82°52.9'	6
	34	D 2/1	N41°42.8'	W82°51.3'	2
	35	D 4/1	N41°43.5'	W82°50.2'	4
	36	D 5/1	N41°39.7'	W82°51.4'	5
	37	D 1/2	N41°34.5'	W82°49.2'	1
	38	D 2/2	N41°35.1'	W82°49.5'	2
	39	D 3/2	N41°37.6'	W82°49.1'	3
	40	D 1/1	N41°39.6'	W82°49.4'	1
	41	D 3/1	N41°41.3'	W82°47.8'	3
	42	D 5/2	N41°39.3'	W82°47.2'	5
	43	D 6/2	N41°41.2'	W82°44.6'	6
	62	D 4/2	N41°36.6'	W82°48.0'	4
E	44	E 1/1	N41°32.5'	W82°46.7'	1
	45	E 3/1	N41°33.4'	W82°47.3'	3
	46	E 3/2	N41°36.0'	W82°45.6'	3
	47	E 6/1	N41°38.7'	W82°42.9'	6
	48	E 5/1	N41°40.7'	W82°41.6'	5
	49	E 2/1	N41°39.8'	W82°40.9'	2
	50	E 5/2	N41°33.6'	W82°43.7'	5
	51	E 2/2	N41°35.2'	W82°40.9'	2
	52	E 1/2	N41°38.3'	W82°38.8'	1
	53	E 2/3	N41°30.4'	W82°42.6'	2
	54	E 4/2	N41°31.1'	W82°41.5'	4
	55	E 6/2	N41°34.8'	W82°39.6'	6
	63	E 4/1	N41°35.0'	W82°45.6'	4
F	57	F 6/1	N41°47.2'	W82°50.0'	6
	58	F 2/1	N41°45.3'	W82°49.5'	4
	59	F 1/1	N41°46.2'	W82°49.1'	1
	60	F 3/1	N41°45.4'	W82°41.7'	3
	61	F 4/1	N41°42.6'	W82°41.2'	4
G	66	G 1/1	N41°26.1'	W82°56.6'	1
	67	G 1/2	N41°27.8'	W82°54.0'	1
	68	G 1/6	N41°29.1'	W82°52.4'	1
	69	G 1/3	N41°27.4'	W82°46.1'	1
	70	G 1/4	N41°30.0'	W82°46.5'	1
	71	G 1/5	N41°29.6'	W82°44.8'	1

APPENDIX B

APPENDIX B

Area and Volume Estimates of Each Sector, by Depth Zone.

Sector	Depth Zone	Depth Range (m)	Area (Km^2)	Volume (m^3)
A	1	0 – 2	57.34	5.73×10^7
	2	2 – 4	31.00	9.30×10^7
	3	4 – 6	34.11	1.71×10^8
		Total	122.45	3.21×10^8
B	4	6 – 8	111.28	7.77×10^8
	5	8 – 10	107.52	9.72×10^8
	6	>10	96.48	1.06×10^9
		Total	315.28	2.81×10^9
C	1	0 – 2	21.70	2.17×10^7
	2	2 – 4	81.42	2.44×10^8
	3	4 – 6	126.47	6.30×10^8
	4	6 – 8	109.41	7.63×10^8
	5	8 – 10	52.57	4.73×10^8
		Total	391.56	2.13×10^9
D	1	0 – 2	7.15	7.15×10^6
	2	2 – 4	8.04	2.41×10^7
	3	4 – 6	12.18	6.10×10^7
	4	6 – 8	35.38	2.48×10^8
	5	8 – 10	92.10	8.29×10^8
	6	>10	57.96	6.38×10^8
		Total	212.81	1.81×10^9
E	1	0 – 2	7.02	7.02×10^6
	2	2 – 4	9.80	2.94×10^7
	3	4 – 6	23.33	1.17×10^8
	4	6 – 8	37.15	2.60×10^8
	5	8 – 10	39.66	3.57×10^8
	6	>10	137.02	1.51×10^9
		Total	253.97	2.28×10^9
F	1	0 – 2	4.28	4.28×10^6
	2	2 – 4	7.52	2.26×10^7
	3	4 – 6	20.19	1.01×10^8
	4	6 – 8	49.43	3.46×10^8
	5	8 – 10	72.53	6.53×10^8
	6	>10	155.19	1.71×10^9
		Total	309.13	2.84×10^9
G	1	0 – 2	131.6	1.61×10^8

APPENDIX C

APPENDIX C

Results of a Comparison of Surface/Bottom Tows With Oblique Tows at Station 36. (All numbers are number of larvae/ 100 m^3, only emerald shiners collected.)

Tow No.	Surface	Bottom	Mean S/B	Oblique
1	310	34	172	12
2	458	64	261	49
3	128	25	77	28
4	204	25	114	16
5	225	37	131	63

APPENDIX D

APPENDIX D

Results of a Comparison of Day and Night Sampling at Stations 34 and 36.

Stat.	Time	Species	Surface Length (mm)	Surface No./100 m^3	Bottom Length (mm)	Bottom No./ 100 m^3
34	1120	Gizzard shad	10-15	23	12-13	12
		Emerald shiner	7	17	8	7
		Freshwater drum	8	2		
		White bass	8	2		
	2320	Gizzard shad			12-23	152
		Alewife	14-20	239	17-20	59
		Rainbow smelt			20-40	53
		Emerald shiner	6-14	1431	6-9	106
		Spottail shiner	7	15		
		Freshwater drum	5	15	4-7	28
		White bass			10	1
36	1045	Gizzard shad	10-16	15	6-14	2
		Emerald shiner	7-12	49	7-9	8
		Freshwater drum			5-6	3
	2330	Gizzard shad	13-19	16	10-16	8
		Alewife	20-25	11	20-23	26
		Rainbow smelt	21	1	17-38	48
		Emerald shiner	7-11	5		
		Carp	7	3		
		White bass	10	1	10	2

APPENDIX E

APPENDIX E

Abundance Estimates of Larval Fishes in Study Area, by Depth Zone.

Cruise 1 (May 12-14) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad						3.8×10^6	3.8×10^6
Rainbow smelt							
Emerald shiner							
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch	5.8×10^5	4.0×10^8	1.0×10^7	5.7×10^6			4.1×10^8
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Mooneye							
Crappie							
Smallmouth bass							
Alewife							
Logperch darter							
Unknown							

Cruise 2 (May 21-25) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.6×10^8	2.2×10^8	3.0×10^7	6.5×10^5			4.1×10^8
Rainbow smelt	2.8×10^5	5.0×10^4	5.7×10^6	1.6×10^7	7.5×10^7	2.6×10^8	3.6×10^8
Emerald shiner	7.4×10^4						7.4×10^4
Spottail shiner	9.2×10^4	2.3×10^5	1.4×10^6	1.3×10^6			3.1×10^6
Carp	1.6×10^6	4.7×10^5					2.1×10^6
Freshwater drum	7.4×10^4	2.3×10^5					3.0×10^5
Yellow perch	1.4×10^8	1.9×10^8	5.3×10^7	8.5×10^7	1.1×10^8	1.7×10^8	7.4×10^8
White bass	4.9×10^7	7.3×10^7	3.8×10^6				1.2×10^8
Walleye	2.1×10^6						2.1×10^6
White sucker		2.3×10^5		6.5×10^5			8.8×10^5
Sunfish							
Quillback carpsucker	7.4×10^4						7.4×10^4
Mooneye							
Crappie							
Smallmouth bass							
Alewife							
Logperch darter						3.8×10^6	3.8×10^6
Unknown							

Cruise 3 (June 1-4) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	3.5×10^8	4.5×10^8	2.1×10^9	9.5×10^6	4.1×10^6	3.8×10^6	2.9×10^9
Rainbow smelt	8.1×10^5	8.3×10^5	3.2×10^8	8.3×10^6	1.1×10^7	7.6×10^6	3.5×10^8
Emerald shiner	3.6×10^5	4.7×10^5		5.6×10^6			6.4×10^6
Spottail shiner	3.5×10^4	1.9×10^5	1.7×10^6	7.5×10^6	7.8×10^6	1.9×10^7	3.7×10^7
Carp	1.5×10^6	5.4×10^5	3.7×10^6		5.8×10^6	1.5×10^7	2.6×10^7
Freshwater drum	9.7×10^7	5.2×10^7	2.0×10^9	1.9×10^6	3.3×10^6		2.1×10^9
Yellow perch	3.7×10^6	9.4×10^6	9.6×10^8	1.4×10^7	2.1×10^7	1.3×10^8	1.1×10^9
White bass	3.9×10^7	2.7×10^7	8.6×10^5		3.6×10^6		7.1×10^7
Walleye							
White sucker							
Sunfish							
Quillback carpsucker	2.8×10^4						2.8×10^4
Mooneye							
Crapple	2.8×10^4	6.1×10^5					6.4×10^5
Smallmouth bass							
Alewife							
Logperch darter							
Unknown							

Cruise 4 (June 11-17) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	2.1×10^7	6.8×10^7	4.7×10^7	3.5×10^7	9.2×10^7	7.6×10^7	3.4×10^8
Rainbow smelt	2.8×10^6	4.6×10^6			1.5×10^7	3.8×10^6	2.6×10^7
Emerald shiner	4.3×10^4	8.4×10^5	1.2×10^6	5.4×10^7	3.4×10^7	4.9×10^8	5.8×10^8
Spottail shiner	7.4×10^4	4.4×10^5	4.6×10^5	3.0×10^6	7.1×10^6	4.9×10^7	6.0×10^7
Carp	1.7×10^6	1.0×10^6	2.3×10^6		5.0×10^6	3.8×10^6	1.4×10^7
Freshwater drum	6.0×10^6	3.2×10^5	1.5×10^5		2.1×10^6	1.6×10^6	1.1×10^7
Yellow perch	5.0×10^5	2.8×10^6			3.0×10^6	6.9×10^6	1.3×10^7
White bass	2.1×10^6	1.4×10^6		3.8×10^6	6.0×10^6	6.9×10^6	2.0×10^7
Walleye							
White sucker							
Sunfish						3.8×10^6	3.8×10^6
Quillback carpsucker							
Mooneye							
Crapple	1.1×10^5						1.1×10^5
Smallmouth bass			4.0×10^6				4.0×10^6
Alewife				3.8×10^6			1.6×10^7
Logperch darter					4.9×10^6		4.9×10^6
Unknown							

Cruise 5 (June 21-23) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.1×10^{8}	2.4×10^{7}	2.8×10^{7}	4.8×10^{7}	6.2×10^{7}	1.6×10^{8}	4.3×10^{8}
Rainbow smelt	9.6×10^{6}	6.0×10^{4}	4.3×10^{5}	1.9×10^{6}		3.8×10^{6}	1.6×10^{7}
Emerald shiner	1.1×10^{6}	7.9×10^{5}	8.6×10^{6}	5.9×10^{7}	7.5×10^{7}	3.9×10^{8}	5.3×10^{8}
Spottail shiner	5.0×10^{5}	5.4×10^{5}	4.5×10^{5}	3.8×10^{6}	5.0×10^{6}	6.5×10^{7}	7.5×10^{7}
Carp	4.9×10^{5}	1.8×10^{5}	7.5×10^{5}	5.0×10^{6}	3.3×10^{6}	8.9×10^{7}	9.9×10^{7}
Freshwater drum	4.9×10^{7}	1.3×10^{7}	1.2×10^{6}	2.5×10^{6}		3.8×10^{6}	7.0×10^{7}
Yellow perch	1.7×10^{6}	3.2×10^{5}					2.0×10^{6}
White bass	2.6×10^{7}	3.2×10^{5}		1.9×10^{6}	4.5×10^{6}		3.3×10^{7}
Walleye	7.4×10^{4}						7.4×10^{4}
White sucker							
Sunfish		5.5×10^{5}					5.5×10^{5}
Quillback carpsucker							
Mooneye							
Crappie	1.8×10^{4}						1.8×10^{4}
Smallmouth bass							
Alewife	8.6×10^{5}	2.3×10^{5}	2.9×10^{5}				1.4×10^{6}
Logperch darter	1.3×10^{6}			5.9×10^{5}			1.9×10^{6}
Unknown			4.3×10^{5}				4.3×10^{5}

Cruise 6 (June 30- July 3) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	2.7×10^8	8.3×10^7	3.3×10^7	3.7×10^7	3.3×10^6	1.1×10^7	4.4×10^8
Rainbow smelt	4.3×10^5				2.9×10^6		3.3×10^6
Emerald shiner	7.4×10^6	5.9×10^7	3.2×10^7	9.2×10^7	7.5×10^7	1.6×10^8	4.3×10^8
Spottail shiner		2.3×10^5	5.1×10^6	6.2×10^5	1.2×10^6	1.6×10^7	2.3×10^7
Carp	1.9×10^5	8.9×10^5	2.3×10^6	3.7×10^6	4.5×10^6	4.5×10^7	5.7×10^7
Freshwater drum	5.4×10^5	8.3×10^5	1.5×10^5		3.3×10^6		5.0×10^6
Yellow perch							
White bass	1.1×10^7			1.9×10^6	2.4×10^6		1.5×10^7
Walleye							
White sucker							
Sunfish	4.3×10^5						4.3×10^5
Quillback carpsucker							
Mooneye							
Crappie	7.4×10^4						7.4×10^4
Smallmouth bass							
Alewife		2.3×10^5					2.3×10^5
Logperch darter	4.3×10^5				4.9×10^6		5.3×10^6

Cruise 7 (July 11-15) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.9×10^{7}	6.3×10^{7}	3.4×10^{7}		8.9×10^{5}		1.2×10^{8}
Rainbow smelt		3.8×10^{5}					3.8×10^{5}
Emerald shiner	5.0×10^{5}	8.4×10^{5}	7.9×10^{6}	5.0×10^{7}	4.9×10^{7}	1.1×10^{7}	1.2×10^{8}
Spottail shiner							
Carp	6.5×10^{5}	3.8×10^{5}	1.6×10^{6}	1.2×10^{6}	1.8×10^{6}		5.6×10^{6}
Freshwater drum	5.0×10^{5}	1.4×10^{6}					1.9×10^{6}
Yellow perch							
White bass	1.8×10^{4}						1.8×10^{4}
Walleye							
White sucker							
Sunfish	7.4×10^{4}	6.0×10^{4}	1.1×10^{6}				1.2×10^{6}
Quillback carpsucker							
Mooneye							
Crapple	3.6×10^{5}						3.6×10^{5}
Smallmouth bass							
Alewife		7.0×10^{5}					7.0×10^{5}
Logperch darter							
Unknown							

Cruise 8 (July 31- Aug. 4) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	7.2×10^5	2.3×10^5					1.0×10^6
Rainbow smelt							
Emerald shiner	1.3×10^6	2.3×10^5	4.1×10^6	2.5×10^6	4.7×10^6	1.6×10^6	1.5×10^7
Spottail shiner							
Carp			5.1×10^5	8.8×10^6			9.4×10^6
Freshwater drum					8.9×10^5		8.9×10^5
Yellow perch							
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Mooneye							
Crappie			1.5×10^5			1.6×10^6	1.8×10^6
Smallmouth bass							
Alewife	2.9×10^5						2.9×10^5
Logperch darter							
Unknown							

Cruise 9 (Aug. 24- Sept. 3) 1975

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.4×10^5						1.4×10^5
Rainbow smelt		4.7×10^5					4.7×10^5
Emerald shiner	1.5×10^6	2.5×10^7	2.4×10^6	6.4×10^6	1.0×10^7	3.0×10^7	7.6×10^7
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch							
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Mooneye							
Crappie							
Smallmouth bass							
Alewife							
Logperch darter							
Unknown							

Cruise 1 (April 12-16) 1976

Depth Zones / Species	1	2	3	4	5	6	TOTAL
Gizzard shad							
Rainbow smelt							
Emerald shiner							
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch							
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple							
Alewife							
Logperch darter							
Troutperch							
[illegible]							
Whitefish	3.5×10^4	6.0×10^4		6.2×10^5			7.2×10^5

Cruise 2 (April 21-23) 1976
(partial)

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad							
Rainbow smelt							
Emerald shiner							
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch	5.4×10^4						5.4×10^4
White bass							
Walleye	9.3×10^6						9.3×10^6
White sucker							
Sunfish							
Quillback carpsucker							
Crapple							
Alewife							
Logperch darter							
Troutperch							
Whitefish							

Cruise 3 (April 28- May 1) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.4×10^7	9.3×10^5	1.3×10^6				1.6×10^7
Rainbow smelt							
Emerald shiner							
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch	3.9×10^7	2.7×10^8	2.7×10^8	9.4×10^7	1.9×10^7	8.0×10^6	7.0×10^8
White bass							
Walleye	4.4×10^6	3.3×10^7	1.6×10^7	1.6×10^7	4.2×10^6	9.6×10^6	1.8×10^8
White sucker	2.9×10^5		1.3×10^6				1.6×10^6
Sunfish							
Quillback carpsucker							
Crappie							
Alewife							
Logperch darter							
Troutperch							
Sculpin			1.5×10^5				1.5×10^5
Whitefish	8.9×10^4		1.4×10^6				1.5×10^6

Cruise 4 (May 8-11) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad				3.8×10^6			3.8×10^6
Rainbow smelt	8.8×10^5	1.5×10^6	8.4×10^6	5.4×10^7	2.4×10^6		6.7×10^7
Emerald shiner							
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch	2.6×10^7	8.9×10^6	4.5×10^7	1.7×10^8	1.5×10^8	1.8×10^8	5.8×10^8
White bass							
Walleye	1.4×10^5	6.0×10^4	1.3×10^6	6.2×10^5		1.6×10^6	3.7×10^6
White sucker			1.5×10^5				1.5×10^5
Sunfish							
Quillback carpsucker							
Crapple							
Alewife							
Logperch darter							
Troutperch							
[illegible]							
Whitefish							

Cruise 5 (May 20-23) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.8×10^5	4.9×10^6					5.0×10^6
Rainbow smelt	3.6×10^6	7.8×10^6	4.3×10^7	1.1×10^8	8.6×10^8	3.4×10^8	1.4×10^9
Emerald shiner	2.7×10^5						2.7×10^5
Spottail shiner							
Carp							
Freshwater drum	2.4×10^7	3.5×10^6	1.2×10^7	2.1×10^7	1.8×10^7	3.8×10^6	8.5×10^7
Yellow perch							
White bass	1.5×10^5						1.5×10^5
Walleye							
White sucker							
Sunfish	4.5×10^4						4.5×10^4
Quillback carpsucker							
Crapple							
Alewife							
Logperch darter				6.5×10^5			6.5×10^5
Troutperch			1.5×10^6				1.5×10^6
Sculpin							
Whitefish							

Cruise 6 (May 30) 1976
(partial)

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad							
Rainbow smelt	6.1×10^4	8.1×10^5	4.0×10^6	1.2×10^7	1.2×10^7	8.8×10^7	1.2×10^8
Emerald shiner							
Spottail shiner			4.6×10^5	8.7×10^5			1.3×10^6
Carp		2.3×10^5					2.3×10^5
Freshwater drum							
Yellow perch	4.3×10^4	7.2×10^5	4.6×10^6		1.8×10^6	1.6×10^6	8.7×10^6
White bass							
Walleye							
White sucker	3.6×10^4						3.6×10^4
Sunfish							
Quillback carpsucker							
Crappie							
Alewife							
Logperch darter							
Troutperch							
Whitefish							

Cruise 7 (June 7-9) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	2.2×10^8	1.7×10^7	3.4×10^7	4.1×10^7	3.1×10^7	1.7×10^7	3.6×10^8
Rainbow smelt						2.0×10^7	2.0×10^7
Emerald shiner							
Spottail shiner	8.5×10^4	5.9×10^5	2.8×10^6	7.5×10^6	9.8×10^6	2.7×10^7	4.8×10^7
Carp		1.3×10^7	1.5×10^5		8.6×10^6	3.8×10^7	5.9×10^7
Freshwater drum	9.1×10^6			6.5×10^5			9.7×10^6
Yellow perch		7.6×10^5		3.9×10^6			4.7×10^6
White bass	1.1×10^6						1.1×10^6
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crappie	2.9×10^5		1.1×10^6				1.4×10^6
Alewife							
Logperch darter				3.9×10^6	2.4×10^6	8.6×10^6	1.5×10^7
Troutperch							
[illegible]							
Whitefish							

Cruise 8 (June 19-25) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.5×10^{9}	2.3×10^{8}	6.3×10^{7}	1.3×10^{8}	2.1×10^{8}	1.1×10^{8}	2.2×10^{9}
Rainbow smelt	2.1×10^{4}						2.1×10^{4}
Emerald shiner	8.8×10^{6}	4.0×10^{7}	1.9×10^{8}	4.0×10^{8}	2.4×10^{8}	1.0×10^{9}	1.9×10^{9}
Spottail shiner	2.7×10^{5}	3.2×10^{5}	2.2×10^{6}	5.8×10^{8}		5.4×10^{6}	5.9×10^{8}
Carp	1.1×10^{6}	2.0×10^{6}	1.1×10^{6}	8.7×10^{5}	1.4×10^{7}	4.4×10^{7}	6.4×10^{7}
Freshwater drum	1.3×10^{8}	3.5×10^{6}	3.4×10^{7}	2.0×10^{7}	6.8×10^{6}	1.2×10^{7}	2.1×10^{8}
Yellow perch							
White bass	3.0×10^{6}	4.3×10^{6}	4.3×10^{5}				7.6×10^{6}
Walleye							
White sucker							
Sunfish		2.3×10^{5}					2.3×10^{5}
Quillback carpsucker							
Crapple							
Alewife	2.2×10^{5}	2.1×10^{6}	1.9×10^{6}	1.2×10^{7}			1.6×10^{7}
Logperch darter	6.5×10^{4}						6.5×10^{4}
Troutperch							
[illegible]							
Whitefish							

Cruise 9 (June 30- July 7) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	2.5×10^8	2.3×10^7	7.6×10^7	2.3×10^8	2.6×10^8	3.0×10^8	1.1×10^9
Rainbow smelt		4.7×10^5					4.7×10^5
Emerald shiner	4.3×10^7	1.3×10^7	9.7×10^8	5.9×10^8	2.4×10^9	9.4×10^8	5.0×10^9
Spottail shiner			8.8×10^5	4.5×10^6			5.4×10^6
Carp	2.5×10^6	4.9×10^6	1.5×10^6		4.5×10^6	3.8×10^6	1.7×10^7
Freshwater drum	6.7×10^8	4.5×10^6	8.9×10^6	2.3×10^7	1.9×10^7	2.7×10^7	7.6×10^8
Yellow perch							
White bass	1.1×10^5	1.2×10^5	2.1×10^6	3.9×10^6			6.3×10^6
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple	2.7×10^5		2.9×10^5			8.6×10^6	9.1×10^6
Alewife				6.5×10^5			6.5×10^5
Logperch darter							
Troutperch							
[illegible]							
Whitefish							

Cruise 10 (July 11-16) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	1.1×10^8	3.5×10^7	3.9×10^7	1.5×10^8	4.7×10^7	3.8×10^6	3.8×10^8
Rainbow smelt							
Emerald shiner	1.7×10^7	2.9×10^7	1.4×10^9	1.1×10^9	7.5×10^8	3.2×10^9	6.4×10^9
Spottail shiner	1.8×10^4	7.4×10^4					9.1×10^4
Carp		1.5×10^6			2.4×10^6		3.9×10^6
Freshwater drum	4.0×10^5	7.4×10^4	3.1×10^5		2.4×10^6		3.1×10^6
Yellow perch							
White bass	2.0×10^5						2.0×10^5
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple	6.8×10^5						6.8×10^5
Alewife	2.7×10^5						2.7×10^5
Logperch darter			8.6×10^5	3.9×10^6			4.8×10^6
Troutperch							
Whitefish							

Cruise 11 (July 21-28) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	2.2×10^7	5.2×10^6	4.7×10^6	8.6×10^6	7.4×10^6		4.8×10^7
Rainbow smelt							
Emerald shiner	7.2×10^6	7.4×10^6	1.3×10^8	1.6×10^8	3.3×10^8	6.3×10^7	7.0×10^8
Spottail shiner							
Carp		7.0×10^5					7.0×10^5
Freshwater drum			8.6×10^5				8.6×10^5
Yellow perch	1.5×10^5						1.5×10^5
White bass	2.7×10^5						2.7×10^5
Walleye							
White sucker							
Sunfish	1.5×10^5						1.5×10^5
Quillback carpsucker							
Crapple							
Alewife	5.4×10^4					1.6×10^6	1.7×10^6
Logperch darter							
Troutperch							
Whitefish							

Cruise 12 (Aug. 2-5) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	6.7×10^6	3.4×10^6	4.4×10^6				1.5×10^7
Rainbow smelt							
Emerald shiner	1.6×10^7	1.5×10^7	7.7×10^7	1.1×10^8	1.1×10^8	7.3×10^8	1.1×10^9
Spottail shiner							
Carp							
Freshwater drum	3.8×10^5						3.8×10^5
Yellow perch							
White bass	3.2×10^5						3.2×10^5
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple	3.2×10^5						3.2×10^5
Alewife	3.6×10^4	2.8×10^5	2.0×10^6				2.3×10^6
Logperch darter							
Troutperch							
Whitefish							

Cruise 13 (Aug. 16) 1976
(partial)

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad							
Rainbow smelt							
Emerald shiner	1.8×10^4					1.6×10^6	1.6×10^6
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch							
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple							
Alewife							
Logperch darter							
Troutperch							
[illegible]							
Whitefish							

Cruise 14 (Aug. 25- Sept. 3) 1976

Species \ Depth Zones	1	2	3	4	5	6	TOTAL
Gizzard shad	4.6×10^6						4.6×10^6
Rainbow smelt							
Emerald shiner	1.7×10^6	1.8×10^6	1.5×10^5				3.7×10^6
Spottail shiner							
Carp							
Freshwater drum							
Yellow perch							
White bass							
Walleye							
White sucker							
Sunfish							
Quillback carpsucker							
Crapple (White)	5.5×10^5						5.5×10^5
Alewife							
Logperch darter							
Troutperch							
[illegible]							
Whitefish							

APPENDIX F

APPENDIX F

Population Estimates of Larval Fishes in Study Area During 1975 and 1976, by Cruise.

1975

Species \ Cruise / Date	1 May 12–14	2 May 22–25	3 June 1–4	4 June 11–17	5 June 21–23	6 July 1–3	7 July 11–15	8 Aug 1–4	9 Aug 27–Sept 3	TOTAL
Gizzard shad		4.1×10^8	2.9×10^9	3.4×10^8	4.3×10^8	4.3×10^8	1.2×10^8	9.5×10^5	1.4×10^5	4.6×10^9
Rainbow smelt	3.8×10^6	3.5×10^8	3.5×10^8	2.6×10^7	1.6×10^7	2.5×10^6	3.8×10^5		4.7×10^5	7.5×10^8
Emerald shiner		7.4×10^4	6.4×10^6	5.8×10^8	5.3×10^8	4.3×10^8	1.2×10^8	1.5×10^7	7.6×10^7	1.8×10^9
Spottail shiner		3.1×10^6	3.7×10^7	6.0×10^7	7.6×10^7	2.3×10^7				2.0×10^8
Carp		2.1×10^6	2.6×10^7	1.4×10^7	9.9×10^7	5.6×10^7	5.6×10^6	9.3×10^6		2.1×10^8
Freshwater drum		3.1×10^5	2.1×10^9	1.0×10^7	7.0×10^7	4.9×10^6	1.9×10^6	8.9×10^5		2.2×10^9
Yellow perch	4.1×10^8	7.5×10^8	2.1×10^8	1.3×10^7	2.0×10^6					1.4×10^9
White bass		1.3×10^8	7.1×10^7	2.0×10^7	3.2×10^7	1.6×10^7	1.8×10^4			2.7×10^8
Walleye		2.1×10^6			7.4×10^4					2.2×10^6
White sucker		8.8×10^5								8.0×10^5
Sunfish					5.5×10^5	4.3×10^5	1.2×10^6			2.2×10^6
Quillback carpsucker			2.8×10^4	3.8×10^6						3.8×10^6
Mooneye		7.4×10^4								7.4×10^4
Crappie			6.4×10^5	1.1×10^5	1.8×10^4	7.4×10^4	3.6×10^5	1.7×10^6		2.9×10^6
Smallmouth bass				4.0×10^6						4.0×10^6
Alewife				3.8×10^6	1.4×10^6	2.3×10^5	7.0×10^5	2.9×10^5		6.4×10^6
Logperch darter				4.9×10^6	1.9×10^6	5.3×10^6				1.2×10^5
Unknown		3.8×10^6			4.3×10^5					4.2×10^6

1976

Species \ Cruises	1	2 Partial Survey	3	4	5	6 Partial Survey	7	8
Gizzard shad			1.6×10^7	3.8×10^6	5.0×10^6		3.6×10^8	2.2×10^9
Rainbow smelt				6.7×10^7	1.4×10^9	1.2×10^8	2.0×10^7	2.1×10^4
Emerald shiner								1.9×10^9
Spottail shiner					2.7×10^5	1.3×10^6	4.8×10^7	5.9×10^8
Carp						2.3×10^5	5.9×10^7	6.4×10^7
Freshwater drum							9.7×10^6	2.1×10^8
Yellow perch		5.4×10^4	7.0×10^8	5.8×10^8	8.5×10^7	8.7×10^6	4.7×10^6	
White bass							1.1×10^6	7.6×10^6
Walleye		9.3×10^6	1.8×10^8	3.7×10^6	1.5×10^5			
White sucker			1.6×10^6	1.5×10^5		3.6×10^4		
Sunfish								2.3×10^5
Quillback carpsucker					4.5×10^4			
Crapple							1.4×10^6	
Alewife								1.6×10^7
Logperch darter							1.5×10^7	6.5×10^4
Troutperch					6.5×10^5			
Sculpin			1.5×10^5		1.5×10^6			
Whitefish	7.2×10^5		1.5×10^6					

1976 (continued)

Species \ Cruises	9	10	11	12	13 Partial Survey	14	TOTAL	
Gizzard shad	1.1×10^9	3.8×10^8	4.8×10^7	1.5×10^7		4.6×10^6	4.2×10^9	
Rainbow smelt	4.7×10^5						1.6×10^9	
Emerald shiner	5.0×10^9	6.4×10^9	7.0×10^8	1.1×10^9	1.6×10^6	3.7×10^6	1.5×10^{10}	
Spottail shiner	5.4×10^6	9.1×10^4					6.4×10^8	
Carp	1.7×10^7	3.9×10^6	7.0×10^5				1.5×10^8	
Freshwater drum	7.6×10^8	3.1×10^6	8.6×10^5	3.8×10^5			9.8×10^8	
Yellow perch			1.5×10^5				1.4×10^9	
White bass	6.3×10^6	2.0×10^5	2.7×10^5	3.2×10^5			1.6×10^7	
Walleye							2.0×10^8	
White sucker							1.8×10^6	
Sunfish			1.5×10^5				3.8×10^5	
Quillback carpsucker							4.5×10^4	
Crapple	9.1×10^6	6.8×10^5		3.2×10^5		5.5×10^5	1.2×10^7	
Alewife	6.8×10^5	2.7×10^5	1.7×10^6	2.3×10^6			2.1×10^7	
Logperch darter		4.8×10^6					2.0×10^7	
Troutperch							6.5×10^5	
Sculpin							1.7×10^6	
Whitefish							2.2×10^6	

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