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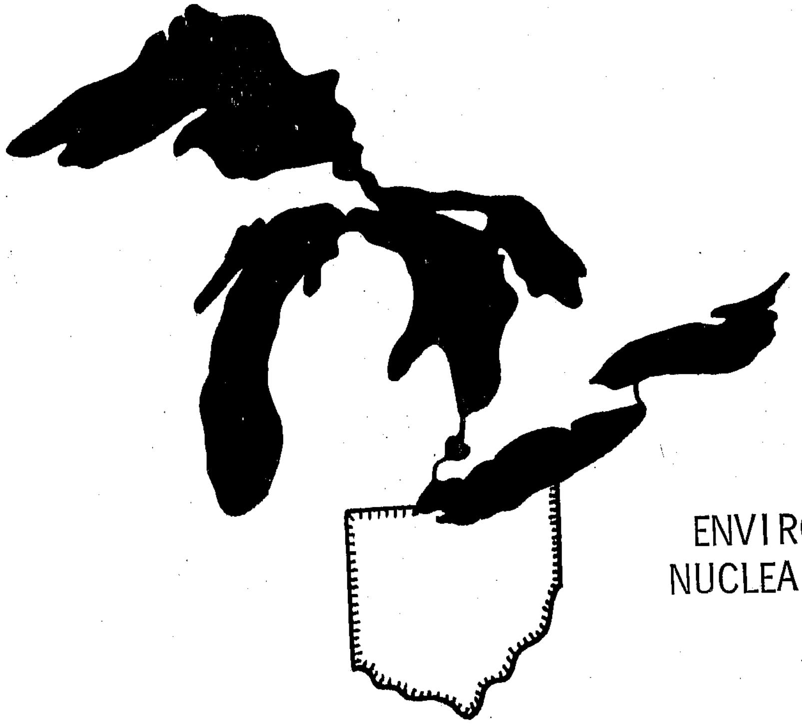

ENVIRONMENTAL EVALUATION OF A NUCLEAR POWER PLANT ON LAKE ERIE

ANNUAL REPORT - 1974
STUDY II
F-41-R-5

Prepared for

U. S. Fish and Wildlife Service
and
Ohio Department of Natural Resources
Division of Wildlife

Prepared by

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THE OHIO STATE UNIVERSITY
CENTER FOR LAKE ERIE AREA RESEARCH
COLUMBUS, OHIO

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F-41-R-5

STUDY II

The Ohio State University
Center for Lake Erie Area Research

ENVIRONMENTAL EVALUATION OF A NUCLEAR POWER PLANT ON LAKE ERIE
Federal Aid Project F-41-R-5

Performance Report

State: Ohio
Study No.: II

Prepared by: Jeffrey M. Reutter
Charles E. Herdendorf

Date Prepared: 31 July 1974

Study Title: Laboratory Estimates of Fish Response to the Heated Discharge from the Davis-Besse Reactor, Lake Erie, Ohio

Period Covered: 1 June 1973 to 31 May 1974

ABSTRACT

The volume of cooling water and, therefore, the volume of thermal effluents will increase in the future along with the imminent increase in nuclear power generation. This is especially true of Lake Erie where the Davis-Besse Nuclear Power Station is under construction and several others are proposed.

It is essential that we have a better understanding of the effects of these thermal effluents on the Lake Erie fishery resource. Therefore, The Ohio State University in cooperation with the Ohio Division of Wildlife and the U. S. Bureau of Sport Fisheries and Wildlife has been conducting laboratory experiments on Lake Erie fish species to determine their seasonal temperature preferences and reactions to sudden temperature change. To accomplish this a 24 m, horizontal thermal gradient was constructed consisting of 28 compartments each of which was 0.5 - 1.5°C warmer than the previous compartment. Fish were placed in this gradient and allowed to choose their temperature preference.

Preference data have been compiled on 24 of the 43 local fish species. Approximately 2000 fish have been tested in the gradient since its conception in 1971. In addition to this, over 800 fish of 30 species have been tested for their response to sudden temperature changes.

Data from young-of-the-year fish were collected for *Micropterus d. dolomieui*, *Morone chrysops*, *Notropis atherinoides*, and *Perca flavescens*. Only data from older fish were collected for the remaining 20 species.

All species tested preferred temperatures above ambient during fall, winter, and spring. Summer preferences were approximately ambient or slightly above ambient. Therefore, it appears that all species tested would be attracted to thermal plumes in fall, winter, and spring. Their reaction during the summer could vary from attraction to indifference to repulsion depending on individual plume characteristics.

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PROJECT STAFF

Charles E. Herdendorf - Principal Investigator

Jeffrey M. Reutter - Co-Principal Investigator; Laboratory Investigation

Richard O. Moore, Jr., and Veronica M. Reutter - Clerical Aid

Marjorie A. Slagle and Carolyn Jenkinson - Secretarial Services

STUDY OBJECTIVE

The objective of this study is to predict the effects that the heated dishcarge from the Davis-Besse Nuclear Power Station will have on the Lake Erie fishery resource.

Job. No. II-a

TEMPERATURE PREFERENCES OF LAKE ERIE FISHES

Objective

The objective of this job is to determine the seasonal temperature preferences of Lake Erie fish species, and from this predict fish response to a thermal plume.

Procedures

Fish for these experiments were captured in Lake Erie with a fyke net near Stone Laboratory on South Bass Island and at the northeast corner of North Bass Island, and by trawling south of Rattlesnake Island and at Locust Point (Fig. 1). Fish for winter testing were caught in November and early December and held in 420-liter 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. Data was desirable from as many species as possible common to western Lake Erie (Table 1).

For preference testing a horizontal temperature gradient approximately 24 m in length and 25 cm in depth was established within a wooden tank 8.7 m long, 79 cm wide, and 50 cm high (Barans and Tubb, 1973). A system of alternating transverse baffles each 56 cm long, formed a series of 28 virtually identical compartments. This arrangement did not greatly restrict the movements of the fish. Filtered lake water was passed through 0.64 cm Tygon tubing at a rate of approximately 2 l/min into the cold end of the gradient. To lower the water temperature during the spring, fall, and summer, the water was first routed through copper pipe in a cooling reservoir. Examination of the water quality 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

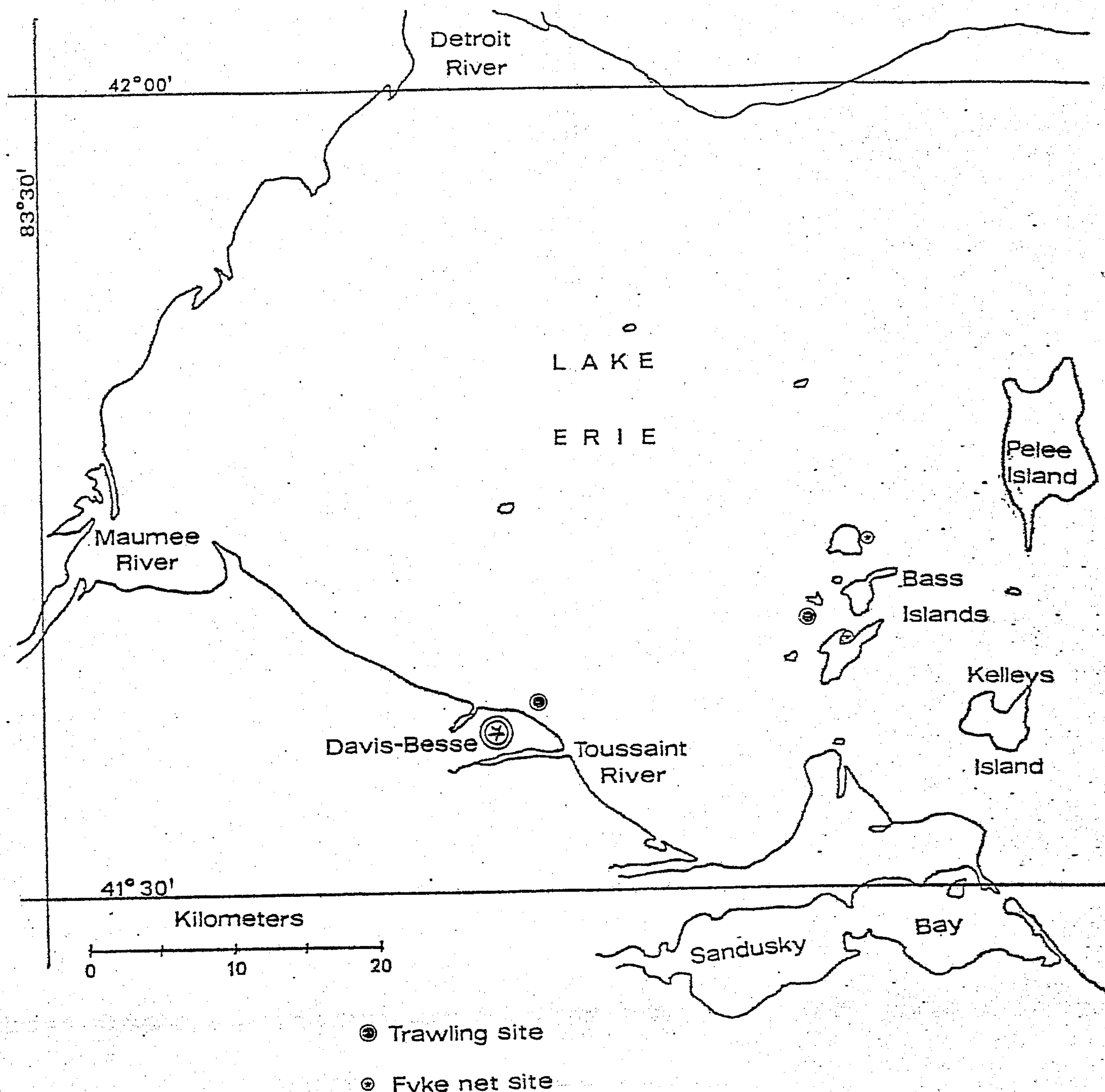

FIGURE 1

WESTERN LAKE ERIE SHOWING PLANT SITE AND LOCATIONS OF FISH CAPTURE

TABLE 1

SPECIES FOUND IN THE LOCUST POINT AREA
1963 – 1973

Amiidae	
Amia calva	bowfin
Catostomidae	
Carpiodes cyprinus	quillback carpsucker
* *Catostomus c. commersoni*	common white sucker
Minytrema melanops	spotted sucker
Moxostoma erythrurum	golden redhorse
Ictiobus cyprinellus	bigmouth buffalo fish
Centrarchidae	
Ambloplites rupestris	northern rockbass
* *Lepomis cyanellus*	green sunfish
* *L. humilis*	orangespotted sunfish
* *L. microlophus*	redear sunfish
* *Micropterus d. dolomieui*	smallmouth bass
* *M. s. salmoides*	largemouth bass
* *Pomoxis annularis*	white crappie
* *P. nigromaculatus*	black crappie
Clupeidae	
* *Alosa pseudoharengus*	alewife
* *Dorosoma cepedianum*	gizzard shad
Cyprinidae	
* *Carassius auratus*	goldfish
* *C. auratus* x *Cyprinus carpio*	Carp x goldfish hybrid
* *Cyprinus carpio*	carp
* *Hybopsis storeriana*	silver chub
* *Notropis a. atherinoides*	emerald shiner
* *N. hudsonius*	spottail shiner
* *N. spilopterus*	spotfin shiner
* *N. v. volucellus*	northern mimic shiner
Esocidae	
Esox lucius	northern pike

TABLE 1 CONT.

SPECIES FOUND IN THE LOCUST POINT AREA
1963 - 1973

Ictaluridae	
* _Ictalurus natalis_	yellow bullhead
* _I. nebulosus_	brown bullhead
* _I. punctatus_	channel catfish
Noturus flavus	stonecat madtom
Lepisosteidae	
Lepisosteus osseus	longnose gar
Osmeridae	
* _Osmerus eperlanus mordax_	American smelt
Percidae	
* _Perca flavescens_	yellow perch
* _Percina caprodes_	logperch darter
* _Stizostedion v. vetreum_	walleye
Percichthyidae	
* _Morone chrysops_	white bass
Percopsidae	
* _Percopsis omiscomaycus_	troutperch
Salmonidae	
Oncorhynchus kisutch	coho salmon
Sciaenidae	
* _Aplodinotus grunniens_	freshwater drum

Other species common to western Lake Erie

Ichthyomyzon unicuspis	silver lamprey
Lepomis gibbosus	pumkinseed sunfish
Lepomis macrochirus	northern bluegill sunfish
Notemigonus crysoleucas	golden shiner
Pimephales notatus	bluntnose minnow

* Species found by Study I in 1973

a standpipe at the opposite end of the trough.

A Vicore 500 watt heater, ARC static switch relay, and corresponding Juno thermoregulator maintained a relatively constant water temperature in the center of each compartment. By adjusting the thermoregulators a change of 0.5 - 1.5°C could be developed between compartments. Each season a different temperature range was established within the gradient 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 maintained dissolved oxygen near saturation levels in all compartments (Barans and Tubb, 1973). The water temperature at the center of alternate compartments was measured with probes from a YSI multi-channel telothermometer. By moving these probes temperatures could be obtained for every compartment.

In order to acquaint the fish with the gradient apparatus, 24 hours prior to testing they were placed in an acclimation tank half as long as the gradient, with the same system of baffles as the gradient, but with no heaters or thermoregulators. The water temperature was kept as close to 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 2-hr intervals during daylight hours. 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 <u>Micropterus dolomieui</u> (smallmouth bass) to 27 for <u>Notropis atherinoides</u> (emerald shiner). The duration of the test varied from 1 - 2 days in the summer to 3 - 4 days in winter. Barricades were necessary in late fall, winter, and early spring to keep fish from entering warm water too fast and being killed. 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 as the fish became acclimated to warmer water. Fish were left in the gradient until the mean temperature preference had remained constant for approximately 24 hours.

Findings

Ambient lake temperatures, as recorded in the holding tanks, ranged from approximately 1.0°C to 25.6°C in 1973 (Fig. 2). Results from tests starting at 5.5°C or lower were considered winter results, spring temperatures were 5.5°C to 20.0°C, summer temperatures were considered to be those of 20.0°C and above, and fall temperatures ranged from 20.0°C to 5.5°C.

Preference data was obtained for 24 of the 43 local species (Table 2). All fish tested preferred temperatures of approximately ambient or above during all seasons. However, Barans and Tubb (1973) found that *Notropis atherinoides* (emerald shiner) preferred temperatures slightly below ambient during the summer.

These preferences represent the final preferendum. The final preferendum is that temperature range in which the fish will ultimately congregate in an infinite gradient (Fry, 1947). In these cases, the final preferendum was considered to be the temperature at which the fish stabilized for approximately twenty-four (24) hours. Whereas this temperature was reached in 1 - 2 days in the summer, it could take four (4) or five (5) days in the winter (the mean preference gradually increased as the fish became acclimated to warmer water).

Recommendations

Additional tests must be performed to fill the gaps in the thermal preference data. The long-range goal of this job should be a graph for each species depicting ambient lake temperature vs. preference temperature. These results can then be compared with field observations after the plant is in operation.

A concerted effort must be put forth to publish these results so that they may be assessable to all interested individuals.

Job No. II-b

EFFECT OF SUDDEN THERMAL CHANGES ON LAKE ERIE FISH SPECIES FOUND IN THE VICINITY OF LOCUST POINT

Objective

The objective of this job is to determine the effects of a sudden temperature change, as could be associated with the operation of the Davis-Besse Nuclear Power Station, on the fish of western Lake Erie.

FIGURE 2

AMBIENT LAKE ERIE TEMPERATURES,
DECEMBER 1972 TO NOVEMBER 1973,
AT PUT-IN-BAY, OHIO

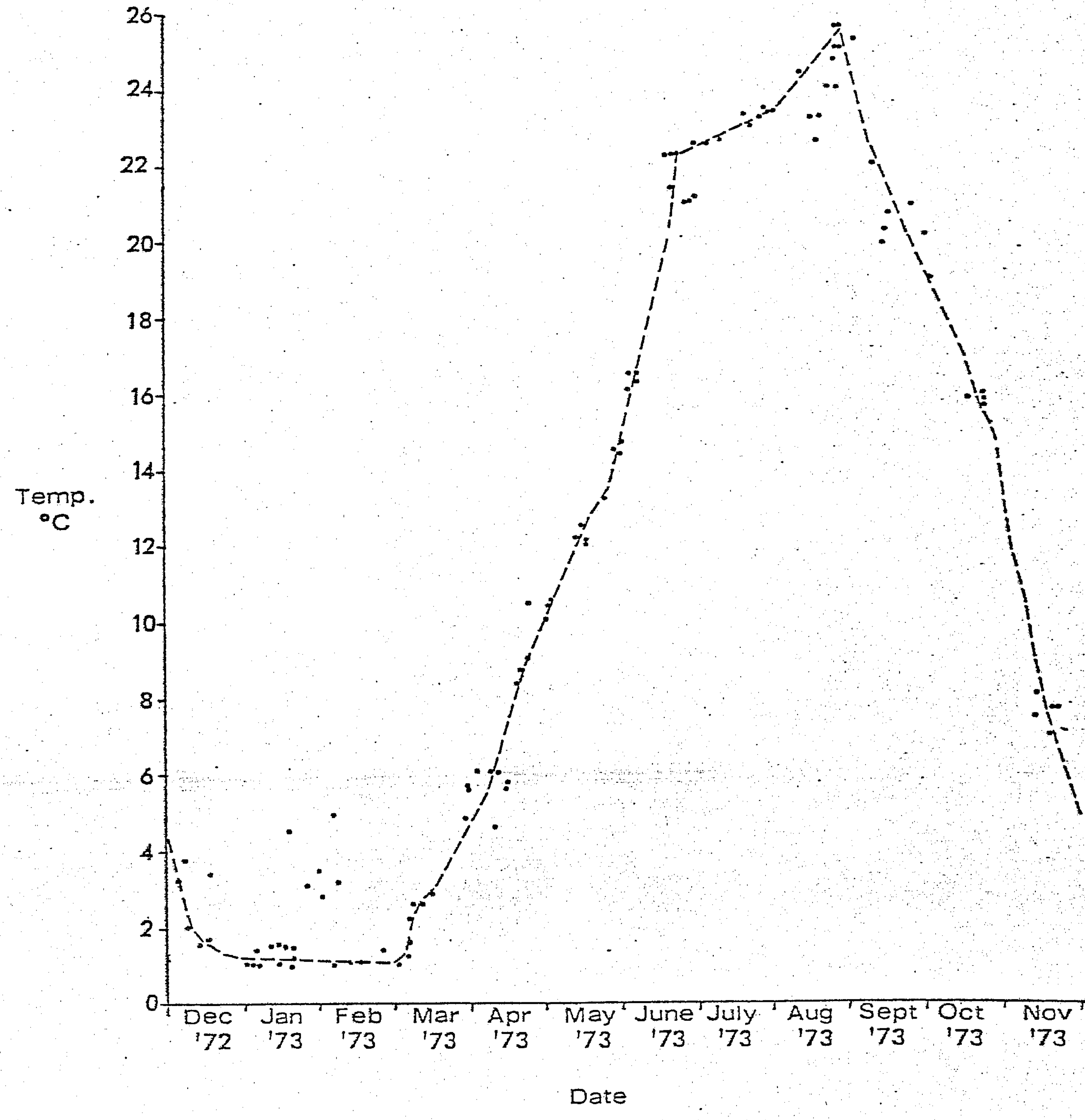

TABLE 2

RESULTS OF PREFERENCE TESTING

Species tested	Date	No. In Test	Length (cm)		Acclimation Temp. °C	Pref. Temp. °C	Standard Deviation
			Mean	Range			
Alosa pseudoharengus	6-4-73	11	16.6	15.0-17.5	16.0	21.3	1.5
Ambloplites rupestris	10-4-72	5	15.7	12.3-20.9	19.4	22.8	3.0
A. rupestris	6-19-73	9	18.9	14.8-21.4	20.3	18.7	1.7
A. rupestris	1-15-74	6	19.2	17.9-21.1	3.0	25.1	3.14
A. rupestris	3-19-74	6	17.9	16.1-20.3	3.5	18.0	2.15
Aplodinotus grunniens	8-12-72	8	15.3	13.2-17.0	22.0	27.2	1.7
A. grunniens	8-14-72	4	14.9	14.0-16.1	22.8	29.2	2.5
A. grunniens	8-19-72	9	16.6	15.3-18.2	22.7	27.2	3.3
A. grunniens	8-21-72	8	16.2	14.7-18.9	23.8	25.8	8.0
A. grunniens	10-26-72	1	29.2		13.7	19.6	1.6
A. grunniens	8-1-73	9	24.1	20.5-28.7	23.0	23.5	3.5
A. grunniens	8-18-73	9	19.8	18.1-22.5	23.8	27.6	2.5
A. grunniens	8-31-73	13	8.8	6.2-10.8	24.5	31.3	0.7
Carassuis auratus	9-8-72	7	20.5	18.5-22.8	23.0	25.8	5.6
C. auratus	10-4-72	1	29.5		19.4	24.0	0.7
C. auratus	1-10-73	12	23.2	19.8-27.9	5.4	24.2	3.4
Carpiodes cyprinus	10-4-72	1	36.7		19.4	22.1	1.0
Catostomus commersoni	10-8-72	2	26.0	21.0-31.0	19.0	23.4	4.8
C. commersoni	10-18-72	1	14.6		14.0	20.4	1.5
Cyprinus carpio	3-22-73	4	31.3	26.5-33.7	7.9	25.2	1.1
C. carpio	7-27-73	6	17.5	14.5-20.0	22.9	31.2	0.3
C. carpio	8-20-73	3	20.1	15.6-22.5	24.2	26.6	3.3
Dorosoma cepedianum	10-26-72	24	14.9	11.7-18.5	13.7	22.1	2.9
D. cepedianum	11-19-73	15	12.0	10.4-13.3	9.0	20.2	1.84
D. cepedianum	11-21-73	10	15.6	13.2-19.0	8.0	17.2	2.93

TABLE 2 CONT.

RESULTS OF PREFERENCE TESTING

Species tested	Date	No. In Test	Length (cm)		Acclimation Temp. °C	Pref. Temp. °C	Standard Deviation
			Mean	Range			
Ictalurus natalis	8-31-72	10	18.2	14.6-23.8	24.0	28.0	3.7
I. natalis	9-19-72	12	18.2	14.6-23.8	23.0	28.5	1.5
I. nebulosus	11-22-72	5	27.5	23.5-30.5	9.0	23.6	7.9
I. nebulosus	5-21-73	11	30.0	28.2-33.4	13.1	18.8	3.3
I. nebulosus	5-24-73	13	20.8	19.2-23.5	13.8	25.9	3.3
I. nebulosus	6-14-73	9	29.6	25.5-32.5	20.4	21.1	4.4
I. nebulosus	7-10-73	11	20.3	17.0-23.5	24.0	28.0	6.5
I. nebulosus	1-21-74	5	31.0	29.0-32.9	2.0	11.9	1.41
I. punctatus	8-29-72	9	12.7	10.9-22.8	23.4	29.8	7.3
I. punctatus	10-13-72	15	17.9	5.5-29.1	15.7	22.4	1.1
I. punctatus	10-18-72	15	16.1	6.1-26.5	14.0	27.8	1.6
I. punctatus	7-3-73	12	17.5	14.7-21.3	21.8	32.0	3.1
I. punctatus	7-5-73	8	18.3	16.8-20.5	22.5	26.4	4.5
I. punctatus	7-12-73	8	18.2	15.5-21.0	24.2	28.6	6.3
I. punctatus	7-18-73	12	17.5	15.0-19.8	23.0	30.4	5.0
I. punctatus	7-23-73	14	17.9	15.5-20.2	23.0	23.8	7.6
I. punctatus	7-24-73	10	18.0	16.2-20.2	29.7	25.5	6.2
I. punctatus	7-31-73	13	17.6	15.2-21.9	23.5	21.7	5.1
I. punctatus	9-18-73	12	19.7	18.0-21.7	20.0	20.6	10.5
I. punctatus	9-20-73	12	21.5	17.5-28.0	20.5*	25.5	7.0
I. punctatus	9-27-73	12	26.6	22.3-30.1	21.0	20.9	5.7
I. punctatus	10-4-73	12	20.8	18.6-23.8	20.3**	20.2	7.2
Lepisosteus osseus	8-8-72	1	23.9		20.2	33.1	1.3
L. osseus	8-8-72	1	4.9		20.2	25.3	0.7
Lepomis gibbosus	9-13-72	9	12.9	9.5-16.8	22.6	26.7	4.3
L. macrochirus	2-15-73	10	12.0	8.9-13.5	4.9	27.0	2.1
L. macrochirus	2-20-73	10	13.7	13.0-14.4	4.0	27.8	0.5

TABLE 2 CONT.

RESULTS OF PREFERENCE TESTING

Species tested	Date	No. In Test	Length (cm)		Acclimation Temp. °C	Pref. Temp. °C	Standard Deviation
			Mean	Range			
Micropterus dolomieui	11-14-73	6	11.1	9.7-14.1	10.0	26.6	2.20
Morone chrysops	8-30-73	17	7.3	5.7-9.3	25.5	27.8	1.7
Notemigonus crysoleucas	9-6-72	2	18.4	16.8-21.7	22.5	23.7	0.6
N. crysoleucas	9-21-72	5	15.4	10.9-19.5	19.8	21.0	3.9
N. crysoleucas	9-26-72	5	14.0	9.9-17.6	21.0	20.8	6.2
N. crysoleucas	3-8-73	6	12.9	12.3-13.9	4.2	16.8	2.5
N. crysoleucas	6-11-73	8	19.4	16.2-24.1	19.6	23.7	2.9
Notropis atherinoides	1-15-73	25	9.1	8.1-11.0	5.0	10.5	1.7
N. atherinoides	1-22-73	10	9.3	8.2-10.8	4.0	6.4	1.5
N. hudsonius	3-2-73	15	11.2	10.3-12.5	4.5	10.2	2.8
N. hudsonius	5-11-73	27	11.6	10.5-14.0	13.2	14.3	1.5
Noturus flavus	10-8-72	4	22.8	21.9-23.8	19.0	25.0	1.0
N. flavus	3-5-73	5	22.0	19.2-25.0	3.1	5.2	0.6
N. flavus	10-24-73	9	20.7	19.0-23.0	16.9	25.1	1.6
N. flavus	2-14-74	5	21.6	20.8-22.2	2.1	5.8	2.33
Oncorhynchus kisutch	3-14-73	5	15.0	14.0-16.0	11.0	11.4	4.0
Perca flavescens	11-30-72	11	19.1	17.1-22.0	6.1	14.5	4.1
P. flavescens	12-7-72	7	24.6	23.5-26.0	4.0	13.3	3.1
P. flavescens	12-18-72	10	19.9	18.8-21.2	3.0	16.1	4.0
P. flavescens	12-26-72	16	18.2	14.0-28.8	3.6	12.9	2.0
P. flavescens	8-26-73	10	19.1	17.5-20.3	23.5	22.7	3.4
P. flavescens	8-27-73	10	15.6	13.4-18.2	24.0	25.6	3.7
P. flavescens	8-29-73	4	18.3	16.6-20.2	25.0	13.9	1.3
P. flavescens	9-12-73	12	17.4	13.1-20.0	21.3	21.3	4.5
P. flavescens	9-14-73	12	18.1	16.2-19.5	21.2***	21.8	5.5

TABLE 2 CONT.

RESULTS OF PREFERENCE TESTING

Species tested	Date	No. In Test	Length (cm)		Acclimation Temp. °C	Pref. Temp °C	Standard Deviation
			Mean	Range			
Perca flavescens	10-2-73	13	18.9	17.7-21.0	20.2	16.6	5.6
P. flavescens	10-29-73	10	19.5	17.0-22.3	15.5	25.8	2.7
Pomoxis annularis	9-14-72	9	17.0	13.3-25.8	22.9	21.8	3.2
P. annularis	2-12-73	4	16.1	11.2-19.7	5.0	15.9	4.5
P. annularis	4-19-73	7	24.6	21.7-32.5	10.0	21.0	3.5
P. annularis	5-16-73	15	19.4	15.6-25.0	13.1	17.8	6.5
P. annularis	6-6-73	13	25.1	22.0-29.0	16.5	16.2	7.2
P. annularis	11-6-73	5	19.4	16.6-20.8	11.0	10.4	3.42
P. annularis	2-10-74	10	17.7	16.0-19.5	3.0	21.4	4.23
P. nigromaculatus	9-11-72	19	13.4	9.7-20.8	22.1	26.0	3.0
P. nigromaculatus	9-28-72	18	20.8	15.5-23.6	20.2	15.3	4.9
P. nigromaculatus	1-25-73	12	16.8	15.2-19.2	5.0	21.4	5.6
P. nigromaculatus	2-8-73	8	17.6	13.9-23.0	3.0	15.8	3.1
P. nigromaculatus	4-16-73	10	21.0	16.5-24.4	10.0	18.6	2.8
P. nigromaculatus	4-23-73	7	20.0	16.5-23.2	11.3	18.2	3.6
P. nigromaculatus	5-14-73	12	17.0	15.2-20.8	13.1	14.9	4.1
P. nigromaculatus	5-18-73	13	15.7	13.7-16.5	12.1	26.3	3.0
P. nigromaculatus	6-2-73	13	17.5	14.3-22.9	15.5	24.6	4.8
P. nigromaculatus	10-9-73	12	21.1	19.1-23.1	20.7	24.6	4.2
P. nigromaculatus	12-6-73	12	16.8	15.2-18.1	7.5	22.2	1.19
P. nigromaculatus	12-17-73	12	17.2	16.2-18.5	1.8	21.3	2.91
P. nigromaculatus	12-20-73	12	16.5	14.2-18.1	2.0	24.2	2.32
P. nigromaculatus	1-2-74	10	24.0	21.5-27.4	1.2	23.5	4.57
P. nigromaculatus	1-7-74	12	17.8	15.5-19.3	2.3	22.7	3.52
P. nigromaculatus	1-28-74	10	17.3	15.5-18.4	4.0	18.8	6.71
P. nigromaculatus	2-21-74	10	16.9	16.0-17.5	2.4	18.7	6.28

TABLE 2 CONT.

RESULTS OF PREFERENCE TESTING

Species tested	Date	No. In Test	Length (cm)		Acclimation Temp. °C	Pref. Temp. °C	Standard Deviation
			Mean	Range			
<u>Poxomis</u> <u>nigromaculatus</u>	3-4-74	10	22.2	21.0-24.6	3.8	14.7	3.24
<u>P.</u> <u>nigromaculatus</u>	3-11-74	10	16.0	14.8-17.7	5.0	21.8	6.43

* Start compartment temperature 31.6°C

** Start compartment temperature 31.0°C

*** Start Compartment temperature 30.0°C

Procedures

Fish for this phase of testing were captured by the same methods and in the same locations as those used in Job No. II-a.

Testing was accomplished using two 190-liter aquaria equipped with a Juno thermoregulator, ARC static switch relay, Vicore 500 watt heater, and 2 air stones.

To determine the effect of a hot shock (swimming into the plume) fish were transferred from ambient lake temperature to the 190-liter hot shock tank, which was maintained at 11.1°C above ambient (the theoretical maximum change due to the Davis-Besse thermal discharge, [U. S. Atomic Energy Commission, 1973]), and observed for one hour. It was also deemed necessary to determine the C.T.M. of each species during each season. Subsequently, the C.T.M. was determined by gradually increasing the temperature when the one hour observation period was over. If the original shock temperature was above the C.T.M. of the fish, as was often the case in summer, the fish was removed after it lost swimming ability, returned to ambient temperature, and observed to test survival. This was done to simulate a fish losing locomotor control in the plume and being forced to cooler water by the discharge current.

To determine the effect of a cold shock (a fish which had resided in the plume swimming out of the plume) fish were maintained at 11.1°C above ambient in a 190-liter aquarium for at least 24 hours. They were then transferred to a 420-liter holding tank at ambient lake temperature and observed.

Findings

A total of 533 fish of 30 species and one hybrid, *Carassius auratus* x *Cyprinus carpio*, have been tested in hot shock (Table 3).

The most delicate species tested and therefore possibly the most likely to be harmed by the plume were *Alosa pseudoharengus* (alewife) and *Dorosoma cepedianum* (gizzard shad). However, gizzard shad have been found to be present in very large numbers in thermal plumes from other power plants and appeared to go unharmed (Gammon, 1971). Both shad and alweife were very fragile and could only be maintained in the holding tanks for short periods (usually 2 – 3 weeks maximum). Beyond this time the condition of the fish became questionable and shed doubt on the test results. *Aplodinotus grunniens* (freshwater drum or sheepshead) was also quite delicate and difficult to test and maintain. The other twenty-six (26) species were tested and

TABLE 3

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C.Hr	C.T.M. °C
Alosa pseudoharengus	6-5-73	5	17.1	16.0-19.5	16.5	27.5	1 expired		
A. pseudoharengus	6-6-73	5	16.4	15.0-17.3	16.5	27.5	2 expired	1.71	27.9
A. pseudoharengus	6-7-73	9	16.4	14.7-17.7	16.3	27.3	stressed	2.24	28.5
Ambloplites rupestris	7-72	1			27.1	35.1	normal		
A. rupestris	3-14-73	1	20.3		2.9	13.6	normal	3.11	24.5
A. rupestris	3-30-73	1	13.3		5.6	16.6	normal	4.48	24.8
A. rupestris	4-25-73	1	18.9		10.5	21.8	normal	3.30	27.0
A. rupestris	6-1-73	1	20.6		14.6	25.5	normal	3.41	31.2
A. rupestris	1-22-74	1	51.5		1.9	13.0	normal	4.0	25.8
Amia calva	5-17-73	1	37.9		12.0	23.2	normal	2.58	29.0
A. calva	8-14-73	1	41.0		24.4	35.5	1*	2.58	29.0
A. calva	1-29-74	1	51.5		1.9	13.0	normal	4.0	25.8
Aplodinotus grunniens	8-72	3		13.0-19.0	18.9	30.5	expired		
A. grunniens	11-72	1	29.0		9.0	24.1	stressed		
A. grunniens	7-2-73	3	10.5	10.2-11.1	21.2	32.3	2*		
A. grunniens	7-2-73	3	20.0	18.0-21.2	21.2	32.3	normal	2.00	34.0
A. grunniens	8-21-73	4	16.0	14.0-18.0	23.2	34.2	3*		
A. grunniens	8-28-73	3	21.9	19.5-24.7	24.0	35.1	4*		
A. grunniens	8-28-73	5	9.0	8.0-10.7	24.0	35.1	5*		
A. grunniens	8-30-73	6	9.2	7.1-11.1	25.6	36.7	6*		
A. grunniens	8-30-73	5	18.5	15.8-21.1	25.6	36.7	7*		
A. grunniens	8-30-73	7	9.6	8.2-10.6	25.6	36.2	8*		
A. grunniens	12-31-73	2	23.6	22.5-24.8	0.8	11.8	normal		
A. grunniens	12-31-73	1	26.9		0.8	11.9	normal	4.1	25.2

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm)		Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
			Mean	Range					
Carassus auratus	11-72	1	20.4		9.0	24.1	normal		
C. auratus	11-72	1	18.3		9.3	15.3	normal		
C. auratus	2-8-73	2	11.0	10.0-11.9	3.2	13.8	normal	7.46	29.2
C. auratus	4-20-73	1	24.9		8.7	19.7	normal	3.69	27.7
C. auratus	6-1-73	1	25.5		14.6	25.5	normal	3.18	34.0
C. auratus	8-30-73	1	30.2		25.6	34.3	normal		
C. auratus	9-12-73	2	15.1	14.5-15.6	22.0	33.0	normal		
Carpiodes cyprinus	12-4-72	1	36.3		3.2	14.3	normal	3.30	28.2
C. cyprinus	7-24-73	3	4.7	4.3-5.2	23.3	34.4	normal	2.07	37.2
C. cyprinus	7-24-73	4	5.0	4.2-5.6	23.3	34.3	normal		
Catostomus c. commersoni	10-72	1	21.0		14.3	29.9	stressed		
C. commersoni	1-22-73	1	14.5		3.0	14.0	normal	3.61	25.4
Cyprinus carpio × *Carassius auratus*	11-72	1	28.2		9.0	24.1	normal		
Cyprinus carpio × *Carassius auratus*	11-72	1	22.8		9.3	25.3	normal		
Cyprinus carpio	12-5-72	1	35.5		3.8	14.8	normal	3.36	30.5
C. carpio	1-10-74	1	38.0		1.5	12.5	normal	3.43	22.8
C. carpio	2-7-73	1	42.2		1.0	12.5	normal	3.73	26.5
C. carpio	2-12-73	1	36.2		1.1	11.1	normal	3.46	29.0
C. carpio	4-9-73	1	36.4		6.0	17.0	normal	3.38	30.5
C. carpio	4-19-73	1	37.0		8.3	18.7	normal	3.59	28.3

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
Cyprinus carpio	6-25-73	1	27.0		22.2	32.8	normal		
C. carpio	7-24-73	1	6.3		23.3	34.4	normal	2.00	39.0
C. carpio	7-24-73	2	6.2	5.3-7.1	23.3	34.3	normal		
C. carpio	9-6-73	3	19.0	18.0-20.0	25.2	36.1	normal		
C. carpio	2-27-74	1	32.6		1.3	11.9	normal		
C. carpio	3-7-74	1	47.0		4.2	14.2	normal	4.2	31.0
Dorosoma cepedianum	9-26-73	1	21.7		20.9	32.0	9*		
D. cepedianum	10-17-73	2	17.5	17.5-17.5	15.9	27.0	normal		
D. cepedianum	10-17-73	3	16.0	15.2-16.7	15.9	27.3	normal	4.70	31.7
D. cepedianum	10-24-73	2	16.3	15.0-17.5	15.9	27.0	normal	3.70	30.2
D. cepedianum	11-13-73	5	12.9	11.2-14.3	7.5	18.6	normal	3.9	26.1
D. cepedianum	11-14-73	4	12.1	11.2-12.7	8.1	19.2	normal	3.9	26.6
D. cepedianum	11-14-73	2	16.0	15.7-16.3	8.1	19.2	normal		
C. cepedianum	11-19-73	3	14.9	14.5-15.5	7.0	18.0	normal		
D. cepedianum	11-20-73	1	16.8		7.7	18.8	normal	2.76	25.7
D. cepedianum	11-21-73	6	13.1	12.0-14.2	7.7	18.8	1 expired		
D. cepedianum	11-21-73	1	20.5		7.7	18.8	normal	3.6	21.5
D. cepedianum	12-19-73	5	13.4	12.0-15.1	0.9	12.0	normal		
D. cepedianum	12-24-73	3	12.9	11.5-15.6	0.8	11.8	1 expired		
Ictalurus natalis	9-72	7	18.3	14.6-24.8	19.7	35.0	expired		
I. nebulosus	9-72	3	16.9	14.4-19.3	19.7	35.0	normal		
I. nebulosus	3-5-73	1	18.5		1.2	12.2	normal	7.23	27.9
I. nebulosus	5-24-73	3	24.1	23.3-25.1	13.2	24.3	normal	3.05	31.8
I. nebulosus	5-30-73	3	31.8	30.5-34.0	14.5	25.5	normal	3.49	31.0
I. nebulosus	6-4-73	4	21.4	19.4-23.0	16.0	27.1	normal	3.20	33.5

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm)		Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
			Mean	Range					
Ictalurus nebulosus	7-13-73	7	1.5		22.5	33.6	normal		
I. nebulosus	7-23-73	3	20.6	18.7-22.3	23.0	34.1	normal	3.30	37.4
I. nebulosus	8-29-73	1	28.7		25.0	36.0	10*		
I. nebulosus	1-21-74	2	32.2	32.0-32.3	1.0	12.1	normal	3.9	27.7
I. punctatus	10-72	12	16.5	5.5-29.1	14.3	29.2	stressed		
I. punctatus	10-72	5	16.5	5.5-29.1	20.9	34.9	expired		
I. punctatus	11-72	4	24.0		9.3	25.3	normal		
I. punctatus	7-5-73	2	22.5	21.0-24.0	22.5	33.6	normal		
I. punctatus	7-5-73	3	16.4	15.5-17.3	22.5	33.5	normal	2.70	36.2
I. punctatus	7-30-73	1	38.7		23.2	34.3	normal	2.32	37.2
I. punctatus	7-30-73	2	27.3	26.5-28.0	23.2	34.3	11*		
I. punctatus	8-28-73	2	27.8	24.0-31.5	24.0	34.4	12*		
I. punctatus	9-18-73	2	35.2	33.3-37.0	20.7	31.7	normal		
I. punctatus	10-2-73	3	17.3	14.5-20.5	20.1	31.0	normal		
I. punctatus	12-17-73	2	24.2	23.0-25.3	0.8	11.9	normal		
I. punctatus	12-21-73	1	37.5		1.0	12.0	normal	4.5	25.5
I. punctatus	12-21-73	2	24.4	24.0-24.8	1.0	12.1	normal		
I. punctatus	12-24-73	1	31.0		0.8	11.8	normal	4.3	26.8
I. punctatus	1-24-74	2	27.6	24.4-30.8	1.0	12.0	normal	4.3	22-24
Icthyomyzon unicuspis	1-18-73	1	30.5		4.5	15.5	normal	9.94	31.6
Lepomis gibbosus	8-72	4		14.6-17.8	22.5	34.8	expired		
L. gibbosus	10-72	3	10.0		20.9	34.9	expired		
L. gibbosus	6-28-73	5	15.0	13.6-18.1	21.0	32.2	stressed	3.00	34.2
L. humilis	3-30-73	1	15.6		5.6	16.6	normal	4.52	26.0
L. macrochirus	6-26-73	1	15.4		21.3	32.4	13*		

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm)		Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
			Mean	Range					
Lepomis macrochirus	7-6-73	1	15.5		22.5	33.5	normal	2.50	36.0
L. macrochirus	8-29-73	1	20.5		24.8	34.3	14*		
Micropterus dolomieui	3-29-73	2	18.9	18.8-19.0	4.8	16.0	normal	4.00	28.0
M. dolomieui	6-25-73	1	29.2		22.2	32.2	15*		
M. dolomieui	8-28-73	1	21.6		24.1	35.2	16*		
M. samoides	1-7-74	1	28.0		0.7	12.0	normal		
M. samoides[a]	1-15-74	1	34.1		0.9	12.0	normal	6.0	18.0
Morone chrysops	6-1-73	1	13.5		14.6	25.5	normal	3.28	29.6
M. chrysops	8-1-73	1	24.0		23.3	34.4	17*		
M. chrysops	8-29-73	5	6.7	6.0-7.2	25.0	36.0	18*		
M. chrysops	1-14-74	1	13.5		0.8	11.9	normal		
Notemigonus crysoleucus	10-72	5	14.0	9.9-17.6	19.6	34.4	expired		
N. crysoleucus	12-8-72	3	18.3	17.3-20.1	2.0	13.0	normal	3.46	26.2
N. crysoleucus	5-31-73	2	21.2	20.4-22.0	14.4	25.5	normal	3.33	30.5
N. crysoleucus	3-22-74	2	15.7	15.0-16.4	2.9	13.9	normal		
Notropis atherinoides	2-13-73	6	9.0	8.0-9.7	1.1	12.1	1 expired	3.57	24.0
N. atherinoides	2-28-73	5	9.7	9.1-10.5	1.5	12.5	1 expired	7.27	24.3
N. atherinoides	3-1-73	7	9.1	8.3-10.5	1.0	12.0	normal	8.47	24.0
N. atherinoides	3-8-73	5	9.0	8.2-9.6	2.6	13.6	3 expired	7.56	20.5
N. atherinoides	5-2-73	10	3.0	2.8-3.5	10.4	21.6	normal	4.41	27.7
N. atherinoides	5-3-73	14	4.0	3.5-4.5	10.5	21.5	normal	3.23	26.6
N. hudsonius	4-11-73	5	12.1	10.9-12.9	6.0	16.6	normal	4.12	27.6
N. hudsonius	4-12-73	7	12.3	11.1-13.8	5.6	16.7	normal	3.95	27.0
N. hudsonius	4-13-73	8	11.5	10.7-12.1	5.8	16.8	normal	3.87	27.0
N. hudsonius	5-1-73	10	11.0	9.7-12.5	10.0	21.5	normal	3.80	27.9
N. hudsonius	3-22-74	1	12.4		2.9	13.9	normal		

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm)		Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
			Mean	Range					
Noturus flavus	12-12-72	1	19.5		1.6	12.8	normal	3.69	26.0
N. flavus	12-12-72	1	21.0		1.6	12.8	normal	3.28	29.0
Osmerus eperlanus	4-10-73	1	14.7		6.0	17.1	normal	3.90	24.9
Perca flavescens	1-2-73	4	19.5	17.6-21.7	1.0	12.2	normal	3.83	26.0
P. flavescens	1-3-73	1	26.0		1.0	12.7	normal	3.51	25.0
P. flavescens	1-4-73	3	24.5	23.7-26.0	1.5	12.5	normal	3.63	25.4
P. flavescens	1-5-73	3	24.2	23.5-25.5	1.0	12.1	normal	3.63	26.0
P. flavescens	1-11-73	3	20.5	19.9-21.4	1.6	12.7	normal	9.00	26.0
P. flavescens	1-16-73	4	20.1	19.6-20.5	1.5	12.6	normal	9.88	26.4
P. flavescens	1-17-73	2	19.7	19.6-19.7	1.5	12.5	normal	2.05	25.3
P. flavescens	2-6-73	3	18.4	17.3-19.1	1.0	12.0	normal	0.12	29.7
P. flavescens	2-14-73	3	20.4	20.1-20.9	1.1	12.0	normal	1.00	25.7
P. flavescens	3-6-73	2	18.2	17.9-18.5	1.6	12.6	normal	7.80	24.3
P. flavescens	3-7-73	2	17.3	17.2-17.3	2.2	13.2	normal	7.60	24.0
P. flavescens	3-8-73	3	16.3	14.2-18.5	2.6	13.6	normal	6.27	23.5
P. flavescens	4-24-73	2	24.8	23.0-26.5	9.0	19.8	normal	4.00	25.8
P. flavescens	5-28-73	4	20.3	19.0-21.5	13.8	25.0	normal	3.72	29.7
P. flavescens	6-25-73	2	18.5	17.8-19.2	22.2	32.9	19*		
P. flavescens	7-6-73	2	17.5	16.3-18.6	22.7	33.7	20*		
P. flavescens	8-21-73	3	18.7	18.5-19.0	23.2	34.3	21*		
P. flavescens	8-22-73	3	17.8	14.2-20.5	21.5	32.0	normal	2.41	33.3
P. flavescens	8-28-73	1	13.1		24.0	35.0	22*		
P. flavescens	8-30-73	6	7.8	7.0-8.5	25.6	36.7	23*		
P. flavescens	9-6-73	1	15.2		25.2	36.2	24*		
P. flavescens	9-12-73	3	18.2	16.5-19.5	22.0	33.3	normal	3.40	35.0

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
Perca flavescens	9-17-73	4	18.7	17.6-19.1	19.9	31.0	stressed	4.41	31.9
P. flavescens	9-19-73	3	14.4	14.1-14.7	20.2	31.3	normal	2.29	32.8
P. flavescens	1-21-74	3	26.6	24.5-28.4	1.0	12.1	normal		
P. flavescens	1-24-74	3	23.7	23.0-25.0	1.0	12.0	normal		
P. flavescens	3-1-74	1	32.7		1.0	12.3	normal	4.3	23.0
P. flavescens	3-7-74	3	25.0	24.2-25.7	3.2	14.0	normal		
P. flavescens	3-13-74	3	25.0	24.0-26.0	1.8	12.9	normal	4.4	24.0
Percopsis omiscomayus	12-15-72	2	10.1	8.9-11.3	1.7	12.8	normal	3.96	22.9
Pimephales notatus	4-3-73	3	9.3	9.2-9.4	6.0	17.0	normal	4.04	27.8
Pomoxis annularis	10-72	3		10.2-12.5	20.9	34.9	expired		
P. annularis	2-6-73	2	25.5	24.9-26.0	5.0	16.0	normal	3.50	33.0
P. annularis	5-16-73	5	22.1	20.5-23.3	12.1	23.1	normal	2.93	27.0
P. annularis	6-26-73	4	18.6	16.6-21.9	21.3	32.4	25*	4.0	23.5
P. annularis	8-14-73	2	14.3	13.1-15.5	24.4	35.5	26*		
P. annularis	10-23-73	3	21.2	20.5-22.3	15.7	26.8	normal	3.50	30.3
P. annularis	1-10-74	2	29.5	29.3-29.7	0.7	12.0	normal	4.0	23.5
P. annularis	1-29-74	3	18.5	18.4-18.7	1.3	12.4	normal		
P. annularis	2-12-74	3	23.4	21.5-24.4	1.0	12.0	normal		
P. annularis	2-13-74	3	19.6	19.3-20.0	0.9	12.0	normal	4.5	24.0
P. annularis	2-13-74	3	16.8	15.3-18.0	1.0	12.1	normal		
P. annularis	2-14-74	3	10.9	9.7-13.0	1.0	12.0	normal	4.5	22.7
P. annularis	2-14-74	2	9.5	9.0-10.0	1.0	12.0	normal		
P. nigromaculatus	11-72	7	17.3	16.5-18.7	9.0	24.1	normal		
P. nigromaculatus	11-72	3	20.2	18.2-22.2	9.3	25.3	normal		
P. nigromaculatus	12-20-72	3	9.3	9.1-9.5	3.4	14.4	normal	3.68	24.3

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

Species tested	Date	No. In Test	Length (cm) Mean	Length (cm) Range	Temp. Ambient	Shock °C	Condition After Test	Temp. Inc. °C/Hr	C.T.M. °C
Pomoxis nigromaculatus	12-20-72	2	6.7	6.2-7.1	3.4	14.4	normal	3.99	23.1
P. nigromaculatus	1-3-73	2	18.6	17.4-19.8	1.0	12.7	normal	3.68	22.4
P. nigromaculatus	1-25-73	1	16.0		3.0	14.0	normal	3.67	19.5
P. nigromaculatus	1-31-73	2	17.4	17.4-17.5	3.5	15.0	normal	3.62	23.4
P. nigromaculatus	2-1-73	2	15.8	15.5-16.1	2.8	13.8	normal	3.88	23.5
P. nigromaculatus	2-5-73	5	16.5	16.2-17.2	11.3			2.86	33.5
P. nigromaculatus	5-14-73	1	39.7		12.1	23.5	stressed	3.59	29.0
P. nigromaculatus	5-15-73	3	23.0	22.7-23.4	12.5	26.6	normal	3.33	28.0
P. nigromaculatus	6-28-73	5	20.2	15.7-25.9	21.0	32.1	27*		
P. nigromaculatus	7-31-73	3	19.1	18.5-19.7	23.5	34.5	28*		
P. nigromaculatus	10-5-73	5	17.1	16.0-17.9	19.0	30.0	29*		
P. nigromaculatus	10-5-73	5	17.4	14.7-19.0	19.0	30.0	normal		
P. nigromaculatus	10-23-73	2	16.8	16.2-17.3	15.7	26.8	normal		
P. nigromaculatus	12-22-73	3	19.8	19.0-21.0	1.0	12.1	normal		
P. nigromaculatus	3-12-74	3	21.6	21.0-22.3	2.8	13.9	normal		
Stizostedion v. vitreum	7-31-73	3	26.5	24.5-27.6	23.5	34.5	30*		
S. v. vitreum	8-1-73	1	28.4		23.3	34.4	31*		

Notes:
- a Fish in poor condition
- 1* Test terminated after 15 minutes; fish lived upon cooling.
- 2* Test terminated after 6 minutes; fish lived upon cooling.
- 3* Test terminated after 9 minutes; fish lived upon cooling.
- 4* Test terminated after 7.3 minutes; fish lived upon cooling.
- 5* Test terminated after 4.5 minutes; fish lived upon cooling.

TABLE 3 CONT.

RESULTS OF HOT SHOCK TESTING

6*	Test terminated after 1.3 minutes; 1 died upon cooling.
7*	Test terminated after 3.4 minutes; 1 died upon cooling.
8*	Test terminated after 1.5 minutes; fish lived upon cooling.
9*	Test terminated after 24 minutes; fish died upon cooling.
10*	Test terminated after 20 minutes; fish lived upon cooling.
11*	Normal after 1 hour, dead after 24 hours.
12*	Normal after 8 hours, dead after 24 hours.
13*	Normal after 3 hours, dead after 19 hours.
14*	Normal after 8 hours, dead after 24 hours.
15*	Normal after 1 hour, dead after 5 hours.
16*	Test terminated after 20 minutes; fish died upon cooling.
17*	Stressed after 1.25 hours, dead after 2.75 hours.
18*	Test terminated after 30 seconds; fish lived upon cooling.
19*	Test terminated after 10 minutes; fish lived upon cooling.
20*	Test terminated after 5 minutes; 1 died upon cooling.
21*	Test terminated after 5 minutes; fish lived upon cooling.
22*	Test terminated after 6 minutes; fish lived upon cooling.
23*	Test terminated after 1 minute; fish lived upon cooling.
24*	Test terminated after 2 minutes; fish lived upon cooling.
25*	Test terminated after 8 minutes; 1 died upon cooling.
26*	Test terminated after 4 minutes; fish lived upon cooling.
27*	Test terminated after 7 minutes; fish lived upon cooling.
28*	Test terminated after 7.5 minutes; fish lived upon cooling.
29*	Normal after 24 hours, 2 dead after 68 hours.
30*	Test terminated after 5 minutes; fish lived upon cooling.
31*	Test terminated after 5 minutes; fish lived upon cooling.

maintained easily.

No fish died from a hot shock when ambient lake temperature was 16.5°C or less (hot shock temperature 27.6°C or less).

The C.T.M. of each species increased as ambient lake temperature increased, but the C.T.M. did not increase as fast as ambient lake temperature. Therefore, there came a time during some part of the summer when the temperature of the plume would be above or very close to the C.T.M. of every species tested. Carassius auratus (goldfish), Cyprinus carpio (carp), and the ictalurids had very high C.T.M.'s and could possibly go unaffected by summer hot shocks. All other species tested would die if held in the center of the plume during the summer where temperatures ranged from 31.1°C to 36.7°C (Table 3). However, sixty-nine (69) of the seventy-five (75) fish (92.0%) that were returned to ambient temperature after a hot shock which exceeded their C.T.M. lived.

A total of 273 fish of 19 species have been tested in cold shock (Table 4). No fish died due to a cold shock during any season except winter. This supports our past conclusions that it is not the 11.1°C temperature change that causes the harm but rather the absolute temperature to which the fish is subjected. Therefore, as the results point out, the greatest possibility for harm lies with a summer hot shock or winter cold shock.

Recommendations

Further testing is necessary to substantiate current results and obtain data on species which have not yet been tested.

More effort must be put into testing the more delicate species in both hot and cold shock.

Continued effort should be put into publication of results or else the study will lose its greatest impact.

STUDY ANALYSIS

Results indicated that the temperatures in a plume would attract all species tested during fall, winter, and spring. Actual location of fish in the anticipated plume was difficult to determine. Although they could be attracted to the hottest point in the plume, the velocity of the discharge under actual conditions would undoubtedly keep many from reaching this area. Attraction to a plume will be the greatest in

TABLE 4

RESULTS OF COLD SHOCK TESTING

Species Tested	Date	No. In Test	Length (cm)		Ambient Temp °C	Time in Ambient (Hrs)	Shock Temp. °C	Condition After Shock
			Mean	Range				
Aplodinotus grunniens	1-2-74	2	23.6	22.5-24.8	11.8	54.0	0.6	1 expired
Carassius auratus	1-14-73	12	23.2	19.8-27.9	24.0	56.0	3.0	12 expired
C. auratus	8-31-73	1	30.2		34.3	24.5	25.0	normal
C. auratus	9-13-73	2	15.1	14.5-15.6	33.1	24.8	21.8	normal
Carpiodes cyprinus	7-27-73	4	5.0	4.2-5.6	34.3	67.0	23.1	normal
Cyprinus carpio	3-27-73	2	29.6	26.5-32.7	20.0	100.0	5.0	normal
C. carpio	3-28-73	1	33.7		17.5	28.0	4.4	normal
C. carpio	6-25-73	1	27.0		33.4	48.0	21.5	normal
C. carpio	7-27-73	2	6.2	5.3-7.1	34.3	67.0	23.1	normal
C. carpio	2-28-74	1	32.6		12.0	31.5	0.9	normal
Dorosoma cepedianum	10-18-73	2	17.5	17.5-17.5	27.0	24.0	15.5	normal
D. cepedianum	10-24-73	2	16.8	16.2-17.3	26.8	24.0	15.9	normal
D. cepedianum	11-19-73	2	16.0	15.7-16.3	19.3	117.5	8.0	normal
D. cepedianum	11-21-73	3	14.9	14.5-15.5	18.0	119.0	7.7	normal
D. cepedianum	11-26-73	13.7		13.2-14.2	18.8	119.5	7.6	normal
D. cepedianum	12-21-73	5	13.4	12.0-15.1	12.1	56.5	1.0	stressed
D. cepedianum	12-26-73	2	12.9	11.5-15.6	13.0	53.0	0.1	stressed
Ichthyomyzon unicuspis	12-4-72	1	30.5		15.0	28.0	4.4	normal
Ictalurus nebulosus	7-72	3			31.0		23.5	normal
I. nubulosus	7-15-73	3	2.5		34.0	53.0	23.0	normal
I. punctatus	7-72	1			34.0		23.5	normal
I. punctatus	7-7-73	2	22.5	21.0-24.0	34.6	48.0	23.5	normal
I. punctatus	9-19-73	2	35.2	33.3-37.0	31.7	24.0	20.2	normal
I. punctatus	10-4-73	3	17.3	14.5-20.5	31.0	44.0	20.1	normal
I. punctatus	12-22-73	2	24.4	24.0-24.8	12.1	21.0	1.0	normal
I. punctatus	12-19-73	2	24.2	23.0-25.3	12.0	44.0	0.9	normal

TABLE 4 CONT.

RESULTS OF COLD SHOCK TESTING

Species Tested	Date	No. In Test	Length (cm)		Ambient Temp °C	Time in Ambient (Hrs)	Shock Temp. °C	Condition After Shock
			Mean	Range				
Lepomis gibbosus	4-6-73	6	12.9	11.3-16.2	25.0	33.0	6.5	normal
L. macrochirus	2-20-73	10	12.0	8.9-13.5	27.0	40.0	12.0	normal
L. macrochirus	2-26-73	4	12.0	8.9-13.5	9.5	144.0	1.0	4 expired
L. macrochirus	2-26-73	6	13.7	13.2-14.3	27.6	70.0	12.0	normal
L. macrochirus	3-8-73	4	13.7	13.2-14.3	12.0	242.0	2.6	normal
Micropterus dolomieui	3-2-73	2	18.9	18.8-19.0	12.0	56.0	1.0	normal
M. salmoides	1-8-74	1	28.0		11.8	24.0	0.9	normal
Morone chrysops	1-15-74	1	13.5		13.5	24.0	0.9	normal
Notemigonus crysoleucas	9-72	5	15.4	10.7-19.7	28.2		12.1	normal
N. crysoleucas	3-27-74	2	15.7	15.0-16.4	14.0	125.0	3.0	normal
Notropis atherinoides	1-18-73	24	9.1	8.1-11.0	15.6	17.0	3.9	normal
N. atherinoides	1-24-73	10	9.3	8.2-10.8	14.0	19.0	3.0	normal
N. hudsonius	3-5-73	12	11.2	10.3-12.5	12.0	81.5	1.6	normal
N. hudsonius	5-4-73	7	11.5	10.6-12.2	21.5	72.0	11.5	normal
N. hudsonius	3-27-74	1	12.4		14.0	125.0	3.0	normal
Perca flavescens	12-5-72	4	20.5	18.0-22.0	16.0	70.0	5.0	normal
P. flavescens	12-12-72	7	24.6	23.5-26.0	17.0	50.0	3.0	normal
P. flavescens	12-21-72	10	19.9	18.8-21.2	21.2	40.0	3.0	normal
P. flavescens	12-29-72	16	18.2	14.0-21.8	15.0	40.0	4.0	normal
P. flavescens	1-22-74	3	26.6	24.5-28.4	13.0	25.0	1.0	normal
P. flavescens	1-25-74	3	23.7	23.0-25.0	12.1	26.8	1.2	normal
P. flavescens	3-11-74	3	25.0	24.2-25.7	13.9	96.0	2.8	normal
Pomoxis annularis	2-15-73	2	16.7	16.2-17.2	12.0	25.5	1.0	1 expired
P. annularis	4-23-73	6	23.1	21.7-25.5	20.5	58.0	9.3	normal

TABLE 4 CONT.

RESULTS OF COLD SHOCK TESTING

Species Tested	Date	No. In Test	Length (cm)		Ambient Temp °C	Time in Ambient (Hrs)	Shock Temp. °C	Condition After Shock
			Mean	Range				
Pomoxis annularis	1-31-74	3	18.5	18.4-18.7	13.5	48.0	2.0	normal
P. annularis	2-13-74	3	23.4	21.5-24.4	12.5	28.5	1.0	normal
P. annularis	2-14-74	3	16.8	15.3-18.0	12.0	23.0	1.0	normal
P. annularis (YOY)	2-15-74	2	9.5	9.0-10.0	11.8	26.5	1.0	normal
P. nigromaculatus	1-30-73	10	16.8	15.2-19.2	12.5	144.0	1.0	8 expired
P. nigromaculatus	2-27-73	2	15.8	15.5-16.1	13.0	24.0	2.0	normal
P. nigromaculatus	2-12-73	5	19.0	17.2-23.0	15.0	71.5	4.0	normal
P. nigromaculatus	4-19-73	10	21.0	16.5-24.4	19.0	54.0	8.3	normal
P. nigromaculatus	4-25-73	5	20.0	16.5-23.2	19.0	50.0	8.5	normal
P. nigromaculatus	6-4-73	7	17.8	15.5-22.9	26.6	40.0	16.0	normal
P. nigromaculatus	10-8-73	3	17.7	17.5-17.9	30.0	68.0	19.0	normal
P. nigromaculatus	12-24-73	3	19.8	19.0-21.0	11.8	45.5	0.8	stressed
P. nigromaculatus	3-13-74	3	21.6	21.0-22.3	14.0	24.0	2.9	normal

winter when the difference between the temperature preference and ambient lake temperature is greatest. Therefore, large fish populations should be found in and around the plume during fall, winter, and spring when attraction should be greatest.

All fish species tested to date would be repelled by the hottest water at the plume origin during the summer, but could be attracted to the plume periphery where temperatures are much lower. This summer attraction should not be as great as the winter attraction, since the difference between temperature preference and ambient lake temperature appeared small. Species such as Cyprinus carpio (carp), Morone chrysops (white bass), and the various ictalurids should be the most common plume dwellers during the summer due to their high temperature preferences and relative abundance in the discharge area. In addition, Gammon (1971) also found Corosoma cepedianum (gizzard shad) to be common plume dwellers as long as the temperature was below 34°C. Therefore, although little preference data is available on gizzard shad due to difficulties in maintaining them in the laboratory, this field evidence indicates that they would be common plume dwellers.

Sudden temperature change testing demonstrated that the temperature extremes to which the fish were subjected were more important than the 11.1°C temperature change. Therefore, the greatest potential for harm would lie with a summer hot shock or a winter cold shock.

According to Eugene C. Novak, Chief Mechanical Engineer for Toledo Edison (personal communication, January, 1974), under adverse high lake level conditions the discharge structure can hydraulically handle a maximum flow of 190,000 l/min. It is designed with 2 slots 137 cm long which could each discharge 76,000 l/min at 200 cm/sec. He also said one slot would be closed initially resulting in a velocity of 113 cm/sec at the average flow rate of 41,000 l/min for the first unit.

Consequently, the danger due to hot shock should be minimal for the following reasons: temperature preference results indicated that fish would avoid the hottest parts of the plume, thus making the only fish to encounter this area those that would be drawn in or swim in from the shoreside of the discharge; and, due to the discharge velocity of 200 cm/sec, fish which were drawn into the plume and lost swimming ability would be carried to safer waters where our results indicate approximately 92% would recover. The lower initial velocity of 113 cm/sec will not carry fish to safer waters as rapidly as the 200 cm/sec current. Consequently, the fish will be subjected to the heat stress for a longer period of time.

Cold shock hazards could occur when fish acclimated to the warm water of a plume swim out of the plume into ambient temperature water or if the plant were to shut down, thus eliminating the plume. Agersborg (1930) observed this in the field with Dorosoma cepedianum (gizzard shad). A fish which left the plume when the temperature change was great enough or ambient lake temperature extremely low could experience loss of swimming ability and, therefore, inability to return to the plume. Even if a fish survived the shock, the stress could be severe enough to make it more susceptible to secondary fungal infections (Horning and Pearson, 1973). It would be very hard to monitor these secondary affects since they are not immediately evident.

These cold shock hazards could be greatly reduced by maintaining a discharge velocity high enough to keep fish out of the hottest plume temperatures. A discharge velocity of 200 cm/sec would probably be sufficient but a velocity of 113 cm/sec is questionable as will be explained later. This possibility was called to the attention of the Toledo Edison Company. If problems occur, it would be possible, according to plant specifications to increase the amount of dilution water thereby increasing the discharge velocity. It would be necessary to monitor this closely for the use of additional water would mean greater intake velocities and a greater possibility of entrapment. The Toledo Edison Company was also informed that plant shut-downs should be avoided in winter due to the cold shock danger.

It is generally felt that fish can attain burst speeds of 10 body lengths (B.L.) per second and cruising speeds of 3 - 4 B.L./sec (Bainbridge, 1958; Blaxter, 1969). These burst speeds can be maintained for only a period of seconds, but cruising speeds can be maintained for up to several hours (Bainbridge, 1960; Blaxter, 1969). This swimming ability decreases rapidly in hot or cold water (Fry and Hart, 1947). Assuming this, a fish must be at least 20 cm long to attain the maximum discharge velocity of 200 cm/sec and 50 - 67 cm long to maintain position in the hottest section of the plume for any length of time. Therefore, from swimming speed data alone, it would appear that no larvae or young-of-the-year fish and few adults could maintain position in the hottest section of the plume long enough to become acclimated and, therefore, susceptible to cold shock dangers. (The actual length of time necessary for the fish to become acclimated to the plume temperature and lose acclimation to the colder ambient lake temperature is difficult to determine, but we have found that acclimation to warm water is faster than acclimation to cold water, and loss of acclimation to warm water is slower than to cold). Thus, it becomes evident that an initial discharge velocity of only 113 cm/sec could cause some problem.

Undoubtedly a small number of fish could locate in the warmer water by finding places where the current was reduced behind rocks in the rip-rap apron which will extend 61 m in front of the discharge. This is not expected to be a significant factor.

STUDY RECOMMENDATIONS

Additional testing is necessary on all phases to further substantiate present data and obtain data on species not yet tested.

A concerted effort must be made by all involved to pool information with the Toledo Edison Company so that purposeful management practices can be developed prior to operation.

A comprehensive monitoring program is required after the plant is in operation to compare actual field observations with laboratory predictions.

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