Transactions of the American Fisheries Society 128:962–964, 1999
American Fisheries Society 1999

The Growth–Temperature Relation of Juvenile Lake Whitefish

THOMAS A. EDSALL*

U.S. Geological Survey, Biological Resources Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, Michigan 48105, USA

Abstract.—The lake whitefish *Coregonus clupeaformis* supports major commercial fisheries in Lakes Superior, Huron, and Michigan, where it is managed on a sustained-yield basis; it also supports a recreational hook-and-line fishery in some Great Lakes embayments and nearshore areas. To better understand habitat use by juvenile lake whitefish in the Great Lakes, we acclimated groups of test fish in the laboratory to 5, 10, 15, 18, 21, and 24°C and fed them to excess twice daily for 55 d. The test fish increased in length and weight at all of the test temperatures and at the end of the study were heaviest and longest at 18.1°C. A curve fitted to the specific growth rate data indicated that the optimum temperature for growth was 18.5°C and, thus, that the fundamental thermal niche for juvenile lake whitefish is 15.5–19.5°C. Our results support the limited, published information on thermal ecology of wild, free-ranging juvenile lake whitefish in the Great Lakes.

The lake whitefish *Coregonus clupeaformis* is native to portions of the northeastern United States and most of Canada and is at the southernmost edge of its geographic range in Lake Erie (Scott and Crossman 1973). The species supports major commercial fisheries in Lakes Superior, Huron, and Michigan (Fleischer 1992) and recreational, hook-and-line fisheries in some Great Lakes embayments and nearshore areas.

This report describes the growth of juvenile lake whitefish over the range of temperatures that would be available to them in the Great Lakes during the warmer months of the year, when they would be expected to be growing most rapidly. Of particular interest is the optimum temperature for growth, which can be used to define the fundamental thermal niche (FTN). The FTN, defined as the optimum temperature for growth ''+2 and −2°C'' (Magnuson et al. 1979) or ''+1 and −3°C'' (Christie and Regier 1988), can be used to predict habitat use by juvenile lake whitefish in the Great Lakes. Similar information for other Great Lakes fishes has been used to predict and evaluate habitat use (Crowder and Crawford 1984; Edsall et al. 1993; Edsall and Frank 1997) and to develop forage estimates and energetics models (Stewart et al. 1983; Binkowski and Rudstam 1994; Rudstam et al. 1994) for use in fisheries management.

Methods

The lake whitefish used in this study were reared from eggs taken from spawning fish in northern Lake Michigan in late fall. The eggs were fertilized in the field and incubated through hatching in spring in the laboratory (Great Lakes Science Center) at temperatures mimicking those over winter in the nearshore waters of northern Lake Michigan. The fish were then held at 7–10°C until December, when they were placed in groups of 30 in paired, 30-L fiberglass tanks at 10°C for acclimation and testing.

During acclimation, temperature in one pair of test tanks was held at 10°C while the temperature in the other five pairs was raised 1.0°C/d or lowered 0.5°C/d until the desired test temperature (5, 10, 15, 18, 21, or 24°C) was reached. Acclimation from 10°C to the test temperatures began at different dates in each of these five pairs of tanks so that all tanks reached the desired test temperatures on December 21. Test fish were anesthetized with tricane methanesulfonate (MS-222), measured to the nearest 1.0 mm (total length), and weighed to the nearest 0.1 g at the start of the study on December 21 and again at the end of the study on February 14.

Temperature was recorded daily in each tank. An immersion heater operated by an adjustable thermostat and a power relay held temperature within 0.1°C of the desired level in each tank during acclimation and testing. Well water flowed into each tank at a rate of 2 L/min, and dissolved oxygen was maintained at 88–99% of air saturation. Fish were fed to excess twice daily during acclimation and testing with a mixture of live brine shrimp *Artemia*, Purina Trout Chow,[1] and freshly thawed opossum shrimp *Mysis relicta* from Lake Michigan. Feeding was adjusted as needed to ensure that a small amount of uneaten food remained

* Corresponding author: thomas_edsall@usgs.gov

Received June 22, 1998; accepted November 2, 1998

[1] Mention of trade names or manufacturers does not imply U.S. government endorsement of a commercial product.

TABLE 1.—Survival and growth of juvenile lake whitefish fed to excess at different constant temperatures for 55 d.

Mean (SD) temperature, °C	Number of fish at start	Survival (%)	Mean (SD) total length, mm		Mean (SD) wet weight, g		Weight–length ratio, end	Specific growth rate[a]
			Start	End	Start	End		
5.0 (0.1)	26	88	89.6 (9.8)	101.1 (11.5)	4.78 (1.71)	7.52 (2.85)	0.07	0.82
10.1 (0.2)	59	98	88.5 (9.4)	115.7 (13.5)	4.54 (1.52)	12.07 (4.72)	0.10	1.78
15.0 (0.1)	59	98	91.7 (9.9)	132.8 (17.0)	5.19 (1.72)	21.14 (8.48)	0.16	2.55
18.1 (0.5)	60	97	92.0 (10.6)	136.9 (16.7)	5.20 (1.88)	24.16 (9.54)	0.18	2.79
21.0 (0.5)	59	93	91.8 (9.1)	132.4 (17.1)	5.12 (1.89)	21.03 (8.69)	0.16	2.57
24.1 (0.6)	26	81	93.9 (9.7)	105.0 (15.0)	5.40 (1.76)	9.95 (5.07)	0.10	1.11

[a] Specific growth rate (Ricker 1979) = $[(\log_e W_2 - \log_e W_1)/(t_2 - t_1)] \times 100$, where W_2 = the mean wet weight at the start of the study (t_1 = day 1) and W_2 = the weighted mean wet weight at the end of the study (t_2 = day 55).

in each tank until the next feeding. This uneaten food was removed before new food was presented. Mortality was recorded daily.

About midway through the study, the power relay on one of the 5°C tanks failed. As a result, the temperature in the tank rose to acutely lethal levels overnight, killing all 30 fish in the tank. We excluded these fish from further consideration in the study. A comparison of the mean weights of the fish in each remaining pair of test tanks at 10, 15, 18, 21, and 24°C at the end of the study revealed no significant difference at the start of the study or at the end of the study (*t* test for paired means; P = 0.01). As a result, the data for each pair of tanks was pooled for presentation and further analysis.

By convention, the test fish became one year older on January 1; thus, they were age 0 during acclimation and the first 10 d of testing and were age 1 during the remaining 45 d of testing.

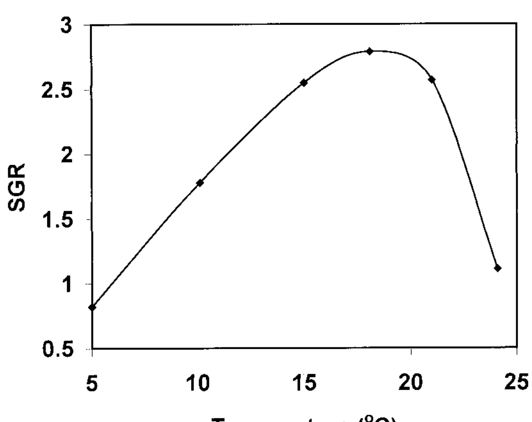

FIGURE 1.—Specific growth rate (SGR) of juvenile lake whitefish fed to excess twice daily for 55 d at various constant temperatures.

Results and Discussion

Survival was highest at 10.1 and 15.0°C (98%) and lowest at 24.1°C (81%), which is near the ultimate upper lethal temperature for lake whitefish (26.7°C; Edsall and Rottiers 1976). Reduced survival of fish in growth studies at temperatures approaching the upper lethal range is to be expected and has been reported for lake herring *C. artedi* by McCormick et al. (1971) and for bloater *C. hoyi* by Edsall and Frank (1997). The relatively low survival in the single 5.0°C tank (88%) was unexpected and cannot be explained with the available data.

Fish increased in length and weight at all of the test temperatures (Table 1). At the end of the study, fish were heaviest and longest at 18.1°C. The ending weight-to-length ratio increased from 0.07 at 5.0°C to 0.18 at 18.1°C and then decreased to 0.10 at 24.1°C. The specific growth rate displayed a similar trend, increasing from 0.82 at 5°C to 2.79 at 18.1°C and then falling to 1.11 at 24.1°C. Thus, the fish grew most rapidly and were most robust at 18.1°C.

A curve fitted to the specific growth rate data (smoothing fit; Excel 97) indicated that the optimum temperature for growth in weight with excess feeding was 18.5°C (Figure 1), and consequently that the FTN (Christie and Regier 1988) is 15.5–19.5°C. This optimum temperature for growth and the FTN are virtually identical to those reported for yearling bloater (18.6°C and 15.6–19.7°C; Edsall and Frank 1997).

There are no published estimates of the optimum temperature for growth or the FTN of juvenile lake whitefish, but Reckahn (1970) found age-0 lake whitefish in a small embayment of Lake Huron were closely associated with the lake bed at the 17°C isotherm from early July through early September. This selected temperature is within the

FTN but is 1.5°C lower than the optimum for growth found in the present study.

The behavioral response for food-limited fishes can be to seek temperatures lower than the optimum temperature for growth (Mac 1985), where the maintenance energy requirement is lower (Brett et al. 1969). The wild population described by Reckahn (1970) was undoubtedly more food-limited than the laboratory population in the present study, which was fed to excess. Thus, the 1.5°C difference between the optimum temperature for growth displayed by the laboratory population and the 17°C selected by the wild population may largely reflect the influence of food availability on temperature selection in the wild population.

Acknowledgment

This is contribution 1050 of the Great Lakes Science Center, Ann Arbor, Michigan.

References

Binkowski, F. P., and L. G. Rudstam. 1994. Maximum daily ration of Great Lakes bloater. Transactions of the American Fisheries Society 123:335–343.

Brett, R. A., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. Journal of the Fisheries Research Board of Canada 26:2363–2393.

Christie, G. C., and H. A. Regier. 1988. Measures of optimal thermal habitat and their relations to yields of four commercial fish species. Canadian Journal of Fisheries and Aquatic Sciences 45:301–314.

Crowder, L. B., and H. L. Crawford. 1984. Ecological shifts in resource use by bloater in Lake Michigan. Transactions of the American Fisheries Society 113: 694–700.

Edsall, T. A., and A. M. Frank. 1997. The effect of temperature on growth of juvenile bloater. Journal of Great Lakes Research 23:468–471.

Edsall, T. A., and D. V. Rottiers. 1976. The temperature tolerance of young-of-the-year lake whitefish, *Coregonus clupeaformis.* Journal of the Fisheries Research Board of Canada 33:177–180.

Edsall, T. A., J. H. Selgeby, T. J. DeSorcie, and J. R. P. French III. 1993. Growth–temperature relation for young-of-the-year ruffe. Journal of Great Lakes Research 19:630–633.

Fleischer, G. M. 1992. Status of coregonine fishes in the Laurentian Great Lakes. Polish Archives of Hydrobiology 39:247–257.

Mac, M. J. 1985. Effects of ration size on preferred temperature of lake charr, *Salvelinus namaycush.* Environmental Biology 14:227–231.

Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19:331–343.

McCormick, J. H., B. R. Jones, and R. F. Syrett. 1971. Temperature requirements for growth and survival of larval ciscos (*Coregonus artedii*). Journal of the Fisheries Research Board of Canada 28:924–927.

Reckahn, J. A. 1970. Ecology of young lake whitefish (*Coregonus clupeaformis*) in South Bay, Manitoulin Island, Lake Huron. Pages 437–460 *in* C. C. Lindsey and C. S. Woods, editors. Biology of coregonid fishes. University of Manitoba Press, Winnipeg.

Rudstam, L. G., F. P. Binkowski, and M. A. Miller. 1994. A bioenergetics model for analysis of food consumption patterns of bloater in Lake Michigan. Transactions of the American Fisheries Society 123: 344–357.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184.

Stewart, D. J., D. Weininger, D. V. Rottiers, and T. A. Edsall. 1983. An energetics model for lake trout, *Salvelinus namaycush*: application to the Lake Michigan population. Canadian Journal of Fisheries and Aquatic Sciences 40:681–698.