Arch. Hydrobiol.	90	1	121—126	Stuttgart, September 1980

Temperature preference of the northern redbelly dace, *Phoxinus eos* (COPE)

By JAY R. STAUFFER, Jr., EDWARD L. MELISKY and CHARLES H. HOCUTT

With 1 figure in the text

Abstract

The temperature preference of the northern redbelly dace was investigated in a horizontal thermal gradient. Fish were collected in Michigan and shipped via air express to the test facilities at Frostburg, Maryland. Fish were acclimated to 6, 12, 18, 24, 30 and 33 °C (± 0.5 °C). The relationship between preference temperature and acclimation temperature was best explained by the model: $P = 1.152\ A - 0.017\ A^2 + 7.03$, where P is equal to the preference temperature and A the acclimation temperature. The final temperature preferendum was determined to be 25.3 °C.

Introduction

Within the last decade, fishery scientists have directed much effort toward the behavior of fishes as it is influenced by temperature (COUTANT, 1977). Federal legislation mandates that behavioral aspects be investigated to effectively understand the ethological reactions of fishes toward thermal effluents. Impact studies utilizing these guidelines focus upon a number of thermally related parameters (i.e., temperature preference, temperature avoidance, thermal shock, growth) to establish criteria which protect species exposed to thermal additions. Because poikilothermic metabolism is controlled by temperature (BROWN, 1946; BALDWIN, 1957; BRETT, 1970), selection of temperatures which allow optimal physiological performance assists in the successful establishment of stable, healthy fish populations. A review of the literature concerning physiological parameters manifests the relationship between selected temperatures and optimal physiological performance. Optimal temperatures for metabolic activity (BRETT, 1956), cruising speed (FRY & HART, 1948), appetite (NORRIS, 1963), growth (Ecological Analysts, 1978), and other physiological processes (see BRETT, 1971) are consistently similar to the final preferred temperature in a number of fish species. GIFT

0003-9136/80/0090-0121 $ 1.50

(1977) noted that utilization of this preference-physiology relationship would reduce time and expense needed to predict temperatures for optimal physiological processes, since preference tests are of significantly shorter duration than experiments historically used to obtain physiological data.

Traditionally, the vast majority of temperature related investigations examined the important sport or commercial fishes such as rainbow trout (McCauley et al., 1977), brook trout (Ferguson, 1958; Cherry et al., 1975), various salmonid species (Brett, 1952; Hurley & Woodall, 1968), smallmouth bass (Reynolds & Casterlin, 1976), and yellow perch (Barans & Tubb, 1973; Reutter & Herdendorf, 1974). Gift (1977) noted that knowledge of thermal criteria of forage fishes is severely lacking. This paucity of knowledge concerning requirements of the prey species can reduce the overall ecological understanding of sport and commercial fishes, for these ichthyofauna frequently occupy areas which are not at their final temperature preferenda, but at the preferenda of the prey fishes (Fairbanks, Collings & Sides, 1971; Neill & Magnuson, 1974).

This study investigated the thermal preference of the northern redbelly dace (*Phoxinus eos*, Cope), which can be an important forage fish (Scott & Crossman, 1973). The northern redbelly dace occurs from Nova Scotia south to Pennsylvania, west to Colorado and British Columbia (Scott & Crossman, 1973). Establishment of the final selected temperature for this species will provide insight into the behavior and physiological aspects of this species.

Methods and materials

Northern redbelly dace were collected from Spratt Creek (tributary of Thunder Bay System, Lake Huron), Alpena County, Michigan, on 8 September, 1978. Ten to 15 fish were placed in 2 liter double lined plastic bags, which were filled with 200 ml of water and inflated with pure O_2. Fish were shipped in insulated containers via air express to the Appalachian Environmental Laboratory, Frostburg, Maryland.

Fish were acclimated to 6, 12, 18, 24, 30, and 33 °C (± 0.5 °C) at a rate which did not exceed 1 °C/day. Fish were held at the acclimation temperature for a minimum of five days prior to testing. Constant aeration in holding aquaria maintained oxygen levels above 90 percent air-saturation. Tests were conducted from mid-September through November with photoperiod mimicing the natural cycle for this time of year. Vita-lites (flourescent lights emitting wavelengths equal to those of solar radiation) illuminated holding and testing areas. Fish were fed daily on all days except for days of testing.

A horizontal trough, as described by Hall, Hocutt & Stauffer (1978) was used to conduct the preference tests. This trough was patterned after that described by Meldrim & Gift (1971) and made of aluminum, coated with a non-toxic epoxy paint. Heat lamps, positioned beneath the trough and set at increasing intensities, were used to create a temperature gradient within the apparatus. Water 3—8 °C below the acclimation temperature was introduced at one end of the trough to insure the presence of temperatures below the acclimation temperature.

Low flow and varying heat lamp intensities created a heterothermal gradient of approximately 16 °C. Observations indicated that this gradient was sufficient since fish never remained at the extremes of the gradient. Additionally, previous studies at our laboratory showed that the presence of a thermal gradient throughout a wide portion of the respective species' biokinetic range often caused mortality due to exposure to temperatures beyond the upper lethal limits of the species at the respective acclimation temperatures. The entire trough was enclosed to minimize external stimuli.

Twenty-two numbered thermistors equally spaced along the length of the trough monitored the temperatures within the unit. The position of the fish relative to these thermistors was monitored via overhead mirrors. Whenever a specimen was observed between probes, the temperature of the probe nearest the fish's head was taken as the temperature selected at that time since MULLER (1977) showed that the thermal history of the head of the fish determines its preferred temperature.

The six fish individually tested at each acclimation temperature were sacrificed upon completion of their respective trials. Specimens were introduced in the trough at their acclimation temperature. After an initial 40-minute orientation period, the water temperature in the vicinity of the fish was recorded each minute for 20 minutes. The mean of the 20 observations was deemed the preferred temperature for that particular test (STAUFFER et al., 1976).

The relationship between preferred temperature (P) and acclimation temperature (A) was explored via the following models:

$$P = \alpha A + \beta;\ P = \alpha A + \sigma A^2 + \beta;\ \text{and}\ P = \alpha A + \sigma A^2 + \chi A^3 + \beta.$$

A stepwise regression procedure was used to determine the model which described the highest percentage of variance in preferred temperature due to acclimation temperature. The selected model was then solved for the point where P = A to determine the final temperature preference as conceived by FRY (1947).

Results and discussion

Northern redbelly dace preferred temperatures higher than their acclimation temperature between 6 and 18 °C. At 24 °C acclimation temperature they preferred 24 °C, and at acclimation temperatures of 30 and 33 °C their preferred temperature was lower than their acclimation temperature (Fig. 1). Stepwise regression analysis indicated that the data were best explained by the quadratic equation:

$$P = 1.152\,A - 0.017\,A^2 + 7.03,$$

which explained 53 percent of the variability of the raw data (N = 720). Solving this equation for the point at which P = A, yielded a final temperature preferendum of 25.3 °C.

Additional information concerning thermal behavior of the northern redbelly dace could not be found. TYLER (1966) reported that this species exhibited 50 percent mortality when specimens acclimated to 24 °C were exposed to 33 °C during summer conditions. When we attempted to ac-

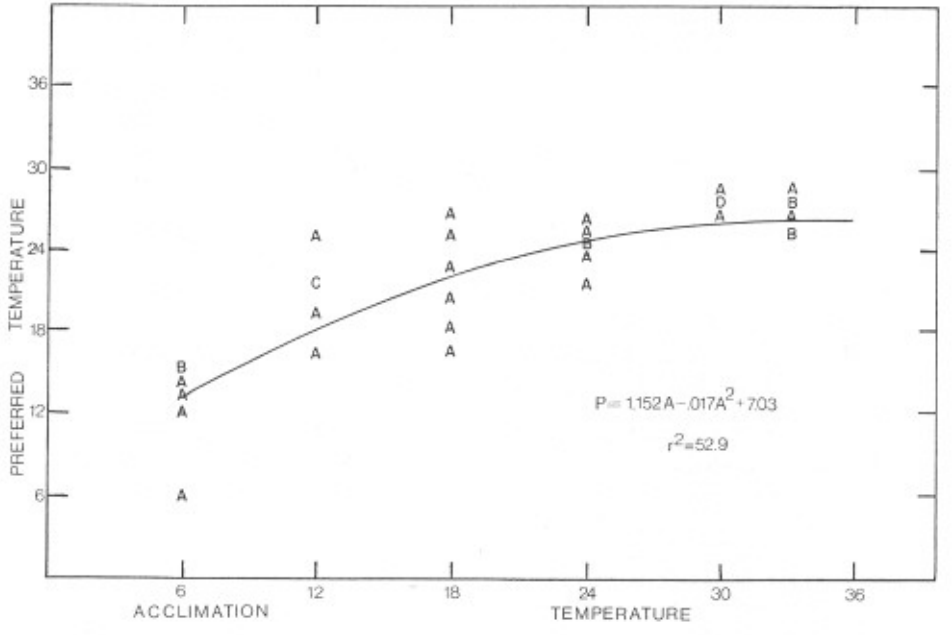

Fig. 1. Relationship between temperature preference and acclimation temperature for the northern redbelly dace, *Phoxinus eos* (COPE) (P = preference temperature; A = acclimation temperature; A = 1 observation; B = 2 observations; etc.)

climate fish to temperatures above 33 °C (at a rate of 0.5 °C/day), all specimens died.

TYLER (1966) also demonstrated that dace had higher lethal temperatures when collected during the summer than during the winter, even when acclimated to the same temperatures. A similar phenomena has been reported by MELDRIM & GIFT (1971) in relation to preference responses for some species. They found that fish exhibited a higher temperature preference when collected during falling temperature (autumn) conditions than when collected during rising temperature (spring) conditions. However, when CHERRY et al. (1977) increased the acclimation period in the laboratory, no differences between responses during rising and falling temperature regimes could be discerned for six of nine species. Fish for these experiments were all collected during the fall, and the same acclimation procedures were used as described by CHERRY et al. (1977).

Acknowledgements

The authors wish to thank PATRICK J. ENGLISH and GERARD R. JOSWIAK who collected the specimens and shipped them to the Appalachian Environmental Laboratory.

Zusammenfassung

Die Temperatur-Präferenz von *Phoxinus eos* wurde aufgrund eines horizontalen Thermalgradienten untersucht. Die Fische wurden im Spratt Creek (Michigan State) gefangen und per Flugzeug zum Appalachen-Umwelt-Laboratorium in Frostburg, Maryland, transportiert, wo die Einrichtungen zur Akklimatisation der Fische an 6, 12, 18, 24, 30 und 33 °C (± 0,5 °C) vorhanden sind. Die Beziehung zwischen Temperatur-Präferenz (P) und Akklimatisations-Temperatur (A) entsprach der Gleichung: $P = 1{,}152\ A - 0{,}017\ A^2 + 7{,}03$. Die von den Fischen bevorzugte Endtemperatur betrug 25,3 °C.

Literature cited

Baldwin, N. S. (1957): Food consumption and growth of brook trout at different temperatures. — Trans. Am. Fish. Soc. **86:** 323—328.

Barans, C. A. & Tubb, R. A. (1973): Temperatures selected seasonally by four freshwater fishes from Lake Erie. — J. Fish. Res. Board Can. **30:** 1697—1703.

Brett, J. R. (1952): Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. — J. Fish. Res. Board Can. **9:** 265—323.

— (1956): Some principles in the thermal requirements of fishes. — Quart. Rev. Biol. **31:** 75—87.

— (1970): Temperature. Pages 513—560. — In: O. Kinne (ed.), Environmental factors. Wiley Interscience, New York.

— (1971): Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon *(Oncorhynchus nerka)*. — Am. Zool. **11:** 99—113.

Brown, M. E. (1946): The growth of brown trout (*Salmo trutta* Linn.). III. The effect of temperature on the growth of two-year-old trout. — J. Exp. Biol. **22:** 145—155.

Cherry, D. S., Dickson, K. L. & Cairns, J. Jr. (1975): Temperatures selected and avoided by fish at various acclimation temperatures. — J. Fish. Res. Board Can. **32:** 485—491.

Cherry, D. S., Dickson, K. L., Cairns, J. Jr. & Stauffer, J. R. Jr. (1977): Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. — J. Fish. Res. Board Can. **34:** 239—246.

Coutant, C. C. (1977): Compilation of temperature preference data. — J. Fish. Res. Board Can. **34:** 739—745.

Ecological Analysts (1978): Final report: Hudson River thermal effects studies for representative species — Report to Central Hudson Gas and Electric Corp., Consolidated Edison Co. of New York, Inc., and Orange and Rockland Utilities, Inc. 236 pp.

Fairbanks, R. B., Collings, W. & Sides, W. (1971): An assessment of the effects of electrical power generation on marine resources in Cape Cod canal. — Mass. Dept. of Nat. Res. 48 pp.

Ferguson, R. G. (1958): The preferred temperatures of fish and their mid-summer distribution in temperate lakes and streams. — J. Fish. Res. Board Can. **15:** 607—624.

Fry, F. E. J. (1947): Effects of the environment on animal activity. — Univ. of Toronto Stud. Biol. Series No. **55**. Publ. Ont. Fish. Res. Lab. **68:** 1—62.

Fry, F. E. J. & Hart, J. S. (1948): Cruising speed of goldfish in relation to water temperature. — J. Fish. Res. Board Can. **7**: 169—175.

Gift, J. J. (1977): Application of temperature preference studies to environmental impact assessment. — J. Fish. Res. Board Can. **34**: 746—749.

Hall, L. W., Jr., Hocutt, C. H. & Stauffer, J. R. Jr. (1978): Implication of geographic location on temperature preference of white perch, *Morone americana*. — J. Fish. Res. Board Can. **35**: 1464—1468.

Hurley, D. A. & Woodall, W. L. (1968): Responses of young pink salmon to vertical temperature and salinity gradients. — Int. Pac. Salmon Fish. Comm. Prog. Rep. **19**.

McCauley, R. W., Elliott, J. R. & Read, L. A. A. (1977): Influence of acclimation temperature on preferred temperature in rainbow trout, *Salmo gairdneri*. — Trans. Am. Fish. Soc. **106**: 362—365.

Meldrim, J. W. & Gift, J. J. (1971): Temperature preference, avoidance, and shock experiments with estuarine fishes. — Ichthyol. Assoc. Bull. **7**. 75 pp.

Muller, R. (1977): Temperature selection of goldfish (*Carassius auratus* L.) and brook trout (*Salvelinus fontinalis*, Mitch.) after heterogenous temperature acclimation. — J. Ther. Biol. **2**: 5—7.

Neill, W. H. & Magnuson, J. J. (1974): Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluents from a power plant at Lake Monona, Wisconsin. — Trans. Am. Fish. Soc. **103**: 663—708.

Norris, K. S. (1963): The function of temperature in the ecology of the percoid fish *Girella nigricans* (Ayers). — Ecol. Monogr. **33**: 23—62.

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

Reynolds, W. W. & Casterlin, M. E. (1976): Thermal preferenda and behavioral thermoregulation in three centrarchid fishes. Pages 185—190. — In: G. W. Esch and R. W. McFarlane (eds.), Thermal Ecology II. Nat. Tech. Info. Ser., Springfield, Va.

Scott, W. B. & Crossman, E. J. (1973): Freshwater fishes of Canada. — Fish. Res. Board Can. Bull. **184**: 1—966.

Stauffer, J. R., Jr., Dickson, K. L., Cairns, J. Jr. & Cherry, D. S. (1976): The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. — Wildl. Monogr. **50**: 1—40.

Tyler, A. V. (1966): Some lethal temperature relation of two minnows of the genus *Chrosomus*. — Can. J. Zool. **44**: 349—361.

Address of the authors:

Jay R. Stauffer, Jr.; Edward L. Melisky; Charles H. Hocutt; Appalachian Environmental Laboratory, University of Maryland, Center for Environmental and Estuarine Studies, Frostburg State College Campus Gunter Hall, Frostburg, Maryland 21532, USA.