Temperature preference and avoidance studies of six North American freshwater fish species

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Introduction

Temperature is probably the most important factor which governs aquatic poikilotherms. Several authors (Ferguson, 1958; Neill & Magnuson, 1974; Stauffer *et al.* 1976) have shown that there is close agreement between laboratory generated information and field observations. The purpose of this paper was to generate laboratory temperature preference and avoidance data for *Notemigonus crysoleucas* (golden shiner), *Notropis analostanus* (satinfin shiner), *Rhinichthys atratulus* (blacknose dace), *Catostomus commersoni* (white sucker) *Lepomis gibbosus* (pumpkinseed), and *Micropterus salmoides* (largemouth bass).

Methods and materials

Fishes were acclimated to temperatures which ranged from 6 to 36 °C depending upon tolerance levels, at a rate which did not exceed 1 °C/day (Fry, 1971). Once the desired temperature was reached, fish were held within ±0.5 °C for a minimum of 5 days before tests were initiated.

Temperature preference and upper avoidance procedures and equipment were modeled after those reported by Meldrim & Gift (1971) and Stauffer *et al.* (1976). The relationship between acclimation temperature (A) and preference temperature (P) was determined for each species through the following models: $P = ø A + \beta$, $P = ø A + \alpha A^2 + \beta$, and $P = ø A t \alpha A^2 + \infty A^3 + \beta$. A stepwise regression procedure was used to determine which model provided the best fit (Cherry *et al.* 1977). The final preferred temperature was determined by solving the model which provided the best fit for the point where $P = A$ (Stauffer, 1981). This point theoretically represented the highest temperature a fish will prefer it given an unlimited temperature range and indefinite time (Fry, 1947).

Avoidance data were analyzed with a technique proposed by Stauffer *et al.* (1976). A two-way factorial analysis of variance table was prepared using the total number of tested fish (usually eight) and the higher of the two temperature alternatives as classes. Time the fish spend in the lower of the two temperature choices was recorded in each block of the tables. During the control segment, the time located on the side of each tank specified as the lower temperature side was tabulated. Temperature intervals were considered a 'fixed effect' and the particular fish groups were 'random effects'. This arrangement allowed the mean square of the fixed temperature effect to be tested by the interaction term 'fish group x temperature interval' (Sokal & Rohlf, 1969). A Duncan's multiple range test for the fixed effect was then conducted with the aid of the mean square and degrees of freedom for the interaction term. The point at which significantly ($P \leqslant .05$) more time was spent on the lower temperature section of the trough in the experimental run than spent on the designated lower temperature section of the trough in the control run, was declared the avoidance temperature.

Results and discussion

A stepwise regression analysis showed that the quadratic equation of the form $P = ø A + \alpha A^2 + \beta$

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best explained the relationship between preference temperature (P) and acclimation temperature for all species (Figs. 1–6).

The final temperature preference for golden shiner was 23.84 (Fig. 1). Reutter & Herdendorf (1975) reported a range of final temperature preference of 16.8–23.7 °C.

Upper avoidance temperatures ranged from 15 to 36 °C when acclimated from 6 to 36 °C, respectively (Table 1). Meldrim & Gift (1971) indicated an 18 °C laboratory avoidance temperature for this species when acclimated to 6 °C. Reutter & Herdendorf (1975) reported that *N. crysoleucas* would not avoid thermal discharges in the fall, winter or spring months, and death, as a result of thermal shock, occurred in the effluent areas if barricades were not utilized. However, Trembley (1961) reported that this species avoided 37.8 °C *in situ*.

The final temperature preference for the satinfin was 27.17 °C (Fig. 2).

Upper avoidance temperatures ranged from 21 to 39 °C for fish acclimated from 6 to 36 °C, respectively (Table 1). Trembley (1961) observed that this species avoided 28.9 °C water in August, however, he also recorded satinfin shiners at temperatures of 36.7 °C. Woolcott & Maurakis (1976) indicated that this shiner avoided a heated plume when temperatures exceeded 30 °C.

The final temperature preference for the blacknose dace was 24.63 (Fig. 3).

Upper avoidance temperatures ranged from 24 to 34 °C when acclimated to 6 and 28 °C, respectively (Table 1).

The final temperature preference for the white sucker was 27.1 °C (Fig. 4). Final field temperature preference estimates for lacustrine populations ranged between 14.1–21.2 °C (Cooper & Fuller, 1945; Hile & Juday, 1941; Horak & Tanner, 1964), however, recent laboratory final preferenda predictions were higher. Reutter & Herdendorf (1975) found a 22.4 °C final preference, while Reynolds & Casterlin (1977a) found a diel activity range of 22.8–26.1 °C with an estimated 24.1 °C final preference.

Upper avoidance temperature ranged from 15 to 30 °C when specimens were acclimated from 6 to 24 °C, respectively (Table 1). Physical deterioration of the stock resulted when acclimation temperatures above 24 °C were attempted. Stauffer *et al.* (1976) demonstrated that white suckers in the New River, Glen Lyn, Virginia, avoided discharge areas when temperatures exceeded 26.7 °C.

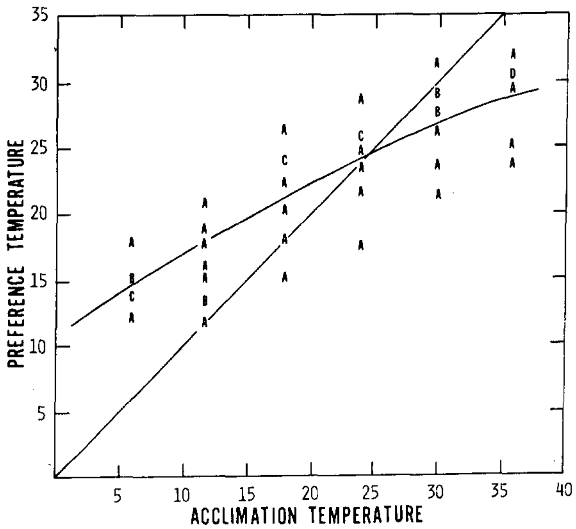

Fig. 1. Relationship between preference and acclimation temperatures for the golden shiner (size range 40–87 mm) as explained by the quadratic equation $P = -.004A^2 + .667A + 9.97$ $R^2 = .65$ (P = A at 23.84 C). Line (—) with the slope of one and number of observations (A = 1 observation, B = 2 observations, etc.) at each acclimation temperatures are noted.

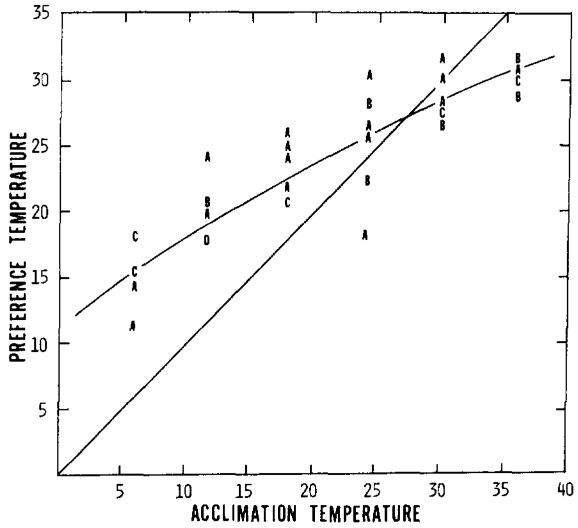

Fig. 2. Relationship between preference and acclimation temperatures for the satinfin shiner (size range 36–68 mm) as explained by the quadratic equation $P = -.004A^2 + .66A + 12.19$ $R^2 = .72$ (P = A at 27.17 C). Legend as in Fig. 1.

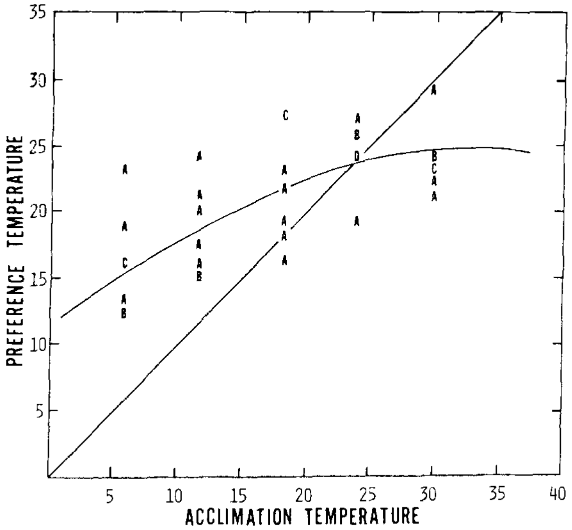

Fig. 3. Relationship between preference and acclimation temperatures for the blacknose dace (size range 29–63 mm) as explained by the quadratic equation $P = -.012A^2 + .803A + 11.19$ $R^2 = .40$ (P = A at 24.63 C). Legend as in Fig. 1.

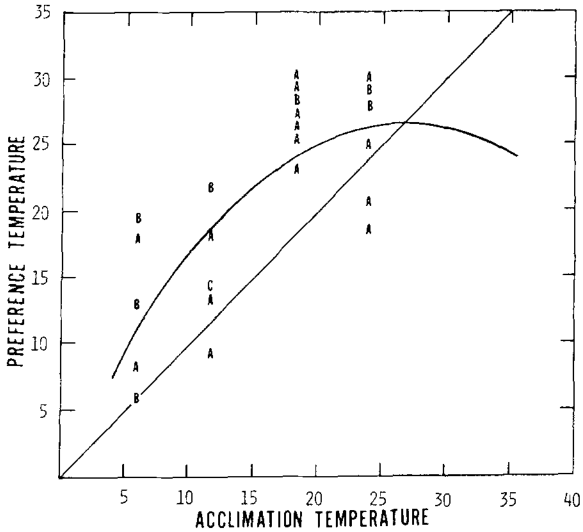

Fig. 4. Relationship between preference and acclimation temperatures for the white sucker (size range 42–101 mm) as explained by the quadratic equation $P = -0.034A^2 + 1.85A + 1.92$ $R^2 = .54$ (P = A at 27.10 C). Legend as in Fig. 1.

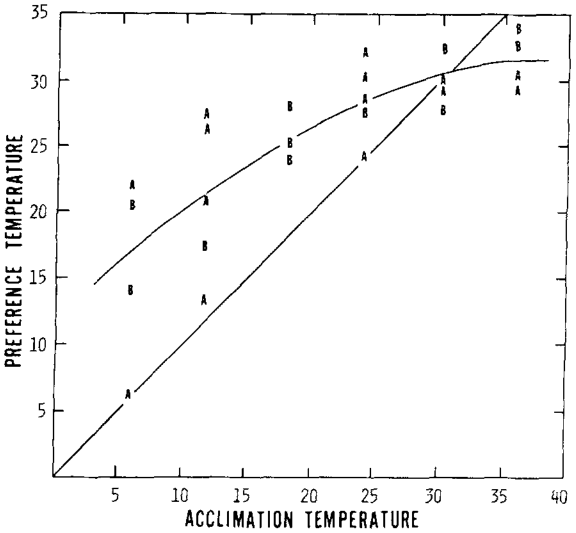

Fig. 5. Relationship between preference and acclimation temperatures for the pumpkinseed (size range 28–44 mm) as explained by the quadratic equation $P = -.006A^2 + .74\,A + 13.80$ $R^2 = .63$ (P = A at 31.06 C). Legend as in Fig. 1.

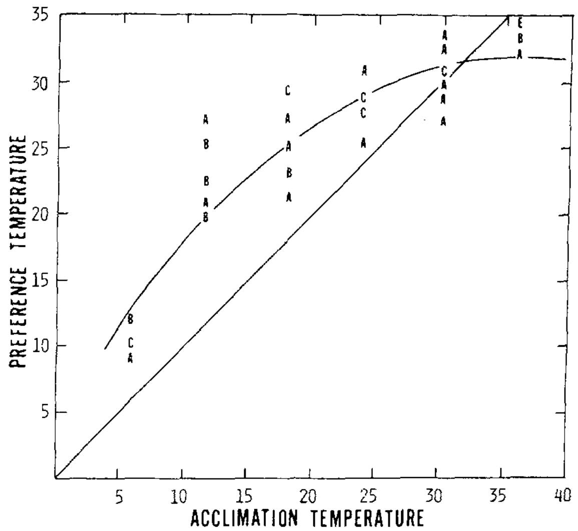

Fig. 6. Relationship between preference and acclimation temperatures for the largemouth bass (size range 27–66 mm) as explained by the quadratic equation $P = -.023A^2 + 1.63A + 3.59$ $R^2 = .78$ (P = A at 32.2 C). Legend as in Fig. 1.

Table 1. Upper avoidance temperatures (C) at each acclimation temperature for all tested species.

Species	Acclimation temperatures (° C)						
	6	12	18	24	28[a]	30	36
Golden shiner	15	24	30[b]	30[b]	–	36[b]	39[b]
Satinfin shiner	21	21	24	27	–	33	39
Blacknose dace	24	24	24	27	34	–	–
White sucker	15	15	27	30	–	–	–
Pumpkinseed sunfish	*	**	33	36	–	36	39
Largemouth bass	27[b]	30[b]	33[b]	36[b]	–	36[b]	39[b]

[a] Blacknose dace were tested at 28 ° C since they could not be acclimated at 30 ° C at testing time.
[b] Test specimens purchased from commercial Pennsylvania fish hatchery.

* Demonstrated no avoidance reaction through a test temperature of 27 ° C; when test temperature was raised to 30 ° C, all specimens died.

** Demonstrated no avoidance reaction through a test temperature of 30 ° C; when test temperature was raised to 33 ° C, all specimens died.

The final temperature preference for the pumpkinseed was 31.06 ° C (Fig. 5). Neill & Magnuson (1974) obtained day and night final field temperature preferenda that ranged from 27 to 32 ° C. Laboratory final preference was determined to be 31.5 for young *L. gibbosus* (Anderson, unpubl. data, cited in Ferguson, 1958) and 27.7 ° C for adults (Reutter & Herdendorf, 1975). Furthermore, Reynolds & Casterlin (1977b) and Muller & Fry (1976) demonstrated a final laboratory preferendum of 26 and 28.5 ° C, respectively. A visual estimation of data presented by Peterson & Schutsky (1976, 1977a, b, c) for young and adult pumpkinseeds suggested a final preference of approximately 33 ° C.

Avoidance temperatures ranged from an indiscernible temperature when acclimated to 6 ° C, to 39 ° C when acclimated to 36 ° C (Table 1). Knowledge of the adult pumpkinseeds' ability to perceive temperature changes of 0.1 ° C (Bardach & Bjorklund, 1957) raises questions concerning the indiscernible avoidance temperature at acclimation temperatures of 6 and 12 ° C. Cherry *et al.* (1974) and Meldrim & Gift (1971) attributed size as the reason for low thermal responsiveness while testing small fishes. Trembley (1960) found pumpkinseeds rather abundant in a thermal discharge, but stated later that they usually avoided temperatures around 32.2 ° C (Trembley, 1961). Reynolds (unpubl. data, cited in Coutant, 1977) suggested an upper avoidance temperature greater than 31 ° C.

The temperature preference for largemouth bass was 32.2 ° C (Fig. 6). Field final temperature preference values for the largemouth bass were estimated to fall within the range 26.5–30.9 ° C by Clugston (1973), Coutant (1975), Dendy (1948), Neill & Magnuson (1974), and Wrenn (1976). Laboratory final preferences were recorded in the range of 29–32 ° C (Fry, unpubl. data, cited in Ferguson, 1958; Neill & Magnuson, 1974). A visual estimation of data reported by Peterson & Schutsky (1976, 1977a, b, c) suggested a final preference of 32 ° C.

Upper avoidance temperatures ranged from 27 to 39 ° C when specimens were acclimated from 6 to 36 ° C, respectively (Table 1). Meldrim & Gift (1971), demonstrated this species avoided 32–34 ° C when acclimated to 25 ° C. A Susquehanna River deme was shown to avoid temperatures from 25.5 to 38 ° C at acclimation temperatures of 2 to 34 ° C (Peterson & Schutsky 1976, 1977a, b, c). Other authors reported upper and lower avoidance temperatures which ranged between 21 and 34 ° C (Coutant, 1977).

For the most part, preferred temperature increased as fish were acclimated to higher temperatures, until the final preferred temperature was reached. Once the final preferred temperature was reached, fish selected temperatures at or below the FTP. The white sucker was the only species tested here that did not exhibit this decreasing trend; however, the thermal responsiveness of this species in laboratory experiments has been questioned (Cherry *et al.*, 1974).

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