Implication of Geographic Location on Temperature Preference of White Perch, *Morone americana*

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Temperature preference tests were conducted on freshwater white perch (*Morone americana*) collected from Albemarle Sound, N.C.; Wicomico River, Md.; and Mullica River, N.J. Collection temperatures for each population were 25°C (±2°C) and acclimation temperatures used in temperature preference tests were 6, 12, 18, 24, 30, and 33°C. Analysis of covariance determined that a significant difference exists in the temperature preference of the white perch populations tested. The calculated final temperature preference using linear regression for North Carolina, Maryland, and New Jersey populations was 32.4, 28.9, and 29.6°C, respectively. Calculated final temperature preferenda using the quadratic equation for North Carolina, Maryland, and New Jersey populations were 31.6, 29.3, and 29.2°C, respectively. Visual estimation yielded final temperature preference values of 32.5, 30.6, and 29.6°C for North Carolina, Maryland, and New Jersey populations, respectively.

Key words: White perch, *Morone americana*, temperature preference, final preferenda, population responses, linear regression, quadratic equation, visual estimation

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Nous avons fait des essais de préférence de température chez des gattes d'eau douce (*Morone americana*) capturées dans l'Albemarle Sound, N.C., la rivière Wicomico, Md., et la rivière Mullica, N.J. Les températures au moment de la cueillette étaient de 25°C (±2°C) pour chacune des populations, et les températures d'acclimatation utilisées dans les essais furent de 6, 12, 18, 24, 30 et 33°C. L'analyse de covariance révèle une différence significative dans les températures préférées des populations de gattes testées. Les températures préférées finales, calculées par régression linéaire pour les populations de la Caroline du Nord, du Maryland et du New Jersey sont de 32.4, 28.9 et 29.6°C respectivement. Les températures préférées finales calculées à l'aide de l'équation quadratique pour les populations de la Caroline du Nord, du Maryland et du New Jersey sont de 31.6, 29.3 et 29.2°C respectivement. Une estimation visuelle donne des valeurs de 32.5, 30.6 et 29.6°C pour les températures préférées finales des populations de la Caroline du Nord, du Maryland et du New Jersey respectivement.

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DUE to the species specific nature of temperature responses, the possible differences in temperature responses of subspecies of fish were studied by Hart (1952) and McCauley (1958). Their conclusions indicated differences in lethal temperatures among some subspecies, but not between races. Other data on physiological comparison of races of marine and landlocked populations of Atlantic salmon (Black and Black 1946) demonstrated no physiological differences in the blood. Heuts (1945) found that populations of *Gasterosteus aculeatus* from different localities in Europe showed gradations in the temperature–salinity range within which osmotic equilibrium was maintained, but these gradations were associated with well-defined morphological differences in lateral plates. Temperature preference data on fish are abundant (Coutant 1977; Raney et al. 1973); however, comparative data on races using identical laboratory temperature-preference procedures are lacking (Gift 1977).

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The objective of this research was to compare the temperature preference responses of white perch (*Morone americana*) from different geographic locations along the east coast of the United States from North Carolina to New Jersey. This species was selected for the following reasons: (1) wide distribution along the east coast of the United States (Goode 1903); (2) simple identification can be performed without handling the species, thus preventing increased stress; (3) previous temperature data on this species demonstrate reliable results using analysis of variance (Meldrim and Gift 1971); (4) it is a hardy species that tolerates conditions involved in transportation; (5) it has a previous history as a problem species in the vicinity of estuary-based steam electric stations (Meldrim and Gift 1971).

Materials and Methods

Field Procedures

White perch were collected in freshwater (less than 1‰ salinity) from May through August 1977 in the following localities: Albemarle Sound, North Carolina (36°05'N, 76°45'W); Wicomico River, Maryland (38°25'N, 76°65'W); and Mullica River, New Jersey (39°55'N, 74°42'W). Specimens were collected from North Carolina in May, Maryland in July, and New Jersey in August to minimize the effects of field temperature (Meldrim and Gift 1971). Collection temperatures ranged from 24.5 to 26.5°C and fish were held initially in 76-L plastic trash cans at their respective capture temperatures. Specimens collected ranged in standard length from 53 to 75 mm ($\bar{x} = 58$ mm). All fish were collected by seine (18.3 × 1.5 m or 7.6 × 1.8 m with .64-cm mesh) or wing trawl (9.1 m). Wing trawl collections were made with a worn trawl to minimize damage to the specimens. Perch were transported in 76-L plastic trash cans equipped with mino-mizers for aeration. Ice bags were placed in the water when necessary to lessen temperature fluctuations. Transportation periods ranged from 5 to 13 h and water temperatures were checked every 2 h during the trips.

Laboratory Procedures

Specimens were transferred by dip net from the trash cans to 38- or 76-L aquaria and held initially at their respective capture temperatures for 3 d. If fish developed fungal infections, as is common with laboratory studies (Hart 1952), they were treated with sulfa drugs and discarded if improvement was not shown in 2 d. Water temperatures in the aquaria were controlled with Supreme aquarium heaters and Koch refrigerator thermostats and were monitored daily. White perch were acclimated to the following temperatures at the rate change of 1°C per day: 6, 12, 18, 24, 30, and 33°C. A 5-d holding period at each acclimation temperature preceded the temperature preference tests with maximum deviations of (±1°C) from this acclimation temperature. White perch were fed approximately .05 g of Tetramin Tropical Fish Food per fish each day, but were not fed on testing days to ensure consistency of stomach contents. Constant aeration in the holding aquaria maintained oxygen levels between 90 and 100% saturation. Natural photoperiod was maintained using Vitalities with light intensities at the surface of the aquaria ranging from 162.0 to 269.0 lm/m² (2769.5 lm/m² represents a sunny summer day). All tests were conducted between 0600 and 2200 h.

The linear horizontal trough used in the preference trials was patterned after Meldrim and Gift (1971) and made of aluminum (3.6 × 0.203 × 0.254 m) coated with a nontoxic epoxy paint. Beneath the trough twelve heat lamps controlled by dimmer switches could be operated at increasing levels of intensity. Twenty-two thermistors were distributed horizontally along the trough at equal distances (190 mm) to record the temperature gradient. Cold water, introduced at one end of the preference trough from a Neslab circulating water bath was warmed as it flowed over the series of heat lamps to establish the horizontal gradient. The gradient was maintained at approximately 8°C above and below the acclimation temperature of the test specimen. Using 8°C was sufficient for providing an upper temperature range and this was reflected when fish selected a lower temperature when acclimated to the highest temperature (Table 1). Water depth in the trough was maintained at approximately 4 cm. Overhead lights supplied constant illumination of approximately 239 lm/m² during the test.

A test specimen was introduced into the trough at its acclimation temperature. A 60-min habituation period allowed for position effects that could interfere with the actual temperature preferred. This 60 min was determined to be an appropriate period to prevent fish from moving sporadically. After the habituation period, the position of each test specimen was recorded every minute for 20 min using overhead mirrors. Temperatures preferred by each fish were based on their proximity to one or more of the 22 thermistors. The mean of the 20 observations was deemed the preferred temperature for that particular test (Stauffer et al. 1975). Six fish from the Maryland population and eight from each North Carolina and New Jersey were tested individually at each acclimation temperature. Only six fish from the Maryland population were tested at each acclimation temperature due to availability of specimens. All populations were subjected to the same acclimation procedures as mentioned previously in this section. Standard length and weight were recorded for each fish.

Statistical Procedures

Linear regression (Stauffer et al. 1976), quadratic equation (Cherry et al. 1977), and visual estimation (see Panel Discussion in Richards et al. 1977) were used in an attempt to determine the effect of acclimation temperature on preferred temperature. Stepwise regression analysis selected the most valid test for comparing the temperature responses of the various populations. Additionally, data were fitted using log transformations and third and fourth degree polynomials. The point at which each of the above curves intersected a theoretical line passing through the origin with a slope of 1 was deemed the final temperature preferendum (Fry 1947). Analysis of covariance ($P \leq .05$) in conjunction with Duncan's multiple range test was used to determine the influence of geographic location on temperature selected.

Results and Discussion

Fish preferred temperatures higher than their acclimation temperature for all the acclimation temperatures between 6 and 24°C (Table 1). Acclimation

TABLE 1. Temperature (°C) preference data for three populations of *Morone americana*.

	North Carolina acclimation temp (°C)						Maryland acclimation temp (°C)						New Jersey acclimation temp (°C)					
Obs.	6	12	18	24	30	33	6	12	18	24	30	33	6	12	18	24	30	33
1	9.9	20.9	24.8	32.1	28.9	31.2	17.0	15.8	29.2	26.9	30.1	31.7	17.2	17.5	21.3	29.2	30.8	29.5
2	18.6	21.2	25.2	29.0	30.6	31.7	16.5	14.0	18.5	25.3	34.8	32.5	16.3	18.6	26.0	29.2	29.0	29.2
3	17.0	18.1	26.6	28.3	28.3	33.3	17.7	23.5	19.9	27.3	30.5	30.5	17.0	15.9	23.4	29.6	30.8	29.8
4	20.3	20.8	23.6	30.4	29.5	33.7	16.0	29.0	21.2	26.3	30.5	30.2	19.0	17.4	25.1	26.1	30.5	30.3
5	18.5	19.5	24.2	27.5	30.5	33.0	11.2	25.1	23.6	27.2	30.2	31.3	21.0	19.6	21.1	32.5	26.5	31.6
6	15.7	23.3	24.4	29.8	30.0	32.8	12.6	21.0	19.7	25.2	29.6	29.7	12.0	22.8	29.2	32.5	28.4	29.2
7	16.7	21.8	24.9	30.8	28.3	—	—	—	—	—	—	—	15.9	17.7	28.7	27.0	—	30.4
8	17.8	20.4	24.0	31.8	31.1	—	—	—	—	—	—	—	17.0	23.0	17.5	28.7	—	30.1
$\bar{x}$ =	16.8	20.7	24.7	30.0	29.6	32.6	15.2	21.4	22.0	26.3	31.0	30.7	16.9	19.0	24.0	29.3	29.3	30.0
Final preferendum						N.C.						Md.						N.J.
Linear regression						32.4						28.9						29.6
Quadratic						31.6						29.3						29.2
Visual estimation						32.5						30.6						29.6

TABLE 2. Analysis of covariance for independent variable location with adjusted means for each population.

Source of variation	Sum of squares	df	Mean sq.	*F*	Significance of *F*
Covariates acclimation	71974.195	1	71974.19	70.845	.001
Main effects location	990.040	2	495.020	42.441	.001
Error term	29812.134	2556	11.664		
Total	102776.369	2559	40.163		

Adjusted Mean for N.C. = 23.42°C (919 observations)
Adjusted Mean for Md. = 23.92°C (721 observations)
Adjusted Mean for N.J. = 24.51°C (920 observations)

temperatures of 30°C resulted in selected temperatures between 29 and 31°C while acclimation temperatures of 33°C resulted in preferred temperatures lower than the acclimation temperature. A temperature of 33°C was selected as the highest acclimation temperature due to mortality of several individuals at higher temperatures. Each white perch population had a significantly different temperature response as determined by analysis of covariance in conjunction with Duncan's multiple range test (Table 2).

The final temperature preferendum is defined as the point where preferred temperature equals acclimation temperature and which an animal will finally select regardless of its previous thermal history (Fry 1947). Theoretically, the final temperature preferendum is the temperature that an organism will prefer given sufficient time and expanded temperature gradient. Richards et al. (1977) discussed the validity of various methods used to calculate the final preferendum from acute preferred temperature vs. acclimation temperature curves. The results of the three methods for plotting these data are presented below.

The linear least-squares regression equation $P = 0.566A + 14.04$, where P is the preferred temperature and A the acclimation temperature, explained 85% of the variability for the North Carolina population. Using linear regression for the Maryland population, the equation $P = 0.572A + 12.36$ explained 85% of the variability, and 83% of the New Jersey variability was explained by the equation $P = 0.544A + 13.53$. The calculated final temperature preference using the linear regression technique for North Carolina, Maryland, and New Jersey populations was 32.4, 28.9, and 29.6°C, respectively.

Results obtained with linear regression were compared with other statistical transformations in an attempt to obtain a better fit for the data. The quadratic equation $P = 0.925A - 0.009A^2 + 11.35$ explained 85% of the variability from North Carolina perch populations. This method was used for the Maryland population and the equation $P = 0.57A + 0.0002A^2 + 12.42$ explained 85% of this variability, and $P = 0.97A - 0.011A^2 + 10.31$ explained 84% of the variability for the New Jersey population. Stepwise regression indicated that the quadratic equation did not significantly ($P \leq .05$) explain more of the data. Calculated temperature preferenda using the quadratic equation for North Carolina, Maryland, and New

Jersey populations were 31.6, 29.3, and 29.2°C, respectively. Other transformations and higher order polynomials did not significantly explain more of the data.

In a recent symposium, Coutant (Panel Discussion in Richards et al. 1977) stated that he preferred to visually interpret the final preferendum from the data points. Using this method, final temperature preferenda for North Carolina, Maryland, and New Jersey populations were 32.5, 30.6, and 29.6, respectively.

Although linear regression was selected by stepwise regression analysis as the test to use in comparing the temperature response of the various populations, often the relationship between acclimation vs. preferred temperature is not linear (see Panel Discussion in Richards et al. 1977). If each respective population were compared using a visual technique as recommended by Coutant, results similar to the linear regression method would be reported with highest temperature preference from North Carolina, and lower values recorded for both Maryland and New Jersey. The quadratic equation would demonstrate a similar trend.

Data presented by Meldrim and Gift (1971) suggest a final preferendum of 32°C for white perch from the Delaware River. However, their data were collected on perch from low salinity water (4–9‰) which may not be valid for comparison with freshwater populations such as these. Pertinent conclusions from their study indicated that field temperature (temperature to which fish were acclimated) and salinity significantly affected temperature preference. Final preferenda of 23.0, 22.8, and 21.5°C were recorded for New Jersey white perch populations acclimated to 5.0, 8.0, and 10.0°C, respectively; however, this data was taken from adult white perch in early spring in high salinity water (Terpin et al. 1977). McErlean and Brinkley (1971) concluded that season significantly ($P < 0.01$) affected the thermal tolerance in this species.

Conclusions from this research indicate significantly different temperature preference responses for white perch collected in various geographic areas. Since most physiological properties are dependent on temperature, it is not unusual to find physiological differences in fish of different thermal environments. Differences in lethal temperature for fish species correlated with their range was observed by other investigators (Battle 1926 and Storey 1937). Observed physiological differences of these species were correlated with the thermal environment. These physiological differences may be responsible for the different lethal responses for each geographic population. Hart (1952) and McCauley (1958) conducted lethal temperature studies comparing responses of fish from various geographic areas and found differences in lethal temperatures among some subspecies but not within physiological races. Kinne (1963) concluded that within the same species, the biological effects of a certain temperature regime may be population specific, dependent on the temperature history of the individual. This conclusion would be relevant to this study due to the various thermal regimes experienced by each geographic population of white perch.

Possible Factors Responsible for Geographic Variation

Geographic variation in temperature responses of white perch are a result of the environmental differences found in each ecosystem. Although the collection temperatures, season, fish size, and methodology for testing were comparable for each population, the yearly water temperature extremes were different. It is well established that average water temperature increases from north to south and this trend was reflected by highest temperature response for the most southern population. However, the Maryland population that is south of New Jersey demonstrated a slightly lower response curve than its northern counterpart (based on linear regression analysis). Each local environment subjects continuous selection pressure on localized demes of every species and this allows for adaptation (Mayr 1975). Local populations may differ in numerous genetically controlled adaptive features such as behavioral and physiological responses. Mayr (1975) states that freshwater animals appear to be more sensitive to changes in temperature than land animals. This causes much geographic variation in temperature tolerance, growth rate, and other physiological constants that provide for their existence in a particular thermal regime.

Nonthermal seasonal influences associated with each geographic location could represent another possible means for influencing temperature preference of these perch populations. Although this particular area of study has received minimal attention with fish, the existence of such effects are possible (Zahn 1962).

Biochemical adaptation to environmental parameters such as temperature represents a possible mode for geographic variation in thermal responses of white perch. Somero and Hochachka (1971) reported that habitat temperature influenced quantities and types of molecules present in the chemistry of an organism. These investigators also concluded that adult poikilotherms may demonstrate a considerable degree of "biochemical restructuring" on a seasonal basis in response to environmental temperature. Variance in thermal environments for each geographic population of white perch could affect biochemical restructuring and produce different thermal responses.

The phenotype of every local population is precisely adjusted to the exact requirements of its environment, and optimal phenotypes result from the adjustment of gene selection (Mayr 1975). The concept of phenotypic plasticity (Hart 1952) may indirectly represent a means for variation among populations. Theoretically, temperate fishes exposed to wide temperature extremes during the year would be less affected by natural selection if the individuals of the population can adjust physiologically within these limits. Eurythermal species such as white perch would probably be less affected by selection than stenothermal species occurring within the same temperature range. Gause (1947) demonstrated that genotypic specialization varied inversely with phenotypic plasticity. Since all white perch populations were similar in appearance, genotypic specialization in each population is another possible mode for variations in temperature preference.

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