INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT
No. 22

IMPLICATION OF WATER QUALITY AND SALINITY IN THE SURVIVAL OF FRASER RIVER SOCKEYE SMOLTS

BY
I. V. WILLIAMS

NEW WESTMINSTER, B. C.
CANADA
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the Sockeye and Pink Salmon Fisheries
in the Fraser River System

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ABSTRACT

Seaward migrating juvenile sockeye (Oncorhynchus nerka) from five lakes in the Fraser watershed were examined in a preliminary attempt to define some of the factors causing variable marine survival to the adult stage. Water quality of rivers utilized by the seaward migrating smolts appeared to be good. No toxicants in the form of heavy metals, herbicides, pesticides, or detergents were detected at lethal threshold concentrations. At the onset of migration, the different groups varied in their tolerance of sea water, but all could tolerate 30 parts per thousand ($^{o}/oo$) salinity within the time required to reach the estuary. Preference tests of smolt behavior in a vertical salinity gradient indicated a time lag from the onset of migration to the acceptance of sea water which increased in proportion to the distance between the individual lake of origin and the estuary. However, once each group of smolts had accepted sea water, little or no acclimation was needed to transfer smolts from fresh water directly into 30 $^{o}/oo$ salinity. A delay in salinity preference and tolerance relative to the onset of seaward migration is suggested as a possible factor related to variation in marine survival of sockeye smolts.

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IMPLICATION OF WATER QUALITY AND SALINITY IN THE SURVIVAL OF FRASER RIVER SOCKEYE SMOLTS

INTRODUCTION

For several years the International Pacific Salmon Fisheries Commission has been collecting survival information for a number of populations of sockeye salmon (Oncorhynchus nerka) from the Fraser River watershed. The most detailed survival measurements available are for the Chilko Lake race, where the numbers of eggs deposited and the surviving fry, smolts and returning adults have been estimated annually since 1949. During this period, egg-to-fry survival has varied from 5 to 14 per cent; fry-to-smolt survival during the lake residence period has ranged from 32 to 73 per cent. However, the survival from smolt to adult has been strikingly variable, from 1 to 22 per cent, indicating the great fluctuation in survival which takes place after the smolts leave the lake.

There is considerable evidence to suggest that the ultimate survival rate to the adult stage of seaward migrating smolts is determined before these fish reach the open sea. A correlation ($r = 0.935$) significant at the 1 per cent level between Chilko River discharge during smolt migration and subsequent marine survival indicates that as discharge increases, survival rates increase (FIGURE 1). Furthermore, some relationship ($r = 0.76$, d.f. = 11) also exists between the survival rates of 1-year-old and 2-year-old smolts migrating to sea in the same year and returning 2 years later, even though the two age groups originate from different broods. On the other hand, there is no apparent relationship ($r = 0.08$) between the survival rates of 1- and 2-year-old smolts from the same brood which migrate to sea in different years.

These relationships suggest some environmental influence affecting the seaward migrating smolts, either prior to or after the onset of migration, but definitely causing the mortality to occur after the smolts have left the lake. The relationship between survival and discharge would also suggest that regardless of where the mortality actually occurs, it is determined for the most part before ocean residence begins. Clearly, a greater understanding of this variation in survival will allow more accurate forecasting of returning adult runs.

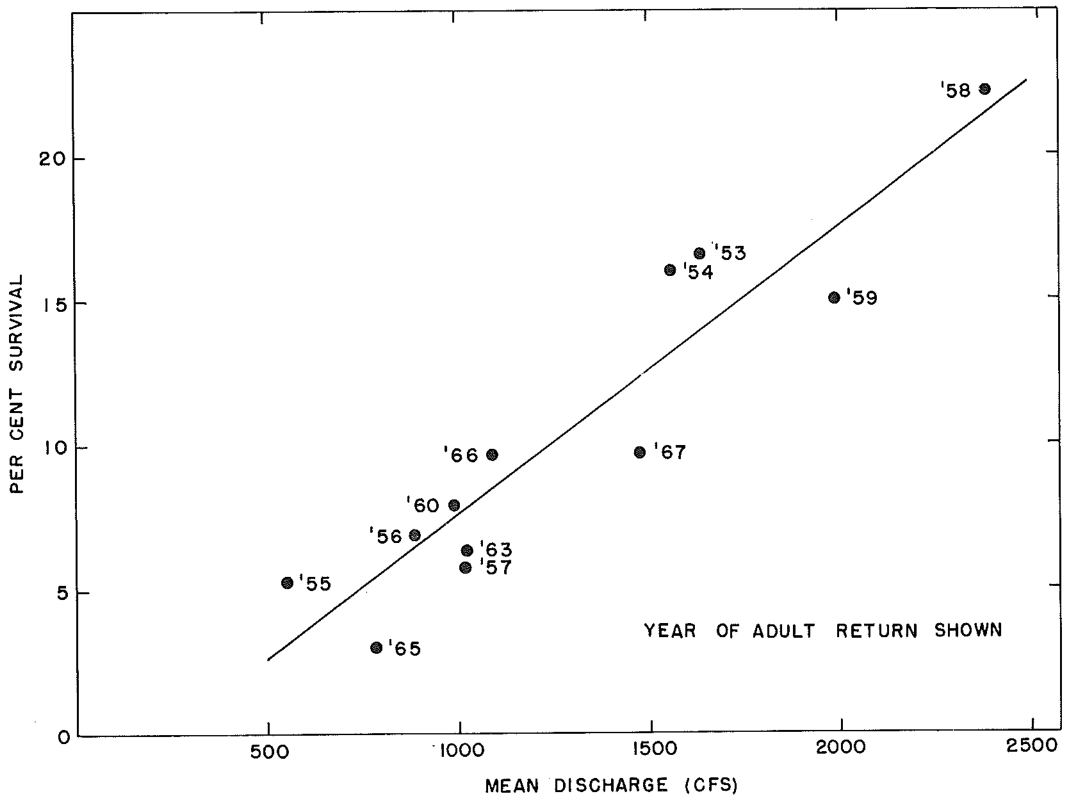

FIGURE 1 - Mean discharge of Chilko River during seaward migration of yearling smolts (weighted to smolt abundance one day previous) and survival rate to age 4_2 adults. Discharge data unavailable for years not shown.

Based on the hypothesis that smolt survival is determined prior to ocean residence, two aspects of this period of the life cycle have been examined in the present study. The first aspect deals with environmental conditions in the river during smolt migration. Evidence of smolt mortality during seaward migration in certain isolated instances has prompted measurement of the water quality in rivers used as migration routes by several major populations of Fraser sockeye. Second, the present study examines migrating smolts during the period of transition from fresh to sea water. There have been many previous studies on the behavior and physiology of anadromous salmonids during conversion to sea water (Houston, 1957; Baggerman, 1960; McInerney, 1964; and Zaks and Sokolova, 1961 and Conte et al., 1966). In this study an attempt is made to compare the tolerance and rate of transition to sea water for several populations of sockeye smolts at the onset of their normal migration. Implications for survival are discussed.

MATERIALS AND METHODS

Water Quality

Five tributaries of the Fraser River serving as smolt migration routes, Stuart, Quesnel, Little, Chilko and Sweltzer Rivers, were examined in the present study. Water samples were taken from each tributary near the lake outlets and from the main Fraser River at Mission (FIGURE 2). Dissolved oxygen was determined immediately using the Azide modification of the Winkler method (Amer. Public Health Assoc., 1965). Alkalinity and pH were also measured in the field, while hardness, solids and conductivity were determined later in the laboratory. Additional water samples from the Fraser, Chilko, and Little Rivers were analyzed by Coast Eldridge Ltd., Vancouver, B.C. for evidence of any potentially toxic constituents.

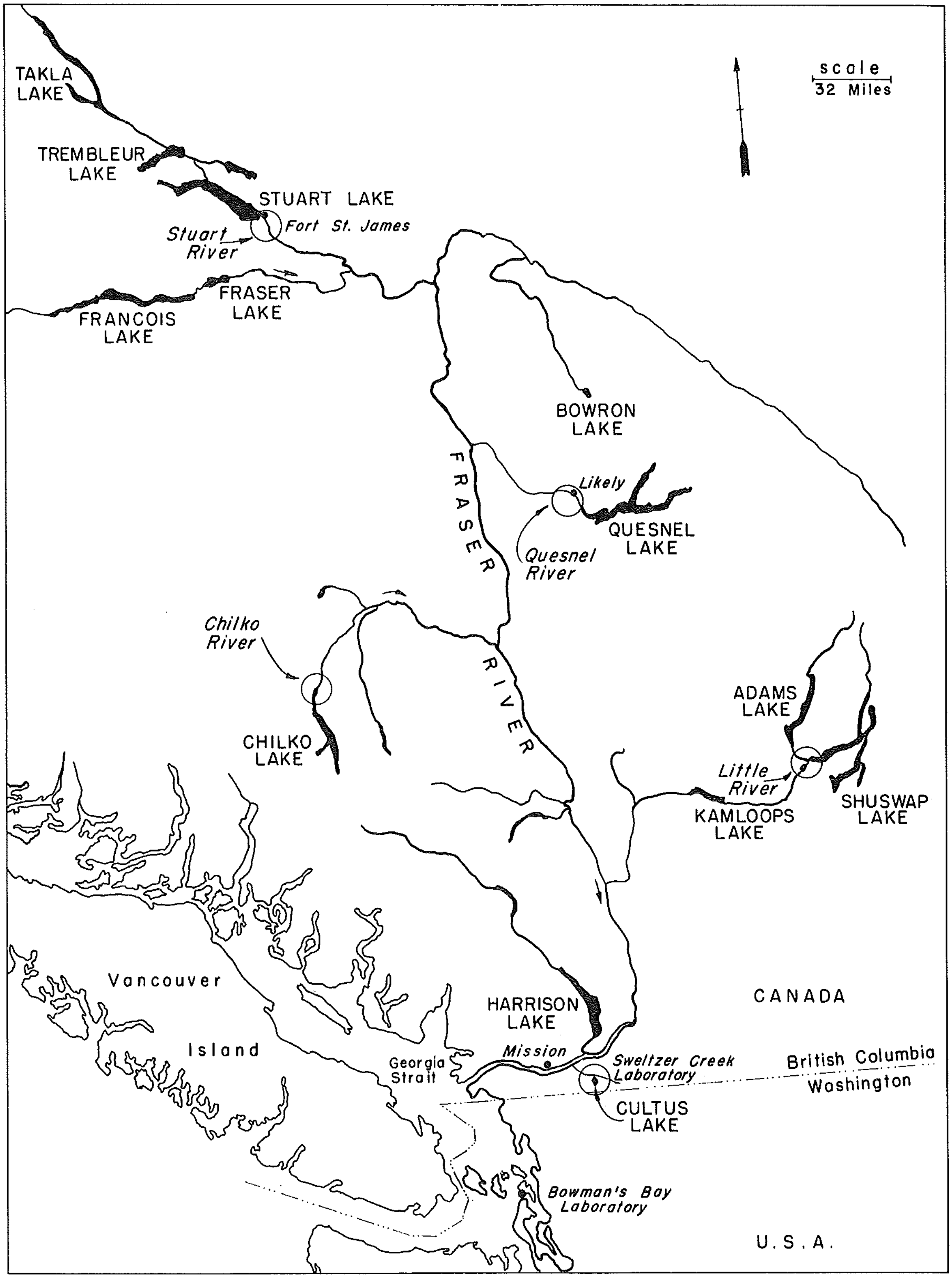

FIGURE 2 - Fraser River watershed showing the locations of smolt sampling and water quality testing, 1966, 1967 and 1968.

Source of Fish

Smolts from Chilko and Cultus Lakes were tested during both 1966 and 1967. Stuart and Quesnel Lake smolts were examined in 1967 and Shuswap Lake smolts during 1968. Twelve groups of fish were taken from the five sampling areas and sample size varied from 75 to 2,250 smolts. Twenty-five to 30 fresh dead yearling smolts from the principal samples were measured to indicate size of fish during testing (TABLE 1). The smolts sampled varied in size from 2.5 gm for Chilko fish to 8.5 gm for smolts from Stuart Lake, but these measurements did not necessarily represent average smolt size for the total migration from each lake.

TABLE 1 - Mean weights and lengths of yearling sockeye smolts tested in 1966, 1967 and 1968.

POPULATION	DATE CAPTURED	NUMBER OF SMOLTS		MEAN WEIGHT gm	MEAN FORK LENGTH mm
		Total	Measured		
Cultus, 1966	April 20	200	25	7.5	88
	April 27	200	-	-	-
Cultus, 1967	April 16	1,000	30	8.1	96
Chilko, 1966	April 26	75	10	2.5	-
	May 1	2,250	25	3.3	70
Chilko, 1967	May 11	1,250	30	5.4	89
Quesnel, 1967	May 2	1,250	30	6.8	90
Stuart, 1967	May 12	1,200	30	8.5	99
Shuswap, 1968	May 27	450	30	3.7	76
	May 31	600	-	-	-

Capture and Transport of Fish

The 1966 and 1967 smolt samples were captured with stationary scoop traps located in the rivers just downstream from the lake outlets. The 1968 Shuswap smolts were captured in Shuswap Lake near the outflow of Little River using a 600 ft by 44 ft modified lampera net.

Although an attempt was made to obtain the samples from the peak day of migration in order to have a sample representative of the largest number of migrants, this was not always possible (FIGURE 3). The 1966 Chilko and 1967 Stuart smolts were sampled relatively close to the peak of migration. The Quesnel sample, although trapped on the peak day, May 2, was considered to be part of the May 1 migration. The sample was trapped between 0200 and 0400 hr, well before the beginning of the large May 2 migration, the bulk of which passed the trapping site at dusk. The 1967 Chilko smolts were sampled at a later date than the 1966 sample but earlier with respect to the peak of migration. Shuswap Lake smolts were sampled from the end of the 1968 migration.

All samples were held in live-boxes until loaded for transport. The duration of holding varied from less than 1 hr for Cultus smolts up to 34 hr for one sample of Shuswap smolts (TABLE 2). Smolts for salinity testing were transported from the respective trapping sites to Bowman's Bay Laboratory near Anacortes, Washington. Fish were placed in plastic bags containing water and oxygen. The bags (14 in. square at the base and 32 in. high) were filled to approximately one fifth capacity with a ratio of 1 lb fish to 15 lb of water. Air was squeezed from the bag, oxygen was added briefly into the water and then used to inflate the bag. The bag was then sealed, and placed inside a second bag to insure against leakage. Each loaded bag was placed on its side (to provide the maximum water surface area for oxygen exchange) in a double-walled corrugated carton lined with 0.5-in. styrofoam insulation. All samples were flown from the various lakes to the laboratory at Bowman's Bay, with the exception of Cultus and Shuswap fish which were moved by truck. Duration of transport varied from as little as 2.5 hr for Cultus smolts to 9 hr for one of the Chilko samples (TABLE 2).

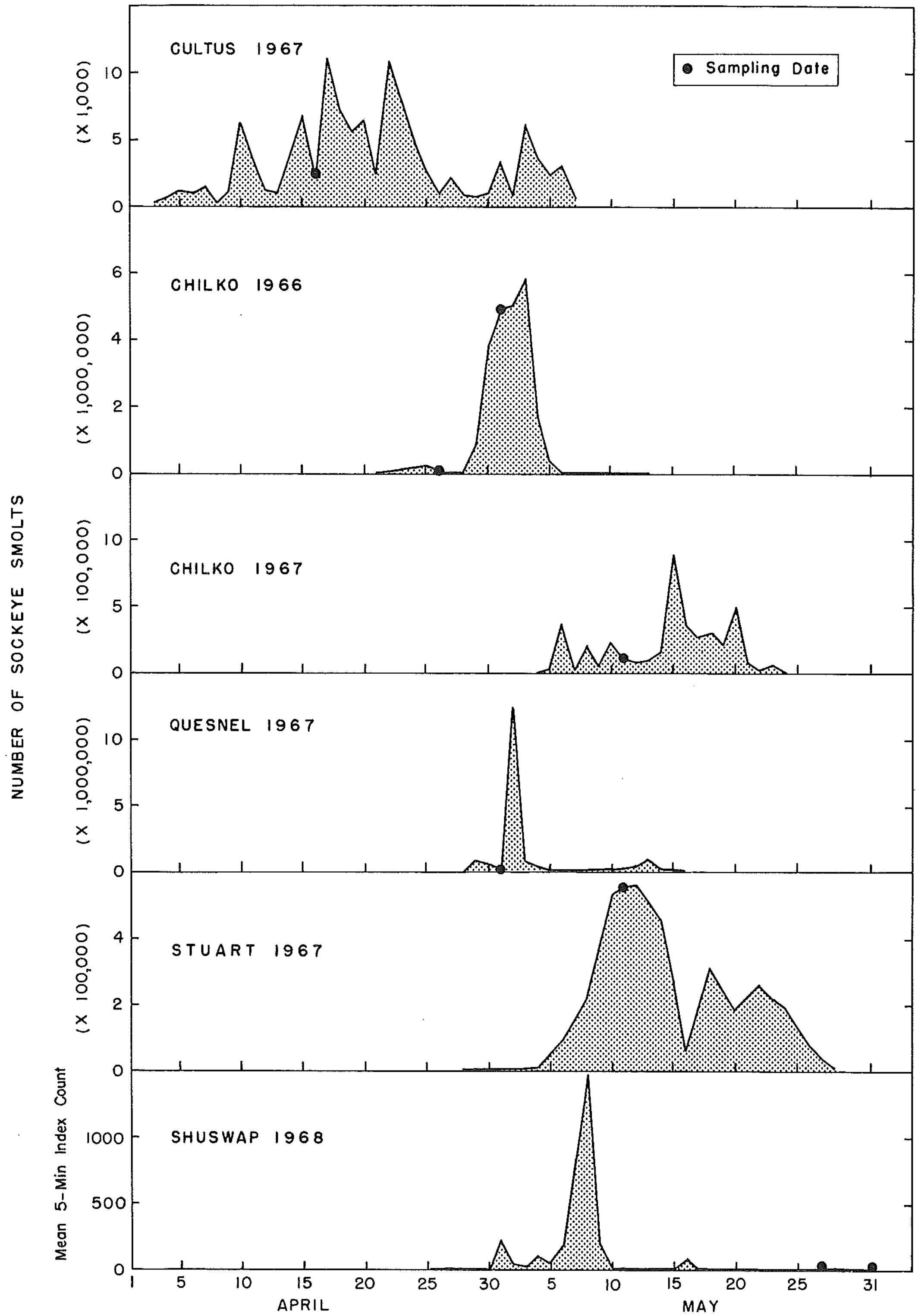

FIGURE 3 - Patterns of smolt migration and dates fish captured for salinity tests, 1966 to 1968. (Cultus smolt migration not enumerated in 1966.)

TABLE 2 - Sampling and transport schedule for sockeye smolts moved to Bowman's Bay Laboratory.

POPULATION	SAMPLING		HOLDING	TRANSPORT			
	Date	Time PST	Duration hr	Duration hr	Temperature °F Start	Temperature °F End	Per Cent Mortality
Cultus, 1966	April 20	2100	.75	2.5	47	49	0.5
	April 27	1300	.75	9.0	49	52	0
Cultus, 1967	April 16	2100	.75	3.0	43	45	0.5
Chilko, 1966	April 26	2200	17.0	9.0	38	52	20.0
	May 1	2200	14.0	6.0	39	45	2.0
Chilko, 1967	May 11	2200	14.0	3.0	41	45	0.4
Quesnel, 1967	May 2	0200-0400	5.5	3.5	40	44	3.8
Stuart, 1967	May 11-12	2300-0100	5.0	7.0	42	45	1.5
Shuswap, 1968	May 27	2000	19.3	7.0	60	59	1.3
	May 31	2100	34.0	6.0	54	56	0.3

The smolt mortalities presented in TABLE 2 represent total losses from beginning of transport to 48 hr past arrival at Bowman's Bay. The 20 per cent mortality in the first 1966 Chilko sample was probably due to the prolonged duration of transport (9 hr) and the large temperature rise (14°F). Most of the mortality in both the Quesnel and Stuart samples of 1967 can be accounted for by leaking or poorly sealed bags. Both these samples were loaded when air temperatures were well below freezing, causing the plastic to become inflexible and making it very difficult to seal the bags.

Holding Facilities

At Bowman's Bay, the principal sample of smolts from each lake was divided into two groups, one group being held continuously in fresh water, and the other in water of variable salinity, based on daily tests of salinity preference in a vertical gradient. Seawater concentrations for the groups held in variable salinities are shown in TABLE 3. Small groups of smolts were also tested for salinity tolerance and the remaining fish were used in other research studies not related to the present report.

In 1966, the principal smolt samples were held in cement raceways (4 ft x 38.5 ft x 1.6 ft) at an initial density of 2.9 fish per cu ft of water. The 1967 and 1968 samples were held in circular fiberglass tanks (6 ft diam x 2 ft deep) at an initial density of 8.8 fish per cu ft of water, or approximately 1 lb fish per 380 lb water. The holding ponds and aquaria were disinfected with Roccal and thoroughly rinsed before use.

Both fresh water and sea water are supplied to the Bowman's Bay holding facilities. Fresh water is piped from a small shallow lake situated near the station, the seawater supply is pumped directly from Bowman's Bay. Mixing boxes were constructed to provide complete mixing of sea water and fresh water when required. A minimum flow of 20 gpm was maintained in each raceway (replacement time 1.25 hr) and 10 gpm in each fiberglass tank (replacement time 0.6 hr). Temperature of the water supplies at Bowman's Bay ranged from a low of 44°F for fresh and sea water

TABLE 3 - Seawater concentrations in variable salinity holding areas.

Population	Date		Salinity °/oo
Cultus, 1966	April	21	2
		22-23	30
Cultus, 1967	April	17	2
		18-21	29
Chilko, 1966	May	3	2
		4	5
		5	20
		6	30
Chilko, 1967	May	13-14	2
		15	10
		16	12
		17	29
Quesnel, 1967	May	2-3	2
		4	7
		5-6	12
		7	18
		8-9	25
Stuart, 1967	May	13-14	2
		15	7
		16	13
		17-18	20
		19	23
Shuswap, 1968	May	29	2
		30-31	12
	June	1-2	20
		3	29

at the beginning of the holding period in early April to 52°F for sea water and 59°F for fresh water by the end of salinity experiments in late May 1967. Freshwater temperatures reached 64.5°F by the end of testing in early June 1968.

The fish were exposed to natural illumination in the holding areas and were fed four times daily. In 1966, a wet diet developed at Abernathy Creek Laboratory and fresh frozen plankton caught in the vicinity of Bowman's Bay were both used to feed experimental stocks. Brine shrimp was used exclusively during the 1967 and 1968 holding periods. All fish were held a minimum of 30 days (up to a maximum of 80 days) and then released. Very little mortality occurred during the holding period (TABLE 4).

Salinity Testing

Salinity tolerance was tested as soon as the sample of each group of smolts arrived at Bowman's Bay. Ten fish were placed in each of four 20-gal aquaria containing 2, 10, 20, and 29-30 °/oo salinity, respectively. A record was kept of the mortalities up to 120 hr, after which time the surviving fish were released. If heavy mortality (50 per cent or more) occurred within the first 24 hr, an additional 10 smolts were tested in an identical salinity.

Salinity preference tests of smolts held in the variable salinity ponds were performed daily. The experimental chamber used to measure salinity preference was essentially the same as that described by Hurley and Woodall (1968). The chamber, 32 in. square at the base and 92 in. high, was constructed of plywood with a plexiglass front. Separate inlets on the back wall of the chamber allowed the apparatus to be filled with six distinct salinity layers in a vertical gradient. Fourteen glass sampling tubes spaced evenly from top to bottom were inserted into the tank to test salinities and check for any mixing between layers. In the present tests, from four to six layers were used with salinities usually ranging from 28 to 30 °/oo in the bottom layer (2 ft deep) up to 23 °/oo, 16 °/oo, 8 °/oo and finally fresh water on the top (each layer 1 ft deep).

TABLE 4 - Mortality in holding ponds after initial 48-hr holding period.

POPULATION	ORIGINAL NO. SMOLTS	NUMBER DEAD Date	Fresh Water	Sea Water	Total	PER CENT MORTALITY
Cultus, 1966	200	April 23-May 31	1	2	3	1.5
Cultus, 1967	1,000	April 18-May 26	0	0		
		May 27	5*	0	5	0.5
Chilko, 1966	2,250	May 4-5	0	0		
		May 6	9	3		
		May 7	5	2		
		May 31	2*	0	21	1.1
Chilko, 1967	1,250	May 13-24	1	3		
		May 26	3*	0	7	0.6
Quesnel, 1967	1,250	May 5-17	4	2		
		May 18	5*	0	11	0.9
Stuart, 1967	1,200	May 14-24	4	3		
		May 25	2	0		
		May 26	3*	0	12	1.0
Shuswap, 1968	450	May 29-June 7	1	2	3	0.7

* Fish showing gross signs of disease and were transferred to sea water.

In order to prevent the layers from mixing, each salinity was pumped in at a comparatively slow rate of 3 gpm and the gradient allowed to stabilize for 30 min before the fish were introduced. Initially, the salinity of each layer in the test chamber was measured with a hydrometer at the beginning and end of each experiment. However, as the layers remained essentially intact over a 16-hr period, the salinities were usually measured only at the end of each test. Periodically the hydrometer readings were checked against a modified Mohr salinity titration (Hoar, 1960).

Another identical tank filled with water of a uniform salinity served as a control to check for any extraneous influences exerted upon the smolts during a test. The salinity in the control chamber was changed throughout the season, based on the salinity in the holding pond from which the fish were taken.

In 1967, cooling tubes were installed in both tanks to maintain more uniform temperatures. During salinity tests, the temperature variation within the tanks never exceeded 5°F and in most cases was within 2°F.

Artificial light was used in order to keep the test and control tanks constant with respect to light. During tests in 1967 and 1968, a single 100-watt light bulb was situated over each tank and gave a reflected light reading halfway down the tank of 0.6 foot candles (ft-c). Light intensity from the 50-watt bulbs used in 1966 was not measured, however in a test where 1966 light conditions were simulated, a light intensity of 0.2 ft-c was recorded at the same position.

In order to determine whether oxygen depletion caused an avoidance of specific areas within the apparatus, dissolved oxygen was measured at the end of several preference tests using the Azide modification of the Winkler method (Amer. Public Health Assoc., 1965). Results indicated that the oxygen supply remained at a high level throughout the experiments. The lowest level of saturation recorded was 93.9 per cent, the highest was 95.4 per cent.

A sample of five fish per tank was considered optimum due to space limitations. The fish were placed in the test and control tanks from the top and left undisturbed for up to 1 hr. Observations then commenced and the number of fish present in each 6-in. vertical layer were recorded every 5 min for 4 hr. In some cases the test was continued for an additional 4 hr after a 1-hr intermission. These observations were recorded from a sufficient distance to prevent any fright reactions caused by movement of the observer.

When all the required observations and samples had been taken, the tanks were drained and the fish released. Once the salinity preference for the day had been established, the seawater concentration in the variable salinity holding pond was adjusted accordingly, as shown previously in TABLE 3. Testing continued until these smolts "accepted" sea water based on the criterion of 50 per cent of the observations in sea water of 25 $^{o}/oo$ or greater. Fish from the freshwater holding pond were not tested in the gradient until the variable salinity group had completed the transition to 25 to 30 $^{o}/oo$ sea water.

WATER QUALITY OF MIGRATION ROUTES

Analysis of water samples indicated that the water quality of the migration rivers was good. Dissolved oxygen ranged from 10.9 to 12.5 ppm and in every case was saturated. Alkalinity varied from 24 to 59 ppm and total hardness from 50 to 81 ppm (TABLE 5).

Water samples from the Fraser, Chilko and Little Rivers were subjected to a detailed analysis for any potentially toxic constituents. No detergents, pesticides, or herbicides were detected in Little River or in the Fraser River at Mission, and all heavy metals were considered below toxic levels (TABLE 6). Relatively high concentrations of copper (0.060 and 0.065 ppm) were measured in the Fraser River once in 1967 and once in 1968. These concentrations are considerably greater than those measured previously in 1965 and 1966 when a total of 81 analyses revealed copper ranging from nil to 0.018 ppm and averaging 0.002 ppm, including 45 samples in which copper was not detected (Servizi and Burkhalter, MS,1969). Thus the high values measured in 1967 and 1968 may represent experimental error or instantaneous variation in river copper concentration.

In any case, all copper concentrations measured appear to be well below the lethal threshold levels of approximately 0.12 and 0.15 ppm established for hardness of 63 and 77 ppm (FIGURE 4), the hardness measured in the

TABLE 5 - Water quality of rivers during seaward migration of sockeye smolts, 1966, 1967 and 1968.

CONSTITUENT	FRASER RIVER AT MISSION			CHILKO RIVER AT NARROWS		SWELTZER CREEK AT CULTUS LAKE		QUESNEL RIVER AT LIKELY	STUART R. AT FORT ST. JAMES	LITTLE RIVER
	May 5 1966	May 12 1967	May 17 1968	May 2 1966	May 12 1967	Apr. 27 1966	Apr. 16 1967	May 2 1967	May 12 1967	May 16 1968
Dissolved Oxygen - ppm	11.7	12.3	12.0	12.1	11.2	11.4	12.5	11.3	11.6	10.9
Oxygen Saturation - %	103	101	103	105	101	100	100	100	99	100
Temperature - °F	48.9	44.7	48.0	38.8	41.0	49.0	43.0	40.0	41.5	50.0
Total Alkalinity - ppm	47	50	48	24	24	59	59	52	44	40
Total Hardness - ppm	70	77	63	50	52	81	81	80	71	61
Suspended Solids - ppm		351	201		ND	ND	ND	0.6	0.5	ND
Total Soilds - ppm		434	292		34	86	86	74	72	64
Conductivity µ mhos @ 25°C	103	107	108	53	59	165	165	117	94	92
pH	7.3	7.3	7.5	7.3	7.4	7.5	7.5	7.6	7.1	7.2

ND Not detected.

TABLE 6 - Analysis for dissolved toxicants (ppm) in the Fraser, Chilko and Little Rivers, 1966, 1967 and 1968.

SUBSTANCE	FRASER RIVER					CHILKO RIVER			LITTLE RIVER
	Apr. 25 1966	May 5 1966	May 13 1966	May 12 1967	May 17 1968	Apr. 27 1966	May 2 1966	May 12 1967	May 16 1968
Aluminum	.40	.40	.38	.26	.64	.80	ND	.18	.38
Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	.004	Trace	.010	.060	.065	.016	.010	.016	.02
Mercury	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	.60		Trace	.12	.44	Trace		Trace	.10
Iodine*	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	.002	.004	ND	.040	.017	.008	.010	.007	ND
Nickel	.020	.015	.010	.020	.007	.012	.010	.010	ND
Silver	Trace	Trace	Trace	Trace	.006	Trace	Trace	Trace	.005
Zinc	ND	ND	ND	ND	.01	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cyanide	ND	ND	ND	ND	ND	ND	ND	ND	ND
Detergents	ND	ND	ND	ND	ND				ND
Pesticides and Herbicides									
Organochlorides	ND	ND	ND	ND	ND				ND
Organophosphates	ND	ND	ND	ND	ND				ND

* Test accurate to 0.001 ppm.

ND Not detected.

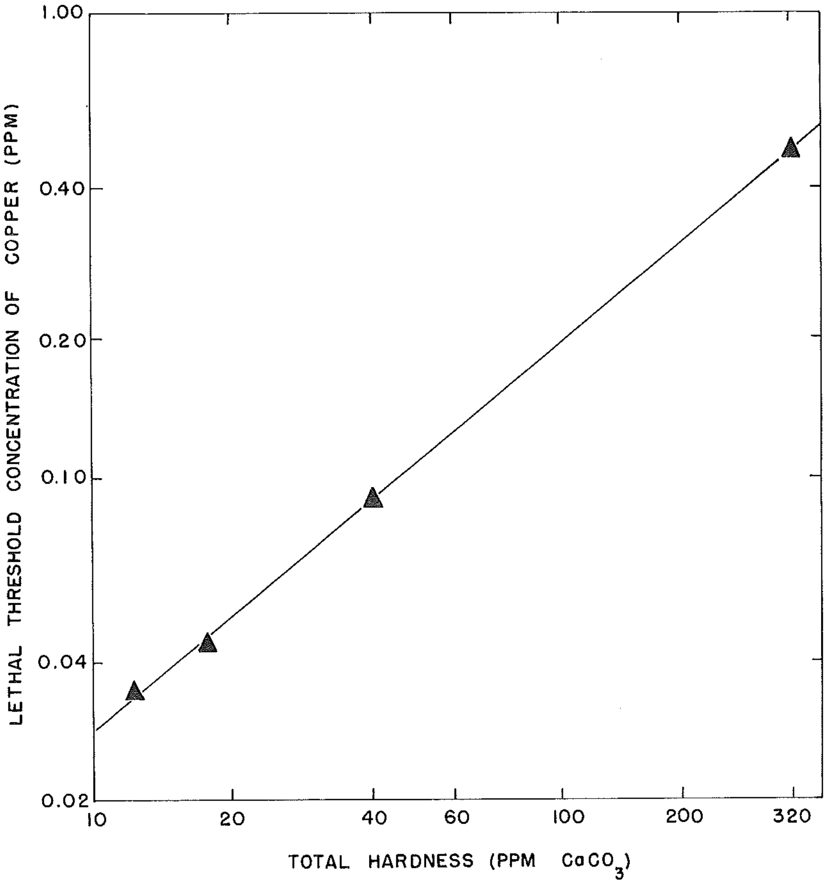

FIGURE 4 - Relation between total hardness of the water and the lethal threshold concentrations of dissolved copper for rainbow trout (from Lloyd, 1965).

Fraser River. Although Lloyd's (1965) results shown in FIGURE 4 were obtained from tests on rainbow trout, the incipient lethal levels of copper for Atlantic salmon (Sprague and Ramsay, 1965) and Fraser River pink salmon fry also approximate these values, at least at low hardness (e.g., a lethal threshold level of approximately 0.03 ppm copper established for pink fry at hardness of 14 ppm). Thus if these data can also be applied to sockeye, even the highest copper concentrations appear to be well below lethal levels at the hardness recorded in the Fraser River.

Of all the metals present in Chilko River, only aluminum was noticeably high on April 27, 1966 (0.80 ppm) but was not detected in a subsequent sample on May 2, 1966 (TABLE 6). In any case, Doudoroff and Katz (1953) reviewed studies by other authors who found that rainbow trout survived a somewhat higher concentration of aluminum sulfate (1.0 ppm aluminum) for 48 hr without apparent ill effects. Therefore, these data indicate the quality of the water used for seaward migration was good and that any subsequent mortality was probably not a direct result of water quality.

SALINITY TOLERANCE

Salinity tolerance tests of seaward migrating smolts resulted in no mortalities in the freshwater (2 $^{o}/oo$) controls or at 10 $^{o}/oo$ salinity, but some losses occurred at higher concentrations of sea water. One Stuart fish died in 20 $^{o}/oo$ sea water; all other smolts survived when placed in this salinity within 26 hr or less after being captured at the lake outlets (TABLE 7).

The reaction to salinities of 29-30 $^{o}/oo$ varied for the different groups of smolts tested. Smolts from Quesnel Lake suffered a 40 per cent mortality when tested 9 hr after capture, but no deaths occurred when the test was repeated the next day (30 hr after capture). The 1967 Chilko and Stuart smolts displayed a lower tolerance for 30 $^{o}/oo$ sea water. Almost all fish died during the first day's tests and some mortalities occurred in tests initiated on the second day (35 to 37 hr) after the fish were captured at the lake outlets. The 1966 Chilko samples had the lowest tolerance of all groups

TABLE 7 - Tolerance of sockeye smolts to sea water, 1966 and 1967. Each test of 120-hr duration except where noted.

Population	Date Captured	Elapsed Time* hr	Temp. at Testing °F	Per Cent Mortality in:			
				2 ‰	10 ‰	20 ‰	29-30 ‰
Cultus, 1966	April 20	4	51	0	0	0	0
	April 27	10	49	0	0	0	0
Cultus, 1967	April 16	4	46	0	0	0	0
Chilko, 1966	April 26	26	49	0	0	0	100(6 hr)
		50	49	0			100(8 hr)
		74	49	0			100(8 hr)
	May 1	20	49	0	0	0	100(8 hr)
		41	49	0			100(8 hr)
		65	49	0			20
		89	49	0			0
Chilko, 1967	May 11	17	48	0	0	0	100(14 hr)
		37	48	0			20
Quesnel, 1967	May 2	9	46	0	0	0	40
		30	46	0			0
Stuart, 1967	May 11-12	15	48	0	0	10	90(14 hr)
		35	48	0		0	10

* Time interval from trapping to testing.

tested. Losses continued to occur among smolts placed in 30 °/oo sea water on the third day (65 to 74 hr) after capture. In contrast, smolts from Cultus Lake tested within 4 hr after capture tolerated 30 °/oo salinity without mortality in both years of testing (TABLE 7).

It is difficult to evaluate the variable response to 30 °/oo salinity noted for the different groups of smolts tested, since certain aspects of the testing environment may have influenced the results. Nelson (1968) found that temperature influenced salinity tolerance of the brook stickleback (Culaea inconstans), with tolerance being significantly greater at 8°C (46.5°F) than at 16°C (60.8°F). The present tests, although carried out within a fairly restricted temperature range (46 to 51°F), were preceded by periods of considerable temperature change for certain groups of smolts (temperature at capture ranged from 38 to 49°F, TABLE 2) which may have contributed to mortality. The stress of prolonged holding and transport experienced by Chilko, Quesnel and Stuart smolts may also have contributed to the mortalities in the subsequent tolerance tests. "Laboratory diuresis" and other conditions of electrolyte imbalance in fish have been shown to result from handling procedures (Meyer, 1948; Forster and Berglund, 1956). However, an additional test of the 1966 Cultus smolts resulted in no mortality in 30 °/oo salinity (TABLE 7), even though duration of holding and transport was extended to 10 hr in an attempt to duplicate the pretesting conditions imposed on fish from other lakes.

Recent tests have shown that even without the stress of prolonged transport, some juvenile sockeye are unable to tolerate high salinities at or shortly before the onset of seaward migration. In 1969, tests of Cultus Lake sockeye were carried out at the lake exit, thus avoiding the stress of transport, and generally were of 48-hr duration. On March 5, 1969, hatchery-raised sockeye yearlings of Cultus Lake stock weighing 10.1 gm were tested in 30 °/oo salinity and suffered 100 per cent mortality within 48 hr. On March 20, pre-migratory yearling sockeye of the same year class were captured in Cultus Lake. These fish, weighing only 2.3 gm, were also unable to tolerate 30 °/oo sea water and all died within 24 hr. Subsequent tests in 30 °/oo salinity of the first smolts migrating out of Cultus Lake continued to result in some mortalities: 70 per cent mortality on April 15, 27 per cent on April 21 (yearling mean weight 4.5 gm), 4 per cent on April 24, but no losses among yearling smolts weighing 5.6 gm captured April 28. It was not until early May 1969 that smolts began leaving Cultus Lake in large numbers, and tests at this time indicated smolts could tolerate 30 $^{o}/oo$ salinity without significant mortality.

Similar mortalities of sockeye smolts in high salinities have been noted by other workers. Zaks and Sokolova (1961) found that seaward migrating sockeye smolts from Lake Dalnee, Kamchatka, ranging in age from 1 to 3 years (mainly 2-year-olds) could tolerate moderate salinities at the time of lake exit but suffered a mass mortality when salinity was increased to 25 $^{o}/oo$.

The factors controlling development of salinity tolerance in sockeye smolts have not been determined, but both size and time have been shown to be related to the development of osmotic regulation in Salmonidae. In Atlantic salmon (Salmo salar) and other related species, Parry (1960) found that size was the main determining factor in development of salinity tolerance. Tolerance tests of juvenile coho salmon (O. kisutch) in salinities of 20 to 30 $^{o}/oo$ also indicated the same relationship of greater survival with increasing size (Conte et al., 1966). However, temporal (seasonal) changes also exist in the developmental relationships of seawater adaptation. Baggerman (1960) studied chum, pink, coho and sockeye, and concluded that "The increasing day length in spring controls the time at which the change in preference from fresh to salt water takes place ...." In discussing sockeye smolt migrations from Redfish Lake in Idaho, Bjornn, Craddock and Corley (1968) suggested that: "Photoperiod may be the environmental cue (if one is needed) that initiates the physiological changes and could be the releaser for migration. But the seasonal change in day length does not appear to be the only factor regulating the smolt transformation. Both juvenile sockeye salmon and steelhead trout (Salmo gairdneri) may pass through one or two seasonal photoperiod cycles without becoming smolts. The age of the fish when smolt transformation takes place appears to be regulated partially by growth, especially for sockeye salmon and steelhead trout. Thus we speculate that photoperiod may be the releaser for the parr-smolt transformation but only if the fish have attained a threshold size."

In the present tests, the smallest seaward migrants (Chilko) suffered the most extensive mortalities in high salinities, although the response of larger fish varied considerably. Similarly, the earliest and smallest members of the 1969 Cultus smolt migration could not tolerate high salinities. However, large size alone was not necessarily an indication of salinity tolerance. Not only did the large (10.1 gm) hatchery-reared Cultus yearlings suffer complete mortality in early March, but some 2-year-old migrants included in the tests on April 15 and April 21 also died in salt water. Mortality among the larger 2-year-olds was, however, lower than for yearling migrants during concurrent salinity tests. Although size appears to influence the development of salinity tolerance in sockeye, as in other salmonids, there are evidently other factors of major importance.

SALINITY PREFERENCE

Results of the salinity preference tests were analyzed by examining the frequency distribution of the fish during each 2-hr period throughout tests in both the gradient and control tanks. As noted previously, these tests were carried out using fish from the variable salinity holding ponds. Once the variable salinity group had completed the transition to sea water (based on the criterion of 50 per cent of the observations in 25 to 30 $^{o}/oo$), smolts from the freshwater holding ponds were tested in the gradient. Salinity of the control tank coincided with that of the holding pond from which the fish were taken.

The following sections describe the results of the daily salinity tests to indicate the rate of transition to sea water. Effects of influences other than salinity are then examined.

Rate of Transition to Sea Water

Daily tests in the salinity gradient indicated that sockeye smolts from each lake differed somewhat in their rate of transition from fresh water to sea water. Behavior of the Cultus smolts was similar in both 1966 and 1967, in that conversion to sea water of 25 to 30 $^{o}/oo$ occurred during the first day's test. The fish generally sounded upon introduction to the gradient tank and then returned to a depth corresponding to 10 to 20 $^{o}/oo$ salinity. Within 1 to 4 hr, the Cultus fish adjusted to sea water of 25 to 30 $^{o}/oo$ (TABLES 8 and 9).

Following these initial tests, salinity in one of the holding areas was increased directly to 29-30 $^{o}/oo$ and the Cultus fish were tested again the following day. Smolts from the freshwater holding ponds were not tested until 3 days after capture. In 1967, a more definite preference for sea water of 25 to 30 $^{o}/oo$ was displayed by smolts from the freshwater holding areas (see tests April 17 and 19, TABLE 9) whereas smolts taken from holding ponds of 29 $^{o}/oo$ sea water wandered through a wider range of salinity layers, and did so much more frequently (see tests April 18 and 21, TABLE 9). Fish were widely dispersed in the control tanks and, in 1966, began to exhibit a continuous vertical swimming motion. Fish became extremely active and swam incessantly up and down the face of the glass with the dorsal surface to the glass going down and the ventral surface to the glass going up. This appears to be the same type of activity described for sockeye smolts by Hoar (1954) who has since labeled it escape behavior (Hoar, Keenleyside and Goodall, 1957). In general, smolts in the gradient tank usually retained a tighter schooling behavior while those in the control tank were distributed over a larger area.

The general pattern of salinity preference exhibited by all upriver smolts during the 1966, 1967 and 1968 tests differed considerably from that of the Cultus fish. Although there was some variability in the results, there was a general trend of increasing salinity preference with time. As shown in TABLES 10 and 11, Chilko smolts initially remained in the low salinity

TABLE 8 - Per cent distribution of 1966 Cultus smolts (captured April 20) in gradient and control tanks during 2-hr periods.

	APRIL 21* (Test 1)			APRIL 21 (Test 2)		
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	3-4hr	Sal. °/oo	Smolts % 1-2hr	3-4hr
Gradient Tank						
0-3.5	2	4	4	2	38	39
3.5-5.0	12	43	15	12	33	15
5.0-7.0	29	53	81	29	29	46
Control Tank						
0-3.5	2	39	46	2	49	88
3.5-5.0	2	41	35	2	16	7
5.0-7.0	2	20	19	2	35	5

	APRIL 22					APRIL 23				
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	3-4hr	6-7hr	8-9hr	Sal. °/oo	Smolts % 1-2hr	3-4hr	6-7hr	8-9hr
Gradient Tank										
0-3.0	2	7	25	8	2	4	4	11	-	1
3.0-4.0	5	8	11	5	-	4	7	3	-	-
4.0-5.0	15	73	62	25	5	13	77	78	2	1
5.0-5.5	25	8	-	44	45	25	7	8	3	4
5.5-7.0	30	4	2	18	48	31	5	-	95	94
Control Tank										
0-3.0	30	52	32	59	**	2	**	**	**	**
3.0-4.0	30	22	36	30	**	2	**	**	**	**
4.0-5.0	30	12	12	6	**	2	**	**	**	**
5.0-5.5	30	2	9	1	**	2	**	**	**	**
5.5-7.0	30	12	12	4	**	2	**	**	**	**

* First date of seawater acceptance.

** Escape behavior.

TABLE 9 - Per cent distribution of 1967 Cultus smolts (captured April 16) in gradient and control tanks during 2-hr periods.

DEPTH ft	APRIL 17* Sal. °/oo	APRIL 17* Smolts % 1-2hr	APRIL 17* Smolts % 3-4hr	APRIL 18 Sal. °/oo	APRIL 18 Smolts % 1-2hr	APRIL 18 Smolts % 3-4hr
Gradient Tank						
0-1.5	2	3	1	2	2	1
1.5-2.0	5	1	2	5	4	1
2.0-3.0	9	1	-	9	7	9
3.0-4.0	13	1	1	13	20	16
4.0-5.0	19	2	2	19	24	18
5.0-6.0	24	14	30	24	21	20
6.0-7.0	30	78	64	30	23	35
Control Tank						
0-1.5	2	6	12	29	1	1
1.5-2.0	2	9	4	29	2	5
2.0-3.0	2	28	29	29	13	18
3.0-4.0	2	11	13	29	12	13
4.0-5.0	2	5	8	29	20	19
5.0-6.0	2	14	13	29	21	30
6.0-7.0	2	26	21	29	30	14

* First date of seawater acceptance.

DEPTH ft	APRIL 19 Sal. °/oo	APRIL 19 Smolts % 1-2hr	APRIL 19 Smolts % 3-4hr	APRIL 21 Sal. °/oo	APRIL 21 Smolts % 1-2hr	APRIL 21 Smolts % 3-4hr
Gradient Tank						
0-1.5	2	4	-	2	3	1
1.5-2.0	5	10	-	5	4	1
2.0-3.0	9	16	-	9	17	2
3.0-4.0	13	12	3	13	18	29
4.0-5.0	19	23	7	19	31	39
5.0-6.0	24	22	56	24	21	25
6.0-7.0	30	13	34	30	6	3
Control Tank						
0-1.5	2	21	23	29	10	29
1.5-2.0	2	10	15	29	5	8
2.0-3.0	2	23	39	29	7	20
3.0-4.0	2	18	14	29	19	17
4.0-5.0	2	7	5	29	30	14
5.0-6.0	2	7	2	29	19	5
6.0-7.0	2	15	2	29	9	7

TABLE 10 - Per cent distribution of 1966 Chilko smolts (captured May 1) in gradient and control tanks during 2-hr periods.

DEPTH ft	MAY 3 Sal. °/oo	Smolts % 1-2hr	3-4hr	5-6hr
Gradient Tank				
0-2.5	2	100	99	85
2.5-3.5	10	-	1	6
3.5-4.5	20	-	-	8
4.5-7.0	30	-	-	1
Control Tank				
0-2.5	2	4	-	2
2.5-3.5	2	8	1	8
3.5-4.5	2	4	4	8
4.5-7.0	2	84	95	82

DEPTH ft	MAY 4 Sal. °/oo	Smolts % 1-2hr	3-4hr	6-7hr	8-9hr	DEPTH ft	MAY 5* Sal. °/oo	Smolts % 1-2hr	3-4hr
Gradient Tank									
0-2.5	1	63	53	32	23	0-3.0	2	10	-
2.5-3.5	6	33	32	30	23	3.0-4.0	10	18	-
3.5-4.0	9	2	2	5	7	4.0-5.0	20	24	6
4.0-5.0	28	2	8	14	32	5.0-7.0	30	48	94
5.0-7.0	30	-	5	19	15				
Control Tank									
0-2.5	5	2	1	6	4	0-3.0	20	20	7
2.5-3.5	5	3	5	2	4	3.0-4.0	20	7	6
3.5-4.0	5	4	4	7	6	4.0-5.0	20	2	8
4.0-5.0	5	9	18	7	12	5.0-7.0	20	71	79
5.0-7.0	5	82	72	78	74				

* First date of seawater acceptance.

TABLE 11 - Per cent distribution of 1967 Chilko smolts (captured May 11) in gradient and control tanks during 2-hr periods.

DEPTH ft	MAY 13 Sal. °/oo	MAY 13 Smolts % 1-2hr	MAY 13 Smolts % 3-4hr	MAY 14 Sal. °/oo	MAY 14 Smolts % 1-2hr	MAY 14 Smolts % 3-4hr	MAY 15 Sal. °/oo	MAY 15 Smolts % 1-2hr	MAY 15 Smolts % 3-4hr
Gradient Tank									
0-1.5	2	2	-	2	22	17	2	16	6
1.5-2.5	9	34	4	9	57	40	9	47	16
2.5-3.5	14	30	7	14	12	18	14	27	27
3.5-4.5	20	-	8	20	2	22	20	7	26
4.5-5.5	25	4	31	25	1	2	25	3	14
5.5-7.0	30	30	50	30	6	2	30	-	12
Control Tank									
0-1.5	2	24	19	2	11	9	10	5	**
1.5-2.5	2	21	24	2	33	16	10	17	**
2.5-3.5	2	2	10	2	21	20	10	17	**
3.5-4.5	2	13	13	2	21	34	10	18	**
4.5-5.5	2	7	11	2	12	10	10	23	**
5.5-7.0	2	33	23	2	2	11	10	20	**

DEPTH ft	MAY 16* Sal. °/oo	MAY 16* Smolts % 1-2hr	MAY 16* Smolts % 3-4hr	MAY 17 Sal. °/oo	MAY 17 Smolts % 1-2hr	MAY 17 Smolts % 3-4hr
Gradient Tank						
0-1.5	2	3	3	2	2	8
1.5-2.5	9	11	18	9	12	13
2.5-3.5	14	17	24	14	14	10
3.5-4.5	20	16	19	20	16	28
4.5-5.5	25	15	23	25	38	23
5.5-7.0	30	38	13	30	18	17
Control Tank						
0-1.5	12	15	**	29	14	**
1.5-2.5	12	27	**	29	21	**
2.5-3.5	12	11	**	29	24	**
3.5-4.5	12	20	**	29	34	**
4.5-5.5	12	15	**	29	4	**
5.5-7.0	12	12	**	29	3	**

* First date of seawater acceptance.

** Escape behavior.

(2 to 10 $^{o}/oo$) surface layers in the gradient and over a period of 4 to 5 days after leaving the lake adjusted to sea water of 25 to 30 $^{o}/oo$. One major difference between the two groups of Chilko smolts was a salient avoidance of sea water during the initial stages of testing in 1966 (see May 3 test, TABLE 10) which did not occur during 1967. In fact, the 1967 Chilko smolts moved into fairly high salinities (up to 25 $^{o}/oo$) for several hours during the first test on May 13 (TABLE 11). However, on the following day the fish showed a strong preference for water of 8 $^{o}/oo$ and then progressed to sea water during the next 3 to 4 days. Another obvious difference between the behavior of 1966 and 1967 Chilko smolts was an attraction or preference for the bottom of the tank during the 1966 tests, as evident in the behavior of the control fish. In the 1967 tests there did not appear to be an attraction for any specific area in the control chamber.

The pattern of behavior exhibited by the 1967 Stuart smolts (TABLE 12) was similar to the 1967 Chilko fish except for a difference in the time of acceptance of 25 to 30 $^{o}/oo$ sea water. Stuart Lake smolts required 7 days to convert to sea water, whereas Chilko smolts converted to sea water in 4 to 5 days.

Smolts from Quesnel Lake also followed the general pattern of Chilko and Stuart fish in their conversion to sea water. However, the Quesnel smolts initially showed less avoidance of sea water and remained in 25 to 28 $^{o}/oo$ during the first day's test (TABLE 13). In this test, the behavior of the control fish was very similar to the test fish, indicating that salinity preference may not have been the mechanism determining the position selected in the gradient. Even during the second day of testing the Quesnel smolts ranged widely throughout the gradient. However, on the third day after the onset of migration, the smolts remained concentrated at salinities of 8 to 14 $^{o}/oo$, showed very little straying and progressed over the next 2 days into water of 26-27 $^{o}/oo$. Within a week after leaving the lake, the Quesnel smolts did not show the preference for salinities greater than 27 $^{o}/oo$ exhibited by the smolts from other lakes.

Smolts from Shuswap Lake displayed the same general pattern of behavior as the 1966 Chilko fish. During the first day of testing, the Shuswap smolts remained in sea water of approximately 12 $^{o}/oo$ and over the next 4 days progressed into salinities of 25 to 30 $^{o}/oo$ (TABLE 14).

TABLE 12 - Per cent distribution of 1967 Stuart smolts (captured May 11-12) in gradient and control tanks during 2-hr periods.

	MAY 13				MAY 14			MAY 15		
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
Gradient Tank										
0-1.5	2	11	-	0-1.5	2	46	29	2	12	3
1.5-2.0	11	15	1	1.5-2.5	8	50	59	8	59	18
2.0-3.0	16	53	54	2.5-3.5	13	4	12	13	29	50
3.0-7.0	30	21	45	3.5-4.5	19	-	-	19	-	29
				4.5-5.5	25	-	-	25	-	-
				5.5-7.0	30	-	-	30	-	-
Control Tank										
0-1.5	2	-	3	0-1.5	2	1	8	7	2	7
1.5-2.0	2	3	8	1.5-2.5	2	15	22	7	10	12
2.0-3.0	2	18	23	2.5-3.5	2	24	24	7	21	22
3.0-7.0	2	79	66	3.5-4.5	2	12	19	7	27	9
				4.5-5.5	2	11	8	7	21	18
				5.5-7.0	2	38	19	7	19	32

	MAY 16			MAY 17			MAY 18*		
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
Gradient Tank									
0-1.5	2	1	-	2	-	2	2	2	2
1.5-2.5	8	13	3	8	10	8	8	5	11
2.5-3.5	13	55	10	13	21	25	13	26	19
3.5-4.5	19	18	43	19	30	38	19	33	17
4.5-5.5	25	9	22	25	21	13	25	15	17
5.5-7.0	30	4	23	30	18	15	30	19	35
Control Tank									
0-1.5	13	2	-	20	2	1	20	19	22
1.5-2.5	13	7	14	20	13	12	20	30	28
2.5-3.5	13	2	18	20	20	18	20	17	13
3.5-4.5	13	2	30	20	13	24	20	9	8
4.5-5.5	13	26	20	20	19	18	20	11	6
5.5-7.0	13	61	18	20	33	28	20	14	23

* First date of seawater acceptance.

TABLE 13 - Per cent distribution of 1967 Quesnel smolts (captured May 2) in gradient and control tanks during 2-hr periods.

DEPTH ft	MAY 2 Sal. °/oo	MAY 2 Smolts % 1-2hr	MAY 2 Smolts % 3-4hr	MAY 3 Sal. °/oo	MAY 3 Smolts % 1-2hr	MAY 3 Smolts % 3-4hr	MAY 4 Sal. °/oo	MAY 4 Smolts % 1-2hr	MAY 4 Smolts % 3-4hr
Gradient Tank									
0-1.0	2	23	-	2	-	3	2	3	6
1.0-2.0	7	18	16	7	14	27	7	50	46
2.0-3.0	14	11	17	14	35	4	14	32	41
3.0-4.0	20	15	3	20	30	15	20	6	1
4.0-5.0	26	5	1	26	12	32	26	2	2
5.0-6.5	30	28	63	30	9	19	30	6	5
Control Tank									
0-1.0	2	8	7	2	8	36	7	6	-
1.0-2.0	2	22	28	2	17	19	7	7	24
2.0-3.0	2	8	12	2	6	8	7	11	19
3.0-4.0	2	5	2	2	5	8	7	4	9
4.0-5.0	2	10	1	2	21	4	7	5	3
5.0-6.5	2	47	50	2	43	25	7	67	44

DEPTH ft	MAY 5 Sal. °/oo	MAY 5 Smolts % 1-2hr	MAY 5 Smolts % 3-4hr	MAY 7* Sal. °/oo	MAY 7* Smolts % 1-2hr	MAY 7* Smolts % 3-4hr	MAY 8 Sal. °/oo	MAY 8 Smolts % 1-2hr	MAY 8 Smolts % 3-4hr
Gradient Tank									
0-1.0	2	17	8	2	1	-	2	-	6
1.0-2.0	7	22	31	7	8	1	7	3	13
2.0-3.0	14	21	17	14	31	11	14	13	20
3.0-4.0	20	22	20	20	12	19	20	38	18
4.0-5.0	26	15	13	26	28	41	26	31	19
5.0-6.5	30	3	12	30	21	28	30	14	24
Control Tank									
0-1.0	12	13	11	18	4	23	25	14	4
1.0-2.0	12	39	48	18	15	18	25	6	15
2.0-3.0	12	28	28	18	16	11	25	9	15
3.0-4.0	12	15	10	18	13	13	25	29	21
4.0-5.0	12	2	3	18	16	13	25	16	23
5.0-6.5	12	4	-	18	37	23	25	26	22

* First date of seawater acceptance.

TABLE 14 - Per cent distribution of 1968 Shuswap smolts (captured May 27) in gradient and control tanks during 2-hr periods.

	MAY 29				MAY 30		
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
Gradient Tank							
0-2.5	2	15	-	0-2.5	2	36	46
2.5-4.5	13	85	100	2.5-3.5	12	40	43
4.5-5.0	23	-	-	3.5-4.5	19	22	10
5.0-6.0	25	-	-	4.5-5.5	24	2	1
6.0-7.0	30	-	-	5.5-7.0	30	-	-
Control Tank							
0-2.5	2	8	13	0-2.5	12	45	39
2.5-4.5	2	13	29	2.5-3.5	12	15	21
4.5-5.0	2	6	3	3.5-4.5	12	13	18
5.0-6.0	2	24	22	4.5-5.5	12	8	9
6.0-7.0	2	49	33	5.5-7.0	12	18	13

	MAY 31				JUNE 1			JUNE 2*		
DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	DEPTH ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
Gradient Tank										
0-2.0	2	4	-	0-3.0	2	18	28	2	10	2
2.0-2.5	8	10	5	3.0-4.0	13	20	26	13	10	13
2.5-3.5	12	21	20	4.0-5.0	19	13	9	19	19	17
3.5-4.5	20	37	26	5.0-5.5	25	4	3	25	8	8
4.5-6.0	25	20	32	5.5-7.0	30	45	34	30	53	60
6.0-7.0	30	8	17							
Control Tank										
0-2.0	12	33	67	0-3.0	20	69	60	20	40	45
2.0-2.5	12	17	8	3.0-4.0	20	16	18	20	21	25
2.5-3.5	12	20	11	4.0-5.0	20	6	4	20	17	14
3.5-4.5	12	4	6	5.0-5.5	20	-	5	20	6	3
4.5-6.0	12	8	8	5.5-7.0	20	9	13	20	16	13
6.0-7.0	12	17	2							

* First date of seawater acceptance.

After each group had accepted sea water of 25 to 30 ‰, a sample of smolts was taken from the freshwater holding pond and tested for salinity preference. As already noted for the Cultus fish, the Chilko and Stuart smolts adapted to sea water within 2 to 4 hr after introduction to the tank, displayed a more defined "preference" for sea water than smolts taken from a seawater holding pond, and showed less straying into the lower salinity layers (TABLE 15). The Shuswap fish captured May 27 and tested 7 days later (June 3) did not show this preference for sea water of 25 to 30 ‰ but remained at a level corresponding to approximately 13 ‰. However, the Shuswap fish captured May 31 and held in fresh water moved into salinities of 25 to 30 ‰ when tested on June 7 (TABLE 15). Quesnel fish were not tested in this manner because of time limitations.

As the season advanced the schooling behavior of all races during testing began to deteriorate and eventually the behavior in the gradient tank became one of escape. Fish in the control tank displayed this behavior first. The same behavior was also observed occurring simultaneously in a number of 60-gal glass-front aquaria where smolts were being held. Approximately 2 to 8 days past the time of seawater acceptance, fish in the salinity gradient tank displayed the same activity, thus making further tests impossible.

Influence of Holding and Testing Methods

During the course of testing it became evident that there were other factors, exclusive of salinity, which would affect behavior of sockeye smolts in the vertical gradient chamber. Some of the smolts transported to Bowman's Bay entered sea water on the first day of testing, but returned to low salinities on the second day. A possible explanation may be found in Black's work on lactic acid buildup in sockeye fingerlings following severe exercise. Black (1957) reported that sea water appeared to be of immediate benefit to fingerling sockeye salmon in coping with the metabolites of muscular fatigue. This may be of significance, especially in the case of Quesnel smolts which were tested the same day as arrival at Bowman's Bay with very little rest period.

TABLE 15 - Per cent distribution of sockeye smolts in gradient and control tanks during 2-hr periods. All fish held continuously in fresh water before testing.

POPULATION	MAY 8, 1966 Depth ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
	Gradient Tank			
CHILKO	0-3.0	2	-	2
Captured	3.0-4.0	10	2	1
May 1	4.0-5.0	20	1	2
	5.0-7.0	30	97	95
	Control Tank			
	0-3.0	2	35	27
	3.0-4.0	2	9	18
	4.0-5.0	2	13	14
	5.0-7.0	2	43	41

POPULATION	MAY 25, 1967 Depth ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
	Gradient Tank			
CHILKO	0-1.5	2	15	-
Captured	1.5-2.5	9	15	4
May 11	2.5-3.5	14	33	21
	3.5-4.5	20	11	5
	4.5-5.5	25	11	2
	5.5-7.0	30	16	68
	Control Tank			
	0-1.5	2	49	23
	1.5-2.5	2	6	15
	2.5-3.5	2	7	14
	3.5-4.5	2	7	15
	4.5-5.5	2	8	7
	5.5-7.0	2	23	26

POPULATION	MAY 26, 1967 Depth ft	Sal. °/oo	Smolts % 1-2hr	Smolts % 3-4hr
	Gradient Tank			
STUART	0-1.5	2	10	3
Captured	1.5-2.5	8	9	2
May 11-12	2.5-3.5	13	27	8
	3.5-4.5	19	18	22
	4.5-5.5	25	11	16
	5.5-7.0	30	25	49
	Control Tank			
	0-1.5	2	**	**
	1.5-2.5	2	**	**
	2.5-3.5	2	**	**
	3.5-4.5	2	**	**
	4.5-5.5	2	**	**
	5.5-7.0	2	**	**

POPULATION	JUNE 7, 1968 Depth ft	Sal. °/oo	Smolts %
	Gradient Tank		
SHUSWAP	0-1.5	13	4
Captured	1.5-2.5	18	5
May 31	2.5-3.5	23	14
	3.5-7.0	30	77
	Control Tank		
	0-1.5	2	4
	1.5-2.5	2	14
	2.5-3.5	2	19
	3.5-7.0	2	63

** Escape behavior.

Intensity of light also affected behavior of the smolts. During the course of two tests on Shuswap Lake smolts, light intensity was varied from 0.2 ft-c to 0.6 ft-c (FIGURE 5). At 0.2 ft-c there appeared to be a slowing down of activity and the fish settled to the bottom of both the gradient and control tanks. At 0.6 ft-c activity was renewed and fish began to range further within the chambers. Results obtained from these tests would explain why the fish appeared attracted to the bottom of the tanks when tested at a light intensity of 0.2 ft-c in 1966, in comparison with the behavior observed during tests under greater light intensity (0.6 ft-c) in 1967 and 1968. Under these conditions, it is considered that the rate of conversion to sea water in 1966, if affected at all, was hastened and that these tests would perhaps be better considered tolerance or avoidance tests rather than preference tests.

Another possible factor influencing smolts in a vertical gradient is temperature. As the season progressed the freshwater supply became as much as 12.5°F warmer than the sea water. When the two water supplies were mixed to supply the various layers for the salinity gradient, a temperature gradient was also created. Although most tests were carried out early in the season when the temperature gradient was minimal (less than 2°F), the existing data do not indicate the influence, if any, of the 5°F temperature gradient during tests in late May and early June.

Based on results of tests in the salinity gradient, the variable salinity holding ponds were adjusted daily. That is, at the completion of a salinity preference test, the salinity of the holding pond was changed to correspond with the approximate mean salinity preference observed from that day's results. It is possible that this in turn influenced smolt behavior in subsequent tests. Rate of transition to higher salinities in the gradient could have been increased or decreased, depending on the rate of salinity change in the holding pond and the response of fish to these changes. Evidence of a possibly increased rate of transition to sea water by acclimation was apparent in a test of Shuswap fish (trapped May 27) held in fresh water and tested on June 3, 7 days after capture. These fish remained in a salinity of 12 to 15 ‰ and did not enter 30 ‰ salinity,

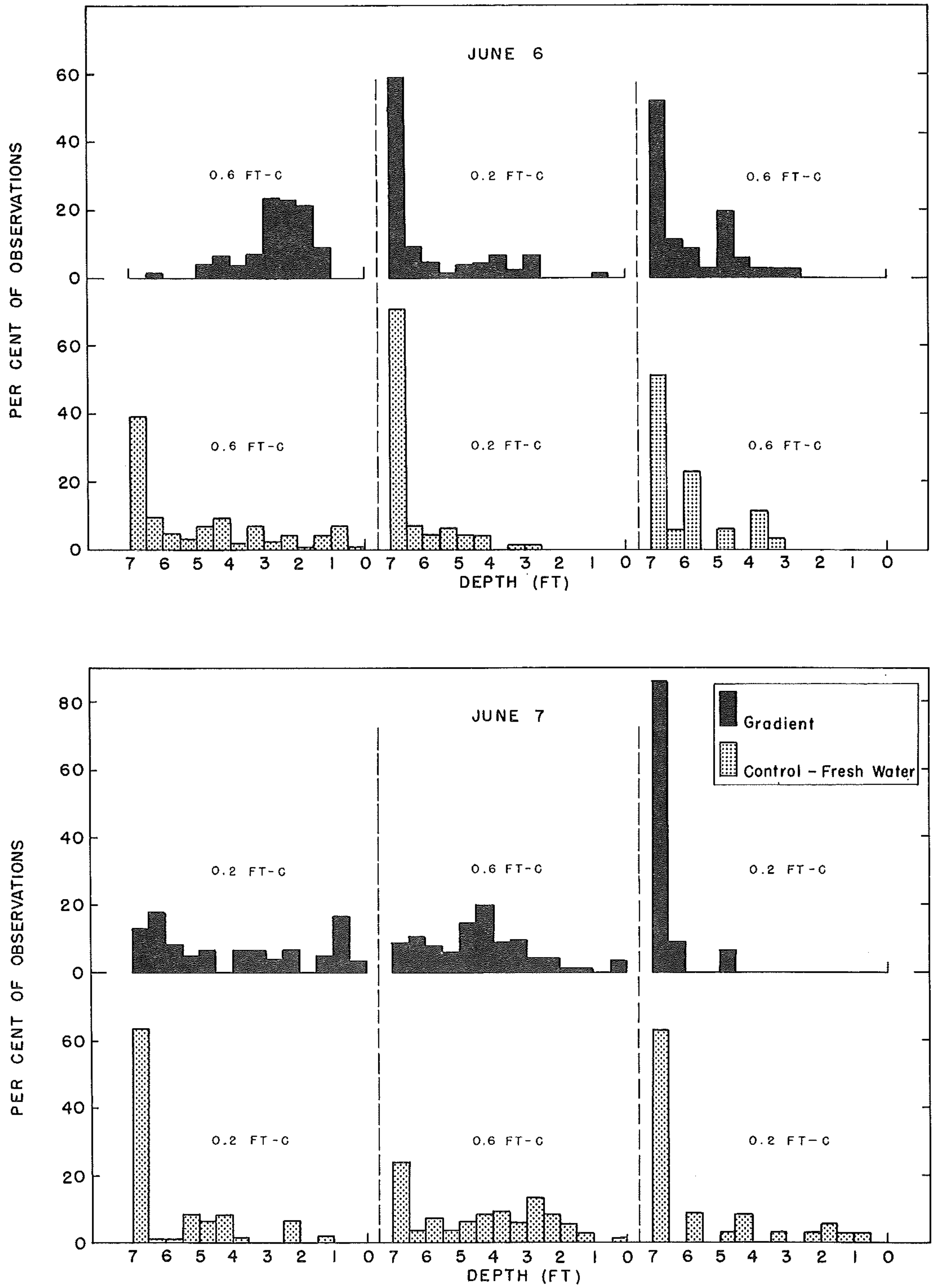

FIGURE 5 - Effect of light intensity on vertical distribution of Shuswap smolts captured May 31, 1968 during two tests (June 6 and 7) in gradient and control tanks.

even though fish of the same stock from the variable salinity pond had accepted sea water on June 2. However, the stock of Shuswap smolts trapped on May 31 and held in fresh water entered sea water of 29 $^{o}/oo$ in a test on June 7, also within 7 days of capture. Results of the latter test may not be entirely comparable due to the low light intensity used during the first hour of the test; nevertheless, the fish did remain in sea water of 29 $^{o}/oo$ for the next 2.4 hr when the light intensity was increased to 0.6 ft-c (FIGURE 5). While it is possible that other factors also affected behavior of sockeye smolts in the vertical gradient chambers, the factors discussed above are considered to be the main influences possibly affecting results of the salinity tests.

Except for the effect of low light intensity in 1966, the salinity gradient appeared to be the major or dominating factor affecting behavior of smolts, at least up to the time of seawater acceptance. This is evident by comparing the schooling behavior in the control and test tanks. In most cases the fish in the control tank were spread over a larger area than the fish in the test tank. The influence of the gradient was also evident in the fact that, in populations displaying escape behavior, it invariably occurred first in the control tank with a uniform salinity and then, as much as several days later, became evident in the tank with a salinity gradient. Thus although there were other influences affecting behavior of smolts in the test tanks, the response to the salinity gradient could be observed among the effects of other stimuli.

Seawater Acceptance versus Time Required for Migration

From the results of salinity preference tests it can be seen that there were several days separating the five populations of smolts in the time of seawater acceptance. Cultus smolts tested on the day after migration moved into sea water almost immediately. Chilko, Quesnel, Shuswap and Stuart smolts accepted sea water within approximately 111, 132, 138 and 161 hr, respectively. The 1966 Chilko smolts accepted sea water within 88 hr, but results were not considered comparable due to the influence of the lower light intensity, discussed previously. These times of seawater acceptance increased as the distance from the estuary to the freshwater rearing area increased (FIGURE 6). The foregoing led to the hypothesis that the time to seawater acceptance may be related to the time required for smolt migration from the rearing lake to the estuary.

The one exception evident in FIGURE 6 was Shuswap, where the time to seawater acceptance was much longer than the other populations tested, relative to its distance from the estuary. However, the major difference between Shuswap and the other populations is the presence of two lakes through which the Shuswap downstream migrants must pass, thus increasing migration time. One of these lakes, Little Shuswap, is relatively small (5 miles long) and shallow (mean depth of 47 ft) with a mean rate of water movement during May of 0.75 miles per day. The other, Kamloops Lake, is longer (17.2 miles) and deeper (mean depth 243 ft) but also has a rapid rate of water replacement. The outstanding characteristic of Kamloops Lake is the large volume of inflow relative to the size of the basin, accounting for a mean flow rate of 0.91 miles per day during April-May 1963, which represents a relatively fast moving body of water within a lake (Ward, 1964).

In spite of this flow, the intervening lakes would cause a significant slowing in the rate of Shuswap smolt seaward migration. The average swimming speed of sockeye smolts migrating through 50 ft of Shuswap Lake has been measured at 1.4 ft per sec (Andrew, MS,1960a). If smolts maintained this speed and swam directly and continuously toward the lake outlet, which is very unlikely, the rate of travel through lakes would be approximately 23 miles per day. Actual rates of migration are not available for the Shuswap system, but smolts caught in Seton Creek in 1958, marked, and reintroduced to Seton Lake showed a mean migration rate of 2 miles per day. This figure was considered a minimum rate of travel due to handling, marking and reintroduction to Seton Lake (Andrew, MS,1960b). Also, tagged smolts migrating toward the outlet of Babine Lake averaged 3.2 miles per day in 1960 and 4.9 miles per day with a maximum of 6 miles per day in 1961 (Johnson and Groot, 1963). Assuming some effect from handling and tagging in the foregoing experiments, and allowing for the significant movement of water

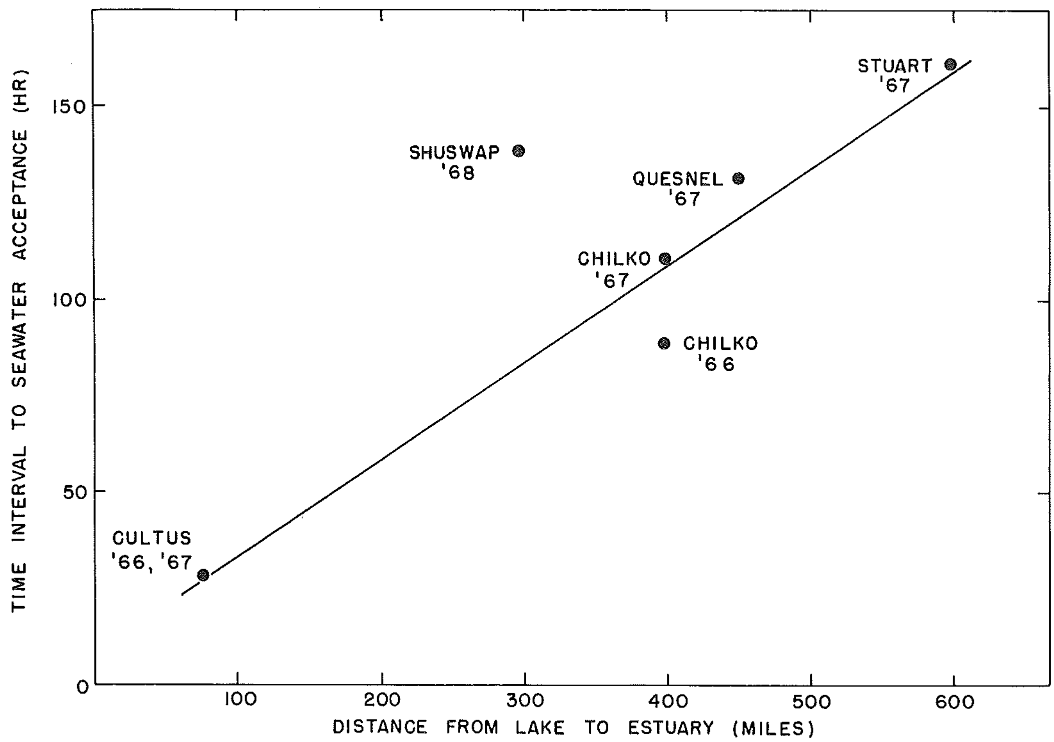

FIGURE 6 - Relationship of distance from the estuary to time of seawater acceptance.

through Little Shuswap and Kamloops Lakes, a migration rate of 7 miles per day for Shuswap smolts would probably be within the realm of credibility.

Migration rate in rivers, however, is considerably faster. Observations in Little River indicate that the rate of sockeye smolt migration is very close to the rate of water flow in velocities greater than 0.9 ft per sec (FIGURE 7) but in slower velocities smolts will swim faster than the current (Andrew, MS,1960a). Similarly, studies on smolt migration rate in Chilko River, based on a release-recapture method over an 80-mile section of river, indicated that migrating fish traveled at very close to the speed of water (Remington, MS,1959). Direct underwater observations also show that smolts swim actively with the current unless they approach some obstacle at which time they may orient upstream (Hartman, Heard and Drucker, 1967). These data indicate that a major factor affecting the rate of seaward migration for sockeye is the flow rate of the water mass in which the smolts are traveling.

Another major factor influencing rate of smolt migration is the amount of holding in rivers. Remington (MS,1959) concluded that Chilko smolts migrated continuously in turbid water but delayed during daylight in clear water. Also, surface traps on the relatively clear Thompson River failed to capture any smolts during daylight, suggesting a holding period. There have been, however, isolated observations indicating heavy smolt migrations occurring deep in the river during daylight. Trap catches in the Fraser River at Mission from 1962 to 1968 also suggest that smolts migrate round the clock in the turbid Fraser River. These additional data tend to corroborate Remington's conclusions on the behavior of sockeye smolts during seaward migration.

Migration times were therefore estimated for each population of smolts from the foregoing data. Flow time was used as an index of migration time and a 12-hr delay was added for every 12-hr migration in clear rivers. In the case of Shuswap smolts, 24 hr were added for every 7 miles of lake travel. These estimated travel times were plotted against the time to seawater acceptance (FIGURE 8). It should be noted that the flow times used were estimates only, based on the slope, roughness, contours and mean

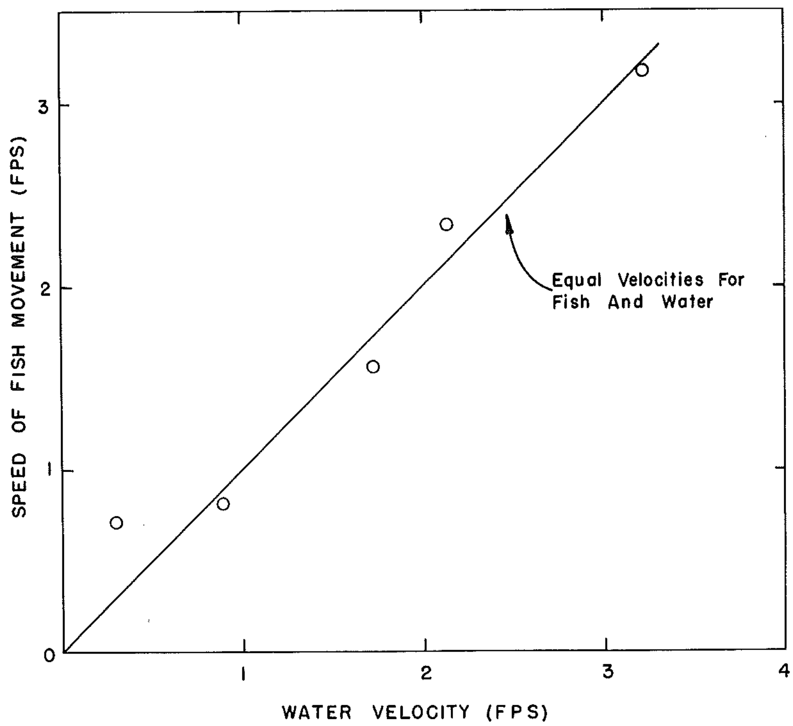

FIGURE 7 - Migration speed of sockeye smolts in relation to water velocity, South Thompson River (from Andrew, MS,1960a).

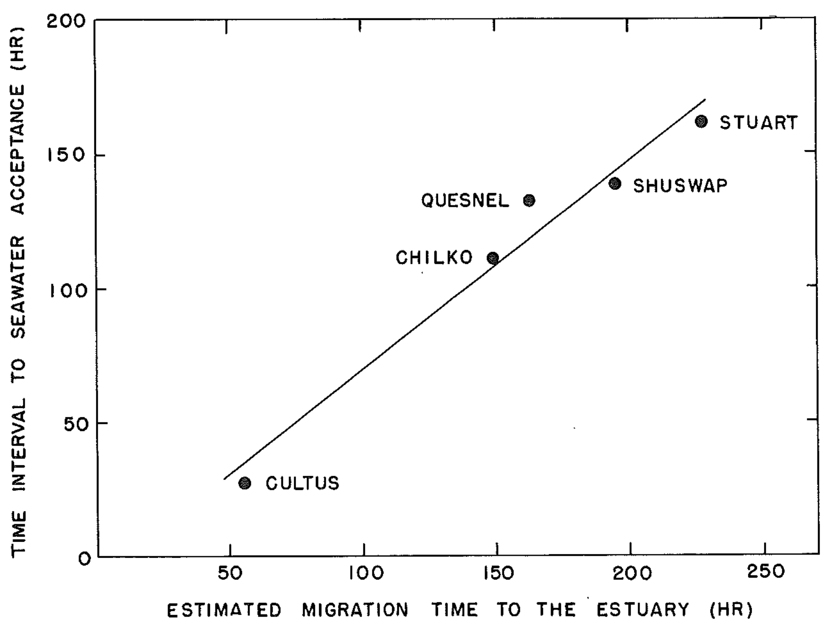

FIGURE 8 - Relationship of estimated migration time to time of seawater acceptance.

discharge during the smolt migration period for each river. Also the travel time of Shuswap smolts through Little Shuswap and Kamloops Lakes remains uncertain. However, trap catches of smolts in the Fraser River at Mission suggest a migration time of 96 to 120 hr for Chilko smolts and 144 to 168 hr for Shuswap smolts, tending to confirm the estimates of migration time shown in FIGURE 8. Thus the results imply that the time of seawater acceptance is related to the time required by smolts to reach the estuary from the freshwater rearing areas.

SURVIVAL DURING TRANSITION TO SEA WATER

The evidence accumulated here indicates that the time of seawater acceptance is not necessarily simultaneous with the onset of migration, but that there is a time lag related directly to migration time. The present data do not necessarily indicate the timing of seawater acceptance to the exact hour as many other factors could have influenced the results. Also, one would not expect a population of fish to be this precise in its timing. However, results indicate that the time to seawater acceptance increases as the time required to reach salt water increases.

The factors determining duration of the seaward river migration of Fraser River smolts are at present uncertain, although river turbidity and flow time of the water mass from the rearing area to salt water appear to be of major importance. Several years of observations and trap catches suggest strongly that Fraser sockeye smolts migrate from lake to estuary with little delay. Although annual variations in river flow may affect the rate of migration, once the smolts leave the lake they appear to progress directly to the estuary. Here fish must cope with higher salinities or remain restricted to the river or to the plume of fresh water spreading into Georgia Strait from the Fraser River. If this is the case, some of the variation in survival occurring after smolts leave the lake might be explained by a delayed physiological change within the smolt, out of phase with the time of migration. A delay in salinity tolerance or preference change could cause mortality, probably indirectly, either by placing the smolt under stress or by influencing its behavior upon entering the estuary, thus rendering it more vulnerable to other sources of mortality.

The close correlation between river flow and survival rate of Chilko smolts is not explained by the results of the present tests. If high river flow contributes to a more rapid seaward migration, one might expect a lower survival if smolts migrated during high flow and reached the estuary before the time of seawater acceptance. On the contrary, however, high flow coincides with good survival indicating that flow may be an index of environmental conditions prior to lake emigration, contributing to the physiological condition of the seaward migrant, rather than a factor directly influencing survival during the migration and seawater transition periods.

Once the fish reach the point of accepting sea water, very little if any acclimation is necessary for survival. Those fish held in fresh water and tested in a gradient after the variable salinity group had accepted sea water moved into 30 $^{o}/oo$ salinity within 2 to 4 hr after introduction to the tank. Prior to this time, however, salinity tolerance of sockeye smolts may be influenced by acclimation to sea water. When placed in sea water of 29 to 30 $^{o}/oo$ without acclimation, the Chilko, Quesnel and Stuart smolts suffered a considerable mortality on the first day past the onset of migration. However, on the same day, a considerable number of the 1967 Quesnel and Chilko smolts were observed in the 29 to 30 $^{o}/oo$ salinity layer after approximately 3 hr exposure to a salinity gradient. It was evident that within 1 day after leaving the lake, these fish could tolerate sea water for at least a 2- to 4-hr period after a brief acclimation at lower salinities.

Under natural circumstances it seems unlikely that Fraser River smolts would be subjected to 30 $^{o}/oo$ sea water without at least some acclimation. Furthermore, the time required for seawater acceptance of all smolts tested was less than the estimated migration time to the estuary, suggesting that conversion to sea water would not be expected to be a direct cause of smolt mortality.

On the other hand, those concerned with the hatchery rearing of sockeye salmon should be aware of the salinity tolerance of the smolts prior to release. Several authors have indicated the relationship of size to the development of salinity tolerance in various species of Salmonidae (Parry, 1960; Houston, 1961; Conte et al., 1966). However, the mortality of 2-year-old smolts and large hatchery-reared Cultus sockeye tested in sea water in March and April 1969 indicates that large size does not necessarily indicate a favorable physiological state for tolerance of sea water.

As suggested by Bjornn et al. (1968), some threshold size may be required for sockeye parr-smolt transformation and development of salinity tolerance. Evidence supporting this suggestion comes from the fact that sockeye remaining in Chilko Lake for 2 years attain much less growth during their first year of lake residence than concurrently resident fish migrating seaward as yearlings (Clutter and Whitesel, 1956). On the other hand, seaward migrant sockeye populations comprised of small individuals may exhibit a high survival rate, as for example the dominant year classes produced in certain years, and evidently are not hampered by any lack of osmoregulatory ability. Thus although some threshold size may be necessary for parr-smolt transformation, subsequent survival of smolts above this size appears to be influenced by other factors.

The escape behavior noted in the present experiment raises the question of the effect of dams and reservoirs in delaying smolt seaward migration and may also provide indirect evidence of smolt behavior after reaching the estuary. In most cases, approximately 24 to 36 hr past the time of seawater acceptance, fish in the control chamber displayed a characteristic vertical swimming motion described as escape behavior. Approximately 3 days past the time of seawater acceptance, fish in the test chamber began to display the same pattern of increased activity, regardless of the salinity gradients. While a brief delay in fresh water, as such, did not influence smolt transition to sea water, a prolonged period of escape activity in a reservoir might be unfavorable to subsequent survival. However, this increase in activity occurred among fish from both the freshwater and the variable salinity holding ponds and began at roughly the same time relative to salinity preference change. Thus this escape behavior may be indicative of an active seaward migration once the fish reach the estuary. This implies that upon entering Georgia Strait, the fish may begin an active migration to the sea with very little or no holding period.

SUMMARY AND CONCLUSIONS

Some of the wide fluctuations in survival during the smolt-to-adult period of sockeye life history appear to be determined prior to ocean residence. In an attempt to define the possible causes of mortality during this period, the conditions encountered by smolts during river migration were measured, and the response of smolts to increasing salinities typical of the estuarial environment were examined.

Water quality of the Fraser River and of four tributaries serving as migration routes for sockeye smolts appeared to be good in the spring of 1966, 1967 and 1968. Constituents which might cause mortalities among seaward migrating young sockeye were not evident. All metals were below toxic levels and no pesticides, herbicides or detergents were detected.

Salinity tolerance tests in 1966 and 1967 indicated that smolts from Cultus Lake, located 75 miles from the estuary, survived immediate transfer to 30 ‰ sea water, but some mortalities occurred among the earliest migrants in 1969. All populations whose freshwater rearing areas are more distant from sea water suffered mortalities for up to 3 days after the onset of migration.

Salinity tolerance of the 1966 Chilko smolts was lowest of the four populations tested and lower than that of Chilko smolts in 1967, indicating the possibility of annual variations in seawater tolerance within a race.

Tests in a vertical salinity gradient indicated a definite time period, distinct from the onset of migration, when the preference of sockeye smolts changed from fresh water to sea water, defined here as seawater acceptance. The time interval prior to seawater acceptance appeared to be related to the travel time from the lake to salt water.

Once past the period of seawater acceptance, virtually no acclimation was required for smolts to select 30 ‰ salinity in a gradient. Prior to this time, however, it is felt that a period of acclimation is required for optimum survival at high salinities.

If duration of seaward migration is determined primarily by rate of river flow, a delay in salinity preference and tolerance, relative to the onset of migration, might be indirectly responsible for some of the variations in smolt survival occurring in sea water.

LITERATURE CITED

American Public Health Association, Inc. 1965. Standard methods for the examination of water and wastewater. 12th ed. New York. 626 p.

Andrew, F.J. MS,1960a. Migration speed of sockeye smolts in the Shuswap system. Internat. Pacific Salmon Fish. Comm.

MS,1960b. Migration speed of sockeye smolts in Seton Lake. Internat. Pacific Salmon Fish. Comm.

Baggerman, B. 1960. Salinity preference, thyroid activity and seaward migration of four species of Pacific salmon (Oncorhynchus). J. Fish. Res. Bd. Canada 17(3): 295-322.

Bjornn, T.C., D.R. Craddock and D.R. Corley. 1968. Migration and survival of Redfish Lake, Idaho, sockeye salmon, Oncorhynchus nerka. Trans. Amer. Fish. Soc. 97(4): 360-373.

Black, E.C. 1957. Alterations in the blood level of lactic acid in certain salmonoid fishes following muscular activity. III. Sockeye salmon, Oncorhynchus nerka. J. Fish. Res. Bd. Canada 14(6): 807-814.

Clutter, R.I. and L.E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Internat. Pacific Salmon Fish. Comm., Bull. 9. 159 p.

Conte, F.P., H.H. Wagner, J. Fessler and C. Gnose. 1966. Development of osmotic and ionic regulation in juvenile coho salmon Oncorhynchus kisutch. Comp. Biochem. Physiol. 18: 1-15.

Doudoroff, P. and M. Katz. 1953. Critical review of the literature on the toxicity of industrial wastes and their components to fish. II. The metals, as salts. Sewage and Industr. Wastes 25(7): 802-839.

Forster, R.P. and F. Berglund. 1956. Osmotic diuresis and its effects on total electrolyte distribution in plasma and urine of the aglomerular teleost, Lophius americanus. J. Gen. Physiol. 39(3): 349-359.

Hartman, W.L., W.R. Heard and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. J. Fish. Res. Bd. Canada 24(10): 2069-2099.

Hoar, W.S. 1954. The behavior of juvenile Pacific salmon, with particular reference to the sockeye (Oncorhynchus nerka). J. Fish. Res. Bd. Canada 11(1): 69-97.

1960. Environmental physiology of animals. 2nd ed. Scholars Library, New York. 98 p.

Hoar, W.S., M.H.A. Keenleyside and R.G. Goodall. 1957. Reactions of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada 14(6): 815-830.

Houston, A.H. 1957. Responses of juvenile chum, pink and coho salmon to sharp seawater gradients. Canadian J. Zool. 35: 371-383.

1961. Influence of size upon the adaptation of steelhead trout (Salmo gairdneri) and chum salmon (Oncorhynchus keta) to sea water. J. Fish. Res. Bd. Canada 18(3): 401-415.

Hurley, D.A. and W.L. Woodall. 1968. Responses of young pink salmon to vertical temperature and salinity gradients. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 19. 80 p.

Johnson, W.E. and C. Groot. 1963. Observations on the migration of young sockeye salmon (Oncorhynchus nerka) through a large, complex lake system. J. Fish. Res. Bd. Canada 20(4): 919-938.

Lloyd, R. 1965. Factors that affect the tolerance of fish to heavy metal poisoning, p. 181-187. In C.M. Tarzwell (ed.) Biological problems in water pollution, third seiminar, 1962. U.S. Dept. Health, Educ., Welfare, Public Health Serv. Pub. No. 999-WP-25. Cincinnati, Ohio.

McInerney, J.E. 1964. Salinity preference: an orientation mechanism in salmon migration. J. Fish. Res. Bd. Canada 21(5): 995-1018.

Meyer, D.K. 1948. Physiological adjustments in chloride balance of the goldfish. Science 108: 305-307.

Nelson, J.S. 1968. Salinity tolerance of brook sticklebacks, Culaea inconstans, freshwater ninespine sticklebacks, Pungitius pungitius, and freshwater fourspine sticklebacks, Apeltes quadracus. Canadian J. Zool. 46: 663-667.

Parry, G. 1960. The development of salinity tolerance in the salmon, Salmo salar (L.) and some related species. J. Expt. Biol. 37: 425-434.

Remington, J.D. MS,1959. Speed of downstream migration of sockeye smolts. Internat. Pacific Salmon Fish. Comm.

Servizi, J.A. and R.A. Burkhalter. MS,1969. Water quality and bottom-dwelling organisms of the Fraser River watershed, 1963 to 1968. Internat. Pacific Salmon Fish. Comm.

Sprague, J.B. and B. Ann Ramsay. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. J. Fish. Res. Bd. Canada 22(2): 425-432.

Ward, F.J. 1964. Limnology of Kamloops Lake. Internat. Pacific Salmon Fish. Comm., Bull. 16. 47 p.

Zaks, M.G. and M.M. Sokolova. 1961. On the mechanisms of adaptation to changes in water salinity by sockeye salmon (Oncorhynchus nerka Walbaum). Voprosy Ikhtiologii 1(2): 333-346. Fish. Res. Bd. Canada, Transl. No. 372(1962). 13 p.