LARVAL FISH SAMPLING AND POPULATION DISTRIBUTIONS RELEVANT TO ESTIMATING POWER PLANT ENTRAINMENT IN WESTERN LAKE ERIE

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ABSTRACT

LARVAL FISH SAMPLING AND POPULATION DISTRIBUTIONS RELEVANT TO ESTIMATING POWER PLANT ENTRAINMENT IN WESTERN LAKE ERIE

By

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Larval fish were sampled near the west shore of Lake Erie in 1973, 1974, and 1975. Sampling efficiencies were compared for a 1-m, 571μ-mesh, plankton net, a Kenco pump, and a modified, "high-speed", Hardy, plankton sampler. The sampling effectiveness was also evaluated for different mesh apertures and the length of towing time. Studies of larval fish distributions included day and night assessments of vertical stratification and the relationship between distance from shore and relative larval abundance along a 16-km transect. Spatial distributions, abundances, and species composition were estimated at seven stations in and around the cooling system of an electric generating station in 1973, 1974, and 1975. The mortality of larval fish was estimated following condenser passage in the cooling system.

The most effective sampling technique tested was an oblique tow from a deep position near bottom to the surface at night using a 571μ-mesh, 1-m, plankton net towed for 1-2 minutes. During the daytime, the most effective technique tested was a combination of oblique tows with the same net from a deep position to the surface and a 1-m, 571μ-mesh, plankton net attached to a bottom sled.

Vertical, spatial, and temporal variation was great, requiring extensive sampling to identify significant differences in larval fish abundance. However, the analysis indicated considerable differences in the relative vulnerabilities of different species to entrainment. Freshwater drum and clupeids appeared especially vulnerable. Estimated mortalities, following condenser passage, were high for all species captured. Therefore, power plant entrainment potentially has a measurable impact on adult populations of a few particularly vulnerable species, especially if cooling water requirements continue to expand.

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INTRODUCTION

Any environmental alterations affecting larval fish survival may significantly influence the subsequent abundance of reproductively mature fish. But, the early life history of most wild fish populations is poorly understood. This is particularly true in the Great Lakes, where demands on lake resources could influence the survival of young fish. Once-through cooling at steam-electric generators uses more water than any other process on the Great Lakes. More importantly, potential for this use could grow at several times the rate of other resource development on the lakes. This increasing demand for cooling water could drastically modify the ecology of early life stages of fish in some environments. The purpose of this paper is to present data on larval fish distributions and discuss the potential impact of a large power-plant, cooling system on larval fish survival.

Marcy (1973) concluded that virtually all larval fish died after they passed through a cooling system on the Connecticut River. Edsall and Yocom (1972) called attention to the potential for damage of larval fish entrainment into Great Lakes power plant cooling systems. However, because data on distributions is practically non-existent, potential damage is usually calculated on the assumption that many important Great Lakes larval fish are totally planktonic and concentrated close to shore.

A series of mechanistic questions follows as a consequence of the indicated need to assess the impact of power plant entrainment on larval fish populations. Where are larval fish located in relation to the intake?

For how long are their movements determined mostly by currents? What currents are they associated with over that period of vulnerability? How are the currents determined? How many larvae pass through the cooling system? How many die following passage? In short, what proportion of the larval fish from the lake community are entrained and killed by the power plant cooling system.

These questions were addressed in order to attain preliminary estimates of the potential impact of intake entrainment at the Monroe Power Plant on western Lake Erie. Several commonly used sampling techniques were compared for sampling effectiveness. Vertical distributions were examined under day and night conditions. Horizontal distributions were sampled in the cooling system and the lake waters for a distance up to 16 km from the intake. Larval fish mortality was estimated in the cooling system. These data were then discussed in light of statistical complications, the local hydrodynamics as reported by other investigators, and the potential impact of intake entrainment on fish populations in the western basin of Lake Erie.

METHODS

Power Plant Description

The study was conducted at the Monroe Power Plant which is operated by the Detroit Edison Company on the western shore of Lake Erie at the mouth of the Raisin River. All four of the plant's 800-megawatt units were completed for operation by mid-1974 with a net total capability of 3,150 megawatts. The cooling water demands for the once-through cooling system depend on power generation and ambient water temperatures, but maximum requirements are about 85 m^3 per second. The water is obtained in varying proportions from the Raisin River and Lake Erie. During spring runoff the Raisin River may contribute more than 95 percent of the total cooling water requirements while during the low flow of late summer it contributes about 5 percent of the total. The biota of each water source is different so the species and numbers of individuals passing through the condenser system vary accordingly.

Water enters the cooling system through a 100-m long intake canal that is located about 650 m upstream from the river mouth. Prior to condenser entry, the water passes through a traveling screen with 1-cm diagonal openings. Water then enters the condenser where water velocities usually exceed 2 m/sec and the temperature rises to 10-12 C above ambient at full operation. But, both power generation and pumping rates have varied widely so temperature elevations have ranged from 0 to 13 C. The highest temperature elevations were recorded in winter when pumping rates per unit of power generation were reduced to supply heated effluent for a recirculation system that is used to control ice accumulation.

The cooling system has a 27,917 m^2 double-flow, Type M, single-pass, divided-surface condenser with 18,154 tubes. Each tube has an effective length of 17.6 m and 2.54 cm outside diameter. The heated condenser water is released into a 350-m long concrete conduit where water velocities are about 1 m/sec at full operation. The water then passes into a rock-walled discharge canal which averages 175 m-wide, 7 m deep in the upper end, 3 m deep in the lower end, and is 2000 m long. At full pumping, the upper discharge canal velocities average about 6 cm/sec and lower canal velocities average about 12 cm/sec. However, the velocity is not cross-sectionally uniform because high velocity waters approaching 1 m/sec enter the discharge canal from the overflow conduit and form an eddy of slower water on the east side. This adds to the variability of organism residence times in the discharge canal. Plum Creek drains into the discharge canal but contributes less than 1 percent of the volume-flow through the canal.

The time of water passage through the cooling system back to Lake Erie averages 4.5 hrs at full operation. Calculated times are 7 sec through the condenser, 20 min through the conduit, and 4 hrs through the discharge canal.

The first plant unit began in May, 1971, and the remaining units were started at approximately one-year intervals thereafter until completion in May, 1974. Operation began erratically but stabilized as more units contributed power; 94 percent of all plant shutdowns to date occurred in 1971 and 1972. Total heat loss from the condenser to the lower discharge canal was about 10 percent of that added. After leaving the discharge canal, the heated effluent forms a plume which may extend over 4 km from the mouth of the canal. The largest plume measured by the Detroit Edison Company (1976) encompassed about 760 ha to the 1.7 C isotherm. The plume position and size depended on the pumping rate, power generation and the direction and velocity of the wind. Heat dissipation within the plume occurred in 1 to 2 days.

Chlorine was added to the cooling water at the intake to control growths in the condenser; two times per day during summer and once per day during winter. During the warm months (April-October) chlorine was added at one-hour intervals for four hours starting at 0700 hrs and then again for four hrs at 2030 hrs. In winter, chlorine was injected for half-hour periods at 0700, 0900, 1100, and 1300 hrs. Forty-five kg of chlorine were added at each application. The highest concentration of chlorine measured in the discharge canal by the Company was 0.20 mg/liter (The Detroit Edison Company, 1976).

The Cooling Water Sources

The western basin of Lake Erie is a shallow (7.3 m mean depth), highly turbid water body which is partially separated from the rest of Lake Erie by the Bass Islands and Point Pelee. Beeton (1961) attributed the high turbidity to the wind-generated resuspension of sediments, river discharges, and plankton densities. Submarine photometric measurements made during this study indicate that only 0.1 percent of the total mean surface light penetrated to the 5 m depth during spring and summer. Wind-generated mixing usually maintains vertical homeothermy in the basin but calm spells may allow temporary stratification for a few days (Carr et al., 1965). Water temperatures are presented in Figure 1 for selected dates during the study.

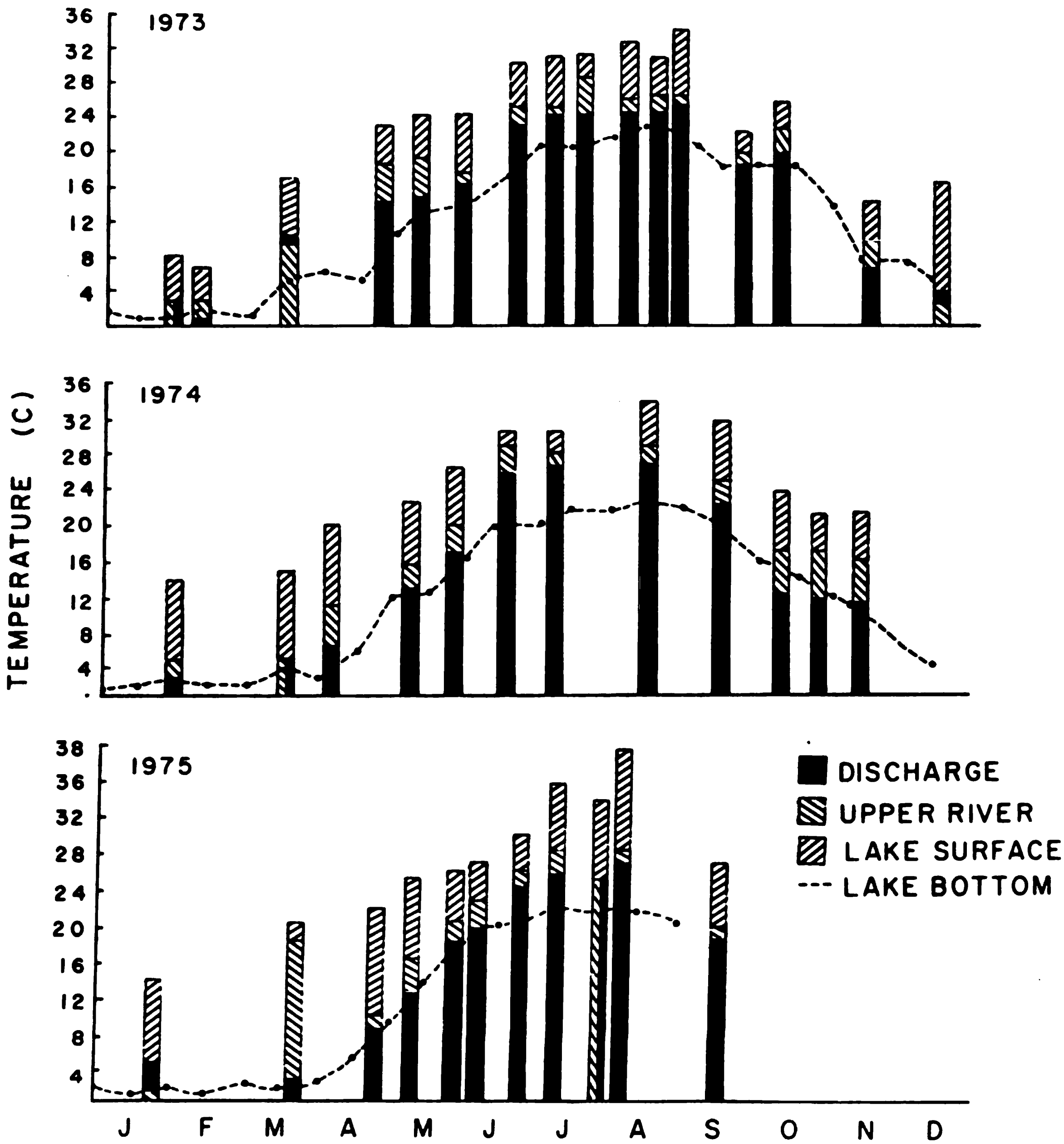

Figure 1. SURFACE TEMPERATURES IN THE RAISIN RIVER, DISCHARGE CANAL, AND ALONG THE WEST SHORE OF LAKE ERIE AT THE SURFACE AND BOTTOM DURING 1973, 1974, and 1975.

The surface area of the basin is 3,276 km^2 (Carr _et al._, 1965) and the shoreline is well developed by islands, peninsulas, spits, and flooded river mouths. The spatial diversity along the shores provides many kinds of fish spawning habitat including marshes, rocky reefs, and sand and gravel bars. The bottom sediment near shore is composed primarily of coarse, medium, and fine sand which grades into silt and clay in the deeper waters off shore (Kelley and Cole, 1976).

The Detroit River annually contributes about 95 percent of the flow to the western basin of Lake Erie while the Maumee River, the second largest tributary, contributes 2.5 percent. The locations of these rivers are shown in Figure 2. The Raisin River contributes less than 0.3 percent (Ecker and Cole, 1976). Significant numbers of larval fish may enter the study area from each of these rivers. The combination of tributaries and prevailing southwesterly winds generally causes the water in the southwestern corner of the basin to circulate in a clockwise eddy (Hartley, _et al._, 1966). But, pronounced day to day variations may occur because of changing winds and tributary discharge. Detroit River water predominates off shore while water from the Maumee and Raisin River dominate the inshore areas. Mean resultant water velocities in the lake are 1.6 to 2.0 km/day, but during storms fish larvae from either the Detroit or Maumee River could reach the study area within a day and larvae from the island region of the basin could reach the power plant in two days. Wind velocities of 51.5 km/hr or more occur on an average of 23 days/yr. Mean wind velocity and direction are presented in Figure 3.

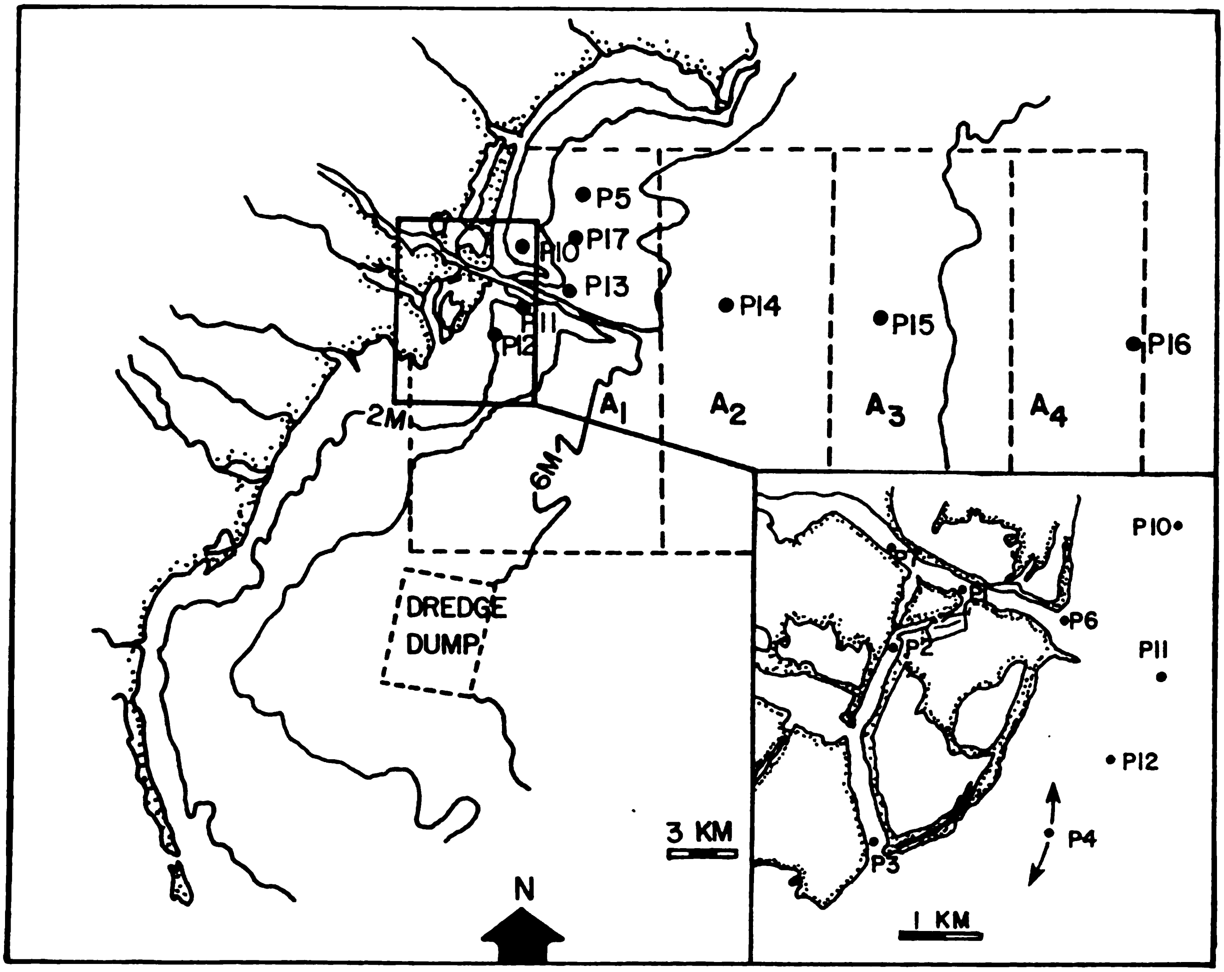

Figure 2. MAP OF THE STUDY AREA SHOWING SAMPLING STATIONS IN WESTERN LAKE ERIE AND IN THE COOLING SYSTEM.

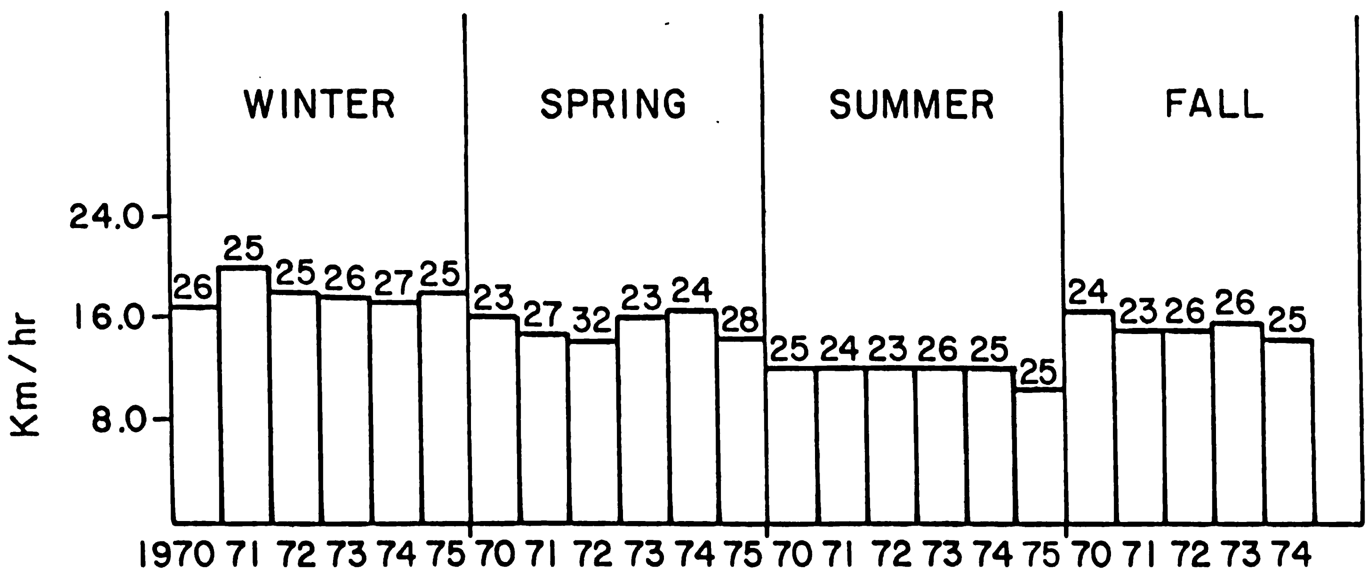

Figure 3. SEASONAL MEAN WIND DIRECTION (tens of degrees azimuth) AND VELOCITY (km/hr) FROM 1970 TO 1975.

The lower Raisin River, until recently, was highly polluted with municipal and industrial wastes, particularly biodegradable organics. Anoxia was once common during the summer, but improvements in waste treatment have partially rectified this situation. Environmental conditions remain unsuitable for spawning by at least some fish species.

Sampling

The efficiencies of different sampling techniques were computed at station P17 (Figure 2) in 1975. A submersible, Kenco pump, with a realized pumping capacity of 6.9 liters/sec, was submersed at the bow of an anchored boat to a depth of 0.25 m and run for one hour. The pump effluent was filtered through a 571μ-mesh, nylon, plankton net with a 1.8-liter, plankton bucket. Approximately 25 m^3 were processed in one hour. Five replicates were made per sampling date.

A modified, Hardy, plankton sampler (Miller, 1961) was towed initially at 0.5 m/sec but that was decreased to about 0.2 m/sec because larval fish extrusion was suspected from the condition of mutilated larvae found in the samples. The sampler was mounted off the side of the boat and towed at a depth of 0.25 m for 15 min. Approximately 18 m^3 were sampled at the reduced speeds. Five replicates were made on each sampling date.

The larval fish rate of capture in 1-m nets of different size was compared using 361, 571, 760, and 1000μ mesh sizes. Five replicate samples were taken with each mesh size. The nets were towed at 0.1 m/sec at the surface for 3 minutes, and filtered about 90 m^3 of water.

The variation in catch with length of towing time was estimated with a 571μ-mesh, plankton net. Samples of 1, 2, 3, 4, and 5 minutes were made at the surface at station P17. An average of 33 m^3/min was sampled in the tows with no apparent variability related to towing time. Five replicate samples were taken with each length of towing time.

Samples of surface, midwater, deep (1 to 2 m above bottom), and oblique tows were made at station P17 with a 571μ-mesh net. Oblique tows were drawn at a constant rate from the deep position, at about the 5-m depth, to the surface. Five, 1-min replicates (filtering about 33 m^3 of water) were made for each stratum sampled. The station was similarly sampled at night with surface, midwater, deep and oblique tows. In addition, during the day a 571μ-mesh, plankton net was towed on a bottom sled for 3 min at a speed of 0.2 m/sec. Approximately 31 m^3 of water was sampled (estimate based upon known speed and net area). Five replicates were collected on each date sampled. A General Oceanics (Model 2030) digital flowmeter was suspended in the center of all 1-m nets to measure flow through the net.

A transect perpendicular to shore was sampled to define differences in larval fish densities at various distances from shore (Figure 2). Four stations along the transect were sampled during the day with a 571μ-mesh net. At each of the transect stations, three replicates were collected from the surface, three from deep water, and three with oblique tows from deep water to the surface. About 100 m^3 of water were sampled during a three-minute tow (1 m/sec). Stations P13, P14, P15 and P16, all along the transect, were 2, 6, 11, and 16 km from shore, respectively.

Tows with 571μ-mesh, 1-m nets were used during 1973, 1974, and 1975 to estimate larval fish abundance and distributions in the study area. Preliminary sampling was conducted at different depths in 1973 (at stations

P1, P2, P3, P4, and P5), but it indicated no consistent significant differences among the surface, midwater, and deep samples (Nelson and Cole, 1975). Therefore, in 1974 and 1975, a 1-m, 571μ-mesh, nylon, plankton net was towed at an oblique angle through the water column at a constant rate from a deep position to the surface for 2.5 minutes. Towing speed was approximately 1 m/sec. A General Oceanics (Model 2030) digital flowmeter was fitted at the center of the net opening and a 1.8-liter, plastic, plankton bucket was attached to the codend of the net. Because of the unmixed nature of water entering the intake, two stations were sampled in the Raisin River channel (Figure 2). An upstream river site (P7) was located about 1 km upstream from the plant intake and a "downstream" station (P6) was located at the mouth of the river to sample lake water that was drawn up the old river channel. An intake station (P0) abundance was calculated from concentrations at P6 and P7, which were weighed for river and lake volume-flow contributions to the cooling system. River discharge rates were provided by the U.S. Geological Service and plant pumping rates were provided by the Detroit Edison Company. Virtually all river water is drawn into the cooling system before the balance is made up by lake water (Ecker and Cole, 1976). Samples also were taken from the upper (P2) and lower (P3) ends of the discharge canal, and three Lake Erie stations (P10, P11, and P12). The latter were sampled to assess the concentration and spatial variation of lake larval abundances.

Mortality was estimated at three stations within the immediate vicinity of the plant. Larvae were captured with a stationary 1-m, 571μ-mesh, cone shaped, nylon, plankton net with a General Oceanics (Model 2030) digital flowmeter suspended at its center. A modified (bolting cloth on the inside rather than the outside of the bucket) 582μ-mesh, plankton bucket was attached to the codend of the net. The stationary net was set in a slow current of 0.15 to 0.25 m/sec to reduce mortality stemming from the technique and to ensure comparable sampling conditions. A reference station was sampled in the intake canal at station P1 to estimate combined natural and net-caused mortalities. The second station was located near P2 within 100 m of the outfall from the concrete conduit in the discharge canal. Station P3 was located 1,5000 m downstream, near the mouth of the discharge canal. Dead or dying larvae were separated from live animals by color and mobility. Translucent or mobile individuals were counted as alive while opaque, immobile ones were assumed to be dead. A field observation device described by Marcy (1971) was used to maintain the ambient and elevated water temperatures around separation dishes while live larvae were counted.

All larvae collected were preserved in 5-percent formalin and later counted and identified to the most specific taxa possible. Rose-bengal dye was added to ease sorting. All samples were standardized to number per 100 m^3.

All data were tested for normality using the Shapiro-Wilk test (Gill, in press) and homogeneous variance using Bartlet's test. A log (x + 1) transformation was applied to all data to correct for non-normality and variance heterogeneity. Then Bartlet's test was applied to the transformed data. Heterogeneous variance was usually indicated and a modified Scheffe's post-data test (Gill, 1971) was applied when applicable. Tukey's multiple range test was used to identify differences among means when departures from homogeneity were minor. It was applied to the technique comparisons, comparisons of stations along the transect, and the comparisons among stations in 1975. Analysis of variance was applied to comparisons of day and night abundances.

RESULTS

Species Composition

Out of 15 taxa captured from 1973-1975, the most abundant included gizzard shad, *Dorosoma cepedianum*, and alewife, *Alosa pseudoharengus* (43.6 percent; hereafter referred to as "clupeids"); yellow perch, *Perca flavescens* (25.3 percent); carp, *Cyprinus carpio*, goldfish, *Carassius auratus*, and their hybrids (10.6 percent); white bass, *Morone chrysops* (7.3 percent); emerald and spottail shiners, *Notropis atherinoides* and *N. hudsonius* (3.2 percent); and freshwater drum, *Aplodinotus grunniens* (2.0 percent). The combinations of species listed above could not be routinely separated to species as larvae. These species accounted for 92 percent of the total catch. Yolk sac larvae (prolarvae) represented 19.1 percent of the total catch and post larvae represented 80.9 percent. Less abundant species are listed in Tables 1 and 2.

Comparison of Surface Sampling Techniques

The 1-m plankton net was the most effective surface sampling technique tested in the comparison of the Kenco pump, the modified Hardy plankton sampler, and the 571μ, 1-m, plankton net. Significantly ($\alpha = 0.05$) more larvae were captured by the 1-m net on most of the dates sampled (Appendix A-1). White bass were captured only in the 1-m plankton net (Table 3).

The Kenco pump was the least effective sampling technique tested. Significantly ($\alpha = 0.05$) fewer larvae of all taxa were captured (Appendix A-1). Fish larvae were captured on June 18 and 19 only (Table 3). On these

Table 1. RELATIVE ABUNDANCES OF FISHES IN THE STUDY AREA BASED ON TRAWL[1], GILL NET[2] AND TOW NET CAPTURES FROM 1970 TO 1975. (A = abundant, over 5%; C = common 1 to 5%, S = scarce, less than 1%; and NC = not captured).

Species	Adults and Juveniles	Larvae
Gizzard shad, *Dorosoma cepedianum*	A	A[3]
Yellow perch, *Perca flavescens*	A	A
Emerald shiner, *Notropis atherinoides*	A	A[4]
Spottail shiner, *Notropis hudsonius*	A	A[4]
White bass, *Morone chrysops*	A	C
Goldfish, *Carassius auratus*	A	S[5]
Alewife, *Alosa pseudoharengus*	A	C[3]
Freshwater drum, *Aplodinotus grunniens*	A	C
Carp, *Cyprinus carpio*	A	C[5]
Channel catfish, *Ictalurus punctatus*	C	C
Common shiner, *Notropis cornutus*	C	NC
Brown bullhead, *Ictalurus punctatus*	C	NC
Carp-goldfish	C	?[2]
Trout perch, *Percopsis omiscomaycus*	C	S
Walleye, *Stizostedion vitreum*	C	S
White crappie, *Pomoxis annularis*	C	S
Rainbow smelt, *Osmerus mordax*	C	A
Quillback carpsucker, *Carpiodes cyprinus*	C	NC
Silver chub, *Hybopsis storeriana*	S	NC
Log perch, *Percina caprodes*	S	S
Black bullhead, *Ictalurus melas*	S	NC
Pumpkinseed, *Lepomis gibbosus*	S	S
White sucker, *Catostomus commersoni*	S	S
Longnose gar, *Lepisosteus osseus*	S	NC
Bluegill, *Lepomis macrochirus*	S	S
Yellow bullhead, *Ictalurus natalis*	S	NC
Smallmouth bass, *Micropterus dolomieui*	S	S
Fathead minnow, *Pimephales promelas*	S	NC
Stone cat, *Noturus flavus*	S	NC
Northern pike, *Esox lucius*	S	NC
Rock bass, *Ambloplites rupestris*	S	NC
Chinook salmon, *Oncorhynchus tschawytscha*	S	NC
Coho salmon, *Oncorhynchus kisutch*	S	NC

[1]From Cole (1976)
[2]From Cole (1976)
[3]Gizzard shad and alewife are difficult to separate completely
[4]Shiners are difficult to separate completely
[5]Carp and goldfish are difficult to separate completely

Table 2. MEAN CATCH OF FISH LARVAE PER 100 M^3 IN OBLIQUE 1-M PLANKTON NET TOWS FROM MAY THROUGH JULY IN 1974[1] AND 1975[2].

	P_6		P_7		P_2		P_3		P_{10}		P_{11}		P_{12}	
	74	75	74	75	74	75	74	75	74	75	74	75	74	75
Clupeids	13.7	7.8	3.6	2.3	17.0	11.0	15.4	6.7	9.5	8.5	36.8	9.0	20.4	3.8
Yellow perch	15.0	9.7	1.6	0.4	11.7	7.1	6.2	0.6	7.6	5.6	1.5	2.5	1.0	13.2
Carp-goldfish	1.4	0	12.7	3.8	10.7	4.1	3.5	0.9	0.2	0	0.2	0	0.8	0
White bass	2.4	0.6	0.1	1.1	14.5	1.3	3.5	0.4	1.0	0.4	1.5	0.8	2.6	0.5
Shiners	0.5	0.2	0.4	3.6	2.5	2.6	0.5	0.1	0.7	0.4	0.8	0.8	1.6	0.2
Freshwater drum	2.4	0	2.1	0	3.0	0	1.1	0.1	1.7	0.1	1.2	0	0.8	0
Smelt	0.1	0.4	0.1	0.5	0	0.5	0	0	0.2	0.2	0.4	0.1	0.1	0.5
Sunfish	0.7	0	1.9	1.0	1.1	0.2	0.6	0.2	0.1	0	0.1	0	0.2	0
Black bass	0	0	0.9	0.5	0.1	0	0	0	0	0	0	0	0.3	0.1
Channel catfish	0.1	1	0.1	0.3	4.0	0.3	0.5	0	0	0	0	0	0	0
Crappie	0	0	0.3	0.5	0	0.1	0	0	0	0	0	0	0.1	0
Trout perch	0.1	0.1	0	0	0.1	0	0	0	0	0	0	0	0	0
Log perch	0.1	0	0	0	0	0.3	0	0	0	0	0	0	0	0
Walleye	0.2	0	0	0	0.1	0	0	0	0	0	0	0	0	0
White sucker	0.1	0	0	0.4	0	0	0	0	0	0	0	0	0	0
Total	36.8	18.8	21.4	15.4	64.8	27.5	31.3	9.0	21.0	15.2	42.5	13.2	27.9	18.3

[1] Sampled on 6 dates; 5 replicates/date

[2] Sampled on 5 dates; 5 replicates/date

dates, clupeids were the only identifiable taxa captured. About 40 percent of the larvae captured were damaged. Of the total, 20 percent were damaged so badly that they could not be identified or included in the statistical analysis.

The modified, "high-speed", Hardy, plankton sampler was most effective when larval densities at the surface were relatively high (Table 3). This occurred only on June 18. On this date significantly ($\alpha = 0.05$) more yellow perch and clupeid larvae were captured than with the other surface techniques (Appendix A-1).

Mesh Size and Length of Time Towed

The 363μ-mesh, 1-m net usually caught more fish larvae than 1-m nets with larger mesh sizes (Figure 4). The 1000μ-mesh nets caught significantly ($\alpha = 0.05$) fewer larvae than the 363μ or 571μ-mesh nets on both dates for which it was compared. The 760μ-mesh net caught significantly ($\alpha = 0.05$) fewer larvae on only one of the two dates that it was compared. However, the relative capture effectiveness of the two smaller mesh sizes appeared to depend on the species and size (age) of the larvae (Appendix A-2). Prolarval fish were caught most effectively with the 363μ-mesh net. Significantly ($\alpha = 0.05$) more smelt prolarvae were caught with the 363μ-mesh net compared to the others on May 21. On May 20, significantly ($\alpha = 0.05$) more yellow perch postlarvae were caught with the 571μ-mesh net. On June 21, significantly ($\alpha = 0.05$) more postlarval clupeids were captured using the 363μ-mesh net.

Table 3. COMPARISON OF THE MEAN CATCH (5 replicates) PER 100 M^3 IN A 571μ, 1-M PLANKTON NET; A MODIFIED, HARDY, "HIGH-SPEED", SAMPLER; AND A KENCO PUMP (all sampling conducted near the surface).

	05/21/75	05/23/75	05/24/75	06/18/75	06/19/75	06/20/75	Total
Clupeids							
1-m net	0	2.8	0	62.1	8.3	0	73.2
Hardy	0	0	0	343.7	0.9	0	344.6
Pump	0	0	0	21.3	0	0.7	22.0
Yellow perch							
1-m net	4.3	3.7	0	0.7	0	0	8.7
Hardy	0	0	0	5.3	0	0	5.3
Pump	0	0	0	0	0	0	0
White bass							
1-m net	0	0	0	0.7	0	0	0.7
Hardy	0	0	0	0	0	0	0
Pump	0	0	0	0	0	0	0
Smelt							
1-m net	1.4	0.8	0	8.7	0	0	10.9
Hardy	0	0	0	0.9	0	0	0.9
Pump	0	0	0	0	0	0	0
Shiners							
1-m net	0	0	0	9.3	0	0	9.3
Hardy	0	0	0	0.9	0	0	0.9
Pump	0	0	0	0	0	0	0
Total							
1-m net	5.7	7.3	0	63.5	8.3	0	84.8
Hardy	0	0	0	350.8	0.9	0	351.7
Pump	0	0	0	21.3	0	0.7	22.0

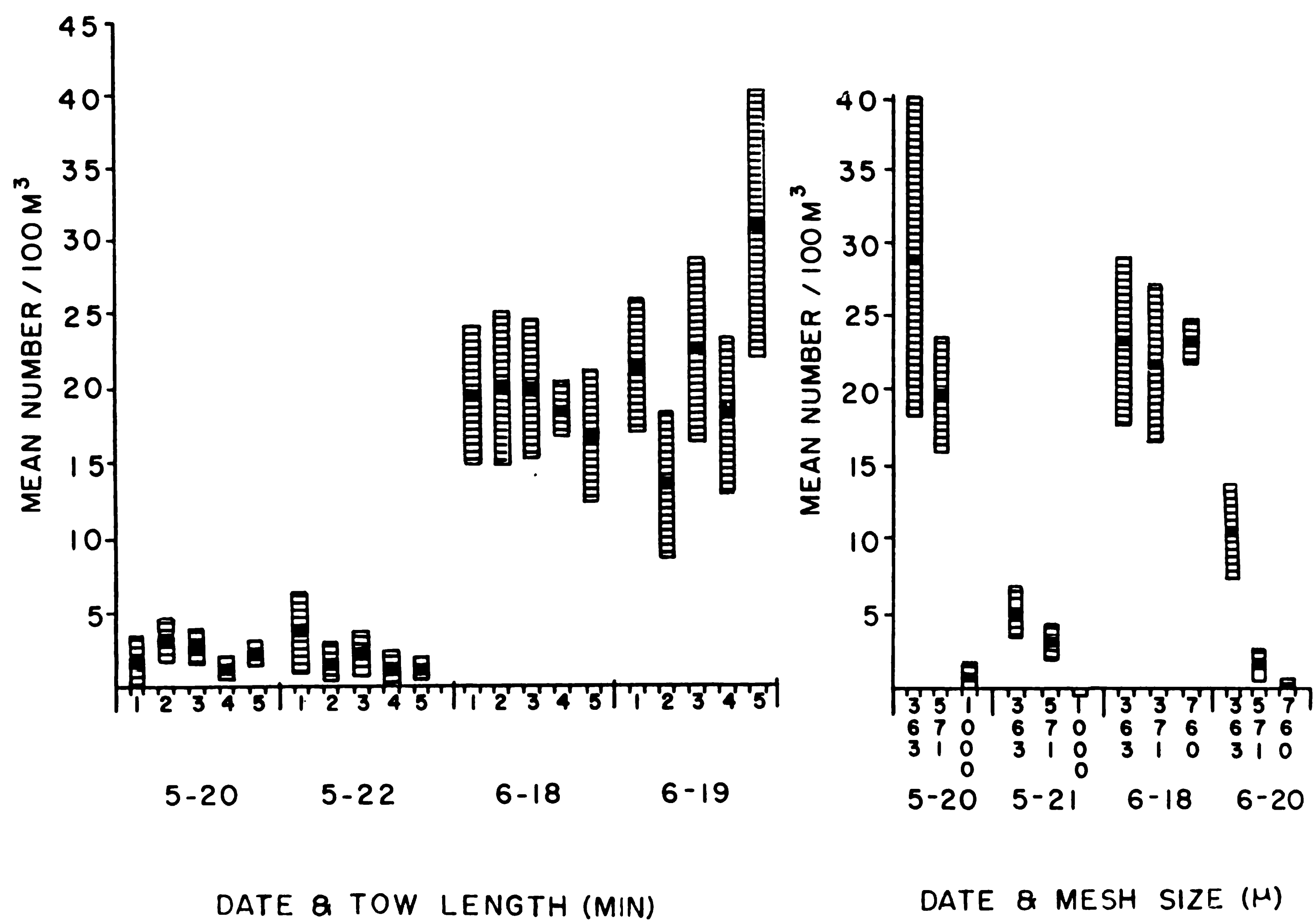

Figure 4. COMPARISON OF THE MEAN NUMBER OF LARVAL FISH CAPTURED (±SE) FOR LENGTH OF TIME TOWED (1, 2, 3, 4, and 5 min) AND A COMPARISON OF THE MEAN NUMBER OF LARVAL FISH CAPTURED (±SE) FOR EACH MESH SIZE TESTED (363, 571, 760, and 1000μ mesh).

No consistently significant ($\alpha = 0.05$) or large differences were apparent between 1, 2, 3, 4, and 5-min tows (Figure 4; Appendix A-3). The 1, 2, and 3-min tows tended to catch slightly more fish larvae per unit effort but on June 19, the 5-min tow caught more fish larvae per unit effort than the others (Appendix A-4).

Vertical Distributions

Daytime Tows

Transect stations: Generally, oblique tows from deep water to surface were as effective as the mean of stratified tows made at the surface and deep position along the transect sampled perpendicular to shore. But, some general species variations existed. Clupeids and smelt tended to be captured more effectively with stratified tows although they were not statistically different from the oblique tows. Yellow perch and white bass tended to be caught more efficiently with oblique tows (Figure 5). No consistent differences in the catch effectiveness appeared between stratified and oblique tows along the transect, regardless of distance from shore or differences in depth to the bottom (Appendix A-5).

Station P17: The daytime net capture efficiency at different depths was inconsistent in time and by species but in no instances were the means of oblique and stratified tows different (Table 4). Fish larvae appeared to be concentrated near the bottom during the day (according to bottom sled yield) but populations above the bottom did not exhibit any consistent vertical distributional patterns. Significantly ($\alpha = 0.05$) more yellow perch prolarvae were captured using surface and midwater tows (Appendix A-1) on May 21 and 23 than in deep or oblique tows, but on May 24, no yellow perch

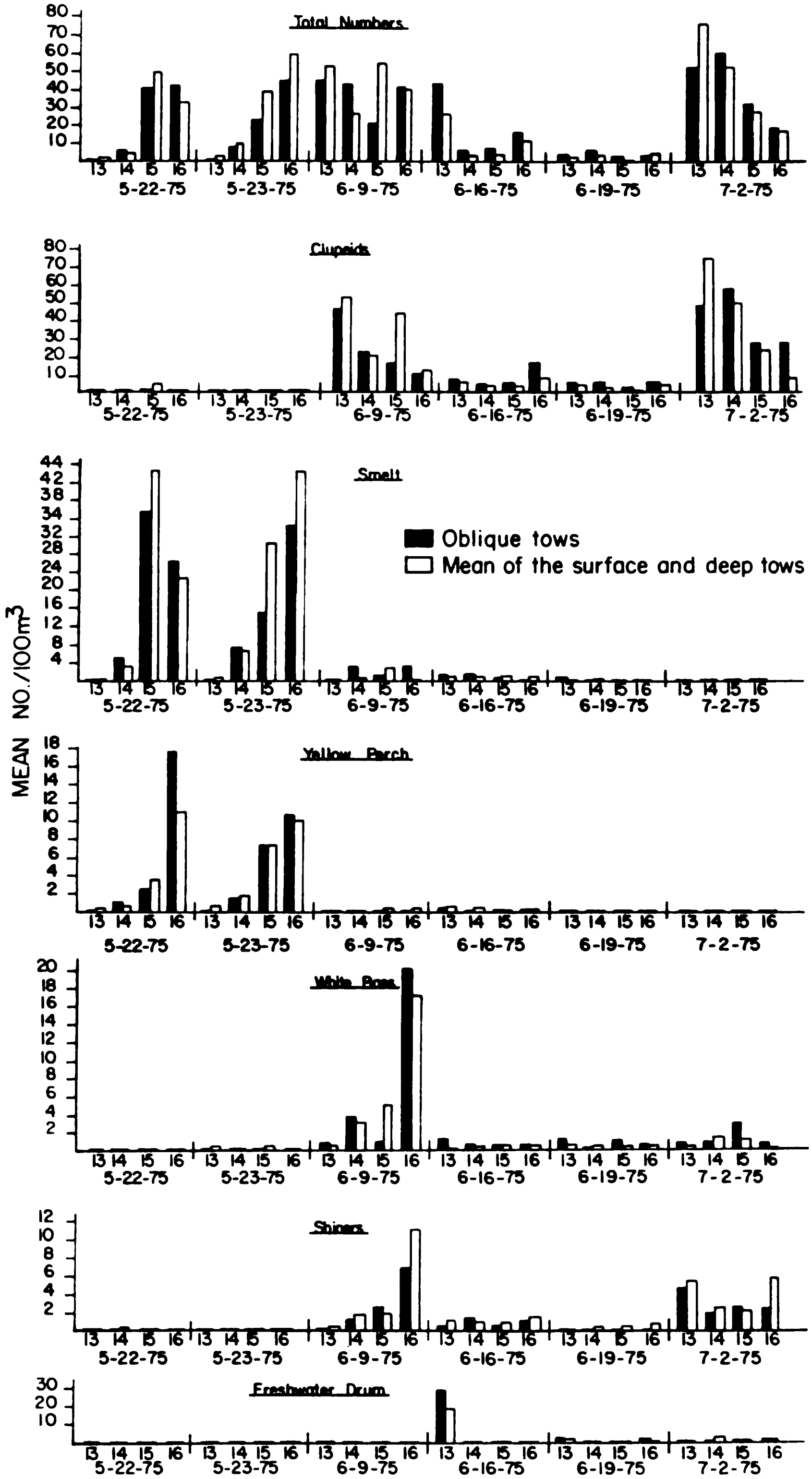

Figure 5. COMPARISON OF MEAN OF OBLIQUE TOWS TO THE MEAN OF SURFACE AND DEEP TOWS ALONG THE TRANSECT.

Table 4. DAYTIME AND NIGHTTIME COMPARISONS OF MEAN CATCH (5 replicates) PER 100 M^3 IN OBLIQUE, SURFACE, MIDWATER, AND DEEP TOWS AND TOWING WITH A BOTTOM SLED USING A 571μ, 1-M PLANKTON NET.

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
<u>Clupeids</u>							
5/21/75							
Day	0	0	0	0	0.9	--	0
Night	2.2	3.4	5.2	3.6	4.3		18.0
5/23/75							
Day	2.8	0.5	0	1.1	1.2	--	5.5
Night	0	0.6	0.5	0.4	1.8		1.8
5/24/75							
Day	0	0	0	0	0.3	--	0
Night	0	1.7	0	0.6	0.7		2.8
6/18/75							
Day	62.1	21.9	3.3	29.1	12.7	698.6	815.0
Night	81.0	89.3	94.9	88.4	89.4		442.0
6/19/75							
Day	8.3	1.3	0	3.3	7.4	81.1	93.9
Night	45.0	88.9	64.1	66.0	103.5		330.0
6/20/75							
Day	0	1.1	0.5	0.5	1.2	124.2	126.3
Night	3.2	6.8	0.5	3.5	2.6		17.5
Mean							
Day	12.4	4.4	0.6	5.7	3.4	301.3	173.4
Night	21.9	31.8	27.5	27.1	33.7		135.4

Table 4. (cont'd.)

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
Yellow Perch							
5/21/75							
Day	4.3	2.2	1.6	2.7	0.9	--	13.5
Night	29.0	57.7	32.7	39.8	33.5		199.0
5/23/75							
Day	3.7	0.5	0.5	1.6	2.0	--	8.0
Night	0	3.6	35.1	12.9	17.9		64.5
5/24/75							
Day	0	0.7	0.7	0.5	2.0	--	2.5
Night	1.3	13.0	31.3	15.2	23.1		76.0
6/18/75							
Day	0.7	0	3.0	1.2	0.3	0.0	4.8
Night	1.1	7.6	7.3	5.3	9.7		26.7
6/19/75							
Day	0	0	1.0	0.3	0	11.0	12.2
Night	0	3.0	10.4	4.5	2.2		22.3
6/20/75							
Day	0	0	0	0	0	3.9	3.9
Night	0	0	4.3	1.4	0.9		7.2
Mean							
Day	1.5	1.1	2.3	1.2	1.2	6.2	7.5
Night	5.2	14.2	20.2	13.2	14.6		65.9

Table 4. (cont'd.)

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
White Bass							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0	0.6	0	0.2	0		1.0
5/23/75							
Day	0	0.6	1.1	0.6	0.5	--	3.0
Night	0	0	0	0	0		0
5/24/75							
Day	0	0	0.7	0.2	0	--	1.0
Night	0	0	0	0	0		0
6/18/75							
Day	0.7	1.6	2.8	1.7	2.3	36.7	43.5
Night	6.6	7.3	5.8	6.6	4.9		32.8
6/19/75							
Day	0	0.5	0	0.2	0	27.0	27.8
Night	0	5.0	1.0	2.0	1.2		10.0
6/20/75							
Day	0	0	0	0	0	25.1	25.1
Night	0.8	10.8	9.2	6.9	9.6		34.7
Mean							
Day	0.1	0.5	0.8	0.5	0.5	29.6	16.7
Night	1.2	4.0	2.7	2.6	2.6		13.1

Table 4. (cont'd.)

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
Smelt							
5/21/75							
Day	1.4	2.7	1.1	1.7	3.5	--	8.7
Night	18.5	11.8	13.4	14.6	10.2		72.8
5/23/75							
Day	0.7	0.6	1.1	0.8	1.5	--	4.0
Night	8.3	35.1	46.6	30.0	42.5		150.0
5/24/75							
Day	0	0	1.2	0.4	0.2	--	2.0
Night	17.5	61.0	29.1	35.9	44.2		179.3
6/18/75							
Day	8.7	5.7	8.1	7.5	7.2	632.0	662.0
Night	6.3	11.3	15.1	10.9	10.0		54.5
6/19/75							
Day	0	0.5	0.5	0.3	0.7	27.7	28.0
Night	0	2.5	0.9	1.1	0.2		5.7
6/20/75							
Day	0	0	0	0	0	2.6	2.6
Night	0.8	3.4	13.3	5.8	0.9		29.2
Mean							
Day	1.8	1.6	2.0	1.8	2.2	222.9	117.9
Night	8.6	20.8	19.7	16.4	18.0		81.9

Table 4. (cont'd.)

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
<u>Shiners</u>							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0.6	0	0	0.2	0		1.0
5/23/75							
Day	0	0	0	0	0	--	0
Night	1.4	0	0	0.5	0.7		2.3
5/24/75							
Day	0	0	0	0	0	--	0
Night	0.7	1.2	0	0.6	0.5		3.2
6/18/75							
Day	9.3	2.1	3.2	4.9	7.3	33.5	53.1
Night	6.9	7.6	7.3	7.3	6.5		36.3
6/19/75							
Day	0	0	0	0	0	3.2	3.2
Night	2.4	0.5	0.5	1.1	0.2		5.7
6/20/75							
Day	0	0.6	0	0.2	0	2.6	2.8
Night	0.9	2.0	0.5	1.1	1.8		5.7
Mean							
Day	1.6	0.5	0.5	0.9	1.2	6.6	9.8
Night	2.2	1.9	1.4	1.8	1.6		9.0

Table 4. (cont'd.)

Species	Surface	Midwater	Deep	Mean[1]	Oblique	Bottom Sled	Water Column Mean[2]
Carp							
5/21/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
5/23/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
5/24/75							
Day	0	0	0	0	0	--	0
Night	0	0	0	0	0		0
6/18/75							
Day	0	0	0	0	0	12.9	12.9
Night	4.0	5.3	2.9	4.1	3.1		20.3
6/19/75							
Day	0	0	0	0	0	9.0	9.0
Night	8.1	24.0	53.2	28.4	29.9		142.2
6/20/75							
Day	0	0	0	0	0	0.6	0.6
Night	70.2	130.7	61.4	87.4	80.6		437.2
Mean							
Day	0	0	0	0	0	7.5	7.5
Night	13.7	26.7	19.6	20.0	18.9		99.9

[1]Mean of surface, midwater and deep tows.

[2]Weighted mean of all strata for a 5 m depth.

prolarvae were captured at the surface even though they were captured in all other tows. Similarly, the catches of clupeid and shiner larvae at the three discrete depths usually were not significantly ($\alpha = 0.05$) different from one another. Yet on exceptional dates, significantly ($\alpha = 0.05$) more clupeids were captured at the surface (June 19) and significantly fewer shiners were captured in midwater (June 18). Much of the inconsistent variation that occurs in vertical distribution above the bottom appears to be caused by day to day vertical changes in the clumped distribution of larvae.

When the 571μ,1-m,plankton net was towed on a bottom sled, it yielded significantly ($\alpha = 0.05$) more fish larvae of all important species than all netting at other strata above the bottom (Appendix A-1). Capture rates with the bottom sled were greatest on June 18 when clupeids and smelt dominated the catch. On this date, over 100 times more larvae were captured with the bottom sled than with all the other tows tested. Daytime catches of all taxa were greatest with the bottom sled. It appears that most larvae concentrate near the bottom during the day, but any larvae caught above that bottom concentration do not exhibit any consistent stratification.

Nighttime tows

Nighttime capture rates in the water column above the bottom averaged at least two to three times the daytime capture rates (excluding the bottom sled) for all of the major taxa. The ratios ranged from 1.5:1 to 49:1. The nighttime capture rates of yellow perch, white bass, and freshwater drum were significantly ($\alpha = 0.05$) greater than daytime capture rates on all dates sampled. Nighttime capture rates of clupeids, smelt, and shiners were significantly (α = 0.05) greater than daytime capture rates on most of the dates sampled. The mean ratios over all sampling dates of daytime to nighttime captures were: freshwater drum, 0.07; yellow perch, 0.18; smelt, 0.20; clupeids, 0.24; white bass, 0.29; and shiners, 0.41. Although the nighttime ratios of most larval taxa captured at each depth were not always consistent over the whole sampling period, deep catches tended to be highest and the surface catch lowest (Table 4). Relatively more yellow perch and smelt were caught near the bottom at night compared to other species, while relatively more shiners and clupeids were caught closer to the surface (Figure 6).

Distribution in Relation to Distance from Shore

Daytime larval distribution along the 16-km transect revealed species specific gradients. Clupeids generally were relatively abundant at near-shore stations (Figure 7) where on June 9 and July 2, these stations yielded significantly (α = 0.05) more larvae (Appendix A-6). Gradients were unrecognizable when larval catch was relatively low. Yellow perch prolarvae were significantly (α = 0.05) more abundant at offshore stations as were smelt, and, to a lesser extent, white bass and shiners (Appendix A-6). On May 22 and 23, yellow perch larvae were caught along a distinct gradient from shore and station P16 had the greatest abundance. White bass were captured mostly at station P16. Freshwater drum were captured primarily on June 16. On this date most (α = 0.05) were captured near shore at station P13.

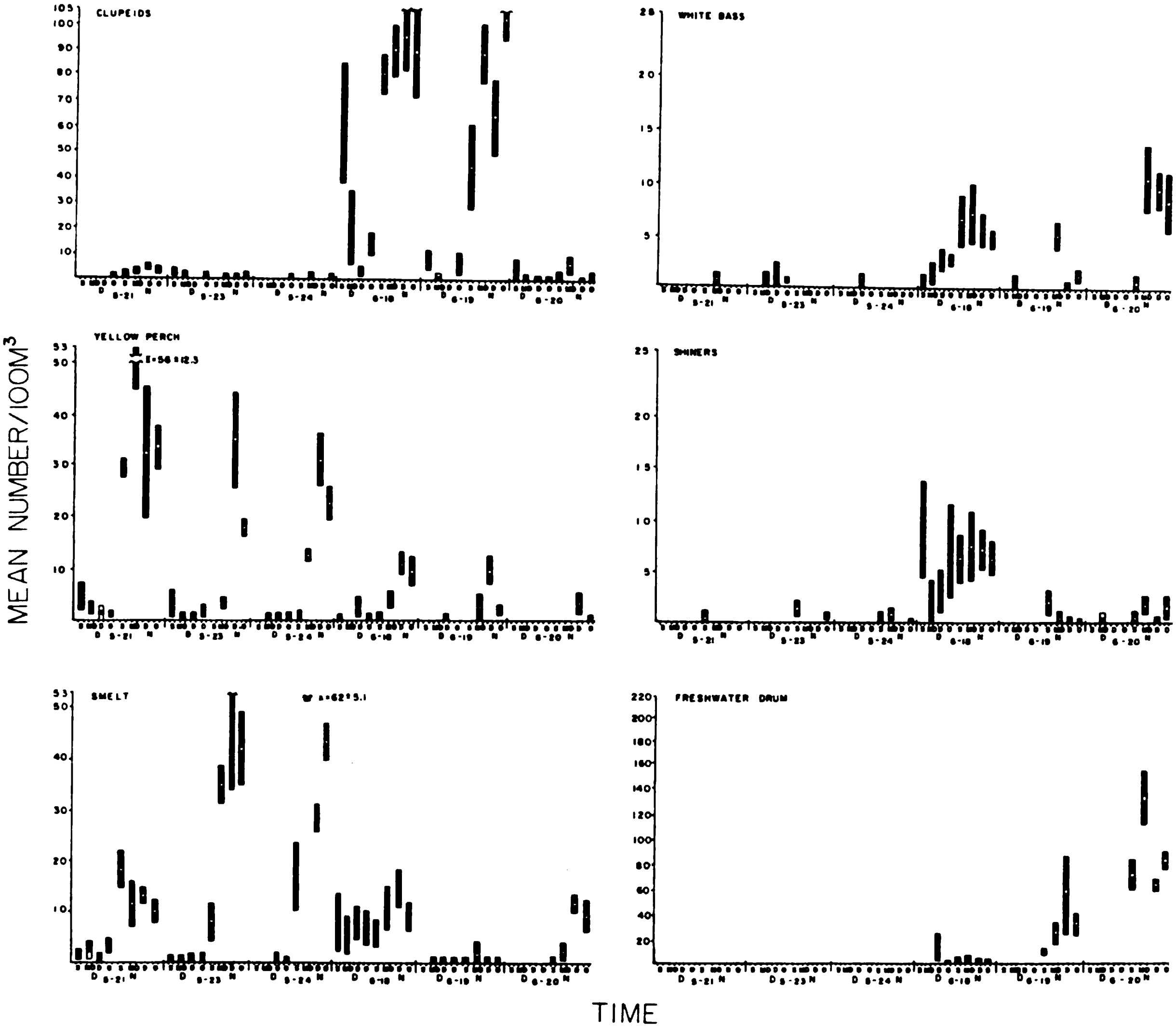

Figure 6. MEAN NUMBER OF LARVAL FISH CAPTURED (±SE) DURING THE DAY (D) AND NIGHT (N) FOR EACH DEPTH STRATUM (S=SURFACE; MD=MIDWATER; D=DEEP WATER; O=OBLIQUE TOW).

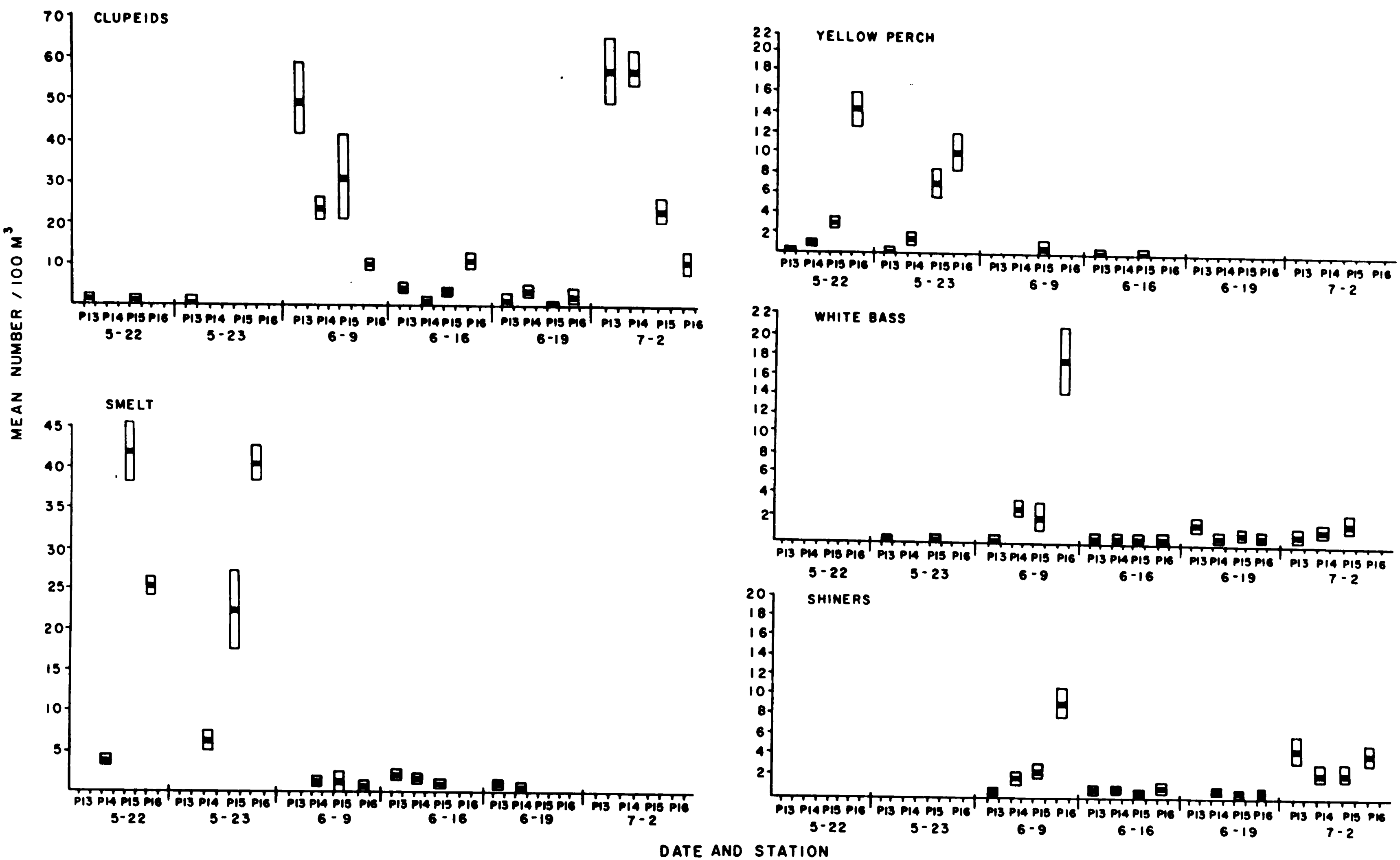

Figure 7. MEAN NUMBER OF LARVAL FISH (±SE) CAPTURED ALONG A 16-KM TRANSECT.

Distributions in the Cooling System

Seasonal

Figure 8 shows the seasonal variation in the capture of larvae of several important taxa captured in the upper discharge canal and the intake region. The comparative annual data from 1973 and 1974 were obtained partly from Nelson and Cole (1975). Seasonal patterns repeatedly emerged in each year even though there was very great temporal variation in the abundance of larvae captured during the periods of time that they were found there. Peak abundances of yellow perch and smelt were the first to appear in May. followed by carp-goldfish and white bass, and finally, clupeids, shiners, and freshwater drum. The differences in the length of time that different species were present appeared more obvious than the time of peak abundance. The earliest spawners tended to persist as catchable larvae for the shortest time period, while the species that are most abundant later in the year were more likely to maintain catchable larvae for a longer period of time. Larvae of carp, white bass, and clupeids consistently appeared in the discharge canal before they appeared in the intake region, indicating that some recruitment took place in the discahrge canal. The larvae of one rarer species, channel catfish, were almost exclusively captured in the discharge canal and the intake region.

Spatial

The probability that recruitment of some species could be occurring in the upper discharge canal is indicated by the annual comparison of total larval numbers shown in Table 2. Carp-goldfish, white bass and clupeids were captured consistently in greater numbers in the upper discharge canal

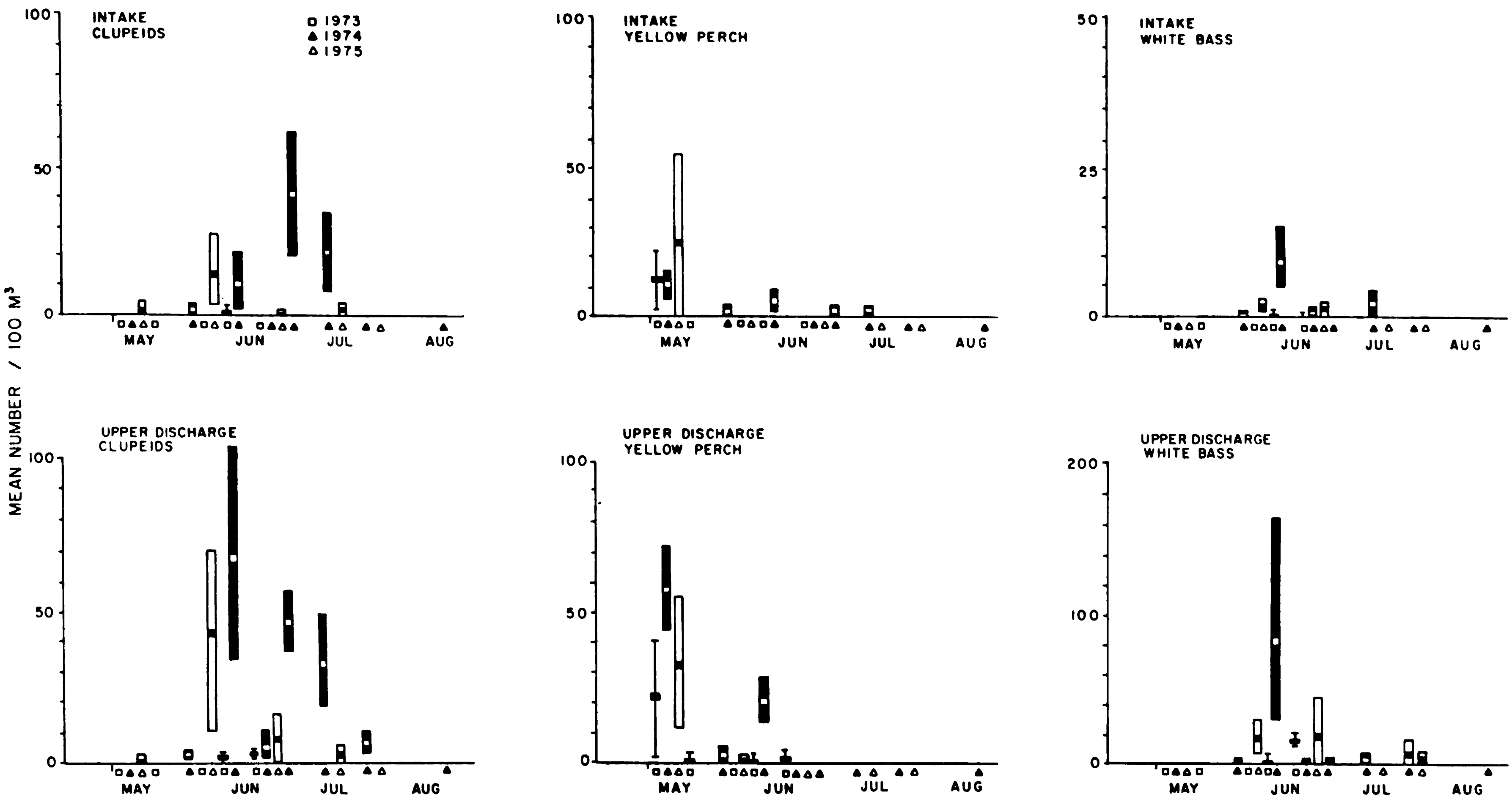

Figure 8. SEASONAL VARIATION IN ABUNDANT SPECIES OF LARVAL FISH IN THE INTAKE REGION AND UPPER DISCHARGE CANAL OF THE COOLING SYSTEM (Mean ±95% Conf. Int.).

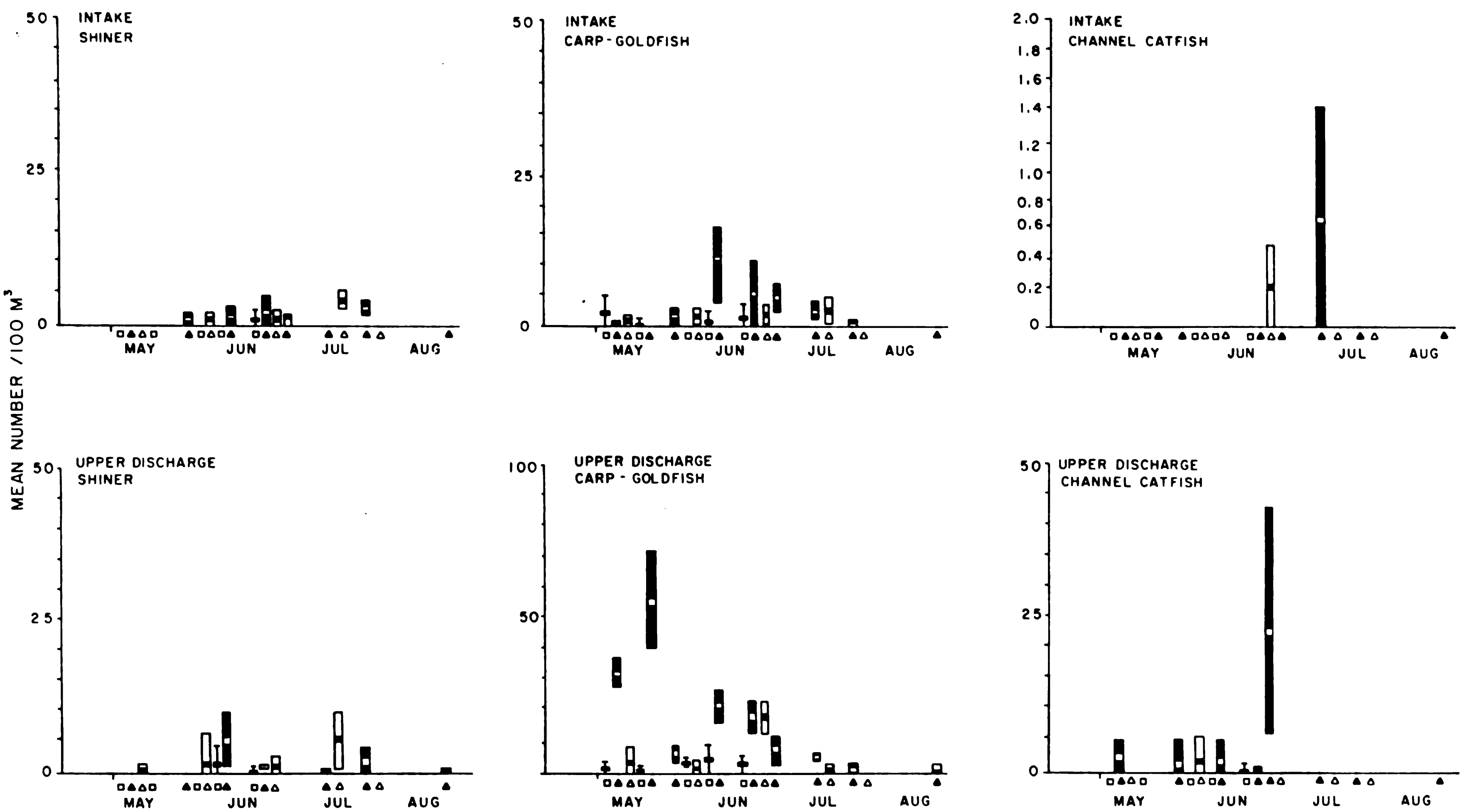

Figure 8 (cont'd).

than in the intake region. This was not apparent with the perch, shiners or drum larvae. It also appears that larvae of most species are consistantly less abundant in the lower end of the discharge canal than in the upper end of the discharge canal. Most of the abundant taxa were relatively common in the lake. The exception, carp-goldfish larvae, were much more abundant in the river, like several of the rarer taxa including the ictalurids and centrarchids (Table 2).

Variability of Results

Even though consistent annual patterns emerge in the temporal and spatial patterns of larvae around the cooling system, great spatial variation only allows the statistical discrimination ($\alpha = 0.05$) of major differences at the intensity sampled. This variability appeared to be caused by "patchy" distributions and strong fluctuations in recruitment during the spawning season.

The influence of patchy variation is exhibited in Figure 9 which shows, for important species, the dates that spatial variation was minimum and maximum in the cooling system. Abundances tended to fluctuate at any one particular station in response to patches of larval fish moving through the lake ecosystem and the cooling system. Differences in concentrations at the three lake stations, which were all within 4 km of each other, could exceed an order of magnitude on one date and be virtually indistinguishable on another date.

The degree of variation determines the sampling intensity required to differentiate concentrations in different areas at various permissable errors of the mean. Figure 10 illustrates how the variation is influenced by patchy

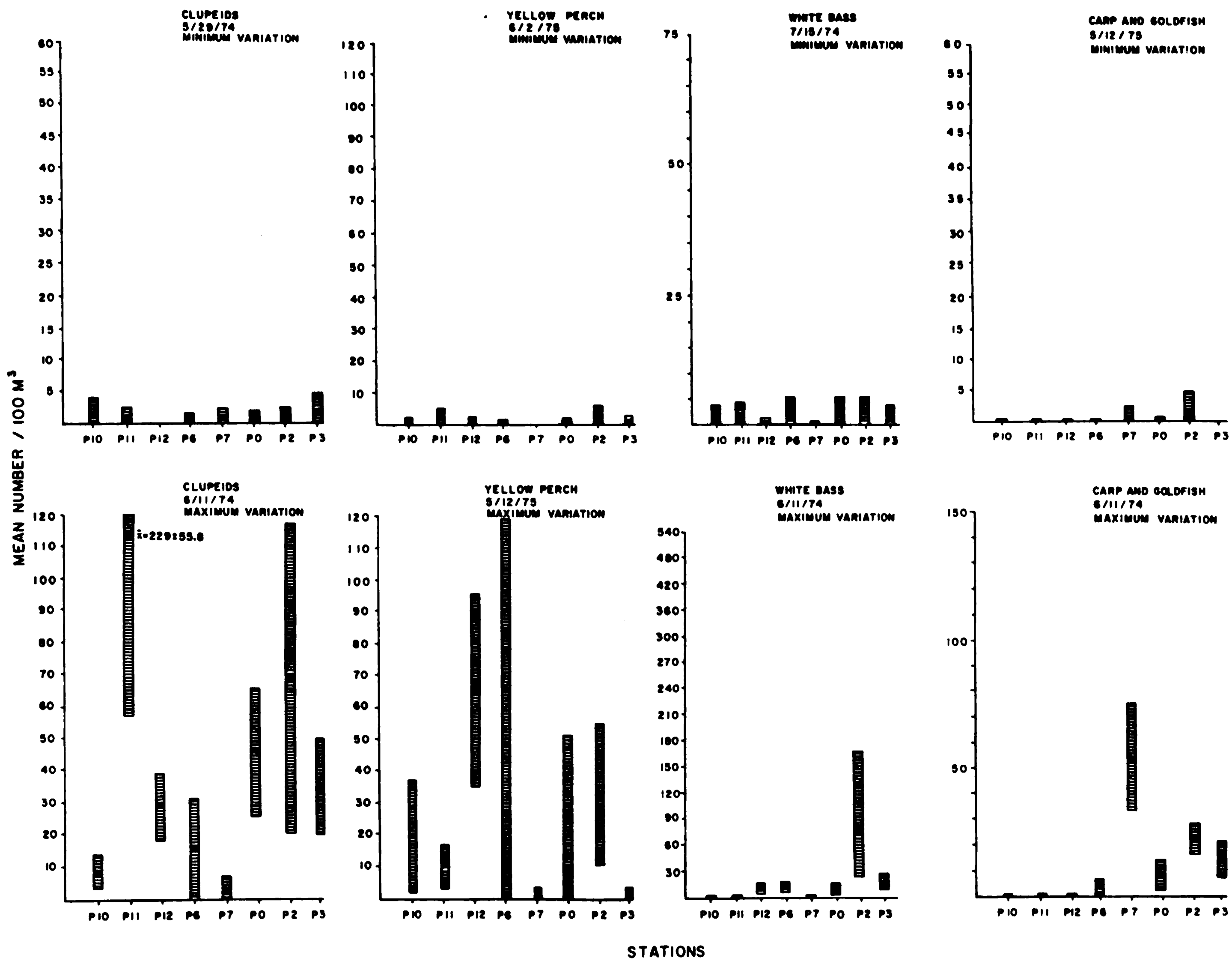

Figure 9. MINIMUM AND MAXIMUM VARIATION (±95% CONF. INT.) IN THE CATCH OF LARVAL FISH NEAR THE MONROE POWER PLANT.

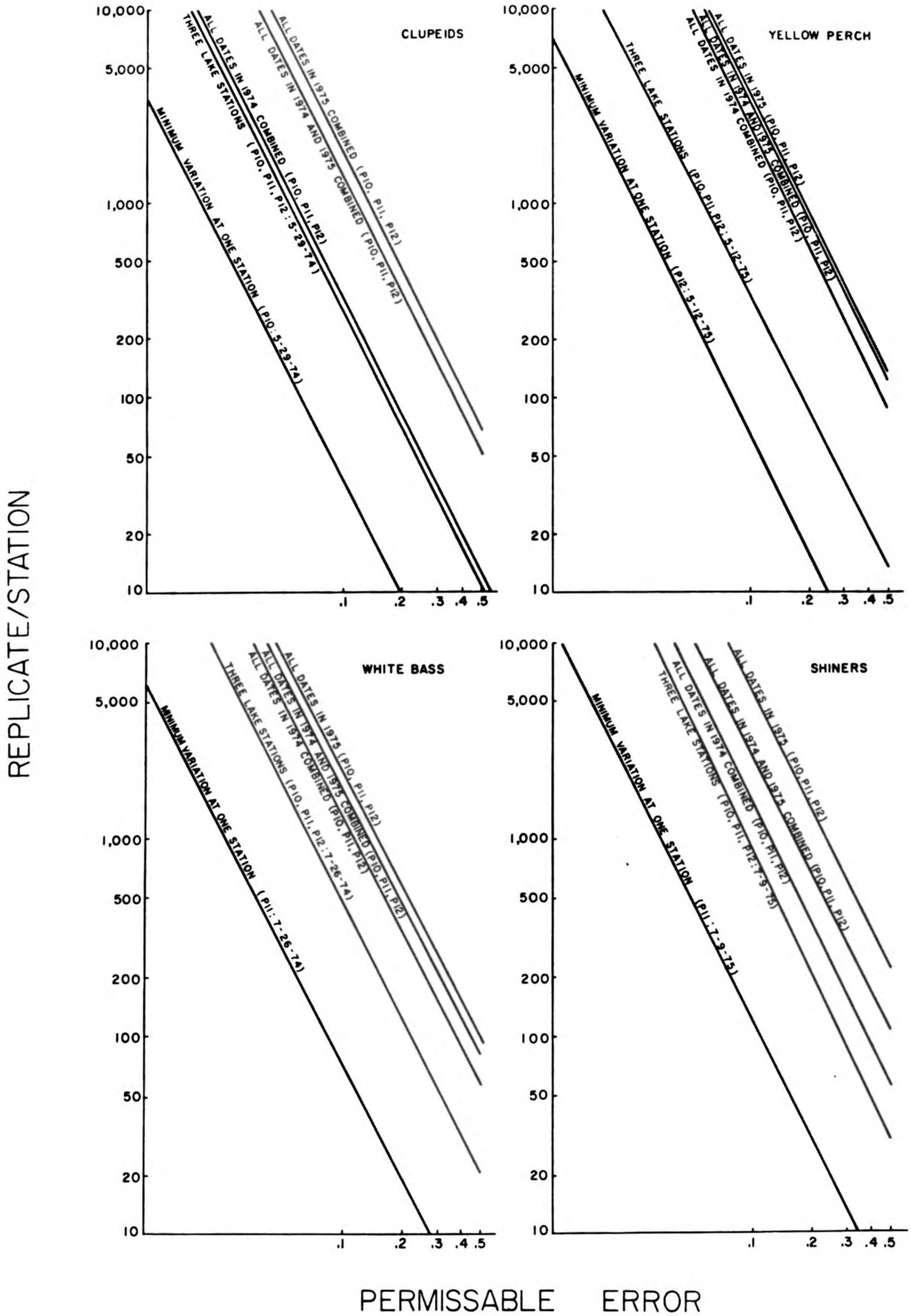

Figure 10. SAMPLING INTENSITY REQUIRED AT VARIOUS PERMISSABLE ERRORS OF THE MEAN.

distributions and temporal change. The variation was greatest when the mean catch was low and least when the mean catch was high. The minimal variation that is plotted for variation among replicates defines an ideal situation requiring the least sampling intensity. The additional spatial variation introduced by sampling at two other nearby (2 to 4 km apart) stations on the same date requires 6 to 10 times more intensive sampling to maintain the same permissable error. When sampling at all three stations, the intensity of sampling must be increased at least 100 times (depending on species and date) to reduce the permissable error from 50 percent to 10 percent of the mean with a 95 percent confidence interval.

When seasonal variation is also introduced, the sampling intensity required may be increased from 10 to 1000 percent depending on the species and the year sampled.

There was considerable difference in the seasonal variability defined for the two years; 1974 was less variable than 1975 for all important species. This demonstrates that the long-term sampling intensity required over a sequence of annual studies to meet a specified error cannot be precisely determined with one year of data. To a certain extent, the variability encountered is proportional to the mean concentration of larvae captured. The rare species encountered in the study area would require an extraordinary sampling intensity to precisely estimate their population sizes.

Estimated Mortality

The studies of larval fish mortality in the cooling system indicate that substantial mortality occurs following condenser passage (Table 5). The mortality at the intake station caused by technique and natural events

Table 5. PRELIMINARY ESTIMATES OF MORTALITY IN THE COOLING SYSTEM AT THE MONROE POWER PLANT.
(ratio of dead to total catch of alive and dead)

Species	Intake	Total Number Caught	Upper Discharge	Total Number Caught	Lower Discharge	Total Number Caught
Carp	0.09	20	0.27	8	low abundance	1
Yellow perch	0.20	40	0.72	5	low abundance	2
Clupeid	0.15	66	0.79	11	0.80	2
White bass	0.04	25	0.25	3	0.80	5
All larvae	0.16	176	0.73	29	0.59	10

appeared to be species specific. A relatively large proportion of white bass and carp larvae were dead in the intake canal while a relatively large proportion of yellow perch were alive. Following condenser passage, the proportion of dead larvae of all taxa captured increased from 20 to 80 percent compared to the reference station in the intake canal. Considering the probability that some larvae hatch in the discharge canal, the estimates of larval mortality caused by condenser passage may be conservative. For example, yellow perch were the least likely to hatch in the discharge canal and their death rate was about the highest. The total catch of dead larvae in the lower discharge canal was similar to that in the upper discharge canal, but there were fewer fish captured in total. Coefficients of variation (Table 6) were consistently high making precise estimation of mortality difficult. These estimates, in combination with the consistently lower numbers observed in the lower discharge canal compared to the upper discharge canal, indicate that very large mortalities take place among larvae that pass through the condenser.

Entrainment Estimates

Estimates of the total annual entrainment of all species are presented in Table 7 for the three years of study, based on captures in the upper discharge canal. These values were calculated from the estimated length of time larvae were present and the mean catch on the dates sampled. In some cases, the 1973 estimates are low because sampling was discontinued before the season ended for several of the taxa. However, species like yellow perch and white bass should be comparable and, of the three years, 1973

Table 6. COEFFICIENTS OF VARIATION OF ALL LARVAL FISH SPECIES CAPTURED AT MORTALITY STUDY STATIONS.

Date	Intake	Upper Discharge	Lower Discharge
4/28	172.0%	61.1%	95.0%
5/18	338.4%	108.0%	245.0%
6/3	66.6%	127.1%	97.3%
6/26	82.6%	75.3%	103.0%

Table 7. ESTIMATED NUMBER OF LARVAE POTENTIALLY ENTRAINED AT THE MONROE POWER PLANT IN 1973[1], 1974 AND 1975.
(millions/year ± 95% conf. int.[2])

Species	1973	1974	1975
Clupeids	0 ≤ 0.8 ≤ 1.6	102.1 ≤ 168.9 ≤ 255.0	29.0 ≤ 62.9 ≤ 102.3
Carp	0 ≤ 3.3 ≤ 6.9	94.4 ≤ 132.6 ≤ 180.3	14.8 ≤ 25.7 ≤ 36.6
White bass	1.1 ≤ 2.6 ≤ 4.1	28.1 ≤ 95.2 ≤ 200.0	0.3 ≤ 7.8 ≤ 15.3
Yellow Perch	0 ≤ 2.2 ± 5.1	59.6 ≤ 83.1 ≤ 111.5	13.7 ≤ 29.3 ≤ 44.9
Channel catfish	~ .1	6.8 ≤ 28.6 ≤ 64.9	0 ≤ 1.7 ≤ 4.3
Freshwater drum	0	7.8 ≤ 20.3 ≤ 38.3	~ 0.1
Shiners	0.8 ≤ 1.6 ≤ 2.4	1.1 ≤ 15.7 ≤ 39.6	1.4 ≤ 10.3 ≤ 19.2
Sunfish	~0.3	1.1 ≤ 8.6 ≤ 19.9	0 ≤ 1.4 ≤ 3.4
Bass	0	~0.7	~0.9
Smelt	~0.2	~0.7	0.2 ≤ 3.2 ≤ 6.2
Crappie	~0.6	~0.3	0
Walleye	~0.1	~0.2	0

Table 7. (cont'd)

Species	1973	1974	1975
Suckers	~0.2	~0.2	0
Trout perch	~0.1	~0.2	~0.2
Log perch	~0.1	~0.1	~1.0
Total Larvae	$1.9 \leq 12.2 \leq 20.1$	$398.4 \leq 556.0 \leq 841.3$	$59.4 \leq 144.5 \leq 232.2$

[1]1973 sampling was completed in mid-June.

[2]Calculated by multiplying the number of larvae/m^3/sampling date (and associated confidence intervals) at the upper discharge by the volume flow through the cooling system on that date to determine a daily estimate of entrainment. The daily estimate was assumed to represent that sampling date plus half the number of days to a subsequent sampling date. Each daily estimate was multiplied by the number of days that it represented and the sum of these gave the annual estimate of entrainment.

produced the lowest numbers while 1974 produced the highest. The differences in the estimate between years usually was less than an order of magnitude among species fairly represented by full seasonal sampling.

Although variances are great, as indicated by mean confidence intervals, the annual differences in density among the more abundant species are surprisingly consistent. This would indicate that some universal environmental feature was strongly influencing the capture rate of all species.

The relative abundance of larvae caught in this system is not necessarily indicative of the actual entrainment ratio because taxa like carp-goldfish, white bass, clupeids and channel catfish probably hatch in the discharge canal. Therefore, estimated entrainment abundances are probably high for those species.

DISCUSSION

Technique

The results of the technique comparisons made in western Lake Erie should be widely applicable to any comparable, turbid shallow lake or reservoir that is inhabited by the same or similar fish populations. One of the primary tenets of practical sampling is to representatively, but efficiently, assess the relevant characteristics of larval fish distributions. Practicality urges that the information gained from sampling be measured against the effort expended. Therefore, time and expense must be included among the determinants of the most suitable techniques.

The most effective daytime sampling approach used to assess larval fish density is a combination of oblique, 1-m net tows and 1-m net tows made at the bottom with a sled. During the day, oblique tows alone do not include the greatest concentration of larval fish at the bottom because the obliquely towed net cannot be set close enough to the bottom. Above the bottom, there appeared to be no consistent, depth related pattern to the vertical distribution so towing at discrete depths yields less information per unit effort than oblique tows of the same length.

Neither the Kenco pump or the modified "high-speed" Hardy plankton sampler were any better than sampling with a 1-m plankton net. Their capture rate at the surface was the same or less than the rate with a 1-m, plankton net and both techniques were more time consuming. Icanberry and Richardson (1972), in using a pump for zooplankton sampling, found no significant difference in their catch compared to a 150µ-mesh plankton net. In this study, pumping took about 20 times as long as tow netting to process the same amount of water. Both the pump and the "high-speed" sampler are more difficult to use than the tow net for depth-integrated sampling. The "high-speed" sampler is particularly impractical in relatively shallow, shore zone waters.

The nighttime sampling effort yielded more larvae then the daytime effort, just as others (Miller et al., 1963; Clutter and Anraku, 1968; Noble, 1970; Faber, 1967; and Marcy, 1973) have described for a variety of environments. From 2 to 50 times as many larvae were captured in oblique tows at night compared to day. The estimated catch per square meter of surface at night, without the bottom sled, averaged close to the daytime estimate with the bottom sled. This similarity suggests that larvae do not appear to be consistently concentrated near the bottom at night, so the sled, which is particularly cumbersome to use at night, may be unnecessary if all sampling were conducted at night. The variability among sample replicates was less at night than during the day. Therefore, night sampling can yield more information per unit effort about horizontal distributions.

Oblique night sampling is more effective than stratified night sampling. Although species like perch and smelt tend to concentrate in the lower strata, the differences in nighttime vertical distributions above the bottom are not nearly as great as differences in current velocities. Depth related variations in water velocity are much more likely to influence the determination of the nighttime changes in larval fish distributions than the relatively minor vertical variations in larval densities. Studies of wind-generated movements in various environments indicate that velocities can easily decrease an order of magnitude within a few meters of the surface (Hutchinson, 1957; Hartley et al., 1966) and this is substantiated by other studies (Cole, 1976) in western Lake Erie.

Hypothetically, both the mesh size and the towing time can influence the catch rate of plankton nets. Heron (1968), Wichstead (1963) and Tranter (1963) all found that different mesh sizes affect the yield of zooplankton because of the animals size distribution, the net filtration efficiency and the rate of net clogging with suspended matter. In this study, all nets larger than 363μ captured far fewer prolarvae than the 363μ net. However, 571μ and 760μ-mesh appeared to be suitable for most postlarvae while 1000μ mesh was unsuitable. In environments like western Lake Erie, where there are often strong spatial and temporal variations in the concentrations of suspended solids, the optimum net size will vary accordingly. Either the mesh size will have to be adjusted to suit the conditions, or a "compromise" mesh size should be selected. In this part of Lake Erie, the compromise mesh size appeared to be near 400μ to 500μ.

The length of a tow that can be made without affecting the capture rate also is likely to depend on the mesh size because the amount of clogging from suspended matter depends on the time towed (Vanucci, 1968). The results of towing 571μ-mesh nets from 1 to 5 min indicated no differences in capture rates for any towing times under conditions that were sampled in Lake Erie. The patchiness of larval fish distributions may influence the choices of a tow length if the fileering efficiency isnnot greatly affected by the towing time. Noble (1970) noted that short tow times may enable an increased number of samples and decrease the variability at a station which may be introduced by longer tows. This is likely to be true when the larvae are grouped in relatively large patches or are not at all clumped in their distributions. On the other hand, Wiebe (1971) thought he gained precision by lengthening tows whenever larvae formed small "pat :es" because there is greater probability of sampling a similar ("right") number of patches.

In our studies the length of tow between 1 and 5 min did not affect the catch rate or variability of catch even though the variability among replicates was up to a 300 percent coefficient of variation. The Lake Erie distributions appear to be less variable than those deccribed by Wiebe (1971). Considering the information return per unit effort in western Lake Erie, shorter tows of 1 to 2 min seem to yield more than longer tows of 4 to 5 min because more sampling replication can be gained within the total time limits.

The most efficient approach to defining horizontal distributional variations near shore seems to be sampling at night with 1 to 2 min oblique tows. Even though night navigation can be difficult and night sampling is more time-consuming than day sampling, greater information appears to be gained from night sampling. The size of water body, distance from shore and availability of lighted landmarks and buoys will help to determine the relative effectiveness of night sampling.

Distributions

The kinds of distributions exhibited by different fish species not only helps to clarify their relative vulnerability to intake entrainment but also aids in choosing a suitable sampling design. The combination of physical heterogeneity and behavioral attributes typically causes nonrandom, "patchy" (Cushing, 1961), "clumped" (Wiebe, 1970), "aggregated" (Barnes and Marshall, 1951), or "over-dispersed" (Cassie, 1959) distributions which are usually described or approximated by the negative binomial (Taylor, 1953) or Poisson-log-normal distribution. These distributional variants have been hypothesized to originate from water discontinuities and heterogeneity arising from weather phenomena and tributary hydrodynamics or interspecific and intraspecific behavioral patterns (Cassie, 1962; Saville, 1965; Barnes and Marshall, 1951; and Wiebe, 1971). In western Lake Erie, both wind and tributaries could influence the patchiness of larval fish distributions. The relatively great sample variation among replicates at a station may indicate that the larvae are concentrated in "swarms" of relatively small volume (less than a few meters in diameter) like those described by Barnes and Marshall (1951). However, the average concentration within groups of swarms at different stations could vary by an order of magnitude within a few kilometers, just as Silliman (1946) found in the distributions of pilchard, Sardinops caerula, eggs. The distributions of most larval species frequently seemed to occur as patches over 100 m long (length of a 3 min tow). It was not possible to tell whether gradual density gradations or large discontinuous patches existed among stations. Therefore, the upper size limits of the patches are unknown.

The configuration of these patchy distributions may be at least partly dependent on the fluctuations of tributary mixing with lake water, wind-generated vascillations, and larval locimotion. Both Bishai (1960) and Saville (1965) state that current is the most important determinant of larval fish distribution in oceanic environments. In western Lake Erie, currents are controlled mostly by the wind and the Detroit River. Prevailing southerly winds tend to maintain a clockwise gyre off the mouth of the Maumee River in the southwestern corner of the lake (Ecker and Cole, 1976), therefore, the prevailing currents move a combination of Maumee and Detroit River water northward along the shore past the power plant intake. Several kilometers off shore the water is derived almost entirely from the Detroit River (Hartley et al., 1966). The results from the sampling transect, which extended deeply into Detroit River waters, indicate that densest concentrations of yellow perch, smelt, and white bass larvae are entering the western basin from the Detroit River. Species of fish like the shiners did not demonstrate any clear density gradient associated with the distance from shore. But, species like the clupeids and freshwater drum are most abundant near shore and they may have hatched near the power plant or were carried northward from the Maumee Bay region. Species groups like the catfishes, sunfishes, and carp-goldfish were common in the river but not in the lake. These species require marshy or protected shoreline environments for successful spawning and most river larvae probably came from marsh overflow and protected river edges.

Similarly, the larvae of fish species in Lake Erie are not all distributed alike in the water column, although all of the abundant larvae appear able to move vertically in apparent response to changing light intensity. Nighttime concentrations in the water column were much greater than daytime concentrations above the bottom, but they were similar (although variable) when daytime bottom tows were included in the comparison. An alternative explanation for the apparent difference between day and night concentrations is differential net avoidance. But, that seems less plausible than vertical movement because the slower prolarvae are more likely to be vulnerable to capture during the day than the faster postlarvae. There was little evidence of such differences. Also, the "high-speed", modified, Hardy, plankton sampler would have been much more effective than tow nets if net avoidance had been important. This diurnal vertical migration between the slowly moving bottom waters and the relatively rapidly moving surface waters strongly affects the probability that larvae will be carried near an intake.

Some subtle differences occurred in the vertical distribution of the abundant species. Most members of all species remained close to the bottom during the day and mostly in the lower half of the water column at night. But, freshwater drum larvae seem to move toward the bottom almost immediately after hatching from their floating eggs, and remain closer to the bottom during the day than other species. Yellow perch, smelt, and white bass also tend to avoid surface waters, at least more so than the clupeids which are the least likely af all the species sampled to avoid the relatively rapid currents near the surface. Therefore, a larger proportion of the clupeids may be carried greater horizontal distances away from the points of origin than other species. Relatively small proportions of the bottom oriented species are likely to be carried long distances away from their hatching sites.

Entrainment Susceptability

Counting entrained animals alone cannot reveal what impact a once-through cooling system has on populations in the source waters. Data also should be gathered in the source waters as well as the cooling system. These results, similar to Marcy's (1971; 1973), point out that entrainment probably does kill larvae at high rates. But, the sampling intensity required to identify an entrainment effect on lake populations depends on what proportion of the population can be sacrificed to plant operation without endangering the fishery resource.

It is possible from the data presented here to tentatively estimate the vulnerability of more abundant larval fishes to entrainment.

Table 8 was constructed to show the relative impact of entrainment on abundant larval fish populations near the west shore of Lake Erie. The relative vulnerability of the population to entrainment was estimated by using information gathered from the 16-km transect, the proportion of daytime and nighttime larvae in the water column, and the estimated rate of water movements at different depths in the water column. It was assumed that the proportions of larvae captured at each of the transect stations was representative of a lake area between lines 8 km to the north and south of the transect. Data from stations P10, P11, and P12 were used to estimate the abundances in the shore zone (within 4 km of shore) and abundances in the three off shore zones centered on the transect where proportioned in relation to known concentrations in the shore zone and the percent captured at stations along the transect. All data from lake stations P10, P11, and P12 and the cooling system were sampled at two to three week intervals, and it was assumed that few if any larval cohorts were sampled more than once. An estimate of the total abundance of larvae present in the water column during the day was then calculated for an area 16 by 16 km (approximately 10 percent of the shoreline and area of the western basin). At average wind speeds, all of this area could be within a one-week drift time to the plant intake.

Table 8 reveals that based on these estimates, there may be considerable differences in the vulnerability of species to entrainment. Of course these estimates are crude because of the nature of the sampling effort, but they give some indication of the magnitude of entrainment impact. These estimates will be improved by further research efforts in progress, but present indications certainly indicate that the proportions entrained could be potentially fairly large for certain species, especially

Table 8. ESTIMATED RELATIVE VULNERABILITY OF IMPORTANT LARVAL FISH TO ENTRAINMENT AT THE MONROE POWER PLANT FROM AN AREA 16 KM BY 16 KM IN LAKE ERIE IMMEDIATELY ADJACENT TO THE POWER PLANT.
(numbers in millions)

Species	Vel.[1]	Dist.[2]	Days to Shore[3]	Yr.	Estimated Numbers in Relation to Shore[4] 2 km	6 km	11 km	16 km	Entrainment Est.[5]	Entrainment Est.[6]	Entrainment Percent Est.[7]	Entrainment Percent Est.[8]
Drum	1.0	2.0	2	74	27.5	0.56	0	0	22.47	21.68	80%	77%
				75	0.64	0.01	0	0	49.5	20.56	76%	31%
Clupeids	1.0	7.9	8	73	60.16	51.04	32.81	38.28	37.45	3.30	21%	2%
				74	498.34	422.83	271.82	312.12	688.39	122.67	46%	8%
				75	113.81	218.56	62.08	72.42	141.87	55.67	41%	16%
Shiners	0.9	11.0	12	74	69.44	52.08	86.80	138.88	85.89	17.99	25%	5%
				75	9.05	6.79	11.32	18.11	10.72	9.56	24%	21%
White bass	0.7	13.7	15	74	114.24	371.28	314.16	205.63	119.97	104.04	4%	4%
				75	9.06	29.46	24.93	163.20	7.08	6.88	3%	3%
Smelt	0.9	13.4	15	73	133.12	665.60	272.89	3128.32	85.27	1.18	1%	0.1%
				74	1.47	73.60	301.76	345.92	20.37	0	3%	0
				75	3.93	19.68	80.68	92.49	3.24	2.77	2%	1%
Yellow Perch	0.9	13.9	16	73	19.52	683.20	224.48	653.92	14.90	9.25	2%	1%
				74	75.84	265.44	872.16	2540.64	58.58	83.89	2%	2%
				75	113.92	398.92	1310.08	3816.32	54.90	36.60	1%	0.1%

[1]This is the average velocity (km/day) that a species population moves. It is calculated from the proportion of fish captured during the day and night from each of the three depths sampled

over all dates that larvae were captured. Daytime was assumed to be 14 hrs and nighttime was assumed to be 10 hrs. Each stratum represented a proportion of the total population present. The proportion captured was multiplied by the estimated water velocity for that stratum and the results summed over all strata. Mean surface and midwater current velocities were assumed to represent 2% of the mean resultant wind velocity while the deep current represented 10% of the surface current (Hutchinson, 1957):

$$\sum_{i=1}^{n} \left(\frac{\sum_{i=1}^{x} \bar{D}_i P_D + \bar{N}_i P_N}{\sum_{i=1}^{n} \left(\sum_{i=1}^{x} \bar{D}_i P_D + \bar{N}_i P_N \right)} \cdot V_D \right) = V_H$$

Where $\bar{D}_i$ = mean number/m^3 captured during the day for each depth strata; where N_i = mean number/m^3 **captured during the night for each depth strata; P_D = proportion of daylight hrs; P_N = proportion of dates mean number represents; n = number of strata; x = number of dates with fish samples; and V_H = mean horizontal velocity of population.**

[2]The mean capture distance from shore was calculated by apportioning the total number of larvae for each species captured along the transect into the propotion of the total each transect station represented. The proportion captured at each station was then multiplied by the distance from shore and the results were summed:

$$\sum_{i=1}^{n} \left(\frac{t_i D_i}{T} \right) = \bar{D}$$

Where T = total number/m^3 caught at all 4 stations along the transect; t_i = number/m^3 caught at each station along transect over all sampling dates; D_i = distance of each transect station from shore; and $\bar{D}$ = mean capture distance from shore.

[3]The average number of days to move larvae to the intake at the power plant was calculated by dividing the mean capture distance from shore by the weighted horizontal velocity:

$$\frac{\overline{D}}{V_H} = \text{Days}$$

[4]The estimated numbers present at different distances from shore was calculated by assuming the mean catch at the three lake stations (or one in 1973) within 2 km of shore represented the total capture within the first 2 km plus half the distance to the second transect station during the time larvae were estimated to be present. The volume within an area 16 x 4 km was calculated with a mean depth of 5 m, and the number of larvae within that volume was determined. Using the prior proportion of larvae captured along the transect in 1975, the total present within a 16 x 16 km area was determined and the number within each transect sector was determined:

$$A_1 = \overline{F} \cdot V_1$$

$$A_2 = \overline{F} \cdot V_2 \cdot t_2/T$$

$$A_3 = \overline{F} \cdot V_3 \cdot t_3/T$$

$$A_4 = \overline{F} \cdot V_4 \cdot t_4/T$$

Where $\overline{F}$ = mean catch/m^3 at station P10, P11, and P12 (or station P5 in 1973) over all dates of capture. Where V = volume of area surrounding P10, P11, and P12 (16 x 4 km) to a depth of 5 m; A_1 = area in first transect sector (Figure 2); A_2 = area in second sector; A_3 = area in third transect sector; A_4 = area in fourth sector; T = total number/m^3 caught at all 4 stations along the transect; t_2 = number/m^3 caught at station P14; t_3 = number/m^3 caught at station P15; and t_4 = number/m^3 caught at station P16.

[5]Theoretical maximum lake entrainment was estimated by assuming maximum pumping of cooling water ($85 m^3/sec$). By weighting the amount of water derived from the lake compared to the amount from the river for each month the larvae were present, a mean daily lake water requirement was computed. The weighted mean lake water requirements per day was extrapolated to the length of time a particular larval species would be present to yield the total lake water requirements. This water was assumed to be obtained primarily from the immediate, 4-km area while any additional requirements would be met by the succeeding areas. The percent of the water derived from each transect sector was calculated and that percent also represented the percentage number of larvae entrained. This percent was multiplied times the number present in the transect sector to yield numbers entrained. G = larvae in first transect sector plus any additional larvae from adjacent sector, if required; V = volume within first sector of transect and additional volume from adjacent sector, if required; L = length of time (captured days + 14) larvae estimated to be present; R_i = riverine larvae entrained over period larvae present:

$$E = \frac{G\ V}{\sum_{i=1}^{n} \left(1 - \frac{R_i}{C} \right) (C)(L)}$$

[6]The theoretical maximum condenser passage assumed an 85 m^3/sec pumping rate. The mean number/m^3 of larvae captured in the upper discharge canal was multiplied by the total number of days the larvae were estimated to be present. This number was then multiplied by the total amount of water pumped during a comparable time period yielding the total number of larvae present.

C = as above

$\overline{U}$ = mean number of larvae/m^3 captured in upper discharge canal

L = length of time larvae estimated to be present (days of capture = 14 days)

M = estimated number of larvae to pass through condenser

$M = L\ [(\overline{U})(C)]$

[7]Percent total entrainment was calculated by comparing the theoretical maximum entrainment to the total number of larvae estimated to be present within a 16 x 16 km area.

[8]Percent total condenser passage was calculated by dividing the estimated lake population by the maximum number estimated to pass through the condenser.

freshwater drum and clupeids. Assuming the study area is roughly representative of the whole basin, less than 1 percent of most fish populations are being entrained at the plant. However, from 5 to 15 percent of the drum and clupeid larvae may be entrained. Based on theoretical considerations of commercial catch and fecundities, Nelson and Cole (1975) estimated similar percentages. At the present time, the intake at the Monroe Power Plant exceeds the intake of all other cooling waters taken from the western basin of Lake Erie about 2 to 1. However, future expansion on the Great Lakes may require 10 times the present cooling needs over the next few decades. Therefore, the potential mortality percentages in drum and clupeids border on those that may have a measurable impact on adult populations, especially in the distant future.

Jensen (1971) has indicated that reduction of as little as 5 percent in recruitment may eventually affect the adult population of at least one species of fish. However, this is debatable, since Beland (1974) has questioned Jensen's conclusions and there have been no empirical studies published that verify these kinds of projections. Determining a 5 percent impact on recruitment with statistical confidence for any particular year of study would demand a much more intensive sampling effort than that executed during this study because of the high variability in larval fish distributions.

The variability is derived from vertical and horizontal variation, and temporal variation caused by changing rates of larval recruitment. Although variability at a particular sampling site in the lake may be only moderately high, the variability among different stations only a few kilometers apart often is high and inconsistent from one day to the next. This "patchiness" greatly affects any assessments of change in population abundance within the cooling system as well as estimates of the proportions of lake populations that are entrained. We do not know enough about the lengths of time that larvae are susceptible to net capture and the probability of overestimating or underestimating the actual number of larvae recruited into the lake population. At the intensity of sampling applied during these studies, the annual entrainment of populations may be reasonably estimated, at a 95 percent confidence interval, within 100 to 1000 percent of the mean.

Variability in the lake is as great as variability in the cooling system. The intensity of sampling in the lake must consequently be comparable to that in the cooling system to produce similar confidence interval proportions.

There could be a prohibitively great expense involved in generating precise enough estimates of entrainment proportions that would be meaningful to the resource manager. But, one sampling method which could be applied to reduce variability would be to pool temporal variation by continuous sampling procedures using pumping devices. Although this is a reasonable approach for sampling most cooling systems, formidable technical and economic problems thwart any continuous larval fish sampling scheme in the source waters.

Taking into consideration the exploratory nature of these pilot studies, there is a need to refine estimates. However, there does not appear to be any immediate indication that the power plant is extremely destructive to larval fish life, particularly to recreationally and commercially important species. Future estimates of larval fish distribution and potential entrainment could be improved in several ways. Almost all of the fish are most vulnerable to entrainment at night because they are in the faster moving waters nearer the surface. Therefore, horizontal distributions would be better estimated at night anywhere night navigation is feasible. The actual growth rate of larval fish and their capacity to avoid net capture as they grow should be better evaluated. Also, the relative vulnerability of larval fish to natural mortality should be identified as it relates to distribution. Are near-shore populations more likely to die from natural causes than offshore populations? Are hatches in the tributaries more likely to survive to reproductive age classes that hatches in the lake? Answers to these questions will provide information for suitable coastal zone management including appropriate siting and operation of cooling systems.

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APPENDIX

Table A-1. TUKEY'S POST-HOC COMPARISON OF MEAN CATCH[1] USING DIFFERENT SAMPLING TECHNIQUES[2].

Clupeids							
5-21	F	A	C	D	E	H	
Mean	0.2314	0	0	0	0	0	
5-23	C	F	D	A	E	H	
Mean	0.4823	0.2891	0.1214	0	0	0	
5-24	F	A	C	D	E	H	
Mean	0.0698	0	0	0	0	0	
6-18	G	H	C	A	F	D	E
Mean	2.7101	2.4386	1.7411	1.2800	1.1721	1.1294	0.5678
6-19	G	C	F	D	E	A	H
Mean	1.8491	0.8921	0.8265	0.3387	0.1200	0	0
6-20	G	F	D	A	C	E	H
Mean	2.0791	0.2868	0.2341	0.1821	0	0	0
Yellow Perch							
5-21	C	D	E	F	A	H	
Mean	0.6104	0.4434	0.3422	0.2891	0	0	
5-23	C	F	D	E	H	A	
Mean	0.5281	0.4434	0.2287	0.1241	0	0	
5-24	D	E	F	C	H	A	
Mean	0.1832	0.1241	0.0713	0	0	0	
6-18	G	H	E	C	F	D	A
Mean	0.9522	0.6926	0.4434	0.0720	0.0611	0	0
6-19	G	E	F	H	C	D	A
Mean	0.4934	0.0700	0.0700	0.0700	0	0	0
6-20	G	C	D	E	F	H	A
Mean	0.5741	0	0	0	0	0	0

Table A-1 (cont'd.)

White Bass

5-23	E	F	A	C	D	H	
Mean	0.2301	0.1421	0	0	0	0	
5-24	E	A	C	D	F	H	
Mean	0.1792	0	0	0	0	0	
6-18	G	H	F	D	C	A	H
Mean	1.4214	0.5687	0.4891	0.3398	0.1821	0	0
6-19	G	D	E	F	A	C	H
Mean	1.3478	0.1184	0	0	0	0	0
6-20	G	D	E	F	A	C	H
Mean	1.3921	0	0	0	0	0	0

Smelt

5-21	F	D	C	E	A	H	
Mean	0.5687	0.4421	0.2884	0.2315	0	0	
5-23	F	E	C	D	A	H	
Mean	0.3922	0.1794	0.1794	0.1211	0	0	
5-24	E	F	A	C	D	H	
Mean	0.2913	0.0695	0	0	0	0	
6-18	G	C	D	E	F	H	A
Mean	2.6871	0.8867	0.8001	0.8001	0.7619	0.1821	0
6-19	G	H	F	E	D	A	C
Mean	1.3211	0.1800	0.1800	0.1245	0.1245	0	0
6-20	G	A	C	D	E	F	H
Mean	0.4920	0	0	0	0	0	0

Table A-1 (cont'd.)

Shiners							
6-19	G	C	F	E	D	H	A
Mean	1.4234	0.8849	0.7284	0.4911	0.2902	0.1821	0
6-19	G	A	C	D	E	F	H
Mean	0.5342	0	0	0	0	0	0
6-20	G	D	A	C	E	F	H
Mean	0.3871	0.1189	0	0	0	0	0

[1]Mean corrected for normality and homogeneity by log (x + 1) transformation.

[2]A = Kenco pump
C = Surface net tow
D = Midwater net tow
E = Deep net tow
F = Oblique net tow
G = Bottom sled
H = Modified Hardy Plankton Sampler

Table A-2. COMPARISON OF MEAN CATCH BY DIFFERENT SIZES OF MESH IN 1-M PLANKTON NETS.

	05/20/75			05/21/75			06/18/75			06/20/75		
	363μ	571μ	1000μ	363μ	571μ	1000μ	363μ	571μ	1000μ	363μ	571μ	1000μ
Clupeids												
Prolarvae	12.4	1.6	0.0	0.4	0.0	0.0	0.8	0.0	0.0	5.2	0.0	0.0
Postlarvae	6.6	4.4	0.0	1.6	0.6	0.0	11.2	7.6	8.0	0.0	1.0	0.2
Yellow perch												
Prolarvae	3.6	2.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	2.6	8.0	0.2	0.4	1.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0
White bass												
Prolarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Smelt												
Prolarvae	0.8	0.2	0.0	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.4	1.6	0.0	0.8	0.4	0.0	0.0	0.4	0.4	0.0	0.0	0.0
Shiners												
Prolarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.0	0.2	0.0	0.0	0.0	0.0	1.4	0.2	0.0	0.6	0.0	0.0
Total	26.4	18.4	0.2	4.6	3.0	0.0	14.0	8.4	8.4	5.8	1.0	0.2

Table A-3. TUKEY'S POST-HOC COMPARISON OF MEAN CATCH[1] FOR LENGTH OF TIME TOWED[2].

Clupeids					
5-20	3	2	5	1	4
Mean	0.5621	0.5243	0.3384	0.3121	0.2818
5-22	1	5	2	3	4
Mean	0.3621	0.1498	0.0821	0.0645	0.0641
6-18	2	4	3	5	1
Mean	1.6592	1.4234	1.2491	1.1810	1.0498
6-19	5	1	3	2	4
Mean	1.4011	1.2659	1.2541	1.1000	1.0681
Yellow Perch					
5-20	2	5	4	1	3
Mean	0.1834	0.1592	0.1510	0.1434	0.1211
5-22	3	2	4	1	5
Mean	0.2664	0.2311	0.1441	0.1422	0.0291
White Bass					
6-18	5	3	4	2	1
Mean	0.1413	0.1211	0.0941	0.0813	0
6-19	1	5	3	4	2
Mean	0.3738	0.2014	0.1876	0.1711	0
Smelt					
5-22	2	1	3	4	5
Mean	0.3891	0.2210	0.2114	0.1847	0.1181
6-18	1	5	2	3	4
Mean	0.2311	0.1842	0.0834	0.0834	0.0414
6-19	4	5	1	3	2
Mean	0.2231	0.2231	0.1341	0.1217	0

Table A-3. (cont'd.)

Shiners					
6-18	3	4	5	2	1
Mean	0.2841	0.2408	0.2341	0.2184	0
6-19	4	5	3	2	1
Mean	0.1341	0.0689	0	0	0

[1]Means corrected for normality and homogeneity by log (x + 1).

[2]1 = 1 minute; 2 = 2 minute; 3 = 3 minute; 4 = 4 minute; 5 = 5 minute lengths of tow.

Table A-4. COMPARISON OF MEAN CATCH BY DIFFERENT LENGTH OF TIME TOWED IN A 571μ, 1-M, PLANKTON NET.

	05/20/75					05/22/75					06/18/75					06/19/75				
	1 min	2 min	3 min	4 min	5 min	1 min	2 min	3 min	4 min	5 min	1 min	2 min	3 min	4 min	5 min	1 min	2 min	3 min	4 min	5 min
Clupeids																				
Prolarvae	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.0	0.3	0.8	1.7	2.8
Postlarvae	1.3	3.2	2.0	0.8	1.5	0.7	0.3	0.2	0.2	0.5	18.0	18.0	18.1	17.0	14.7	19.8	13.3	20.0	13.1	26.3
Yellow perch																				
Prolarvae	0.0	0.0	0.4	0.2	0.2	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.6	0.7	0.2	0.3	0.5	2.0	0.9	0.9	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
White bass																				
Prolarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.4	1.7	0.0	1.0	0.6	0.7
Smelt																				
Prolarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.0	0.0	0.0	0.0	0.0	1.3	1.4	0.4	0.3	0.4	1.9	0.3	0.2	0.2	0.7	0.6	0.0	0.4	0.9	1.1
Shiners																				
Prolarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Postlarvae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2	1.0	0.9	0.0	0.0	0.0	0.5	0.2
Total	1.9	3.9	2.8	1.5	2.2	4.0	2.9	2.1	1.5	1.0	19.9	20.2	19.1	19.2	16.9	22.1	13.6	22.2	16.9	31.1

Table A-5. COMPARISON OF MEAN NUMBER CAPTURED AT EACH DEPTH STRATUM TO OBLIQUE CAPTURE ALONG THE 16 KM TRANSECT. (No./ 100 m^3)

	STATION															
	P13				P14				P15				P16			
Species	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique
Clupeids																
5/22	0.2	0	0.1	0.3	0	0	0	0	0	0	0	0.1	0	0	0	0
5/23	0.5	1.1	1.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0
6/9	51.2	90.5	70.8	48.6	20.2	2.7	11.5	21.3	44.2	87.4	65.8	29.9	10.2	20.4	15.3	10.1
6/16	4.0	4.7	4.4	5.0	0.9	0.6	0.7	1.7	2.6	2.9	2.8	3.5	8.6	15.3	12.0	11.7
6/19	1.5	1.1	1.3	1.2	1.7	0.4	1.0	3.7	0	0	0	0.8	3.3	0	1.6	2.9
7/2	71.3	40.5	55.9	59.2	48.0	73.4	60.7	58.3	21.0	12.9	17.0	23.4	5.5	8.6	7.0	10.3
Yellow Perch																
5/22	0.4	0.3	0.4	0.2	0.5	1.0	0.8	0.8	3.5	4.5	4.0	3.0	10.8	8.4	9.6	14.2
5/23	0.5	0.3	0.4	0.3	1.8	1.7	1.8	1.6	7.4	10.1	8.8	7.4	9.7	12.0	10.8	10.0
6/9	0	0	0	0	0	0	0	0	1.0	0	0.5	0.2	0	0	0	0
6/16	0.4	0.9	0.6	0.4	0	0	0	0	0.2	0	0.1	0.1	0	0	0	0
White Bass																
5/23	0.3	0.3	0.3	0.2	0	0	0	0	0.2	0.4	0.3	0.1	0	0	0	0
6/9	0	0	0	0.3	3.4	0	1.7	3.6	4.7	9.4	7.0	2.6	17.0	33.3	25.2	18.4
6/16	0	0	0	0.6	0.2	0.3	0.2	0.2	0.3	0.6	0.4	0.3	0.2	0.3	0.2	0.2
6/19	0.6	0.7	0.7	1.2	0.4	0.4	0.4	0.4	0.2	0.3	0.2	0.6	0.2	0.3	0.2	0.2
7/2	0.2	0.4	0.3	0.3	1.7	3.4	2.6	1.2	1.2	2.5	1.8	2.2	0	0	0	0

Table A-5. (cont'd.)

	STATION															
	P13				P14				P15				P16			
Species	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique	Surface	Deep	Mean	Oblique
Smelt																
5/22	0	0.2	0.1	0	3.2	6.4	4.8	4.1	46.0	87.4	66.7	41.9	24.4	37.4	30.9	25.2
5/23	0	0	0	0	6.6	13.2	9.9	6.8	29.5	58.6	44.0	22.5	47.0	89.5	68.3	40.8
6/9	0	0	0	0	0.3	1.0	0.6	1.7	2.2	4.3	3.2	1.7	0	0	0	1.4
6/16	0	2.0	1.0	1.3	0.6	1.2	0.9	1.1	0	0	0	0.3	0	0	0	0
6/19	0	0	0	0.2	0.2	0.4	0.3	0.1	0	0	0	0	0	0	0	0
Shiners																
6/9	0.2	0.3	0.3	0.1	1.8	0.7	1.2	1.6	1.9	2.6	2.2	2.2	11.5	13.5	12.5	9.1
6/16	1.0	1.1	1.0	0.8	0.8	0	0.4	1.1	0.7	0	0.4	0.5	1.4	0.6	1.0	1.2
6/19	0	0	0	0	0.4	0.4	0.4	0.2	0.2	0	0.1	0.1	0.2	0.3	0.2	0.1
7/2	5.3	1.6	3.5	4.8	2.4	0.8	1.6	2.2	2.4	0.3	1.4	2.5	5.9	2.3	4.1	3.9

Table A-6. TUKEY'S POST-HOC COMPARISON OF MEAN CATCH[1] ALONG THE TRANSECT.

Clupeids				
5-22	P15	P13	P14	P16
Mean	0.0614	0.0411	0	0
5-23	P13	P14	P15	P16
Mean	0.0841	0	0	0
6-9	P13	P15	P14	P16
Mean	1.6341	1.3412	1.0114	0.0621
6-16	P16	P15	P13	P14
Mean	1.0514	0.6278	0.5932	0.4241
6-19	P14	P16	P13	P12
Mean	0.6123	0.4935	0.2761	0.2218
7-2	P13	P14	P15	P16
Mean	1.7562	1.7119	1.3694	0.8791
Yellow Perch				
5-22	P16	P15	P14	P13
Mean	0.9641	0.4879	0.2278	0.0608
5-23	P16	P15	P14	P13
Mean	0.8438	0.6911	0.1305	0.0381
6-9	P15	P16	P14	P13
Mean	0.0634	0.0315	0	0
6-16	P13	P15	P14	P16
Mean	0.1211	0.0315	0	0
White Bass				
5-23	P13	P15	P14	P16
Mean	0.0401	0.0294	0	0
6-9	P16	P14	P15	P13
Mean	1.0391	0.4915	0.3294	0.1011
6-16	P14	P13	P15	P16
Mean	0.1401	0.1295	0.0962	0.0811

Table A-6.(cont'd.)

6-19	P13	P15	P14	P16
Mean	0.3001	0.1609	0.1237	0.0811
7-2	P15	P14	P13	P16
Mean	0.3421	0.2767	0.1000	0.0941
Smelt				
5-22	P15	P16	P14	P13
Mean	1.5654	0.3321	0.5109	0.0314
5-23	P16	P15	P14	P13
Mean	1.4237	1.0642	0.6281	0
6-9	P16	P15	P14	P13
Mean	0.3101	0.3049	0.2791	0
6-16	P14	P13	P15	P16
Mean	0.3017	0.2512	0.1776	0.0314
6-19	P13	P14	P15	P16
Mean	0.0641	0.0291	0	0
7-2	P14	P13	P15	P16
Mean	0.0294	0	0	0
Shiners				
6-9	P16	P15	P14	P13
Mean	0.9676	0.4681	0.3933	0.02943
6-16	P16	P13	P14	P15
Mean	0.3574	0.2341	0.1901	0.1617
6-19	P14	P16	P15	P13
Mean	0.0651	0.0651	0.0286	0
7-2	P16	P13	P15	P14
Mean	0.8125	0.6850	0.4623	0.4117

Table A-6. (cont'd.)

Freshwater Drum				
6-16	P13	P15	P14	P16
Mean	1.0487	0.0321	0	0
6-19	P13	P16	P14	P15
Mean	0.0938	0.0611	0	0
7-2	P14	P13	P15	P16
Mean	0.0294	0	0	0

[1]Means corrected for normality and homogeneity by log (x + 1) transformation.

Table A-7. TUKEY'S POST-HOC COMPARISON OF MEAN CATCH[1] AT STATIONS SAMPLED IN 1975.

Clupeids

5-12	P10	P7	P3	P0	P2	P11	P6	P12
Mean	0.3868	0.3785	0.3396	0.3365	0.1981	0.1410	0.0600	0
6-2	P2	P7	P10	P0	P3	P12	P11	P6
Mean	1.5862	1.5369	1.3492	1.3260	1.1942	0.0841	0.7589	0.0571
6-25	P2	P11	P3	P10	P12	P7	P0	P6
Mean	0.9488	0.8373	0.7046	0.4687	0.3932	0.3899	0.2943	0
7-9	P11	P6	P3	P10	P0	P12	P2	P7
Mean	1.4581	1.0628	0.9257	0.6137	0.5821	0.4586	0.4537	0.0719
7-31	P6	P0	P10	P11	P12	P2	P3	P7
Mean	0.0634	0.0170	0	0	0	0	0	0

Yellow Perch

5-12	P12	P7	P2	P0	P10	P11	P3	P6
Mean	1.8012	1.5293	1.4911	1.4180	1.2440	0.0256	0.3197	0.2982
6-2	P2	P11	P3	P12	P7	P10	P0	P6
Mean	0.4429	0.4133	0.2174	0.1418	.0663	0.634	0.0461	0
6-25	P6	P0	P2	P12	P10	P11	P3	P7
Mean	0.0634	0.0041	0	0	0	0	0	0
7-9	P6	P0	P10	P11	P12	P2	P3	P7
Mean	0.0601	0.0146	0	0	0	0	0	0

White Bass

6-2	P11	P2	P7	P0	P3	P12	P10	P6
Mean	0.6601	0.5245	0.4786	0.3909	0.2398	0.2027	0.1372	0
6-25	P6	P0	P2	P12	P2	P7	P10	P11
Mean	0.6499	0.3617	0.2479	0.0571	0	0	0	0
7-9	P12	P6	P2	P10	P3	P0	P7	P11
Mean	0.2745	0.2167	0.1206	0.0842	0.0842	0.0792	0	0

Table A-7.(cont'd.)

Shiners								
5-12	P2	P12	P10	P11	P3	P7	P0	P6
Mean	0.1355	0	0	0	0	0	0	0
6-2	P6	P2	P3	P0	P11	P7	P12	P10
Mean	0.4101	0.3739	0.2745	0.2528	0	0	0	0
6-25	P6	P2	P0	P3	P7	P10	P13	P10
Mean	0.4428	0.3258	0.2788	0.2441	0.1267	0.1204	0.0927	0.0603
7-9	P6	P11	P0	P3	P2	P10	P7	P12
Mean	1.6458	0.6687	0.6096	0.6044	0.5784	0.2076	0.0632	0
7-31	P10	P7	P0	P6	P11	P12	P2	P3
Mean	0.0571	0.0571	0.0557	0	0	0	0	0
Carp								
5-12	P2	P6	P0	P10	P11	P12	P7	P3
Mean	0.4183	0.0911	0.0777	0	0	0	0	0
6-2	P6	P0	P2	P3	P7	P10	P11	P12
Mean	0.5358	0.3670	0.1655	0.1559	0.0634	0	0	0
6-25	P2	P6	P0	P3	P7	P10	P11	P12
Mean	1.2946	0.7114	0.3802	0.3298	0	0	0	0
7-9	P6	P0	P3	P2	P11	P7	P12	P10
Mean	1.1146	0.5798	0.3846	0.0927	0.0842	0	0	0
7-31	P6	P0	P7	P2	P3	P10	P11	P12
Mean	0.0634	0.0170	0	0	0	0	0	0

Table A-8. COEFFICIENTS OF VARIATION INCLUDING MEAN COEFFICIENT OF VARIATION AT STATIONS SAMPLED IN 1974 AND 1975 FOR ABUNDANT SPECIES.

	STATIONS						
Species	P6	P7	P2	P3	P10	P11	P12
Clupeids							
5/29/74	73.9	99.3	45.6	54.6	30.2	39.0	62.3
6/11/74	73.1	131.7	51.8	29.2	44.6	17.7	26.0
6/21/74	45.4	0	107.0	24.8	60.3	63.2	51.4
7/1/74	36.4	46.9	20.7	23.2	79.4	40.8	33.0
7/15/74	39.9	101.5	48.3	64.6	35.4	30.0	32.8
7/26/74	118.2	154.9	71.2	70.0	49.0	24.6	107.6
Mean	75.3	87.0	56.3	42.9	49.0	35.2	51.4
5/12/75	138.5	244.9	130.0	0	84.0	142.1	116.7
6/2/75	36.9	244.9	56.7	16.7	79.0	56.1	38.7
6/25/75	65.6	0	82.7	55.9	81.6	61.6	81.3
7/2/75	52.2	244.9	93.5	34.8	74.8	53.8	152.1
Mean	73.2	153.0	75.6	22.4	66.5	65.4	81.0
Yellow Perch							
5/10/74	0	44.7	21.4	36.1	Not Sampled		
5/29/74	43.8	244.9	78.1	98.6	39.4	45.5	64.1
6/11/74	47.0	244.9	34.7	37.8	244.9	0	164.7
Mean	30.3	178.2	44.7	57.5	142.2	22.8	114.4
5/12/75	110.1	112.5	49.3	73.4	63.7	43.9	39.0
6/2/75	306.2	0	95.6	118.6	244.9	113.9	173.3
Mean	208.2	56.2	72.4	96.0	154.3	78.9	106.2
White Bass							
5/29/74	244.9	244.9	155.0	33.9	83.4	244.9	94.6
6/11/74	127.8	165.9	90.1	44.1	88.8	143.0	46.2
6/21/74	244.9	0	0	167.3	0	0	0
7/1/74	110.2	0	244.9	244.9	0	0	244.9
7/15/74	80.0	0	90.0	72.2	95.0	108.3	244.9
7/26/74	244.9	0	72.9	244.9	125.5	226.4	114.0
Mean	175.4	68.5	108.8	134.6	65.4	120.4	100.6
Shiners							
5/29/74	122.0	0	83.4	155.1	244.9	0	0
6/11/74	110.0	109.8	92.0	92.7	149.7	67.2	38.1
6/21/74	155.1	109.5	63.2	0	155.1	0	0
7/1/74	244.9	244.9	164.9	109.7	0	244.9	244.9
7/15/74	0	164.7	244.9	0	0	0	0
7/26/74	142.2	166.0	93.3	164.7	125.5	66.0	63.1
Mean	129.0	132.5	123.6	87.0	112.5	63.0	57.7

Table A-8. (cont'd.)

Species	P6	P7	STATIONS P2	P3	P10	P11	P12
5/12/75	0	0	160.2	0	0	0	0
6/2/75	0	53.9	123.4	61.2	0	0	0
6/25/75	154.9	109.3	115.6	244.9	155.6	244.9	127.0
7/2/75	244.9	31.2	61.4	62.8	168.0	53.7	0
Mean	99.9	48.6	115.2	92.2	80.9	74.6	31.8
<u>Carp</u>							
5/10/74	0	172.5	14.4	63.2	0	0	0
5/29/74	106.4	93.6	55.8	0	126.5	0	0
6/11/74	98.2	33.8	23.2	37.7	0	0	0
6/21/74	183.7	80.3	28.9	114.4	0	0	0
7/1/74	244.9	35.9	79.4	98.9	244.9	151.2	4.3
7/15/74	49.4	28.4	23.4	64.1	0	170.9	244.9
7/26/74	244.9	244.9	244.9	244.9	0	0	0
Mean	132.5	98.5	67.1	89.0	53.1	46.0	35.6
5/12/75	0	234.7	90.5	0	0	0	0
6/2/75	285.8	59.4	160.0	173.8	0	0	0
6/25/75	0	62.4	29.2	84.8	0	0	0
7/2/75	0	44.6	244.9	61.3	0	0	0
Mean	71.4	100.3	131.2	80.0	0	0	0