Preferred, Avoided, and Lethal Temperatures of Fish During Rising Temperature Conditions

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4 authors, including:

John Cairns,Jr.
Virginia Tech (Virginia Polytechnic Institute and State University)

Jay Richard Stauffer
Pennsylvania State University

Preferred, Avoided, and Lethal Temperatures of Fish During Rising Temperature Conditions

DONALD S. CHERRY, KENNETH L. DICKSON, JOHN CAIRNS JR.

Biology Department and Center for Environmental Studies, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

AND JAY R. STAUFFER

Appalachian Environmental Laboratory, Center for Environmental and Estuarine Studies, University of Maryland, Frostburg State College Campus, Frostburg, Maryland 21532, USA

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Selected temperatures increased for 15 fish species in a laboratory gradient when acclimated to 3°C increments from 12 to 27°C. Temperature preferences exceeded acclimation temperatures between 12 to 27°C for all except the telescope shiner (*Notropis telescopus*), yellow perch (*Perca flavescens*), rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*). At 30, 33, or 36°C acclimation, preferred temperatures were less than the acclimation temperature. The highest temperature preferences occurred at acclimations of 27, 30, or 33°C. Bluegill (*Lepomis macrochirus*), spotted bass (*Micropterus punctulatus*), rockbass (*Ambloplites rupestris*), and the spotfin shiner (*Notropis spilopterus*) consistently selected the highest temperatures while the lowest temperatures were preferred by the salmonids. Final temperature preferences were usually greater than 29°C for most centrarchids, above 24°C for most cyprinids, and less than 19°C for salmonids.

Avoidance temperatures increased as acclimation temperature increased. Upper avoidances tested at high acclimation temperatures (30–36°C) either equalled or exceeded the 7-day upper lethal temperature limit of the species by 1–2°C, while avoidances were below this upper lethal limit when tested at the acclimation temperature closest to the species' final temperature preference.

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Les températures choisies augmentent pour 15 espèces de poissons dans un gradient en laboratoire lorsque acclimatés à des augmentations de 3°C entre 12 et 27°C. Les températures préférées dépassent les températures d'acclimatation entre 12 et 27°C chez toutes les espèces, sauf le méné télescope (*Notropis telescopus*), la perchaude (*Perca flavescens*), la truite arc-en-ciel (*Salmo gairdneri*), la truite brune (*Salmo trutta*) et l'omble de fontaine (*Salvelinus fontinalis*). A des températures d'acclimatation de 30, 33 ou 36°C, les températures préférées sont inférieures à la température d'acclimatation. Les températures préférées les plus élevées se rencontrent à des températures d'acclimatation de 27, 30 ou 33°C. Le crapet arlequin (*Lepomis macrochirus*), l'achigan tacheté (*Micropterus punctulatus*), le crapet de roche (*Ambloplites rupestris*) et le méné bleu (*Notropis spilopterus*) choisissent invariablement les plus hautes températures, alors que les salmonidés préfèrent les plus basses températures. Les préférences finales de température sont ordinairement supérieures à 29°C pour la plupart des centrarchidés, supérieures à 24°C pour la plupart des cyprinidés et inférieures à 19°C pour les salmonidés.

Les températures d'évitement augmentent à mesure que la température d'acclimatation augmente. Les températures d'évitement supérieures essayées à de hautes températures d'acclimatation (30–36°C) sont égales à la limite supérieure de température létale après 7 jours pour l'espèce ou les dépassent de 1–2°C, alors que les températures d'évitement sont inférieures à cette limite létale supérieure lorsque essayées à la température d'acclimatation la plus rapprochée de la préférence de température finale de l'espèce.

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THE preferred, avoided, and lethal temperatures were determined for 15 fish species at a field laboratory during rising temperature conditions. The laboratory is located near the confluence of the thermally influenced New and East rivers, Glen Lyn, Virginia. The impact of thermal loading has prompted many investigations and literature reviews about this discharge, but few studies have analyzed the relationship of these temperature criteria at the power plant site during a full year of falling and rising temperature conditions. Specific advantages of this study over traditional laboratory investigations include the ease of evaluating fish responses to thermal discharges by reducing transportation time after capture, and in utilizing river water to acclimate and test fish responses (Cherry et al. 1975).

A temperature preference and avoidance review has been compiled by Coutant (1975), and differences between temperatures selected during rising versus falling conditions have been reported (Meldrim and Gift 1971; Sullivan and Fisher 1953). Temperature responses under various conditions and thermal histories are necessary for understanding and predicting fish movements in thermal discharges. In this study the responses between each temperature condition are analyzed and the final temperature preferendum for each species calculated. At acclimation temperatures closest to the final preferendum, the avoidance response is compared to the lethal temperature in order to provide information related to the optimum temperature range.

Materials and Methods

Sources of Fish

Most fish were collected by seining in the New River drainage system and were immediately brought to the field laboratory and maintained there. Holding conditions, feeding, and acclimation procedures were reported in Cherry et al. (1975) where a description of the research site is also given. Five species, bluegill (*Lepomis macrochirus*), rainbow trout (*Salmo gairdneri*), brown trout (*S. trutta*), brook trout (*Salvelinus fontinalis*), and yellow perch (*Perca flavescens*) were obtained from state or commercial fish hatcheries since they were either uncommon or absent from the Glen Lyn site. All species except the cyprinids were 1 yr old or less, and no gravid individuals were used. Most species tested ranged from 50 to 100 mm fork length (FL) except yellow perch which were 30–50 mm FL.

Temperature Preference Trials

Group preference temperatures were obtained as described by Cherry et al. (1975). Data points were evaluated by a least squares regression analysis (with 95% confidence limits) between acclimation and preference temperatures (Sokal and Rohlf 1969). Statistical linear and curvilinear hypotheses were used to test the equality of regression lines calculated for the same acclimation temperature during falling conditions (Cherry et al. 1975) with those calculated for rising conditions. Statistical significance ($P = 0.05$) was obtained from the equation:

$$F = \frac{(SS_{e3} - [SS_{e1} + SS_{e2}])/\times}{SS_{e1} + SS_{e2}/df_1 + df_2}$$

where SS_{e1} and SS_{e2} are the sum of squares for the regressions during rising and falling temperature, SS_{e3} is the sum of squares of the joint regression (rising and falling conditions combined), df_1 and df_2 are the degrees of freedom for rising and falling temperatures, and $\times$ is the number of factors regressed in the regressions of rising and falling conditions minus the number regressed in the joint regression (Myers, Department of Statistics, Virginia Polytechnic Institute and State University, personal communication).

A stepwise regression procedure was used to analyze whether a linear or first to fifth order curvilinear regression could significantly ($P = 0.05$) fit the temperature preferences through the acclimation temperatures tested (Sokal and Rohlf 1969). From the best fit calculated, the final temperature preferences or temperature preferenda were obtained as the point where the regression line intersected a theoretical acclimation line with a slope of one (Fry 1947).

Avoidance Trials

The avoidance trials were conducted in a trough described by Cherry et al. (1975) with some modifications in the gradient formation and in the statistical analysis. The trough consisted of two distinct temperature regions (T_1 and T_2), one on each side of the center drains. A control trial run consisted of T_1 and T_2 being equal to the acclimation temperature and after a 40-min orientation period (to as much as 120 min for slowly adjusting species) fish were continuously monitored for 10 min to establish a control or reference response. Responsive fish spent approximately 5 min on each half of the trough through continuous random movement. In successive trials, each with a 10-min monitoring period, first one side (T_2) was elevated by 3°C followed by raising both sides by 3°C with the higher side always being 3°C greater. This procedure attempted to simulate fish movement up the thermal gradient in the New River where temperature tended to increase upstream toward the discharge condensor pipes. Since statistically significant avoidances always occurred at the first 3°C increment for tests conducted at the highest acclimation temperature (e.g. $T_1 = 36$°C and $T_2 = 39$°C), adjustments were made in the gradient to identify the first specific temperature within this 3°C increment in which 9 min of the 10-min monitoring period was spent away from a temperature above acclimation ("absolute" avoidance). In this procedure, the center and side drains were manipulated to allow mixing to occur on each side of the drain which ɪBLE 1. Preferred temperatures with (in parentheses) 95% confidence limits of 15 fish species, each tested in groups of eight with one ɔlication, sampled continuously during rising temperature conditions from the New and East rivers Virginia, and from state fish hatch-es at acclimation temperatures from 12 °C in March to 36 °C in October.

	Acclimation temp (°*C*)								
	12	15	18	21	24	27	30	33	36
prinidae									
Campostoma anomalum (Stoneroller)	16.5 (18.2–14.2)	17.0 (19.8–16.7)	21.0 (21.6–19.2)	22.4 (23.6–21.4)	25.1 (25.9–23.4)	28.2 (28.3–25.2)	27.4 (30.8–26.9)	—[b]	—[b]
Pimephales promelas (Fathead minnow)	19.5 (20.7–17.0)	21.2 (21.9–18.9)	20.9 (23.2–20.8)	22.0 (24.6–22.6)	25.4 (26.4–24.0)	27.6 (28.3–25.3)	28.7 (30.3–26.5)	—[b]	—[b]
Pimephales notatus (Bluntnose minnow)	19.3 (20.0–18.0)	20.9 (21.5–19.9)	21.9 (23.0–21.7)	23.2 (24.6–23.5)	26.4 (26.4–25.2)	27.9 (28.8–26.7)	29.0 (30.2–28.2	—[b]	—[b]
Notropis rubellus (Rosyface shiner)	20.8 (22.2–18.7)	21.7 (23.0–20.2)	22.2 (24.0–21.7)	22.5 (25.0–23.0)	25.8 (26.2–24.2)	28.1 (27.5–25.2)	28.0 (29.0–26.2)	27.7 (30.5–27.0)	—[b]
Notropis spilopterus (Spotfin shiner)	21.4 (24.4–19.3)	21.8 (25.2–21.0)	24.1 (26.2–22.7)	26.4 (27.2–24.3)	27.3 (28.4–25.7)	30.6 (29.8–26.9)	31.8 (31.4–28.0)	31.0 (33.1–28.9)	29.2 (34.8–29.8)
Notropis telescopus (Telescope shiner)	14.2 (16.3–11.5)	15.4 (18.0–14.4)	17.7 (19.9–17.0)	22.6 (22.1–19.3)	23.2 (24.8–21.2)	24.4 (27.6–22.8)	—[b]	—[b]	—[b]
ntrarchidae									
Lepomis macrochirus[a] (Bluegill)	24.1 (25.7–23.2)	25.2 (26.5–24.5)	26.8 (27.4–25.7)	27.8 (28.3–26.8)	28.2 (29.2–27.8)	30.0 (30.3–28.9)	32.4 (31.5–29.8)	30.9 (32.7–30.6)	31.8 (33.9–31.4)
Micropterus dolomieui (Smallmouth bass)	—[c]	20.2 (25.7–19.5)	25.5 (26.6–21.7)	25.8 (27.5–23.7)	28.2 (28.8–25.4)	29.7 (30.6–26.7)	30.9 (32.6–27.7)	29.4 (34.8–28.5)	—[b]
Micropterus punctulatus (Spotted bass)	—[c]	24.8 (24.4–20.5)	26.8 (28.2–25.6)	28.0 (28.8–26.8)	30.6 (29.6–27.8)	29.9 (30.5–28.7)	30.5 (31.6–29.5)	31.5 (32.7–30.2)	31.4 (33.9–30.8)
Ambloplites rupestris (Rockbass)	—[c]	—[c]	23.2 (26.3–21.3)	24.0 (27.2–23.2)	28.4 (28.2–25.1)	28.4 (29.4–26.6)	29.7 (31.0–27.9)	32.2 (32.8–28.9)	30.4 (34.8–29.8)
ostomidae									
Hypentilium nigricans (Northern hog sucker)	15.3 (12.5–19.8)	20.2 (21.2–15.4)	16.9 (22.8–18.1)	23.0 (24.6–20.6)	27.0 (26.8–23.7)	28.7 (29.2–24.5)	29.4 (32.0–26.1)	28.8 (34.8–27.6)	—[b]
cidae									
Perca flavescens[a] (Yellow perch)	—[c]	19.2 (19.9–18.5)	20.4 (20.7–19.8)	21.1 (21.8–20.8)	22.4 (28.0–21.6)	—[b]	—[b]	—[b]	—[b]
monidae									
Salmo gairdneri[a] (Rainbow trout)	14.1 (15.7–13.4)	17.1 (17.3–15.7)	18.6 (19.1–17.8)	20.2 (21.1–19.6)	22.2 (23.4–21.2)	—[b]	—[b]	—[b]	—[b]
Salmo trutta[a] (Brown trout)	11.7 (16.2–9.5)	15.5 (17.0–12.4)	17.9 (18.4–14.7)	18.8 (20.8–16.0)	18.5[d] (22.8–16.6)	—[b]	—[b]	—[b]	—[b]
Salvelinus fontinalis[a] (Brook trout)	13.7 (15.0–12.8)	15.2 (16.1–14.5)	17.2 (17.3–16.0)	18.3 (18.8–17.2)	19.0 (20.5–18.2)	—[b]	—[b]	—[b]	—[b]

Fish obtained from state hatcheries.
Acclimation temperature approached or exceeded lethal limits.
No fish available.
Acclimation temperature was 23°C.

formed four different temperature regions (e.g. from $T_1 = 36°C$ and $T_2 = 39°C$ to $T_{1\text{-}4} = 36, 37, 38, 39°C$).

Statistical avoidances were determined only at 3°C increments from a 2-way factorial analysis of variance (Sokal and Rohlf 1969) whereas in the previous study (Cherry et al. 1975), avoidances were obtained at specific 1°C increments. A Duncan's new multiple range test was conducted by utilizing the mean square term from the time spent in the fixed temperature increment with the degrees of freedom from the interaction term, "fish group × temperature interval". A statistical avoidance occurred when significantly ($P = 0.05$) less time was spent at the higher temperature side of the trough relative to that during the control run. A thorough description of the statistical analysis is presented in Stauffer (1975).

7-Day Upper Lethal Temperature Limit

Fish were seined during the highest summer temperature and acclimated upward in the laboratory to their upper lethal temperature limit, the highest temperature at which no mortality occurred during a 7-day period. At maximum summer ambient (27°C) and heated discharge (35°C) temperatures, fish were seined and held in 188-ℓ aquaria (10 fish per aquarium) for 7 days, after which the temperature was increased by 1°C daily to the next acclimation temperature (30°C or 36°C for species captured in ambient or heated areas) and held for 7 days. Control groups of each species were maintained in aquaria at their field temperature. If thermal mortality occurred during a 3°C temperature change, new trials were conducted by raising the temperature 1°C followed by a 7-day holding period.

Results

Preferred Temperatures

Temperatures preferred by all species tested in Table 1 increased as water temperatures changed from winter to summer conditions, and except for the telescope shiner (*Notropis telescopus*), yellow perch, and the rainbow, brown, and brook trout, temperature selections exceeded each respective acclimation temperature between 12 to 27°C. Most species selected temperatures lower than their acclimation temperature when tested at 30, 33 or 36°C. Of the 10 species acclimated at 30°C or above, only the fathead minnow (*Pime-*

TABLE 2. Final temperature preferenda of 15 species tested at the Glen Lyn field laboratory calculated by linear and curvilinear regression procedures, with the best statistical fit of the data represented by *(0.05) and **(0.10), "by eye" or connection of data points through a theoretical line with a slope of one, and as reported in the literature.

Species	Final preferendum (C) obtained at Glen Lyn			Other investigations
	Linear	Curvilinear	"By eye"	
Stoneroller	26.2*	26.6	28.8	28.5[a]
Fathead minnow	26.6*	26.2	26.0	—
Bluntnose minnow	28.1*	28.4	29.3	28.4[b]
Rosyface shiner	26.0*	26.1	28.4	27.6[b]
Spotfin shiner	29.4	31.0*	31.9	29.4[b]
Telescpoe shiner	20.0*	21.0	23.6	—
Bluegill	30.9	31.4*	32.1	29.4–31.3,[c] 32.3[d]
Smallmouth bass	30.3	30.3*	31.5	28.0,[d] 31.0[e]
Spotted bass	30.8	31.2*	31.4	24.4[f]
Rockbass	29.0	30.6*	29.8	20.7,[d] 26.8–28.3[c]
Northern hog sucker	26.6	28.6**	29.8	29.2[b]
Yellow perch	21.4*	21.4	22.2	20.2–21.2,[g] 23.3[h]
Rainbow trout	19.2*	19.7	19.8	13.0,[i] 18–19[j]
Brown trout	14.3	17.4*	17.8	12.0,[k] 17.6[d]
Brook trout	15.5*	16.0	16.8	16.0,[l] 19.0[m]

[a]Opuszynski 1971; [b]Cherry et al. 1975; [c]Neill 1971; [d]Ferguson 1958; [e]Barans and Tubb 1973; [f]Dendy 1945; [g]Hile and Juday 1941; [h]McCauley and Read 1973; [i]Garside and Tait 1958; [j]McCauley and Pond 1971; [k]Jammes 1931; [l]Peterson 1973; [m]Creaser 1930.

phales promelas) and bluntnose minnow (*P. notatus*) preferred the highest temperature at the final or highest acclimation level (Table 1). The preferred temperatures for the four species acclimated at 36°C (spotfin shiner, *N. spilopterus*), bluegill, spotted bass (*Micropterus punctulatus*), and rockbass (*Ambloplites rupestris*) were from 0.1 to 2.0°C less than that selected at a lower acclimation temperature (30 or 33°C).

Bluegill and spotted bass consistently preferred the highest temperatures at most levels of acclimation followed by the spotfin shiner and rockbass (Table 1). Of the cyprinids, the telescope shiner followed by the stoneroller (*Campostoma anomalum*) preferred the lowest temperatures. Salmonids generally preferred the lowest temperatures of all species tested with the brown trout consistently selecting the lowest temperatures.

Final temperature preferenda values varied according to the method employed for each species. The highest values for 12 of the 15 species were obtained by connection of the preference data points at the top of the range ("by eye") through the acclimation temperature line with a slope of one (Table 2). Temperature preferenda calculated by curvilinear regression were also higher for 12 of the 15 species when compared to the linear regression procedure (Fig. 1). The fathead minnow was the only species that had the highest final preferendum determined by linear regression, and two species, bluegill and rockbass, had the highest preferendum calculated from the curvilinear regression procedure. From the stepwise regression program, the linear regression model had a significantly ($P = 0.05$) better fit of the preference data for 9 of the 15 species tested, while the curvilinear procedure was the best fit for all but one (rosyface shiner [*N. rubellus*]) of the species acclimated to 33 or 36°C. From either statistical (linear or curvilinear) program used, or from direct data point connection, final preferenda were highest for the bluegill, basses, and spotfin shiner, and least for the trouts.

TEMPERATURES AVOIDED

Upper avoidance temperatures increased with rising acclimation temperatures, but the difference between upper avoidances and the acclimation temperatures was greater at cold acclimation temperatures (12–15°C) than at warmer levels (27–36°C, Table 3). Bluegill, spotted bass, rockbass, and spotfin shiner avoided the highest temperatures at all acclimation levels with the highest avoidance temperature being 37–39°C when acclimated at 36°C. Species that avoided the highest temperatures also had the widest temperature avoidance range, and for most species this range was greater at colder acclimation temperatures (e.g. 18°C difference for spotted bass and

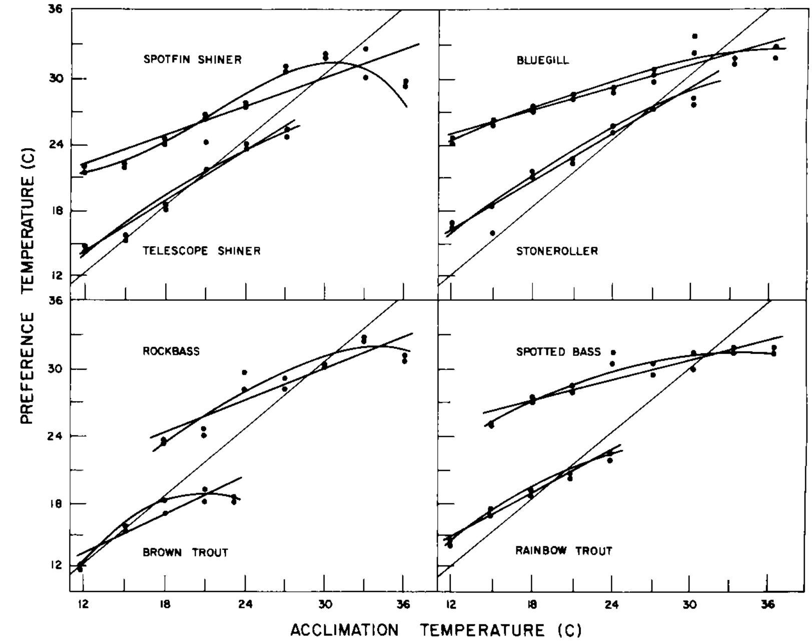

FIG. 1. Final temperature preferenda from linear and curvilinear regressions generated by a stepwise regression procedure.

spotfin shiner acclimated at 18 and 9°C, respectively, and 9–12°C range for both at 36°C). Centrarchids had the widest avoidance ranges, 12–15°C overall, followed by cyprinids with a 9–12°C range (excluding the spotfin shiner), and then by salmonids (9° C).

At the highest acclimation level tested for each species, the upper avoidance temperature either equalled or surpassed the 7-day upper lethal temperature limit by 1–2°C (Table 3). Of the four species tested at 36°C, the statistical upper avoidance occurred at the first temperature increment tested (39°C). The absolute avoidance temperature, which allowed for interaction in four temperature regions (36, 37, 38, 39°C), was 1–2°C less than the statistical avoidance. The four centrarchids tested had the highest 7-day upper lethal temperatures (35–36°C), followed by cyprinids (27°C for the telescope shiner to 36°C for the spotfin shiner, yellow perch (26°C), and salmonids (23–25°C).

Discussion

Temperature Preferences and Final Preferenda

Although increasing acclimation temperatures had a direct effect upon preferred temperatures from winter through spring, preferences declined when acclimation levels above 30°C approached lethal limits (Fig. 1). This was evident for all eurythermal species acclimated at 33 or 36°C but did not occur for fish (except the brown trout) acclimated to 27°C or less (Table 1). At their maximum acclimation temperatures, fish were highly mobile, often required longer orientation periods in the trough, and more variability occurred between replicates than at lower acclimation levels. Other investigators have shown either a leveling off or decline in preferred temperatures as fish approached lethal temperatures (e.g. Pitt et al. 1956 *Cyprinus carpio*; Fry 1947 *Carassius auratus*; Doudoroff 1938 *Girella nigricans*; Brett 1952 *Oncorhynchus nerka*). During falling temperature conditions (Cherry et al. 1975) this trend was not readily apparent, since these higher acclimation temperatures (33, 36°C) were not tested.

The temperature response of the telescope shiner, which was similar to that recorded for trout, was lower than expected as field investigations in the thermally influenced areas indicated higher preferences for the species (Stauffer 1975). This low response may be attributed to the thermal history of the telescope shiner which was seined in a nearby cold, spring-fed stream that received no thermal loading and offered no interaction in a heated plume throughout the year.

Attempts are currently being undertaken to

TABLE 3. Statistical and (in parentheses at the highest acclimation level) absolute upper and lower temperatures avoided, 7-day upper lethal temperature limits, and extreme avoidance temperature ranges of fish, each tested in pairs with four or eight replications, and sampled continuously from the New and East rivers, Virginia, and from state hatcheries at rising acclimation temperatures from 12 to 36°C.

	Acclimation temp (°C)									Ranges (degrees) between temp avoided at extreme acclimation temp		7-day Upper lethal temp limit
Species	12	15	18	21	24	27	30	33	36	Lowest	Highest	
C. anomalum[a]	21	24	24	27	30	33	(33)			12	12	31
	9	12	15	18	21	21	21	—[c]	—[c]			
P. promelas[a]	18	24	24	27	30	33	(32)			9	8	—
	9	12	15	15	21	21	24	—[c]	—[c]			
P. notatus	21	24	27	27	27	30	(33)			12	9	32
	9	12	15	18	21	21	24	—[c]	—[c]			
N. rubellus	21	24	21	27	27	33	33	(34)		12	10	33
	9	12	15	15	21	21	21	24	—[c]			
N. spilopterus	27	24	27	27	30	33	36	36	(38)	18	11	36
	9	12	15	18	21	21	24	24	27			
N. telescopus	18	21	24	27	27	(29)				9	11	30
	9	9	15	15	18	18	—[c]	—[c]	—[c]			
L. macrochirus[b]	24	27	30	30	33	36	36	39	(38)	15	11	36
	9	12	15	18	21	21	21	27	27			
M. dolomieui			27	30	33	33	33	(35)		12	8	35
	—[d]	—[d]	15	18	21	24	24	27	—[c]			
M. punctulatus			33	30	33	33	36	39	(38)	18	11	36
	—[d]	—[d]	15	18	21	24	27	27	27			
A. rupestris			27	27	30	33	33	36	(37)	15	10	36
	—[d]	—[d]	12	15	15	18	18	21	27			
H. nigricans[a]			27	30	33	33	33	(34)		15	10	33
	—[d]	—[d]	12	12	15	21	21	24	—[c]			
P. flavescens[b]		21	27	27	(29)					9	11	26
	—[d]	12	15	18	18	—[c]	—[c]	—[c]	—[c]			
S. gairdneri[b]	18	21	21	27	(26)					12	11	25
	6	9	12	12	15	—[c]	—[c]	—[c]	—[c]			
S. trutta[a,b]	15	18	21	24	(25)					9	8	23
	6	9	12	15	17	—[c]	—[c]	—[c]	—[c]			
S. fontinalis[b]	15	18	21	24	(26)					9	8	24
	6	9	15	15	18	—[c]	—[c]	—[c]	—[c]			

[a]Four replicates per acclimation temperature.
[b]Fish obtained from fish hatcheries.
[c]Acclimation temperature approached or exceeded lethal limits.
[d]No fish available.
[e]Acclimation temperature was 23°C.

standardize the method for calculating the final temperature preferendum (C. C. Coutant, Oak Ridge National Laboratory, Tennessee, personal communication). For the same set of preference data, different final preferendum values may be obtained for a species (Table 2). Calculations from the linear regression procedure produced the lowest final preferendum value, although this method generally provided the best fit ($P = 0.05$ level) of the data for species acclimated to 30°C or less. The curvilinear regression model supported the best fit of data for those species where the preferences obtained near or at the highest acclimation temperature were lower than those recorded at a previous acclimation level (Fig. 1). These behavior responses may be attributed to the stressed condition of the fish as acclimation temperatures approached lethal conditions. For preferences that were curvilinear near the top of the range, connection of these points "by eye" may provide the best intersect of the temperature acclimation line with a slope of one. Temperature preferenda determinations are generally highest by this method. Final preferenda from the Glen Lyn species were generally similar to those reported by others except for the high temperature response by rockbass and spotted bass at Glen Lyn. Variations may be attributed to differences in laboratory experimental designs, age of fish, thermal history, and seasonal conditions (Coutant 1975, Meldrim and Gift 1971, Javaid and Anderson 1967, Sullivan and Fisher 1953).

Preferences During Rising and Falling Temperature Conditions

Comparisons of the lineally or curvilineally regressed temperature preferences of each species between falling (Cherry et al. 1975) and rising (this study) temperature conditions showed that only three (bluegill, fathead minnow, and stoneroller) of the nine species studied had significantly ($P = 0.05$) different responses. Differences in temperature preference responses have been reported for fish captured and tested at the field temperature when conditions were declining (summer to winter) from that observed when water temperature was rising from winter to summer (Sullivan and Fisher 1953, Meldrim and Gift 1971). For fish acclimated 18–24 h and then tested, Meldrim and Gift (1971) reported that during rising temperature conditions, temperature preferences were greater than those tested at the same acclimation levels during falling conditions. In Cherry et al. (1975) and the present study, this trend was significant in only one species (fathead minnow), not significantly different in seven others, and in two cases (bluegill and stoneroller), the trend was reversed. Weaknesses exist in the duration of constant holding periods prior to testing. In short holding periods (e.g. 24 h or less), the response of a species may not be indicative of that acclimation temperature. For holding periods of 5–7 days in the present study, the response may be more reflective of the acclimation temperature, but additional variables (artificial food, prolonged stress to laboratory holding conditions) may influence or alter the response.

Avoidances and Lethal Limits

Avoidance temperatures were a function of acclimation temperatures with maximum upper and lower avoidances occurring at the highest and, in some cases, at the final two highest acclimation levels. The difference between the acclimation and upper avoidance temperatures was least at the highest acclimation level, since in most cases the final acclimation temperature was at or near the 7-day upper lethal temperature limit. At final acclimation temperatures (30, 33 or 36°C), the statistical avoidance occurred at the first 3°C increment with the absolute avoidance (first temperature within this increment in which 90% avoidance occurred) being 1–2°C lower (Table 3). Temperature avoidance data are lacking in the literature as seen in the review by Coutant (1975), especially in correlating lethal temperatures with upper avoidances taken at high acclimation levels.

The 7-day upper lethal temperatures reported here for the spotfin shiner, bluegill, spotted bass, and rockbass (36°C), are higher than those reviewed by Brett (1970) and others. In support of these high values and those for the smallmouth bass (35°C), rosyface shiner (33°C), and northern hog sucker (*Hypentilium nigricans*) (33°C), Stauffer (1975) reported that these species were abundant in maximally heated discharges (35°C) of the New River. Since the temperature response of fish is dependent upon its thermal history (Fry 1947), these species may have adapted to the thermal regimes resulting from the operation of the power plant for the past 56 yr. Mosquito fish (*Gambusia affinis*) with a high thermal history at the Savannah River Project (Aiken, South Carolina) have been reported to live at temperatures higher than the critical thermal maxima reported for northern populations (Falke and Smith 1974). Also, in seining fish that inhabit the thermal discharges during maximum ambient summer temperatures in the New River, only the more eurythermal members of each species are sampled and tested which probably tends to inflate the upper lethal temperatures.

Most species tested at their highest acclimation temperature avoided temperatures that just exceeded their 7-day upper lethal temperature limit which was usually equal to the final acclimation temperature (Table 3). Maximum thermal discharges in the New River at Glen Lyn rarely surpassed 35°C, and fish responses at these high temperatures generally were more erratic and variable. Comparison of temperature avoidances to lethal limits at the maximum acclimation level tested was not a reliable indication that fish would avoid sublethal temperatures since fish were probably in a stressed state. Absolute avoidances, which were slightly lower than the statistical avoidance, occurred at temperatures where 50–90% mortality occurred, while temperatures resulting in 100% mortality occurred at the statistical avoidance. The best relationships between upper avoidance, lethal, and 7-day upper lethal temperatures occurred when comparing these values at the acclimation temperature nearest the final temperature preferendum. A fish may interact maximally in its environment when acclimated near or at its final temperature preferendum and also avoid undesirable or lethal temperatures. In most cases, the upper temperature avoided at this acclimation level was less than or equal to the 7-day upper lethal temperature (Tables 1 and 3). As seen in the eurythermal species, final temperature preferenda for all centrarchids and the spotfin shiner were near 30°C and upper avoidances at the 30°C acclimation level did not exceed the 7-day upper lethal temperature. The same tendency was evident for other cyprinids that had final temperature preferenda near 24 or 27°C and for stenothermal species with lower final preferenda. Hence, at this acclimation level fish may have the best ability to actively avoid potentially hazardous lethal temperatures and select a temperature range most conducive to optimal environmental interaction.

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