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Project Summary

Reproduction and Distribution of Fishes in a Cooling Lake: Wisconsin Power Plant Impact Study

Dennis W. Rondorf and James F. Kitchell

Spatial and temporal patterns during reproduction and early life history of fishes were studied in a manmade cooling lake. Lake Columbia, impounded in 1974, near Portage, Wisconsin, has an area of 190 ha, a mean depth of 2.1 m, and a 15°C temperature gradient derived from the thermal effluent of a 527-MW fossil-fueled generating station which began operation in 1975.

The lake was initially colonized by fishes when filled with Wisconsin River water. Observations suggested a decline of species diversity of the fish community due to: (1) direct action of upper lethal temperatures, (2) absence of colonization by warm-water, lake-dwelling species, and (3) lack of recruitment for certain species.

Spatial and temporal patterns of spawning of black crappie (*Pomoxis nigromaculatus*) were altered by a rapid rise in water temperatures following plant startup after a 3-week shutdown. Water temperatures above expected spawning temperatures reduced available spawning area and induced aggregation of sexually mature black crappie at coolest available temperatures. Elevated temperatures subsequently shortened the spawning season, induced resorption of ova, and caused loss of secondary sexual characteristics.

A second generating unit began operation in February 1978. Spawning of black crappie and white bass (*Morone chrysops*) occurred 1 month earlier during the spring of 1978 than in 1977.

Species abundance of larval fish catches was greater in 1978 when the spawning season was not unusually abbreviated, as in 1977. After initially drifting with water current, juvenile stages of sunfish (*Lepomis* sp.) and gizzard shad (*Dorosoma cepedianum*) responded to changes in the thermal gradient by horizontal and vertical shifts in abundance.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Impoundment of a man-made cooling lake provides an opportunity for development of a recreational fishery. Thermally elevated areas of a cooling lake can increase angler use in temperate climates (McNurney *et al.* 1977). Because the cooling lake is a relatively small man-made system, it has greater potential and flexibility for recreational fishery management than many systems.

Fish management strategies of stocking or fish harvest for temperate lakes based on surface area of morphoedaphic characteristics are not valid for lakes substantially altered by thermal input. The elevated thermal conditions of cooling lakes create temporal and spatial limitations of organisms native to nearby lakes. Growth (Bennett and Gibbons 1974), distribution (Merriman and Thorpe 1976), and reproduction (Bennett and Gibbons 1975, Kaya 1977) are modified in thermally altered areas. Lake Columbia, located at the Columbia Generating Station near Portage, Wisconsin, provided an opportunity for research and development of management strategies specifically for cooling lakes in the Great Lakes region.

As a subproject of an assessment of a developing cooling lake ecosystem (Lozano *et al.* 1978), this study of fishes concerned the reproductive responses of adults and distributional patterns of adult, larval, and early juvenile forms in Lake Columbia. The objectives were (1) determine changes in species composition of the fish population; (2) delineate temporal and spatial limits of fish reproduction; and (3) determine distributional patterns of larval and early juvenile fishes.

Relative Abundance of Fishes

New impoundments are known for the dramatic changes they cause in fish communities after filling. Studies suggest these changes can be attributed to changes of biotic and abiotic characteristics of the impoundment (Jenkins and Morais 1971). In the cooling lake environment, the effects of the unique thermal regime are imposed on these expected changes in the fish community. Therefore, the first objective was to determine if changes in species composition of the fish population occurred with time.

Methods

Composition of the fish community and the relative abundance of adults at locations in Lake Columbia were assessed using fyke nets. Netted fish were identified, measured for total length, and weighed. Water temperatures were measured at 0.5, 1.0, 1.5, and 2.0-m depths when nets were set and raised. Diel temperature changes were continually monitored with recording thermographs.

The number of fish per fyke net set—catch per effort (CPE)—was used as a measure of the relative abundance of fish species over time. Species diversity of the fish population in quarterly fyke net catches was calculated using the Shannon and Weaver (1963) general index of diversity ($\bar{H}$).

Results

The Shannon-Weaver diversity index suggested a decline in diversity of quarterly catches that began in the winter of 1975-76 and continued through the fall of 1976 (Figure 1). In fall 1976 only 34% of the catch was similar to that of the summer quarter 1975. Species diversity did not return to 1975 levels (Figure 2).

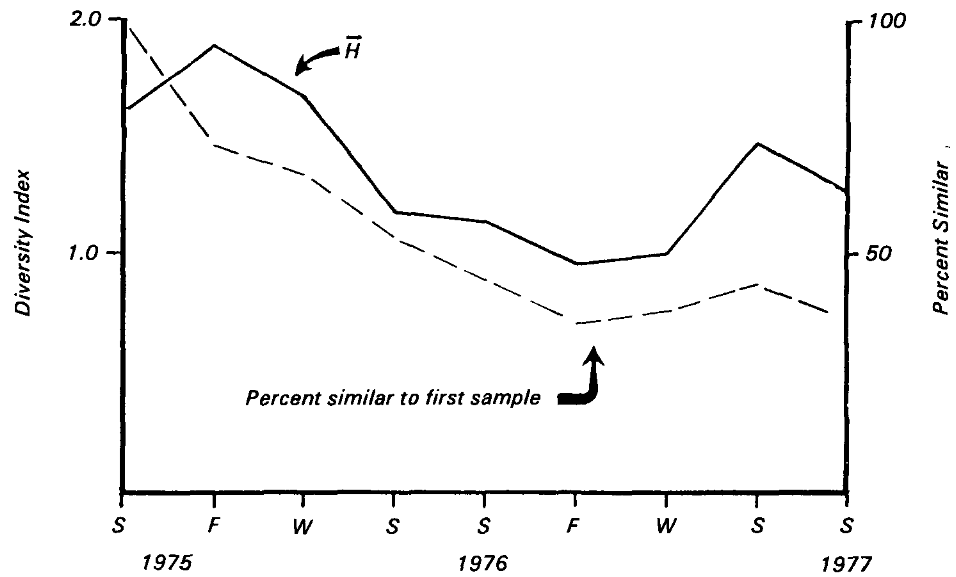

Figure 1. *Shannon-Weaver diversity index ($\bar{H}$) and percent similarity to first sample of quarterly fyke net catches in Lake Columbia.*

Changes in the diversity of fyke net catches were attributed to a decline of CPE for some species and numerical dominance by others. The mean quarterly CPE of centrarchids in Lake Columbia (Figure 2A) indicated that the abundance of pumpkinseed sunfish (*Lepomis gibbosus*) declined somewhat between July 1975 and August 1977. The mean CPE for white bass (*Morone chrysops*) (Figure 2B) was high in the winter quarter samples. Bluegill (*Lepomis macrochirus*) catches increased dramatically, while gizzard shad (*Dorosoma cepedianum*) CPE increased from none caught during the first quarter to a CEP >5 in 1977 (Figure 2B). Bluegill and gizzard shad length frequencies indicated successful growth and reproduciton in the new lake environment, as evidenced by increased CPE.

Other fish species common to the Wisconsin River were collected in Lake Columbia. The relationship between changes in relative abundance, final temperature preferenda, and upper incipient lethal temperatures of the most abundant species in fyke net catches is shown in Figure 3. Yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*) made up <0.5% of all catches. Species at low abundance that decreased in CPE included quillback (*Carpoides cyprinus*), smallmouth buffalo (*Ictiobus bubalus*), and carp (*Cyprinus carpio*) (Figures 2C, 3). Minnow trap catches indicated fathead minnows (*Pimephales promelas*) and mud minnows (*Umbra limi*) were abundant when the plant began

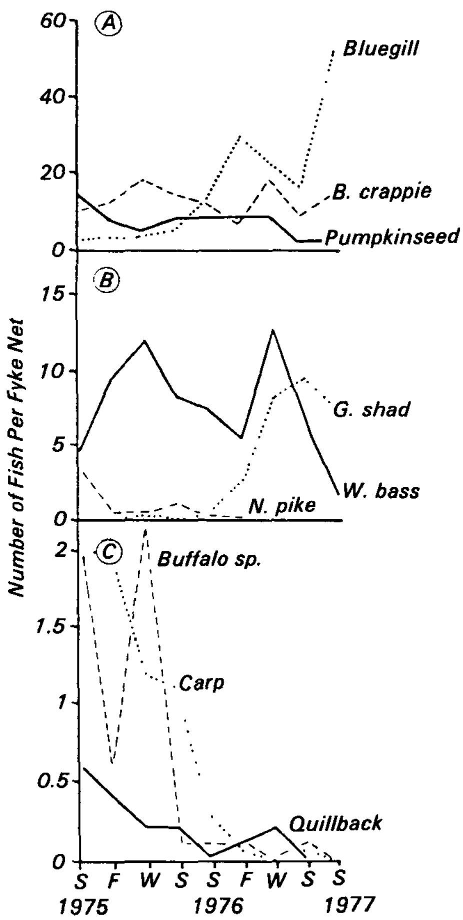

Figure 2. *Mean catch per effort in fyke nets during quarterly sampling periods in Lake Columbia.*

operation in March 1975, but abundance declined by July. The mean quarterly CPE of northern pike declined 99% between the first and third year of the study and disappeared from catches during the summer quarter of 1976 (Figure 2B). Bluegill abundance increased more than eight-fold between the first and third years (Figure 3). This species was well adapted for the cooling lake environment because of its relatively high thermal preference, ability to forage in open water, and the presence of suitable spawning habitat.

Reproduction of Fishes

Thermal requirements for reproduction of a species are one of the primary limits to distribution and abundance (Alderdice and Forrester 1968, Hokanson 1977). Temperature and photoperiod are environmental factors important in the recrudesence of gametogensis of many teleosts (De Vlaming 1972, 1974, Schreck 1974, Hokanson 1977). The unique thermal regimes in the cooling lakes create temperatures during winter and early spring at or above those associated with the initiation of spring spawning. The thermal gradient was expected to determine the spatial and temporal location of spawning within limits of photoperiod control. Thus, the second objective was to study the temporal and spatial limits of reproduction within Lake Columbia.

Methods

White bass and black crappie were selected for study because adults were growing well but did not appear to be producing young.

Temporal patterns of reproduction were determined by monitoring the maturity of white bass and black crappie from the initiation to the completion of spawning during the springs of 1977 and 1978. The percent gonad weight of total body weight or gonadosomatic index was calculated as a measure of maturity at 2-week intervals starting in February 1977.

Spatial limitations of spawning relative to the thermal gradient were examined during the springs of 1977 and 1978. Relative abundance of sexually mature fish at varous locations in Lake Columbia was determined by fyke net sampling and regression analysis methods (Rondorf and Kitchell, 1983). Thermal exposure of adult black crappie was estimated from equations describing distribution of adults and the thermal gradient.

Results

A rapid rise in water temperatures following a 3-week power plant shutdown during 1977 stimulated spawning, reduced available spawning area, and induced aggregation of black crappie at coolest available water temperatures. Elevated water temperatures subsequently induced resorption of black crappie ova, loss of secondary sexual characteristics, and were probably near upper lethal temperatures of embryo and larval stages. A temporally shortened spawning season was associated with a rapid rise in water temperatures, while additional thermal input by the Columbia II generating unit caused spawning to occur 30 days earlier in the spring.

Distribution of Larval Fishes

Larvae of many spring spawning fishes initially disperse into limnetic waters (Faber 1967, Werner 1969, Netsch *et al.* 1971, Amundrud *et al.* 1974, Kelso and Ward 1977) and later aggregate as juveniles in littoral areas that have higher water temperatures. Juvenile fishes exhibit thermoregulatory behavior in the laboratory (Cherry *et al.* 1977) and after reviewing temperature preference data

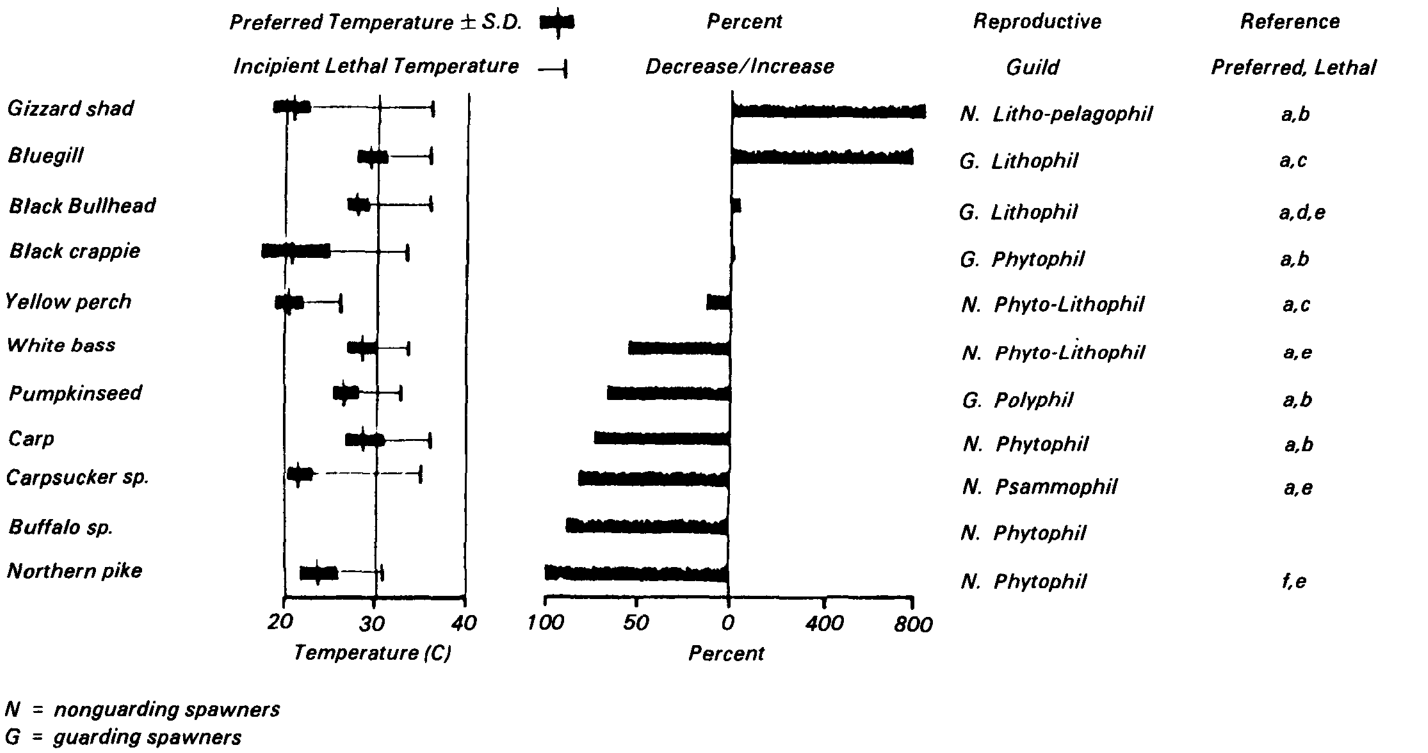

Figure 3. *Percent increase or decrease in abundance of selected fishes in Lake Columbia. Preferred and upper incipient lethal temperatures of fish are from other sources ([a]Reutter and Herdendorf 1974; [b]Brungs and Jones 1977; [c]Cherry et al. 1977; [d]Hart 1952; [e]Cvancara et al. 1977; [f]Coutant 1977).*

of fish, Coutant (1977) concluded that laboratory and field results were reasonably consistent. During the development of thermoregulatory behavior, increasing mobility probably facilitates the ability of individual juveniles to thermoregulate. However, little is known about the thermal responsiveness of pelagic larvae and early juveniles of fish when distributed in the limnetic zone. Therefore, an objective of this study was to describe distributional responses of pelagic larvae and juvenile fish to changes in the thermal gradient. Certain abiotic factors—i.e., temperature—are correlated with year-class strength of some fish populations (Kramer and Smith 1962, Koonce *et al.* 1977).

Methods

Gizzard shad and bluegill, two species whose populations increased in the cooling lake, were studied to determine how the larval forms responded to the dynamic heterothermal environment of the cooling lake. Additional observations were designed to investigate factors affecting the relative abundance of larval fish. Time of capture, depth of capture, station location, and diel movement patterns were examined.

Tows to assess horizontal distribution patterns were made at a depth of 0.5 m between 1900 and 2400 h central standard time (CST). Clear plexiglass traps equipped with lights were used to collect larval fish. Larval and juvenile fish were preserved in the field then counted and identified in the laboratory.

Data were analyzed using mathematical methods to describe horizontal distribution patterns.

Results

Species diversity of larval fish catches was low in 1977 when water temperatures increased rapidly. The median temperature of capture of larval *Lepomis* sp. and gizzard shad was near 30°C. Temperatures >31°C during thermal stratification reduced the abundance of gizzard shad completing diel vertical movements. After initially drifing with the current, *Lepomis* sp. and gizzard shad responded to water temperature changes by horizontal shifts in abundance with a mode at 28° to 31°C.

Conclusions

Observations suggest that the species diversity of fish in Lake Columbia, Wisconsin, declined during the first year of thermal input by the plant. Habitat modification, such as reduced vegetation as a direct result of thermal input, may be the reason for the decrease in abundance of some species. The decline in species diversity was accentuated by fish mortality from temperatures exceeding upper lethal limits, an absence of colonization of warm-water lake-dwelling species, and limited reproductive success.

Thermal inputs by the power plant modified temporal and spatial characteristics of spawning white bass and black crappie. Resumption of plant operation following a 3-week shutdown resulted in a rapid increase in water temperatures that stimulated spawning, reduced available spawning area, and induced aggregation of sexually mature black crappie at coolest available water temperatures. Water temperatures above expected spawning temperatures induced partial resorption of ovaries, loss of secondary sexual characteristics, and abbreviation of spawning duration. The combined operation of the Columbia I and II generating units induced spawning about 1 month earlier than when only Columbia I was operating.

The rapid increase in water temperatures that induced spawning and subsequent gonadal resorption in 1977 was associated with a lower number of species of larval fishes. If a number of species were stimulated to spawn, then a greater number of ichthyoplankton species would be expected at that time, but this was not observed. Therefore, factors associated with the increase in temperatures must have been responsible for reducing ichthyoplankton species abundance. The number of species of larval fishes was lower during 1977 when water temperatures increased rapidly and reproductive responses were aberrant. This may explain the limited reproductive success observed for some species successful as adults in the cooling lake environment.

Larval and early juvenile stages of bluegill and gizzard shad were responsive to temperature changes within the thermal gradient. Larval forms initially drifted downstream. Pelagic larval and juvenile stages of bluegill and gizzard shad were most abundant at 28° to 31°C and were capable of responding to changes in the thermal gradient induced by changing air temperatures. Larval gizzard shad exhibited reduced diel vertical movements when temperatures were >31°C. Pelagic larval and early juvenile forms responded to thermal dynamics of the cooling lake by modifying horizontal and vertical distribution patterns.

Recommendations

1. The disappearance of aquatic vegetation should be expected in cooling lakes with heavy thermal loading. Management to enhance fish populations of species that require vegetation to spawn should not be attempted.
2. Initiation of spawning was approximately 1 month earlier with the thermal input of two 527-MW generating units. If fishery management agencies protect spawning adult fish during spring by closed season, the regulations may not be applicable to cooling lake fisheries. The accelerating of spawning during spring can provide the opportunity to open a fishery while other temperate lake fisheries are closed during normal reproductive season.
3. Power plant shutdowns are often scheduled during spring but rapid temperature increases when plants resume operation can cause aberrant reproductive responses in spring-spawning fish. The operation and more than one generating unit may be beneficial because additional units buffer the effects of rapid changes in temperature of a single unit.
4. Successful reproduction of fish in a cooling lake is spatially limited to water temperatures within the thermal tolerance limits of reproduction. Cooling lake water temperatures and corresponding areas can be estimated during planning. Design should provide adequate area with water temperatures within the thermal tolerance limits of oogenesis, spawning, and incubation during spring.
5. Pelagic larval stages drift downstream in a recirculating cooling lake and will subsequently be entrained by the power plant if cooling lake turnover time is not adequate to permit metamorphosis into the more mobile early juvenile stages. Entrainment should be accepted as a part of the cooling lake environment, however, careful design can minimize entrainment of larval and early juvenile stages. Additional generating units should be augmented by increasing cooling lake area and volume or by providing cooling towers to increase lake turnover time.

6. Early juvenile fish in pelagic stages are mobile and respond to thermal gradients and water currents by congregating in preferred habitats. Cooling lake design can increase juvenile nursery areas and species diversity by providing heterogeneous habitats with a diversity of water depths, substrates, and shoreline configurations. These design modifications would not inhibit the cooling capacity of the lake because cooling is most dependent on surface area.
7. After power plant operation began, species diversity declined as a few eurythermal species incresed in abundance and other species declined. Sport fish should be stocked early in the operation of the lake so that juveniles can utilize forage species likely to become abundant after the power plant begins operation. Thermally tolerant nest-guarding Centrarchids and Ictalurids, such as largemouth bass and channel catfish, are likely to be the most successful native species in cooling lakes and should be preferred for initial stocking.
8. After the power plant begins operation, water temperatures of the cooling lake may exceed the upper lethal limits of popular cool water sport fish resulting in fish kills. Design can create thermal refugia using water depth and circulation patterns. Fishery managers and the public should anticipate fish kills as a part of starting the long-term management of a cooling lake, but recurrent fish kills can be avoided through careful design.
9. Largemouth bass, a species susceptible to over-harvest, was caught at the highest rate by angling near the outfall in winter (0.28 bass/cast) and in cool water near the intake in late spring (0.27 bass/cast: Lozano *et al.* 1978). Thus, the area near the intake nad outfall should be permanently closed to fishing to protect summer and winter aggregations of fish under seasonally extreme thermal conditions.
10. Small reservoirs are often subject to over-exploitation of sport fish populations, particularly when fish are spatially limited by temperature or lake morphometry. Thus, when power plant security is designed, consideration should be given to minimize over-harvest of fish in outfall and intake areas and reduce potential conflicts between power plant security and fisherman.

References

Alderdice, D. F., and C. R. Forrester. 1968. Some effects of salinity and temperature on early development and survival of the English sole (*Parophrys vetulus*). J. Fish Res. Bd. Can. 13:799-841.

Amundrud, J. R., D. J. Faber, and A. Keast. 1974. Seasonal succession of freeswimming perciform larvae in Lake Opinion, Ontario. J. Fish Res. Bd. Can. 31:1661-1665.

Balon, E. K. 1975. Reproductive guilds of fishes: A proposal and definition. J. Fish. Res. Bd. Can. 32:821-864.

Bennett, D. H., and J. W. Gibbons. 1974. Growth and condition of juvenile largemouth bass from a reservoir receiving thermal effluent. In: J. W. Gibbons and R. R. Sharitz (eds.) Thermal ecology. AEC Symposium Series, CONF-730505, NTIS. National Technical Information Service, Springfield, Virginia. p. 246-254.

Bennett, D. H., and J. W. Gibbons. 1975. Reproductive cycles of largemouth bass (*Micropterus salmoides*) in a cooling reservoir. Trans. Am. Fish. Soc. 104:77-82.

Brungs, W. A. and B. R. Jones. 1977. Temperature criteria for freshwater fish: Protocol and procedures. EPA-600/3-77-061. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Cherry, D. S., K. L. Dickson, and J. Cairns, Jr. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. J. Fish. Res. Bd. Can. 34:239-246.

Coutant, C. C. 1977. Compilation of temperature preference data. J. Fish. Res. Bd. Can. 34:739-745.

Cvancara, V. A. S. F. Steiber, and B. A. Cvancara. 1977. Summer temperature tolerance of selected species of Mississippi River acclimated young of the year fishes. Comp. Biochem. Physiol. 56A:81-85.

De Vlaming, V. L. 1972. Environmental control of teleost reproductive cycles: A brief review. J. Fish. Biol. 4:131-140.

De Vlaming, V. L. 1974. Environmental and endocrine control of teleost reproduction. In: C. B. Schreck (ed.) Control of sex in fishes. COM-75-10484, NTIS. National Technical Information Service, Springfield, Virginia. p. 13-83.

Faber, D. J. 1967. Limnetic larval fish in northern Wisconsin lakes. J. Fish. Res. Bd. Can. 24:927-937.

Hart, J. S. 1952. Geographic variations of some physiological and morphological characters in certain freshwater fish. University of Toronto Biology Series No. 60. University of Toronto Press, Toronto, Canada. 79 pp.

Hokanson, K. E. F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Bd. Can. 34:1524-1550.

Jenkins, R. M., and D. I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. In: G. E. Hall (ed.) Reservoir fisheries and limnology. Special Publication No. 8. American Fisheries Society, Bethesda, Maryland. p. 371-384.

Kaya, C. M. 1977. Reproductive biology of rainbow and brown trout in a geothermally heated stream: The Firehole River of Yellowstone National Park. Trans. Am. Fish. Soc. 106:354-361.

Kelso, J. R. M., and F. J. Ward. 1977. Unexploited percid populations of West Blue Lake, Manitoba, and their interactions. J. Fish. Res. Bd. Can. 34:1655-1669.

Koonce, J. F., T. B. Bagenal, R. F. Carline, K. E. F. Hokanson, and M. Nagiec. 1977. Factors influencing year-class strength of percids: A summary and a model of temperature effects. J. Fish. Res. Bd. Can. 34:1900-1909.

Kramer, R. H., and L. L. Smith, Jr. 1962. Formation of year classes in largemouth bass. Trans. Am. Fish. Soc. 91:29-41.

Lozano, S. J., D. W. Rondorf, and J. F. Kitchell. 1978. Assessment of a cooling lake ecosystem. Tech. Rept. WIS-WRC-78-08. Water Resources Center, University of Wisconsin, Madison, Wisconsin. 108 pp.

McNurney, J. M., H. M. Dreier, and M. A. Frakes. 1977. Analysis of sport fishing in a reservoir receiving a thermal effluent. 39th Midwest Fish and Wildlife Conference, Madison, Wisconsin.

Merriman, D., and L. M. Thorpe (eds.). 1976. The Connecticut River ecological study. Monograph No. 1. American Fisheries Society, Bethesda, Maryland. 252 pp.

Netsch, N. F., G. M. Kersh, Jr., A. Houser, and R. V. Kilambi. 1971. Distribution of young gizzard and threadfin shad in Beaver Reservoir. In: G. E. Hall (ed.) Reservoir fisheries and limnology. Special Publication No. 8. American Fisheries Society, Bethesda, Maryland. p. 95-105.

Reutter, J. M., and C. E. Herdendorf. 1974. Laboratory estimates of the seasonal final temperature preferenda of some Lake Erie fish. 17th Conf. Great Lakes Res. 1974:59-67.

Rondorf, D. W., and J. F. Kitchell. 1983. Reproduction and distribution of fishes in a cooling lake. Wisconsin Power Plant Impact Study. U.S. Environmental Protection Agency, Duluth, Minnesota. 58 p.

Schreck, C. B. (ed.). 1974. Control of sex in fishes. COM-75-10484, NTIS. National Technical Information Service, Springfield, Virginia. 106 pp.

Shannon, C. E., and W. Weaver. 1963. The mathematical theory of communication. University of Illinois Press, Urbana, Illinois. 117 pp.

Werner, R. G. 1969. Ecology of limnetic bluegill (*Lepomis macrochirus*) fry in Crane Lake, Indiana. Am. Midl. Nat. 81:164-181.

Dennis W. Rondorf and James F. Kitchell are with Water Resources Center, University of Wisconsin-Madison, Madison, WI 53706.

***Gary E. Glass** is the EPA Project Officer (see below).*

The complete report, entitled "Reproduction and Distribution of Fishes in a Cooling Lake: Wisconsin Power Plant Impact Study," (Order No. PB 85-217 669/AS; Cost: $10.00, subject to change) will be available only from:

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