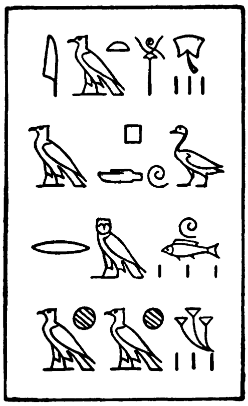
WILDLIFE MONOGRAPHS

A Publication of The Wildlife Society

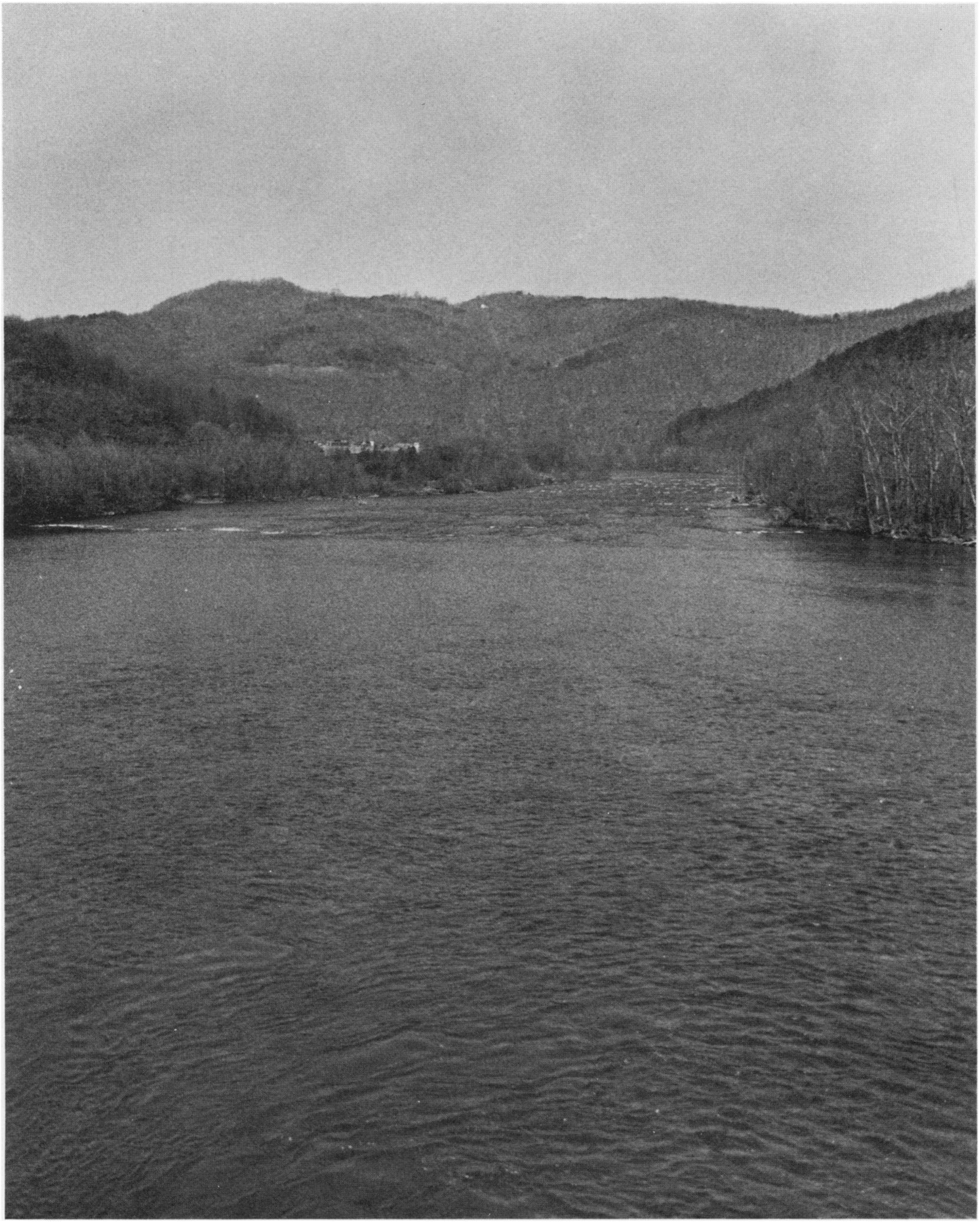


THE POTENTIAL AND REALIZED INFLUENCES OF TEMPERATURE ON THE DISTRIBUTION OF FISHES IN THE NEW RIVER, GLEN LYN, VIRGINIA

by

JAY R. STAUFFER, JR., KENNETH L. DICKSON,
JOHN CAIRNS, JR., AND DONALD S. CHERRY

NOVEMBER 1976 NO. 50



Frontispiece. The New River at Glen Lyn, Virginia.

THE POTENTIAL AND REALIZED INFLUENCES OF TEMPERATURE ON THE DISTRIBUTION OF FISHES IN THE NEW RIVER, GLEN LYN, VIRGINIA

Jay R. Stauffer, Jr.,[1] *Kenneth L. Dickson, John Cairns, Jr.,*
and Donald S. Cherry
Center for Environmental Studies, Virginia Polytechnic Institute and State University,
Blacksburg, Virginia 24061

CONTENTS

FOREWORD 6
INTRODUCTION 6
ACKNOWLEDGMENTS 8
DESCRIPTION OF STUDY AREA 8
METHODS AND MATERIALS 9
Laboratory Responses 11
RESULTS 12
Annotated List of Species 14
DISCUSSION 34
SUMMARY 36
LITERATURE CITED 37

---

[1] Present address: University of Maryland, Center for Environmental and Estuarine Studies, Appalachian Environmental Laboratory, Frostburg State College Campus, Gunter Hall, Frostburg, Maryland 21532.

FOREWORD

For many decades, ecologists have been applying their talents and energies to developing significant and comprehensive data about the environment. Yet, until recently, their findings have been little noted outside the academic community.

Only within the past 10 years have government officials, industrialists, and the general public begun to appreciate the transcendent importance of what ecologists have discovered. So long ignored, these scientists are now sought out by a society which requires more and more data about a broad variety of environmental subjects. The quest for information about ecological problems has created a demand for site specific studies and for research on individual factors which threaten ecosystems.

Without reasoned and responsible guidance of ecologists, a climate of bewilderment and antagonism would prevail. The attitude of many industrial and commercial leaders toward the environment is permissive, founded on self-interest and profit motives. Conversely, the overly protective attitude of a large segment of the lay public threatens to strangle the necessary expansion of the vigorous, modern culture. One side holds that the cost of protecting the environment is too high, the other that it isn't high enough.

To resolve the dilemma, both sides must turn for facts to the environmental scientist. His information is crucial. In the final analysis, sound management decisions and environmental policy must be based on data that are species specific, site specific, and factor specific.

This monograph deals with one fundamental parameter of aquatic ecosystems: temperature. Without dispute, temperature is a primary determinant of the kinds and abundance of vegetational and animal life in our streams and rivers. None of our culture's manifold activities modifies the temperature of the nation's waterways so much as electric generating plants. Because of the world's thirst for ever greater quantities of power, the effects of the electric industry on the aquatic ecosystem is a concern of the highest priority.

The authors of this monograph have succeeded admirably in their goal of assembling as much as possible of the extant information about the temperature preference and avoidance of fishes in the New River and its tributaries. Such data are invaluable for extending the knowledge of the effects of temperature in waterways, and should further serve as a reference source for future recommendations about temperature alterations of America's major river systems.

Joseph A. Chapman, Head,
Appalachian Environmental Laboratory
Center for Environmental and Estuarine Studies,
University of Maryland

INTRODUCTION

Temperature is one of the most important environmental parameters which affects the biota of an aquatic system. Fry (1947) proposed 6 categories through which an environmental factor can affect an organism: (1) lethal factors which "destroy the integration of an organism," (2) masking factors which "prevent a second identity from operating on the organism to the extent that it would if the masking factor were not present," (3) directive factors which "require a response on the part of the organism directed in some relation to a gradient of the factor," (4) controlling factors which "govern the metabolic rate by operating in the internal medium which is the actual site of metabolism," (5) limiting factors which "govern the metabolic rate by virtue of their operation within the metabolic chain," and (6) accessory factors which "impose a metabolic load upon the organism in excess of the rate to which the organism is confined by the factor which is governing the overall metabolic rate."

The electric generating industry is the most important artificial factor which influences the temperature of our waterways.

The electric utilities presently use 70–80 percent of all water taken by industry for cooling purposes (Berkowitz and Squires 1969, Parker and Krenkel 1969). Clark (1969) hypothesized that within 30 years approximately one-third of the average freshwater runoff in the United States would be required for once-through cooling. Mihursky and Corey (1965) demonstrated that over 100 percent of flows in certain watersheds in the Northeast already are used for once-through cooling, under low-flow conditions (cited in: Carlson unpublished report Cornell University). The concern about heated water discharges from electric utilities is further intensified because the electric power demand in the United States has been doubling every 6–10 years (Cairns 1972, Picton 1960, Trembley 1965). The current shift from fossil fuel powered electric generation to nuclear power generation also increases the amount of water needed for condenser cooling. Less than 1 percent of the total electrical output in the summer of 1967 was produced by nuclear power (Hogerton 1968). However, McKee (1968) predicted that by the year 2000 more than half of our electrical output is expected to be nuclear power originated (cited in: Carlson unpublished report). Approximately 50 percent more cooling water is required by nuclear power facilities than that required by fossil fuel plants (Cairns 1971). Thus, the evaluation of heated discharge is a problem now, and will continue to be in the future.

The importance of site specific data in the development of guidelines for the regulation of heated discharges is finally beginning to get the recognition it deserves. In the absence of biological and ecological information about the system into which heated wastewater is discharged, regulations are likely to be either over- or under-protective. In the former case, money is wasted by requiring excessive cooling past the point of measurable biological benefits. In the latter case, a particularly sensitive system may be degraded because the discharge rates were designed for "average" conditions.

The importance of site specific analysis was demonstrated when the Environmental Protection Agency (1973) published their proposed criteria for important species on which thermal standards will be based: (1) ultimate upper incipient lethal temperature, (2) temperature cold shock, (3) optimum temperatures for growth and reproduction, (4) maximum temperatures for short-term exposures.

The fact that fishes can select specific temperatures was not considered when the Environmental Protection Agency (1973) published their proposed criteria on which thermal standards will be based. Coutant (1974) and Stauffer et al. (1975a) suggested that temperature preference and avoidance data of fishes should be considered in the site specific evaluation of a thermal discharge. Other authors have recognized the importance of temperature preference and avoidance studies, and have tested several species in the laboratory (Doudoroff 1938, Fisher and Elson 1950, Fry 1947, Brett 1952, Garside and Tait 1958, Meldrim and Gift 1971). Although laboratory studies provided useful information about temperature preference and avoidance of fishes, they usually did not evaluate other physical, chemical, and biological parameters which affected fish distribution.

Field studies of the temperature selection of freshwater fishes are rare (Ferguson 1958). Those studies which used field data for this purpose were mostly limited to reservoir and lake studies in which temperature varied with depth (Fry 1947, Dendy 1948, Kennedy 1941, Neill and Magnuson 1974). Ferguson (1958) attempted to relate laboratory temperature preference data taken from the literature to field data. Neill and Magnuson (1974) integrated the results from laboratory studies to explain the distribution of fishes near the thermal outfall in Lake Monona, Wisconsin.

The purpose of this study was fourfold: (1) to assimilate and report available information concerning the range of temperature at which each of the 48 species collected in this study have been observed; (2) to generate laboratory temperature preference and avoidance data for selected species; (3) to determine the effect of temperature on fish distribution from field data as outlined by Stauffer et al. (1975b); and (4) to determine and define any relationships between the laboratory and field information.

ACKNOWLEDGMENTS

This report is a revision of a major portion of a dissertation submitted by J. R. Stauffer to the graduate faculty of Virginia Polytechnic Institute and State University. The following individuals gave freely of their time for both the laboratory and field studies: D. Bailey, R. Gross, M. Grubb, P. Hambric, F. Hatt, J. Hinchion, C. Hocutt, D. Kuhn, G. Lane, A. Maciorowski, M. Masnik, D. Messenger, P. Newman, R. Paul, J. Rogers, J. Slocomb, W. Van der Schalie, and J. Wilson. W. F. Calhoun and M. T. Masnik gave assistance in computer programming. Correspondence and discussion with the following individuals provided much needed information: R. E. Jenkins, S. E. Peterson, E. C. Raney, T. W. Robbins, and F. J. Schwartz. This study was supported by American Electric Service Power Corporation and Appalachian Power Company.

DESCRIPTION OF STUDY AREA

The New River, the main stream of the Kanawha River System, flows northward through Virginia and crosses the Virginia–West Virginia state line at Glen Lyn, Virginia.

Heated wastewater (i.e., above ambient temperatures) entered the New River from 2 Appalachian Power Company's (APCo) discharges at Glen Lyn, Virginia. One unit discharged 5.3 m^3/sec directly into the New River approximately 45.7 m above the Highway 460 bridge. The second unit discharged 7.6 m^3/sec via a 274.3-m-long effluent channel, into the East River (a fourth order tributary to the New River) upstream from its confluence with the New River, and 1.9 m^3/sec into the New River. Water from both units remained along the left bank (facing downstream) of the New River. In 1973, the New River varied in flow from 2,345 m^3/sec in May to 39 m^3/sec in September. In 1974, the New River fluctuated between 1,345 m^3/sec in April and 38.9 m^3/sec in July. Flow data were not available for the East River. The ambient temperature regime and the theoretical temperature regime at maximum load for 1973 and 1974, respectively, are shown in Fig. 1.

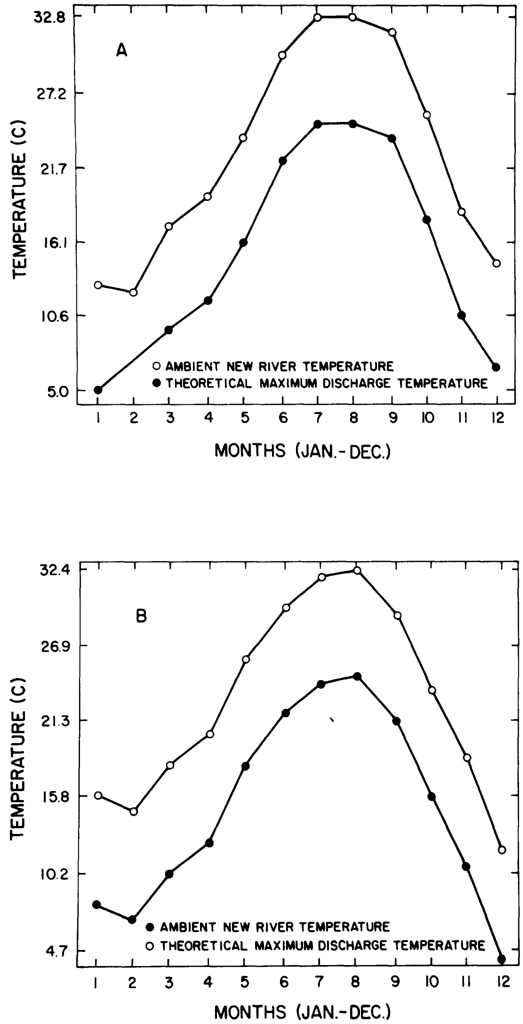


FIG. 1. Ambient temperature and theoretical temperature regime of the New River at maximum power plant load for 1973 (A) and 1974 (B), Glen Lyn, Virginia.

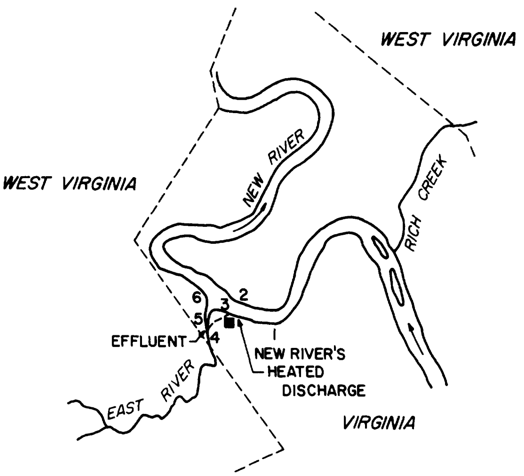


FIG. 2. Collecting stations in the New and East rivers in the vicinity of Appalachian Power Company's fossil fuel plant, Glen Lyn, Virginia.

Field sampling stations, all in Giles County, Virginia (Fig. 2) were selected for accessibility, proximity to heated discharges, substrate composition, and presence of riffles and pools. The substrate at all locations consisted of varying amounts of silt, gravel, rubble, and bedrock.

Station 1.—Left bank of New River, 4.0 road km east of the Hwy. 460 bridge; Glen Lyn, Virginia. Shoreline: Deciduous trees. Aquatic vegetation: *Justicia, Elodea.* Gradient: 2.0 m/km. Depth: 0.15–3.0 m.

Station 2.—Right bank of New River, Hwy. 460 bridge, Glen Lyn, Virginia. Shoreline: Grass, shrubs. Aquatic vegetation: *Justicia, Elodea.* Gradient: 5.0 m/km. Depth: 0.15–3.0 m.

Station 3.—Left bank of New River, 276 m downstream from the Hwy. 460 bridge, Glen Lyn, Virginia. Downstream of New River heated discharge and upstream of East River confluence. Shoreline: Deciduous trees. Aquatic vegetation: *Justicia, Elodea, Potamogeton.* Depth: 0.3–2.1 m. Gradient: 6.0 m/km.

Station 4.—East River at West Virginia–Virginia state line. Upstream of East River thermal discharge. Shoreline: Deciduous trees. Aquatic vegetation: *Justicia, Vallisneria.* Depth: 0.15–1.5 m. Gradient: 8.0 m/km.

Station 5.—Right bank of East River directly below thermal discharge. Shoreline: Deciduous trees. Aquatic vegetation: *Elodea.* Depth: 0.3–1.5 m. Gradient: 4.0 m/km.

Station 6.—Left bank of New River directly below influent of the East River. Shoreline: Deciduous trees. Aquatic vegetation: *Justicia, Elodea, Vallisneria.* Depth: 0.15–2.1 m. Gradient: 2.0 m/km.

Stations 1 and 2 (New River) and Station 4 (East River) were not exposed to thermal discharges and, therefore, were selected as ambient temperature reference sites. Due to the location of the sampling stations at varying places in and out of the thermal plume, a variety of temperatures was present for each collection date. Thus, fish had the opportunity to select their preferred temperature or to avoid high temperatures.

The Glen Lyn laboratory was a 18.2-m mobile research unit located on the confines of the power plant approximately 3 m from the edge of the New River (Fig. 3). The laboratory consisted of 3 compartments, 2 areas for holding facilities (3 946.2-liter holding tanks and several 189.2-liter aquaria), and a central area for conducting fish responses. The central laboratory section included preference and avoidance troughs, circulating water baths, continuous temperature monitors, and a closed-circuit television unit.

METHODS AND MATERIALS

Fish were collected with seine and rotenone from February 1973 to December 1974. Rotenone was used in conjunction with a block net to sample both pool and riffle habitats at each locality as described by Hocutt et al. (1973).

Water of a particular temperature (± 1.1 C) was enclosed by the block net and then rotenone applied. All fish were sorted, identified to species, and placed in permanent storage in the Virginia Polytechnic Institute

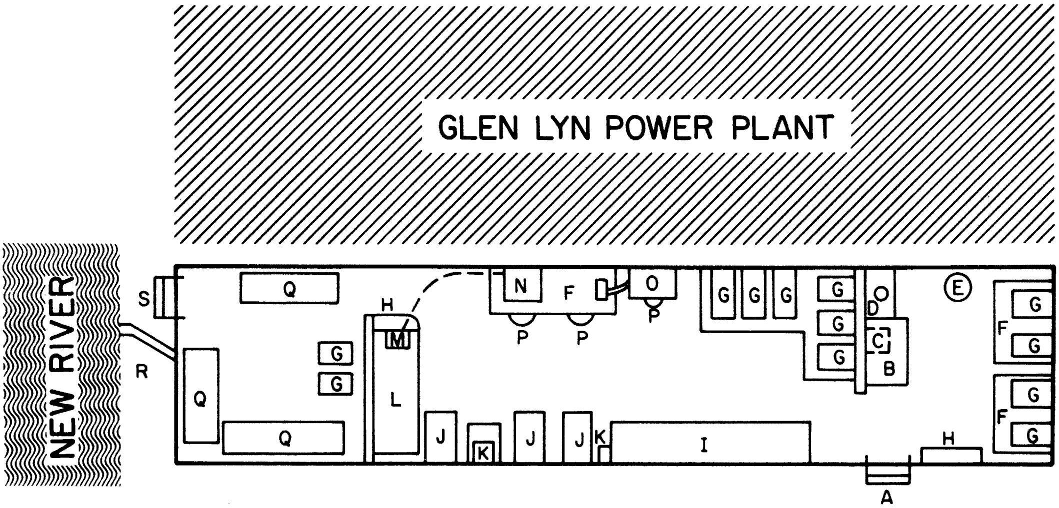


FIG. 3. Laboratory design and equipment (A, front door; B, table; C, refrigerator; D, sink; E, refuse receptacle; F, desk; G, aquarium; H, shelf; I, preference trough; J, circulating water bath; K, temperature recording unit; L, avoidance trough; M, television camera; N, closed-circuit TV monitor; O, computer teletype monitor and telephone coupler system; P, chair; Q, holding tank; R, water intake pipes from immersion pump in river; S, back door for studies at Glen Lyn, Virginia.

and State University Fish Museum. Collection temperatures for the rotenone samples ranged from 20.5 to 35.5 C in 1973, and from 19.4 to 30.0 in 1974.

The EPA criteria for important species (important sport or commercial species, important forage species, rare or endangered species) was applied to the data base and several were deemed "important."

The percentage abundance of several species was calculated for each temperature regardless of date or location of capture. The total abundance for each year at a particular temperature was then divided by the number of collections made at that temperature and plotted against temperature.

The wider temperature range for the 1973 data made possible the application of a stepwise linear regression procedure used to partition the effects of temperature, length of day, river flow, stream gradient, and time since last chlorination on fish distribution as described by Stauffer et al. (1975b).

Temperature was measured with a Taylor hand thermometer. Gradient was determined at each location with standard surveying techniques (lock level and jig stick). Photoperiod was defined as the time between sunrise and sunset. River flow was measured by a gauging station on the New River near Glen Lyn, Virginia, and chlorine levels were determined with a Wallace and Tiernan amperometric titrator.

Since total chlorine levels remained fairly constant (0.3 mg/l) in the discharge areas throughout the study period, and were of short duration (10–19 min), the variable "time since last chlorination period" was recorded. Stations upstream of the effluent which did not receive chlorine were assigned 8 hours for the purpose of regression analysis. Since the effluent was chlorinated every 8 hours, this corresponded with the maximum time since the last chlorination period for the downstream stations. If a species response was influenced by chlorine, 8 hours represented the maximum time available for recolonization of a downstream station. In light of this, it was thought that 8 hours was the most reasonable value to use for this variable at the reference stations.

The plots of percentage abundance versus temperature (corrected for sampling effort) for each species was used in conjunction with the stepwise regression technique to determine temperature preference from the field data (Stauffer et al. 1975b). If a large percentage (50% +) of a particular species occurred within a narrow temperature range (1.1–1.7 C), and the stepwise regression did not select any of the other variables tested, that temperature range was selected as the final temperature preference for the species. If the percentage abundance versus temperature plot did not show an abrupt change in abundance with temperature, but did show a trend, and the stepwise regression analysis selected only the variable temperature, then the highest temperature at which the slope of the curve approached zero, was deemed the final temperature preference.

Laboratory Responses

Temperature preference and temperature avoidance trials were patterned after those reported by Meldrim and Gift (1971). All trials were conducted under rising field conditions from January through August 1974.

The temperature preference trials were conducted in a stainless steel preference trough (3.6 × 0.203 × 0.254 m) coated with epoxy paint, and heated on the underside by a battery of 12 infrared lamps set at progressively increasing heat intensity. Cold water from a circulating water bath was introduced at one end to intensify the temperature gradient. This increased the temperature range of the horizontal gradient to give the fish the broader selection temperatures between cold and hot extremes. Twenty-two thermistors equally spaced throughout the trough recorded the gradient. Water depth in the trough varied from 1 to 2.5 cm depending upon the size of each species tested. Constant illumination was provided by 3 fluorescent lights at a level consistent with solar radiation during a clear day.

Eight fish of each species were tested individually at each acclimation temperature. Fish were tested in the trough prior to gradient formation to test for position effects. A gradient was established and fish were placed in the trough at their acclimation temperature and allowed to orient to the experimental conditions for 20–60 min, depending upon the response of each species. Fish movement and temperature selection relative to each thermistor was then monitored at 1-min intervals through overhead mirrors for 20 min.

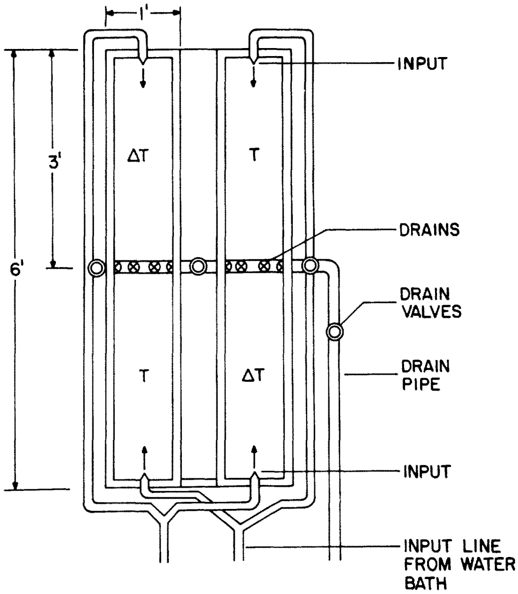


FIG. 4. Diagram of the temperature avoidance unit used for laboratory studies of fishes.

The relationship between acclimation temperature and preference temperature was determined by calculating a regression line via the least squares method (Sokal and Rohlf 1969). The final temperature preference was defined as the point where the above regression line intersected a theoretical line with a slope of 1, according to Fry (1947). This point would theoretically represent the highest temperature a fish would prefer given an expanded temperature range and enough time for reacclimation to each preferred temperature.

The temperature avoidance trials were conducted using 2 subtroughs coated with epoxy paint (Fig. 4). Each trough was approximately 1.9 × 0.305 × 0.203 m. The flow from 2 circulating water baths entered at opposite ends of each subtrough and drained at the center. This arrangement allowed the investigator to provide the fish with a choice of 2 temperatures. To correct for positional effects, water from the same bath which supplied one end of one subtrough was split, and supplied the opposite end of the other subtrough. The avoidance unit was enclosed in a plywood room and fish movement was monitored by a closed-circuit television unit. Constant illumination was provided by fluorescent lights. The above unit was modified by Meldrim and Gift (1971) from designs of Shelford and Allee (1913), Jones (1952), Sprague (1964), and Hill (1968).

Eight groups of 2 fish each were tested for each species at several acclimation levels except for the northern hog suckers *Hypentelium nigricans*. Due to the relative scarcity of northern hog suckers, only 4 groups of 2 fish each were tested at each acclimation temperature.

Two fish were placed in each subtrough with water from both baths set at the acclimation temperature. Fish were allowed to orient to the trough for 20–60 min depending on the species. The amount of time fish spent on each half of each subtrough was then recorded for 10 min. At the end of 10 min, one water bath was increased to 3 C above the acclimation temperature to create a temperature differential between halves of each experimental unit. Fish movement was again monitored for 10 min and the number of seconds spent in the temperature closer to the acclimation temperature was recorded. The experiment was continued by raising both water baths 3 C and repeating the monitoring procedure. This process was repeated until the fish showed avoidance for more than 500 of the possible 600 sec. Fish were then removed and discarded.

A 2-way, factorial, analysis of variance table was constructed using the 8 groups of fish and the higher of the 2 temperature choices as classes. The time in seconds the fish spent in the lower of the 2 temperature choices was recorded in each block of the tables. During the control experiments, the number of seconds spent on the side of each subtrough which was designated as the lower temperature side throughout the experiment was recorded. Since the temperature intervals were a "fixed effect" and the particular fish groups were "random effects" the mean square for the fixed temperature effect was tested by the interaction term "fish group × temperature interval" (Sokal and Rohlf 1969). The mean square and degrees of freedom for the interaction term were then used to conduct a Duncan's multiple range test for the fixed effect. The point at which significantly ($P = .05$) more time was spent on the lower temperature half of the trough in the experimental run than spent on the designated lower temperature half of the trough in the control run, was deemed the avoidance temperature. The above analysis was applied to each acclimation temperature for each species tested.

RESULTS

A total of 15,342 specimens represented by 41 species were captured in 1973 (Table 1), while in 1974, 29,255 specimens represented by 47 species were collected (Table 2). Laboratory temperature preference data were generated for 10 species and avoidance data for 10 species.

The results from laboratory temperature preference and avoidance studies, the results from field determined estimates of temperature selection (rotenone data), the total range of temperatures at which a species was collected (rotenone and seine data), and a literature review were used to evaluate and predict the potential or realized influence of temperature on the distribution of each of the 48 species collected in this study.

The temperature preference and field data when available for the following species are taken from Stauffer et al. (1975a, 1975b): stoneroller *Campostoma anomalum*, spotfin shiner *Notropis spilopterus*, northern hog sucker *Hypentelium nigricans*, channel catfish *Ictalurus punctatus*, smallmouth bass *Micropterus dolomieui*, spotted bass *Micropterus punctulatus*, and the fantail darter *Etheostoma flabellare*. These

TABLE 1.—NUMBER OF SPECIMENS OF EACH FISH SPECIES CAPTURED AT STATIONS 1–6, FEBRUARY–OCTOBER 1973, IN THE NEW RIVER DRAINAGE, GLEN LYN, VIRGINIA

	Stations					
Family and species	1	2	3	4	5	6
CLUPEIDAE						
Alewife						
Alosa pseudoharengus	15	5			1	
CYPRINIDAE						
Stoneroller						
Campostoma anomalum	335	133	3	1,599	32	10
Carp						
Cyprinus carpio				1		
Cutlips minnow						
Exoglossum maxillingua	2	1		1	2	
Bluehead chub						
Nocomis leptocephalus	13	19	1	45	32	4
Bigmouth chub						
Nocomis platyrhynchus	16	9	1	17		
Golden shiner						
Notemigonus crysoleucas				1	1	
White shiner						
Notropis albeolus	31	48	3	404	80	
Rosefin shiner						
Notropis ardens	2	4	4	8	30	
Common shiner						
Notropis chrysocephalus				2		
Whitetail shiner						
Notropis galacturus	43	10	10	19	38	2
Spottail shiner						
Notropis hudsonius	57	181	8	105	24	20
Silver shiner						
Notropis photogenis	89			5	3	
Swallowtail shiner						
Notropis procne					1	
Rosyface shiner						
Notropis rubellus	122	107	24	111	107	8
Spotfin shiner						
Notropis spilopterus	716	598	348	986	1,090	111
Sand shiner						
Notropis stramineus					1	
Telescope shiner						
Notropis telescopus	3	3	1	22	28	1
Mimic shiner						
Notropis volucellus	391	528	209	68	58	33
Bluntnose minnow						
Pimephales notatus	823	272	19	786	138	48
Fathead minnow						
Pimephales promelas				7	5	
Blacknose dace						
Rhinichthys atratulus	4	20		54	2	4
Longnose dace						
Rhinichthys cataractae		12		2		
Creek chub						
Semotilus atromaculatus	1	2		37	1	1
CATOSTOMIDAE						
White sucker						
Catostomus commersoni				238	20	
Northern hog sucker						
Hypentelium nigricans	157	17	9	76	19	18

TABLE 1 (Continued)

Family and species	Stations 1	2	3	4	5	6
ICTALURIDAE						
Channel catfish						
Ictalurus punctatus	51	60	405	3	421	69
Flathead catfish						
Pylodictis olivaris	63	305	87	8	47	10
CENTRARCHIDAE						
Rock bass						
Ambloplites rupestris	66	24	17	47	36	2
Redbreast sunfish						
Lepomis auritus	32	16	13	53	24	1
Green sunfish						
Lepomis cyanellus		1		1		
Pumpkinseed						
Lepomis gibbosus	1					
Bluegill						
Lepomis macrochirus	39	10	2	1	15	1
Smallmouth bass						
Micropterus dolomieui	43	68	22	11	11	4
Spotted bass						
Micropterus punctulatus	19	24	9		11	
PERCIDAE						
Greenside darter						
Etheostoma blennioides	135	176	80	118	84	11
Fantail darter						
Etheostoma flabellare		1		63	1	
Piedmont darter						
Percina crassa roanoka	71	78	42	1	48	17
Blackside darter						
Percina maculata				1		
Sharpnose darter						
Percina oxyrhyncha	11	1			6	5
COTTIDAE						
Banded sculpin						
Cottus carolinae	65	123		51	4	
Total specimens	3,416	2,856	1,317	4,952	2,421	380
Total species	30	31	22	35	34	21

data are included here so that this monograph on temperature relationships of the New River fishes may be as complete as possible.

Annotated List of Species

Alewife *Alosa pseudoharengus.*—A total of 21 specimens was collected in 1973 at water temperatures that ranged from 26.1 to 28.9 C and 11 specimens in 1974 at temperatures of 21.6–26.6 C. The alewife comprised less than 0.1 percent of the total catch. Because of the relative scarcity of this species, it was not possible to evaluate the effects of the heated effluent on its distribution. However, according to Wollitz (1968), attempts have been made to establish this species as a forage fish in the New River. If these efforts continue, the alewife may become widespread throughout the drainage.

The greatest potential threat to alewife populations would be caused by acute exposure to cold temperatures, which would follow plant shutdowns during the winter months. Stanley and Colby (1971) hypothesized that alewife mortality in the Great Lakes was caused by osmoregulatory failure induced by acute exposure to cold water

TABLE 2.—NUMBER OF SPECIMENS OF EACH FISH SPECIES CAPTURED AT STATIONS 1–6, JANUARY–DECEMBER 1974, IN THE NEW RIVER DRAINAGE, GLEN LYN, VIRGINIA

	Stations					
Family and species	1	2	3	4	5	6
CLUPEIDAE						
Alewife						
Alosa pseudoharengus	7	4				
CYPRINIDAE						
Stoneroller						
Campostoma anomalum	1,085	804	13	3,683	113	120
Rosyside dace						
Clinostomus funduloides		2		1		
Carp						
Cyprinus carpio					1	
Silverjaw minnow						
Ericymba buccata		1		1		
Cutlips minnow						
Exoglossum maxillingua		3		1	1	
Bluehead chub						
Nocomis leptocephalus		2		75		1
Bigmouth chub						
Nocomis platyrhynchus		6	1			1
White shiner						
Notropis albeolus	102	107	16	520	87	59
Rosefin shiner						
Notropis ardens	6			5	5	2
Common shiner						
Notropis crysocephalus				1		
Whitetail shiner						
Notropis galacturus	16	15	9	20	159	32
Spottail shiner						
Notropis hudsonius	19	12	1	72	41	5
Silver shiner						
Notropis photogenis	5	2	2	1	6	7
Swallowtail shiner						
Notropis procne		1		1		
Rosyface shiner						
Notropis rubellus	2,020	1,087	484	823	2,127	715
Spotfin shiner						
Notropis spilopterus	463	880	453	1,026	2,523	644
Telescope shiner						
Notropis telescopus	109	46	13	162	338	61
Mimic shiner						
Notropis volucellus	348	327	9	74	332	47
Mountain redbelly dace						
Phoxinus oreas		1		2		
Bluntnose minnow						
Pimephales notatus	400	108	33	540	97	65
Fathead minnow						
Pimephales promelas		2		3	1	
Blacknose dace						
Rhinichthys atratulus	90	12	1	141	48	93
Longnose dace						
Rhinichthys cataractae		4	8	6	1	13
Creek chub						
Semotilus atromaculatus	1	5		57	1	1

TABLE 2 (Continued)

Family and species	Stations					
	1	2	3	4	5	6
CATOSTOMIDAE						
White sucker						
Catostomus commersoni	43	77	7	594	179	15
Northern hog sucker						
Hypentelium nigricans	427	364	92	312	315	93
ICTALURIDAE						
Channel catfish						
Ictalurus punctatus	1	4	19		12	2
Margined madtom						
Noturus insignis					1	
Flathead catfish						
Pylodictis olivaris	1	8	25		13	
CENTRARCHIDAE						
Rock bass						
Ambloplites rupestris	44	20	33	42	60	5
Redbreast sunfish						
Lepomis auritus	2	1		1	7	
Green sunfish						
Lepomis cyanellus				9	4	
Bluegill						
Lepomis macrochirus	3	3	5		39	
Smallmouth bass						
Micropterus dolomieui	54	58	38	9	54	7
Spotted bass						
Micropterus punctulatus	13	9	19	1	16	3
Largemouth bass						
Micropterus salmoides				1		
White crappie						
Pomoxis annularis					3	
PERCIDAE						
Greenside darter						
Etheostoma blennioides	90	289	70	139	117	26
Rainbow darter						
Etheostoma caeruleum		1				
Fantail darter						
Etheostoma flabellare				14		
Finescaled saddle darter						
Etheostoma osburni		1	1			
Piedmont darter						
Percina crassa roanoka	50	231	42	31	176	12
Blackside darter						
Percina maculata			1			
Sharpnose darter						
Percina oxyrhyncha	1	20	4		2	1
COTTIDAE						
Mottled sculpin						
Cottus bairdi		1		3		1
Banded sculpin						
Cottus carolinae	41	49	5	523	11	28
Total specimens	5,441	4,567	1,404	8,894	6,890	2,059
Total species	27	38	27	35	33	27

temperatures. Meldrim and Gift (1971) reported upper avoidance temperatures of 26.1, 24.4, and 30 C when fish were acclimated to 17.2, 17.8, and 25 C, respectively.

Stoneroller *Campostoma anomalum michauxi.*—A total of 2,112 specimens was collected in 1973 at water temperatures of 20–34.3 C, and 5,818 specimens in 1974 at temperatures of 8.9–32.2 C. The stoneroller comprised 17.8 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 5A. Stepwise regression analysis showed that temperature was the only variable that significantly influenced the distribution of this species (P=.05, df=8). More than 90 percent of this species was captured in water cooler than 23.8 C in 1973. In 1974, more than 95 percent of the specimens were collected in water cooler than 23.8 C (Fig. 5B).

Laboratory temperature preference trials were conducted for 7 acclimation temperatures that ranged from 12 to 30 C. The preference data were defined by TP=.71A+7.8 (P=.01, df=54), where TP is the temperature preference and A the acclimation temperature, with 94 percent of the data explained by the regression equation (Fig. 5C). A final temperature preference of 26.8 C was calculated from the above equation.

Upper avoidance temperatures were established for 6 acclimation levels. The upper avoidance ranged from 21 C, when fish were acclimated to 12 C, to 33 C when fish were acclimated to 27 C (Table 3).

The 26.8 C calculated final temperature preference agreed reasonably well with the field determined preference temperature of 22.7 to 23.8 C. The presence of some specimens of the stoneroller in 33.8 C water also supported the relatively high upper avoidance temperature of 33 C.

The above data indicated that the thermal outfall did alter the distribution of this species when water temperatures exceeded 29.4 C. However, some specimens of the stoneroller were present in discharge areas at water temperatures as high as 33.8 C.

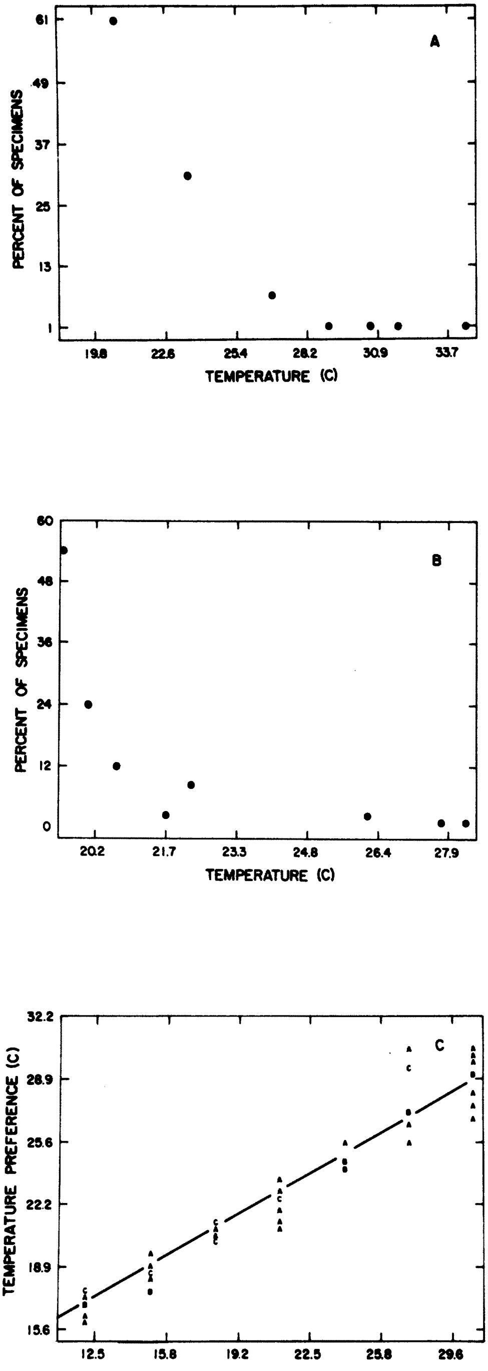


FIG. 5. Stoneroller. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

TABLE 3.—ACCLIMATION AND UPPER AVOIDANCE TEMPERATURES (°C) FOR FISH SPECIES CAPTURED IN THE NEW RIVER, GLEN LYN, VIRGINIA

Species		Acclimation	Upper Avoidance
Stoneroller	1	12	21
	2	15	24
	3	18	24
	4	21	27
	5	24	30
	6	27	33
Rosyface shiner	1	12	21
	2	15	24
	3	18	21
	4	21	27
	5	24	27
	6	27	33
Spotfin shiner	1	12	24
	2	15	24
	3	21	27
	4	24	30
	5	27	33
	6	30	36
	7	33	36
Telescope shiner	1	12	18
	2	15	21
	3	18	24
	4	21	27
	5	24	27
Bluntnose minnow	1	12	21
	2	15	21
	3	18	27
	4	21	27
	5	24	27
	6	27	30
Northern hog sucker	1	18	27
	2	21	30
	3	24	33
	4	27	30
	5	30	33
Rock bass	1	18	27
	2	21	27
	3	24	30
	4	27	33
	5	30	33
Bluegill	1	12	24
	2	15	27
	3	18	30
	4	21	30
	5	24	33
	6	27	33
	7	30	33
	8	33	36
Smallmouth bass	1	18	27
	2	21	30
	3	24	33
	4	27	33
	5	30	33
	6	33	36
Spotted bass	1	18	33
	2	21	30
	3	24	33
	4	27	33
	5	30	39
	6	33	39

Rosyside dace *Clinostomus funduloides* ssp. —The rosyside dace was not collected in 1973. Three specimens were captured in 1974 at water temperatures of 20–22.2 C. No specimens were collected at stations within the heated discharge. Burton and Odum (1945) recorded it in both Sinking Creek and Spruce Run, New River Drainage, Giles County, Virginia. Jenkins and Freeman (1972) categorized it as a headwater pool inhabitant in the Roanoke Drainage. Its habitat preference for small streams and headwater areas suggested a relatively cool final temperature preference. However, its scarcity in the main channel of the New River and the mouth of the East River made it doubtful that the heated discharge significantly altered its distribution.

Carp *Cyprinus carpio.*—One specimen was collected in September 1973 at Station 4 in 23.3 C water and another in 26.1 C water at Station 5 in June 1974. Field observations, reported in Brown (1974), varied in results. Trembley (1961, cited in Brown 1974) reported no observable temperature preference in water temperatures from 22.8 to 32.2 C. Gammon (1973) stated that carp demonstrated a field temperature preference between 26.7 and 34.4 C while Neill (1971, unpublished doctoral dissertation, University of Wisconsin, Madison, Wisconsin, cited in Brown 1974) reported a field temperature preference of 29.5 C for adult fish. The highest water temperature in which carp were observed in situ was 36.1 C (Proffitt and Benda 1971). Pitt et al. (1956) reported a laboratory final temperature preference of 32 C. The above reports indicated that the distribution of carp would not be adversely affected by the presence of heated discharge in the New River. There was some concern that the warm water may have attracted large numbers of this species into the area. However, our field observations indicated that this did not occur.

Silverjaw minnow *Ericymba buccata*.—Two specimens were captured in 1974 at water temperatures of 20–22.2 C. It was thought that the silverjaw minnow was introduced into the New River, Giles County, Virginia, via fishermen's bait buckets. There is no evidence that the silverjaw minnow is becoming established in this section of the New River, and, therefore, its distribution was not considered to be potentially affected by the heated discharge.

Cutlips minnow *Exoglossum maxilingua*.—Six specimens were collected in 1973 at water temperatures of 20–26.1 C and 5 specimens in 1974 at temperatures of 20–26.1 C. Although present in the heated discharge areas during the cooler months, no specimens were taken when water temperatures increased above 27.2 C. Trembley (1961) reported that the cutlips minnow was sensitive to temperature changes and would avoid temperatures above 27.2 C. However, there is not enough information available to make any definite conclusions about the effect of temperature on its distribution in the New River.

Bluehead chub *Nocomis leptocephalus*.—A total of 114 specimens was collected in 1973 at water temperatures of 20.5–35 C, and 78 specimens in 1974 at water temperatures of 4.4–22.2 C. The bluehead chub comprised 0.4 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 6A. Stepwise regression analysis showed that temperature was the only variable which significantly explained the distribution of this species (P=.05, df=8). Approximately 50 percent of this species was captured in 20 C water in 1973, while more than 90 percent of the specimens were collected in water cooler than 20 C in 1974 (Fig. 6B). No information concerning the laboratory temperature relationships of this species was available. Lachner and Jenkins (1971) described this species as preferring warm streams. It would appear from the field data that the thermal outfall limited the distribution of bluehead chub during certain periods of the year.

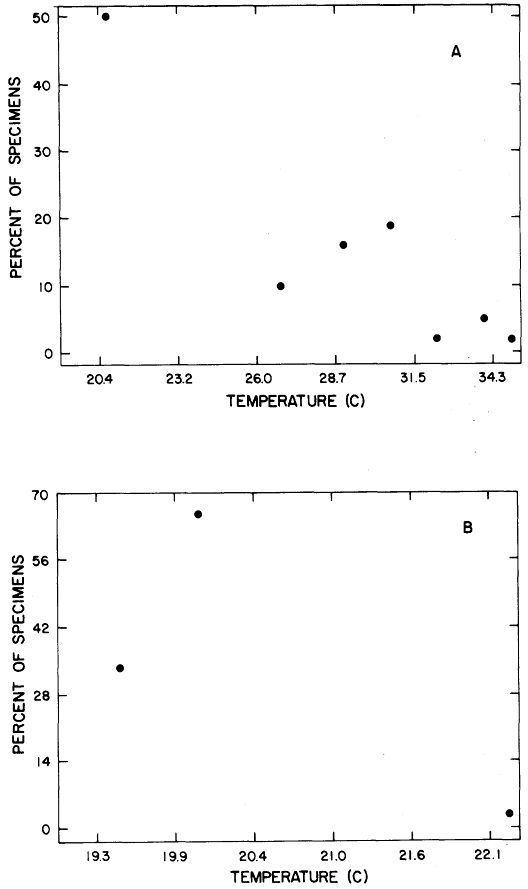


FIG. 6. Bluehead chub. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974.

Bigmouth chub *Nocomis platyrhynchus*.—A total of 43 specimens was collected in 1973 at water temperatures of 23.3–30 C, and 8 specimens in 1974 at temperatures of

21.7–28.3 C. The bigmouth chub comprised 0.1 percent of the total catch. Lachner and Jenkins (1971) described this species as preferring warm streams, but because of its relative scarcity, no definite relationships could be determined from the field data.

Golden shiner *Notemigonus crysoleucas crysoleucas*.—Two specimens of the golden shiner were collected in 1973 at water temperatures of 23.3 and 28.9 C. Trembley (1961, cited in Brown 1974) reported golden shiners in water that ranged from 21.1 to 32.2 C. The presence of the golden shiners in the East River probably was the result of a bait bucket introduction. The high lethal temperature of 40 C for golden shiners acclimated to 22 C would indicate, that should this species increase in abundance, the heated effluent would not adversely affect its distribution (Alpaugh 1972).

White shiner *Notropis albeolus*.—A total of 566 specimens was collected in 1973 at water temperatures of 2.8–35 C, and 891 specimens in 1974 at temperatures of 4.4–32.2 C. The white shiner comprised 4.5 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 7A. Stepwise regression analysis showed that a 2 variable model consisting of both temperature and gradient significantly ($P=.05$, df=6) explained the distribution of this species. More than 90 percent of this species was captured in water cooler than 25.5 C in 1973. In 1974, more than 80 percent of this species was collected in water cooler than 25.5 C, with 71 percent of the specimens collected at 20 C (Fig. 7B). Forty-five percent of the white shiners were collected at Station 4. This indicated a preference for the steeper gradient and cooler water temperatures which characterized that station.

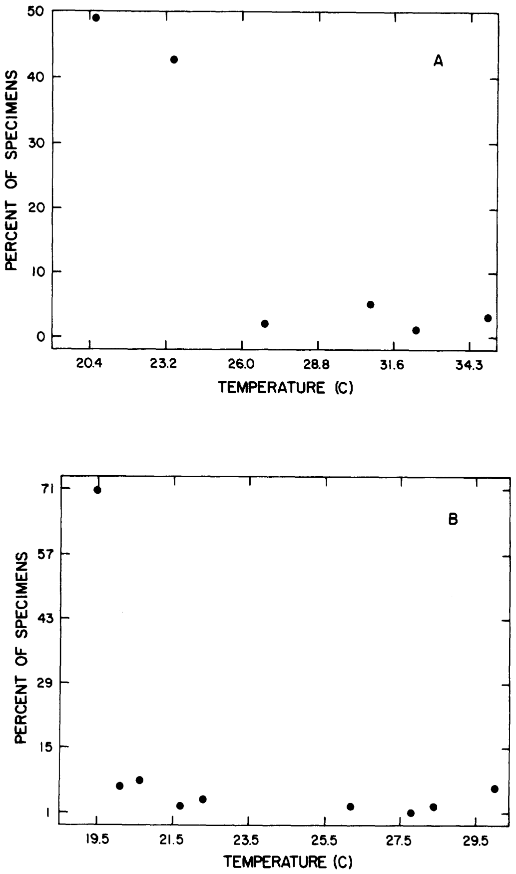


FIG. 7. White shiner. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974.

Rosefin shiner *Notropis ardens lythrurus*.—A total of 48 specimens was collected in 1973 at water temperatures of 15.5–32.2 C, and 18 specimens in 1974 at temperatures of 20.5–30 C. The rosefin shiner comprised 0.1 percent of the total catch. Although the rosefin shiner occurred only rarely in this study, the above data indicated that this species did exist for at least short periods of time in water as high as 33.3 C.

Striped shiner *Notropis chrysocephalus*.—Two specimens were collected in 1973 in 20.5 C and 23.3 C water, and 1 specimen in 1974 in 19.4 C water, all at Station 4. Gilbert (1964) described this species as having a preference for relatively warm water.

Whitetail shiner *Notropis galacturus*.—A total of 122 specimens was captured in water temperatures of 4.4–35 C in 1973, and 251 specimens in 1974 at temperatures of 10–34.4 C. The whitetail shiner comprised 0.8 percent of the total catch. Stepwise regression analysis indicated that none of the variables tested could significantly explain the distribution of this species. However, it should be noted that this species did exist at water temperatures as high as 35 C.

Spottail shiner *Notropis hudsonius.*—A total of 395 specimens was collected in 1973 at water temperatures of 20–35 C, and 150 specimens in 1974 at temperatures of 10–31 C. The spottail shiner comprised 1.2 percent of the total catch.

None of the variables tested significantly (P=.05) explained the distribution of the spottail shiner. Wells (1968, cited in Brown 1974), reported spottail shiners distributed in water temperatures that ranged from 12.2 to 22.2 C in Lake Michigan. Meldrim and Gift (1971) reported a laboratory temperature preference of 15 C when fish were acclimated to 13.8 C and tested in 6 ppt saline water. Wells and House (1974) stated that the spottail shiner was present in the warmest temperatures available in Lake Michigan. Field data indicated that the thermal outfall did not limit the distribution of this species.

Silver shiner *Notropis photogenis.*—A total of 97 specimens was collected in 1973 at water temperatures of 15.5–35 C, and 23 specimens in 1974 at temperatures of 15.5–31.1 C. The silver shiner comprised 0.3 percent of the total catch. Gruchy and Bowen (1973) collected the silver shiner in water from 19 to 23 C. The silver shiner did exist at water temperatures as high as 35 C. However, no definite conclusions relative to temperature could be made.

Swallowtail shiner *Notropis procne procne.*—One specimen was collected in 1973 at Station 5 in 31.7 C water, and 2 specimens in 1974 at 19.4 C and 22.2 C. Trembley (1960, cited in Brown 1974) reported the swallowtail shiner in 33.9 C water.

Rosyface shiner *Notropis rubellus.*—A total of 479 specimens was collected in 1973 at water temperatures of 2.8–35 C, and 7,256 specimens in 1974 at temperatures of 22.2–32.2 C. The rosyface shiner comprised 17.3 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 8A. Stepwise regression analysis showed that temperature was the only variable which significantly (P=.05, df=7) explained the distribution of this species. More than 60 percent of this species was captured in water cooler than 28.3 C. In 1974, 58.7 percent was collected at 30 C (Fig. 8B).

The laboratory temperature preference data were explained by $TP=.56A+12.7$ (P=.05, df=54), with 86 percent of the data explained by the regression equation (Fig. 8C). The calculated final temperature preference, according to Fry (1947), was 28.8 C. The laboratory upper avoidance temperatures (Table 3) ranged from 21 C when fish were acclimated to 12 C to 33 C when fish were acclimated to 27 C.

The field determined temperature preference of 28.3 to 30 C agreed very well with the final laboratory temperature preference of 28.8 C. The presence of the rosyface shiner in water temperatures as high as 35 C also agreed reasonably well with the laboratory determined upper avoidance temperature of 33 C.

The data indicated that temperature was definitely influential in determining the distribution of the rosyface shiner.

Spotfin shiner *Notropis spilopterus.*—A total of 3,849 specimens was collected in 1973, at water temperatures of 2.7–35 C, and 5,989 specimens in 1974 at temperatures of 2.2–35 C. The spotfin shiner comprised 22 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 9A. Stepwise regression analysis indicated that none of the variables significantly (P=.05, df=8) explained the distribution of this species. The spotfin shiner was equally abundant at 20.5 and 35 C in 1973,

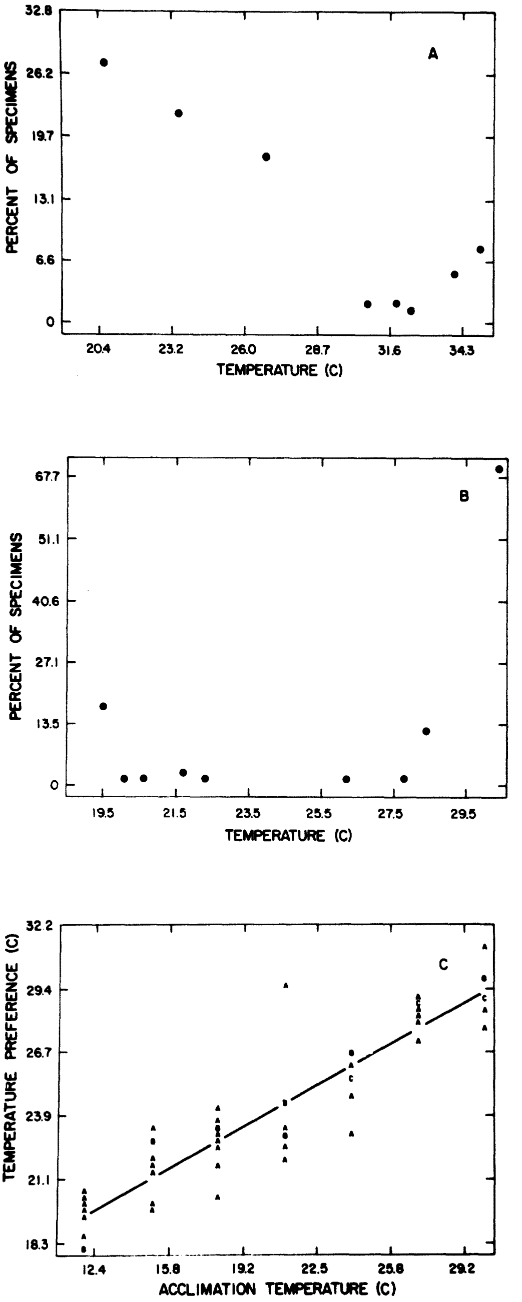


FIG. 8. Rosyface shiner. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

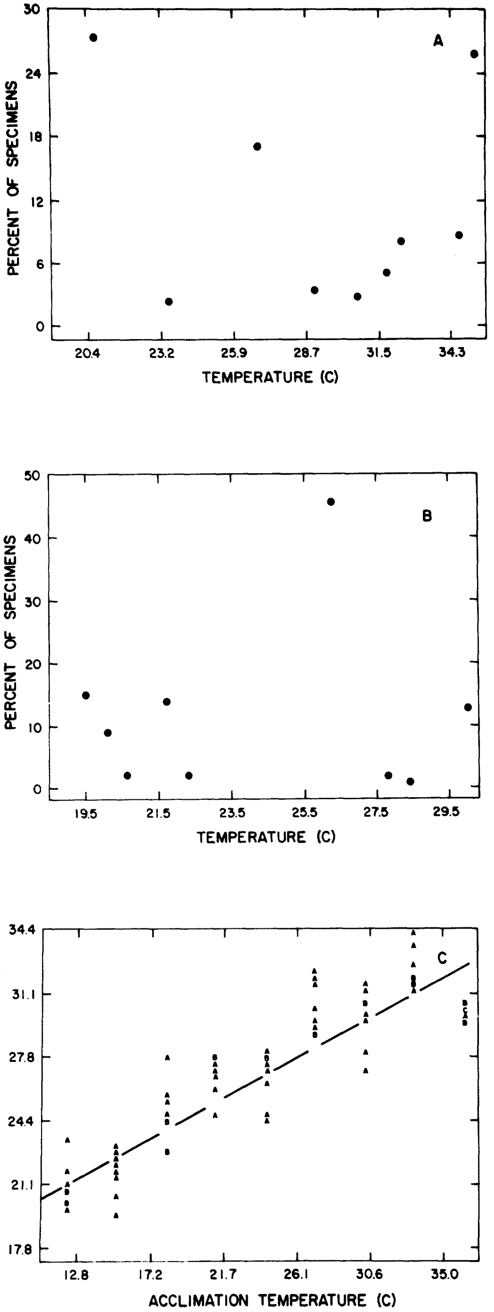


FIG. 9. Spotfin shiner. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

while in 1974 it was most abundant at 26.6 C (Fig. 9B). The distribution of spotfin shiner was unaffected by temperature on the basis of data from both years. The maximum temperature at which Proffitt and Benda (1971) observed spotfin shiners in a heated discharge was 31.1 C.

Laboratory temperature preference data were explained by TP=.47A+15.8A (*P*=.01, df=70) with 82 percent of the data explained by the regression equation (Fig. 9C). The calculated final temperature preference, according to Fry (1947), was 29.8 C. The laboratory upper avoidance temperatures ranged from 24 C when fish were acclimated at 12 C to 36 C when fish were acclimated at 33 C (Table 3). Cherry et al. (1974) reported an upper avoidance of 35 C when spotfin shiners were acclimated in 30 C water. Robbins and Mathur (1974) reported an upper avoidance of 32.2 C at an acclimation of 25.5 C, and also reported that 30 C was the highest preferred temperature exhibited by this species when acclimated to 26.7 C.

There was general agreement among laboratory studies. However, there did not seem to be any correlation between laboratory studies and field observations. The field distribution data indicated that the spotfin shiner was extremely euryecious, which probably accounted for its being the most abundant species in this study.

Sand shiner *Notropis stramineus.* — One specimen was collected in 1973 in 20 C water at Station 5. The presence of that specimen added the sand shiner to ichthyofauna of Virginia (R. E. Jenkins, pers. comm.). Summerfelt and Minckley (1969) collected this species at water temperatures of 0 to 34 C.

Telescope shiner *Notropis telescopus.*—A total of 58 specimens was collected in 1973 at water temperatures of 2.8–35 C, and 729 specimens in 1974 at temperatures of 16.7–32.2 C. The telescope shiner comprised 1.7 percent of the total catch.

Percentage abundance is compared with temperature for the telescope shiner in Fig. 10A. More than 44 percent of this species was collected at temperatures above 32.2 C in 1973. In 1974, 71 percent of the specimens were captured at 30 C (Fig. 10B).

The laboratory temperature preference data were explained by TP=.70A+5.9, (*P*=.01, df=46) with 93.3 percent of the data explained by the regression equation (Fig. 10C). The final calculated temperature preference was 19.6 C. The laboratory upper avoidance temperatures ranged from 18 C when fish were acclimated at 12 C to 27 C when fish were acclimated at 24 C (Table 3).

The laboratory final temperature preference is low when compared to the field determined preference of 30 to 32.2 C. The laboratory upper avoidance temperature is also low, since some specimens of the telescope shiner were collected at water temperatures as high as 35 C. There are 2 possible explanations for the above phenomena: (1) the highest acclimation temperature used for the laboratory experiments was 24 C and (2) specimens for laboratory experiments were collected from a springfed stream upstream from the study area, because of relative scarcity of this species. It is possible that these fish had a different thermal history and/or had a different genetic background than populations at the study site.

Mimic shiner *Notropis volucellus volucellus.*—A total of 1,287 specimens was collected in 1973 at water temperatures of 10–35 C and 1,137 specimens in 1974 at temperatures of 4.4–34.4 C. The mimic shiner comprised 5.4 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 11A. Stepwise regression analysis indicated that none of the variables tested could explain the distribution of this species (*P*=.05, df=11). More than 35 percent of the specimens in 1973 were collected at 26.1 and 32.2 C. In 1974, approximately 38 percent of the specimens were collected at

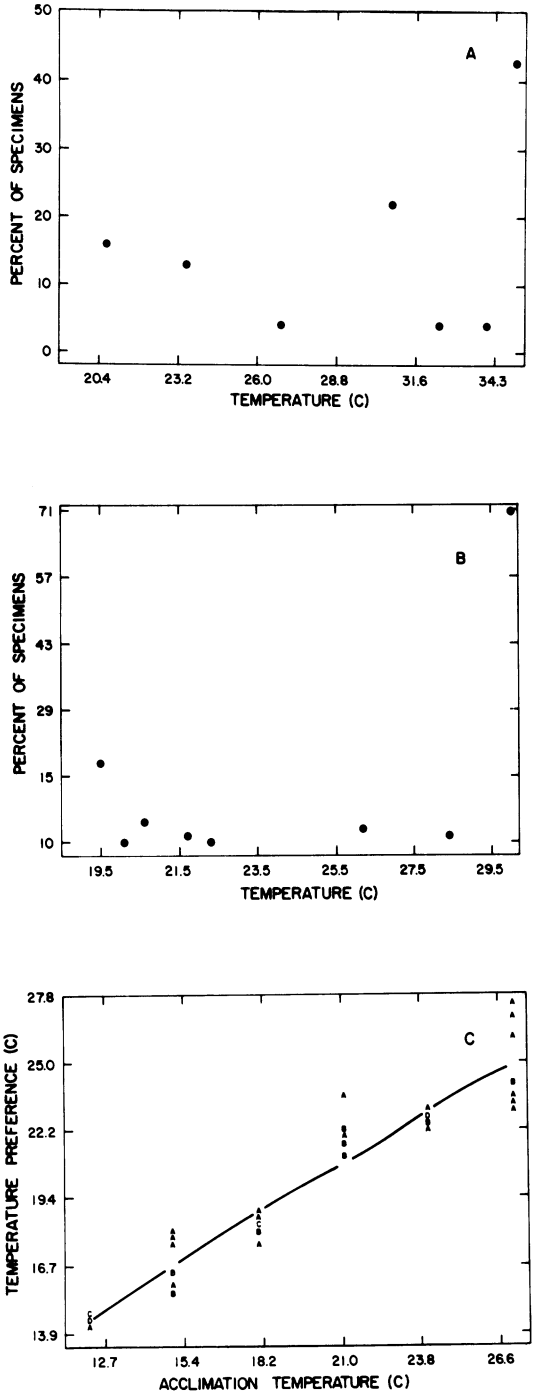


FIG. 10. Telescope shiner. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

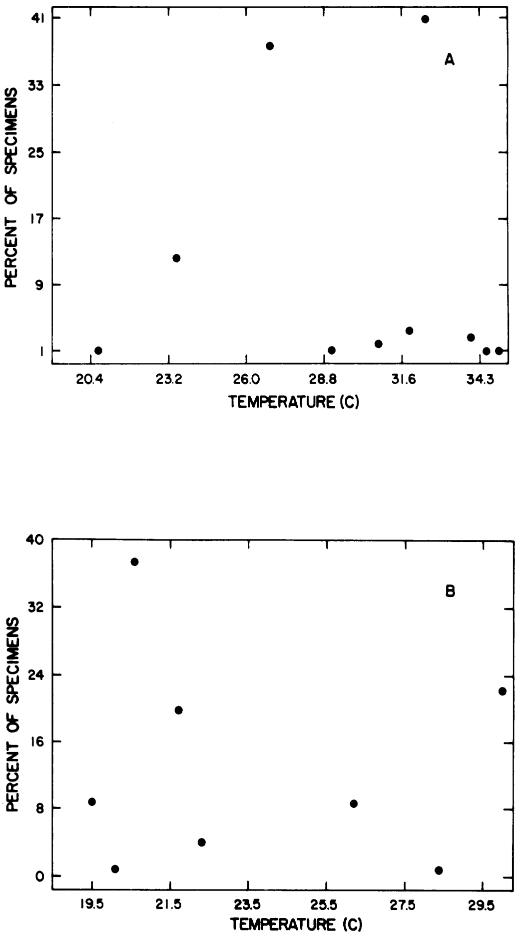


FIG. 11. Mimic shiner. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974.

20.5 C (Fig. 11B). The field data indicated that the thermal outfall did not limit the distribution of this species.

Mountain redbelly dace *Phoxinus oreas*.—Three specimens were collected in June 1974 at water temperatures of 20–21.7 C. Because of the scarcity of this species it was not possible to evaluate the influence of temperature on its distribution.

Bluntnose minnow *Pimephales notatus*.—A total of 2,086 specimens was collected in 1973 at water temperatures of 2.8–35 C, and

1,243 specimens in 1974 at temperatures of 5.8–32.2 C. The bluntnose minnow comprised 6.2 percent of the total catch.

Stepwise regression analysis indicated that a 2 variable model consisting of both temperature and photoperiod significantly ($P=.05$, df=9) explained the distribution of this species with 88 percent of the data explained by the regression. The inclusion of photoperiod in the model probably was caused by the recruitment of young-of-the-year fish on a seasonal basis. Temperature by itself significantly ($P=.05$, df=10) explained 60 percent of the data. More than 90 percent of the specimens were collected in water cooler than 26.7 C in both 1973 and in 1974 (Figs. 12A, 12B).

The laboratory temperature preference data were explained by TP=.51A+13.1 with 86.7 percent of the data explained by the regression (Fig. 12C). The calculated final temperature preference, according to Fry (1947), was 26.7 C. The laboratory upper avoidance temperature ranged from 21 C when fish were acclimated to 12 C to 30 C when fish were acclimated to 27 C (Table 3).

The final temperature preference of 26.7 C agreed very well with the field observations. The laboratory upper avoidance temperature appeared low, since bluntnose minnows were observed at water temperatures as high as 35 C. A higher laboratory upper avoidance temperature might be observed if fish were acclimated above 30 C.

Fathead minnow *Pimephales promelas*.—A total of 12 specimens was collected in 1973 at water temperatures of 15.5–25.6 C, and six specimens in 1974 at temperatures of 16.7–22.8 C.

Fathead minnows were obtained from upstream tributaries for laboratory temperature preference tests. The preference data were explained by TP=.55A+11.8 ($P=.01$, df=54) with 90 percent of the data explained by the regression equation in Fig. 13. The calculated final temperature preference was 26.2 C. The use of this final preference to predict the distribution of

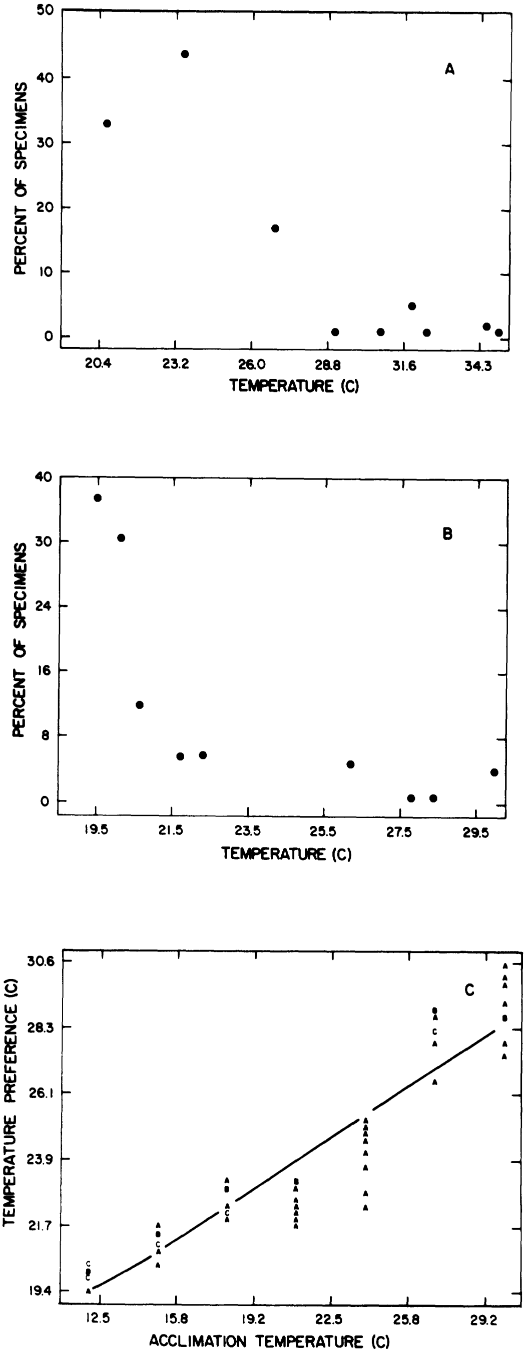


FIG. 12. Bluntnose minnow. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

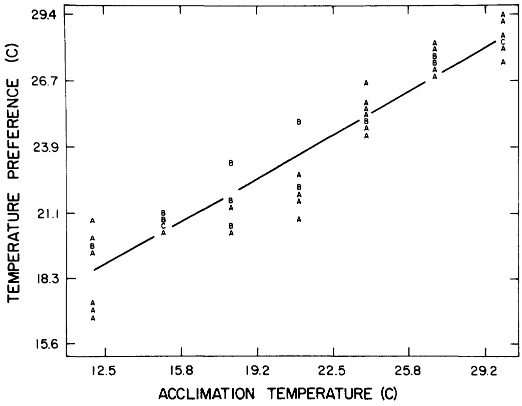


FIG. 13. Fathead minnow. Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

New River populations must be cautioned, because the thermal history of the laboratory specimens was unknown. Brown (1974), on the basis of information collected by Brett (1944), Trembley (1961), and Nickum (1966, unpublished doctoral dissertation, Southern Illinois University, Carbondale, Illinois), characterized the fathead minnow as "tolerant of high temperatures." It is doubtful that the heated discharge would adversely affect the distribution of fathead minnows.

Blacknose dace *Rhinicthys atratulus obtusus*.—A total of 84 specimens was collected in 1973 at water temperatures that ranged from 10 to 33.9 C, and 385 specimens in 1974 at temperatures of 20.5–26.1 C. The blacknose dace comprised 1 percent of the total catch. Stepwise regression analysis showed that gradient best explained ($P=.05$, df=5) the distribution of this species, although Fig. 14 indicated that temperature was also influencing the distribution of this species.

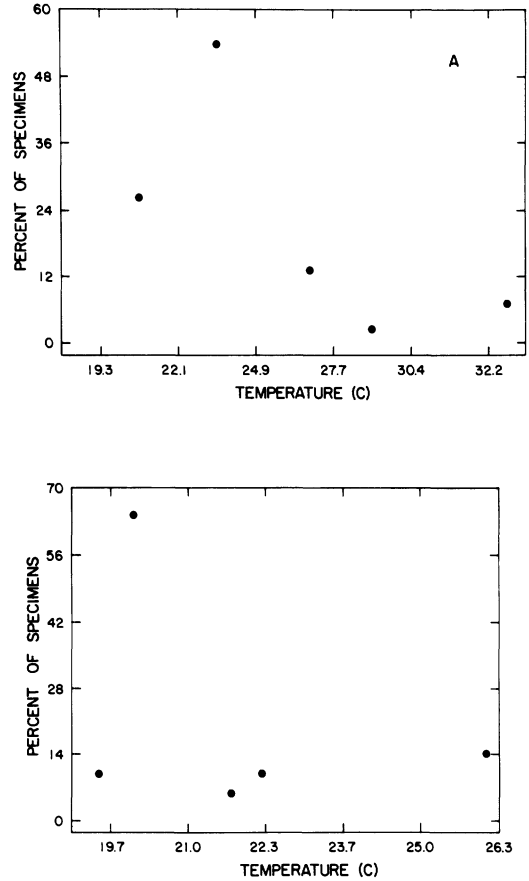


FIG. 14. Blacknose dace. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974.

Longnose dace *Rhinicthys cataractae*.—A total of 14 specimens was collected in 1973 at water temperatures of 20.6–26.7 C, and 32 specimens in 1974 at temperatures of 19.4–30 C. The longnose dace comprised 0.1 percent of the total catch. Because of the relative scarcity of this species, it was not possible to evaluate the influence of temperature on its distribution.

Creek chub *Semotilus atromaculatus* ssp.—A total of 42 specimens was collected in 1973 at water temperatures of 15.6–33.9 C, and 65 specimens in 1974 at temperatures of 19.4–30 C. The creek chub comprised 0.2 percent of the total catch. The fact that 87.8 percent of the total catch was collected at Station 4 suggested that the creek chub may have preferred the steeper gradient and lower temperatures which characterized that station. Stepwise regression analysis showed that the variable gradient significantly explained (P=.01, df=4) 81 percent of the 1973 rotenone data.

White sucker *Catostomus commersoni commersoni.*—A total of 258 specimens was collected in 1973 at water temperatures of 2.8–30.6 C, and 915 specimens in 1974 at temperatures of 18.9–29 C. The white sucker comprised 2.6 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 15A. Stepwise regression analysis indicated that temperature significantly (P=.01, df=2) explained the distribution of this species with 98 percent of the data explained by the regression. More than 90 percent of the specimens in 1973 were captured in water cooler than 23.3 C, and more than 80 percent of the specimens were collected in water cooler than 21.2 C in 1974 (Fig. 15B). It is interesting to note that in 1974, 60.7 percent of the specimens were captured at the heated discharge sites at temperatures below 26.7 C. Cooper and Fuller (1945, cited by Ferguson 1958) reported a temperature preference that ranged from 14.4 to 20.4 C. The above data indicated that the white sucker avoided the heated discharge areas when water temperature exceeded 26.7 C.

Northern hog sucker *Hypentelium nigricans nigricans.*—A total of 296 specimens was captured at water temperatures of 2.8–34.4 C, and 1,603 specimens in 1974 at temperatures of 2.2–35 C. The northern hog sucker comprised 4.3 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 16A. There is a gradual increase in abundance as temperatures rise from 19.4 to 26.1 C followed by an abrupt decrease in abundance when temperatures exceeded 26.6 to 27.7 C. The same general trend was observed for the 1974 data (Fig. 16B).

The laboratory temperature preference data were explained by TP=.27A+20.4 (P=.01, df=38) with 44 percent of the data explained by the regression equation (Fig. 16C). This species demonstrated a very erratic response throughout the laboratory experiments, but especially at the lowest acclimation temperature. The calculated final temperature preference was 27.9 C. The laboratory upper avoidance temperature ranged from 27 C when fish were acclimated at 18 C to 33 C when fish were acclimated to 30 C (Table 3). Cherry et al. (1974) reported an upper avoidance of 35 C when fish were acclimated to 30 C.

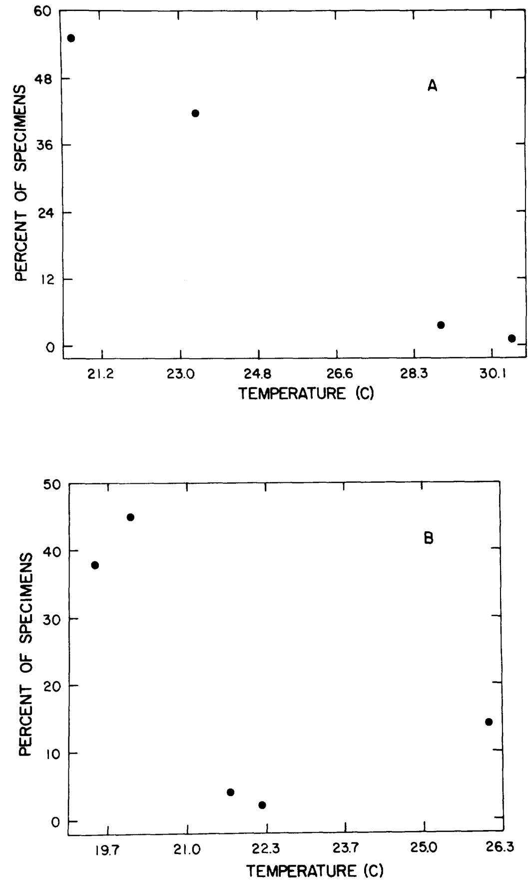


FIG. 15. White sucker. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974.

The field determined final temperature preference of 26.6 to 27.7 C agreed very well with the laboratory determined final temperature preference of 27.9 C. These data also supported the work of Gammon (1973), who found that the northern hog

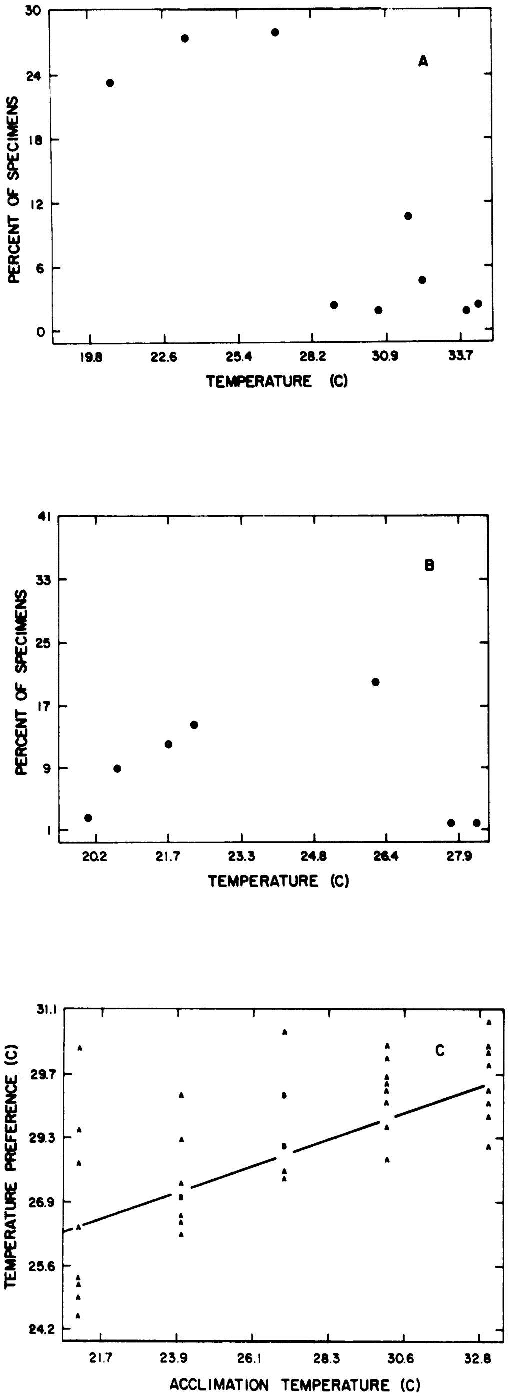


FIG. 16. Northern hog sucker. (A) Percentage abundance compared with temperature for 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

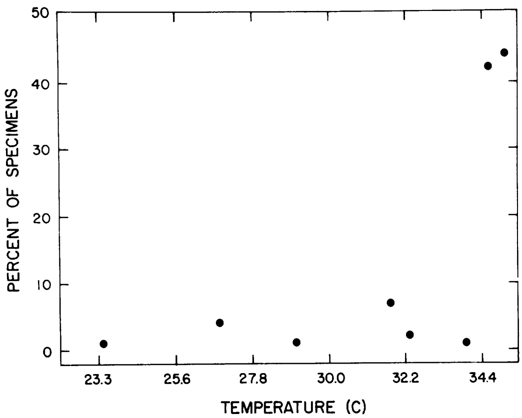


FIG. 17. Channel catfish. Percentage abundance compared with temperature for the 1973 rotenone data.

sucker completely avoided a thermal discharge on the Wabash River. The presence of some specimens in water as high as 35 C supported the relatively high upper laboratory avoidance temperature of 33 to 35 C.

Channel catfish *Ictalurus punctatus punctatus*.—A total of 1,009 specimens was collected in 1973 at water temperatures of 22.2–35 C, and 38 specimens in 1974 at temperatures of 11.7–30 C. The channel catfish comprised 2.4 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 17. More than 93 percent of all specimens were captured in water exceeding 34.4 C. Not enough specimens were collected in 1974 to draw any conclusions about temperature selection. A final temperature preference of 33.8 C was calculated from data collected by Cherry et al. (1974). This figure agreed very well with the field estimate of temperature preference of 33.9–35 C. The channel catfish represented the most important game fish in this section of the New River (Bryson et al. 1975).

Margined madtom *Noturus insignis* ssp.—One specimen was collected in September 1974 at Station 5 in 30 C water. Trembley (1960, cited in Brown 1974) observed one

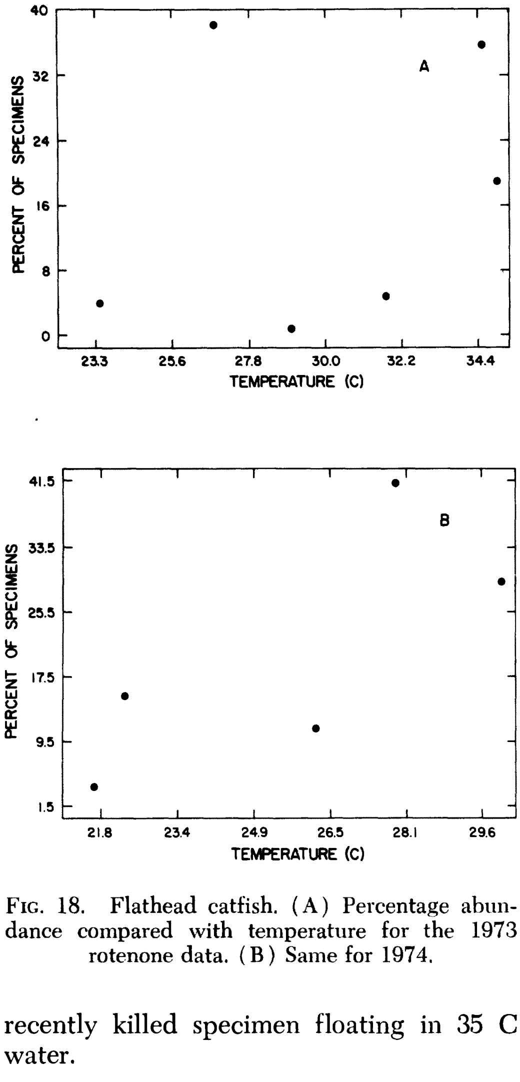


FIG. 18. Flathead catfish. (A) Percentage abundance compared with temperature for the 1973 rotenone data. (B) Same for 1974.

recently killed specimen floating in 35 C water.

Flathead catfish *Pylodictis olivaris* ssp. undet.—A total of 520 specimens was collected in 1973 at water temperatures of 23.3–35 C, and 47 specimens in 1974 at temperatures of 21.7–30 C. The flathead catfish comprised 1.3 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data (Fig. 18A). Stepwise regression analysis indicated that none of the variables tested could significantly (P=.05) explain the distribution of this species. More than 32 percent of this species was collected at 26.7 and 34.4 C.

In 1974, the flathead catfish was most abundant at 27.2 C (Fig. 18B). Gammon (1973) hypothesized that the final temperature preference of flathead catfish in the Wabash River ranged from 31.5 to 33.5 C. Proffitt and Benda (1971) reported flathead catfish in 33.6 C water. It was concluded that the thermal outfall did not significantly alter the distribution of this species.

Rock bass *Ambloplites rupestris rupestris.*—A total of 192 specimens was collected in 1973 at water temperatures of 20.6–35 C, and 204 specimens in 1974 at temperatures of 2.2–34.4 C. The rock bass comprised 0.9 percent of the total catch.

Percentage abundance when compared with temperature for the 1973 rotenone data (Fig. 19A) indicated a slight preference for temperature that ranged from 20 to 25.6 C. However, the stepwise regression analysis indicated that none of the variables tested significantly (P=.05) explained the distribution of this species. In 1974, the rock bass (Fig. 19B) was most abundant at 30 C.

The laboratory temperature preference data were best explained by TP=.51A+14.8 (P=.01, df=46), with 85 percent of the data explained by the regression (Fig. 19C). The calculated final temperature preference was 30.2 C. The laboratory upper avoidance temperature ranged from 27 C when fish were acclimated to 18 C to 33 C when fish were acclimated to 30 C (Table 3).

The laboratory final temperature preference agreed very well with the 1974 field data which indicated that the rock bass was most abundant at 30 C. The presence of some specimens in water temperatures as high as 35 C tended to support the relatively high upper avoidance temperature of 33 C.

Trembley (1960, cited in Brown 1974) found a mean body temperature of less than 30 C, but observed fish at temperatures as high as 32.2 C. Bailey (1955) observed that rock bass at water temperatures of 38 C showed signs of distress. Neill and Magnuson (1974) reported that rock bass main-

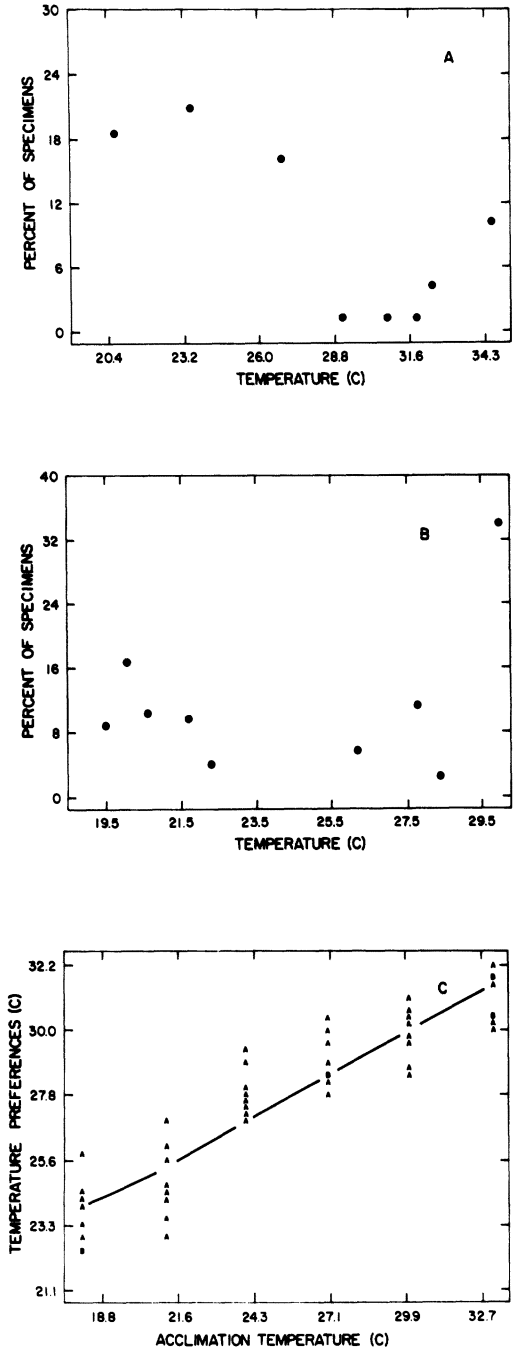


FIG. 19. Rock bass. (A) Percentage abundance compared with temperature for the 1973 rotenone data. (B) Same for 1974. (C) Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

tained a body temperature consistently lower than 29 C in a heated discharge in Wisconsin.

Both the literature review and the preference data indicated that the rock bass generally preferred water temperatures lower than the 35.6 C maximum temperature recorded in the heated effluent during this study. However, the avoidance data and field observations suggested that the rock bass would enter water temperatures as high as 35 C for at least short periods of time.

Redbreast sunfish *Lepomis auritus*.—A total of 139 specimens was collected in 1973 at water temperatures of 23.2–35 C, and 11 specimens in 1974 at temperatures of 12.2–30 C. The redbreast sunfish comprised 0.3 percent of the total catch. Van Vliet (1957, cited in Brown 1974) reported observations of the redbreast sunfish which swam directly into 40 C water, died, and made no effort to avoid the warm water.

Green sunfish *Lepomis cyanellus*.—Two specimens were collected in 1973 at water temperatures of 20.6 C and 26.7 C, and 13 specimens in 1974 at water temperatures of 20–30 C. Roots and Prosser (1962, cited by Brown 1974) determined that the greatest swimming speed of the green sunfish was reached at 35 C when fish were acclimated to 30 C. In light of this observation, it is doubtful if the presence of the thermal outfall significantly affected the distribution of this species.

Pumpkinseed *Lepomis gibbosus*.—One specimen was collected in July 1973 in 26.7 C water at Station 1. Trembley (1960, cited in Brown 1974) reported pumpkinseeds in a heated discharge with a temperature range of 30–35.6 C.

Bluegill *Lepomis macrochirus*.—A total of 68 specimens was collected at water temperatures of 20.6–35 C, and 50 specimens in 1974 at water temperatures of 21.1–30 C. The bluegill comprised approximately 0.3 percent of the total catch.

Specimens of the bluegill were obtained from a commercial dealer for laboratory avoidance experiments. The upper avoidance temperature ranged from 24 C when fish were acclimated at 12 C to 36 C when fish were acclimated at 33 C (Table 3).

Smallmouth bass *Micropterus dolomieui dolomieui*.—A total of 159 specimens was collected in 1973 at water temperatures of 20.6–35 C, and 220 specimens in 1974 at temperatures of 16.7–34.4 C. The smallmouth bass comprised 0.8 percent of the total catch. Stepwise regression analysis indicated that none of the variables tested significantly (*P*=.05) explained the distribution of this species.

The laboratory temperature preference data were best explained by the equation TP=.39A+18.8 (*P*=.01, df=46), with 72 percent of the data explained by the regression equation (Fig. 20A). The calculated final temperature preference was 30.8 C. The upper avoidance temperature ranged from 27 C when fish were acclimated at 18 C to 36 C when fish were acclimated to 33 C (Table 3).

The lack of any observed trends from the field data may have been due to a response of the smallmouth bass to forage fish movements rather than temperature. Hatch (1973, unpublished master's thesis, DePauw University, Greencastle, Indiana) showed that the movement of largemouth bass in the vicinity of a heated discharge was governed by forage fish movements. The avoidance data and the fish observations indicated that the smallmouth bass had the ability to exist at temperatures as high as 35 C.

Spotted bass *Micropterus punctulatus punctulatus*.—A total of 63 specimens was collected in 1973 at water temperatures of 23.3–32.2 C and 61 specimens in 1974 at temperatures of 20.6–32.2 C. The spotted bass comprised 0.3 percent of the total catch. Stepwise regression analysis indicated that none of the variables tested significantly (*P*=.05) explained the distribution of this species.

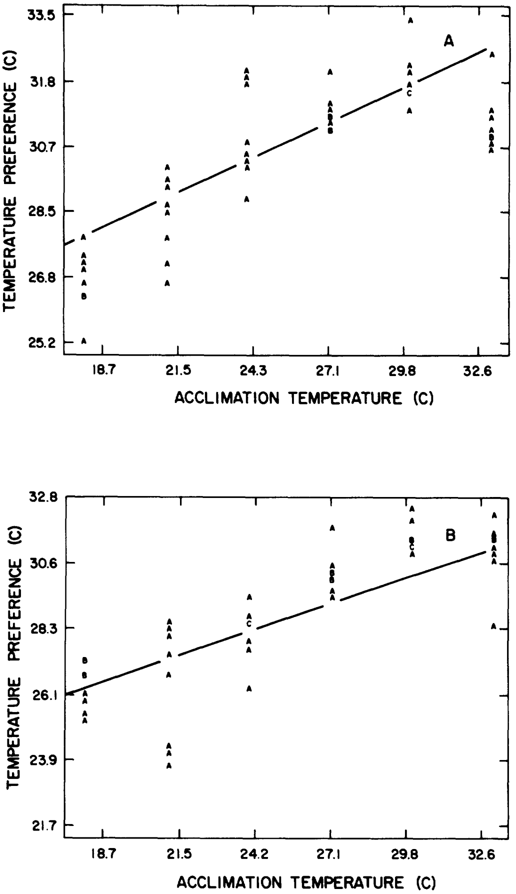


FIG. 20. (A) Smallmouth bass. (B) Spotted bass. Temperature preference compared with acclimation temperature, where A=1 observation, B=2, etc.

The laboratory temperature preference data were best explained by TP=.31A+22.1 (*P*=.01, df=46), with 62 percent of the data explained by the regression equation (Fig. 20B). The calculated final temperature preference was 32.0 C. Upper avoidance temperatures ranged from 33 to 39 C when fish were acclimated to 18 C and 33 C, respectively (Table 3).

Again, the lack of any observed trends from the field data may be due to a response governed by forage fish movement rather than by temperature, such as shown for the largemouth bass (Hatch unpublished master's thesis). The lack of observable trends from field data may have also been caused by the relatively small sample size (124 specimens). The avoidance data and field observations indicated that the spotted bass did exist in temperatures at least as high as 35 C. Therefore, it is concluded that temperatures experienced in this study did not limit the distribution of the spotted bass.

Largemouth bass *Micropterus salmoides salmoides*.—One specimen was collected in 1974 at Station 4 in 20 C water. Gibbons et al. (1972) reported movement of largemouth bass into heated discharge waters during the winter months in South Carolina. Dendy (1948, cited in Bennett 1971) reported that largemouth bass congregated at water temperatures between 26.6 C and 27.7 C.

White crappie *Pomoxis annularis*.—Three specimens of the white crappie were collected in September 1974 at Station 5 in 30 C water.

Gammon (1973) estimated the final temperature preference from field data to be 27 C. Walburg (1969, cited in Brown 1974) collected specimens at water temperatures of 0.5–21.1 C, while Proffitt and Benda (1971) collected specimens in water as high as 31.1 C.

Greenside darter *Etheostoma blennioides blennioides*.—A total of 604 specimens was collected in 1973 at water temperatures that ranged from 2.8 to 35 C, and 731 specimens in 1974 at temperatures of 4.4–35 C. The greenside darter comprised 3 percent of the total catch.

Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 21A. Stepwise regression analysis indicated that none of the variables tested significantly ($P=.05$) explained the distribution of this species. More than 15 percent of the specimens of the greenside darter were present in 20.6, 26.7, and 35 C water. In 1974, the greenside darter was most abundant at 22.2 C (Fig. 21B). Additional data concerning the temperature selection of this species were unavailable. The greenside darter did not respond in our laboratory temperature preference experiments. When placed in the trough, specimens would swim to the nearest corner and remain there, regardless of temperature.

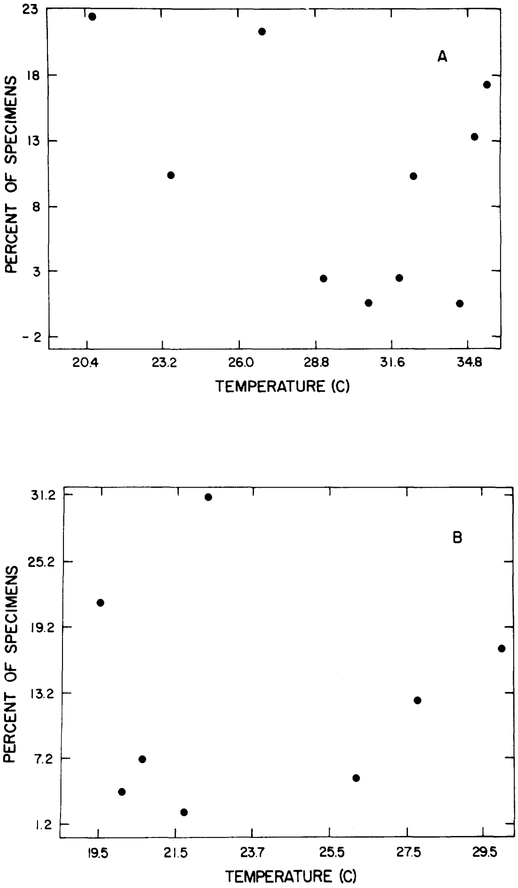


FIG. 21. Greenside darter. (A) Percentage abundance compared with temperature for the 1973 rotenone data. (B) Same for 1974.

Rainbow darter *Etheostoma caeruleum*.—One specimen of this species was captured in September 1974 in 22.2 C water. Hocutt et al. (1973) added the rainbow darter to the ichthyofauna of the upper New River, Virginia. The first record in the East River drainage was reported by Hambrick et al. (1973) in 20 C water. Data concerning the temperature selection of this species were not available.

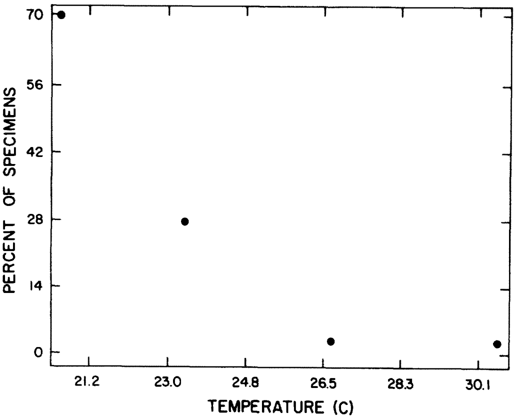


FIG. 22. Fantail darter. Percentage abundance compared with temperature for the 1973 rotenone data.

Fantail darter *Etheostoma flabellare* ssp.—A total of 65 specimens was collected in 1973 at water temperatures of 2.8–30.6 C, and 14 specimens in 1974 at temperatures of 19.4–20 C. The fantail darter comprised 0.2 percent of the total catch.

When placed in the laboratory temperature preference trough, the fantail darter would move to the nearest corner regardless of temperature. However, the field data showed a definite response of this species distribution to temperature (Fig. 22). The 1973 data indicated a preference for water temperatures between 19.4 and 20 C.

Finescaled saddled darter *Etheostoma osburni*.—Two specimens were collected in 1974 at water temperatures of 22.2–27.8 C.

Piedmont darter *Percina crassa roanoka*.—A total of 257 specimens was collected in 1973 at water temperatures of 20–35 C, and 542 specimens in 1974 at water temperatures of 8.9–32.2 C. The piedmont darter comprised 1.8 percent of the total catch.

Stepwise regression indicated that the distribution of the piedmont darter was significantly (P=.05, df=8) explained by photoperiod. The plots of percentage abundance versus temperature for both 1973 and 1974 did not illustrate any response which could be related to temperature (Fig. 23).

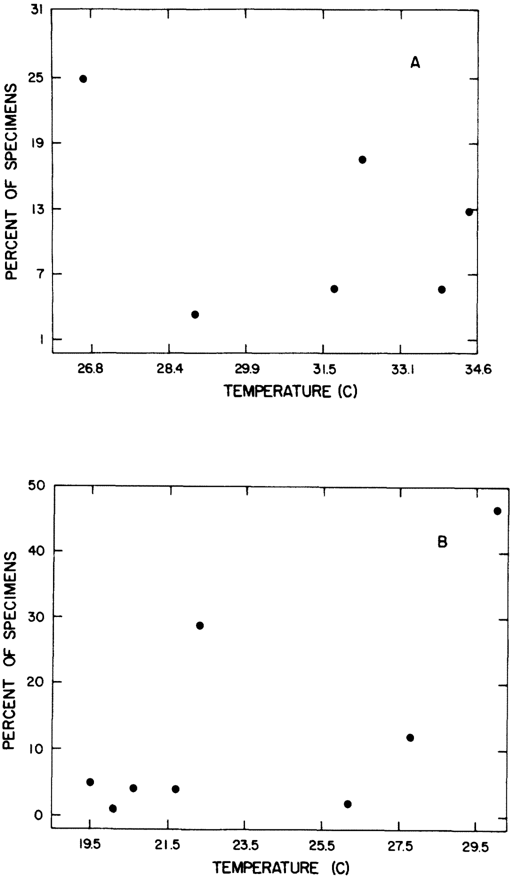


FIG. 23. Piedmont darter. (A) Percentage abundance compared with temperature for the 1973 rotenone data. (B) Samè for 1974.

Blackside darter *Percina maculata*.—One specimen was collected in June 1973 at Station 4 in 20.6 C, and another specimen was captured in September 1974 at Station 3 in 27.8 C water.

Sharpnose darter *Percina oxyrhyncha*.—A total of 23 specimens was collected in 1973 at water temperatures of 26.1–35 C, and 28 specimens in 1974 at temperatures of 20.6–30 C. The sharpnose darter comprised 0.1 percent of the total catch.

The sharpnose darter was originally listed as a possible rare and endangered species

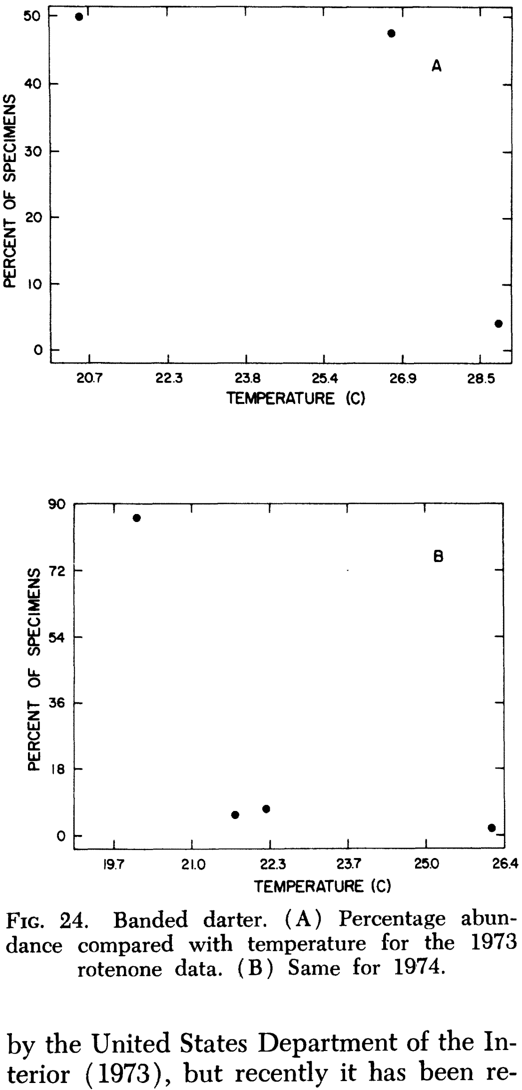


Fig. 24. Banded darter. (A) Percentage abundance compared with temperature for the 1973 rotenone data. (B) Same for 1974.

by the United States Department of the Interior (1973), but recently it has been removed from the list (R. E. Jenkins, pers. comm.). Of particular interest was the presence of the sharpnose darter at water temperatures as high as 35 C. This species was collected immediately below the heated discharge pipe every time rotenone was used at Station 5.

Mottled sculpin, *Cottus bairdi bairdi.*—Five specimens were collected in 1974 at temperatures of 15.6–23.3 C. Pflieger (1971, cited in Brown 1974) and Robins (1954, unpublished doctoral dissertation, Cornell University, Ithaca, New York) both indicated that this species preferred cool water temperatures. Ferguson (1958) listed the preferred summer temperature of a population in Ontario as 16.5 C.

Banded sculpin *Cottus carolinae* ssp.—A total of 243 specimens was collected in 1973 at water temperatures of 15.6–28.9 C, and 657 specimens in 1974 at temperatures of 16.7–29.4 C. The banded sculpin comprised 2.1 percent of the total catch. Percentage abundance is compared with temperature for the 1973 rotenone data in Fig. 24A. The 1973 data suggested that the banded sculpin avoided water temperatures above 28.3 C. The 1974 rotenone data indicated a definite preference for 20 C water (Fig. 24B). This response may have indicated a preference for the steeper gradient at Station 4 rather than a temperature response. Robins (unpublished doctoral dissertation) indicated that the banded sculpin could tolerate warmer temperatures than the mottled sculpin.

DISCUSSION

A plot of percentage abundance for some species demonstrated the drastic influence of temperature on fish distribution. However, the relationship between temperature and distribution was not as clear cut for other species. In the latter cases, it was felt that other variables which may influence fish distribution could modify the effect of temperature, or there was no influence of temperature on the distribution of these species.

Stream gradient, photoperiod, river flow, date, and time since last chlorination period were measured and recorded for each rotenone collection in 1973 (Table 4). The effect of stream gradient on fish distribution has been documented by Larimore (1957), Trautman (1942), and Hocutt and Stauffer (1975). Photoperiod has been reported to influence spawning migrations (Lagler, Bardach, and Miller 1962) and, therefore, distributional patterns. It was felt that river flow might be important since it fluctuates more rapidly than would be expected, due

TABLE 4.—REGRESSING VARIABLES USED IN STEPWISE REGRESSION ANALYSIS FOR EACH SAMPLING DATE FOR THE 1973 ROTENONE COLLECTIONS IN THE NEW RIVER DRAINAGE, GLEN LYN, VIRGINIA

Date	Station	Flow m^3/sec	Duration of Daylight (min)	Temperature C	Gradient m/km	Time Since Last Chlorination (min)
11 Jun	5	7.6	899	30.5	4.0	120
11 Jun	4	—	899	20.5	8.0	480
10 Jul	3	96.0	891	32.2	6.0	210
10 Jul	1	96.0	891	27.2	2.0	480
11 Jul	5	91.2	891	28.8	4.0	120
11 Jul	2	91.2	891	26.7	5.0	480
23 Jul	6	54.4	865	33.8	2.0	180
3 Sep	6	40.2	799	31.7	2.0	30
3 Sep	2	40.2	799	26.7	5.0	480
3 Sep	3	40.2	799	34.4	6.0	120
4 Sep	1	40.2	777	26.7	2.0	480
4 Sep	5	7.6	777	35.0	4.0	150
4 Sep	4	—	777	23.3	6.0	480

to its dependence on the operation of the hydroelectric facility 96.6 km upstream on Claytor Lake. Since all data were lumped over time in the temperature plots, the Julian date for each collection was recorded to account for any seasonal movements of fish not correlated with temperature. Chemical analysis indicated that the only change in water quality caused by the plant was an increase in temperature and the addition of chlorine for slime control. The time since the last chlorination period was recorded because chlorine is known to be toxic to many fish (Brungs 1973). Elevation and distance from source were shown to influence fish distribution (Sheldon 1968, Trautman 1942, Vincent and Miller 1963). Elevation and distance from source were not considered important in this study because all stations were within 4.8 river kilometers from one another. Depth and substrate were not significantly different between stations, because all stations were chosen to be similar.

The above chemical and physical factors could not be controlled under field conditions. Therefore, the influence of individual parameters or selected combinations of parameters could only be determined by analyzing all of the data simultaneously. To do this, a stepwise regression procedure in combination with forward selection, backward elimination, and maximum R^2 improvement procedures were used (Draper and Smith 1966). This technique regressed all possible combinations of variables against the dependent variable abundance. These procedures determined if, after one variable was placed in the model, the addition of another variable significantly ($P=.05$) increased the amount of data explained by the regression. Although this technique assumed a linear model as well as other parametric statistical assumptions, it was felt that it provided enough sensitivity to screen for other variables which may explain the distribution of the fish. If a variable in addition to or in lieu of temperature was selected, it could then be corrected for sampling effort and plotted against abundance. This plot and the temperature abundance plot could then be qualitatively compared to determine the effects on a particular species distribution. For a more detailed discussion of the advantages and disadvantages of this technique, see Stauffer et al. (1975b).

Other studies which evaluated distributional patterns of fishes in large rivers could not describe adequately the effect of temperature, due to its close correlation with locational and seasonal changes. The heated discharge into the New River, however, allowed examination of the effect of varying temperature regimes, which were independent of great differences in time and place, on fish distribution. Furthermore, this study site was unique in that it was virtually free from other industrial and large municipal discharges which could modify fish distribution.

The on-site laboratory studies which were a part of this investigation provided specific advantages: (1) water quality changes were minimized between laboratory and field conditions by pumping river water directly into the laboratory, (2) handling time and transportation distances for fish were greatly reduced, and (3) duplication of dynamic field conditions were more easily attained under the semicontrolled laboratory situation.

The laboratory temperature preference studies established final temperature preferences of 9 species in the New River drainage. Seven of the above species were captured in the vicinity of APCo's fossil fuel plant. Preference data taken from local populations of 2 other species were available from the literature.

There was an excellent correlation between field and laboratory estimates of temperature preference for those species which on-site populations were used for the laboratory data with the exception of the spotfin shiner. The spotfin shiner was euryecious, and, therefore, no estimate of the final temperature preference from field data could be generated. The laboratory upper avoidance temperatures of on-site populations also agreed fairly well with the highest temperature recorded in the field for a particular species.

There was a poor relationship between the laboratory and field determined temperature selection response of the telescope shiner. As stated earlier, this discrepancy may have been because specimens for laboratory experiments were collected from a springfed tributary, upstream from the study area; thus, the laboratory specimens may have had a different thermal history and maybe a different genetic background than those specimens collected at the study site.

In light of this discussion, we believe that laboratory generated temperature selection data is an extremely useful tool in analyzing and predicting the temperature relationships of fish species if laboratory specimens are taken from the populations at the site to which the results will be applied. Not only did laboratory data reflect field observations, but it was essential also to understand the temperature responses of species for which there were not enough data to determine temperature selection from field data; and to determine if the field data were potentially confused by species interactions, such as the case for the smallmouth and spotted basses.

On the other hand, field estimates of temperature selection were also necessary to determine (1) the response of those fishes which did not respond in the laboratory situation, such as the fantail darter; (2) to lend credence to the laboratory data; and (3) to screen for unexpected responses such as those described for the spotfin shiner.

The use of field data to support and understand the laboratory responses is especially important. Based solely on the laboratory data, one might conclude that fishes would not inhabit water temperatures above the upper avoidance temperatures. An examination of the field data showed that fishes generally inhabited warmer waters than the laboratory upper avoidance temperatures.

Another major advantage of the field studies was, in addition to determining temperature preference, they can provide valuable information about population sizes, year class differences, changes in community structure, and relative growth rates without further sampling effort.

SUMMARY

1. Temperature preference and avoidance data of several fish species on which there was previously little or no information were provided. Historically, this type of information was generated for only important sport fishes or extremely abundant forage fishes. We were not able to determine laboratory responses for any of the species of either the genus *Etheostoma* or *Percina*. Modifica-

TABLE 5.—SUMMARY OF FINAL FIELD AND LABORATORY TEMPERATURE PREFERENCES, UPPER AVOIDANCE TEMPERATURES, AND HIGHEST FIELD TEMPERATURES OF IMPORTANT SPECIES CAPTURED IN THE NEW RIVER, GLEN LYN, VIRGINIA.

Species	Field Temp. Pref.	Lab. Temp. Pref.	Upper Avoidance (Acc. Temp.)	Highest Field Temp.
Stoneroller	22.8–23.8 C	26.8 C	33 C (27 C)	34.4 C
Rosyface shiner	28.3–30 C	28.3 C	33 C (27 C)	35 C
Spotfin shiner	[1]	29.8 C	36 C (33 C)	35 C
Bluntnose minnow	26.7 C	26.7 C	30 C (27 C)	35 C 37.8 C[2]
Channel catfish	34.4 C	33.8 C[3]	—	35 C

[1] Could not be determined from field data.
[2] Based on observations by Bailey (1955).
[3] Based on work by Cherry et al. (1974).

tions in technique or design of the laboratory experiments are needed to test those species.

2. The importance of studying the effects of environmental parameters of each species on a site specific basis was demonstrated. There was a good correlation between laboratory and field estimates of temperature preference of those species for which local populations were used to derive both types of data except for the spotfin shiner. Field and laboratory temperature preferences differed primarily when local populations were not used for laboratory studies.

3. There were 5 basic responses to temperature that this study identified: (1) fishes that avoided warm temperatures and had a relatively cool final temperature preference such as the northern hog sucker and the stoneroller; (2) fishes that were attracted to warm temperatures and had a relatively warm final temperature preference such as the channel catfish; (3) fishes that showed a preference temperature–acclimation temperature relationship in the laboratory, but demonstrated no preference temperature in the field, such as the spotfin shiner; (4) fishes, such as the smallmouth bass, that had a distribution potentially affected by forage fish distribution and which were not present in sufficient numbers to make a field determination, but did respond to laboratory conditions; and (5) fishes, such as the fantail darter, that did not demonstrate any temperature selection under laboratory conditions, but did have a field distribution markedly correlated with temperature.

4. The stoneroller, rosyface shiner, spotfin shiner, and bluntnose minnow were designated as important forage species based on abundance. The channel catfish was deemed the most important sport fish based on work by Bryson et al. (1975). None of the species collected in this study was considered either as commercial or rare and endangered.

5. The application of multivariate screening techniques to in situ fish allowed the influence of temperature with respect to other variables which are reported to affect fish distribution to be evaluated. The results indicated that with the exception of the spotfin shiner, temperature was extremely important in determining the local distribution patterns of the important species (Table 5).

LITERATURE CITED

ALPAUGH, W. C. 1972. High lethal temperatures of golden shiners (*Notemigonus crysoleucas*). Copeia 1972(1):185.

BAILEY, R. M. 1955. Differential mortality from high temperatures in a mixed population of fishes in southern Michigan. Ecology 36(3): 526–528.

BENNETT, D. H. 1971. Preliminary examination of body temperatures of largemouth bass (*Micropterus salmoides*) from an artificially heated reservoir. Arch. Hydrobiol. 68(3): 376–381.

BERKOWITZ, D. A., AND A. M. SQUIRES. 1969. *In* Power Generation and Environmental Change. Symposium of the Committee on Environmental Alternation, Amer. Ass. Adv. Sci., Washington, D. C. 440 pp.

BRETT, J. R. 1944. Some lethal temperature relations of Algonquin Park fishes. Univ. Toronto Stud., Biol. Ser. No. 52. Publ. Ont. Fish. Res. Lab. 63:1–59.

———. 1952. Temperature tolerance of young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Bd. Can. 9:265–323.

BROWN, H. W. 1974. A handbook of the effects of temperature on some North American fishes. Amer. Elec. Power Serv. Corp., Canton, Ohio. 431 pp.

BRUNGS, W. A. 1973. Effects of residual chlorine on aquatic life: literature review. J. Water Poll. Cont. Fed. 10:2180–2193.

BRYSON, W. T., R. T. LACKEY, J. CAIRNS, JR., AND K. L. DICKSON. 1975. Restocking after fish kills as a fisheries management strategy. Trans. Amer. Fish. Soc. 104(2):256–263.

BURTON, G. W., AND E. P. ODUM. 1945. The distribution of stream fish in the vicinity of Mountain Lake, Virginia. Ecology 26(2):182–194.

CAIRNS, J., JR. 1971. Thermal pollution—a cause for concern. J. Water Poll. Cont. Fed. 43(1): 55–66.

———. 1972. Coping with heated waste discharges from stream electric power plants. BioScience 22(7):411–420.

CHERRY, D. S., K. L. DICKSON, AND J. CAIRNS, JR. 1974. The use of a mobile laboratory to study temperature responses of fish. Proc. 29th Purdue Indust. Conf., Purdue University, Lafayette, Ind. 28 pp.

CLARK, J. R. 1969. Thermal pollution and aquatic life. Scient. Amer. 220(3):3–11.

COOPER, G. P., AND J. L. FULLER. 1945. A biological survey of Moosehead Lake and Haymock Lake, Maine. Maine Dept. Inland Fish. Game. Fish Surv. Rept. 6:1–160.

COUTANT, C. C. 1974. Temperature selection by fish—a factor in power plant impact assessment. Symposium on the Physical and Biological Effects on the Environment of Cooling Systems and Thermal Discharges at Nuclear Power Stations. Oak Ridge National Laboratory, Oak Ridge, Tenn. 25 pp.

DENDY, J. S. 1948. Predicting depth distribution of fish in three TVA storage type reservoirs. Trans. Amer. Fish. Soc. 75:88–142.

DOUDOROFF, P. 1938. Reactions of marine fishes to temperature gradients. Biol. Bull. 75:494–509.

DRAPER, N. R., AND H. SMITH. 1966. Applied Regression Analysis. John Wiley & Sons, Inc. New York, N. Y. 407pp.

ENVIRONMENTAL PROTECTION AGENCY. 1973. Proposed criteria for water quality. 1:144–170.

FERGUSON, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Can. 15(4):607–624.

FISHER, K. C., AND P. ELSON. 1950. The selected temperature of Atlantic salmon and speckled trout and the effect of temperature on the response to an electrical stimulus. Physiol. Zool. 23:28–34.

FRY, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud., Biol. Ser. No. 55. Publ. Ont. Fish. Res. Lab., No. 68:1–62.

GAMMON, J. R. 1973. The effect of thermal inputs of the populations of fish and macroinvertebrates in the Wabash River. Purdue Univ. Water Res. Res. Cent. Tech. Rept. 32. 106 pp.

GARSIDE, E. T., AND J. S. TAIT. 1958. Preferred temperature of the rainbow trout (*Salmo gairdneri* Richardson) and its unusual relationship to acclimation temperature. Can. J. Zool. 36: 563–567.

GIBBONS, J. W., J. T. HOOK, AND D. L. FORNEY. 1972. Winter responses of largemouth bass to heated effluent from a nuclear reactor. Prog. Fish-Cult. 34(2):88–90.

GILBERT, C. R. 1964. The american cyprinid fishes of the subgenus *Luxilus* (genus *Notropis*). Bull. Fla. St. Mus. 8(2):194.

GRUCHY, P. G., AND R. H. BOWEN. 1973. First records of the silver shiner, *Notropis photogenis*, from Canada. J. Fish. Res. Bd. Can. 30: 1379–1382.

HAMBRICK, P. S., C. H. HOCUTT, M. T. MASNIK, AND J. H. WILSON. 1973. Additions to the West Virginia ichthyofauna, with comments on the distribution of other species. W. Va. Acad. Sci. 45(1):58–60.

HILL, L. G. 1968. Oxygen preference in the spring cave fish, *Chologaster agassizi*. Trans. Amer. Fish. Soc. 97:448–454.

HOCUTT, C. H., P. S. HAMBRICK, AND M. T. MASNIK. 1973. Rotenone methods in a large river system. Arch. Hydrobiol. 72(2):245–252.

———, AND J. R. STAUFFER. 1975. The influence of gradient on the longitudinal distribution of fishes. Chesapeake Sci. 16(1):143–147.

HOGERTON, J. F. 1968. The arrival of nuclear power. Scient. Amer. 218(2):21–31.

JENKINS, R. E., AND C. A. FREEMAN. 1972. Longitudinal distribution and habitat of the fishes of Mason Creek, an upper Roanoke River Drainage tributary, Virginia. Va. J. Sci. 23(4): 194–202.

JONES, J. R. E. 1952. The reactions of fish to water of low oxygen concentrations. J. Exp. Biol. 29:403–415.

KENNEDY, W. A. 1941. The migration of fish from a shallow lake to a deep lake in spring and early summer. Trans. Amer. Fish. Soc. 70:391–396.

LACHNER, E. A., AND R. E. JENKINS. 1971. Systematics, distribution, and evolution of the chubs genus *Nocomis* Girard (Pisces, Cyprinidae) of eastern United States, with descriptions of new species. Smithson. Cont. Zool. 85:1–97.

LAGLER, K. R., J. E. BARDACH, AND R. R. MILLER. 1962. Ichthyology. John Wiley & Sons, Inc. New York, N. Y. 545 pp.

LARIMORE, R. W. 1957. Ecological life history of the warmouth (Centrarchidae). Ill. Nat. Hist. Surv. Bull. 27(1):1–83.

MCKEE, J. E. 1968. The impact of nuclear power on air and water resources. Engin. Sci. 31(9): 19–22, 31–32.

MELDRIM, J. W., AND J. W. GIFT. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyological Associates, Bull. 7:1–75.

MIHURSKY, J. A., AND R. L. COREY. 1965. Thermal loading and the aquatic environment. An approach to understanding an estuarine ecosystem. Paper presented at the International Conference on Industrial Electronics/Control Instrumentation, 8–10 Sep., Philadelphia, Pa.

NEILL, W. H., AND J. J. MAGNUSON. 1974. Distribution ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Trans. Amer. Fish. Soc. 103(4):663–710.

PARKER, F. L., AND P. A. KRENKEL. 1969. Engineering Aspects of Thermal Pollution. Vanderbilt Univ. Press, Nashville, Tenn. 351 pp.

PFLIEGER, W. L. 1971. A distributional study of Missouri fishes. Univ. Kansas, Mus. Nat. Hist. Publ. 20(3):255–270.

PICTON, W. L. 1960. Water use in the United States. 1900–1975. Bull. 136. Water and Sewage Division, U. S. Dept. Comm., Washington, D. C.

PITT, T. K., E. T. GARSIDE, AND R. L. HEPBURN. 1956. Temperature selection of the carp (*Cyprinus carpio*, Linn.). Can. J. Zool. 34:555–557.

PROFFITT, M. A., AND R. S. BENDA. 1971. Growth and movement of fishes, and distribution of invertebrates, related to a heated discharge into the White River at Petersburg, Indiana. Ind. Univ. Water Res. Cent., Bloomington, Ind. Rept. Invest. No. 5. 95 pp.

ROBBINS, T. W., AND D. MATHUR. 1974. Preoperational report on the ecology of Conowingo Pond for units No. 2 and 3. Ichthyological Associates, Inc. (March 1974). p. 5–12.

ROOTS, B. I., AND C. L. PROSSER. 1962. Temperature acclimation and the nervous system in fish. J. Exp. Biol. 39(4):617–629.

SHELDON, A. L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49(2):193–198.

SHELFORD, V. E., AND W. C. ALLEE. 1913. The reactions of fishes to gradients of dissolved atmospheric gasses. J. Exp. Zool. 14:207–266.

SOKAL, R. R., AND F. J. ROHLF. 1969. Biometry. W. H. Freeman and Company San Francisco, Cal. 776 pp.

SPRAGUE, J. B. 1964. Avoidance of copper-zinc solutions by young salmon in the laboratory. J. Water Poll. Cont. Fed. 36:990–1004.

STANLEY, J. G., AND P. J. COLBY. 1971. Effects of temperature on electrolyte balance and osmoregulation in the alewife (*Alosa pseudoharengus*) in fresh and sea water. Trans. Amer. Fish. Soc. 100(4):624–638.

STAUFFER, J. R., D. S. CHERRY, K. L. DICKSON, AND J. CAIRNS, JR. 1975a. Laboratory and field temperature preference and avoidance data of fish related to the establishment of standards. Pp. 110–139. Saila, S. B. (Ed.). *In*: Fisheries and Energy Production. Lexington Books, D. C. Heath and Co., Lexington, Mass. 300 pp.

———, K. L. DICKSON, J. CAIRNS, JR., W. F. CALHOUN, M. T. MASNIK, AND R. H. MYERS. 1975b. Summer distribution of fish species in the vicinity of a thermal discharge—New River, Virginia. Arch. Hydrobiol. 76(3):287–301.

SUMMERFELT, R. C., AND C. O. MINCKLEY. 1969. Aspects of the life history of the sand shiner, *Notropis stramineus* (Cope), in the Smoky Hill River, Kansas. Trans. Amer. Fish. Soc. 98(3):444–453.

TRAUTMAN, M. B. 1942. Fish distribution and abundance correlated with stream gradients as a consideration in stocking programs. Trans. N. Amer. Wildl. Conf. 7:211–224.

TREMBLEY, F. J. 1960. Research project on effects of condenser discharge water on aquatic life, progress report 1956–1959. Inst. Res., Lehigh Univ., Bethlehem, Pa. 154 pp.

———. 1961. Research project on effects of condenser discharge water on aquatic life, progress report 1960. Inst. Res., Lehigh Univ., Bethlehem, Pa. 82 pp.

———. 1965. Effects of cooling water from stream electric power on stream biota. Pp. 334–335. *In*: Biological problems in water pollution, 3rd Seminar (1962). U. S. Public Health Service Publ. 999-WP-25. 434 pp.

UNITED STATES DEPARTMENT OF THE INTERIOR, FISH AND WILDLIFE SERVICE. 1973. Threatened wildlife of the United States. Res. Publ. 114. 289 pp.

VAN VLIET, R. 1957. Effects of heated condenser discharge water upon aquatic life. Amer. Soc. Mech. Engin. Pap. No. 57PWR-4, 10 pp.

VINCENT, R. E., AND W. H. MILLER. 1969. Altitudinal distribution of brown trout and other fishes in a headwater tributary of the South Platte River, Colorado. Ecology 50(3):464–466.

WALBURG, C. H. 1969. Fish sampling and estimation of relative abundance in Lewis and

Clark Lake. U. S. Bur. Sport Fish. Wildl. Tech. Pap. No. 18. 15 pp.

WELLS, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. U. S. Fish Wildl. Serv. Fish Bull. 67(1):1–15.

———, AND R. HOUSE. 1974. Life history of the spottail shiner (*Notropis hudsonius*) in southeastern Lake Michigan, the Kalamazoo River, and western Lake Erie. U. S. Bur. Sport Fish. Wildl. Res. Rept. 78. 10 pp.

WOLLITZ, R. E. 1968. Smallmouth bass stream investigations. Job No. 1, New River study. Virginia's Dingell-Johnson Projects, No. F-14-R-5, Comm. Game Inland Fish., Richmond, Va. 59 pp.