Theodore H. Blahm
and
Robert J. McConnell
National Marine Fisheries Service
Biological Laboratory
2725 Montlake Boulevard East
Seattle, Washington

Mortality of Adult Eulachon (Thaleichthys pacificus) Subjected to Sudden Increases in Water Temperature

Increased industrial use of water and the construction of nuclear plants, storage reservoirs, and dams are expected to change the thermal regime of the Columbia River. Moore (1968) and Clark and Snyder (1970) reported that temperatures in the lower river have already increased.

Fry (1947) pointed out that temperature affects animal activity through metabolism. Temperature governs the amount of energy available for such activities as swimming, feeding, digesting food, and spawning. Brett (1960) stated that water temperature for any species of fish should not exceed that which would curtail activity below three-fourths of the optimum. If activity is depressed, survival of the species is in jeopardy. The energy demands for reproduction impose thermal limitations if the species is to survive. Brett recommends a "freedom" of 3 C (5.5 F) below the ultimate lethal level.

The Columbia River has commercially important runs of eulachon (*Thaleichthys pacificus*) each year (Pruter, 1966). Smith and Saalfeld (1955) report that in the past, large numbers have spawned in the Grays, Cowlitz, Lewis, and Sandy rivers—tributaries of the Columbia River. They add that the runs to tributaries farthest from the mouth of the Columbia are sporadic and may be absent in some years. The commercial and sport fisheries in the Cowlitz River remain the most productive.

Smith and Saalfeld (1955), in three series of tests, found that eulachon exhibited an aversion to three different waste flows from industrial sources. They also reported that the eulachon showed a preference for a narrow range of water temperature; the fish entered the Columbia River and its tributaries when the river temperature was between 2 and 10 C.

Water temperatures above this range could result from the operation of a thermal nuclear power plant. For example, increases in water temperature near the outfall of a 2000 MWe plant can be expected to reach a ΔT[1] of 11.1 C at the plume head (Battelle-Northwest, 1967) and cause an overall increase in the entire receiving body of water after mixing. Flow reversals in the Columbia River, at the confluence of the Cowlitz, could compound the heating effect caused by effluents from proposed thermal plants in this stretch of the river (Clark and Snyder, 1969). The eulachon migrate through this area to enter the Cowlitz River.

Tests were conducted in 1968 and 1969 to examine some aspects of the thermal tolerance of the adults. Samples of eulachon were subjected to lethal and sublethal temperatures. Their resistance times and survival were recorded.

[1] ΔT = increase above ambient water temperature.

Fish Capture and Pretest Holding

Eulachon (Fig. 1) were dipnetted from the Cowlitz River during March 1968 and February 1969 and transported in a tank truck to the experimental temperature laboratory at Prescott, Oregon. Each trip took less than two hours, during which time oxygen was metered into the water. The average weights and fork lengths of the fish captured in 1968 and 1969 were 153 mm and 26 g, 161 mm and 31 g, respectively. The fish were sexually mature but none had spawned. They were assumed to be acclimated to the water temperature of the Cowlitz River, which was 10 C in 1968 and 5 C in 1969.

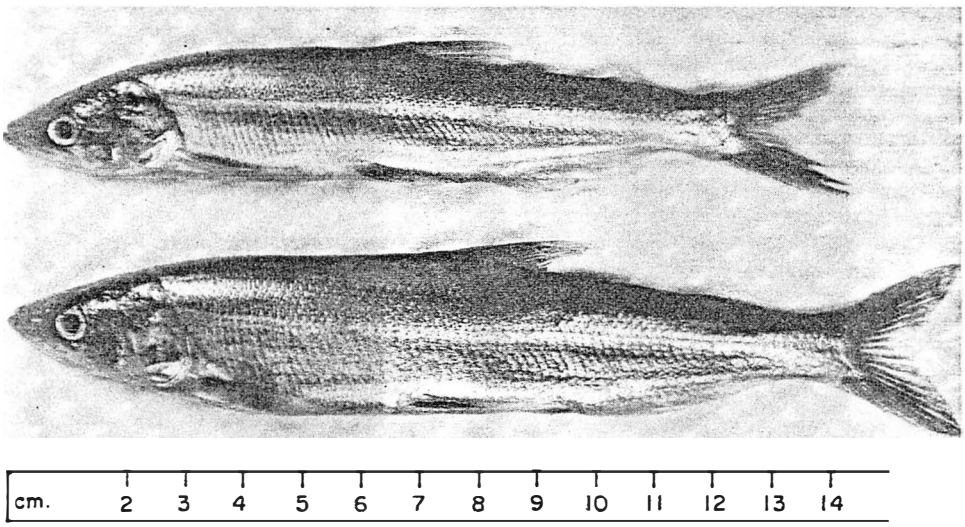

Figure 1. Adult female (above) and male eulachon (*Thaleichthys pacificus*). The scale is in centimeters.

The fish were held in 1.8 x 1.2 m redwood tanks for two days before testing to determine mortality from the stress of handling and transporting. No mortality was recorded during transport and less than 0.1 percent after the two-day holding period. Water from the Columbia River was circulated through the tanks at about seven liters per minute, which gave at least one complete interchange of water each hour. The temperature was maintained within 0.5 C of the temperature of the Cowlitz River at time of capture.

Physical Equipment and Operating Procedure

The wooden test tanks, 80 x 60 cm, were filled to a capacity of 188 liters. Water was replaced in each tank at a rate of 3.8 liters per minute, which provided at least one complete interchange of water each hour. Two air stones, plus the high rate of water exchange, maintained dissolved oxygen at 100 percent saturation or higher.

Water was supplied to the test tanks by gravity flow from two reservoirs, each with a capacity of over 3000 liters. The water in one reservoir was heated to 33 ± 0.5 C by a 100-kw heater that was thermistor controlled. The water in the second was cooled to 5 ± 0.5 C by a water chiller with a capacity of 544 kilocalories/min. Water from the two reservoirs was mixed to produce the temperature range (5-32 C) required in the test tanks. The water temperature in each tank was held within ± 0.5 C of the test temperature and monitored by a thermistor thermometer.

Testing Procedure and Results

Procedures for lethal temperature determinations for fish have been outlined and recommended by various experimenters. We chose the procedures recommended by Fry (1947) and used by Brett (1952).

1968 Tests

The 1968 tests were exploratory; however, the results were used in developing the design for the 1969 test series.

Samples of 10 fish each were immersed for one hour in one of eight test tanks that had been preheated to temperatures of 10 (control), 13, 15, 18, 21, 24, 27, or 32 C (Table 1). At the end of one hour the temperatures were lowered to 10 C within

TABLE 1. Mortality of adult eulachon subjected to various water temperatures for one hour; tested in 1968.[1]

Test water temperature	Temperature increase	TIME TO: First mortality	50% mortality	100% mortality
C		Minutes		
10	None	-----	-----	-----
13	+3	-----	-----	-----
15	+5	-----	-----	-----
18	+8	36.0	1920.0	-----
21	+11	15.0	26.0	-----
24	+14	5.0	14.0	51.0
27	+17	1.4	2.0	3.3
32	+22	0.3	0.3	0.3

[1] One sample of ten fish was used in each test; live fish were held for 50 hours after each test.

about ten minutes. The fish were held for 50 hours after each test. The time was recorded to first mortality, 50 percent mortality, and 100 percent mortality (Table 1).

A one-hour exposure to the sudden temperature increase was chosen to represent roughly the conditions which the animals might possibly experience in a "thermal plume" during a river flow reversal.

Fish exposed to an increase of 3 or 5 C above the control (acclimation) temperature of 10 C did not die within the one-hour exposure nor during the 50-hour post-test holding period (Table 1). At least 50 percent of the test fish died, however, after exposure to a sudden increase of 8 C or more above the control temperature.

The time to first mortality, 50 percent mortality, and 100 percent mortality of fish in a sample decreased with increasing temperatures: at 18 C, 50 percent mortality was recorded in 1920 minutes; at 32 C, all fish in the sample died within 0.3 minute. A lethal level was established at 18 C; this level, however, can be altered by a change in the base acclimation temperature and exposure time.

1969 Tests

The water temperature in the Cowlitz River was lower by 5 C in 1969 than in the previous year. At the time the test fish were captured the river temperature was 5 C. The 1969 tests differed from the 1968 tests in that the range from base to highest temperature was narrowed (5 to 29 C). The animals were held at the test temperatures until death or until termination of test at 11,520 minutes (eight days). Sample

size was increased to 20 fish. Time to mortality was recorded for the fish in each sample. All other procedures were essentially the same as for the previous tests.

The incipient lethal level[2] was established at 11 C, which was 6 C above the control (acclimation) temperature (Table 2). Mortality of 100 percent was recorded at 11 C and above. Resistance times decreased with increasing temperature.

TABLE 2. Mortality of adult eulachon subjected to increased water temperatures for an eight-day test period; tested in 1969.[1]

Test water temperature	Temperature increase	TIME TO: First mortality	50% mortality	100% mortality
C		Minutes		
5	None	7380	-----	-----
8	+3	8880	-----	-----
11	+6	6360	8940	11,520
14	+9	4320	8640	10,080
17	+12	361	4860	8640
20	+15	71	4440	6120
23	+18	2	5.1	59
26	+21	0.8	1.2	1.5
29	+24	.2	.7	1.0

[1] One sample of 20 fish was used in each test.

Effects of Increased Temperature

The most profound difference between the two years of tests is that in 1968 the fish were subjected to a 60-minute exposure to the test temperatures, whereas in 1969 the fish were held at the test temperatures until death or until the eight-day test period had elapsed. The eight-day test period was chosen to provide an approximate duration of 10,000 minutes, used as a criterion by other experimenters.

The base (acclimation) temperatures in the two years of tests differ by 5 C. The difference in exposure time to test temperatures will not allow us to make resistance time comparisons between the two tests. The results of the 1968 test seem to indicate that a 60-minute exposure to a temperature of 18 C or to a +8 C thermal plume differential would cause an unacceptable mortality level.

In the 1969 tests, we were able to establish an upper incipient lethal level for eulachon acclimated to 5 C (Table 2). An exposure to a temperature increase of +6 C above 5 C ambient for 8940 minutes resulted in a 50 percent mortality. As the test temperature increased, the temperature "dose" causing 50 percent mortality was reached in less time (Table 2).

At the higher temperatures, 23 through 29 C, the fish exhibited a stress-panic reaction and their swimming movements were not directional. At 26 and 29 C, 100 percent mortality occurred in 1.5 minutes or less; it is doubtful if any of these fish could have escaped from a thermal plume by their own volition.

It was noted that the temperature-treated females had retained their eggs at death or at the conclusion of the tests; however, the control group had deposited sperm and eggs in the control tank. Approximately 1000 fish (not used in tests)

[2] The temperature beyond which 50 percent of the population can no longer live for an indefinite period of time.

had been held at river temperature during the test period in 1969. These animals spawned in the tank; fertilized and developing eggs were found as were newly hatched larvae. This indicates that the increased temperature had affected the spawning cycle of the test fish.

The data reported here are not conclusive; the lethal levels and resistance times could be altered by changing environmental conditions and the state of maturation of the animals at the time of testing. However, our data do indicate a need for exploration to assess the effects of sublethal temperature exposure on the animals' ability to spawn successfully and carry out functions necessary to survive in a changing environment.

Literature Cited

Battelle-Northwest. 1967. Summary report on nuclear power plant siting in the Pacific Northwest for the Bonneville Power Administration, Contract No. 14-03-67868. Battelle Mem. Inst., Pac. Northwest Laboratories, Richland, Washington, 50 pp. (Processed)

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Bd. Can. 9: 263-323.

————. 1960. Thermal requirements of fish—three decades of study, 1940-1970. *IN:* C. M. Tarzwell (compiler), Biological problems in water pollution, pp. 110-117. U.S. Dept. Health, Educ., Welf., Public Health Serv.; Robert A. Taft Sanit. Eng. Center, Cincinnati, Ohio, Tech. Rep. W60-3.

Clark, S. M., and G. R. Snyder. 1969. Timing and extent of a flow reversal in the lower Columbia River. Limnol. Oceanogr. 14: 960-965.

————and————. 1970. Limnological study of lower Columbia River, 1967-68. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 610. 14 pp.

Fry, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud., Biol. Ser. 55, Ontario Fish Res. Lab. Publ. 68. 62 pp.

Moore, A. M. 1968. Water temperatures in the Columbia River Basin, July 1966 to September 1967. U.S. Dep. Int., Geol. Survey, Open-file report, Portland, Oregon.

Pruter, A. T. 1966. Commercial fisheries of the Columbia River and adjacent ocean waters. U.S. Fish Wildl. Serv., Fish. Ind. Res. 3(3): 17-68.

Smith, W. E., and R. W. Saalfeld. 1955. Studies on the Columbia River smelt (*Thaleichthys pacificus*). Wash. Dep. Fish., Fish. Res. Pap. 1(3): 3-26.

Received September 23, 1970.

Accepted for publication December 29, 1970.