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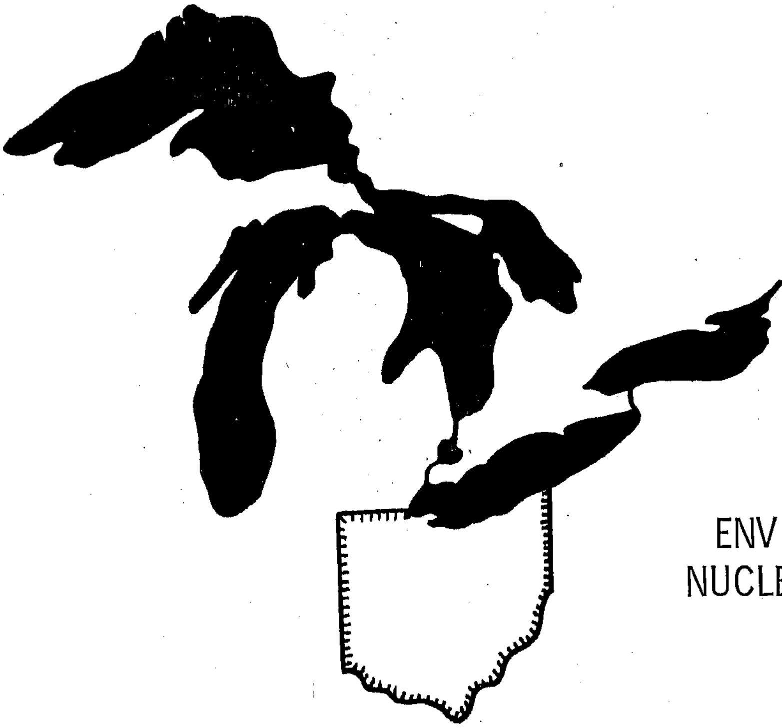

ENVIRONMENTAL EVALUATION OF A NUCLEAR POWER PLANT ON LAKE ERIE

ANNUAL REPORT - 1973
STUDY II
F-41-R-4

Prepared for

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PROJECT NO: F-41-R-4 PROJECT TITLE: Environmental evaluation of a nuclear power plant on Lake Erie

STUDY NO: II STUDY TITLE: Laboratory estimates of fish response to the heated discharge from the Davis-Besse Nuclear Power Station, Lake Erie, Ohio

PERIOD COVERED: June 1, 1972-May 31, 1973

I. SUMMARY

The objective of this study has been to determine the effect the thermal discharge from the Davis-Besse Nuclear Power Station will have on the fishery resource of the surrounding area. The temperature preferences of as many fish as possible were obtained during all seasons so that attraction to or repulsion from the plume could be predicted. The maximum change in the plume is 20.0 F (11.1 C). The effect that this temperature change would have on the fish was also to be determined.

A horizontal temperature gradient with 28 compartments each 0.5-1.0 1.0°C warmer than the previous one was used to determine the fish's temperature preference. They were placed in the gradient and allowed to swim freely and choose the temperature of their choice.

All fish except *Notropis atheriniodes* (emerald shiner) preferred water warmer than ambient during all seasons. The emerald preferred cooler water in the summer (Barans, 1972). Many fish had a preference very close to ambient during the summer. Therefore, all fish will be

attracted to the plume in the winter and repelled from the center of it in the summer, although many fish will be attracted the periphery in the summer.

Hot shocks, an increase of 20.0°F, were conducted by taking a fish from ambient lake temperature and placing it in a tank 20.0°F above ambient lake temperature. The fish was observed for one hour and then the temperature was gradually increased to the Critical Thermal Maximum (C.T.M. temperature at which the fish loses locomotor control).

Cold shock tests were conducted by taking a fish from water 20.0°F above ambient and placing it at ambient lake temperature.

The tests which caused the most problems for the fish were summer hot shocks and winter cold shocks. Therefore, the temperature extremes were more important than the 20.0°F change.

The exact effect these results will have on the fish is hard to determine for it is dependent on the swimming speed and stamina of each fish.

II. CONTENTS

III. BACKGROUND

Toledo Edison and The Cleveland Electric Illuminating Co. are currently building the Davis-Besse Nuclear Power Station on the south shore of Lake Erie at Locust Point. This plant will use water from Lake Erie as cooling water, and then pump the water back into the lake at a maximum of 20.0°F (11.1°C) above the ambient lake temperature. The objective of this project has been to determine the effect of this warmed water on individual fish and entire fish populations.

Project F-41-R-3 worked on obtaining the above information for *Micropterus dolomieui* (smallmouth bass), *Perca flavescens* (yellow perch),*Morone chrysops* (white bass), and *Notropis atherinoides* (emerald shiner). The objective of project F-41-R-4 has been to gather as much data as possible on as many species as possible in an attempt to get a complete overview of the potential benefits or harms due to the Davis-Besse Nuclear Power Station before the plant goes into operation.

To accomplish this goal I have changed the sudden temperature chage testing procedure as explained in the procedure section. Barans (1972) developed our gradient apparatus for use in F-41-R-3.

A horizontal temperature gradient approximately 24 m in length and 25 cm in depth was established within a wooden tank 8.72 m long, 79.0 cm wide and 50 cm high. Asystem of alternating transverse baffles each 56 cm long, formed a series of 28 virtually identical compartments. This arrangement does not greatly restrict the movements of the fish. Filtered lake water was passed through ¼ inch Tygon tubing at a rate of approximately 2 liters per minute into the cold end of the gradient.

To lower the water temperature during spring, fall, and summer, the water was first routed through copper pipe in a cooling reservoir. Examination of the water qulaity in the intake line and in the gradient indicated no significant increase in the level of copper in the water due to this cooling system. The water was then heated progressively higher in each of the 28 compartments as it flowed to a standpipe at the opposite end of the ttrough.

A Vicore 500 watt heater, ARC static relay, and corresponding Juno thermogregulator maintained a relatively constant water temperature in the center of each compartment. By adjusting the thermal regulators a change of 0.5-1.0°C could be developed between compartments. Each seasonaa different temperature range was established within the gradient. The gradient ranged from a low of several degrees below ambient lake temperature (late spring, summer, and early fall) or slightly above ambient (winter), to a high of 15-28°C above ambient.

Aeration from three air stones in each compartment greatly reduced vertical temperature stratification and held dissolved oxygen at nearly saturation levels in all compartments. The water temperature at the center of every other compartment was measured with probes from a YSI multi-channel telothermometer. By moving these probes temperatures could be obtained for every compartment.

IV. OBJECTIVES

To determine the temperature preferences of Lake Erie fishes, and to determine the lethal limits of fishes subjected to sudden thermal shocks and the effects of various rates of temperature change on these lethal limits. Table 1 is a listing of the species found in the Locust Point area. Data on all species is desirable.

V. PROCEDURES

Fish for these experiments were caught with a Fyke net near Stone Laboratory on South Bass Island. Fish for winter testing were caught in November and early December and held in large holding tanks at lake temperature until ready for testing. During all other seasons fish were tested as soon as possible after capture. Fish were maintained and tested under normal seasonal photoperiods. Natural lighting from windows in the north and east walls was adequate for most observations.

Preference Testing: In order to aquaint the fish with the gradient apparatus, 24-48 hours prior to testing they were placed in an acclimati mation tank half as long as the gradient and with the same system of baffles as the gradient, but with no heaters or thermoregulators. The water was kept as near ambient lake temperature as possible. The fish were then placed in the gradient compartment with the temperature closest to ambient lake temperature. Fish location and behavior were observed at two hour intervals. The number of fish in each compartment and the temperature of that compartment were recorded and averaged to give a mean temperature preference for each observation.

The number of fish per test varied from one for large *Micropterus dolomieu* (smallmouth bass) to 25 for *Notropis atheriniodes* (emerald shiner). The duration of the test varied from 1-2 days in summer to 3-4 days in winter. Barricades were necessary in late fall, winter,

TABLE 1

SPECIES FOUND IN THE LOCUST POINT AREA 1963-1972

Alewife	*Alosa pseudoharengus*
American smelt	*Osmerus eperlanus mordax*
Black crappie	*Pomoxis nigromaculatus*
Bowfin	*Amia calva*
Brown bullhead	*Ictalurus nebulosus*
Bigmouth Buffalo fish	*Ictiobus cyprineuus*
Carp	*Cryprinus carpio*
Channel catfish	*Ictalurus punctatus*
Coho salmon	*Oncorhynchus kisutch*
Common emerald shiner	*Nortropis atherinoides*
Common white sucker	*Catostomus commersoni*
Freshwater drum	*Aplodinotus grunniens*
Gizzard shad	*Dorosoma cepedianum*
Golden redhorse	*Moxostoma erythrurum*
Goldfish	*Carassius auratus*
Green sunfish	*Lepomis cyanellus*
Largemouth bass	*Micropterus s. salmoides*
Logperch	*Percina caprodes*
Longnose gar	*Lepissosteus osseus*
Northern pike	*Esox lucius*
Orangespotted sunfish	*Lepomis humilis*
Quillback	*Carpiodes cyprinus*
Rock bass	*Ambloplites rupestris*
Silver chub	*Hybopsis storeriana*
Smallmouth bass	*Micropterus d. dolomieui*
Spotted sucker	*Minytrema melanops*
Spottail shiner	*Notropis spilopterus*
Stonecat	*Notropis hudsonius*
Walleye	*Noturus flavus*
White bass	*Stizostedion v. vitreum*
White crappie	*Morone chrysops*
Yellow perch	*Pomoxis annularis*
	Perca flavescens

OTHER SPECIES TO BE TESTED

Northern bluegill sunfish	*Lepomis macrochirus*
Golden shiner	*Notemigonus crysoleucas*
Silver Lamprey	*Icthyomyzon unicuspis*
Pumpkinseed sunfish	*Lepomis gibbosus*
Troutperch	*Percopsis omiscomaycus*
Yellow bullhead	*Ictalurus natalis*

and early spring to keep the fish from entering warm water too fast and being killed. It was found that all species tested would exceed their Critical Thermal Maximum (C.T.M.-the temperature at which the fish loses locomotor control) if barricades were not present. The barricades were gradually moved along as the fish became acclimated to warmer water. Fish were left in the gradient until the mean temperature preference had remained nearly constant for approximately 24 hours.

Tests prior to November 10, 1972 were conducted by Sharon Dugol. They were not standardized but were similar to those above.

Sudden Temperature Change Testing: Prior to December 1972, there was no set procedure for hot and cold shock testing. I have developed the following procedures so that the data will give a better estimate of fish response to sudden temperature change due to the Davis-Besse Nuclear Power Station, and so that the data can be more readily programmed.

Since December hot shock tests were conducted in a 190 liter (50 gal.) glass aquarium equipped with two air stones, a Vicore 500 watt emersion heater, ARC static switch, and corresponding Juno thermoregulater. The temperature in the tank was maintained 11.1°C above ambient lake temperature. Theoretically this is the largest change that would occur in Lake Erie due to the heated discharge from the Davis-Besse Nuclear Power Station (Atomic Energy Commission, 1973).

Fish were taken directly from ambient lake temperature water and placed into the hot shock tank. They were observed for one hour, and, if normal at the end of this observation period, the heater was started and the water was warmed to the C.T.M. By varying the heaters and the number of heaters used the rate of temperature change could be varied, which (Krenkel and Parker, 1969), should effect the C.T.M. of the fish.

Cold shock tests were conducted in a wire cage 19" x18" x12" lowered into a holding tank at ambient lake temperature. Fish were either taken directly from their preference compartments and placed in the cold shock cage or taken from a holding tank 11.1°C above ambient lake temperature and placed in the cold shock cage. Fish were observed for at least 24 hours in cold shock becuase acclimation to cold water appears to be slower than acclimation to warm water (Krenkel and Parker, 1969).

Few hot or cold shock tests were conducted prior to November 10, 1972, and those that were done were done with a 15.0°C temperature change with fish taken from their temperature preferences.

VI. FINDINGS

Preferences: My results on 22 species (Table 2) and the results of Barans (1972) indicate that fish will be attracted to the plume during all seasons, but the isotherm to which they are attracted will vary. During the winter, all species [illegible] be attracted to isotherms near the center of the plume. In summer, all apecies will be repelled from the center of the plume, but many will be attracted to the outer isotherms. *Notropis atherinoides* (emerald shiner) will be repelled by all isotherms during the summer (Barans, 1972).

It takes 1-2 days longer for fish to reach a stable preference in the winter than in summer. This is to be expected since differences between seasonal preferences are small compared to differences between seasonal lake temperature.

TABLE 2

RESULTS OF PREFERENCE TESTING

Species Tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Acclimation Temp. °C	Pref. Temp. °C	Test Duration (Hrs.)
Alosa pseudoharengus	6-4-73	11	16.6	15.0-17.5	16.0	21.2	48.0
**Ambloplites rupestris*	10-4-72	5	15.7	12.3-20.9	19.4	21.8	49.5
A. rupestris	6-19-73	9	18.9	14.8-21.4	20.3	18.7	48.0
**Aplodinotus grunniens*	8-12-72	8	15.3	13.2-17.0	22.0	27.2	34.0
**A. grunniens*	8-14-72	4	14.9	14.0-16.1	22.8	28.2	26.0
**A. grunniens*	8-19-72	9	16.6	15.3-18.2	22.7	26.5	50.0
**A. grunniens*	8-21-72	8	16.2	14.7-18.9	28.8	25.8	26.0
**A. grunniens*	10-26-72	1	29.2		13.7	19.6	48.0
**Carassuis auratus*	9-8-72	7	20.5	18.5-22.8	23.0	25.8	24.0
**C. auratus*	10-4-72	1	29.5		19.4	24.0	49.5
C. auratus	1-10-73	12	23.2	19.8-27.9	5.4	23.0	103.0
**Carpiodes cyprinus*	10-4-72	1	36.7		19.4	22.1	49.5
**Catostomus commersoni*	10-8-72	2	26.0	21.0-31.0	19.0	23.4	43.0
**C. commersoni*	10-18-72	1	14.6		14.0	20.4	49.0
Cyprinus carpio	3-22-73	4	31.3	26.5-33.7	7.9	25.2	94.0
**Dorsoma cepedianum*	10-26-72	24	14.9	11.7-18.5	13.7	22.3	48.0
**Ictalurus natalis*	8-31-72	10	18.2	14.6-23.8	24.0	28.0	26.0
**I. natalis*	9-19-72	12	18.2	14.6-23.8	23.0	28.5	46.0
I. nebulosus	11-22-72	5	27.5	23.5-30.5	9.0	23.6	48.0
I. nebulosus	11-28-72	2	28.4	28.0-28.8	10.5	Died-no barricades	
I. nebulosus	11-28-72	4	18.2	17.0-19.3	10.5	Died-no barricades	
I. nebulosus	5-21-73	11	30.0	28.2-33.4	13.1	18.8	73.5
I. nebulosus	5-24-73	13	20.8	19.2-23.5	18.8	25.9	75.5
I. nebulosus	6-14-73	9	29.6	25.5-32.5	20.4	21.2	72.0
**Ictalurus punctatus*	8-29-72	9	12.7	10.9-22.8	23.4	29.9	28.0
**I. punctatus*	10-13-72	15	17.9	5.5-29.1	15.7	22.4	51.5
**I. punctatus*	10-18-72	15	16.1	6.1-26.5	14.0	26.3	49.0

*Tests conducted by my predecessor, Sharon Dugal (not standardized).

TABLE 2(cont.)

Species Tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Acclimation Temp. °C	Pref. Temp. °C	Test Duration (Hrs.)
**Lepisosteus osseus*	8-8-72	1	23.9		20.2	33.2	28.0
L. osseus	8-8-72	1	4.9		20.2	21.8	28.0
**Lepomis gibbosus*	9-13-72	9	12.9	9.5-16.8	22.6	26.9	26.0
L. gibbosus	4-3-73	7	13.2	11.3-16.2	9.0	25.0	78.0
Lempomis macrochirus	2-15-73	10	12.0	8.9-13.5	4.9	27.0	120.0
L. macrochirus	2-20-73	10	13.7	13.0-14.4	4.0	27.8	121.5
**Notemigonus crysoleucas*	9-6-72	2	18.4	16.8-21.7	22.5	23.7	27.0
**N. crysoleucas*	9-21-72	5	15.4	10.9-19.5	19.8	21.0	30.0
**N. crysoleucas*	9-26-72	5	14.0	9.9-17.6	21.0	20.8	28.0
N. crysoleucas	3-8-73	6	12.9	12.3-13.9	4.2	16.6	96.0
N. crysoleucas	6-11-73	8	19.4	16.2-24.1	19.6	23.7	50.0
Notropis atherinoides	1-15-73	25	9.1	8.1-11.0	5.2	10.4	52.0
N. atherinoides	1-22-73	10	9.3	8.2-10.8	4.0	6.4	49.0
Notropis hudsonius	3-2-73	15	11.2	10.3-12.5	4.5	10.2	78.0
N. hudsonius	5-11-73	27	11.6	10.5-14.0	13.2	14.2[a]	64.0
**Noturus flavus*	10-8-72	4	22.8	21.9-23.8	19.0	25.1	62.0
N. flavus	3-5-73	5	22.0	19.2-25.0	3.1	5.2	66.5
Oncorhynchus kisutch	3-14-73	5	15.0	14.0-16.0	11.0	11.4	49.5
Perca flavescens	11-30-72	11	19.1	17.1-22.0	6.1	14.6	90.5
P. flavescens	12-7-72	7	24.6	23.5-26.0	4.0	13.6	74.5
P. flavescens	12-18-72	10	19.9	18.8-21.2	3.0	16.1	67.0
P. flavescens	12-26-72	16	18.2	14.0-28.8	3.6	12.6	72.0
**Pomoxis annularis*	9-14-72	9	17.0	13.3-25.8	22.9	21.4	24.0
P. annularis	2-12-73	4	16.1	11.2-19.7	5.0	16.0	65.0
P. annularis	4-19-73	7	24.6	21.7-32.5	10.0	21.1	88.5
P. annularis	5-16-73	15	19.4	15.6-25.0	13.1	17.8	47.5
P. annularis	6-6-73	13	25.1	22.0-29.0	16.5	16.2	50.5
**P. nigromaculatus*	9-11-72	19	13.4	9.7-20.8	22.1	25.2	26.0
**P. nigromaculatus*	9-28-72	18	20.8	15.5-23.6	20.2	15.2	46.0
P. nigromaculatus	1-25-73	12	16.8	15.2-19.2	5.0	21.5	95.0
P. nigromaculatus	2-8-73	8	17.6	13.9-23.0	3.0	16.0	93.5
P. nigromaculatus	4-16-73	10	21.0	16.5-24.4	10.0	18.5	67.0
P. nigromaculatus	4-23-73	7	20.0	16.5-23.2	11.3	18.4	67.5
P. nigromaculatus	5-14-73	12	17.0	15.2-20.8	13.1	15.1	47.0
P. nigromaculatus	5-18-73	13	15.7	13.7-16.5	12.1	26.4	71.0
P. nigromaculatus	6-2-73	13	17.5	14.3-22.9	15.5	24.5	46.5

*Tests conducted by my predecessor, Sharon Dugal (not standardized). [a]no cooler

Some fish, *Ictalurus nebulosus* (brown bullhead) and *Pomoxis nigromaculatus* (black crappie), exhibit an extremely variable preference, whereas the preference of others, *Notemigonus crysoleucas* (golden shiner) is quite constant.

Results indicate that, if allowed, fish will swim into warm water during the winter faster than they can acclimate to it. In the summer, although a fish may prefer a temperature above ambient, it will not swim past its Critical Thermal Maximum (C.T.M.), the temperature at which a fish loses locomotor control. This is as expected, for it is logical that a fish will swim into warm water faster when it is 20.0°C below its preference than when it is at its preference or slightly below it. This is not greatly significant to Davis-Besse for fish will not be harmed in winter even if they swim into the 20.0°F isotherm, but this could be quite important to a plant that allowed a temperature change greater than 20.0°F in the winter.

Effects of Sudden Temperature Changes on Lake Erie Fishes: Hot and cold shock tests are done to simulate a fish swimming in or out of the plume. Twenty-seven species were tested in hot shock and 14 in cold shock (Tables 3 and 4).

This past year I have been probing to locate problem areas. I have found that the 20.0°F (11.1°C) temperature change is not as important as the temperature extremes to which the fish is subjected. (A fish in the area of the plume could be subjected to temperatures ranging from 32.0-100.0°F each year.) Neither a hot shock nor a cold shock in spring or fall appears to cause harm. The greatest possibility of harm will come from a summer hot shock or a winter cold shock.

TABLE 3

RESULTS OF HOT SHOCK TESTING

Date	Species Tested	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. °C Ambient	Temp. °C Shock	Condition After Test	Temp. Inc. °C/Hr.	C.T.M. °C
6-5-73	*Alosa pseudoharengus*	5	17.1	16.0-19.5	16.5	27.5	1 expired	1.71	
6-6-73	*A. pseudoharengus*	5	16.4	15.0-17.3	16.5	27.5	2 expired	1.71	27.9
6-7-73	*A. pseudoharengus*	9	16.4	14.7-17.7	16.3	27.3	stressed	2.24	28.5
*7-72	*Ambloplites rupestris*	1			27.1	35.1	normal		
3-14-73	*A. rupestris*	1	20.3		2.9	13.6	normal	3.11	24.5
3-30-73	*A. rupestris*	1	13.3		5.6	16.6	normal	4.48	24.8
4-25-73	*A. rupestris*	1	18.9		10.5	21.8	normal	3.30	27.0
6-1-73	*A. rupestris*	1	20.6		14.6	25.5	normal	3.41	31.2
5-17-73	*Amia calva*	1	37.9		12.0	23.2	normal	2.58	29.0
*8-72	*Aplodinotus grunniens*	3		13.0-19.0	18.9	30.5	expired		
*11-72	*A. grunniens*	1	29.0		9.0	24.1	stressed		
*11-72	*Carassus auratus*	1	20.4		9.0	24.1	normal		
*11-72	*C. auratus*	1	18.3		9.3	15.3	normal		
2-8-73	*C. auratus*	2	11.0	10.0-11.9	3.2	13.8	normal	7.46	29.2
4-20-73	*C. auratus*	1	24.9		8.7	19.7	normal	3.69	27.7
6-1-73	*C. auratus*	1	25.5		14.6	25.5	normal	3.18	34.6
12-4-72	*Carpiodes cyprinus*	1	36.3		3.2	14.3	normal	3.36	28.2
*10-72	*Catostomus c. commersoni*	1	21.0		14.3	29.9	stressed		
1-22-73	*C. commersoni*	1	14.5		3.0	14.0	normal	3.61	25.4
*11-72	*Cyprinus carpio* x *Carassius auratus*	1	28.2		9.0	24.1	normal		
*11-72	*Carassius auratus* x	1	22.8		9.3	25.3	normal		
12-5-72	*Cyprinus carpio*	1	35.5		3.8	14.8	normal	3.36	
1-10-73	*Cyprinus carpio*	1	38.0		1.5	12.5	normal	3.43	22.8

*Tests conducted by my predecessor, Sharon Dugal (not standardized).

TABLE 3 (cont.)

Date	Species Tested	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. °C Ambient	Temp. °C Shock	Condition After Test	Temp. Inc. °C/Hr.	C.T.M. °C
2-7-73	*C. carpio*	1	42.2		1.0	12.5	normal	3.73	26.5
2-12-73	*C. carpio*	1	36.2		1.1	11.1	normal	3.46	29.0
4-9-73	*C. carpio*	1	36.4		6.0	17.0	normal	3.38	30.5
4-19-73	*C. carpio*	1	37.0		8.3	18.7	normal	3.59	28.3
*9-72	*Ictaluras natalis*	7	18.3	14.6-24.8	19.7	35.0	expired		
*9-72	*I. nebulosus*	3	16.9	14.4-19.3	19.7	35.0	normal		
3-5-73	*I. nebulosus*	1	18.5		1.2	12.2	normal	7.23	27.9
5-24-73	*I. nebulosus*	3	24.1	23.2-25.1	13.2	24.3	normal	3.05	31.8
5-30-73	*I. nebulosus*	3	30.8	30.5-34.0	14.5	25.5	normal	3.49	31.0
6-4-73	*I. nebulosus*	4	21.4	19.4-23.0	16.0	27.1	normal	3.20	33.5
*10-72	*I. punctatus*	12	16.5	5.5-29.1	14.3	29.2	stressed		
*10-72	*I. punctatus*	5	16.5	5.5-29.1	20.9	34.9	expired		
*11-72	*I. punctatus*	4	24.0		9.3	25.3	normal		
1-18-73	*Icthyomyzon unicuspis*	1	30.5		4.5	15.5	normal	9.94	31.6
*8-72	*Lepomis gibbosus*	4		14.6-17.8	22.5	34.8	expired		
*10-72	*L. gibbosus*	3	10.0		20.9	34.9	expired		
3-30-73	*L. humilis*	1	15.6		5.6	16.6	normal	4.52	26.0
3-29-73	*Micropterus dolomieui*	2	18.9	18.8-19.0	4.8	16.0	normal	4.00	28.0
6-1-73	*Morone chrysops*	1	13.5		14.6	25.5	normal	3.28	29.6
*10-72	*Notemigonus crysoleucus*	5	14.0	9.9-17.6	19.6	34.4	expired		
12-8-72	*N. crysoleucus*	3	18.3	17.3-20.1	2.0	13.0	normal	3.46	26.2
5-31-73	*Notemigonus crysoleucus*	2	21.2	20.4-22.0	14.4	25.5	normal	3.33	30.5
2-13-73	*Notropis therinoides*	6	9.0	8.0-9.7	1.1	12.1	1 expired	3.57	24.0
2-28-73	*N. atherinoides*	5	9.7	9.1-10.5	1.5	12.5	1 expired	7.27	24.3
3-1-73	*N. atherinoides*	7	9.1	8.3-10.5	1.0	12.0	normal	8.47	24.0
3-8-73	*N. atherinoides*	5	9.0	8.2-9.6	2.6	13.6	3 expired	7.56	20.5
5-2-73	*N. atherinoides*	10	3.0	2.8-3.5	10.4	21.6	normal	4.41	27.7
5-3-73	*N. atherinoides*	14	14.0	3.5-4.5	10.5	21.5	normal	3.23	26.6
4-11-73	*N. hudsonius*	5	12.1	10.9-12.9	6.0	16.6	normal	4.12	27.6
4-12-73	*N. hudsonius*	7	12.3	11.1-13.8	5.6	16.7	normal	3.95	27.0
4-13-73	*N. hudsonius*	8	11.5	10.7-12.1	5.8	16.8	normal	3.87	27.0
5-1-73	*N. hudsonius*	10	11.0	9.7-12.5	10.0	21.5	normal	3.80	27.9
12-12-73	*Noturus flavus*	1	19.5		1.6	12.8	normal	3.69	26.0
12-12-72	*N. flavus*	1	21.0		1.6	12.8	normal	3.28	29.0

*Tests conducted by my predecessor, Sharon Dugal (not standardized).

TABLE 3 (cont.)

Date	Species Tested	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. Ambient	°C Shock	Condition After Test	Temp. Inc. °C/Hr.	C.T.M. °C
4-10-73	*Osmerus eperlanus*	1	14.7		6.0	17.1	normal	3.90	24.9
1-2-73	*Perca flavescens*	4	19.5	17.6-21.7	1.0	12.2	normal	3.83	26.0
1-3-73	*P. flavescens*	1	26.0		1.0	12.7	normal	3.51	25.0
1-4-73	*P. flavescens*	3	24.5	23.7-26.0	1.5	12.5	normal	3.63	25.4
1-5-73	*P. flavescens*	3	23.5-25.5		1.0	12.1	normal	3.63	26.0
1-11-73	*P. flavescens*	3	20.5	19.9-21.4	1.6	12.7	normal	9.00	26.0
1-16-73	*P. flavescens*	4	19.6-20.5		1.5	12.6	normal	9.88	26.4
1-17-73	*P. flavescens*	2	19.7	19.6-19.7	1.5	12.5	normal	2.05	25.3
2-6-73	*P. flavescens*	3	18.4	17.3-19.1	1.0	12.0	normal	0.12	29.7
2-14-73	*P. flavescens*	3	20.4	20.1-20.9	[illegible]	12.0	normal	1.00	25.7
3-6-73	*P. flavescens*	2	18.2	17.9-18.5	1.6	12.6	normal	7.80	24.3
3-7-73	*P. flavescens*	2	17.3	17.2-17.3	2.2	13.2	normal	7.60	24.0
3-8-73	*P. flavescens*	3	16.3	14.2-18.5	2.6	13.6	normal	6.27	23.5
4-24-73	*P. flavescens*	2	24.8	23.0-26.5	9.0	19.8	normal	4.00	25.8
5-28-73	*P. flavescens*	4	20.3	19.0-21.5	13.8	25.0	normal	3.72	29.7
12-15-72	*Percopsis omiscomayus*	2	10.1	8.9-11.3	1.7	12.8	normal	3.96	22.9
4-3-73	*Pimephales notatus*	3	9.3	9.2-9.4	6.0	17.0	normal	4.04	27.8
*10-72	*Pomoxis annularis*	3		[illegible]	20.9	34.9	expired		
2-6-73	*P. annularis*	2	25.5	24.9-26.0	5.0	16.0	normal	3.50	33.0
5-16-73	*P. annularis*	5	22.1	20.5-23.3	12.1	[illegible]	normal	2.93	27.0
*11.72	*P. nigromaculatus*	7	17.3	16.5-18.7	9.0	24.1	normal		
*11.72	*P. nigromaculatus*	3	20.2	18.2-22.2	9.3	25.3	normal		
12-20-72	*P. nigromaculatus*	3	9.3	9.1-9.5	3.4	14.4	normal	3.68	24.3
12-20-72	*P. nigromaculatus*	2	6.7	6.2-7.1	3.4	14.4	normal	3.99	23.1
1-3-73	*P. nigromaculatus*	2	18.6	17.4-19.8	1.0	12.7	normal	3.68	22.4
1-25-73	*P. nigromaculatus*	1	16.0		3.0	14.0	normal	3.67	19.5
1-31-73	*P. nigromaculatus*	2	17.45	17.4-17.5	3.5	15.0	normal	3.62	23.4
2-1-73	*P. nigromaculatus*	2	15.8	15.5-16.1	2.8	13.8	normal	3.88	23.5
2-5-73	*P. nigromaculatus*	5	16.5	16.2-17.2	11.3	11.3		2.86	33.5
5-14-73	*P. nigromaculatus*	1	39.7		12.1	23.5	stressed	3.59	29.0
5-15-73	*P. nigromaculatus*	3	23.0	22.7-23.4	12.5	26.6	normal	3.33	28.0

*Tests conducted by my predecessor, Sharon Dugal (not standardized).

TABLE 4

RESULTS OF COLD SHOCK TESTING

Date	Species Tested	No. In Test	Length (cm) Mean	Length (cm) Range	Ambient Temp. °C	Time In Ambient (Hrs.)	Shock Temp. °C	Condition After Shock
1-14-73	*Carassius auratus*	12	23.2	19.8-27.9	24.0	56.0	3.0	12 expired
3-27-73	*Cyprinus carpio*	2	29.6	26.5-32.7	20.0	100.0	5.0	normal
3-28-73	*C. carpio*	1	33.7		17.5	28.0	4.4	normal
6-25-73	*C. carpio*	1	27.0		33.4	48.0	21.5	normal
12-4-72	*Ichthyomyzon unicuspis*	1	30.5		15.0	28.0	4.4	normal
*7.72	*Ictalurus nebulosus*	3			31.0		23.5	normal
*7.72	*Ictalurus punctatus*	1			34.0		23.5	normal
4-6-73	*Lepomis gibbosus*	6	12.9	11.3-16.2	25.0	33.0	6.5	normal
2-20-73	*Lepomis macrochirus*	10	12.0	8.9-13.5	27.0	40.0	12.0	normal
2-26-73	*L. macrochirus*	4	12.0	8.9-13.5	9.5	144.0	1.0	4 expired
2-26-73	*L. macrochirus*	6	13.7	13.2-14.3	27.6	70.0	12.0	normal
3-8-73	*L. macrochirus*	4	13.7	13.2-14.3	12.0	242.0	2.6	normal
3-2-73	*Micropterus dolomieui*	2	18.9	18.8-19.0	12.0	56.0	1.0	normal
*9-72	*Notemigonus crysoleucas*	5	15.4	10.7-19.7	28.2		12.1	normal
1-18-73	*Notropis atherinoides*	24	9.1	8.1-11.0	15.6	17.0	3.9	normal
1-24-73	*N. atherinoides*	10	9.3	8.2-10.8	14.0	19.0	3.0	normal
3-5-73	*N. hudsonuis*	12	11.2	10.3-12.5	12.0	81.5	1.6	normal
5-4-73	*N. hudsonuis*	7	11.5	10.6-12.2	21.5	72.0	11.5	normal
12-5-72	*Perca flavescens*	4	20.5	18.0-22.0	16.0	70.0	5.0	normal
12-12-72	*Perca flavescens*	7	24.6	23.5-26.0	17.0	50.0	3.0	normal
12-21-72	*P. flavescens*	10	19.9	18.8-21.2	21.2	40.0	3.0	normal
12-29-72	*Pl. flavescens*	16	18.2	14.0-21.8	15.0	40.0	4.0	normal
2-15-73	*Pomoxis annularis*	2	16.7	16.2-17.2	12.0	25.5	1.0	1 expired
4-23-73	*p. annularis*	6	23.1	21.7-25.5	20.5	58.0	9.3	normal
1-30-73	*P. nigromaculatus*	10	16.8	15.2-19.2	12.5	144.0	1.0	8 expired
2-2-73	*P. nigromaculatus*	2	15.8	15.5-16.1	13.0	24.0	2.0	normal
2-12-73	*P. nigromaculatus*	5	19.0	17.2-23.0	15.0	71.5	4.0	normal
4-19-73	*P. nigromaculatus*	10	21.0	16.5-24.4	19.0	54.0	8.3	normal
4-25-73	*p. nigromaculatus*	5	20.0	16.5-23.2	19.0	50.0	8.5	normal
6-4-73	*P. nigromaculatus*	7	17.8	15.5-22.9	26.6	40.0	16.0	normal

*Tests conducted by my predecessor, Sharon Dugal (not standardized).

Cold shocks do not become a problem until ambient lake temperature is down to approximately 3 or 4°C. In almost all cases, the fish were stressed upon entry into water this cold. Many more tests are needed to give dependable data for all species, but now that this problem area is isolated, plans can be made for a much more thorough testing procedure during the coming winter. I need cold shock results from fish which had not been acclimated to water more than 20.0°F above ambient.

From the C.T.M. testing one can see that hot shocks would cause a problem during the summer for, as the lake warms, the C.T.M. rises, but lake temperature increases much faster than the C.T.M. of the fish increases. Therefore, as one would expect, the C.T.M. of some fish is surpassed by an increase of 20.0°F during the warmest weater *(Alosa pseudoharengus)*.

Each species has its own characteristic safety range (lowest cold shock tolerable to highest hot shock tolerable). The size of the safety range varies inversely with the length of time each year that the fish could be in danger.

It is interesting that the C.T.M. of *Perca flavescens* (yellow perch) and *Notropis atherinoides* (emerald shiner) decreases in March. It appears that spawning preparations may cause this in perch.

The results verify the previously supposed facts that acclimation to warm water is fast while to cold water is slow, but loss of acclimation to hot water is slow and to cold water it is fast (Krenkle and Parker, 1969).

An interesting test was conducted on *Perca flavescens* during the winter. It is reported that a fish can reach a much higher C.T.M. when the rate of temperature increase is 1.0°F/hr than when it is 2.0°F/hr (Krenkel and Parker, 1969). I was using a temperature increase of approximately 4.00°C/hr on perch. I increased the rate of increase to 9.00°C/hr expecting the C.T.M. to be reduced. It was not. In fact there was no change in the C.T.M. of perch when the rate of increase was varied from 1.0°C to 9.88°C/hr. However. the C.T.M. was raised when the rate of increase was reduced to 0.12°C/hr. Therefore, there is a break-off point somewhere between 0.12°C/hr and 1.00°C/hr above which a further increase in the rate of increase up to 9.88°C/hr makes no difference in the winter C.T.M. of perch. This could be important when a plant starts again after refueling.

It is difficult to relate the significance of these laboratory results to the field situation for in the laboratory no restrictions are placed on the movements of the fish. In the field each fish would have to swim against a 200 cm/sec current in order to stay in the center of the plume. Assuming that the fish could reach the center in the winter when the attraction is the strongest, it would have to stay there for approximately 24 hours (safe estimate) in order for the cold shock upon leaving to cause a problem. During this time the fish would have to swim the equivalent of approximately 100 miles.

Some fish could possibly reach the speed of 200 cm/sec for fish have been reported to have burst speeds of up to 10 Body Lengths (B.L.)/sec (Blaxter, 1969), but this is more a question of endurance than burst speeds. Little work has been done in the area of endurance of fish, but it has been found that some fish can cruise at up to 4 B.L./sec for one hour (Blaxter, 1969). Therefore, no fish lesss than 20 cm long could reach the speed of 200 cm/sec, no fish less than 50 cm could maintain the speed for 1 hour, and probably no fish at all could maintain the speed for 24 hours.

As stated previously, fish seem to be able to avoid dangerous temperatures better in summer than winter. Therefore, it is doubtful that a fish would expend the required energy to swim beyond its C.T.M. in the summer. If, however, a fish was pulled into the center of the plume from the shore side of the outlet and lost locomotor control, it would be carried by the current to cooler and safer waters. My results indicate that a fish lives if it is placed back into ambient temperature water after losing locomotor control at its C.T.M.

VII. RECOMMENDATIONS

More work is needed to give current results greater accuracy, to obtain data on species not yet tested, and to develop definite safety ranges for all species. Now that summer hot shocks and winter cold shocks have been found to be problem areas work should be done to define the extent of the problem.

It appears that fishing around the periphery of the plume will be excellent.

An area which is extremely important to investigate is that of fish stamina or endurance. Not much work has been done in this area, and as stated earlier it is much more important than maximum burst speed. No true picture of fish response to the plume can be developed until it is known how far the fish can swim into the plume, and, once there, how long it can maintain position. Most studies have been based on endurance of 1 hour or less (Blaxter, 1969). Studies of 24 hours would probably be more valid in the case of any discharge from a large power plant.

A spawning study is also important. What different temperatures can eggs tolerate, and what temperatures give the most successful hatch? Many of these tests could be done with only slight modifications of our current equipment.

A relatively few tests on "sick" or parasitized individuals have indicated that they can withstand less stress than normal individuals. Is this always the case? Will diseased fish be attracted to or repelled from the plume? Is it possible that the plume will kill the diseased fish and, therefore, reduce disease in fish populations?

These are all important points which warrant much attention.

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