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COLUMBIA RIVER THERMAL EFFECTS STUDY

EFFECTS OF ACCLIMATION ON RESISTANCE OF JUVENILE SALMONIDS TO HIGH LETHAL TEMPERATURES

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INTRODUCTION

Heated water discharges as high as 46 C, with resulting river temperatures over 35 C as far as 5 miles downstream, have been reported from thermal-electric power plants in the eastern United States (Stroud and Douglas, 1968). One plant on the Columbia River in Washington State discharges 1,250 c.f.s. at 21 C over ambient when operating at 860 megawatt production (Snyder, 1969). Other operating conditions could produce discharges as high as 26 C over ambient. Under certain ambient river conditions of flow and temperature, masses of heated water from thermal effluents can maintain their integrity for considerable distances downstream from the point of discharge (Coutant, 1969). As a result, juvenile salmon could be swept into areas of maximum heating and become entrapped by flow conditions for varying periods of time. Perhaps the effects on the fish would differ in regard to their acclimation to different seasonal temperatures. Brett (1952) reported for Pacific salmon the relation of temperature acclimation to their upper limits of heat tolerance. But whether acclimation can increase the resistance of salmonids to lethal temperatures higher than those described by Brett is unknown. The objective of this work was to test the hypothesis that acclimation may affect the resistance of salmonids to the high temperatures described for thermal effluents at their points of maximum heat.

MATERIALS AND METHODS

Three species of yearling salmonids (sockeye, *Oncorhynchus nerka*; coho, *O. kisutch*; and steelhead, *Salmo gairdnerii*) were tested. Sockeye and coho were obtained for the U.S. Fish and Wildlife Service hatchery at Leavenworth, Washington. Steelhead were from Washington State Game Department stock from Chambers Creek, reared in ponds on the Green River at Palmer, Washington. Sockeye ranged from 100-200 mm in fork length, coho from 75-134 mm, and steelhead from 136-229 mm.

After transport to the laboratory, the fish were held at a temperature (8-9 C) duplicating their thermal history in the hatchery for about 2 weeks before we began the acclimation process. After this adjustment period, the temperature in each tank was shifted every 3 or 4 days 2.5 C toward the desired acclimation temperature. Individual populations from each species were acclimated to 5, 10, 15, and 20 C; coho were also acclimated 23 C. Once the acclimation temperature was reached, the fish were held for about 2 weeks at that temperature before they were used in the experiment. Fish acclimated to 5 C were held for 3 weeks prior to testing.

About 1000 (18 kg) coho and 650 (32 kg) steelhead were held in indoor circular fiberglas tanks containing about 200 gal of water replaced at a rate of 4 gal per minute for the coho, and about 8-10 gal per minute for the steelhead. Sockeye were acclimated in smaller groups in 50-gallon aquaria with a water replacement rate of 500 ml/min. Water quality was monitored periodically during acclimation and holding. Dissolved oxygen

was at or near saturation at all times in the sockeye and coho holding tanks and between 75-85% saturation with the steelhead. Total ammonia ranged from 0 to .46 ppm with the sockeye and coho, and from 0.21-0.91 ppm with the steelhead. The higher ammonia levels were always at the highest acclimation temperatures with all fish and most noticeable with the steelhead. This was presumably due to higher metabolic rates at the higher temperatures, and the heavier loading of the tanks due to the larger size of the steelhead. The pH ranged from 7.0 to 7.4.

To determine resistance times, fish from a twenty fish sample from each of the acclimation temperatures were subjected individually to test temperatures of 28, 30, or 32 C. The first event noted was the loss of equilibrium, when the fish could no longer remain upright; and the second was death, defined here as the cessation of opercular movement. It was felt that loss of equilibrium may be as important as resistance to death. Fish that have lost the ability to control their actions are completely helpless to hazards of the environment. Test exposure was abrupt. Each fish was carefully netted from a holding tank at the acclimation temperature and placed directly in the test temperature tank. The chosen events were then timed in seconds.

RESULTS

All of the fish, when subjected to the high temperatures, exhibited a patterned sequence of behavior. Some of the elements were present in every test, whereas others occurred less frequently. Generally, immediately after introduction to the test temperature, the fish slowly swam near the bottom of the test tank and remained stationary for several

seconds to a minute or more, depending on the acclimation and test temperature involved. A few rapid flares of the operculum then preceded a slow swimming about the tank, sometimes dipping the head and tail alternately downward. After a few moments, the fish would ususally return to a state of rest in the lower half of the tank before the next phase of behavior. The fish then passed from the torpid phase of behavior to rapid darting and non-directional swimming. Sometimes this darting took the form of a tight corkscrew swimming pattern, but always resulted in a sudden loss of equilibrium. This was followed by a complete collapse and cessation of opercular movement.

It was apparent that acclimation affected the resistance to loss of equilibrium or death even at the temperatures higher than the upper lethal limits described by Brett (1952). This was especially evident at the 28 C exposures wherein coho acclimated to 20 C had a mean survival of over 26 times as long as those acclimated to 5 C; steelhead acclimated to 20 C survived 23 times longer than those at 5 C; and sockeye at 20 C lived 5 times as long as those acclimated to 5 C. The mean resistance times are summarized in Table 1. Mean resistance time to death (survival time) ranged from approximately 1 minute to nearly 110 minutes. The longest mean resistance times were in the 28 C test water and the shortest at 32 C.

Acclimation also affected the resistance to loss of equilibrium. Loss of equilibrium occurred from 0.7 to 85.4 minutes, depending on the test combinations, with the shortest times at the highest test temperatures and the lowest acclimations. The average time for loss of equilibrium was 63 percent of the elapsed time to death, but ranged from 41 to 91 percent.

Table 1. Mean resistance times of yearling sockeye, coho, and steelhead to high lethal temperatures.

SPECIES		SOCKEYE		COHO		STEELHEAD	
		Time To		Time To		Time To	
Test Temp. °C	Accl. Temp. °C	LE* (seconds)	Death (seconds)	LE* (seconds)	Death (seconds)	LE* (seconds)	Death (seconds)
28	5	77	124	68	165	142	278
	10	114	247	125	398	283	696
	15	206	465	1161	1817	1560	2356
	20	435	693	3617	4266	5125	6534
	23			5070	5582		
30	5	54	80	47	79	99	151
	10	62	94	54	91	104	158
	15	91	122	105	188	243	400
	20	110	177	367	646	688	1072
	23			556	752		
32	5	49	67	43	63	70	122
	10	53	73	40	60	73	107
	15	55	77	51	81	91	140
	20	46	67	75	130	143	206
	23			78	119		

*LE - Loss of Equilibrium

The resistance times to death of the three species are compared in Figure 1. Steelhead survived longer than sockeye or coho at all of the acclimation and test temperature combinations. Coho survived longer than sockeye in all cases at 28 C. At the 5 and 10 C acclimation levels, their resistances were about the same in tests at 30 C and 32 C; but when acclimated to 15 and 20 C, the coho again had longer resistance times at 30 and 32 C than the sockeye. The comparisons must be qualified, however, as the sockeye tests were conducted under somewhat different experimental conditions. Although the steelhead were considerably larger than either the sockeye or coho, analysis of the data did not show a correlation between size and resistance to death or loss of equilibrium.

SUMMARY

Yearling sockeye, coho, and steelhead were tested to determine the affects of their previous temperature acclimation on their resistance to high lethal temperatures. The fish were acclimated to 5, 10, 15, 20, and 23 C. They were tested at 28, 30, and 32 C.

At all test temperatures, the trend was for resistance to loss of equilibrium and death to increase as acclimation temperature increased. The effects were highly positive at the 28 C temperature, much less at 30 C, and barely evident at 32 C, suggesting that 28 C is perhaps a critical upper limit for acclimation to significantly influence resistance to heat.

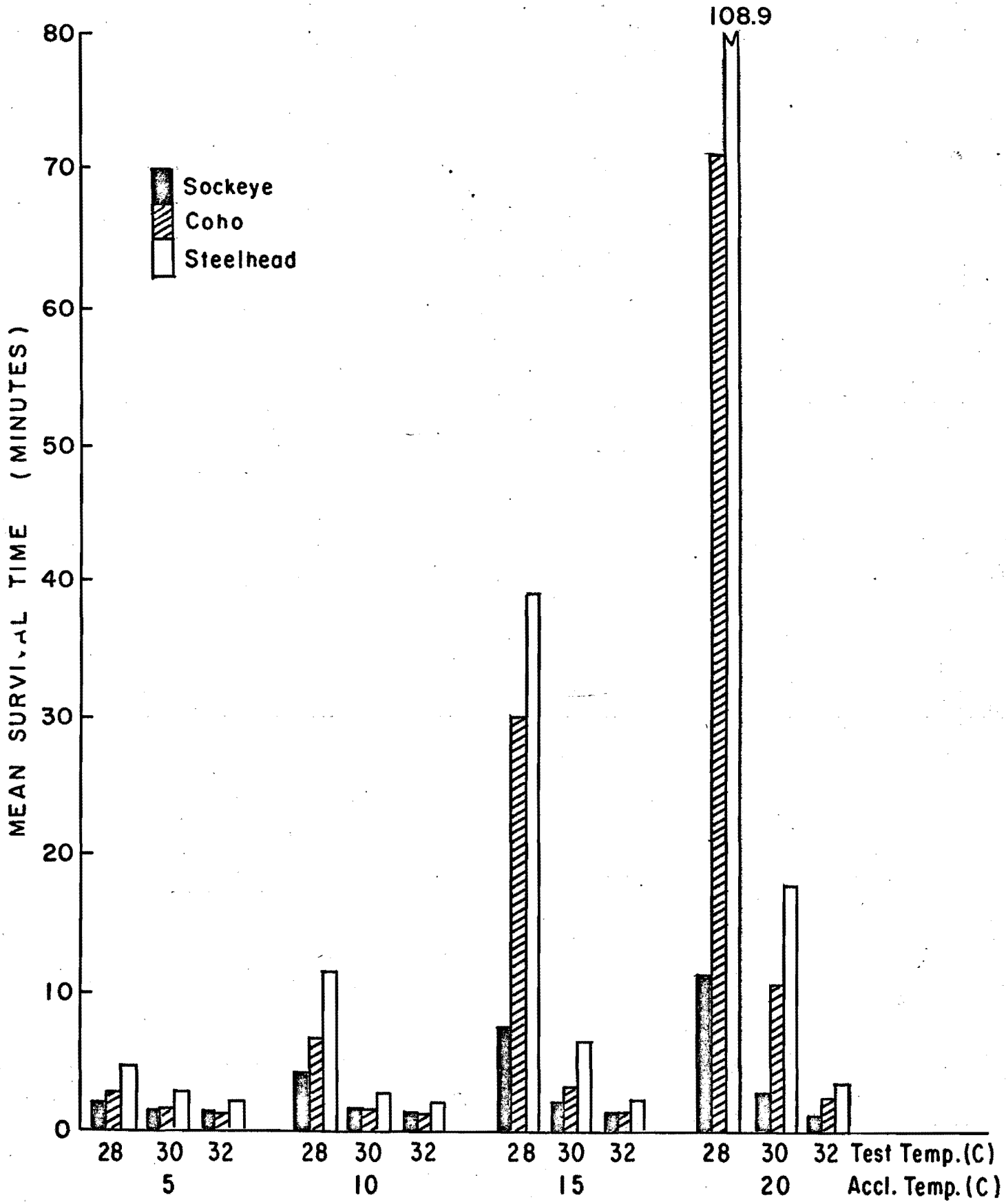

Figure 1.-- Effect of acclimation temperature on survival of yearling sockeye, coho and steelhead at high lethal temperatures

Steelhead showed greater resistance than coho or sockeye in all tests. Sockeye resistance times were lower than either coho or steelhead and they seemed less adaptable to temperatures over 15 C. Size of the fish within ranges tested did not affect resistance times to death or loss of equilibrium.

CONCLUSIONS

Exposures to thermal effluent temperatures of 28 C or over could quickly kill yearling salmonids, especially during the winter and spring when ambient river temperatures are normally below 12 C. In the summer and fall, the migrant fish, though usually fewer in number, would be adjusted to the seasonally higher river temperatures. But this is also the period of declining river flow. This, combined with the higher ambient river temperatures, could result in slower dissipation of added heat from effluents. Thus, even though the thermal resistance of the fish was higher, their exposure time to high temperature could be extended.

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