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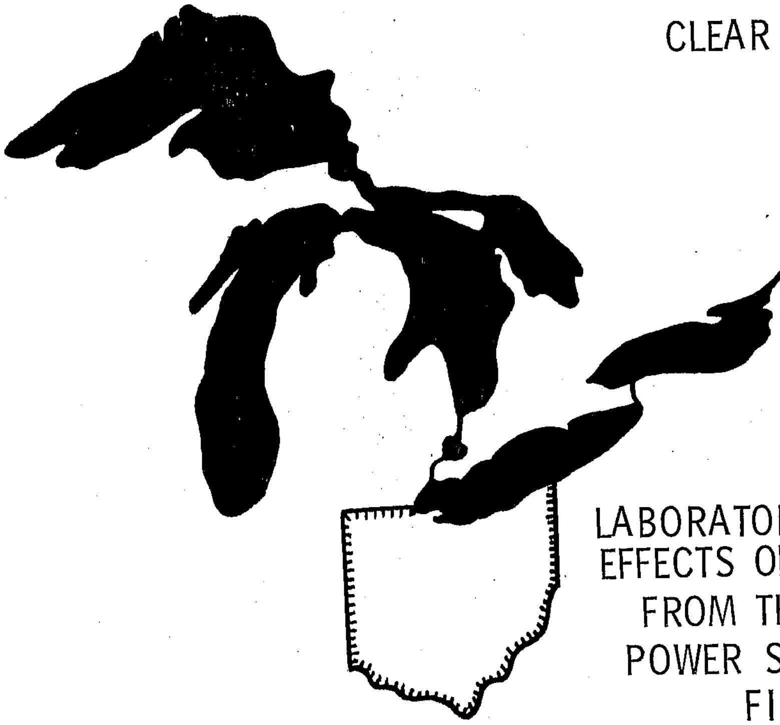

LABORATORY PREDICTIONS OF DIRECT EFFECTS OF THE THERMAL DISCHARGE FROM THE DAVIS-BESSE NUCLEAR POWER STATION ON THE LAKE ERIE FISHERIES RESOURCE

Prepared by

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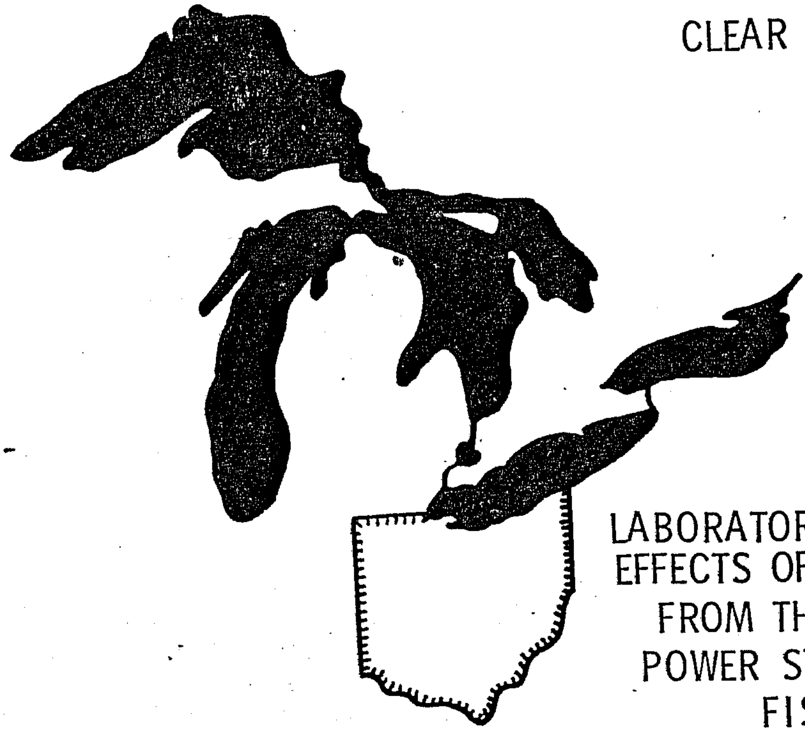

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ABSTRACT

Recent laboratory findings on the direct effects of the heated effluent from the Davis-Besse Nuclear Power Station on the Lake Erie fishery resource are discussed in this paper.

Assuming a plume of less than 1.6 hectares, a maximum temperature change of 11.1°C, and a flow rate of 200 cm/sec from the discharge, it does not appear that the heated effluent will cause large fish kills. Results indicate that fish should be attracted to the plume in the fall, winter, and spring. In summer, it appears that all fish will be repelled from the center of the plume, but some should be slightly attracted or indifferent to the periphery.

INTRODUCTION

Heated effluent (thermal pollution) flowing into our nation's waters has been a subject of great concern in recent years. It has been a source of discontent and fear often due to ignorance on the part of the public and sensationalism on the part of the news media. Granted, any change in the temperature of an ecosystem will cause ecological changes, but these changes need not be as detrimental as the public has been led to believe. Reduction and regulation of the amount of heat added and the manner in which it enters the water can reduce the potential dangers greatly. Add to this the fact that some areas are capable of dissipating a thermal discharge better than others, and one can see that the dangers can be minimized when handled intelligently.

The Toledo Edison Company and The Cleveland Electric Illuminating Company are currently building the Davis-Besse Nuclear Power Station on the south shore of Lake Erie at Locust Point (Fig. 1). This plant will use water from Lake Erie as cooling water, and then return the water to the lake at a maximum of 11.1°C above ambient lake temperature (U. S. Atomic Energy Commission, 1973). The area of the 0.56°C isotherm will be less than 1.6 hectares and the area of the 1.67°C isotherm will be approximately 0.3 hectares (U. S. Atomic Energy Commission, 1973). The effluent will be discharged at the lake bottom through a jet over a rockfill approximately 305 meters off shore. This water is reactor blow-down diluted with lake water to limit the temperature increase to 11.1°C above ambient. According to Eugene C. Novak, Chief Mechanical Engineer of Toledo Edison (personal communication, January, 1974), the discharge 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

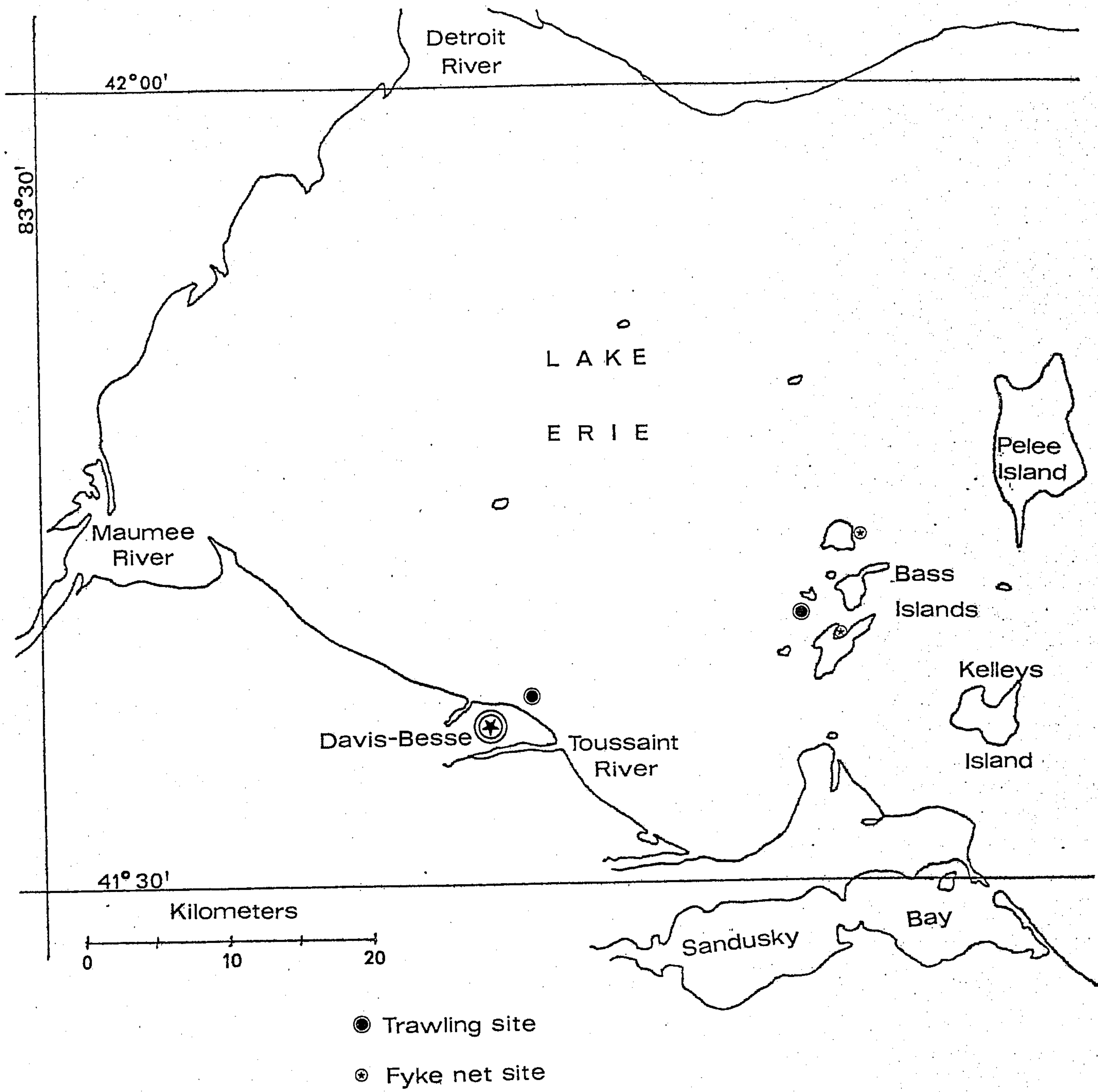

Figure 1. Western Lake Erie showing plant site and fish capture
capture locations.

41,800 l/min for the first unit.

Since June, 1971, 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 experiments to determine the effect of the thermal effluent from this plant on the Lake Erie fishery resource. The first year of this work was conducted by Barans and Tubb (1973) on *Micropterus d. dolomieui* (smallmouth bass), *Morone chrysops* (white bass), *Notropis atheriniodes* (emerald shiner), and *Perca flavescens* (yellow perch).

I have attempted to determine the temperature preferences and and predict the direct effects of sudden temperature changes on the fish of western Lake Erie. This paper briefly summarizes the results and discusses the direct effects of the thermal discharge at Locust Point. A paper containing a thorough test by test analysis of each species by size and season is planned for the future, but a paper which could clear up some of the controversy is essential at this time.

APPARATUS

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 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.

Sudden temperature change testing was done using two 190-l aquaria equipped with a Juno thermoregulator, ARC static switch relay, Vicore 500 watt heater, and 2 air stones.

PROCEDURE

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-l 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).

Preference Testing

In order to aquaint 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. (Recently some tests have been

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
Lepomis humilis	orangespotted sunfish
Micropterus d. dolomieui	smallmouth bass
Micropterus s. salmoides	largemouth bass
Pomosix annularis	white crappie
Pomoxis nigromaculatus	black crappie
Clupeidae	
Alosa pseudoharengus	alewife
Dorosoma cepedianum	gizzard shad

Cyprinidae	
Carassius auratus	goldfish
Cyprinus carpio	carp
Hybopsis storeriana	silver chub
Notropis a. atherinoides	emerald shiner
Notropis hudsonius	spottail shiner
Notropis spilopterus	spotfin shiner
Esocidae	
Esox lucius	northern pike
Ictaluridae	
Ictalurus nebulosus	brown bullhead
Ictalurus punctatus	channel catfish
Noturus flavus	stonecat madtom
Lepisteidae	
Lepisosteus osseus	longnose gar
Osmeridae	
Osmerus eperlanus mordax	American smelt
Percidae	
Perca flavescens	yellow perch
Percina caprodes	logperch darter
Stizostedion v. vitreum	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

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

done by starting the fish at a temperature 11.1°C above ambient lake temperature. From this a statistician hopes to predict rate of acclimation.) 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 Micropterus dolomieui (smallmouth bass) to 27 for Notropis altherinoides (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.

Sudden Temperature Change Testing

To determine the effect of a hot shock (swimming into the plume) fish were transferred from ambient lake temperature to the 190-l hot shock tank, which was maintained at 11.1°C above ambient, 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-l aquarium for at least 24 hours. They were then transferred to a 420-l holding tank at ambient lake temperature and observed.

RESULTS

Preference Testing

Preference data was obtained for twenty-four (24) of the forty (40) local species (Table 2). It is the aim of this paper to present a summary rather than a complete test by test breakdown. This information is available to the public at the Center for Lake Erie Area Research and in progress reports submitted to the Ohio Division of Wildlife and the U. S. Bureau of Sport Fisheries and Wildlife.

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,

Table 2

Mean temperature preference of Lake Erie fish species by season

Species Tested	Winter $\leq 5.5^{\circ}C$ No. Tested	Winter Pref $^{\circ}C$	Spring $5.5^{\circ}C$–$20.0^{\circ}C$ No. Tested	Spring Pref $^{\circ}C$	Summer $\geq 20.0^{\circ}C$ No. Tested	Summer Pref $^{\circ}C$	Fall $20.0^{\circ}C$–$5.5^{\circ}C$ No. Tested	Fall Pref $^{\circ}C$
Alosa pseudoharengus			11	21.2				
Ambloplites rupestris[a]					9	18.7	5	21.8
Aplodinotus grunniens					60	26.7	1	19.6
Carassius auratus	12	23.0			7	25.8	1	24.0
Carpiodes cyprinus							1	22.1
Catostomus commersoni							3	22.4
Cyprinus carpio			4	25.2	9	29.7		
Dorosoma cepedianum							24	22.3
Ictalurus natalis					22	28.3		
I. nebulosus			24	22.6	20	25.2	5	23.6
I. punctatus					134	25.2	30	24.4
Lepisosteus osseus					2	27.5		
Lepomis gibbosus			7	25.0	9	26.9		

(Table 2 continued)

Species Tested	Winter $\leq 5.5^{o}C$ No. Tested	Winter Pref ^{o}C	Spring $5.5^{o}C-20.0^{o}C$ No. Tested	Spring Pref ^{o}C	Summer $\geq 20.0^{o}C$ No. Tested	Summer Pref ^{o}C	Fall $20.0^{o}C-5.5^{o}C$ No. Tested	Fall Pref ^{o}C
L. macrochirus	20	27.4						
Micropterus d. dolomieui (YOY)[c]	13	18	4	19–24	19	31	2	24–27
M. d. dolomieui (AD)[c]	2	12–13	4	15–16	2	30	4	21–23
Morone chrysops					17	21.6		
M. chrysops (YOY)[c]	18	10–13	15	16–18	23	31	55	28
M. chrysops (AD)[c]	6	12–17	30	12–17	13	28–30	22	16–17
Notemigonus crysoleucas[a]	6	16.6	8	23.7	7	21.6	5	21.0
Notropis atheriniodes	35	9.3						
N. atheriniodes (YOY)[c]	89	10–12	52	13–15	95	22–23	76	13–14
N. atheriniodes (AD)[c]	40	5–6	40	16	27	22–24	33	15–17
N. hudsonius	15	10.2	27	14.2				
Noturus flavus	5	5.2[b]					13	25.1
Oncorhynchus kisutch			5	11.4				
Perca flavescens	33	13.8			61	21.0	21	19.9

(Table 2 continued)

Species Tested	Winter ≤5.5°C No. Tested	Winter Pref °C	Spring 5.5°C–20.0°C No. Tested	Spring Pref °C	Summer ≥20.0°C No. Tested	Summer Pref °C	Fall 20.0°C–5.5°C No. Tested	Fall Pref °C
P. flavescens (YOY)[c]	28	10–13	21	18	27	25–27	28	28
P. flavescens (AD)[c]	27	7–12	27	13–16	13	27	38	22–25
Pomoxis annularis	4	16.0	35	17.0	9	21.4		
P. nigromaculatus	20	19.3	55	21.0	49	21.4		

a Discrepancies that occur in this data are due to small sample sizes and tests run either in late spring or early fall when water temperatures are very close to 20.0°C.

b The reason for this extremely low value is undetermined.

c Barans and Tubb (1973).

AD = Adult

YOY = Young-of-the-year

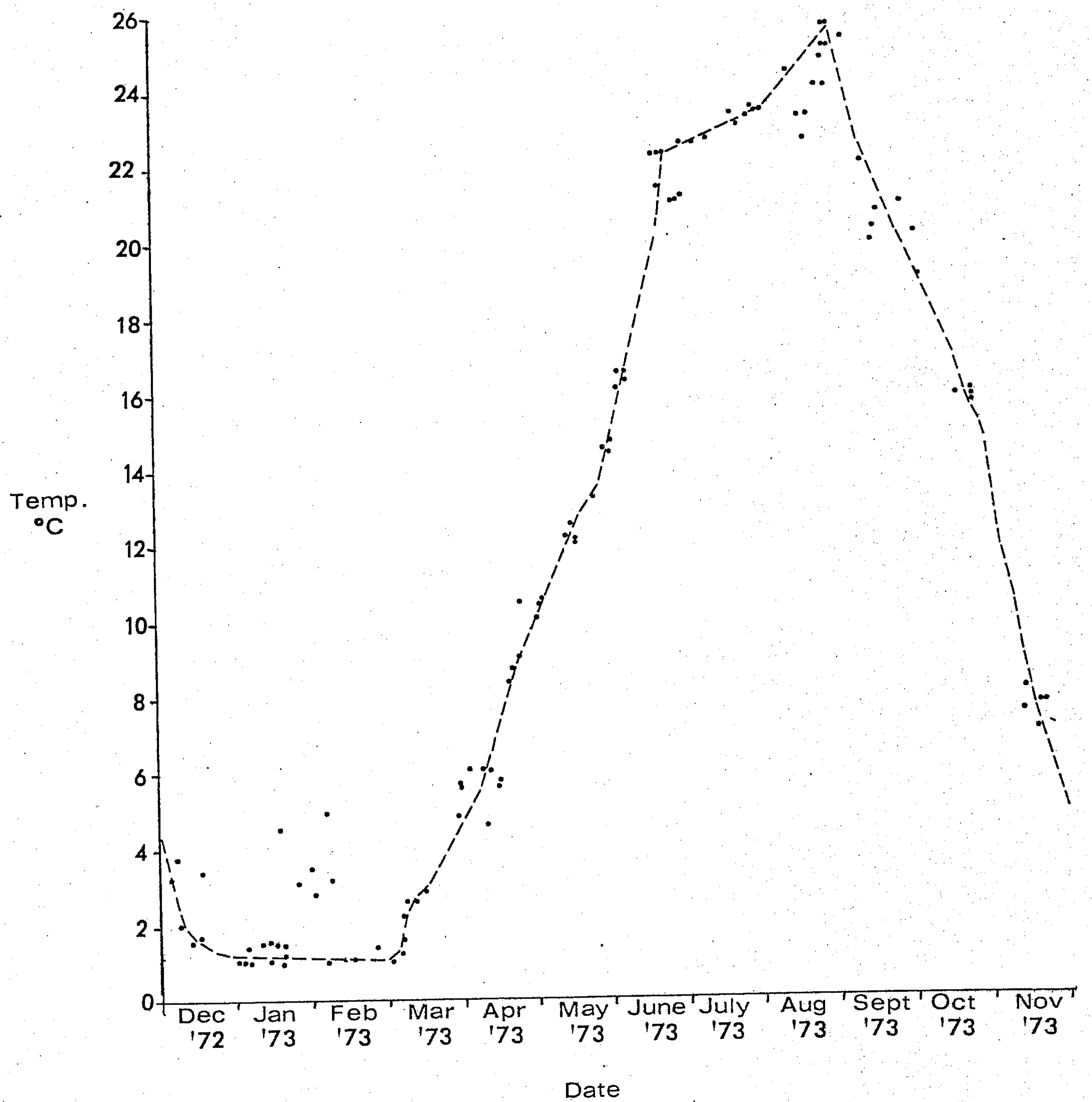

Figure 2. Ambient Lake Erie temperatures, December 1972 to November 1973, at Put-in-Bay, Ohio.

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.

All fish tested preferred temperatures of approximately ambient or above during all seasons. However, Barans and Tubb (1973) found that Notropis atheriniodes (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).

Sudden Temperature Change

One hundred forty-seven (147) hot shock tests on 440 fish of twenty-nine (29) species and one cross (Cyprinus carpio × Carassius auratus) were conducted (Table 3). Data on individual tests and test specimens are available from the previously mentioned sources.

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

Table 3

Highest observed C.T.M. of species tested in hot shock

Species	C.T.M. (summer or highest observed) C	Ambient Temp. C	Season of observation
Alosa pseudoharengus	28.3	16.4	spring
Ambloplites rupestris	31.2	14.6	spring
Amia calva	>29.0 but <35.5	24.4	summer
Aplodinotus grunniens	34.0	21.2	summer
Carassius auratus	>34.3	25.6	summer
Carpiodes cyprinus	37.2	23.3	summer
Catostomus c. commersoni	>29.9	14.3	fall
Cyprinus carpio × *Carassius auratus*	25.3	9.3	fall
Cyprinus carpio	39.0	23.3	summer
Dorosoma cepedianum	31.7	15.9	fall
Ictalurus natalis	35.0	19.7	fall
I. nebulosus	37.1	23.5	summer
I. punctatus	36.5	22.7	summer
Icthyomyzon unicuspis	31.6	4.5	winter
Lepomis gibbosus	34.2	21.0	summer
L. humilis	26.0	5.6	spring
L. macrochirus	36.0	22.5	summer
Micropterus d. dolomieui	>32.2 but <35.2	23.1	summer

Table 3 continued

Species	C.T.M. (summer or highest observed) C	Ambient Temp. C	Season of observation
Morone chrysops	> 34.4 but < 36.0	23.3	summer
Notemigonus crysoleucas	30.5	14.4	spring
N. atheriniodes	27.1	10.5	spring
N. hudsonius	27.9	10.0	spring
Noturus flavus	29.0	1.6	winter
Osmerus eperlanus	24.9	6.0	spring
Perca flavescens	33.5	23.0	summer
Percopsis omiscomaycus	22.9	1.7	winter
Pimephales notatus	27.8	6.0	spring
Pomoxis annularis	> 30.3 but < 35.5	24.4	summer
P. nigromaculatus	> 30.0 but < 34.5	23.5	summer
Stizostedion v. vitreum	> 34.4	23.3	summer

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 alewife 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 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.

Forty-two (42) cold shock tests on 223 fish of sixteen (16) species were conducted. No fish died due to a cold shock during any season except winter.

DISCUSSION

Results indicated that the temperatures in the plume would attract all species tested during fall, winter, and spring. Actual location of fish in the plume was difficult to determine for although they could be attracted to the hottest point in the plume, the velocity of the discharge would undoubtedly keep many from reaching this area. It can be assumed that this attraction would be greatest when the difference between the temperature preference and ambient lake temperature is greatest--winter. Therefore, fishing success should be found in and around the plume during fall, winter, and spring when attraction should be quite strong.

All fish species tested to date would be repelled by the hottest water during the summer, but could be attracted to the plume periphery. Again, since the difference between temperature preference and ambient lake temperature appeared small, this summer attraction should not be as great as the winter attraction. 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. Gammon (1971) also found *Dorosoma cepedianum* (gizzard shad) to be common plume dwellers as long as the temperature was below $34^{o}C$. If this be the case, they would be common in the Davis-Besse plume, also.

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

The danger due to hot shock should be minimal for the following reasons: temperature preference results indicated fish would avoid the area, thus making the only fish affected 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 a fish which was drawn into the plume and lost swimming ability would be carried to safer waters where results indicated approximately 92% would recover. The lower initial velocity of 113 cm/sec should also be sufficient to accomplish this.

Cold shock hazards could occur when a fish acclimated to the warm water of the plume swam out of the plume into ambient temperature water or if the plant would 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 delayed.

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. The Toledo Edison Company was informed of this, and, if problems occur, it would appear quite simple, according to plant specifications, to increase the amount of dilution water thereby increasing the discharge velocity. This would have to be monitored 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 would have to 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 it is known that acclimation to warm water is faster than acclimation to cold water, and loss of acclimation to warm water is slower than to cold (Ericksen-Jones, 1964).) It now becomes evident why 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 would extend out 61 m in front of the discharge. This was not expected to be a significant factor.

These results were mainly from adult fish. No fish larvae were tested since fry and fingerlings have generally been used for much of the laboratory work in fisheries because of their size, and the discharge area was not a spawning area. The Ohio State University had taken monthly benthos samples in the immediate vicinity of the intake and discharge during spring, summer, and fall since 1969, and very few fish eggs were found. In spite of this, a very close monitoring program was recommended since the discharge was less than 6.5 km from the nearest spawning reef.

This paper focused only on the direct effects of the discharge of heat from the point of view of an autecologist. Indirect effects such as fungal infections, early spawning, lactic acid increase due to fatigue, etc., were difficult to predict and would have to be studied in the monitoring program. No attempt was made here to evaluate dangers associated with the intake structure, chlorination, or radiation. Additional testing is progressing on species not yet tested and to substantiate results.

CONCLUSIONS

Fish should be attracted to the thermal plume from the Davis-Besse Nuclear Power Station in fall, winter, and spring. Their exact location in the plume would depend on their swimming speed and temperature preference. In summer fish should be repelled by the hottest section of the plume and slightly attracted or indifferent to the periphery.

The plume should not be a "death trap" for Lake Erie fish due to the heated discharge as long as high discharge velocities were maintained. The most delicate species and therefore the most likely to be harmed by the thermal discharge were *Alosa pseudoharengus* (alewife), *Aplodinotus grunniens* (freshwater drum), and *Dorosoma cepedianum* (gizzard shad).

It was not the intention of this paper to infer that the entire power plant operation would not cause harm, but rather that any harm from the heated effluent should be minimal.

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