AN EVALUATION OF THE COMPOSITION AND ABUNDANCE OF FISHES PUMPED INTO THE LUDINGTON PUMPED STORAGE RESERVOIR FROM 1972 TO 1975

Thesis for the Degree of M. S.
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ABSTRACT

AN EVALUATION OF THE COMPOSITION AND ABUNDANCE OF FISHES PUMPED INTO THE LUDINGTON PUMPED STORAGE RESERVOIR FROM 1972 TO 1975

By

John Andrew Gulvas

The species composition and relative abundance of fishes pumped into the Ludington Pumped Storage Reservoir were studied from 1972-1975 using bottom and surface gill nets, trawls, and mark and recapture methods. Few fish entered during the initial filling of the reservoir; however, thirty-three species were collected over the period of this study. Bottom gill net collections were dominated by rainbow smelt, alewife, and spottail shiner. Carp, steelhead, brown trout, coho and chinook salmon were captured most often with surface gill nets, and alewife, rainbow smelt, spottail shiner, sculpin, and trout-perch were predominant in bottom trawl collections. Increased and continued plant activity did not result in large accumulations of any species of fish in the reservoir over the study period. Seasonal occurrence of most fishes in the reservoir appeared closely associated with the seasonal distribution patterns of those species in nearshore Lake Michigan. Catch per unit effort values of most species were similar each year. However, increased numbers of sculpin, trout-perch, carp, and burbot were observed each year indicating that these species are becoming established in the reservoir. Carp and salmonids concentrated in the surface waters near the reservoir embankment.

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Differences between relative abundance of species in the reservoir and abundance in Lake Michigan indicated that pelagic, night-active, and along-shore migrant species were most vulnerable to the reservoir intake. Demersal populations of yellow perch, white and longnose sucker, round whitefish, and lake trout were seasonally abundant near the plant, but avoided being pumped into the reservoir in large numbers. Smaller size classes of yellow perch, and of white and longnose sucker appeared more susceptible to the intake than larger classes. Number of fishes pumped into the Ludington Pumped Storage Reservoir appeared low enough that no apparent damaging effects to most nearshore and beach zone fish populations of Lake Michigan are expected. However, the potential exists for a considerable loss to trout and salmon populations if numbers similar to those found in this study are pumped annually into the reservoir during the life of the plant.

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John Andrew Gulvas

A THESIS

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INTRODUCTION

The Ludington Pumped Storage Reservoir provided a unique opportunity to study development and dynamics of fish populations that originally, seasonally, or continually inhabited the reservoir, from its beginning to the present. This thesis is not only a descriptive report of the species composition and relative abundance of fishes inhabiting the Ludington reservoir from 1972 through 1975, but also an evaluation of the reservoir intake as a sampler of nearshore and beach zone fish populations of eastern Lake Michigan. The effects of installing and operating this large pumped storage plant on Lake Michigan have been studied by Michigan State University since 1972 (Liston and Tack, 1975).

A major concern of sport and commercial fishermen, and several regulatory agencies was that large numbers of important fish species (yellow perch, salmonids, whitefish, and suckers) would be pumped into the reservoir. The purpose of this study was to determine the relative abundance of fishes in the reservoir and seasonal and yearly fluctuations in their numbers. In addition, comparisons were made with concurrent data from Lake Michigan to determine which populations or segments of Lake Michigan populations were most susceptible to this large shoreline intake.

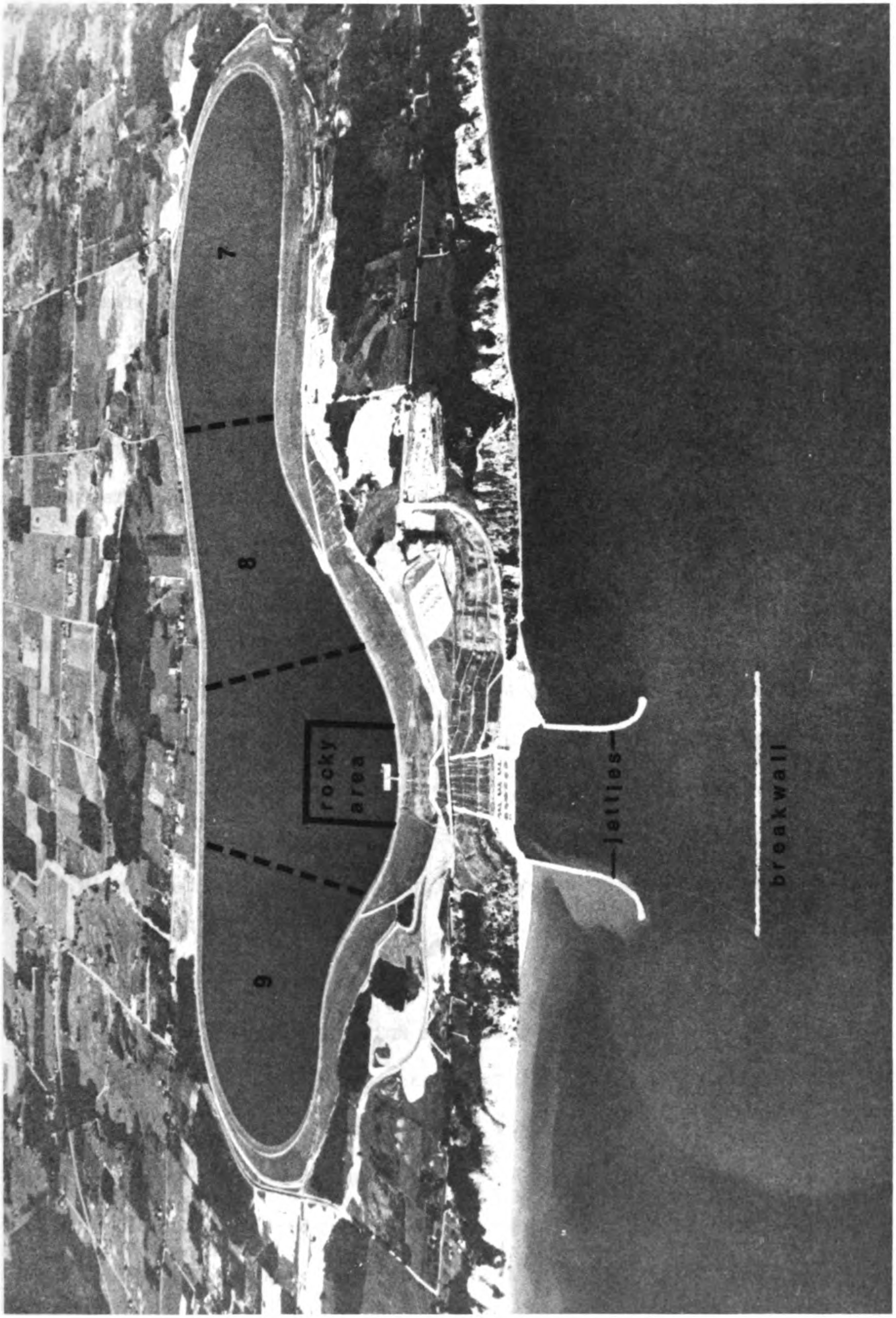
This problem was approached by sampling fish populations with enough replication and variety in method so inferences about yearly and seasonal similarities and differences could be made with some degree of confidence. Sampling included a combination of bottom gill nets, surface gill nets, and trawls and a mark and recapture study of fish in the reservoir was conducted to assist the analysis of sampling results.

DESCRIPTION OF THE STUDY AREA

The Ludington Pumped Storage Reservoir is located on the eastern shore of Lake Michigan about 4 miles (6.4 km) south of Ludington, Michigan. The plant was constructed by Consumers Power and Detroit Edison Companies of Michigan to supply electrical power during peak demand periods. This pumped storage plant is the largest of its kind in existence. The reservoir is 2 1/2 miles (4 km) long, averages about 3/4 mile (1.2 km) wide and has a total surface area of 842 acres (3.41×10^6 m^2) when full (Fig. 1). The reservoir embankment averages 108 feet (33 m) in height and is 6 miles (9.65 km) in circumference. The top of the embankment has an elevation of 950 feet (289.5 m) above sea level, or about 370 feet (112.7 m) above Lake Michigan. Maximum water depth, at elevation 942 (287 m) is approximately 97 feet (29.7 m) in the south and 112 feet (34 m) in the north end. Water level in the reservoir can fluctuate a maximum of 67 feet (20.4 m). The total capacity when full is about 82,300 acre feet (102 million cubic meters). The estimated weekly turnover rate in the reservoir is about 2.4.

The upper wall of the embankment is paved with asphalt down to elevation 875 (266.7 m), at a slope of 2.5:1. At this point there is a clay berm or step that is utilized as a service road when water levels are drawn down for maintenance and repairs. The berm slopes to the bottom at a ratio of 5:1. A ramp of concrete and stone rip rap

Figure 1. Aerial view of the Ludington Pumped Storage Reservoir showing the offshore jetties and breakwater, rocky area and sampling stations in the reservoir.

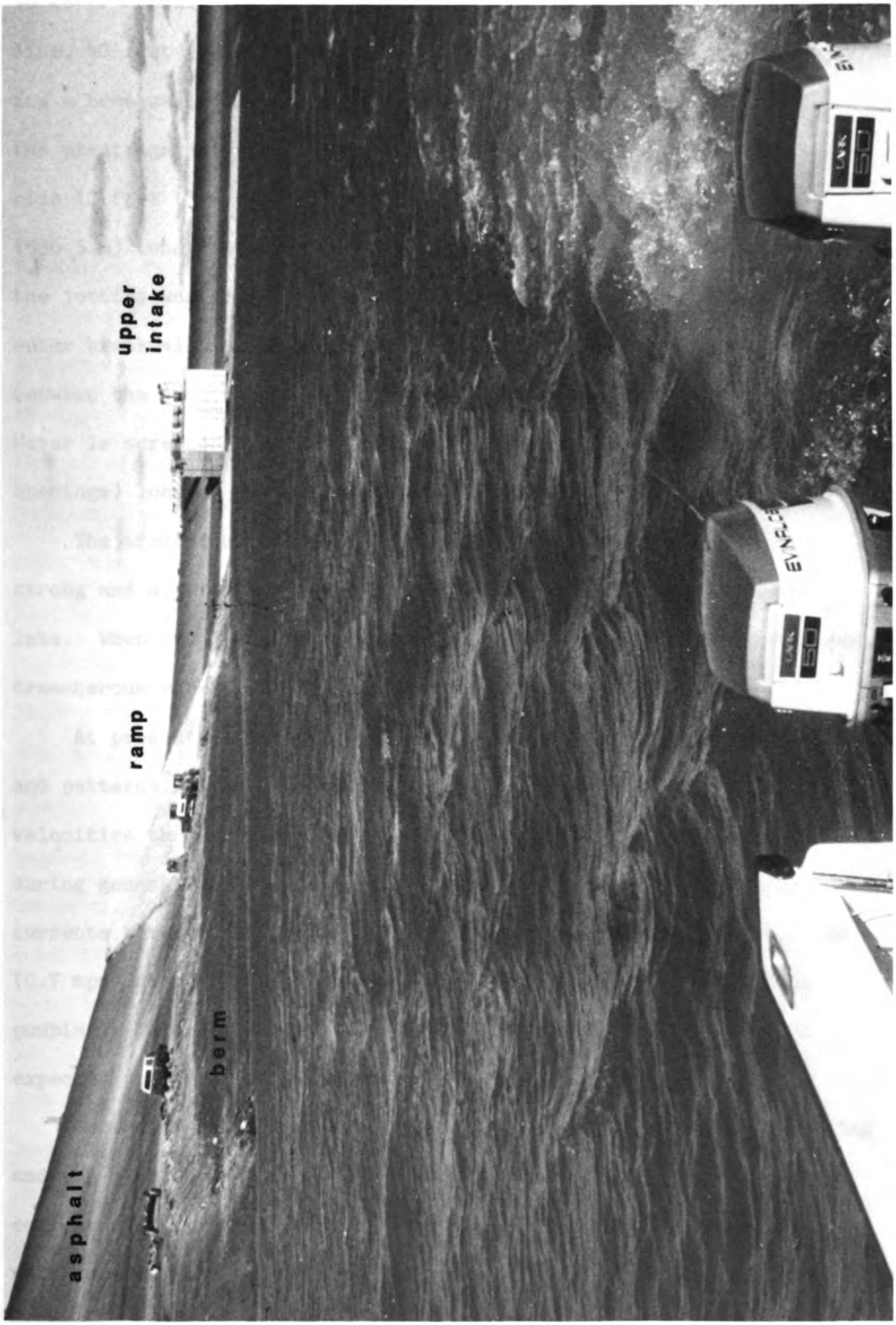

7
8
9
rocky area
jetties
breakwall

about 500 feet (152 m) long leads down to the berm on the west side of the reservoir (Fig. 2). The bottom of most of the reservoir is lined with compacted clay to prevent leakage. A 1200 x 800 foot (366 x 244 m) area in front of the upper intake structure was covered with limestone rocks for scour protection (Fig. 1).

Water is pumped into the reservoir (pumping mode) and drained (generating mode) through six Francis-type reversible turbines located about 40 feet (12.2 m) below the surface of Lake Michigan. Six large penstocks, each about 1300 feet (396 m) long, and 28.5 feet (8.6 m) in diameter at the upper end, and 24 feet (7.3 m) in diameter at the lower end, connect the reservoir with the turbines and Lake Michigan. Each turbine revolves at a maximum rate of 112.5 rpm. During generation, each unit can discharge a maximum of 12,660 cfs (358 cms), and during pumping as much as 11,000 cfs (311 cms) can be passed. In contrast, no tributary into Lake Michigan exceeds 3,400 cfs (96 cms) (Limnetics, 1976). With all six units operating, maximum water flow during generation is about 75,960 cfs (2,151 cms), and during pumping about 66,600 cfs (1886 cms). Estimated discharge of Lake Michigan through the Straights of Mackinac into Lake Huron is 55,000 cfs (1557 cms). Minimum drawdown time is about 8.7 hours and filling time about 10 hours.

The Lake Michigan shoreline here is characterized by high clay bluffs and gravel and stone beaches. The Lake Michigan bottom here has some inshore sandy areas and bars, but is largely clay and stone. Depth increases gradually out into the lake. In this report, the beach zone is considered as the area from the shoreline to the 4 meter depth, and the nearshore zone as the area from the shoreline to the

Figure 2. View from inside the Ludington Pumped Storage Reservoir showing the upper intake structure, ramp, and berm.


upper intake
ramp
berm
asphalt

30 meter depth. The lower intake structure is adjacent to the shoreline, 40 feet (12.2 m) below the water surface. Two large jetties and a breakwall of large rock boulders were constructed to protect the plant against severe wave and ice damage (Fig. 1). The jetties rise 10 feet (3 m) above the water surface, are about 1760 feet (536.5 m) long, and are 1000 feet (304.8 m) apart. The area between the jetties was dredged to a uniform depth of 35 feet (10.6 m). The outer breakwall is about 1700 feet (517 m) long, and the opening between the jetties and the breakwall is about 1300 feet (396 m). Water is screened by large trash racks (18 in x 18 in (45.7 cm x 45.7 cm) openings) located just in front of the turbines.

The tremendous volumes of water passed by the plant create strong and multi-directional currents in the reservoir and in the lake. When coupled with the current and wave action of Lake Michigan, treacherous working conditions prevail.

At present, only rough estimates of the water current velocities and patterns in the reservoir and lake are available. Maximum velocities through the penstocks were estimated at 28 fps (8.5 mps) during generation, and 24.6 fps (7.5 mps) during pumping. Water currents between the jetties were estimated to average about 2.3 fps (0.7 mps) with all units generating and 2.1 fps (0.64 mps) during pumping. Currents between the jetties and the breakwall were not expected to exceed 1-1 1/2 fps (.3-.4 mps).

Currents in the reservoir vary with the number of units operating and the plant operational mode (C. Liston, pers. comm.). Strongest currents were present in front of the upper intake structure and were greater in the north end than in the south end. Current velocities on the reservoir bottom were strongest during the pumping mode.

METHODS AND MATERIALS

Descriptive information of gill nets and trawls used in the Ludington reservoir is provided in Table 1. All gill nets were set approximately 24 hours or for overnight periods. When conditions allowed, nets were cleaned in the field and all samples, except for fish marked and released, were returned to the laboratory and processed. Fish from the reservoir bottom gill nets were not separated according to mesh size, and in most instances, the entire reservoir sample was processed, but when samples were large, a sub-sample of 20 of each species was processed. Information from each collection was recorded directly onto standard form computer code sheets and included trap day, station, date, method, direction of tow or set, distance of tow, collection depth, water temperature, species, number collected, number processed, total weight, species number, weight of each species, total length, tag numbers, sex, maturity, gonad condition, age, fishing time, gill net length and mesh size.

Temperature profiles at 4 meter intervals were taken with a model 43TD Yellow Springs Instrument thermistor at each station and for each sample. Data on other limnological parameters including water transparency, turbidity, pH, alkalinity, dissolved solids, and dissolved oxygen from the reservoir and Lake Michigan through 1974 are given by Liston et al. (1976). Plant operational information,

Table 1. Description of gill nets and trawls used in the Ludington reservoir.

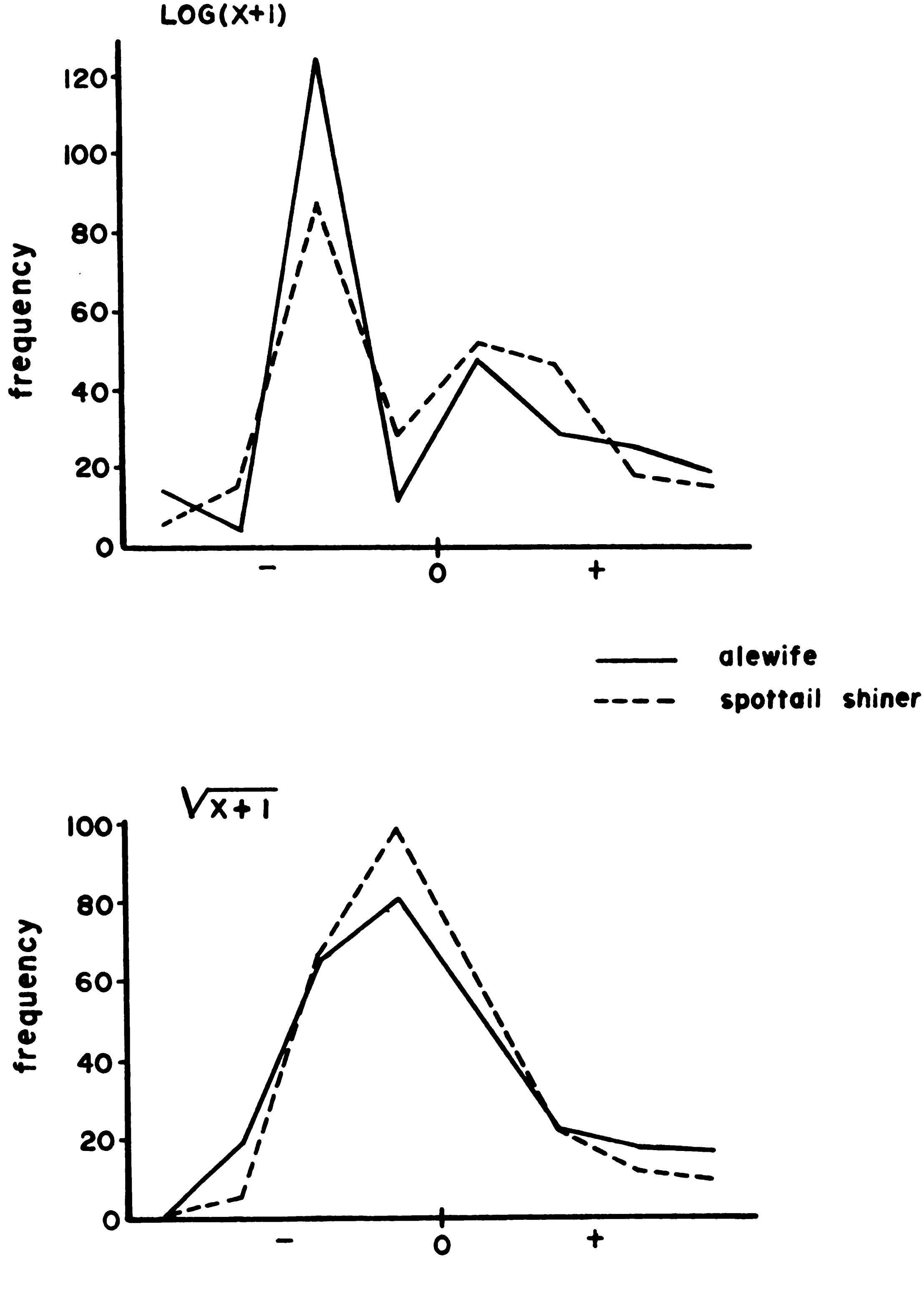
Method	Length	Depth	Stretch Mesh Size	Twine Size	Float Line	Lead Line	Dates Used
Bottom Gill Nets	350'	6'	1", 2", 2½", 3", 4", 4½", 7"	No. 69-177 (1")-monofilament	5/16" polyethylene	No. 120 lead core	1973-1975
Surface gill net 1	150'	15'	5"	No. 69	3/16" braided nylon with floats	No. 120 lead core	1973-1975 (intermittently)
Surface gill net 2	300'	10'	5"	No. 177	3/16" braided nylon with floats	3/16" braided nylon with 4 oz. lead	Aug 1974-1975
Surface gill net 3	300'	10'	7"	No. 177	3/16" braided nylon with floats	3/16" braided nylon with 4 oz. lead	Aug 1974-1975
Surface gill net 4	350'	6'	1", 2", 2½", 3", 4", 4½", 7"	No. 69-177 (1")-monofilament	5/16" polyethylene with floats	No. 120 lead core with 4 oz. leads	April-Dec 1975
Surface gill net 5	300'	10'	5"	No. 104	5/16" polyethylene with floats	No. 120 lead core	Aug-Dec 1975
Otter Trawl	16' headrope	19' footrope	Body 1½", inter-liner ¼" - woven mesh, cod end ¼" - woven mesh				1973
Otter Trawl	21' headrope	25" footrope	Body 1½", inter-liner ¼" - woven mesh, cod end ¼" - woven mesh				1974-1975

such as number of turbine units operating, times and duration of pumping and generation, and water level elevations in the reservoir was supplied by Consumers Power Company. Since reservoir volume was directly related to surface elevation, the elevation records were used to calculate weekly volumes of water pumped, and thus gave accurate estimates of plant activity during the three years.

About once per week from April through November, 1973, 1974, and 1975, experimental bottom gill nets were set within stations 7, 8, and 9 in the reservoir (Fig. 1). Nets were usually set near and perpendicular to the reservoir wall. However, an occasional set was made parallel to the wall and in the middle of each station. Bottom gill net catches were arbitrarily divided into four two-month periods: April-May, June-July, August-September, and October-November. Catch-per-unit-effort values were based on number caught per net day.

Numbers of fish caught per year, season, and station were analyzed by SPSS analysis of variance procedures (Nie et al., 1975). The assumption of normality was tested using a plot of the residual error against the normal distribution. Log and square root transformations of spottail shiner and alewife data show the severity of each transformation, and that a single transformation may not always be sufficient for highly variable data (Fig. 3). Smelt and yellow perch data were analyzed using a log (X+1) transformation and spottail shiner and alewife data using a $\sqrt{X+1}$ transformation. Main effects and interactions having $P < .25$ were further tested using Scheffé's procedure (Kirk, 1968). Other species were not statistically analyzed, because of the large number of zero catches and violations of the assumption of normality.

Figure 3. Frequency plot of residual error of log (X+1) and $\sqrt{X+1}$ transformation of spottail shiner and alewife catch data.


LOG(X+1)
120
100
80
60
40
20
0
frequency
-
0
+
alewife
spottail shiner
√X+1
100
80
60
40
20
0
frequency
-
0
+

Five different surface gill nets were used in this study (Table 1). Since adult salmon and trout were a primary concern, large mesh surface gill nets were initially used. Surface gill net 1 (Table 1) was set on nine occasions in the middle of station 7 (south end of reservoir) in 1973 and several times during April-May, 1974 by attaching additional floats to bring it near the surface. This method indicated the presence of large salmonids in the reservoir and led to further development of surface gill netting. To keep the net at the surface, and straight, it was attached to available structures at the top of the reservoir wall. Depending upon the water elevation and the length of the attaching line, part of the net would fish near or lie on the wall as the water level descended, and fish again at the surface as the water level ascended. This netting method was successful in capturing carp and salmonids that tended to follow along the reservoir wall.

After August, 1974, surface gill nets 2 and 3 (Table 1) were fished in the same manner as described above. Surface gill nets 1, and 2 or 3 were then set weekly through November at several locations along the reservoir wall. A total of 54 sets were made in 1974 with surface gill nets 1, 2, and 3. Surface nets were most often set on the side of the reservoir with the prevailing winds, because high waves on the opposite side made setting difficult, caused the nets to roll, and frequently filled them with plastic and other trash.

Sampling with the variable-mesh surface gill nets (No. 4, Table 1) was begun in 1975 to help determine the distribution and abundance of smaller sizes of fish inhabiting surface waters of the reservoir. The variable-mesh net (4) and surface gill nets 2 and 3 were set weekly during April-May, 1975 but were not fished as near the wall as in 1974. Surface gill net 2 was replaced in June, 1975 by the finer twined and deeper surface gill net 1 because of the greater efficiency of the latter. Extensive use of surface gill net 1 necessitated replacement in August, 1975, by a similar surface gill net (No. 5, Table 1). Surface gill net 5 was then set weekly with nets 3 and 4 through December, 1975 (Table 1). A total of 106 sets were made in 1975 using all surface gill nets.

The reservoir gill net data was supplemented by trawling bottom areas with 16 ft and 25 ft otter trawls during 1972-1975. Tows were made for five minutes at approximately 5 mph. During 1972, a single series of daytime trawls was conducted on 27 October (four days after the initial filling of the reservoir) with the 16 ft trawl. In 1973, monthly samples were made in daytime and evening (37) and at night (4) with the 16 ft trawl between 9 May and 2 November along trawl paths T1-T6 (Fig. 4). In 1974, trawls were conducted mainly at dusk, approximately bi-weekly between 18 April and 31 October. Ten trawl series were made (72 samples: 21 with the 16 ft trawl and 51 with the 25 ft trawl). In addition to the 6 regular trawl paths, tows were made in the middle of reservoir stations 7, 8, and 9 (Fig. 1). A total of 48 trawls was made in 1975 between 9 June and 21 October. All tows were made at night with the 25 ft trawl and stations T1-T9 were sampled. Fluctuating water levels in the reservoir resulted in trawl samples taken over a depth range of 10-90 feet during the four years.

During 1973 and part of 1974, variable-mesh vertical gill nets were used to sample fishes at various depths in the water column.

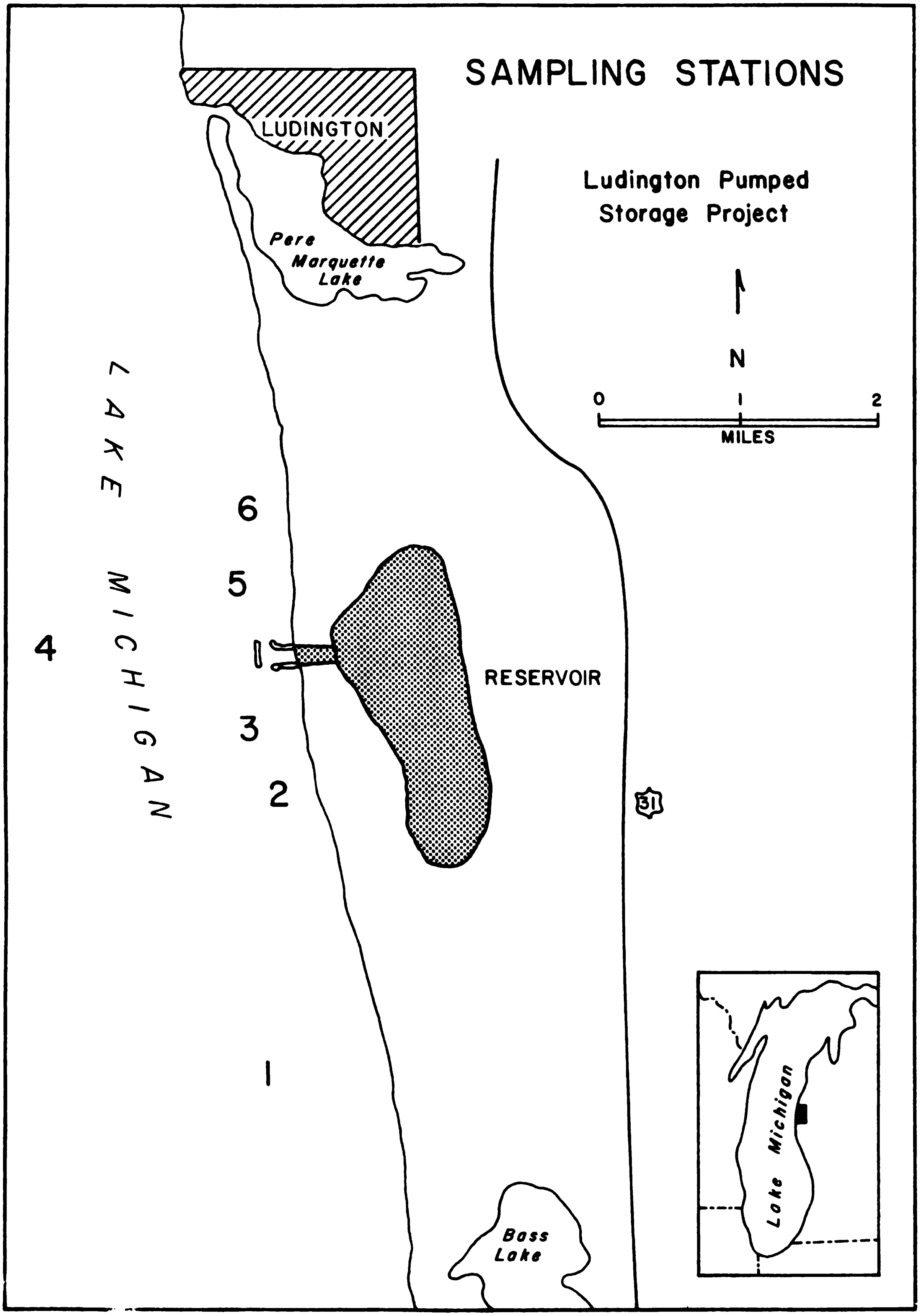
Figure 4. Aerial view of the Ludington Pumped Storage Reservoir showing reservoir trawl paths, T1-T9.

For further description of this method and the results see Liston and Tack (1974).

Forty-two salmon were tagged and released in the reservoir in 1973 (Tack and Liston, 1973). This study expanded the mark and recapture program during 1974 and 1975 using live captured fish from the reservoir and Lake Michigan, and salmonids procured from commercial trout ponds and the Michigan Department of Natural Resources fish weirs on the Little Manistee and Platte Rivers. Length and weight measurements were recorded, then fish were marked with 1 or 2 numbered and addressed floy tags inserted in the back of the fish near the dorsal fin. Some fish from the reservoir gill nets (mainly carp) were fin-clipped. Recaptures came largely from the regular gill net samples in the reservoir, although some were returned by sport fishermen, and from the weirs.

Data from concurrent Lake Michigan studies incorporated into this thesis include percentage composition, catch-per-unit-effort, length frequencies, age, and sex composition of major species also collected in the Ludington reservoir. Those data were selected from bottom gill nets set near the plant at stations 2, 3, 5, and 6 in Lake Michigan (Fig. 5). The bottom gill nets used in the lake contained identical experimental panels as the reservoir bottom gill nets (Table 1), but were hung on braided nylon line with floats and leads. Patriarche (1974) used both types of nets and found no large differences between them. In 1973, all panels of each mesh size of the Lake Michigan bottom gill nets were reduced from 50 to 25 feet in length on July 9 because of work loads associated with other activities in both the reservoir and in Lake Michigan. Consequently, to provide

Figure 5. The location of the Ludington Pumped Storage Project and sampling stations in Lake Michigan.


SAMPLING STATIONS
Ludington Pumped
Storage Project
N
0 1 2
MILES
LUDINGTON
Pere
Marquette
Lake
LAKE MICHIGAN
6
5
4
3
2
1
RESERVOIR
31
Bass
Lake
Lake Michigan

comparisons with other data, catch values after July 9 in 1973 were doubled. Further description of the Lake Michigan sampling stations and netting program can be obtained in Liston and Tack (1975).

RESULTS AND DISCUSSION

Power Plant Activity: 1973-1975

The weekly pumping rates (acre feet/week) for 1973, 1974, and 1975 are graphically shown in Figures 6, 7, and 8 respectively. Initial pumping began in 1972, but commercial operation of the first unit did not begin until January, 1973. The principle of a pumped storage plant is illustrated in these figures. Water is pumped into the reservoir during low electrical demand periods (night), and released out to generate electricity during peak demand periods (day). Volumes pumped during daylight were usually less than 15% of the total weekly volumes, and most daylight pumping occurred on weekends.

In early 1973, pumping rates were less than 50,000 acre feet per week and only one pump-turbine was in operation. Numbers along the bar graphs in Figure 6 indicate the approximate dates when other pump-turbines commenced operation. Maximum pumping rates for 1973 (above 200,000 acre feet/week) were attained after completion of the fifth pump-turbine in August. During 1974, about twice as much water was pumped into and released from the reservoir as all six pump-turbines were in operation for most of the year. Increases over the 1973 volumes pumped occurred mainly from January through July, and plant activity from August through December was similar for both years. The 1975 pumping activity was similar to 1974 (Figs. 7 and 8).

Figure 6. Weekly volumes of water (acre feet) pumped into the Ludington Reservoir during 1973 (from Liston and Tack, 1975).

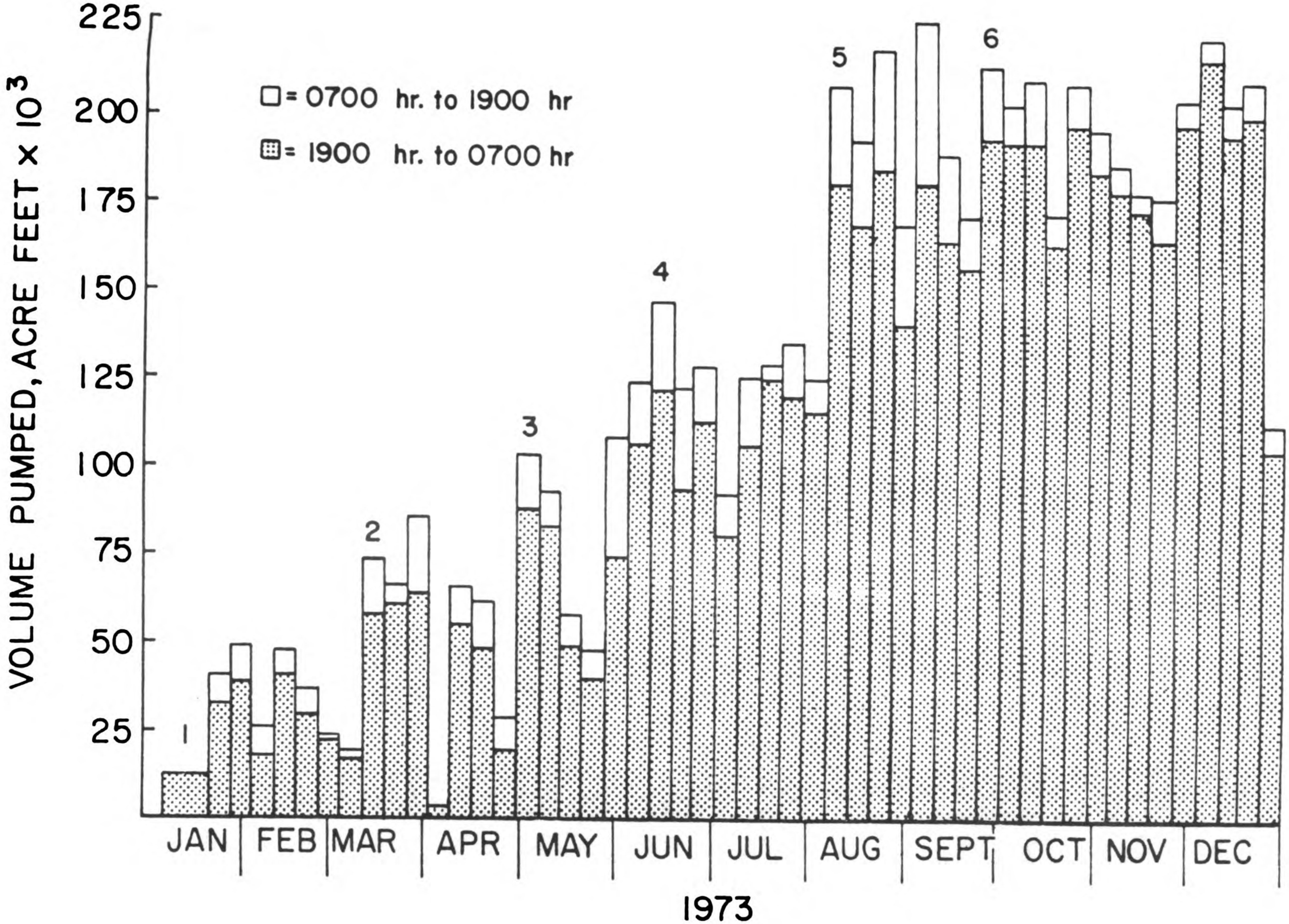
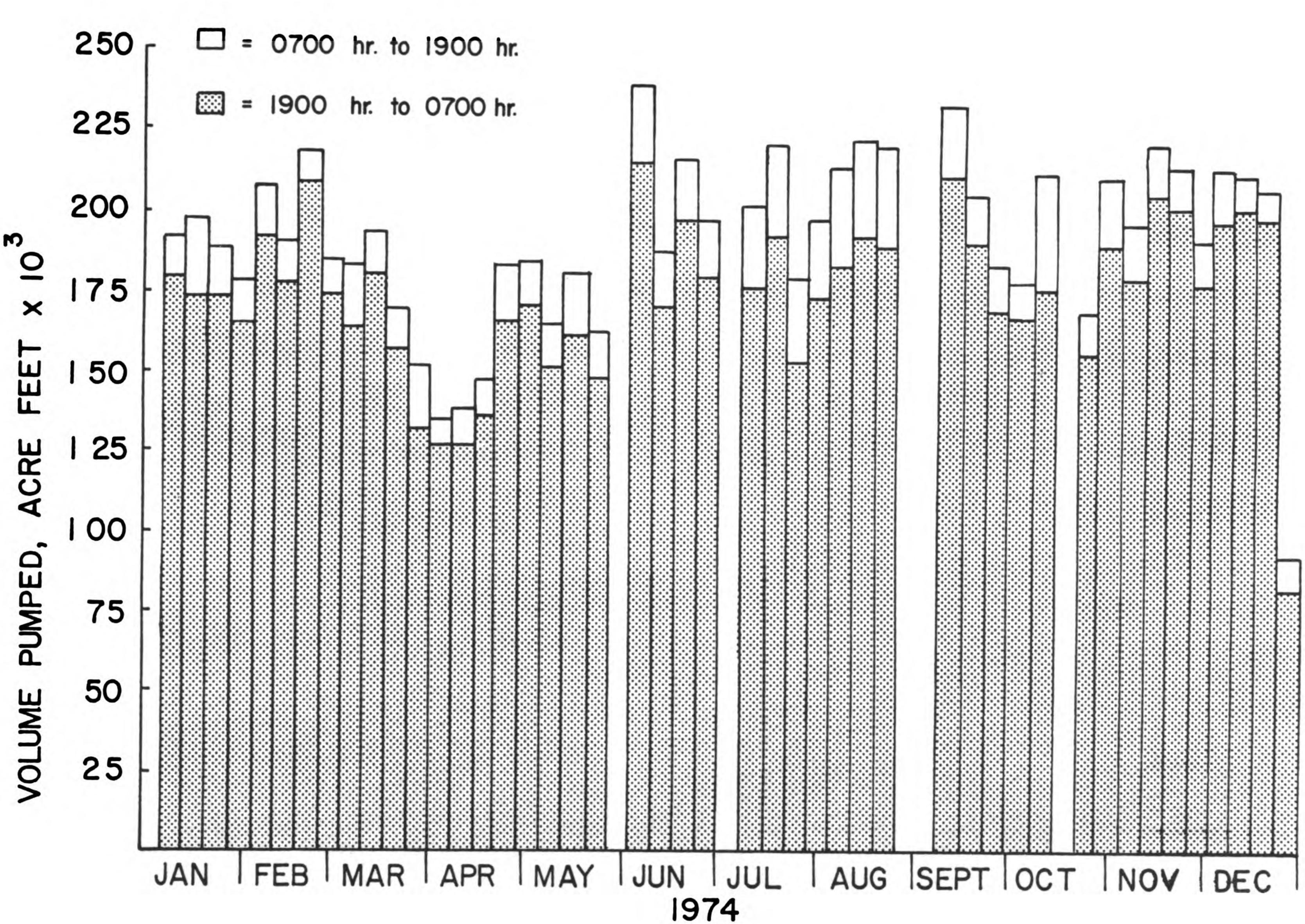
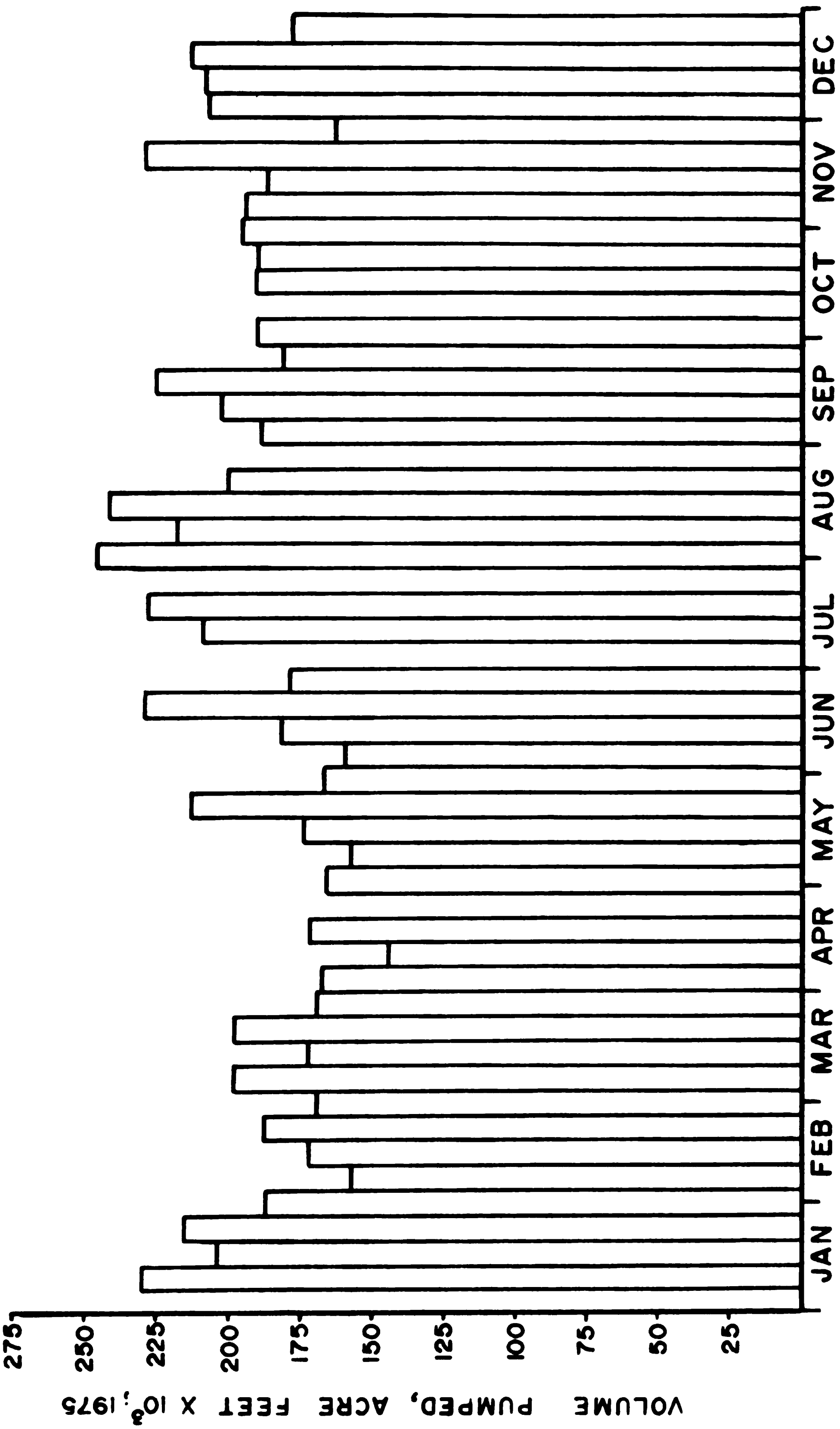

225
200
175
150
125
100
75
50
25
VOLUME PUMPED, ACRE FEET × 10³
= 0700 hr. to 1900 hr
= 1900 hr. to 0700 hr
1
2
3
4
5
6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
1973

Figure 7. Weekly volumes of water (acre feet) pumped into the Ludington Reservoir during 1974 (from Liston and Tack, 1975).



250
225
200
175
1 50
1 25
1 00
75
50
25
VOLUME PUMPED, ACRE FEET x 10^3
= 0700 hr. to 1900 hr.
= 1900 hr. to 0700 hr.
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
1974

Figure 8. Weekly volumes of water (acre feet) pumped into the Ludington Reservoir during 1975.


VOLUME PUMPED, ACRE FEET X 10³, 1975
275
250
225
200
175
150
125
100
75
50
25
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

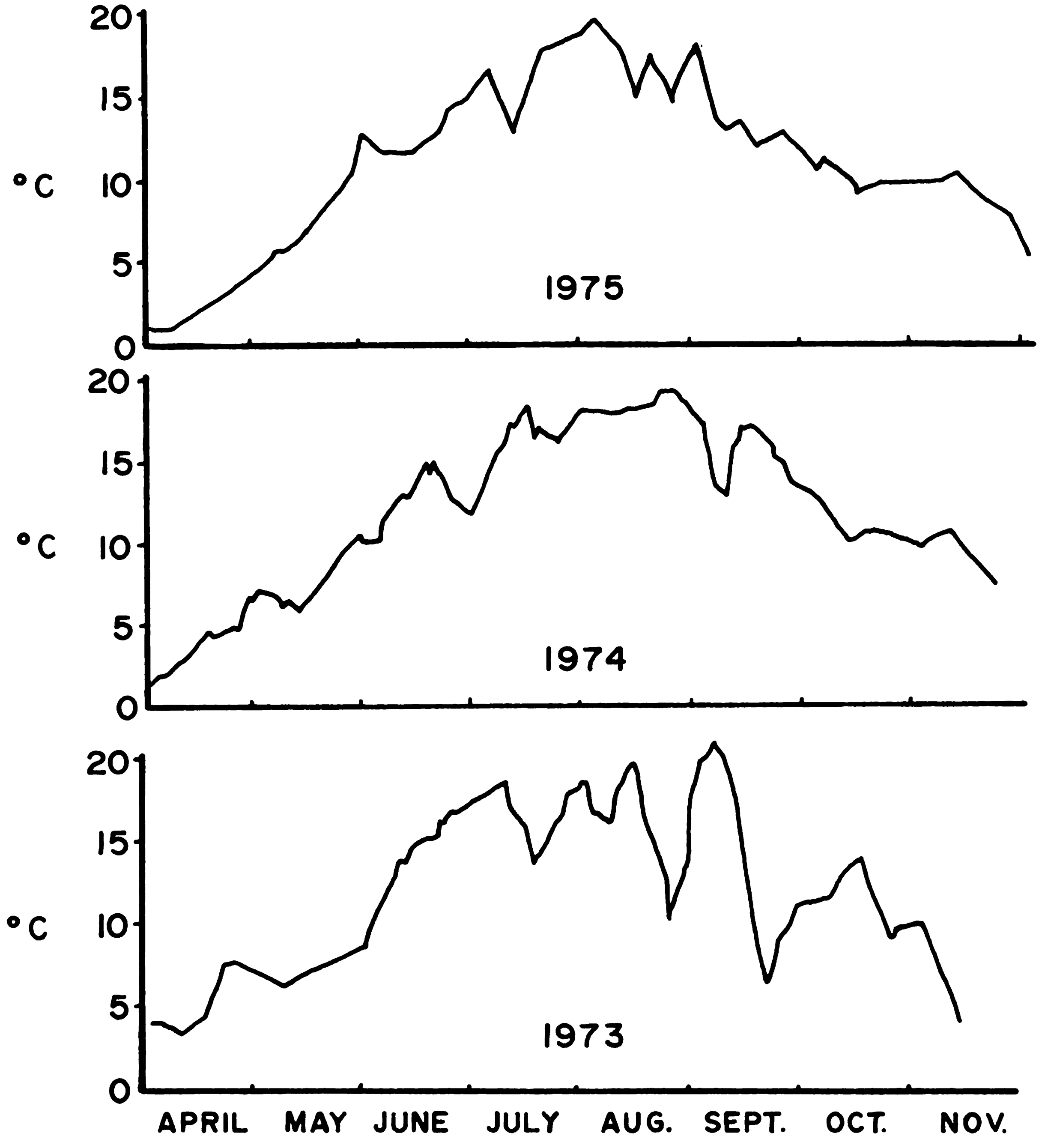
Water Temperature

The results of the reservoir surface temperature determinations during 1973-1975 are shown in Figure 9. Temperatures generally varied from 4°C or less in early April to maximum values of 22-24°C during July, August, and early September. Declining temperatures during fall resulted in readings less than 10°C by late November. However, thermal instabilities were common, especially in 1973 as shown by the large temperature fluctuations in Figure 9. These instabilities were the result of water being drawn from nearshore Lake Michigan during periods of storms, upwelling, and non-upwelling conditions. Generally, reservoir water temperatures were reflective of nearshore lake temperatures, but depending upon the duration of particular temperature conditions in the lake and the mode of plant operation, more sudden temperature changes may not have been observed.

Temperature variation among the reservoir stations on each sampling date was minimal, and only occasionally were horizontal and vertical temperature differences of greater than 1°C observed. Water temperatures in the reservoir were essentially homothermous throughout each year.

The importance and effects of water temperature fluctuations on the distribution of fish species in the beach, inshore, and open-water zones is described and discussed in Limnetics (1976), and by Jude et al. (1973). Also, Jude et al. (1973) state that temperature may be the most important environmental parameter affecting sampling. Water temperature is no less important in this study, and its relationship to fishes in the reservoir will be addressed in the ensuing sections.

Figure 9. Weekly water temperatures recorded in the Ludington Pumped Storage Reservoir during 1973, 1974, and 1975.


20
15
°C
10
5
0
1975
20
15
°C
10
5
0
1974
20
15
°C
10
5
0
1973
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.

Initial Study of Fish Colonization

Fishes entering the Ludington reservoir during the initial filling period were studied by an intensive effort that included seining, gill netting, trawling, trap netting, rotenone, and dip netting (Liston and Tack, 1973). Pumping began on October 23, 1972. A short drawdown occurred on November 4, and by late November the reservoir was filled to maximum level (elev. 942).

A total of 17 fish was taken in this initial study: 5 smelt, 3 yellow perch, 2 steelhead, 2 brown trout, 2 burbot, 1 longnose sucker, 1 spottail shiner, and 1 alewife. Eleven were dead on capture, and some had been cut during their entry. The largest fish to enter unmarked through the turbine was a 20.6 in (523 mm) brown trout. The relatively few fish found in the reservoir at that time could have resulted from movement of many nearshore populations to deeper waters (Limnetics, 1976; Jude et al., 1973; and Wells, 1968).

Bottom Gill Nets

Bottom gill nets were the most reliable method used in the reservoir. Yearly and seasonal population patterns were discernible, although weekly sampling may have missed some inward and outward movement of certain fish species that may have occurred with upwellings, storms, or spawning behaviors. Common names of fish species are used throughout this report, and scientific and common names of all fish species collected in the reservoir are listed in Table 2.

Table 2. Scientific* and common names of fish collected in the Ludington Pumped Storage Reservoir during 1973, 1974, and 1975.

Scientific name	Common name
Acipenser fluvescens	Lake sturgeon
Lepisosteus osseus	Longnose gar
Alosa pseudoharengus	Alewife
Dorosoma cepedianum	Gizzard shad
Coregonus clupeaformis	Lake whitefish
Coregonus hoyi	Bloater
Oncorhynchus kisutch	Coho salmon
Oncorhynchus tshawytscha	Chinook salmon
Prosopium cylindraceum	Round whitefish
Salmo gairdneri	Rainbow-steelhead trout
Salmo trutta	Brown trout
Salvelinus fontinalis	Brook trout
Salvelinus namaycush	Rainbow trout
Osmerus mordax	Rainbow smelt
Esox lucius	Northern pike
Carassius auratus	Goldfish
Couesius plumbeus	Lake chub
Cyprinus carpio	Carp
Notropis hudsonius	Spottail shiner
Pimpehales promelas	Fathead minnow
Rhinichthys cataractae	Longnose dace
Catostomus catostomus	Longnose sucker
Catostomus commersoni	White sucker
Moxostoma sp.	Redhorse
Ictalurus nebulosus	Brown bullhead
Percopsis omiscomaycus	Trout-perch
Lota lota	Burbot
Pungitius pungitius	Ninespine stickleback
Ambloplites rupestris	Rock bass
Lepomis macrochirus	Bluegill
Ethestoma nigrum	Johnny darter
Perca flavescens	Yellow perch
Cottus sp.	Sculpin

*Bailey, R. M., J. E. Fitch, E. S. Herald, E. A. Lachner, C. C. Lindsey, C. R. Robins, and W. B. Scott. 1970. A list of common and scientific names of fishes from the United States and Canada (Third Edition). Amer. Fish. Soc., Spec. Pub. No. 6. 150 pp.

Total Bottom Gill Net Catch and Percentage Composition

The total number caught in 265 bottom gill net collections has not changed significantly over the study period (Table 3). Total catch for 1975 was lower than 1973 and 1974 totals, which indicated fish populations had not accumulated in the reservoir. Early spring and late fall reservoir samples each year were typified by zero catches, and indicated most smelt, alewife, yellow perch, and suckers had left the reservoir and beach zone region during those periods. Contrary to this, studies at the Point Beach nuclear plant in western Lake Michigan (Wis. Elec. Power Co. and Wis. Mich. Power Co., 1973) found that white suckers were permanent residents of the nearshore zone, and smelt and alewife were collected during all months, and yellow perch in all months except February. Also, longnose suckers were collected throughout the year at the submerged intake of the Palisades plant (Benda and Gulvas, 1976) and by studies at the Cook plant in southeastern Lake Michigan (Jude et al., 1975). Low catches in the reservoir could have resulted as fish movement decreased in colder waters thus making them less vulnerable to passive bottom gill nets and to the intake. Without over-winter samples, kind and number of species remaining in the reservoir could not be determined. However, mark and recapture studies showed that 7 carp, 3 steelhead, and 1 white sucker had overwintered in the reservoir.

Percentage composition in the reservoir was dominated each year by rainbow smelt. Spottail shiner was second, followed by yellow perch in 1973 and alewife in 1974 and 1975 (Table 3). Bottom gill net percentage compositions from Lake Michigan stations 2, 3, 5, and 6

Table 3. Total numbers and percentage composition of fish collected in the reservoir by bottom gill nets during 1973, 1974, and 1975.

Species	Total No. 1973	% Comp. 1973	Total No. 1974	% Comp. 1974	Total No. 1975	% Comp. 1975
Rainbow smelt	1156	47.2	1432	48.8	1074	48.4
Spottail shiner	665	27.2	<23	28.0	405	18.2
Alewife	200	8.2	283	9.6	187	8.4
Yellow perch	281	11.5	158	5.4	97	4.3
Longnose sucker	32	1.3	70	2.4	90	4.0
White sucker	19	0.8	54	1.8	59	2.6
Trout-perch	22	0.9	25	0.9	58	2.6
Carp	13	0.5	25	0.9	60	2.7
Brown trout	6	0.5	14	0.5	11	0.5
Lake trout	5	0.5	11	0.4	10	0.5
Burbot	12	0.5	5	0.2	86	3.8
Bloater			5	0.2	25	1.1
Coho salmon	5	0.5	1	<0.1	15	0.6
Chinook salmon	18	0.8	8	0.3	12	0.5
Round whitefish	2	<0.1	5	0.2	13	0.5
Redhorse sp.			3	<0.1	1	<0.1
Northern pike	2	<0.1	2	<0.1	3	0.1
Brown bullhead			2	<0.1		
Steelhead	3	<0.1	2	0.1	6	0.2
Gizzard shad	1	<0.1	1	<0.1		
Sculpin sp.			1	<0.1	2	<0.1
Rockbass			1	<0.1		
Lake whitefish	2	<0.1	2	<0.1	2	<0.1
Lake chub	1	<0.1				
Longnose dace	1	<0.1			1	<0.1
Goldfish	1	<0.1				
Lake sturgeon	1	<0.1				
Ninespine stickleback					1	<0.1
Total number	2448		2933		2218	
Total number of sets	85		89		91	

are compared to reservoir compositions in Table 4. These stations (Fig. 5) were chosen, because they were believed most representative of fish populations in the vicinity of the plant. Since similar methodologies were used in the reservoir and the lake, differences and similarities in percentage species compositions could help determine which species were vulnerable to and which species could avoid the intake. Results showed a markedly different species composition between the two areas (Table 4). Most noticeable was the difference between areas in abundance of yellow perch. This species was seasonally very abundant in the vicinity of the intake but apparently avoided being pumped into the reservoir. Although not as noticeable, the same was true for white and longnose sucker, round whitefish, and lake trout. Bottom gill net results indicated that the smaller pelagic species, particularly smelt and alewife, were most vulnerable to the intake.

Catch-Per-Unit-Effort

Examination of percentage species composition of bottom gill net data provided only a qualitative assessment of the fish populations present. Catch-per-unit-effort data provided a measure of the relative abundance of a species or population. Mean seasonal catches for alewife, smelt, spottail shiner, yellow perch, white and longnose sucker collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975 (Figures 10-15) illustrate differences in mean catch between the reservoir and Lake Michigan, and yearly and seasonal variation in mean catch of those species.

Table 4. Percentage composition of eight fish species collected by bottom gill nets in the three reservoir and four nearby Lake Michigan stations.

Species	Reservoir 1973	Lake Michigan 1973	Reservoir 1974	Lake Michigan 1974	Reservoir 1975	Lake Michigan 1975
Smelt	47.2	3.2	48.8	3.2	48.4	7.1
Spottail shiner	27.2	5.6	28.0	4.7	18.2	11.1
Yellow perch	11.5	65.4	5.4	64.5	4.3	47.3
Alewife	8.2	11.3	9.6	8.2	8.4	8.6
Longnose sucker	1.3	3.2	2.4	4.0	4.0	5.8
White sucker	0.8	7.6	1.8	9.7	2.6	10.2
Round whitefish	0.5	1.6	0.2	2.9	0.5	4.9
Lake trout	0.5	1.7	0.4	2.5	0.5	4.7
Total number	2448	9722	2935	5737	2218	6649
Total number of sets	88	84	85	80	91	108

The three-way analysis of variance (Nie et al., 1976) of season (4), year (3), and station (3) yielded the following results:

Smelt - main effect due to year ($P < .10$)
Smelt - main effect due to season ($P < .25$)
Smelt - main effect due to station ($P < .05$)
Smelt - year season interaction ($P < .005$)

Spottail shiner - no significant differences ($P > .25$)

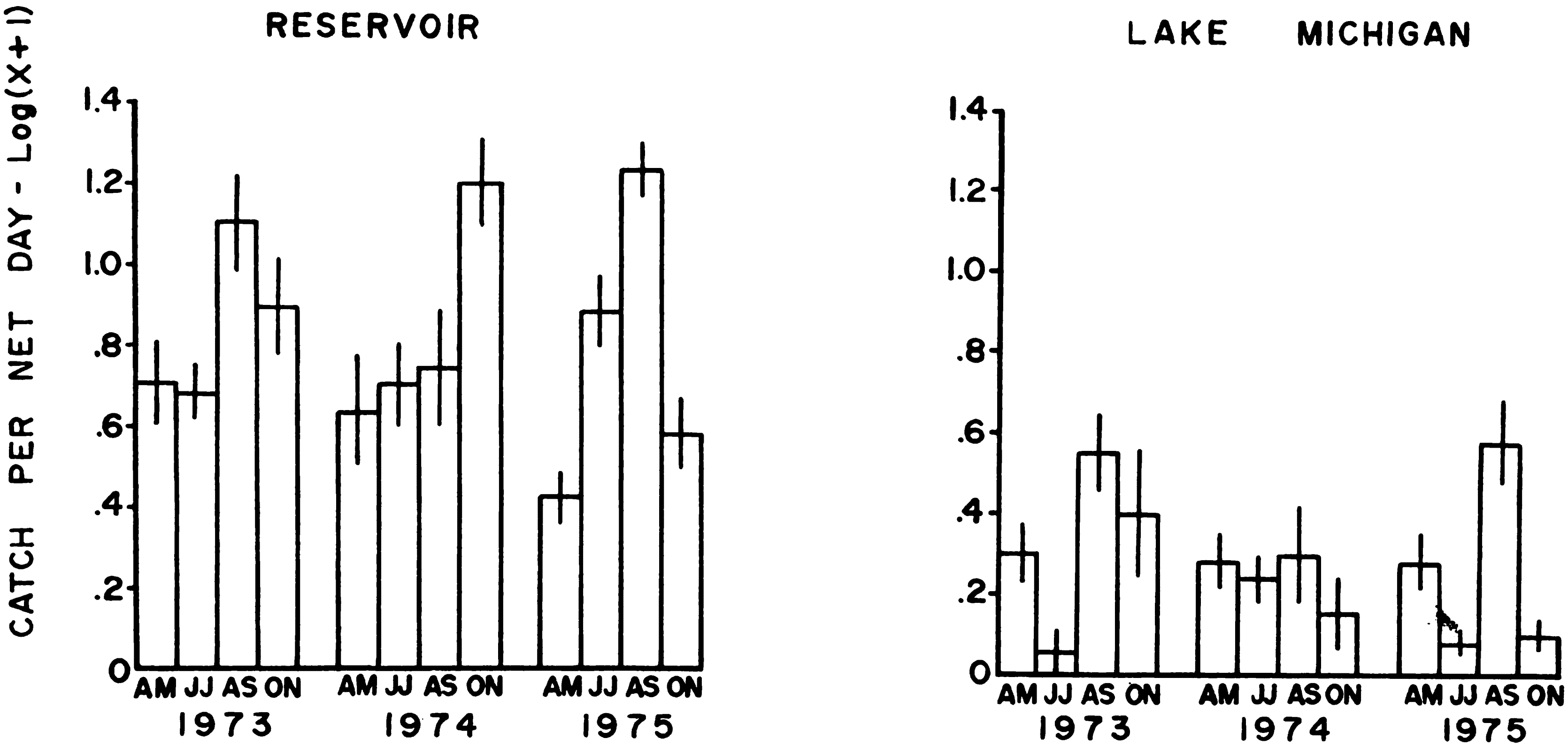
Alewife - main effect due to year ($P < .20$)
Alewife - main effect due to season ($P < .005$)

Yellow perch - main effect due to season ($P < .10$)

Varying probabilities of Type I error are provided to indicate the strength of evidence for each factor. Large differences appeared in the yearly and seasonal mean catches of most species (Figures 10-15), but statistical testing pointed out relatively few significant differences. Only visual comparisons were made between catch of different species in the reservoir and those caught in Lake Michigan, therefore, only large and general differences were singled out and discussed.

Rainbow smelt were the most abundant species collected by bottom gill nets in the reservoir (Fig. 10). No specific differences among the three yearly averages of numbers of smelt caught were significantly large when tested at $P = .25$, although the overall test for years suggested that yearly variation may be important. Highly significant year-season interactions did occur ($P < .005$). The August-September mean catch in 1973 and 1975 was higher than the pooled mean catch of other seasons ($P < .25$). The October-November mean catch of 1974 was higher than the October-November mean catches of 1973 and 1975 ($P < .10$). Smelt move offshore to deeper waters after spawning (Jude et al., 1975;

Figure 10. Seasonal mean catch per net day and standard error of rainbow smelt captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.



RESERVOIR
LAKE MICHIGAN
CATCH PER NET DAY - Log(X+1)
1.4
1.2
1.0
.8
.6
.4
.2
0
AM JJ AS ON
1973
1974
1975

Wells, 1968). High relative abundances of adult smelt in the reservoir during August-September and October-November indicated that smelt remained in nearshore zones during summer and fall, possibly to feed upon young of the year alewife in this region (Robert Kavetsky, pers. comm.).

Similar results were found by Jude et al. (1975) in southeastern Lake Michigan who determined that smelt, a cold water species, was the most abundant fish caught in September, and that smelt come inshore following cold water upwellings in July, August, and September. Smelt catch was expected to peak during April-May (Wis. Elec. Power Co. and Wis. Mich. Power Co., 1973; Jude et al., 1975), but was lower than August-September, and October-November mean catches during all three years. Two explanations for this seem plausible. One is that spawning smelt were concentrated around streams and tributaries during the April-May season and therefore not susceptible to the intake at that time. The second is that smelt, which exhibit a strong upstream migrational behavior in the spring, were attracted by strong generating currents of the reservoir, but when currents were reversed during the pumping mode, their strong reaction to migrate upstream led them away from influences of the intake. Seining results near the project verified that large numbers of smelt were present along the shoreline in April and May (Liston and Tack, 1975). Adult smelt may not have been as abundant nearshore in summer and fall, but a reduction of the upstream spawning behavior and feeding upon young of the year alewife could have made them more vulnerable to the intake. April-May mean catches of smelt in Lake Michigan were also relatively low. It was possible that Lake Michigan sampling missed the peak or that lake stations were too far offshore for effective netting of smelt.

Relative abundance of smelt collected by bottom gill nets was much higher in the reservoir than in Lake Michigan (Fig. 10). This difference in abundance was consistant and did not increase over the study period. Hence, seasonal and yearly inward and outward movements of smelt were quite similar. Also, bottom gill nets in the reservoir fished a more confined area, which could have concentrated smelt populations and allowed nets in the reservoir to fish more efficiently than nets in Lake Michigan. For these reasons and because the reservoir intake sampled smelt populations in the beach zone daily, and because the nearest shore lake stations were at the 6 meter depth, the abundance estimate of smelt in the reservoir was believed to closer approximate their actual abundance in the beach zone of Lake Michigan. Until smelt populations of nearshore and beach zones of Lake Michigan become better defined, it will be difficult to assess the impact of this pumped storage facility on this species.

Smelt was the only species that demonstrated any large differences in mean catch due to station. The mean catch at northern and deeper station 9 was lower than the pooled mean of stations 7 and 8 ($P < .25$), and much higher at station 7 than the pooled mean of stations 8 and 9 ($P < .10$). This reflected a general pattern which occurred for nearly all species in bottom gill net collections. Perhaps smelt and other species occurred more often at station 7 than 8 and 9, or bottom gill nets fished more efficiently at station 7. Nets set in southern station 7 were generally much cleaner and less tangled than nets set in 8 and particularly in 9 where water currents were strongest. These factors could likely have influenced the distribution and catch of fishes in the reservoir.

No significant differences were observed among mean catch of spottail shiner in the reservoir over years, seasons, or stations ($P > .25$). Mean seasonal catches of spottail shiner in the reservoir were similar to Lake Michigan during June-July, August-September, and much higher in the reservoir during the April-May and October-November seasons (Fig. 11). Generally higher abundances of spottails in the reservoir indicated that this species was also vulnerable to the Ludington intake. Again, differences in abundance could have resulted from concentrating effects of the reservoir, the intake daily pumping beach zone waters, or from lake stations being too far offshore for effective netting of spottail shiners. Jude et al. (1975), who, by using a combination of seines, trawls, and bottom gill nets also determined spottail shiner to be the second most abundant species in the nearshore region of southeastern Lake Michigan. Only adult spottail shiners were selectively caught in the 1 in. stretch mesh monofilament panels of the bottom gill nets in the Ludington reservoir and in Lake Michigan. Seining and trawling results at Ludington showed that smaller size classes of spottails were also abundant, but more information is needed before accurate assessments can be made.

Alewife were the third most abundant fish collected by bottom gill nets in the reservoir. Mean catches were not noticeably different between years or stations (Fig. 12), but the overall statistical test for years suggested yearly variations may be important for alewife as was found for smelt. During June-July alewives had moved inshore to spawn and apparently became vulnerable to the intake. Average June-July and August-September catches of alewife were higher in the

Figure 11. Seasonal mean catch per net day and standard error of spottail shiners captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

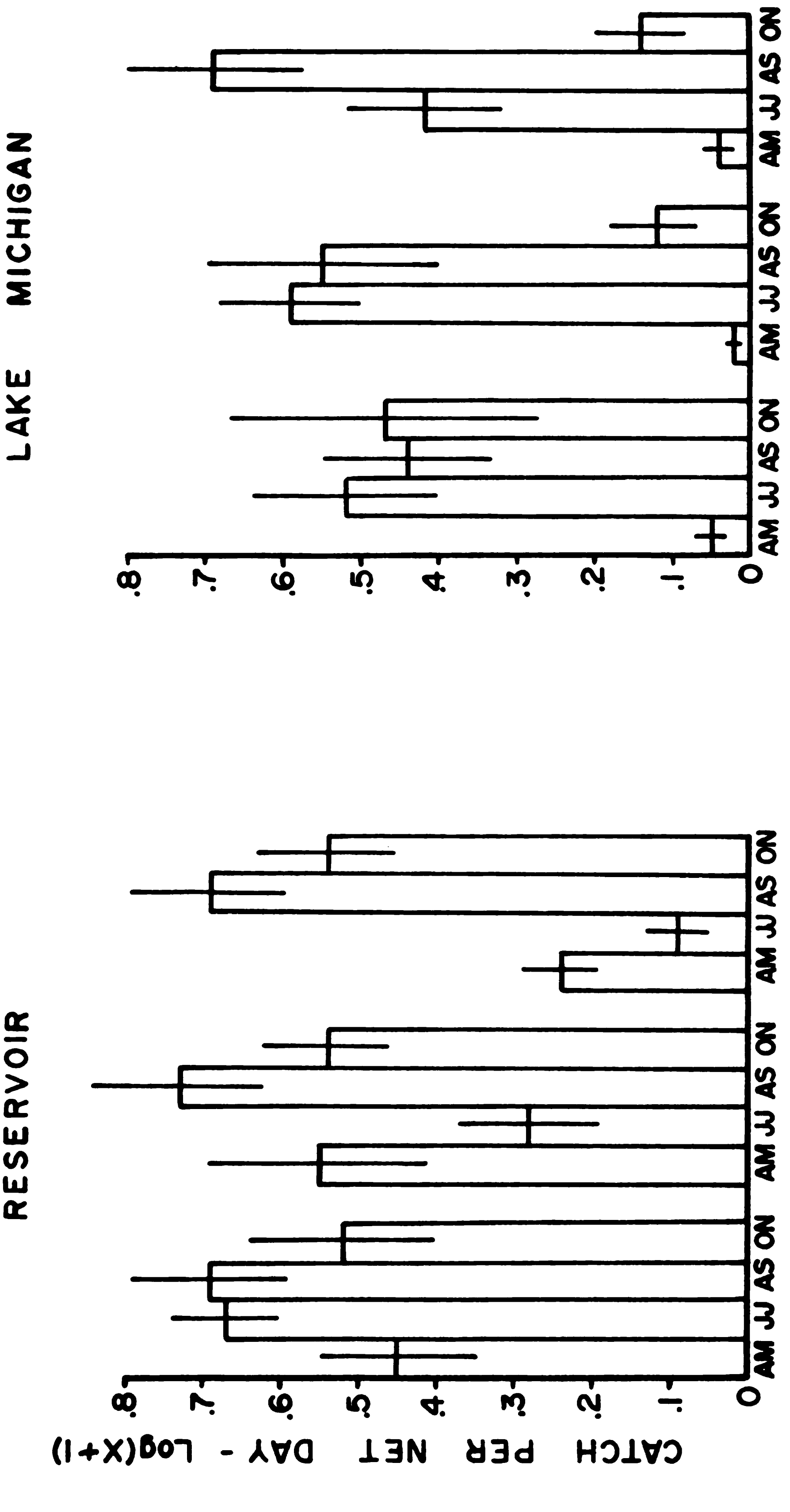
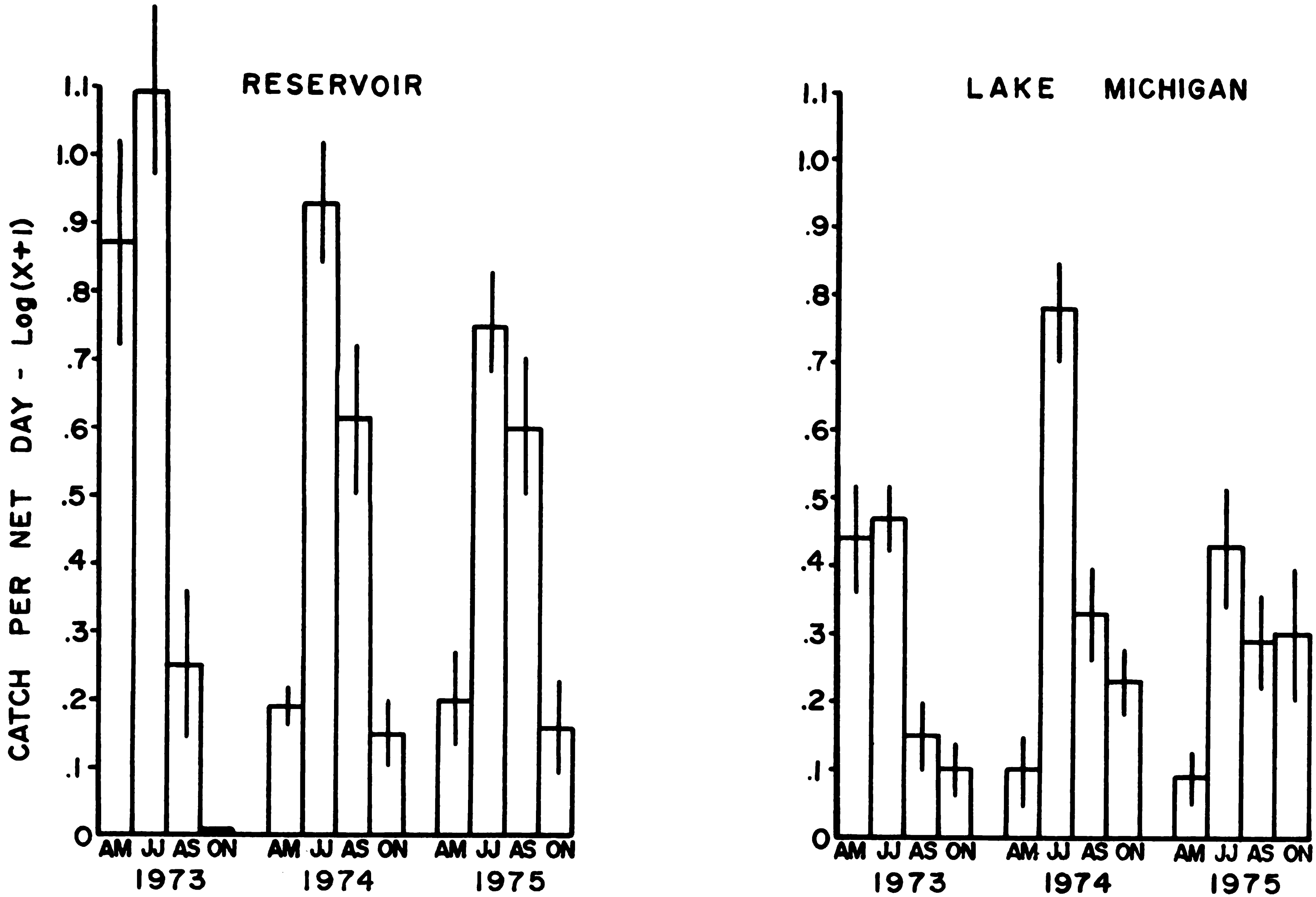

LAKE MICHIGAN
RESERVOIR
CATCH PER NET DAY - Log(X+1)
0
.1
.2
.3
.4
.5
.6
.7
.8
AM JJ AS ON
1973
1974
1975

Figure 12. Seasonal mean catch per net day and standard error of alewife captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.


RESERVOIR
LAKE MICHIGAN
CATCH PER NET DAY - Log(X+1)
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
AM JJ AS ON
1973
1974
1975

reservoir than in Lake Michigan. As with smelt, and spottail shiner, the higher relative abundance in the reservoir may be due to the regular sampling (pumping) of the intake and reservoir nets fishing a more confined area. Large numbers of alewives entered and left the reservoir in relatively short periods, which caused sizable fluctuation in the catch. For example, the total three year trawl catch of alewife was 8729, 6100 of which were captured one night during August, 1975.

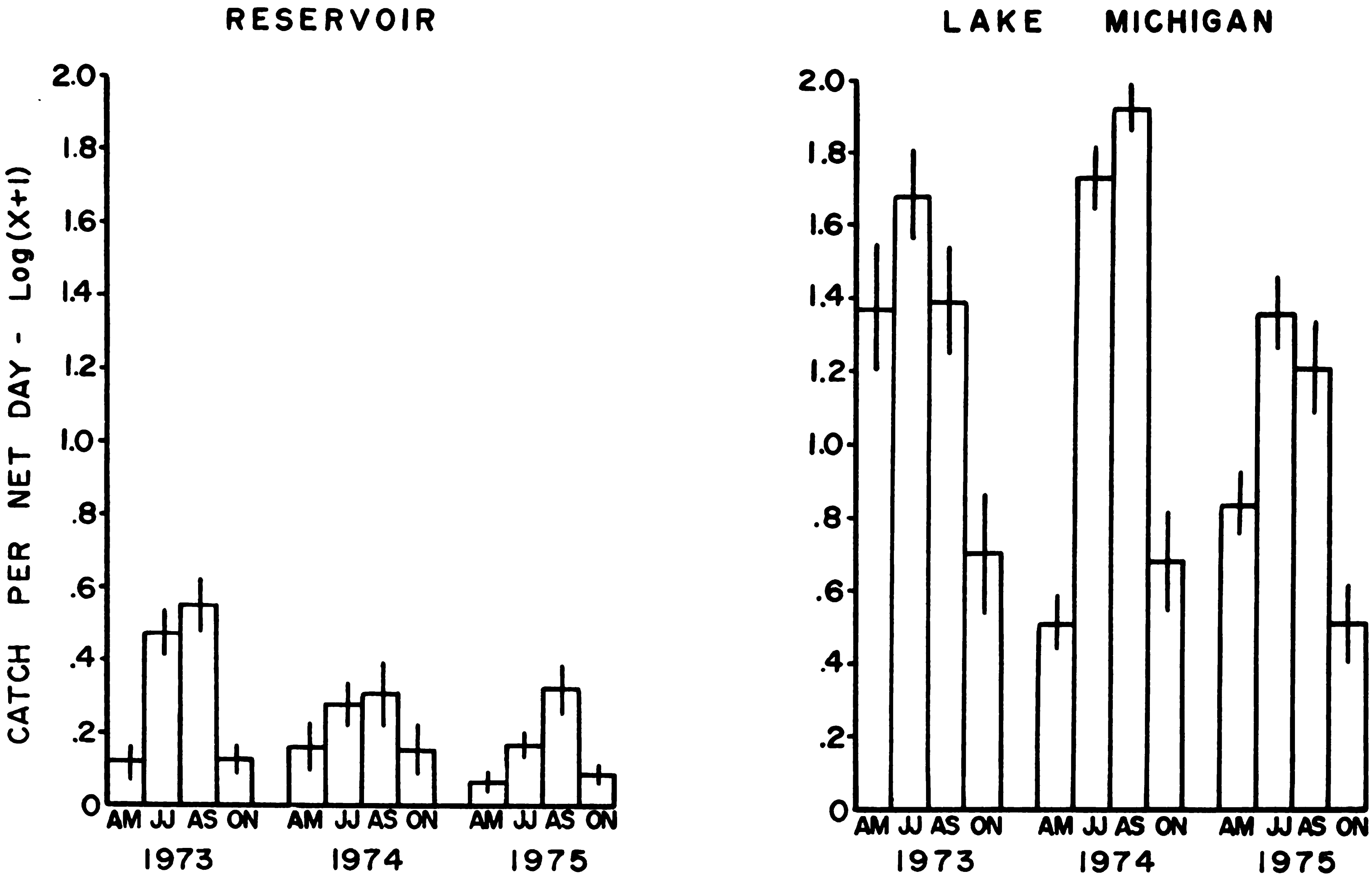
The behavior of yellow perch, like many other species, appeared closely keyed to water temperature. Populations in Lake Michigan, which were offshore in winter, moved inshore to spawn with rising water temperatures of spring and summer, and back offshore in fall as water temperatures declined as has been documented by Wells (1968), Wis. Elec. Power Co. and Wis. Mich. Power Co. (1973), Jude et al. (1975), and Brazo et al. (1976). Their response to sudden temperature changes in nearshore zones has not been clearly established. Even with this seasonal inshore movement and diurnal movement into shallow regions (Emery, 1973), yellow perch did not appear to be harmfully affected by the pumped storage facility. Yellow perch were observed to concentrate around riprap of intake cribs in southeastern Lake Michigan (Jude et al., 1975; Benda and Gulvas, 1976), so rock jetties and breakwall structures of this project (Fig. 1), which provide increased surface area for periphyton growth and an excellent habitat for crayfish (*Orconectus* sp.), could increase the recreational potential for catching yellow perch in this area.

Seasonal mean catch per net day and standard error of yellow perch collected by bottom gill nets in the reservoir and in Lake

Michigan during 1973, 1974, and 1975 are shown in Figure 13. Hauer (1975) reported that summer abundance (June 16 through August 31) of yellow perch in the Ludington reservoir had decreased significantly from 1973 to 1974 (t-test, $\alpha = .05$). However, this overall analysis of 1973-1975 yellow perch data showed that no significant differences ($P > .25$) had occurred between years or stations. Seasonal behaviors of this species did, however, result in June-July and August-September mean catches that were greater than April-May and October-November mean catches. Relative abundance of yellow perch in the reservoir was closely associated with their nearshore abundance in Lake Michigan during these seasons (Fig. 13).

The greater abundance of yellow perch in Lake Michigan than in the reservoir was verified by Hauer (1975), who also stated that yellow perch were avoiding the power plant area. Hauer theorized from his results that yellow perch had left the reservoir as readily as they had entered. With the addition of 1975 data, it was found that Lake Michigan catches at stations 3 and 5, which were very near and in the direct influence of the plant, usually were similar or higher than at other stations. These results indicated that yellow perch were abundant in the vicinity of the plant, and that most of them avoided being pumped into the reservoir. SCUBA observations at the submerged intake of the Palisades plant also revealed that yellow perch were concentrated around that intake structure, but none were recorded on the travelling screens during the period of those observations. On other occasions though, large numbers of yellow perch were impinged on the travelling screens (Benda and Gulvas, 1976). Yellow perch appeared to display a similar behavior at the Ludington

Figure 13. Seasonal mean catch per net day and standard error of yellow perch captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.


RESERVOIR
LAKE MICHIGAN
CATCH PER NET DAY - Log (X+1)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
AM JJ AS ON
1973
1974
1975

intake. Lake Michigan bottom gill net results from areas close to the intake showed that yellow perch were abundant in the vicinity of the intake, but as indicated by the sporadic catches in the reservoir, only occasionally were they pumped in. It could not be determined whether this behavior (avoided intake most often, but occasionally were susceptible) was a response to currents, temperature, feeding, or other factors. Scott and Crossman (1973), Emery (1973), Eddy and Underhill (1974), and Jude et al. (1976), state that yellow perch rest on the bottom at night, which could explain why relatively few were pumped into the Ludington reservoir, but does not explain why yellow perch during daytime, were usually not drawn into the Palisades intake which pumped continuously. Because the yellow perch is a demersal species, it did not appear to be influenced by the Ludington intake as much as the more pelagic species such as smelt and alewife.

White and longnose suckers were species considered to be of commercial and recreational importance and hence were of interest regarding the impact of this pumped storage facility. Very few suckers were pumped into the Ludington reservoir (Figs. 14 and 15). Yearly average catch of longnose and white suckers was lowest in 1973, and about equal in 1974 and 1975. Although both species were abundant in this area of Lake Michigan these results indicate that both species avoided being pumped into the reservoir in large numbers.

The total number of carp captured by bottom gill nets in the reservoir increased from 13 in 1973, to 60 in 1975 (Table 4), and indicated that their relative abundance had increased in the reservoir. Most carp collected by bottom gill nets were taken in late spring and

Figure 14. Seasonal mean catch per net day and standard error of white suckers captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

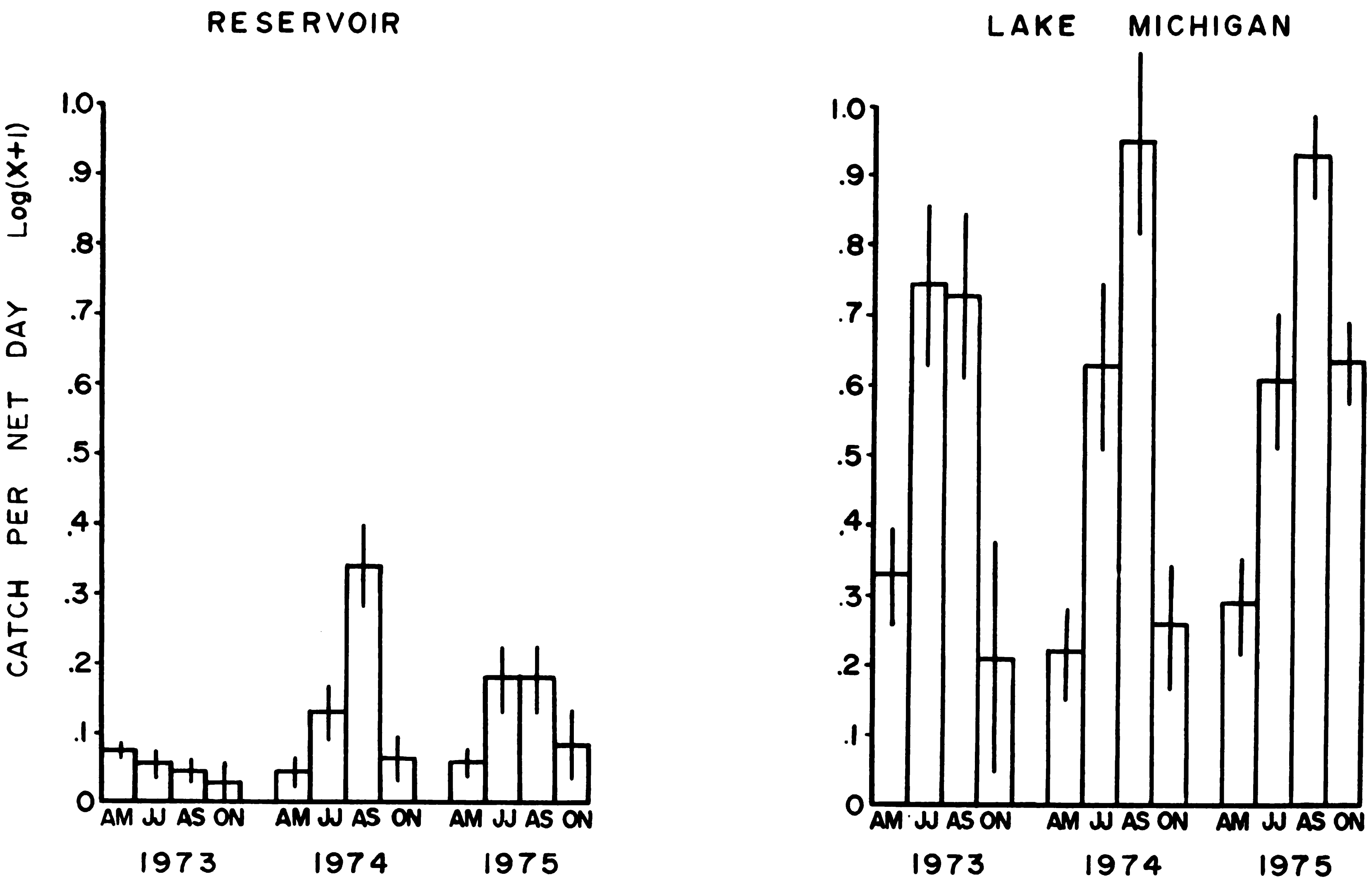
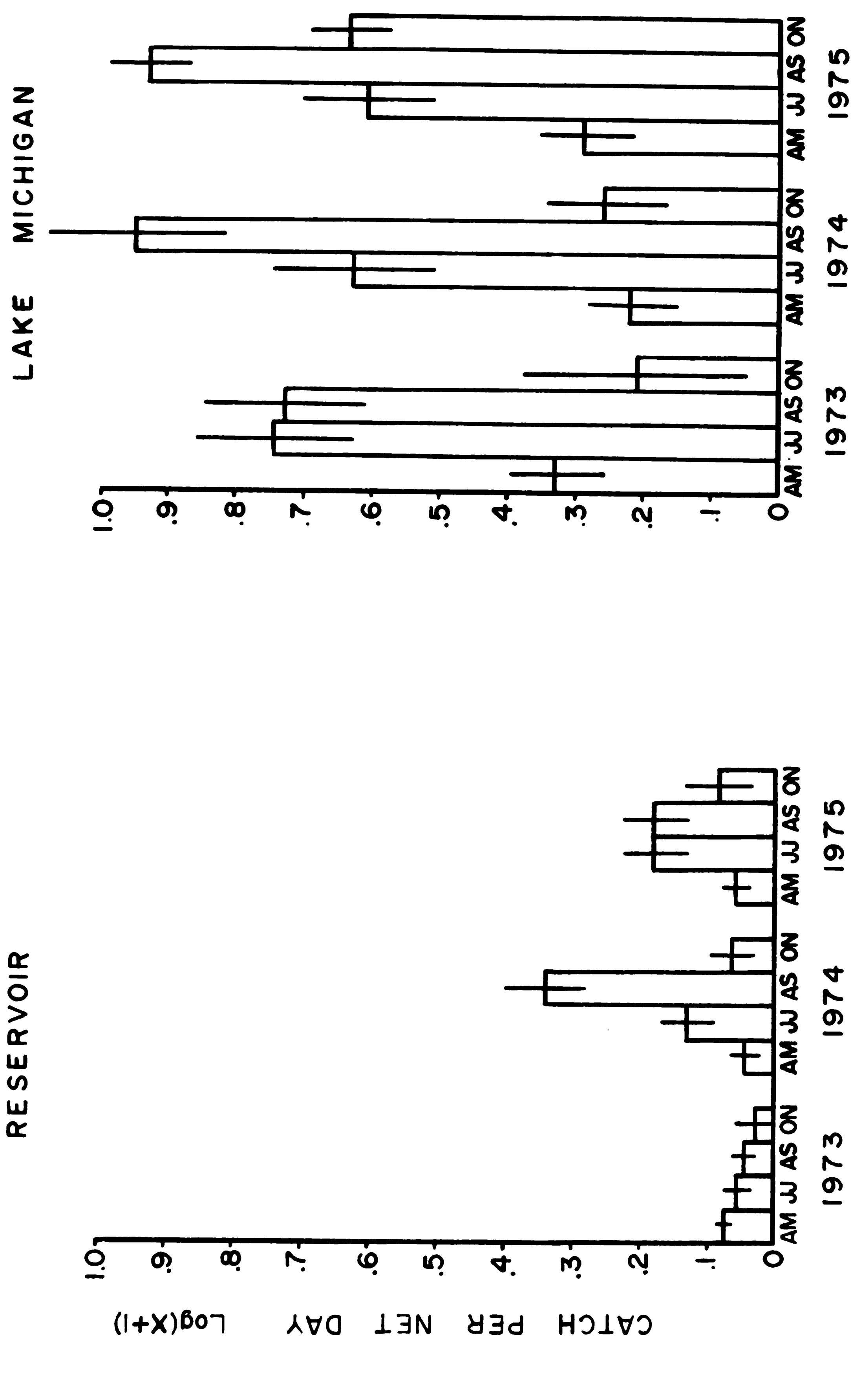
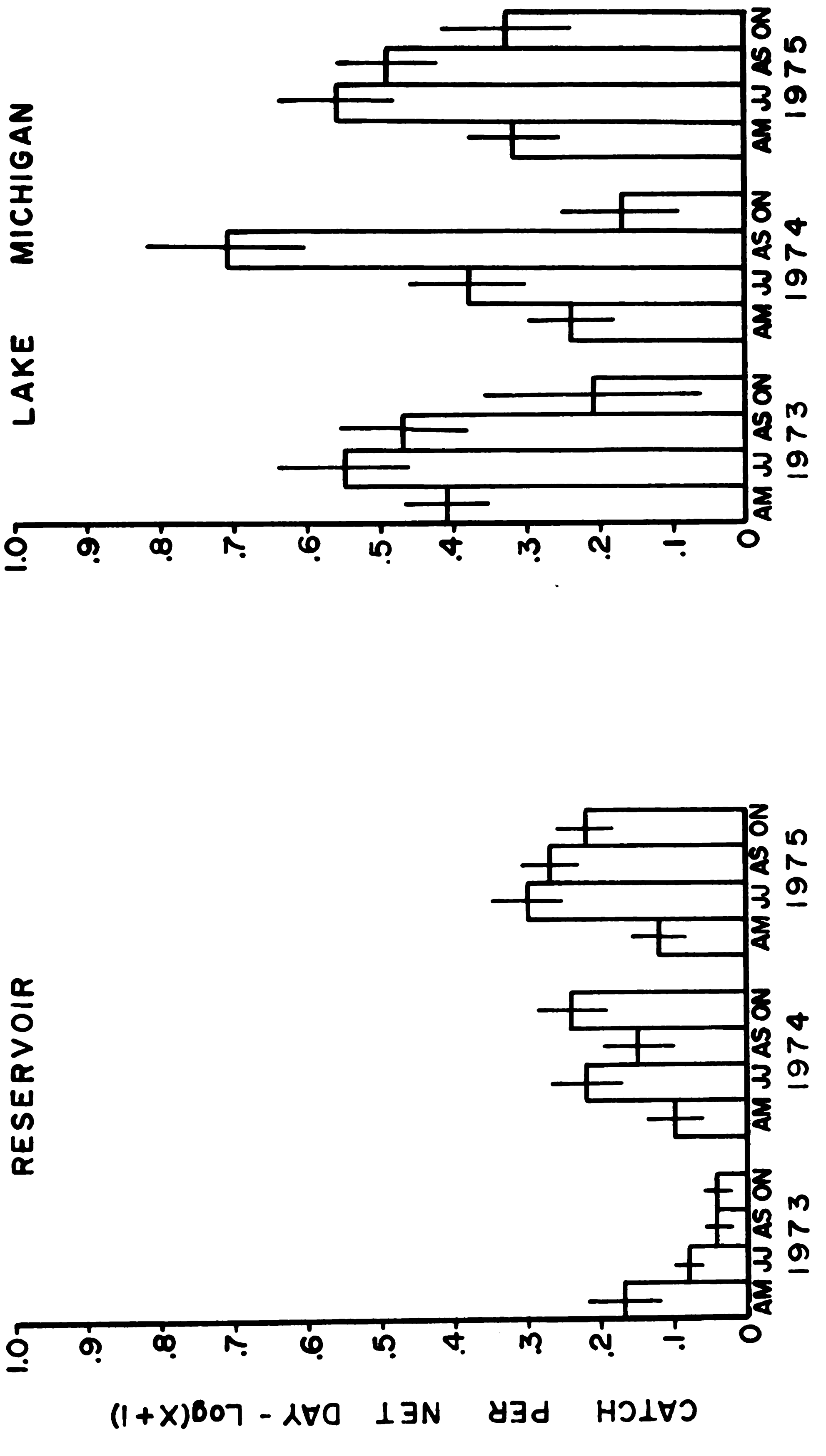

RESERVOIR
LAKE MICHIGAN
CATCH PER NET DAY Log(X+1)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
AM JJ AS ON
1973
1974
1975

Figure 14. Seasonal mean catch per net day and standard error of white suckers captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.



RESERVOIR
LAKE MICHIGAN
CATCH PER NET DAY Log(X+1)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
AM JJ AS ON
1973
1974
1975

Figure 15. Seasonal mean catch per net day and standard error of longnose suckers captured by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.


CATCH PER NET DAY - Log(X+1)
RESERVOIR
LAKE MICHIGAN
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
AM JJ AS ON AM JJ AS ON AM JJ AS ON
1973 1974 1975

fall. During the warmer summer period, most carp were captured in surface gill nets. Tracking studies of carp in the reservoir, by Serchuk (1976), found that carp moved along the wall in the summer and generally moved away from the wall and into deeper water during the late fall season. A similar behavior pattern was indicated by the bottom gill net catch, and was also observed by McCrimmon (1968).

The burbot is a deep water fish (Scott and Crossman, 1973) and hence was not expected to be abundant in the Ludington reservoir. Nevertheless, abundance of burbot increased in 1975 to comprise 3.8% of the total reservoir bottom gill net catch, while in 1973 and 1974 it comprised 0.5% and 0.2% respectively (Table 4). It appeared that burbot moved inshore with frequent upwellings and became vulnerable to the reservoir intake. Most burbot were age class II, which indicated that this may have been a strong year class, or just a segment of the burbot population that was pumped into the reservoir. Rare occurrence of burbot in the Lake Michigan bottom gill net collections demonstrated that even weekly sampling could miss pulses of certain fish populations.

Length-Frequency, Age, and Sex Composition

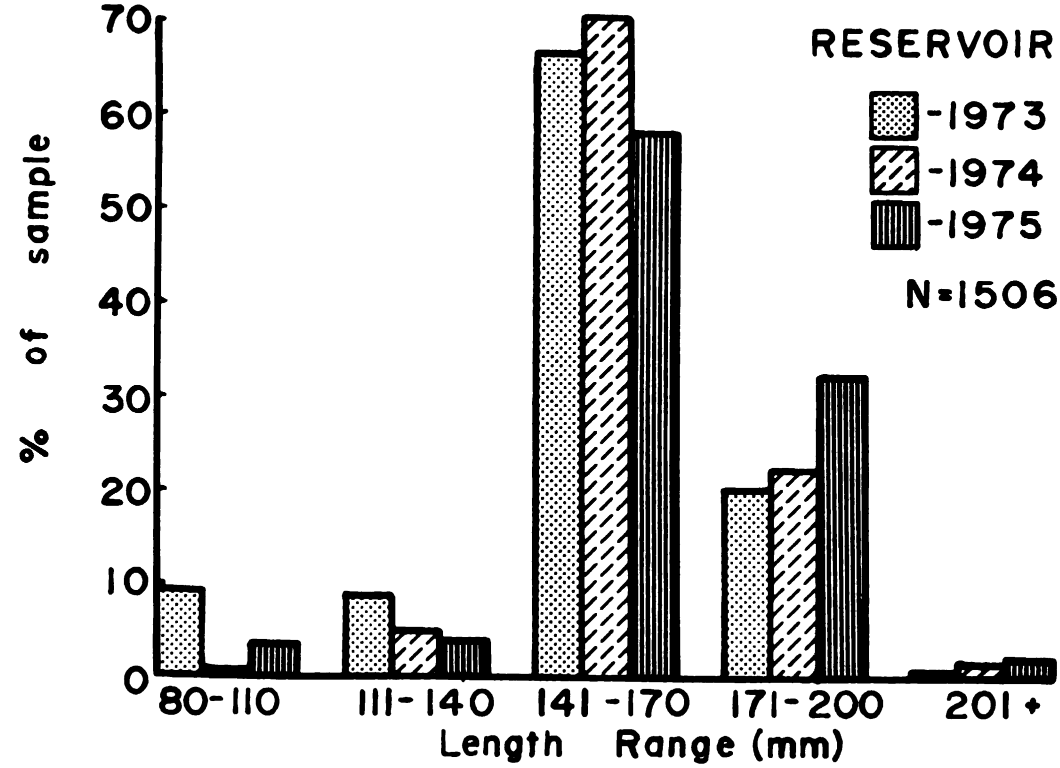
Length-frequency distributions and percentage age and sex compositions of abundant species collected by bottom gill nets in the reservoir and in Lake Michigan were compared to determine whether a certain size or age class, or sex of a particular species was more vulnerable to the Ludington intake than others. Length categories that would closely approximate ages at particular lengths were determined from results of Jude et al. (1975), Liston and Tack (1974), Patriarche (1974), and

Scott and Crossman (1973). The length-frequency distributions of smelt, alewife, yellow perch, white and longnose suckers collected by bottom gill nets in the reservoir and in Lake Michigan are shown for each year in Figures 16, 17, 18, 19, and 20 respectively. A two sample Kolmogorov-Smirnov test (Siegle, 1956) was used to compare length distributions between each year. Mesh sizes in these gill nets were selective for certain size classes of different species, but use of the same nets in both locations rendered this a fair comparison.

The length-frequency distributions of smelt and alewife in the reservoir and in Lake Michigan were not significantly different ($P > .05$). Smelt were only captured efficiently by the 1 in. monofilament mesh so whether other size classes were more or less abundant in either location could not be determined from the data. Most smelt longer or shorther than 140-200 mm were captured by entangling their teeth in larger meshes. Smaller size classes of alewife, smelt, and spottail shiner were observed in trawl and seine collections at Ludington, but their relative abundance was not estimated and hence could not be compared.

Length distributions of yellow perch, longnose and white suckers were different ($P < .05$) from comparable Lake Michigan distributions. Examination of the histograms (Figures 18, 19, and 20) show that the proportion of smaller size classes of yellow perch, longnose and white suckers was higher in the reservoir than in Lake Michigan, and the reverse was true for the larger size classes. Apparently smaller size classes of these species were more vulnerable to the reservoir intake than larger ones. The assertion that larger size classes were cropped by turbine mortality deserves ample consideration. Another explanation

Figure 16. Length-frequency distributions of smelt collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.


RESERVOIR
-1973
-1974
-1975
N=1506
% of sample
0
10
20
30
40
50
60
70
80-110
111-140
141-170
171-200
201+
Length Range (mm)

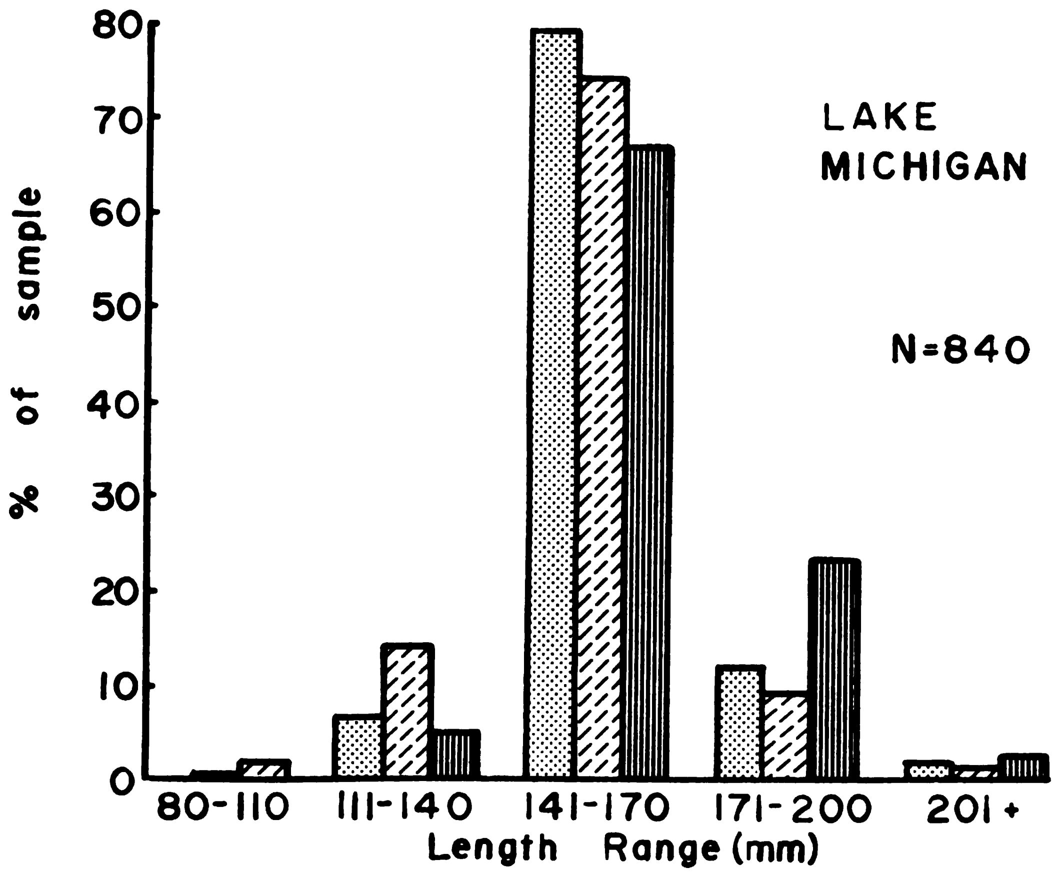
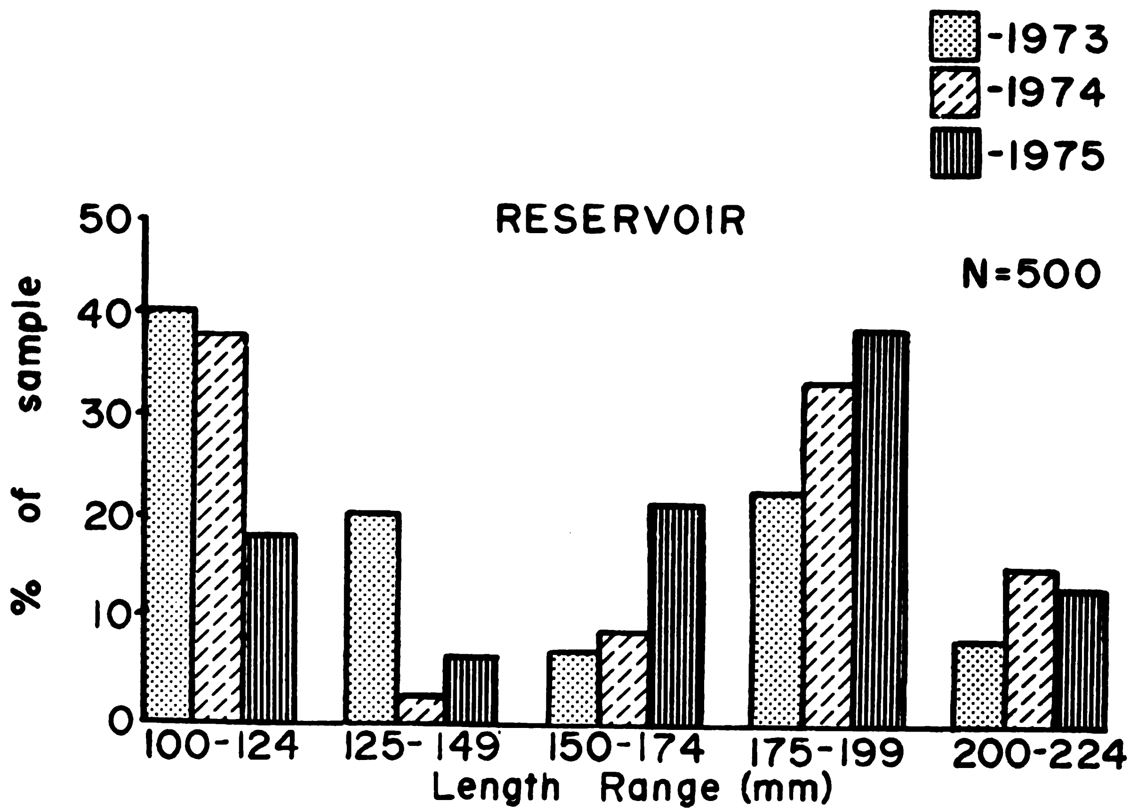
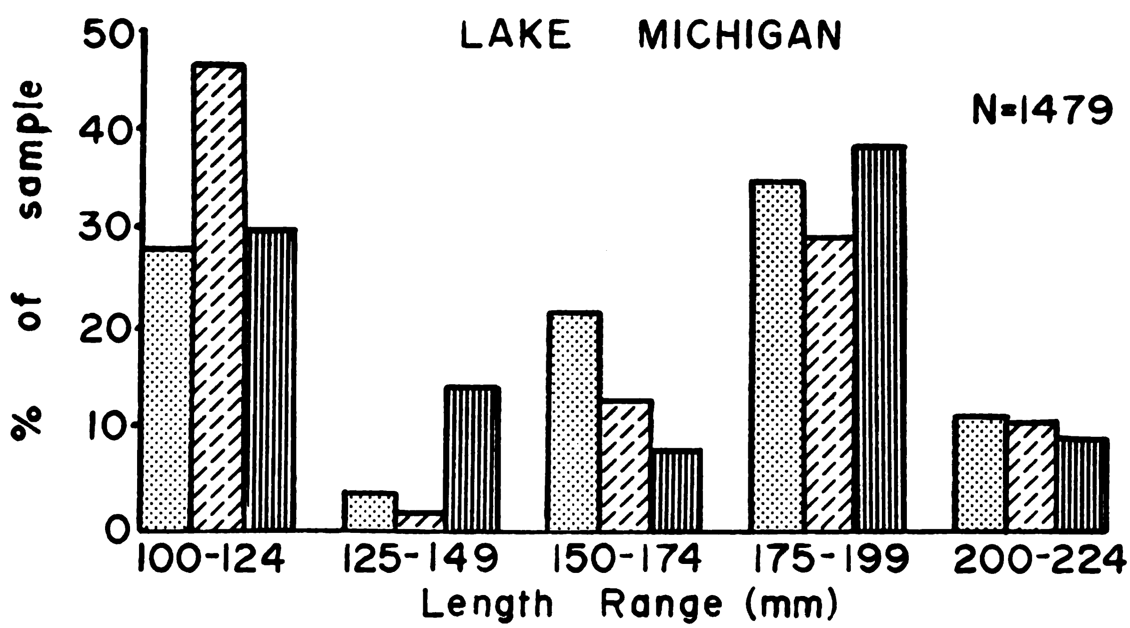

LAKE
MICHIGAN
N=840
% of sample
0
10
20
30
40
50
60
70
80
80-110
111-140
141-170
171-200
201+
Length Range (mm)

Figure 17. Length-frequency distributions of alewife collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.



-1973
-1974
-1975
RESERVOIR
N=500
% of sample
50
40
30
20
10
0
100-124
125-149
150-174
175-199
200-224
Length Range (mm)



LAKE MICHIGAN
N=1479
% of sample
50
40
30
20
10
0
100-124
125-149
150-174
175-199
200-224
Length Range (mm)

Figure 18. Length-frequency distributions of yellow perch collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

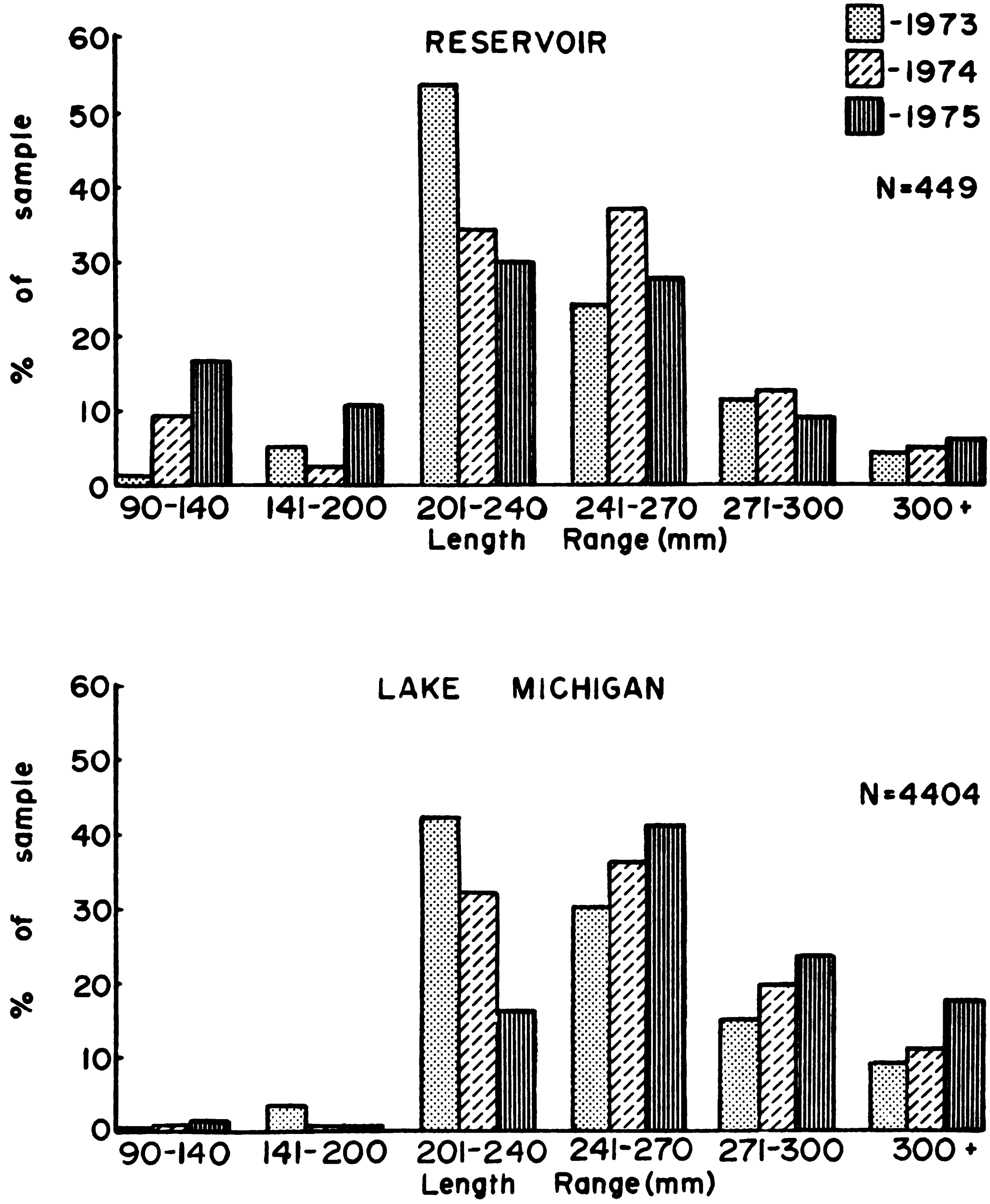

RESERVOIR
-1973
-1974
-1975
N=449
% of sample
60
50
40
30
20
10
0
90-140
141-200
201-240
241-270
271-300
300+
Length Range (mm)
LAKE MICHIGAN
N=4404
% of sample
60
50
40
30
20
10
0
90-140
141-200
201-240
241-270
271-300
300+
Length Range (mm)

Figure 19. Length-frequency distributions of white sucker collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

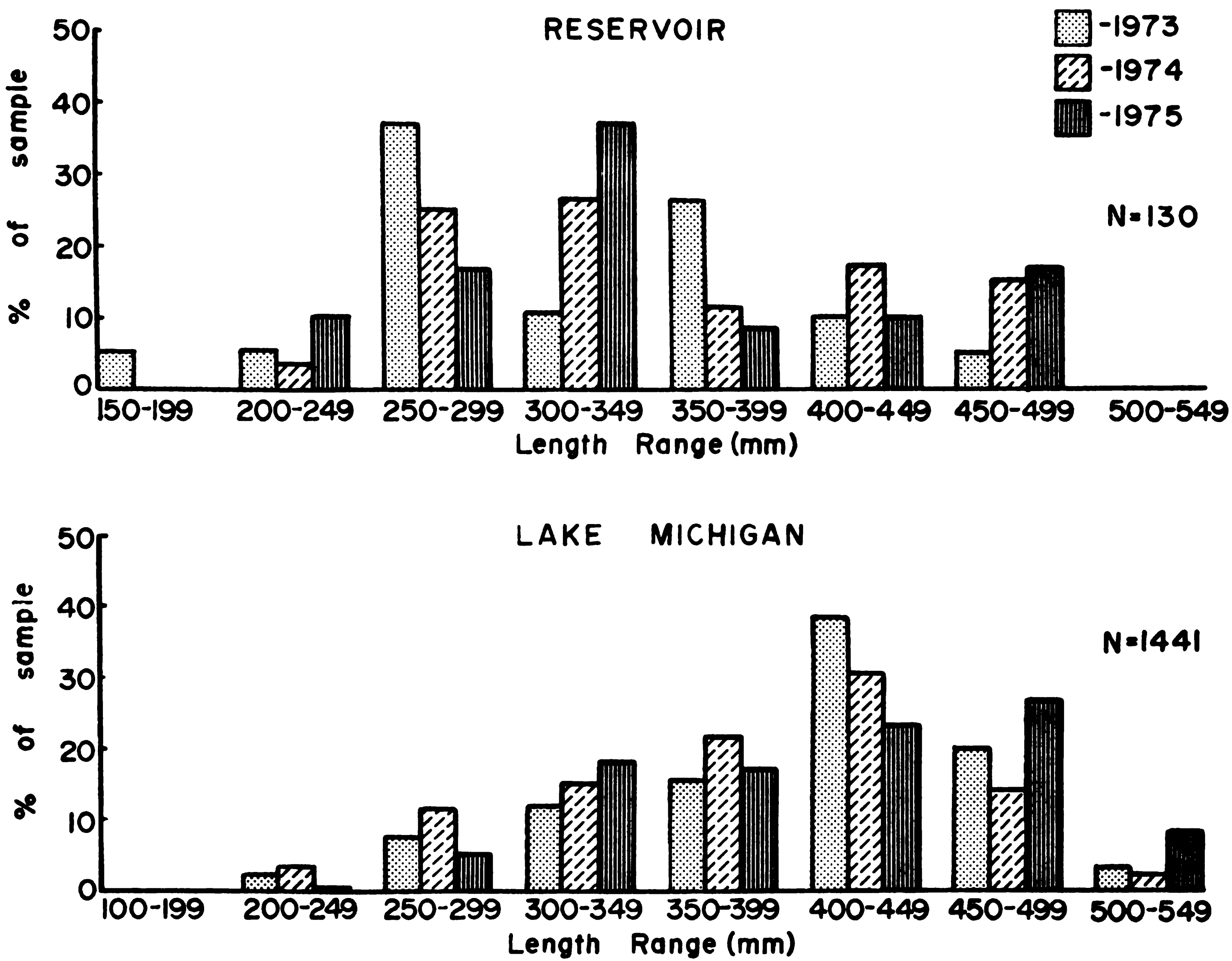
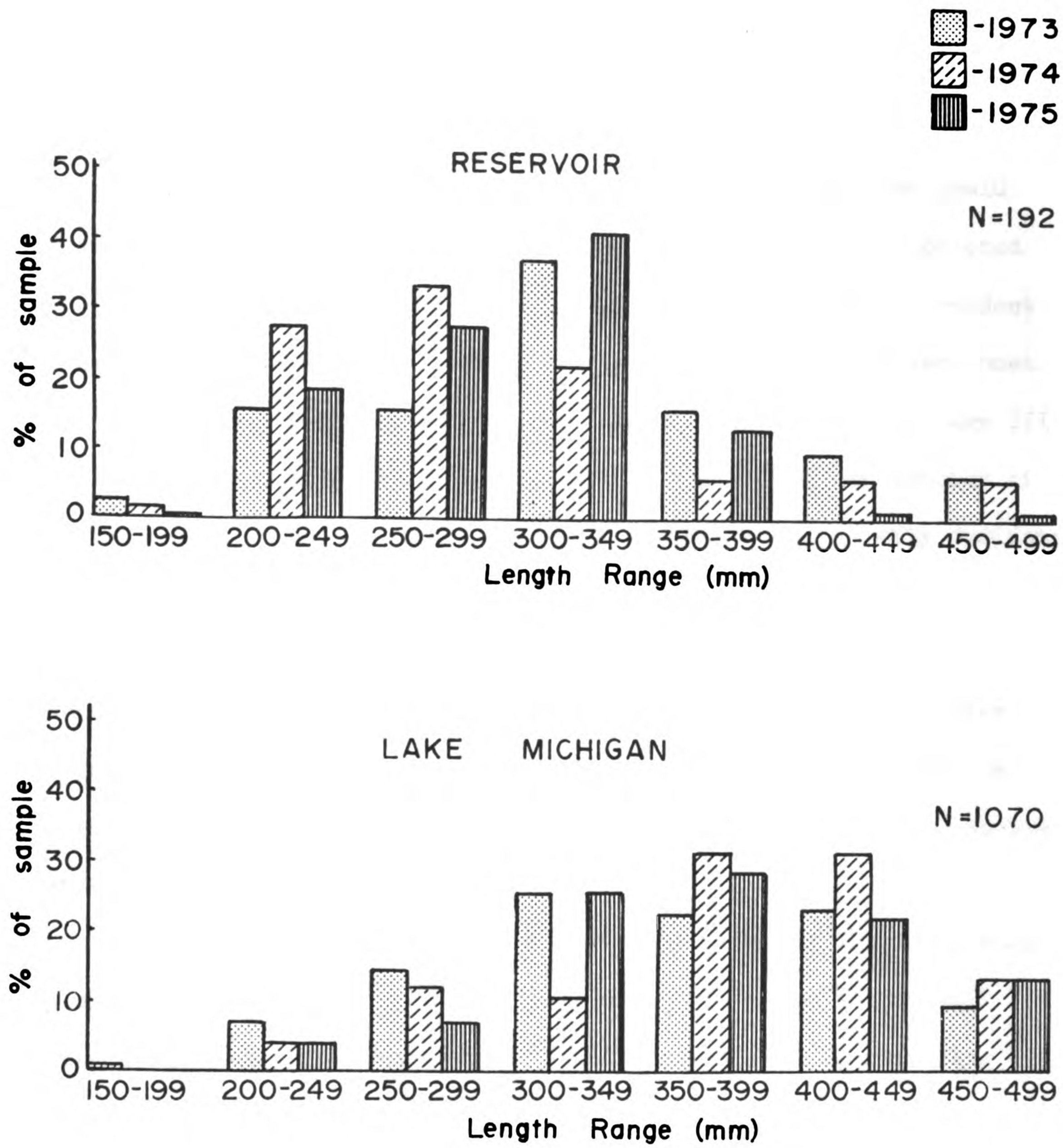

RESERVOIR
-1973
-1974
-1975
N=130
50
40
30
20
10
0
% of sample
150-199
200-249
250-299
300-349
350-399
400-449
450-499
500-549
Length Range (mm)
LAKE MICHIGAN
N=1441
50
40
30
20
10
0
% of sample
100-199
200-249
250-299
300-349
350-399
400-449
450-499
500-549
Length Range (mm)

Figure 20. Length-frequency distributions of longnose sucker collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.


-1973
-1974
-1975
RESERVOIR
N=192
% of sample
0
10
20
30
40
50
150-199
200-249
250-299
300-349
350-399
400-449
450-499
Length Range (mm)
LAKE MICHIGAN
N=1070
% of sample
0
10
20
30
40
50
150-199
200-249
250-299
300-349
350-399
400-449
450-499
Length Range (mm)

may be that smaller size classes of these species inhabited the beach zone and were not proportionally represented in the Lake Michigan length distributions.

The age compositions generally support the same patterns established with the length distributions (Tables 5 and 6). Older age classes of yellow perch, white and longnose sucker appeared to avoid the intake more than younger ones (Tables 6 and 7). Other differences between percentage age compositions in the reservoir and lake could be attributed to small sample sizes in the reservoir which subjected percentages to large changes. Age IV yellow perch were most abundant in Lake Michigan each year (Table 6). Age III yellow perch were most abundant in the reservoir during 1973, age IV during 1974, and age III and IV were equally abundant during 1975. Bottom gill net catches of alewife in both the reservoir and Lake Michigan were generally dominated by age classes I, III, and IV (Table 6). Age II smelt appeared most abundant in Lake Michigan each year and most abundant in the reservoir during 1974 and 1975. In 1973, age III smelt in the reservoir were slightly more abundant than age II, and were relatively numerous in the reservoir and Lake Michigan during 1974 (23.7% and 37.7% respectively, Table 6).

Spottail shiner catches in the reservoir and lake were dominated by age III groups during 1973 and 1974 (Table 7). Age II spottail shiners appeared to increase in abundance in both locations during 1974 (Table 7).

Age class II longnose suckers were more abundant in the reservoir than in Lake Michigan each year while age classes IV, V and VI were more abundant in the lake each year (Table 7). Percentages of younger

Table 5. Percentage age composition of yellow perch, alewife, and rainbow smelt collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

	1973		1974		1975	
	Reservoir	Lake Michigan	Reservoir	Lake Michigan	Reservoir	Lake Michigan
YELLOW PERCH						
I	0.0	0.0	8.3	1.1	15.4	1.6
II	3.0	0.1	0.8	0.1	10.3	2.2
III	54.3	36.1	24.2	16.2	29.9	9.3
IV	36.2	47.4	55.8	62.5	29.9	51.3
V	6.0	13.1	10.8	18.0	13.4	31.1
VI+	0.4	3.2	0.0	2.2	1.0	4.4
n	232	1027	120	1221	97	1677
ALEWIFE						
I	6.0	3.7	36.0	45.6	39.6	29.1
II	16.8	30.2	3.3	2.6	26.0	18.0
III	33.1	17.1	16.0	14.6	18.9	27.4
IV	34.1	41.3	32.0	26.3	13.0	20.0
V	7.0	6.3	9.3	8.4	2.3	4.6
VI	2.7	1.4	3.3	2.6	0.0	0.5
n	184	351	150	274	169	686
SMELT						
I	5.9	2.5	16.6	3.3	10.7	5.9
II	43.4	67.0	56.8	53.6	78.8	87.9
III	47.7	29.1	23.7	37.7	9.3	4.3
IV	2.9	1.5	2.1	4.0	0.5	1.0
V	0.0	0.0	0.7	0.7	0.5	0.7
VI	0.0	0.0	0.0	0.7	0.0	0.0
n	511	223	421	114	567	

Table 6. Percentage age composition of spottail shiner, longnose sucker, and white sucker collected by bottom gill nets in the reservoir and in Lake Michigan during 1973, 1974, and 1975.

	1973		1974		1975	
	Reservoir	Lake Michigan	Reservoir	Lake Michigan	Reservoir	Lake Michigan
SPOTTAIL SHINER						
I	0.0	0.0	0.0	0.0	0.4	0.0
II	12.4	10.3	7.2	0.9	47.4	20.1
III	86.1	87.9	86.5	99.1	48.2	76.0
IV	1.4	1.8	6.3	0.0	2.6	3.0
V	0.0	0.0	0.0	0.0	0.0	0.0
n	346	203	222	151	230	292
LONGNOSE SUCKER						
I	0.0	0.0	0.0	0.0	6.7	2.2
II	24.2	10.4	28.5	11.8	48.3	10.3
III	33.3	44.3	54.3	30.6	35.9	46.2
IV	39.4	39.5	14.3	45.2	6.7	27.1
V	3.0	5.2	2.8	11.3	1.1	11.1
VI+	0.0	0.5	0.0	1.1	1.1	2.2
n	33	212	70	186	89	398
WHITE SUCKER						
I	0.0	0.0	0.0	0.0	1.7	0.5
II	31.5	5.9	7.5	7.7	44.0	8.9
III	31.5	26.9	54.7	32.7	23.7	29.1
IV	31.5	50.1	30.2	40.4	16.9	32.7
V	5.3	16.4	7.5	15.8	8.4	22.0
VI+	0.0	0.7	0.0	3.5	5.0	6.6
n	19	305	53	260	59	589

age class white suckers were usually higher in the reservoir than in Lake Michigan. Although only six white suckers were collected in surface gill nets, all were age V and VI.

Age compositions in these tables are most descriptive of adult populations of those particular species in the reservoir or lake, and show which age classes were most efficiently captured by experimental bottom gill nets at Ludington. A good review and comparison of age and growth information for several Lake Michigan species from different locations is provided in Limnetics (1976). Generally, age and growth information on species from the Ludington area was similar to that found at other nearshore areas of Lake Michigan. However, yellow perch appeared to grow faster in the Ludington area than in other locations (Hauer, 1975; Brazo et al., 1976). Fish ages may vary substantially in different areas, and age determinations are susceptible to inherent and human error and therefore should be interpreted with caution.

No obvious or consistant differences were observed between percentage sex composition of reservoir and Lake Michigan populations of rainbow smelt, alewife, spottail shiner, longnose and white sucker (Tables 8 and 9). The results for all species except yellow perch indicated that neither males or females were selectively drawn into the reservoir. Percentage sex composition of yellow perch in the reservoir and in Lake Michigan were similar during 1973 and 1974. Hauer (1975) showed a highly significant difference between females of the reservoir and lake during summer 1973; 46% of this difference was from a larger proportion of age III females in the reservoir. Abundance of age III females in the reservoir decreased in 1974.

Table 7. Numbers and percentage sex composition of yellow perch, longnose and white sucker collected by bottom gill nets in the reservoir and Lake Michigan during 1973, 1974, and 1975.

	1973		1974		1975	
	Reservoir	Lake Michigan	Reservoir	Lake Michigan	Reservoir	Lake Michigan
YELLOW PERCH						
Number	229	1059	108	1242	79	1651
% Males	71.0	66.0	74.0	71.2	51.9	72.2
% Females	29.0	34.0	26.0	28.8	48.1	27.7
LONGNOSE SUCKER						
Number	14	138	14	117	21	244
% Males	57.1	56.5	42.9	41.9	42.8	38.5
% Females	42.9	43.4	57.1	58.1	57.2	61.4
WHITE SUCKER						
Number	8	249	31	205	29	491
% Males	75.0	55.8	38.7	54.6	41.8	42.2
% Females	25.0	44.2	61.3	45.4	58.8	57.8

Table 8. Numbers and percentage sex composition of spottail shiner, smelt, and alewife collected by bottom gill nets in the reservoir and Lake Michigan during 1973, 1974, and 1975.

	1973		1974		1975	
	Reservoir	Lake Michigan	Reservoir	Lake Michigan	Reservoir	Lake Michigan
SPOTTAIL SHINER						
Number	320	149	203	98	122	291
% Males	40.3	55.0	25.1	33.7	42.1	40.2
% Females	59.7	45.0	74.9	66.3	57.9	59.8
SMELT						
Number	439	195	344	103	400	293
% Males	60.4	66.6	57.8	68.0	56.0	47.8
% Females	39.6	33.4	42.2	32.0	44.0	52.2
ALEWIFE						
Number	152	262	90	157	81	427
% Males	50.6	49.6	40.0	50.3	43.2	63.7
% Females	49.4	50.4	60.0	49.7	56.8	36.3

Table 9. Total number and percent composition of fish collected in surface gill nets in the reservoir, 1974 and 1975.

	1974		1975		1975	
	Total Number nets 1, 2 & 3	Percent Composition	Total Number nets 1, 2, 3 & 5	Percent Composition	Variable Mesh Net 4 Total Number	Percent Composition
Carp	209	29.2	207	22.3	3	0.3
Steelhead	153	21.4	193	20.8	73	8.8
Brown trout	152	21.2	174	18.8	34	4.1
Coho salmon	30	4.2	149	16.1	87	10.5
Chinook salmon	65	9.1	66	7.1	50	6.0
Lake trout	18	2.5	22	2.3	6	0.7
Gizzard shad	12	1.6	20	2.1	0	0.0
Alewife	64	8.9	56	6.0	404	48.8
Rainbow smelt	4	0.5	18	1.9	162	19.5
Redhorse sp.	2	0.2	5	0.5	0	0.0
White sucker	2	0.2	6	0.6	0	0.0
Longnose sucker	1	0.1	0	0.0	0	0.0
Longnose gar	1	0.1	1	0.1	1	0.1
Burbot	1	0.1	0	0.0	0	0.0
Lake whitefish	0	0.0	9	0.9	0	0.0
Round whitefish					1	0.1
Yellow perch					1	0.1
Northern pike					1	0.1
Spottail shiner					5	0.6
Total number	714		926		828	
Total number of sets	54		75		31	

Hauer (1975) suggested that age III females were avoiding the reservoir to a greater extent than males or older females. In 1975, percentage of females in the reservoir increased from 26% to 48% (Table 9), and 20 of the 36 females collected were age III which indicated age III females were being drawn into the reservoir more than males or older females. Length-frequency and age distribution data supported this by indicating that larger and older class yellow perch, in which the percentage of females is usually higher (Jobes, 1952; Patriarche, 1974), were avoiding the reservoir more than smaller younger classes. If the trends observed in 1973 and 1975 age structures were real, several factors could explain this and other differences in sex compositions: small sample sizes; variability in sex determinations; biological segregation or differential sex composition among age groups; or turbine cropping of larger individuals.

Surface Gill Nets

Surface gill nets proved to be an important and effective method for sampling fish populations in pelagic waters of the reservoir, particularly near the asphalt wall. Observations of fish in the reservoir and tracking studies by Serchuk (1976) prompted the expansion of this technique to integrate these collections with regular bottom gill net and trawl collections.

During 1973, surface gill net 1 (Table 1) was set on 9 occasions in the middle of southern station 7 and captured 65 fish including 17 coho salmon, 10 chinook salmon, 3 brown trout, 2 lake trout, 2 steelhead, and 2 lake whitefish (Liston and Tack, 1975).

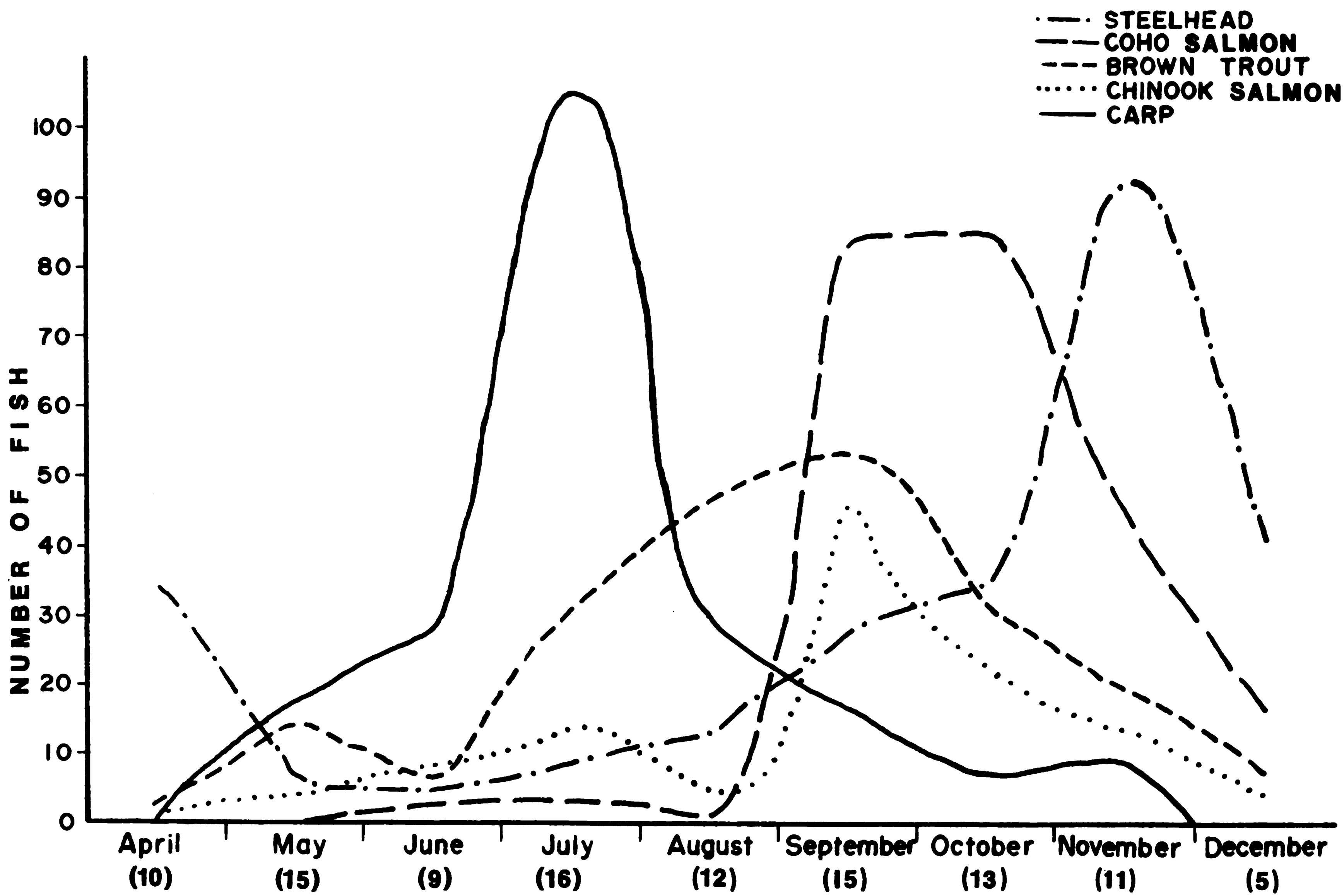
The 1974 results were derived from 54 surface net collections and indicated that many carp and salmon (400-700 mm) had been pumped into the reservoir. Only 13% of the fish collected in 1974 were captured when surface gill nets were set in the middle of station 7. Catch increased several fold when the nets were fished near the reservoir wall. Carp was the most abundant species caught in surface gill nets throughout the summer and early fall, 1974. Brown trout became abundant in late summer, and steelhead were abundant throughout the fall. Several coho and chinook salmon were captured during September, October, and November. Surface net catches of carp and salmonids in the reservoir appeared closely associated with their seasonal migration patterns in Lake Michigan.

Carp were captured over a longer period than salmonids, and mark and recapture studies showed that 7 carp remained in the reservoir over winter, 1975.

Seventy-five sets with surface nets 1, 2, 3, and 5 were made from April to December, 1975 and resulted in 212 more fish being taken than by 54 sets in 1974 (Table 9). Total catch per set of large mesh nets was 13.2 in 1974, and 12.3 in 1975. Total number of carp, steelhead, brown trout, coho and chinook salmon caught per month by all surface gill nets during 1975 is shown in Figure 21. Catches during April-May and part of June, 1975 were believed low because the 5 in. flag net rather than the deep 5 in. surface net was used, and because the nets were not fished as near to the reservoir wall as in 1974.

Similar seasonal patterns of these species were again observed in the 1975 surface net catches. Carp were the most abundant species

Figure 21. Total monthly catch of carp, steelhead, brown trout, coho and chinook salmon collected by surface gill nets in the reservoir during 1975. Number of sets each month in parentheses.


STEELHEAD
COHO SALMON
BROWN TROUT
CHINOOK SALMON
CARP
NUMBER OF FISH
0
10
20
30
40
50
60
70
80
90
100
April (10)
May (15)
June (9)
July (16)
August (12)
September (15)
October (13)
November (11)
December (5)

collected by the large-mesh surface nets. The total catch of carp peaked in July at 110 compared with 27 in June and 29 in August. Carp catches declined rapidly in August-September, 1975, but carp may have remained quite abundant during this time for three reasons: (1) the more easily caught salmonids were abundant in the fall, and their presence decreased the ability of the surface nets to capture carp. Carp have a notorious ability to avoid nets (Tack and Yeck, pers. comm.; Hunter and Wisby, 1964; and Beukema, 1970); (2) with colder water temperatures carp became quiescent and appeared to move into deeper waters as was determined by McCrimmon (1968), by bottom gill net collections, and by 1974 fall tracking studies of carp (Serchuk, 1976); (3) mark and recapture studies showed that 7 carp remained in the reservoir all year, and were not recaptured until summer 1975.

Coho salmon displayed a rapid influx into the reservoir in 1975 with total catch going from 0 in August to 84 and 85 in September and October respectively. Chinook salmon catches followed a similar pattern (Figure 21). Surface net results indicated that peak abundances of coho and chinook salmon in the Ludington reservoir were approximately one month earlier than their peak abundances at the Little Manistee weir (Bonham, 1976). The relative abundance of carp, brown trout, coho and chinook salmon had decreased by late November and December.

Steelhead exhibited peak catches in the spring and late fall (Figure 21). Lower catches in spring, 1974 and 1975 were believed due to different methods used at that time. The number of steelhead recorded at the Little Manistee weir was greater during spring than in fall of 1970-1975 (Ylkanen, 1974; Frankenburger, pers. comm.), and presumably, greatest abundance in the reservoir should also have been during spring. Fall catches of steelhead in the reservoir peaked in November, then decreased during December, possibly because most adult steelhead were in spawning streams in winter (Dodge and MacCrimmon, 1970; Hart, 1973). Although no surface net collections were made from January to March, mark and recapture studies showed that at least 3 steelhead had remained in the reservoir from October to April and June, 1976.

Several lake and round whitefish were collected in November-December reservoir samples which indicated that when these species moved inshore to spawn at this time, some had become susceptible to the reservoir intake.

The number of fish captured per net day by each large-mesh surface gill net in 1975 was 24/net day in surface net 1; 22/net day in surface net 5; 7/net day in surface net 3; and 4/net day in surface net 2. Hamely (1975) gives an excellent account of how several factors influence gill net catches. Net avoidance by carp and steelhead was also discussed by Hunter and Wisby (1964). In this study, the method used to set the nets and the twine size of the nets seemed to have the greatest effect on their fishing success. Surface gill nets constructed of finer twine sizes (nets 1 and 5, Table 1) and set very near or on the wall were most successful. Other factors which contributed to large variability of surface net results were: net-saturation (Hamely, 1975), net-trashing, waves, currents, net construction, and location of sets (Leo Yeck, pers. comm.).

Results of the variable mesh surface gill net used during 1975 showed that smelt, alewife, and smaller salmonids were also present in the surface waters of the reservoir (Table 10). Mean catches in

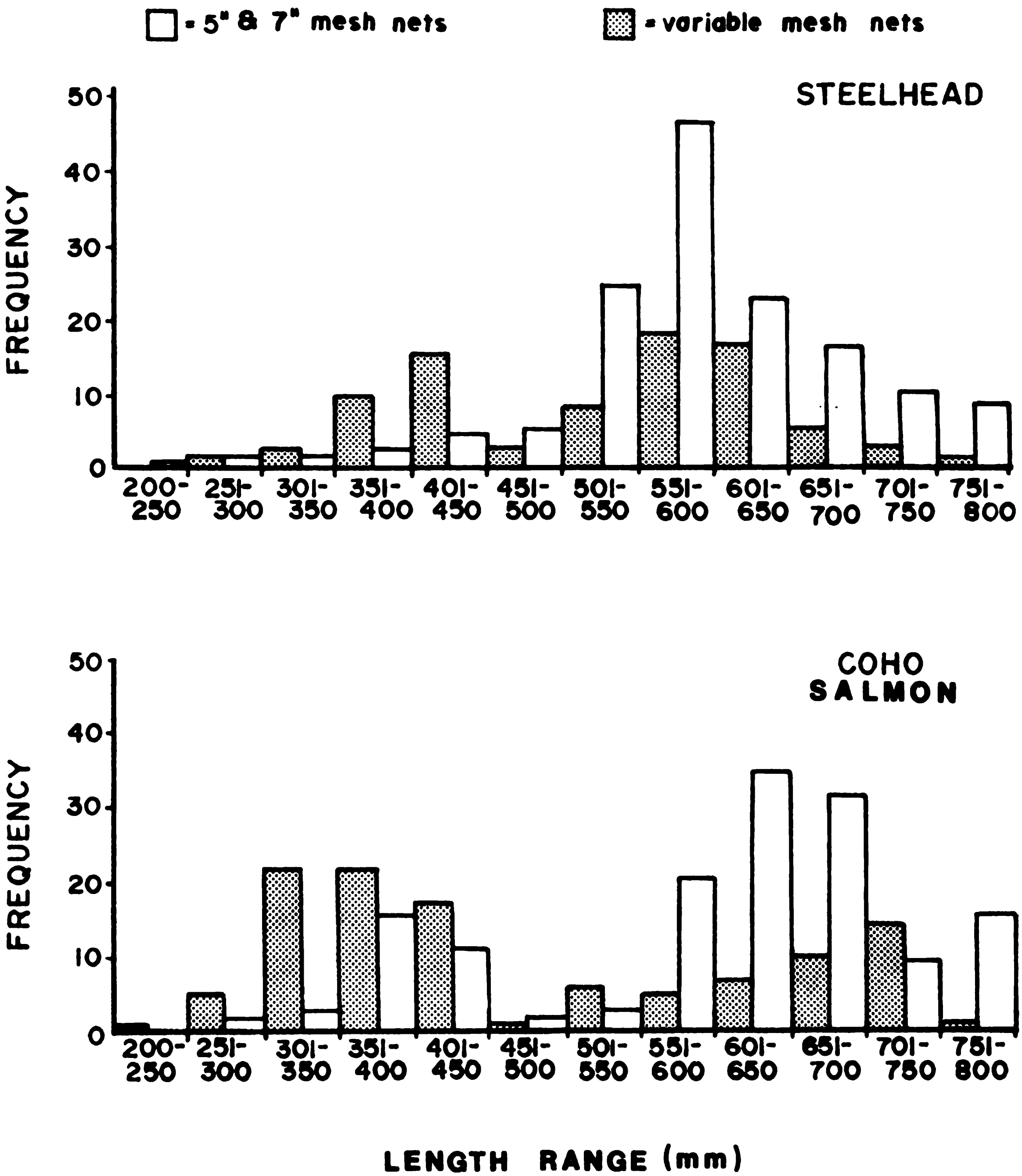
1975 of smelt and alewife in the variable mesh surface net were 5 and 13 per net day respectively and 10 and 2 per net day in bottom gill nets. Surface and bottom gill nets were fished at the Point Beach plant in western Lake Michigan, and there also, alewife were captured more effectively with surface gill nets by a ratio of better than 2:1 (Wis. Elec. Power Co. and Wis. Mich. Power Co., 1973).

The variable-mesh net was not, however, successful at catching carp. Only 3 carp were captured by this net during 1975. There may be several reasons for this low catch: (1) the net was only 6 feet deep, so carp may have been able to avoid it; (2) the net contained only 2 large mesh panels that would effectively catch large carp; and (3) the large mesh panels were only set near the wall on alternate sets.

Length frequencies of steelhead and coho salmon caught in large and variable-mesh surface gill nets shows the selectivity of large-mesh surface nets for 400-700 mm length fish, and the size range of fish that passed through the turbines. Perhaps more importantly, these distributions show that several immature and newly planted salmonids were drawn into the reservoir. Annual cropping off of a number of these younger fishes could be more important than the cropping off of older ones (Figure 22).

The inconsistancies of the reservoir methodology regarding surface gill netting are the result of learning how to sample a new environment for which there were no previous guidelines established. Rigorous physical conditions including sudden changes in surface elevation, and complex water current directions and velocities required much experimentation throughout the program.

Figure 22. Length-frequency distribution of steelhead and coho salmon from variable and 5 in. and 7 in. stretch mesh surface gill nets.



= 5" & 7" mesh nets
= variable mesh nets
STEELHEAD
FREQUENCY
0
10
20
30
40
50
200-250
251-300
301-350
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
751-800
COHO SALMON
FREQUENCY
0
10
20
30
40
50
200-250
251-300
301-350
351-400
401-450
451-500
501-550
551-600
601-650
651-700
701-750
751-800
LENGTH RANGE (mm)

Though the surface gill net results may not be definitive, they did point out that many along-shore migrant fish in Lake Michigan were vulnerable to this pumped storage intake. The combination of variable and large-mesh surface gill nets used from June through December, 1975 yielded the best estimates of species composition and relative abundance of carp, steelhead, brown trout, coho and chinook salmon. The abundance of these species in Lake Michigan, and percentage of them that are pumped into the reservoir is not yet known, but a considerably large number of adult steelhead and brown trout were pumped into the reservoir. Total catch-per-day of steelhead and brown trout in the reservoir ranged from 0 to 39 and 0 to 29 respectively in 1975. Surface net results substantiated that most large carp and salmonids follow closely to the reservoir wall (Serchuk, 1976). Hence, the development of a system to live trap these species and return to the lake should be considered.

Mark and Recapture Studies

Mark and recapture studies were expected to help determine how long fish remained in the Ludington reservoir, if they concentrated at particular locations in the reservoir, help determine the number of fish that pass safely back into Lake Michigan, and their movement patterns in the lake in relation to the reservoir. In 1973, studies showed that some large salmon had successfully passed through the turbines during generating mode.

All fish releases and recapture data for 1974 and 1975 are summarized in Table 10. Ten salmon were recaptured outside the

Table 10. Numbers of fish marked and recaptured in the Ludington Pumped Storage Reservoir and in Lake Michigan during 1974 and 1975.

Species	# Marked	Source	Release Location	Floy Numbers	Recaptures
			1974		
Carp	145	Reservoir	Reservoir	1000-5000 Red	6 in Reservoir
Coho	150	Little Manistee Weir	Reservoir (125)		17 in Reservoir
			Lake Michigan (25)		1 at Pentwater River
Chinook	261	Little Manistee Weir	Reservoir (211)		21 in Reservoir
			Lake Michigan (50)		9 outside Reservoir
Brown trout	18	Reservoir	Reservoir		None
Steelhead	14	Reservoir	Reservoir		None
Lake trout	12	Lake Michigan	Reservoir		None
			1975		
Carp	232	Reservoir	Reservoir	1000-4000 Yellow	26 in Reservoir
Coho	370	Little Manistee Weir (340)	Reservoir		24 in Reservoir
		Reservoir (30)	Reservoir		4 outside Reservoir
Chinook	84	Little Manistee Weir (74)	Reservoir		13 in Reservoir
		Reservoir (10)	Reservoir		
Steelhead	530	Trout Ponds (416)	Reservoir		20 in Reservoir
		Platte River Weir (100)	Reservoir		4 outside Reservoir
		Reservoir (14)			
Brown trout	57	Reservoir	Reservoir		6 in Reservoir
Lake trout	16	Reservoir	Reservoir		None
	160	Lake Michigan	Lake Michigan		None
White sucker	86	Lake Michigan	Reservoir		None
Longnose sucker	31	Lake Michigan	Reservoir		None

reservoir and 38 recaptured inside during 1974. Abundance estimates of these species in the reservoir could not be made using this method, because of the small number marked and recaptured, and because their movement into and out of the reservoir was unknown. Recapture information did further substantiate that several large fish passed safely back into the lake, and that 7 carp had remained overwinter in the reservoir. This also indicated that carp were present during early spring and late fall, but were not collected by sampling methods.

More extensive mark and recapture studies in 1975 resulted in 121 recaptures (8.4%) of all fish released in the reservoir (Table 10). Recapture percentage ranged from 4.5% for steelhead to 15.4% for chinook salmon. None of the lake trout, white suckers, or longnose suckers released in the reservoir and in Lake Michigan have yet been recaptured.

In an attempt to determine netting efficiency, marked fish were released the same day the nets were set (once) and on three occasions on the day before the nets were set. The recapture percentage on these dates ranged from 3.2% to 21% for an average recapture percentage of 12% of the fish that had been released the day before. Twenty-one percent of the marked fish were recaptured when the nets were set on the same day of the release. The above recapture percentages are subject to minor changes (upward), because more recapture information is still forthcoming.

Although admittedly brief, it is hoped that these results will provide some basis for further research and development in estimating fish populations in the reservoir which will, in turn, aide in estimating annual losses for various species. They are sufficient to indicate that surface nets captured a relatively small percentage of reservoir fish populations in the once-per-week samples.

Trawling

Otter trawls were used to sample the reservoir since its initial filling in 1972, and yielded year to year comparative results for several species inhabiting the reservoir. The otter trawl is an active fishing gear that captured several smaller benthic species not collected in the bottom gill nets, which substantially aided in identifying the species composition of the reservoir.

No fish were collected by the trawls in November, 1972, when the reservoir was first filled. As indicated in studies by Wis. Elec. Power Co. and Wis. Mich. Power Co. (1973), western Lake Michigan, Jude et al. (1975), southeastern Lake Michigan, and Wells (1968), several nearshore fish populations move offshore in the fall, which could help explain why no fish were taken then. Jude et al. (1975) also points out that several species which remain in the nearshore become quiescent in colder water and less susceptible to capture.

The total number and percentage composition of fish collected by trawls in the reservoir during 1973, 1974, and 1975 (Table 11) show that alewife, smelt, spottail shiner, sculpin, johnny darter, and trout perch were the most abundant species captured. Ten species were collected by trawls in 1973, 14 in 1974, and 21 in 1975. The smaller benthic species mentioned above rapidly inhabited the reservoir in 1973, and the increased number of species in 1975 could represent increased colonization of the reservoir, but most likely resulted from an increased number of night trawls in 1975.

Table 11. Species list, total number, and percentage composition of fish collected in reservoir trawls during 1973, 1974 and 1975*.

Species	Total No. 1973	% Comp. 1973	Total No. 1974	% Comp. 1974	Total No. 1975	% Comp. 1975	Combined Total No.	Combined % Comp.
Smelt	767	38.6	2379	55.2	1186	13.9	4332	29.2
Spottail shiner	485	24.4	203	5.1	594	7.0	1282	8.6
Alewife	321	16.2	1020	22.0	6181	72.3	7522	50.7
Johnny darter	247	12.4	562	14.2	40	0.5	849	5.7
Sculpin	110	5.6	78	1.9	235	2.8	423	2.8
Trout perch	45	2.3	11	<0.5	223	2.6	279	1.9
Yellow perch	4	0.2	2	<0.5	8	<0.5	14	<0.5
Ninespine stickleback	3	0.2	9	0.2	14	<0.5	26	<0.5
Gizzard shad	3	0.2					3	<0.5
Longnose dace	1	0.1			2	<0.5	3	<0.5
Carp			7	0.2	26	<0.5	33	<0.5
Longnose sucker					10	<0.5	10	<0.5
White sucker			3	<0.5	9	<0.5	12	<0.5
Chinook salmon			30	0.8	4	<0.5	34	<0.5
Steelhead					4	<0.5	4	<0.5
Bluegill					4	<0.5	4	<0.5
Burbot					2	<0.5	2	<0.5
Redhorse sp.					2	<0.5	2	<0.5
Coho salmon					2	<0.5	2	<0.5
Round whitefish			2	<0.5			2	<0.5
Brown trout			1	<0.5			1	<0.5
Fathead minnow			1	<0.5				
TOTAL	1986	100.2	4308		8546	100.0	14839	100.0

* Number of trawls = 41 - 1973; 72 - 1974; 48 - 1975.

Otter trawls were not efficient at capturing larger fish species, presumably because of avoidance behaviors. For example, trawls conducted in more turbid waters of Saginaw Bay (Consumers Power Co., 1972) and in southeastern Lake Michigan (Benda and Gulvas, 1976) were more successful at capturing yellow perch than were trawls at Ludington.

Trawl catches of alewife, smelt, and spottail shiner were variable seasonally and yearly, and only alewife, carp, white and longnose sucker displayed year to year increases (Table 11). The areas of rock substrate could attract and provide increased habitat for many species (Jude et al., 1975; Benda and Gulvas, 1976). Benthos and substrate studies (Fig. 1) by Olson (1974) and Lawson (pers. comm.) indicated a trend towards increased numbers of benthic invertebrates and an increased amount of detrital material on the reservoir bottom which could also provide better habitat for some fish species. There was an apparent trend for larger and more diverse catches in trawls along the berm, especially at station T-1 which is located along the ramp (Fig. 5). Few alewife and smelt were captured at the deeper middle stations. Longnose dace were relatively abundant in seining collections at the project (Liston and Tack, 1975), but very few were taken by trawls in the reservoir.

Trawls were generally much more successful at night than in the daytime. It was possible that species abundance could have increased at night during the pumping mode and decreased by generation during the day. Most night trawls however were made while generation was still going on. Increased catch at night appeared more likely due to increased efficiency of the trawl at night, increased activity of some fish species at night (Emery, 1973), and perhaps because species remaining in the reservoir at this time are concentrated in much less water than was present during the day. Jude et al. (1975) conducted both day and night trawls at the Cook plant, southeastern Lake Michigan, and also collected more fish in the nighttime trawls.

Interpretation of trawl results was made difficult by variability in trawl catches, and missing samples during 1975. Overall observation of trawl results supported gill net results by also indicating that fish populations did not accumulate in the Ludington reservoir in large numbers, although small populations of sculpins, trout-perch, and carp may be permanent residents in the reservoir.

Total Catch and Percentage Composition of Fish Species Using All Gear

Nearly all species collected in Lake Michigan were also collected in the reservoir. Total number of fishes collected in the reservoir by 393 gill net sets and 161 trawls from 1973 through 1975 shows that 32 species and 25,014 fish were collected (Table 12). This species list was relatively low in comparison with 45 species found by Jude et al. (1973), 55 by Benda and Gulvas (1976) during impact studies in southeastern Lake Michigan. Emery (1976) enumerated 90 species currently found in Lake Michigan. Thirty of these were described as common and important as either commercial, sport, or forage species.

The total number of fish collected in the reservoir increased each year, but catch per effort values generally did not. Increases may have resulted largely from increased and more efficient sampling. The data indicate that the increased amount of pumping during 1974 and 1975 did not result in larger reservoir fish populations, and that

Table 12. Total number and percentage composition of all fish collected in the reservoir by bottom gill nets, surface gill nets, and trawls during 1973, 1974, and 1975.

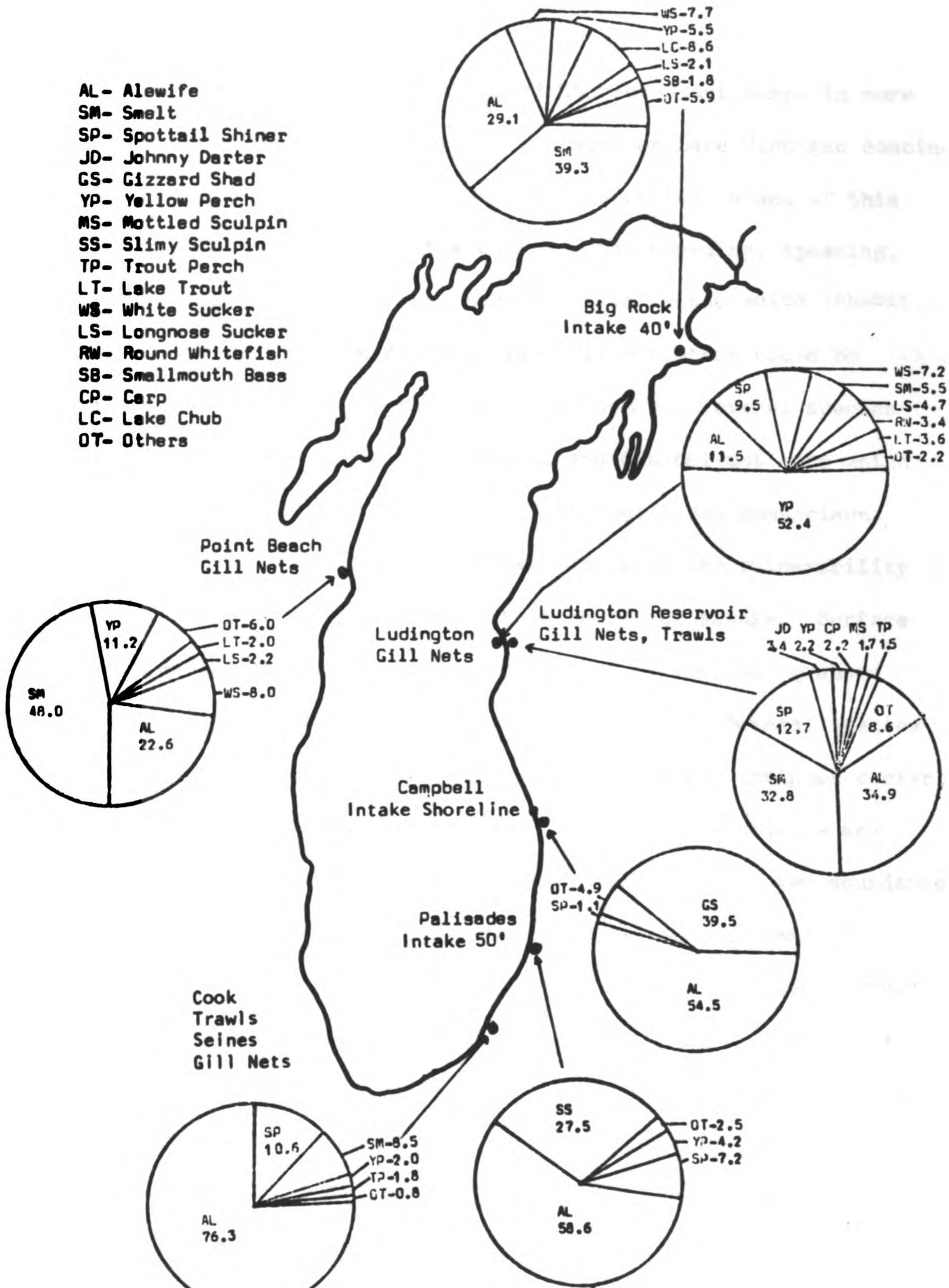
Species	Bottom Gill Nets	Surface Gill Nets	Trawls	Total	Percent
Alewife	670	588	7522	8780	34.9
Smelt	3662	201	4332	8205	32.8
Spottail shiner	1893	5	1282	3180	12.7
Johnny darter	0	0	849	849	3.4
Carp	98	430	33	561	2.2
Yellow perch	536	1	14	551	2.2
Steelhead	11	420	4	435	1.7
Mottled sculpin	3	0	423	425	1.7
Trout perch	105	0	279	384	1.5
Brown trout	31	352	1	384	1.5
Coho salmon	21	283	2	306	1.2
Chinook salmon	38	191	34	263	1.0
Longnose sucker	192	1	10	203	0.8
White sucker	132	8	12	152	0.6
Burbot	103	0	2	105	0.4
Lake trout	26	48	0	74	0.3
Gizzard shad	2	34	3	39	0.1
Bloater	30	0	0	30	0.1
Ninespine stickleback	0	0	26	26	0.1
Round whitefish	20	1	2	23	0.1
Lake whitefish	6	10	0	16	<0.1
Redhorse sp.	4	0	2	6	<0.1
Longnose dace	2	0	3	5	<0.1
Bluegill	0	0	4	4	<0.1
Longnose gar	0	2	0	2	<0.1
Brown bullhead	2	0	0	2	<0.1
Lake chub	1	0	0	1	<0.1
Goldfish	1	0	0	1	<0.1
Lake sturgeon	1	0	0	1	<0.1
Rockbass	1	0	0	1	<0.1
Fathead minnow	0	0	1	0	<0.1
Total	7591	2575	14840	25014	
Number of sets	265	128	161		

residence for most species in the reservoir was seasonal. Residence time in the reservoir varied considerably with species and most fish that were pumped in appeared to leave shortly thereafter during generation periods. Only seven carp, three steelhead, and 1 white sucker were known to overwinter in the reservoir.

The combination of bottom and surface gill nets, and trawls used in this study provided a good estimate of the qualitative species composition of the Ludington reservoir. Together, the reservoir and Lake Michigan percentage species compositions provide a good description of fish populations near Ludington. Any one of the 12 most abundant species may comprise the largest percentage during a particular period, because these species appeared to sequentially use or inhabit the beach zone for a number of feeding, spawning, and other behavioral reasons.

Changes in the fish biota of Lake Michigan has been documented in articles by Van Oosten (1938), Smith (1968), Wells and McClain (1973), Christie (1974), and Michigan Department of Natural Resources (1974). In Limnetics (1976) a literature review of power plant studies on Lake Michigan describes present day abundant species of the nearshore regions in Lake Michigan. The Ludington project is near the boundaries of the northern and southern basins of Lake Michigan, and an attempt was made (Fig. 23) to compare percentage species compositions found at the Ludington project with those found by studies at Palisades (Benda and Gulvas, 1976), Cook plant (Jude et al., 1973), Point Beach (Limnetics, 1973), Campbell and Big Rock Point plants (Benda et al., 1976). Although species composition varied greatly with intake type, size, location, and type of gear and

Figure 23. Percentage species compositions at seven nearshore locations in Lake Michigan.


AL- Alewife
SM- Smelt
SP- Spottail Shiner
JD- Johnny Darter
GS- Gizzard Shad
YP- Yellow Perch
MS- Mottled Sculpin
SS- Slimy Sculpin
TP- Trout Perch
LT- Lake Trout
WS- White Sucker
LS- Longnose Sucker
RW- Round Whitefish
SB- Smallmouth Bass
CP- Carp
LC- Lake Chub
OT- Others
WS-7.7
YP-5.5
LC-8.6
LS-2.1
SB-1.8
OT-5.9
AL 29.1
SM 39.3
Big Rock Intake 40'
WS-7.2
SM-5.5
LS-4.7
RW-3.4
LT-3.6
OT-2.2
SP 9.5
AL 11.5
YP 52.4
Point Beach Gill Nets
Ludington Gill Nets
Ludington Reservoir Gill Nets, Trawls
YP 11.2
OT-6.0
LT-2.0
LS-2.2
WS-8.0
SM 48.0
AL 22.6
JD YP CP MS TP
3.4 2.2 2.2 1.7 1.5
SP 12.7
OT 8.6
SM 32.8
AL 34.9
Campbell Intake Shoreline
OT-4.9
SP-1.1
GS 39.5
AL 54.5
Palisades Intake 50'
Cook Trawls Seines Gill Nets
SP 10.6
SM-8.5
YP-2.0
TP-1.8
OT-0.8
AL 76.3
SS 27.5
OT-2.5
YP-4.2
SP-7.2
AL 58.6

effort used, it appeared that the numerically abundant species of the nearshore region were smelt, alewife, yellow perch, spottail shiner, longnose and white sucker.

The intake of the Ludington Pumped Storage Plant pumps in more water than other electrical generating plants on Lake Michigan combined. The consequences on fish populations of a shoreline intake of this magnitude, and pumping at night are many. The breeding, spawning, and feeding behaviors of several Lake Michigan fishes which inhabit the beach zone during some stage of their life history could be significantly influenced by the reservoir intake. Several species in the Ludington area exhibited seasonal and diurnal patterns which made them susceptible to the intake. Bottom gill net comparisons between the reservoir and Lake Michigan indicated the vulnerability of pelagic, night-active species to this shoreline intake. Surface gill net results in the reservoir showed that several along-shore migrant species were also vulnerable to the intake. Several species collected in the reservoir (alewife, smelt, white and longnose sucker, trout perch, yellow perch, and sculpin) increase in abundance and move to shallower regions at night (Emery, 1973). Increased abundance of fishes in shallower regions of Lake Michigan at night and on a seasonal basis has been documented by Wells (1968), Wis. Elec. Power Co. and Wis. Mich. Power Co. (1973), Jude et al. (1975), Benda and Gulvas (1976), and Limnetics (1976). In view of the results of this and the above studies, it appeared that nighttime pumping and the shoreline location of the intake may have been responsible for the abundance of several species in the Ludington reservoir.

In contrast, offshore submerged intakes (Palisades and Big Rock, Fig. 23) appeared to draw in markedly fewer numbers of fish, and may be a more appropriate location for future intakes on Lake Michigan. Some demersal and pelagic species were also susceptible to submerged intakes, but rarely were along-shore migrant species drawn in (Benda et al., 1976).

Until further standardization of methods, gear, and effort is attained, it will be difficult for fisheries researchers to construct environmental maps, or make fair comparisons between species composition and their relative abundance in different beach and nearshore zones of Lake Michigan. Continued research at Ludington should provide more information to further assess the vulnerability of beach and nearshore Lake Michigan fish populations to the Ludington Pumped Storage intake.

SUMMARY AND CONCLUDING REMARKS

The Ludington Pumped Storage Reservoir is the largest of its kind in existence, pumping in more water than all other Lake Michigan power plant intakes combined. The fish populations that entered with this water were regularly and intensively sampled from 1972 to 1975 by bottom and surface gill nets and otter trawls. The area occupied by the Ludington reservoir was once productive orchard lands that were modified initially into a large, clay and asphalt, abiotic pit which then developed into a biological novelty reflecting many of the physical and biological parameters that characterize this part of Lake Michigan. The reservoir was inhabited by nearly all fish species that were collected in the nearshore and beach zones of Lake Michigan. Selective aspects of this large shoreline intake were pointed out, and fish populations inhabiting the reservoir on a seasonal and yearly basis were described but were not defined accurately enough to make sound determinations of their abundance or estimates of how many were pumped into the reservoir. The following conclusions were drawn:

1. Very few fish appeared to be pumped into the reservoir during the initial filling.
2. Increased plant activity (inward and outward movement of water) did not result in large increases or accumulations of reservoir fish populations, but the majority of pumping done at night could have influenced the abundance of some species in the reservoir.

3. Smelt and alewife were the most abundant species collected in bottom gill nets. Carp, steelhead, brown trout, coho and chinook salmon were the most abundant species in surface net collections, and alewife, smelt, spottail shiners, and sculpin were most abundant in otter trawl collections.

4. Populations of most species appeared to concentrate and fluctuate in the reservoir with their respective periods of seasonal abundance in the nearshore and beach zone region of Lake Michigan.

5. Smaller pelagic species represented by alewife, smelt, and spottail shiner, and along shore migratant species represented by carp, steelhead, brown trout, coho and chinook salmon were quite vulnerable to the Ludington intake.

6. Larger demersal species such as yellow perch, white and longnose suckers, round whitefish, and lake trout were seasonally abundant near the plant, but generally avoided being pumped into the reservoir. Smaller size classes of yellow perch, white sucker and longnose sucker appeared more susceptible to the intake than larger ones.

7. Carp, steelhead, brown trout, coho and chinook salmon were seasonally pumped into the reservoir, and effectively caught in the surface gill nets. These species were not evenly distributed in the surface waters, but appeared to concentrate and follow along the reservoir wall. Alewife appeared more abundant in surface waters (5:1) and smelt more abundant in bottom waters (1:3).

8. Surface gill nets provided estimates of the relative abundance of carp, steelhead, brown trout, coho and chinook salmon in the

reservoir, but could only be vaguely compared to the relative abundance of these species in Lake Michigan.

9. Reservoir and Lake Michigan comparisons revealed that abundances of smelt, alewife and spottail shiners were higher in the reservoir, while abundances of yellow perch, white and longnose suckers, lake trout, and round whitefish were much higher in adjacent Lake Michigan.

10. Trawling results indicated that numbers of smelt, alewife, spottail shiner, sculpin, johnny darter, and trout perch had not substantially increased or accumulated in the reservoir, but resident populations of sculpins, trout perch, and carp may have developed.

11. The mark and recapture study showed that carp remain in the reservoir for extended periods, usually longer than salmonids, and that several fish had passed safely through the turbines into Lake Michigan.

12. Number of fishes pumped into the Ludington Pumped Storage Reservoir were believed low enough that no apparent damaging effects to most nearshore fish populations of Lake Michigan are expected. However, the potential exists for a considerable loss to trout and salmon populations, if numbers similar to that found by this study are pumped annually into the reservoir during the life of the plant.

The fisheries research at Ludington is scheduled for completion at the end of 1977. This study has revealed interesting aspects of fishes in the Ludington reservoir and has pinpointed some important questions that remain unanswered. Though extensive in its present form, further lines of study may aide in the final analysis of the impact of this plant. More accurate estimates of the fish abundance in the reservoir and Lake Michigan determined by echo sounding, expanded mark and recapture studies, or SCUBA observation may be fruitful. Only meager data exist on fish larval abundance in the reservoir and Lake Michigan. More insight into the behavior of fish in Lake Michigan in response to plant activity could be gained by float or sonic tracking and aid in determining the number of fishes being pumped into the reservoir. Also, more detailed information on water currents in the lake and reservoir would help to describe the extent of plant influence. Finally, if it is not possible to prevent salmonids from entering the reservoir, the development of a system to live trap these fish in the reservoir and return them safely back into Lake Michigan should be considered.

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