INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT
No. 34

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in the Fraser River System

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ABSTRACT

The resistance of adult sockeye salmon (Oncorhynchus nerka) to acute thermal shock was measured under laboratory conditions using sockeye treated to resist infection. A graph of geometric mean survival time (GMST) versus temperature was similar to that reported for juvenile sockeye but was displaced lower by 1° to 1.5° C, indicating that adults were less resistant to high temperatures. A discontinuity occurred at the upper end of the curve where a second mortality curve commenced associated with infections of Flexibacter columnaris.

Loss of equilibrium preceded death, with the difference in time between first loss of equilibrium and GMST decreasing as temperature increased. It was concluded that mortalities could be expected for thermal exposures exceeding the temperature-time relations for the loss-of-equilibrium curve. However, since temperatures lower than those causing death by thermal shock are a factor in mortalities caused by F. columnaris, it was recommended that these lower levels take precedence when temperatures are specified for protection of sockeye.

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INTRODUCTION

Early runs of adult sockeye salmon (*Oncorhynchus nerka*) bound for spawning grounds in Nadina River pass Hell's Gate on the Fraser River during mid-July and reach Vanderhoof along the Nechako River about two weeks later. Historically all of the Nechako River drainage was tributary to the Fraser River, but in 1952 the upper Nechako River was dammed and a portion of the water diverted west to a hydroelectric power generation station at Kemano. Proposals have been made to divert additional water to Kemano from the Nechako. Should this occur, flow in the Nechako River would be reduced to less than present levels. As a consequence of reduced flow, summer water temperatures would increase, raising the possibility of excessive stress among early runs of sockeye salmon migrating in the Nechako River.

Three races of "early run" sockeye utilize the Nechako River. Sockeye bound for the Stuart Lake systems migrate in the Nechako to its confluence with Stuart River, while the early and late sockeye bound for Nadina River continue in the Nechako to its confluence with Nautley River at the outlet of Fraser Lake. Early Nadina sockeye would be most likely to encounter the highest temperatures.

The resistance of juvenile sockeye to elevated temperatures was reported by Brett (1952). Coutant (1969) compared resistance times of juvenile and adult chinook (*O. tschawytscha*) and coho (*O. kisutch*) exposed to lethal temperatures, and concluded that temperature resistance of juveniles and adults varied among these species. Furthermore, it was concluded that results obtained using juvenile salmon could not be applied to adults.

An important indirect effect of elevated temperatures is infection caused by *Flexibacter columnaris* (*Chondrococcus columnaris*), which have been the cause of significant pre-spawning mortality among Fraser River sockeye (Colgrove and Wood, 1966).

The combined effect expected from higher water temperatures in the Nechako River would be to raise the potential for epizootics of *F. columnaris* among adult sockeye and to increase the possibility of mortality owing to thermal shock alone. Since some background data concerning relationships between columnaris, temperature, and sockeye mortality exist, measurements of resistance to high temperatures were undertaken using early run sockeye treated to reduce the effect of infection on the resistance.

METHODS

Early run adult sockeye of the Stuart and Nadina races were captured at Hell's Gate on July 11, 12, and 13, 1973 using large dipnets, and were placed individually in 20 gal. plastic vessels containing river water plus 2 phenoxy-ethanol (0.2 ml/gal) as a mild anaesthetic. The fish were quickly transferred to a 300 gal. transportation box and filled to a maximum of 25 fish per load. Water was oxygenated and temperature was maintained near 4° C by addition of ice, but increased to about 12° C by the time fish arrived at Sweltzer Creek Laboratory 6 hours after capture. Upon arrival, 2 phenoxy-ethanol was added at 0.2 ml/gal to quiet the fish for transfer to covered six foot diameter holding ponds at a loading of 10 fish per pond.

As a precaution against bacterial and fungal infections, each fish was administered a 250 mg tetracycline capsule orally during transfer from transportation tank to holding tank. In addition, bath treatments of 1 mg/liter malachite green and 2 mg/liter P7138 were given weekly to fish being held for tests. Fish were not treated during exposure to test temperatures.

Scale and hypural length measurements indicated the population was likely 95 percent Early Stuart and 5 percent Early Nadina.

Water was supplied to holding ponds at about 20 gpm from intakes located above and below the thermocline of Cultus Lake to permit adjustment of temperatures to simulate those experienced by Early Stuart and Early Nadina sockeye during migration (TABLE 1). Peripheral water velocities in holding ponds were about 1 fps.

Experimental ponds were identical to holding ponds in size, and water from Cultus Lake was supplied at 3 to 6 gpm. Heated water was obtained from a heat exchanger and compressed air was used to strip excess dissolved gases and maintain dissolved oxygen near saturation. Peripheral velocities were maintained at about 1 fps by recirculation using a centrifugal pump for each pond.

TABLE 1 - Travel time and temperature for Early Stuart and Early Nadina sockeye.

Location	Date	Travel Time From Hell's Gate[a] Days	Mean Temperature °C	Mean Temperature °F
<u>Fraser River</u>				
Hell's Gate	July 12	-	15.8	60.5
Bridge River Rapids	July 15	3	16.4	61.5
Quesnel	July 21	9	16.8	62.2
<u>Nechako River</u>				
Prince George	July 24	12	18.3	65.0
Upstm. Stuart R. Confluence	July 26	14	18.0	64.3
Vanderhoof	July 27	15	18.0	64.3
Nautley R.	July 28	16	18.0	64.3

[a] Killick (1955)

Since travel times in the Nechako River between Prince George and Nautley River were 4 days (TABLE 1), tests of resistance to high temperatures were scheduled for 96 hr duration. Tests were conducted at fixed temperatures between 18 and 30° C. In cases where all fish survived for 96 hr, the temperature was raised uniformly to 27° C in about 100 min and acute temperature tolerance was measured at 27° C.

Resistance to high temperatures was measured by transferring 5 fish, generally 3 females and 2 males, from holding to experimental ponds at prescribed test temperatures and noting elapsed times to loss of equilibrium and death. Death was defined as cessation of opercular beat. Resistance was quantified by using elapsed time to death to calculate geometric mean survival time (GMST) for each temperature (Davis and Mason, 1973).

RESULTS

Adult sockeye succumbed quickly at 30° C, where the GMST was 9 to 10 minutes (TABLE 2). At 25° C the GMST for four groups increased from 181 to 460 minutes. The slope of the GMST versus temperature curve became nearly vertical at about 24° C, but a discontinuity occurred associated with mortalities at 23° and 22° C (FIGURE 1). No mortalities occurred at 21° and 18° C.

Lesions indicative of _F. columnaris_ were evident on the gills and body of many fish exposed to 24°, 23° and 22° C, but none were observed at lower or higher temperatures. Thus it appeared that mortality was caused by thermal shock at temperatures in excess of 24° C, possibly by a combination of thermal stress and _F. columnaris_ at 24° C and by _F. columnaris_ at temperatures less than 24° C.

Symptoms of distress were noted among fish prior to death (cessation of opercular beat). The first outward sign of distress was failure to maintain position in the tank and a tendency to drift with the current. This was followed by a period of a few minutes in which fish lost and regained equilibrium two or three times before cessation of opercular beat. Although determining the GMST quantified the response to high temperature, it did not reveal minimum temperature and time associated with acute distress. Thus, time to first loss of equilibrium was plotted in FIGURE 1. The difference in time between first loss of equilibrium and first mortality was only a few minutes in most cases (TABLE 2), and the graph of time to first loss of equilibrium versus temperature was similar in shape to the graph of GMST (FIGURE 1). Based upon FIGURE 1, mortality could be expected for exposure to temperatures equal to those of the loss-of-equilibrium curve.

GMST's were similar at 30° C for tests A, B and C, but fish were more resistant to 27° C in test C than in A and B ($p < 0.05$, Duncan's New Multiple Range Test). Similarly, GMST increased at 25° C in order of testing. On the other hand, at 24° C there was an initial increase in

TABLE 2 - Loss of equilibrium and GMST (Min.)

Bioassay and Starting Date	Temp. °C	1st Loss of Equilibrium	Time to Death		GMST
			Min.	Max.	
A, 7/16	30	6	7.5	10.5	8.9
	27	22	27	41	31
	25	109	115	403	186
	25	120	128	328	181
	21		No mortality in 96 hrs.		
	18		No mortality in 96 hrs.		
B, 7/21	30	7	9.0	10.5	9.9
	27	17.5	21	32.5	23
	24.4	277	279	597	378
	24	1805	1835	3900	3013
	23	3207	3222	5214	4050
	21		No mortality in 96 hrs.		
	18		No mortality in 96 hrs.		
C, 7/25	30	6	8.0	12.0	10.4
	27	45	48	77	61
	25	192	195	374	284
C, 7/26	24	2950	2960	4785	3604
	23	3020	3030	4944	3508
	21		No mortality in 15 days.		
	18		No mortality in 15 days.		
D, 8/2	27	52	60	72	63
7/30	25	354	357	900	460
7/31	24	1155	1170	5145	3020
8/3	22	6130	7005	12949	7386

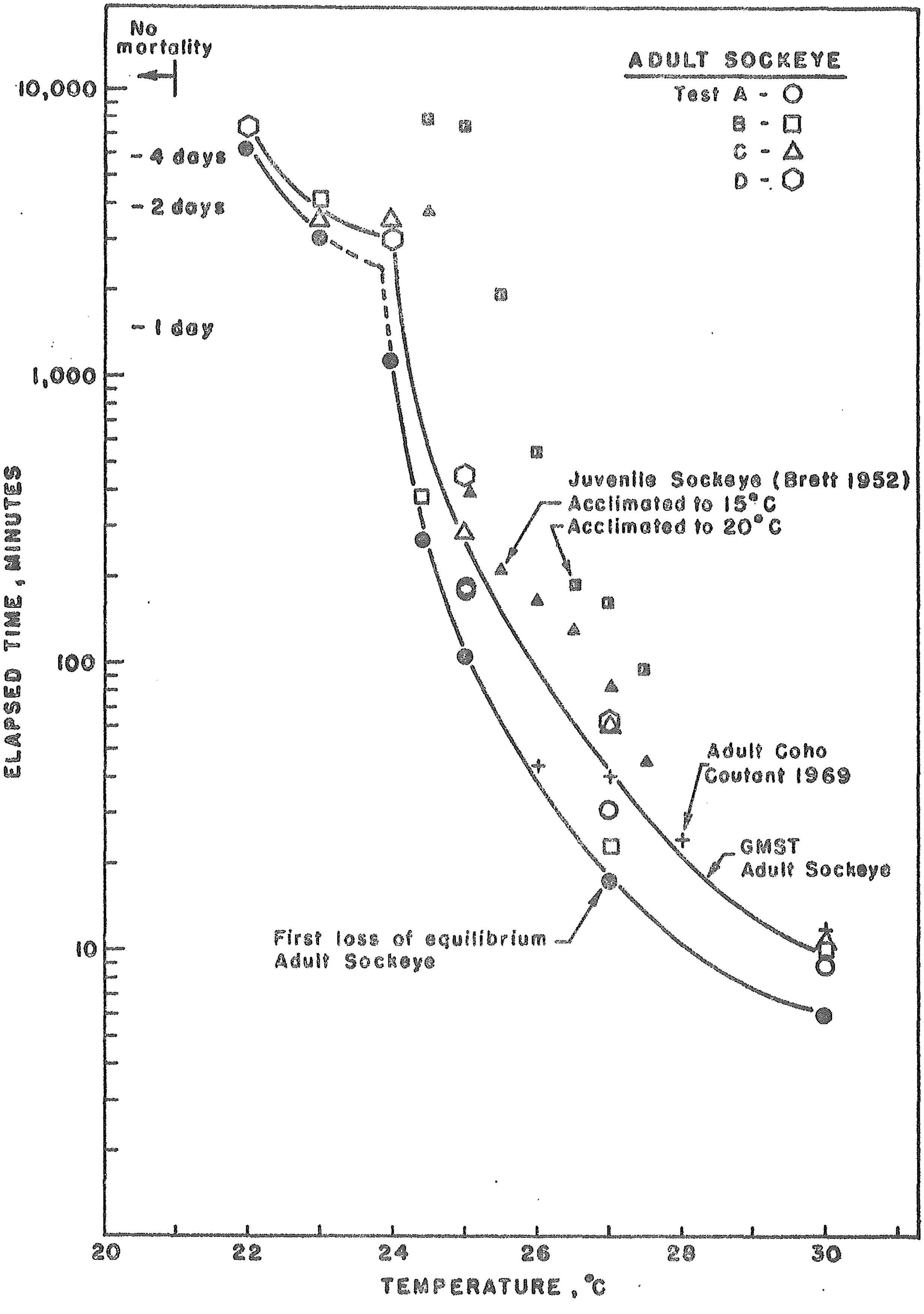

Figure 1. Time to loss of equilibrium and geometric mean survival time

GMST from B to C but a decrease in test D. Furthermore, at 23° C, GMST decreased slightly from test B to C. These results suggest that at temperatures which caused death by thermal shock there was a tendency for increased resistance as testing proceeded from A to D, whereas at temperatures where death was believed related to columnaris infection, there was a tendency toward reduced resistance.

Resistance to 27° C was also measured in tests wherein temperature was raised from 18° or 21° C to 27° C in 100 minutes using fish transferred from 18° or 21° C at conclusion of tests A, B and C. In each case, GMST at 27° C was significantly greater ($p < 0.05$) when fish were exposed to a pre-test temperature of 21° C than when they were transferred directly from average river temperatures to 27° C (TABLE 3). A similar result was noted for tests A and B when the pre-test temperature was 18° C. In test C, GMST was greater for fish previously exposed to average river temperatures than to 18° C, but the difference was not statistically significant. Absence of a statistically significant difference in this case is explained by the fact that the pre-test exposure temperature and average river temperatures were both 18° C.

TABLE 3 - Geometric Mean Survival Time at 27° C for adult sockeye transferred from 18° and 21° C at conclusion of tests A, B and C.

Pre-test Temp. ° C	GMST at 27° C, min.		
	A	B	C
21	76	59	147
18	40	48	38
Average River (TABLE 1)	31	23	61

DISCUSSION

Brett (1952) reported mean survival times (MST shown equivalent to GMST) of juvenile sockeye exposed to lethal temperatures after transfer from a series of acclimation temperatures. For comparison, MST's obtained when the acclimation temperatures were 15° and 20° C, were plotted in FIGURE 1 from which upper lethal temperatures of 24.4° and 24.8°, respectively, were derived for juvenile sockeye (Brett,1952). The MST's obtained when the acclimation temperature was 15° C were parallel, but slightly greater than GMST's for adult sockeye. MST's obtained at 20° C acclimation showed a similar pattern but were displaced higher. The slope of the curve of GMST versus temperature for adult sockeye became vertical at about 24° C, making this point the upper lethal temperature due to thermal stress according to the definition of Brett (1956). Since adult sockeye were held at temperatures between 15.8° 18.3° C prior to testing, and since the upper lethal temperature and GMST's were less than for juvenile sockeye, it can be assumed that adult sockeye were slightly less resistant to high water temperatures than juveniles.

The MST's for adult coho (Coutant, 1969) were near those of adult sockeye in the range 30° to 27° C, but at 26° C the data for coho departed from the trend. However, in view of the general trend of data in FIGURE 1, a substantial transition to lower resistance for adult coho appears unlikely.

Fish have the capacity to increase resistance to high temperatures by acclimation, and less than 24 hours acclimation may be sufficient at temperatures over 20° C (Brett, 1956). Adult sockeye exhibited acclimation by an increase in GMST at 27° C when pre-exposed to 18° and 21° C (TABLE 3). Although resistance to high temperature increases with temperature of acclimation, the extent of increase in upper lethal temperature is limited for salmon. For example, as acclimation temperatures increased from 10° to 23° C, the upper lethal temperatures for juvenile sockeye increased only from 23.5 to 24.4° C (Brett, 1952). Since acclimation results in only a small increase in resistance to high temperatures, it may have limited practical application in establishing temperature criteria for adult sockeye.

The slope of the curve of GMST versus temperature became vertical at about 24° C, which is interpreted as meaning that death from temperature as a primary cause had ceased (Brett, 1956). Thereafter a second curve commenced and examination of fish indicated acute infections of F. columnaris. These mortalities occurred in spite of prophylactic treatment prior to temperature testing. Experience indicated that had treatment not been given, F. columnaris infections were likely to interfere with measurement of resistance to acute thermal shock. Furthermore, the possibility exists that fish exposed to 18° and 21° C might have become infected with F. columnaris if prophylactic treatment had not been given. Thus, the second phase of the GMST versus temperature curve is not believed to represent accurately the relationship between temperature, exposure time and infection which might prevail in the field.

However, elevated temperature is a factor contributory to infection related pre-spawning mortality among adult sockeye. High temperatures can induce stress in salmon (Brett, 1958) while the metabolic changes associated with stress combine to reduce tissue response to microbial invasion and allow infection to spread (Wedemeyer, 1970). In the case of Fraser River sockeye, high temperatures during migration or on the spawning grounds have been correlated with high pre-spawning mortalities caused by infections of F. columnaris (Williams, 1976).

The foregoing has discussed temperature as it relates to death by thermal shock or infection, but temperature also affects the energy expenditure of fish; basic metabolic energy demands increase with temperature. Adult sockeye in freshwater are solely dependent upon body reserves for energy required for migration, gonad maturation and spawning. Furthermore, fish are compelled to put forth more respiratory effort to obtain oxygen at high temperatures because water holds less oxygen as the temperature rises. Sockeye bound for Stuart Lake expend energy at nearly 80% of the maximum rate they can maintain, leaving little margin for any emergency demands (Brett, 1965). Since elevated water temperatures increase the energy demand of adult sockeye, the possibility exists that fish would be abnormally weakened by the additional energy expenditure.

Acute thermal shock, infections and energetics are among the items to be considered when developing criteria for protecting adult sockeye from high temperatures. The loss-of-equilibrium curve (FIGURE 1) represents a greater thermal exposure than could be permitted if perpetuation of sockeye at commercially exploitable levels of abundance is to be assured. On the other hand, since temperatures lower than those causing death by thermal shock are a factor in epizootics of *F. columnaris*, they should take precedence when temperatures are specified for the protection of sockeye.

CONCLUSIONS

1. The upper lethal temperature due to acute thermal shock was about 24° C for adult sockeye.
2. Adult sockeye were slightly less resistant to temperatures causing acute thermal stress than were juvenile sockeye.
3. The thermal exposure causing acute thermal stress exceeded that which led to mortality caused by infections of *F. columnaris*.

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