INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

PROGRESS REPORT

No. 19

RESPONSES OF YOUNG PINK SALMON TO VERTICAL TEMPERATURE AND SALINITY GRADIENTS

BY

D. A. HURLEY and W. L. WOODALL

NEW WESTMINSTER, B. C.
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in the Fraser River System

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ABSTRACT

Evidence that the large variations in Fraser River pink salmon (Oncorhynchus gorbuscha) runs may be determined by mortality rates during early marine residence prompted investigation into the response of pink salmon fry to certain environmental conditions characteristic of the estuarial region. Experimental stocks of pink salmon were held for as much as three months after emergence and tested at regular intervals in separate vertical gradients of temperature and salinity. Stocks of fry held in fresh water died within five weeks, or less, but others were held without mortality in increasing salinities and also tolerated immediate transfer into 30 to 31 parts per thousand (°/oo) sea water within one day of emergence. The diet of marine plankton provided a slightly slower rate of growth than estimated for wild fry but the condition of experimental fish compared favorably with wild pink salmon.

When tested in a vertical gradient, fry up to three months of age selected a restricted range of temperatures which decreased as fish increased in size. The youngest fry generally selected temperatures between 53° and 56°F, older fry were found in temperatures from 49° to 51°F. Increasing salinities were selected in an orderly sequence as fry made the transition from fresh water to sea water. Transition to salinities of 30 to 31 °/oo required less than one month for all stocks tested but varied with the time of emergence. Tests of early, peak and late segments of an emergence curve indicated progressively more rapid movement into sea water by the later emerging fry. The experimental findings are examined in relation to the behavior of pink salmon fry observed in nature and implications for survival are discussed.

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INTRODUCTION

In the Fraser River system, large but variable numbers of adult pink salmon, *Oncorhynchus gorbuscha* (Walbaum), return to spawn in the fall of odd-numbered years. Adult runs have ranged from less than two million to as many as 12 million between 1945 and 1967. The life cycle of Fraser River pink salmon is invariably complete in two years. Returning adults spawn in the main Fraser River and in several tributary streams for distances up to 230 miles from the estuary. The following spring, newly emerged fry immediately migrate back to Georgia Strait where, within a short time, they are found concentrated in shallow beach areas adjacent to the Gulf and San Juan Islands (FIGURE 1). As fry grow larger, they move into deeper water and apparently during the first week in August migrate to the open ocean in peak numbers. However, in one year (1962) juvenile pink salmon were still found as late as October 5 in the Albert Head-Victoria area. Although considerable variation in survival is known to occur during the freshwater incubation period, a greater part of the observed fluctuation in total run size of Fraser stocks is apparently determined during early marine residence.

There is considerable evidence of large variation in the survival of pink salmon in the marine environment. Parker (1964) found the total marine survival (percentage of fry returning as adults to the spawning grounds) of pink salmon from Hook Nose Creek in central British Columbia varied by a factor of 26 times, from 0.2 to 5.2 per cent, for the 14 brood years examined. In the Fraser system, a fourfold variation in marine survival (percentage of fry returning as adults to coastal waters), from 0.8 to 3.7 per cent, has been recorded for two years of pink salmon production (Vernon, 1966) and the higher survival rate of the run returning in 1967 (over 4 per cent) increases this to a fivefold variation in marine survival.

These large variations in survival apparently occur during the initial few weeks after pink salmon fry enter the estuary. Parker (1965) estimated on the basis of marking experiments that 77 per cent of the 1961 brood

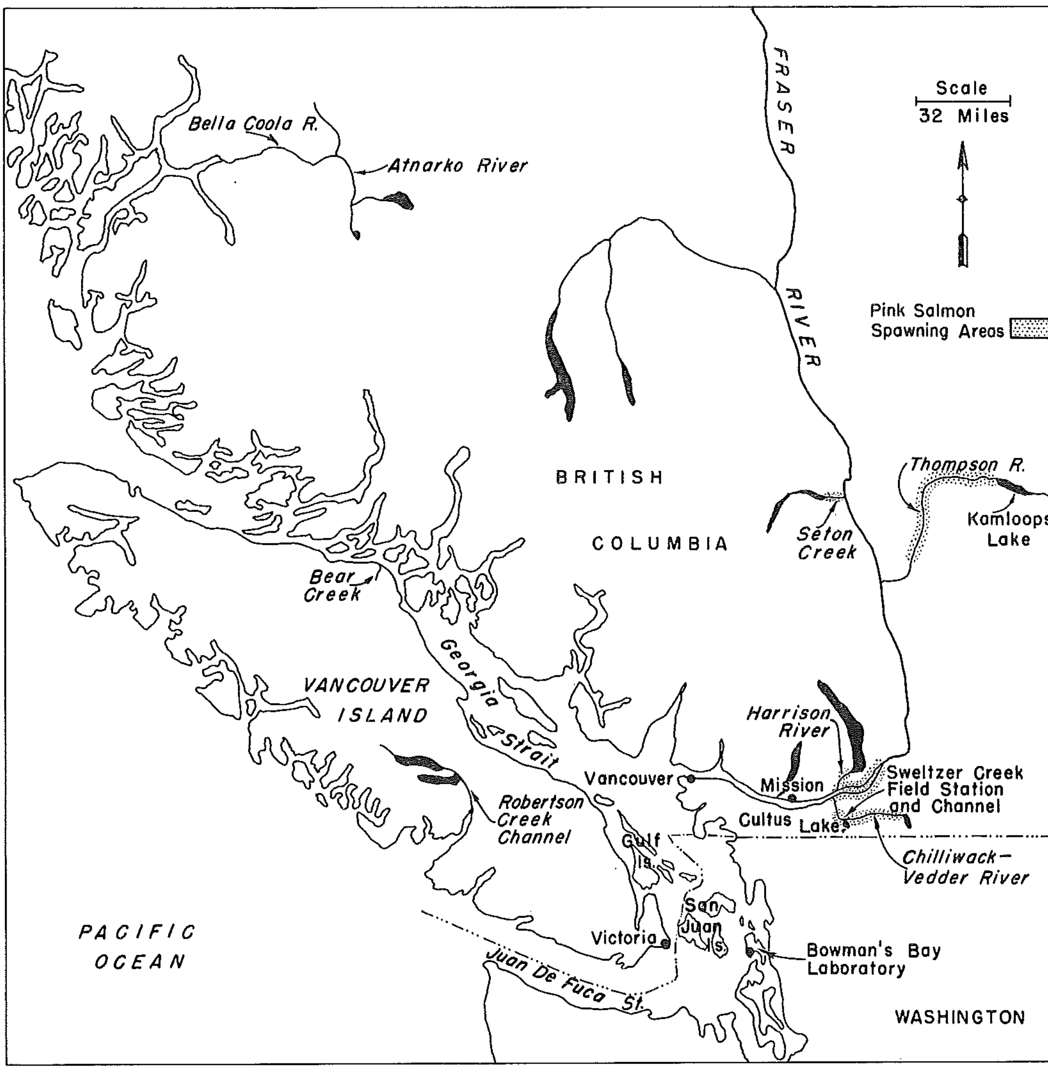

FIGURE 1 - Major spawning locations of adult Fraser River pink salmon and estuarial areas used by young pink salmon during early marine residence. Sources of experimental stocks and location of Bowman's Bay Laboratory also shown.

Bella Coola pink salmon stocks died during the initial 40-day period of marine life. The percentage mortality in this brief period was estimated to equal that of the entire remaining 14 months of marine residence, and Parker concluded that the relatively short initial period of coastal residence was critical to the numerical strength of the adult returns.

There is evidence that environmental conditions encountered by fry in the estuary may contribute to this initial mortality. In this regard, Vernon (1958) found that temperature and salinity of the surface water in Georgia Strait during the summer months following fry migration appeared to be related to the number of adult pink salmon that returned to the Fraser River the following year. Similarly, Wickett (1958) suggested a possible relationship between pink salmon survival at Hook Nose Creek, British Columbia, and adjacent coastal temperature and salinity in June, shortly after seaward migration of the fry.

These data all indicate that abundance of adult pink salmon is in large part determined during estuarial residence and that the temperature and salinity of this environment may be instrumental in determining survival. In the case of temperature, pink salmon fry have been shown to select restricted temperature levels (Brett, 1952) and to attain maximum growth rates within a narrow temperature range (Martin, 1966). If temperature selection is a factor directing behavior of pink salmon fry during estuarial residence, it may be postulated that distribution, growth and ultimately survival may depend on the temperature conditions encountered during this period. In the case of salinity, it is evident that pink salmon fry, at some point in development, must undergo physiological adaptations for transition from fresh to salt water. Changes in histology of the gills (Threadgold and Houston, 1964) and function of the kidneys (Ford, 1958) are important adaptations required for conservation of body fluids and elimination of excess salts in the marine environment. These changes presumably must occur in a correct sequence, timed to seaward migration and to conditions of salinity normally encountered by fry in the estuary. Thus deviations from optimum conditions of temperature and salinity, brought about either by change in time of seaward migration or by differences in climatic and run-off conditions, could upset the normal sequence of behavior and thereby reduce survival of juvenile pink salmon.

The purpose of the present investigation was to determine experimentally, under as natural conditions as possible, the normal sequence of behavioral changes of pink salmon in relation to temperature and salinity during the transition from fresh water to sea water and continuing for several months thereafter. This included a study of the effect of timing of fry emergence on the transition to sea water, and an examination of the tolerance of young pink salmon to unnatural salinity conditions. The experimental results form a basis for examining the behavior, distribution and survival of Fraser River pink salmon under varying natural conditions during their early marine residence.

SOURCE OF STOCKS AND HOLDING METHODS

Considerable difficulty has been experienced in the past in rearing pink salmon in captivity and serious mortalities have been common during the fry and fingerling stages. Thus several requirements had to be met in order to provide healthy stocks of test fish so that experimental studies of fry behavior during the first few months of life would be applicable to pink salmon fry in nature. First, samples of fry had to be obtained immediately after emergence at the onset of their seaward migration. Secondly, facilities were required to provide appropriate salinity and temperature conditions in a holding environment where fish could be reared for several months without mortality. Finally, a suitable food supply was required to ensure uniform growth within stocks and a growth rate comparable to wild fish during the prolonged holding period. Experience gained during the first period of study, from early April until late June 1965, concerned holding and testing methods and provided the basis for more extensive studies carried out during approximately the same period of 1966.

Source of Fry

Since Fraser River pink salmon fry were not available in the spring of 1965, experimental stocks were obtained from Atnarko River, a tributary of the Bella Coola River system in central British Columbia, and from Bear Creek on the northeast coast of Vancouver Island (FIGURE 1). The assistance of the Department of Fisheries of Canada in supplying eggs and fry for the 1965 experiments is gratefully acknowledged. In 1966, pink salmon fry from Sweltzer Creek in the lower Fraser River drainage were used exclusively.

Eggs were incubated in the Sweltzer Creek Field Station and in the Robertson Creek and Sweltzer Creek artificial channels. Although conditions during incubation varied considerably for the different stocks, all fry appeared healthy and all were approximately the same size (35 mm, 0.3 gm) at the time of sampling (TABLE 1).

Fry for experimental stocks were obtained as the young fish emerged from the various incubation areas. In 1965, samples were obtained near the peak of emergence from the gravel-filled troughs of the Sweltzer Creek Field Station on April 1, and during peak emergence from Robertson Creek channel on April 20 (TABLE 1). In 1966, several small samples of fry were obtained at the beginning of emergence (between March 29 and April 11) but the three major groups tested, designated as early, peak and late stocks, were sampled from the normal curve of emergence from the Sweltzer Creek channel on April 14, May 3 and May 13, respectively. These three major samples can be considered representative of the time of emergence for this system. Newly emerged fry originating from natural spawning in Sweltzer Creek were first trapped in early March, numbers rose gradually to reach a peak during the first week in May and seaward migration essentially ended by late May.

Fry obtained from the various incubation areas on the dates indicated were moved the same day by truck to Bowman's Bay Laboratory. Transportation required a period of 5 hr from the Robertson Creek channel and approximately 2 hr from the Sweltzer Creek area. During transport, crushed ice was added to the containers and water temperatures averaged approximately 45°F. Mortalities during transport amounted to less than one per cent in all cases.

TABLE 1 - Stocks of pink salmon used in experimental studies, 1965 and 1966.

SOURCE OF EGGS	DATE OF FERTILIZATION	INCUBATION				PERIOD OF FRY EMERGENCE	FRY SAMPLES		
		Location	Method	Mean Temperature °F			Date	Mean Fork Length mm	Mean Weight gm
Bella Coola Stock									
Atnarko River	Eggs fertilized last week in September, 1964	Sweltzer Creek Field Station	Hatchery trays to eyed stage, then in gravel-filled troughs	Sept. 1-30	50	Mid-March to early April, 1965	Apr. 1	36.6	0.31
				Oct. 1-Nov. 30	45				
				Dec. 1-Feb. 28	40				
				Mar. 1-31	45				
Vancouver Island Stock									
Bear Creek	Eggs fertilized November 5-11, 1964	Robertson Creek Spawning Channel	Hatchery trays to eyed stage, then planted in gravel of spawning channel, Jan. 15, 1965	Jan. 15	38	Peak of emergence mid-April, 1965	Apr. 20	37.5*	0.36*
				Feb. 20	40				
				Apr. 5	45				
				Apr. 20	49				
Fraser Stock									
Sweltzer Creek	Spawning from mid-October to mid-November with peak at end of October, 1965	Sweltzer Creek Incubation Channel	Adults placed in channel and allowed to spawn naturally	Oct. 1-31	52	Early March to end of May, 1966	Mar. 29	-	-
				Nov. 1-30	50		Apr. 5	-	-
				Dec. 1-31	45		Apr. 11	-	-
				Jan. 1-Feb. 28	41		Apr. 14	35.0	0.26
				Mar. 1-31	43		May 3	34.8	0.24
				Apr. 1-30	46		May 4	35.2	0.26
				May 1-13	51		May 13	35.7	0.29

*Fry measured on April 25; all others measured within one day of sampling.

Holding Facilities

The facilities of the Bowman's Bay Marine Biological Laboratory were used to hold the stock fry and to conduct the various experiments. The laboratory is situated at sea level on Fidalgo Island near Deception Pass, Washington, and at the time of these experiments was operated by the Department of Fisheries of that State.

Experimental stocks of pink salmon fry were held in 40 by 4 ft concrete raceways with a water supply of 20 to 30 U.S. gal per min. Water depth was maintained in each raceway at a depth of approximately 6 in. and replacement time ranged from 20 to 30 min.

Fresh water from a small lake and sea water (up to approximately 31.5 $^{o}/oo$ salinity) from an intake in Bowman's Bay were mixed to provide a complete range of salinities for the holding areas.

In 1966, the temperature of the freshwater supply rose rapidly from approximately 50°F in early April to 58°F by mid-May, after which date all fish were held only in sea water. In 1965, freshwater temperatures ranged from approximately 47°F in late April to 57°F in late May. Temperatures of the saltwater supply increased from 44°F in early April to a high of about 53°F by late June 1965, but in 1966 were less variable and ranged from 47° to 51°F during the same period.

Meticulous care was taken to ensure general sanitary conditions in the holding area. Initially, the raceways were disinfected with the recommended dosage of Roccal (0.2 $^{o}/oo$) and thereafter were scrubbed down twice weekly. All brushes, dip nets and rubber boots were disinfected regularly with concentrated Roccal. The fact that no mortalities were recorded among fry held in sea water during both years of the study is witness to the general suitability of their environment.

Environmental Conditions During Holding Period

Experimental stocks of pink salmon fry were held for varying time periods up to a maximum of nearly three months and, as will be described later, small samples of fry were withdrawn at intervals for testing in vertical gradients of temperature and salinity. Several different environmental conditions were utilized for holding these experimental stocks prior to testing (TABLE 2).

In 1965, stocks were held continuously either in sea water of approximately 30 $^{o}/oo$ salinity or fresh water. Fry of the Atnarko River stock incubated at Sweltzer Creek Station were sampled on April 1 and placed in 30 $^{o}/oo$ sea water within a few hours of their arrival at the Bowman's Bay Laboratory. This stock was held without mortality until the study period was terminated on June 23. A second group of fry, sampled on April 20 from Robertson Creek channel, was held in fresh water until heavy mortalities ended the experiment in late May.

In 1966, small groups of fry were again held continuously in fresh water and in sea water of 30 $^{o}/oo$ salinity, but the three major stocks were held under more natural conditions of increasing salinity. The rate of conversion from fresh to sea water, shown for these stocks in TABLE 3, was determined by the response of small subsamples from each stock to frequent tests in a vertical salinity gradient. In the gradient, fry were offered a choice of six different salinities varying between 0 and 30 $^{o}/oo$. Following each test, the salinity in the holding area was adjusted to correspond to the salinity concentration selected most frequently by the fry tested in the gradient. This "natural" conversion to sea water required a period of 17 days for early fry, 16 days for peak fry and 11 days for late fry. Once the conversion to sea water was completed, the salinities varied with the supply and ranged from 30 to 31.5 $^{o}/oo$.

Temperatures in each raceway were measured daily with maximum-minimum thermometers in 1966. In 1965, daily temperatures were recorded only in the seawater holding area. These temperatures were not controlled but depended on the temperature of the water supply. Hence, pink salmon held in fresh water experienced considerably higher temperatures than those in sea water (TABLE 2). Temperatures for stocks held in increasing salinity declined gradually as the quantity of warmer, fresh water was decreased, but averaged approximately 50°F during most of the holding period (TABLE 4).

TABLE 2 - Environmental conditions during holding of pink salmon fry stocks, 1965 and 1966.

SOURCE	SIZE OF EXPERIMENTAL STOCK	HOLDING PERIOD	HOLDING CONDITIONS	
			Salinity	Mean Temp °F
		1965		
Atnarko River stock incubated at Sweltzer Creek Station	3000	April 1-June 23	29-31.5 ‰	April 1-30 44.9 May 1-31 47.6 June 1-23 50.5
		1965		
Bear Creek stock incubated at Robertson Creek Channel	2000	April 20-May 25	0 ‰	April 22 47.5 May 24 57.0
		1966		
Sweltzer Creek stock incubated at Sweltzer Creek Channel	3000	"EARLY" April 14-July 12	0 - 31.5 ‰ (see TABLE 3)	(see TABLE 4)
	5000	"PEAK" May 3-July 12	0 - 31.5 ‰ (see TABLE 3)	(see TABLE 4)
	3000	"LATE" May 13 July 12	0 - 31.5 ‰ (see TABLE 3)	(see TABLE 4)
	200	March 29-30	0 ‰	50.0
	100	April 5- 7	0 ‰	50.0
	200	April 11-13	0 ‰	51.0
	500	May 4-16	0 ‰	57.9
	100	April 5- 6	29-31.5 ‰	47.0
	500	May 4-June 9	29-31.5 ‰	May 4-31 49.4 June 1- 9 50.6

TABLE 3 - Salinities supplied to raceways holding the three major 1966 stocks of pink salmon fry, based on salinities selected by fry in a vertical gradient.

EARLY FRY		PEAK FRY		LATE FRY	
Date	Salinity °/oo	Date	Salinity °/oo	Date	Salinity °/oo
April 14	0	May 3	0	May 13	0
15-17	7.3	3-6	13.9	13-15	13.7
18-19	15.7	7-9	20.6	16-17	16.3
20	18.0	10	25.8	18-19	26.4
21-24	20.8	11-18	26.2	20-23	28.0
25-26	23.9	May 19-July 12	30.5-31.5	May 24-July 12	30.5-31.5
27-28	25.7				
29-30	29.6				
May 1-July 12	30.0-31.5				

TABLE 4 - Mean daily water temperatures in raceways holding three major stocks of pink salmon fry, 1966. Also shown are temperatures of Sweltzer Creek channel on dates stocks were obtained ( ).

EARLY FRY		PEAK FRY		LATE FRY	
Date	Temp. °F	Date	Temp. °F	Date	Temp. °F
April 14	(45)	May 3	(48)	May 13	(51)
14	52	3	54	13	53
15	52	4-6	55	14	53
16-20	51	7-8	54	15-16	52
21-24	50	9-11	53	17-19	53
25-27	49	12-13	52	20	52
28	50	14	51	21-27	51
29	49	15-16	50	May 28-July 4	50
30	48	May 17-June 19	51	July 5-12	51-52
May 1-2	49	June 20-July 4	50		
May 3-July 4	50	July 5-12	51-52		
July 5-12	51-52				

Overcrowding was avoided by releasing approximately one half the numbers of fry in each raceway at monthly intervals. Initially, in the most heavily populated raceways, there was approximately 1 lb of fry to 30 cu ft of water. As fish increased in size, the concentration was never allowed to exceed 1 lb per 15 cu ft of water. These values are much less than the density of 1 lb of fish per 1 cu ft of water often utilized in hatchery rearing of young salmonids (Burrows and Chenoweth, 1955), but were utilized in an attempt to obtain growth rates comparable to wild pink salmon fingerlings.

Diet of Stock Fish

Since young pink salmon were to be held and tested for as long as three months after emergence, one of the major tasks in this study was to find a suitable diet to ensure an approximately normal growth rate. Pink salmon fry feed primarily on zooplankton during estuarial residence, hence a natural diet was duplicated as closely as possible by supplying the experimental stocks exclusively with freshly caught or frozen marine plankton. The waters of Rosario Strait near the Bowman's Bay Laboratory proved to be rich in zooplankton during the months of this study and provided a generally adequate source of food except toward the end of the study (early July, 1966) when zooplankton became more difficult to obtain.

Fishing for plankton was done largely at night when catches were greater than during daylight hours. A cylindrical net, 16 ft long, with a rectangular 4 by 5 ft opening, was towed slowly through the water just beneath the surface. Depending upon the time of year and local plankton blooms, catches varied from less than 1 lb to about 10 lb during one night's fishing. The plankton catch was composed principally of calanoid copepods, larval forms of several other crustaceans and chaetognaths. A small part of the catch was fed to the fry during the next day while the remainder was fast-frozen in thin blocks. Fish were fed by introducing plankton at the upper end of each raceway and allowing the current to move it down the tank. Blocks of frozen plankton were broken into small pieces which floated on the surface of the raceways. Fry quickly gathered around these pieces and ate the plankton freed by the melting ice.

The quantity of plankton supplied each day was gauged largely by observing the manner and rate at which food was consumed and was approximately 20 per cent of the weight of the fry. When fry were small, they were fed hourly, but later the rate of feeding was reduced to about four times daily. The total amount of plankton supplied was increased continually throughout the holding period even though populations were reduced by one half at regular intervals.

TESTING FACILITIES AND METHODS

The gradient chamber used in the study of both temperature and salinity selection was an upright, rectangular box, measuring 32 in. square inside at the base and 8 ft in height. The chamber was filled to within 6 in. of the top and contained 425 U.S. gal of water. The bottom and three sides of the box were constructed of 1-in. plywood while the fourth side was made of 1-in. plexiglass so that the movement and position of fish could be observed. A sloping wire screen, used to direct fish to an outlet as the chamber was drained, formed a false bottom 1.5 ft from the floor of the tank.

To determine the effect of water depth on the distribution of fish in the temperature or salinity gradient, a second chamber was set up to serve as a control. The control chamber was the same size as the experimental tank except that a sloping plywood false bottom was located approximately 6 in. from the base of the chamber. In both tanks, wood surfaces were coated with clear plastic resin.

Both the experimental and control chambers were masked by black plastic sheeting so that movement of personnel would not disturb the fish. Fish were observed through a vertical slit in the plastic sheet located about 4 ft in front of the chambers and the viewing area was also kept dark. As a result of these precautions, fish never appeared to be disturbed during observation periods.

Each chamber was illuminated from the top by four 15-watt white fluorescent bulbs, 16 in. long. The effects of variations in lighting conditions were examined, but no difference in the distribution and behavior of the fish was noticed when the number of bulbs was reduced progressively from four to one. When the chamber was in total darkness, however, the school of fish ordinarily seen in the lighted chamber apparently dispersed since fish were observed to be at the same level in the gradient but more spread out horizontally when the light was first turned on. The school quickly formed again as soon as the chamber was light.

Between May 10 and June 3, 1966, water in the chamber was turbid due to coastal storms influencing the seawater intake, but how this may have influenced results is not known. Water was reported to have cleared by mid-June but became turbid again in early July.

Fry were fed approximately 1 hr prior to each experiment since preliminary testing had shown that unfed fish became disturbed after several hours in the chamber. In each experiment, 10 fry were placed in the experimental chamber and, in most cases, 10 fish from the same stock were also placed in the control chamber. Since all fry were released after testing, fish used in each experiment had no previous experience in the chamber.

Vertical Temperature Gradient

Apparatus

A vertical temperature gradient was established by supplying cold water at the bottom of the test chamber and progressively warming the water with a series of heating coils suspended within the chamber (FIGURE 2). Refrigerated water from 35° to 40°F and of any desired salinity was pumped in through a series of perforated 0.25-in. plastic pipes resting on the bottom of the chamber. A closed system of four U-shaped 0.5-in. stainless steel pipes, suspended inside the chamber from the top, carried hot water at about 105°F and served as heating coils. By adjusting these two water supplies it was possible to establish a thermal gradient with the coldest

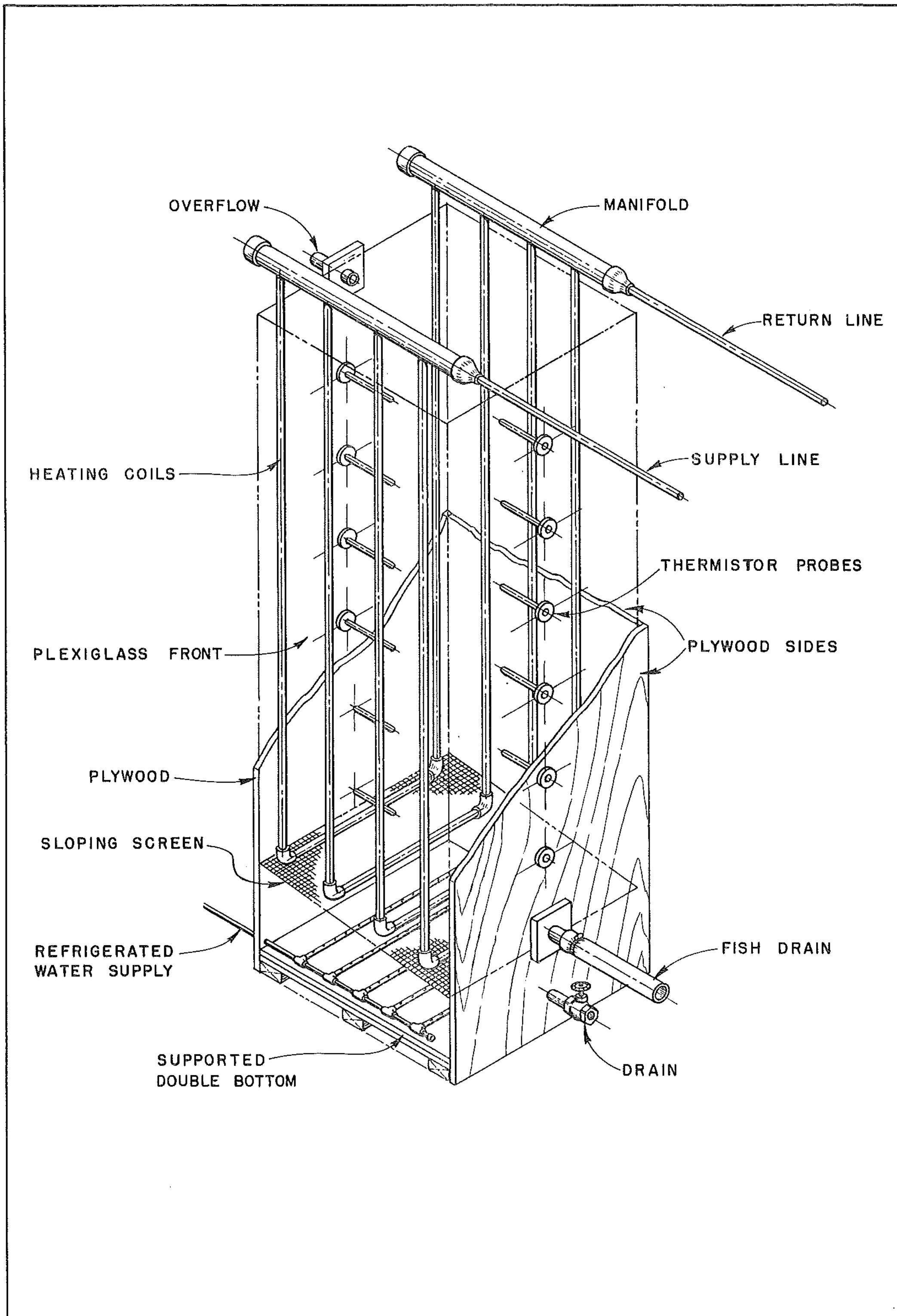

FIGURE 2 - Test chamber adapted for temperature gradient.

water at the bottom of the chamber and progressively warmer water at higher levels. The flow of cold water was maintained at approximately 0.5 U.S. gal per min and the excess water was drawn off at an outlet near the top of the chamber.

Temperatures within the gradient were measured with a series of thermistor probes inserted at 1-ft intervals through both side walls of the chamber. Those on one side were offset 6 in. from those on the other, so that the temperature of the whole water column was measured at 6-in. intervals. Probes were placed halfway between the front and back walls of the tank and extended approximately 7 in. into the chamber.

It was found that a uniform temperature could be maintained within a given horizontal plane except in the immediate vicinity of the heating coils. For a distance of 0.5 to 1 in. surrounding each hot water pipe, the temperature was considerably warmer than in the rest of the water layer. It was consistently observed, however, that fish avoided this restricted zone. Essentially no change in water temperature was recorded near the walls or plexiglass of the chamber.

Procedure

Before each temperature test, the chamber was filled with water of the same salinity as that in the raceway holding the sample of fry to be tested. Refrigerated water of the same salinity was pumped into the base of the chamber and hot water was supplied to the heating coils. During the subsequent 4 to 6 hr a thermal gradient was established in the chamber and testing usually began by early afternoon. Temperatures within the chamber ranged from approximately 40°F at the bottom to 62°F at the top, although these could be varied by adjusting the flow of hot and cold water. Since considerable variation was sometimes encountered in these values, temperatures were measured at 10-min intervals throughout each test.

Once the thermal gradient had been established, 10 pink salmon were placed in the chamber from the open top. Although this procedure exposed the fry momentarily to warm temperatures at the surface, the fish quickly scattered throughout the chamber. It was routinely observed that fry initially searched their new environment for a short time, then became concentrated at a particular level of the gradient within 1 hr. No difference in the average position of the fish was noted when observations began 1 to 4 hr after the fish entered the chamber and normally a 2-hr interval elapsed before observations were recorded.

The location of fish within the chamber was recorded at 5-min intervals for at least 1 hr. In most cases, recording was stopped for approximately 1 hr, during which time the temperature gradient warmed slightly. Observations were then continued for a further 15 min, at 5-min intervals, in order to examine the location of fish in relation to the new gradient. A total of 150 observations (10 fish, 15 observation periods) were usually recorded during each test. The number of observations in each vertical 3-in. segment of the chamber were recorded with reference to the temperature at the midpoint of that segment and the mean selected temperature calculated. Since temperatures were recorded only at 6-in. intervals, temperatures of intervening layers were estimated. Distribution of fish at each depth level was also plotted for comparison with that of fish in the control tank.

In the control chamber, the temperature depended on that of the main water supply which varied during the season from 49° to 53°F. Between the top and bottom of the control chamber, the variation in water temperature was never greater than 2°F and was usually less. Salinity was the same as that supplied to the experimental chamber and in almost every case sea water of approximately 30 ‰ was used. Ten fish were placed in the control chamber and observations were recorded for the same period and in the same manner as described above.

Vertical Salinity Gradient

Apparatus

To create a vertical salinity gradient, the chamber was adapted so that six layers of water, each of a different salinity, could be supplied to the chamber at successive depths from the bottom to the top. Any combination of salinities was possible, providing, of course, that the water of higher salt concentration was always below that of lesser concentrations, otherwise mixing would occur. Each salinity layer was pumped into the chamber through a separate diffuser or funnel attached to the back wall of the chamber (FIGURE 3). The diffusers, constructed of 0.25-in. plywood, were approximately 10.5 in. wide, 7 in. deep, projected 3 in. into the chamber and tapered slightly from top to bottom. An inlet near the bottom of each diffuser allowed water to first fill the diffuser, then overflow its relatively wide lip. The diffusers were located at 1-ft intervals with the lip of the lowest being 3 ft above the bottom of the chamber.

Procedure

Before filling the chamber, the various salinities were mixed in large tanks of approximately 90 U.S. gal capacity. The mixtures ordinarily prepared were 0, 20, 40, 60, 80 and 100 per cent concentrations of the seawater supply (29 to 31.5 $^{o}/oo$ salinity), but variations of these concentrations were also used. Because of the difference in temperature between the fresh and seawater supplies, the various salinities were mixed the day before the test and allowed to reach thermal equilibrium overnight.

The next day, a period of 2 to 3 hr was generally required to establish the vertical salinity gradient in the test chamber. The most concentrated solution was added to the bottom of the chamber until its level reached the lip ofthe first diffuser. The water was shut off and the next concentration was started into the chamber, slowly filling the diffuser first, then very slowly at the lip of the diffuser, allowing this concentration to spread in an even horizontal layer over the one below it.

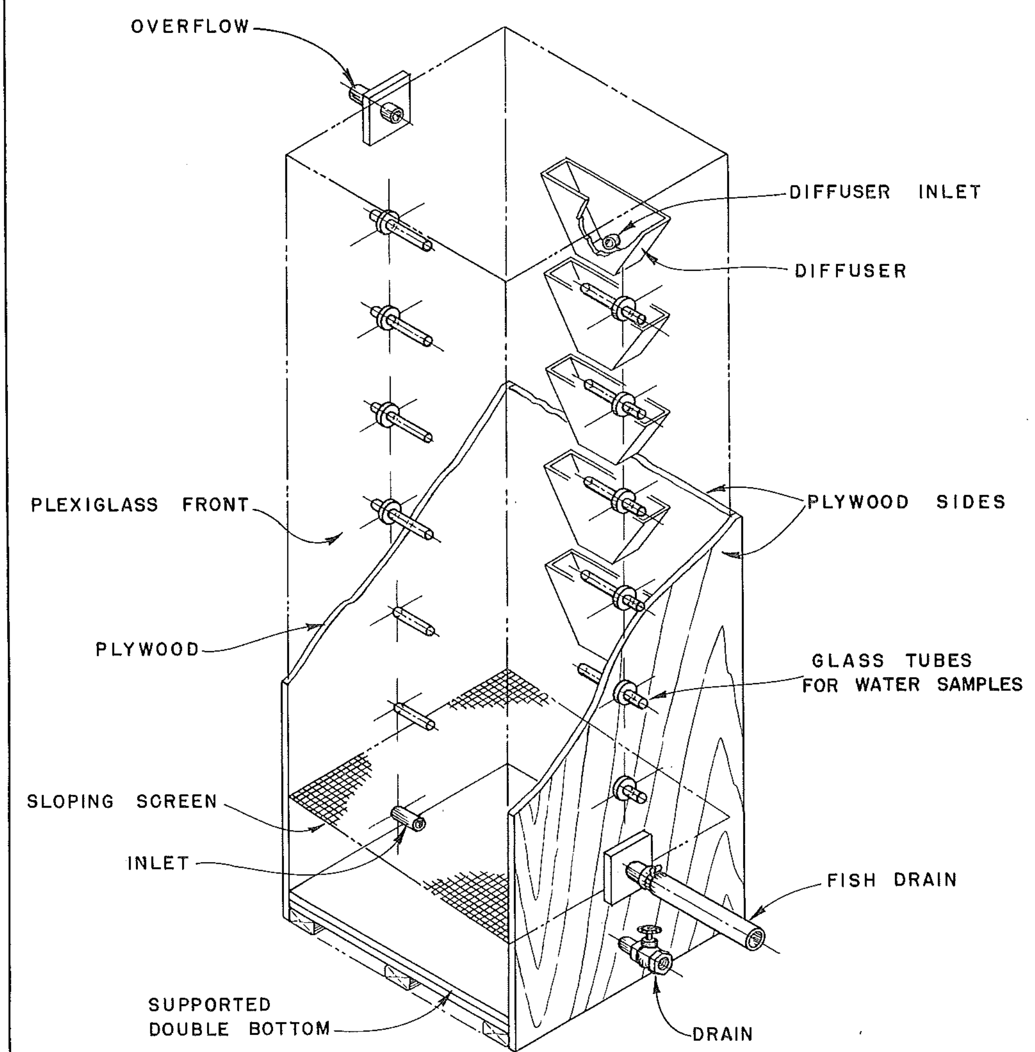

FIGURE 3 - Test chamber adapted for salinity gradient.

It was essential that no mixing occur at these boundaries and great care had to be exercised in this phase of the preparation. Filling continued until the layer reached the lip of the next diffuser above and each level in turn was filled with a different salinity.

After filling the chamber, the salinity of each layer was tested by drawing off water samples from fixed small-bore glass tubes inserted at 1-ft intervals down both sides of the chamber. The tubes on one side were offset 6 in. from those on the other side so that the entire column of water was sampled at 6-in. intervals. Thermistor probes inserted at the same locations recorded temperatures throughout the salinity gradient. Titrations by a modification of Mohr's silver nitrate method (Hoar, 1960) were made to determine salinity concentrations of samples withdrawn from the tank.

Once the salinity gradient had been established, 10 fish were taken from one of the raceways and placed in the chamber from the top. Initially, the fish quickly scattered throughout the entire chamber. Within an hour or less, the fry had explored the tank and became schooled in a region in which they remained. The vertical height of this region was quite shallow, usually from 12 to 18 in. When fish travelled either above or below this region there was usually an increase in their activity, especially in their rate of turning, and the return to the selected location was a well-directed movement.

Recording of observations was begun 1 to 2 hr after the fish had been placed in the chamber. Experiments were carried out at the same time each day, usually from 1 to 5 p.m. P.S.T. Several experiments run in evening hours indicated that the level of salinity selected by the fish did not change from afternoon to night. This agrees with the observations of Baggerman (1960) who found that pink salmon fry, although tested in a somewhat different apparatus, chose the same salinities in the morning, afternoon and night.

In 1965, observations of the location of fish w ere recorded every 15 min. during each experimental period. In 1966, observations were recorded every 5 min for a period of 1 hr and, after a period of approximately 1 hr, further observations were made for another 15 min. In each experiment, the total number of observations was usually 150 (10 fry, 15 observation periods). The distribution of these 150 observations with respect to the salinity within the chamber was determined for each test and the percentage distribution plotted.

The distribution of fry in the chamber was also recorded when there was no salinity gradient. In each case the chamber was filled with water of the same salinity as the fry had been exposed to in the holding raceway. Temperatures were similar throughout the control chamber and did not vary more than 2°F from top to bottom. Ten fry were placed in the chamber and observations of their distribution were recorded in the same manner as described for the experimental chamber.

Special Tests

Certain aspects of the vertical salinity gradient required examination before behavior of fish could be evaluated. First, it was necessary to test the stability of a vertical salinity gradient and determine whether it would remain constant throughout the test period. Secondly, it was possible that other factors such as oxygen concentration or temperature could influence distribution of fish during salinity tests.

Repeated tests showed that a single series of salinity determinations was sufficient to accurately describe the concentrations within the chamber during the 2- to 3-hr period required for testing. In fact, tests extending for 24 hr indicated that salinities did not change more than 2 ^{o}/oo at any level in the gradient.

Furthermore, movement of fry was found to cause very little disturbance of the salinity gradient, even at the end of the season when the largest fish (85 mm, 5.0 gm) were tested (FIGURE 4). Even at locations where fry

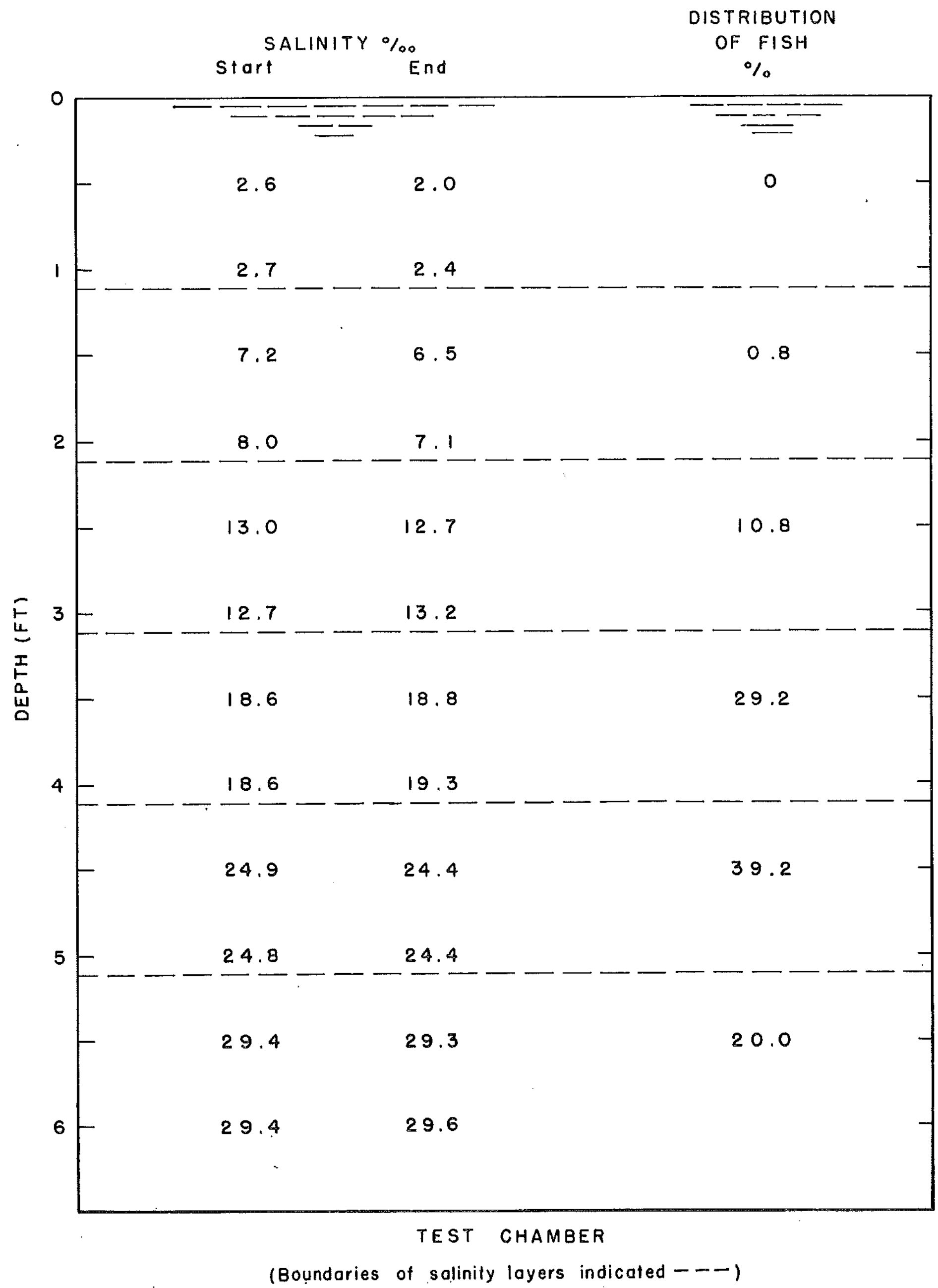

FIGURE 4 - Change in salinity gradient recorded during 2-hr test of 10 pink salmon (mean length 85 mm; mean weight 5.0 gm) on June 24, 1965.

were observed most frequently there was no greater disturbance of the gradient than in other levels of the chamber. Similar results were recorded on several occasions and it was concluded that the vertical salinity gradient was sufficiently stable to remain constant throughout each test period.

In contrast to the tests in a temperature gradient, there was no exchange of water during salinity tests, and it was possible that the dissolved oxygen (DO) at different levels in the chamber could have been utilized by fry to the extent that it would influence their distribution. Although the large volume of water would theoretically have eliminated this possibility, a few experiments were conducted in which the DO at various levels in the chamber was measured prior to and following a routine salinity test.

Results of two of these experiments confirmed that DO remained adequate in all levels of the chamber throughout the test period. As these tests were carried out using relatively large pink salmon fry (63 to 65 mm, 2.2 gm), the amount of DO utilized would have been maximal. However, the greatest depletion was only from 94.0 to 83.5 per cent, recorded following a 4-hr test period at one level in the chamber in which 76 per cent of the fry had been observed. In no location was the DO found to be less than 80 per cent of saturation and was never less than 7.1 ppm. Whitmore, Warren and Doudoroff (1960) examined the behavior of juvenile chinook salmon in water of low DO and found no avoidance of oxygen concentrations above 6.0 ppm. On the basis of these data for another salmonid, it would appear that concentrations of DO in the present experiments were always adequate and did not influence the distribution of pink salmon in the chamber. Measurements of DO concentrations were not considered necessary during temperature tests, since water was continually added to the chamber during these tests unlike the static water in the salinity gradient.

Within the salinity gradient, the temperature of the water was kept as close to a constant value as possible throughout the chamber. However, differences in temperature between the fresh and seawater supplies were responsible for slight temperature differences between the various salinity mixtures. In April, the difference in temperature between fresh water and sea water was only 3°F, but in May this increased to almost 10°F. The fact that the various concentrations of sea water were mixed about 24 hr prior to a test provided almost identical temperatures throughout the chamber in April, but this was not possible later in the season. In April, temperature differences between the top and bottom of the chamber did not exceed 1°F and the entire column averaged 50° to 52°F. During May, differences of about 3°F were encountered between the top and bottom of the chamber and the temperature of the water column averaged 55°F. Temperatures in the salinity gradient were warmer by mid-June varying approximately 4°F between the top and bottom of the chamber and averaging nearly 59°F, but testing was essentially over by this time.

GROWTH OF EXPERIMENTAL STOCKS

Pink salmon fry were sampled and measured at regular intervals to compare growth and condition of the various experimental stocks, to relate size to the results observed during tests in the gradients, and to compare the growth rate and condition of experimental stocks with wild pink salmon fry.

Samples of 15 to 20 pink salmon fry were consistently taken with an 18-in. dip net from the middle of the school as it moved down the raceway. Each stock was sampled twice weekly during most of the 1966 study period for growth measurements. In 1965 similar samples were obtained at one- to two-week intervals. In both years, fish were preserved in 10 per cent formalin, and weights and lengths were recorded between one and two weeks after sampling. Fry were blotted dry to remove excess formalin and weighed individually on a Mettler Gram-atic balance to within 1 mgm. Lengths were measured from the tip of the snout to the fork of the tail (fork length) using steel calipers to within 0.1 mm. Average lengths and weights were then calculated for each stock from samples obtained during approximately

10-day intervals throughout the holding period. Fish withdrawn from stocks for tests in the temperature and salinity gradients were not measured, but average size of each test group was estimated from growth rates of the above samples.

Growth in Sea Water

In 1965, pink salmon fry from Atnarko River incubated at the Sweltzer Creek Station were held continuously in sea water from April 1 until June 23, a period of 87 days. During this period, fry increased from approximately 37 mm in length to 84 mm and from 0.3 gm to 4.5 gm (TABLE 5). In 1966, fry from Sweltzer Creek channel were held in a similar environment and attained a length of 57 mm and a weight of approximately 1.6 gm by the end of the 35-day holding period.

In both years, growth rates appeared similar (FIGURE 5) and the increase in size averaged approximately 0.6 mm and 0.04 to 0.05 gm per day during the holding period.

Growth in Fresh Water

In 1965, pink salmon fry from Bear Creek (incubated at Robertson Creek channel) were held in fresh water from April 20 until heavy mortalities occurred in late May. For the first four weeks of the holding period (until mid-May) growth appeared relatively good, and fish increased in length from 37.5 mm to 52 mm and from 0.4 gm to 1.1 gm in weight (TABLE 6 and FIGURE 5). The final samples of fry from this stock, five weeks after emergence, were dead and dying fish.

In 1966, Sweltzer Creek pink salmon fry were placed in fresh water on May 4 but heavy mortalities occurred by mid-May. Very little growth was recorded in this stock during the brief holding period (TABLE 6).

Growth in Increasing Salinities

In 1966, three groups of pink salmon representative of early, peak and late emerging fry from the Sweltzer Creek channel were held in gradually increasing salinities.

TABLE 5 - Length and weight measurements of two stocks of pink salmon fry reared continuously in sea water (29-31 $^{o}/oo$ salinity), 1965 and 1966.

Stock	Date Sampled	Mean No. Days After Emergence	No. Fry Sampled	Average Fork Length mm	Average Weight gm
Atnarko R. 1965	Apr. 1-7	3	38	36.5	0.28
	Apr.27-May 5	30	40	56.2	1.30
	May 12-19	44.5	36	63.5	2.02
	May 26-June 3	59	23	72.9	3.42
	June 16-23	79.5	14	83.8	4.52
Sweltzer Cr. 1966	May 5-9	3	24	36.5	0.30
	May 16	12	20	40.9	0.47
	May 23-30	22.5	30	48.2	0.89
	June 7-9	35	35	57.2	1.56

TABLE 6 - Length and weight measurements of two stocks of pink salmon fry reared continuously in fresh water, 1965 and 1966.

Stock	Date Sampled	Mean No. Days After Emergence	No. Fry Sampled	Average Fork Length mm	Average Weight gm
Bear Cr. 1965	Apr. 25	5	40	37.5	0.36
	May 7	17	34	44.5	0.69
	May 13-19	26	40	52.2	1.12
	May 25	35	12	57.3	1.42
Sweltzer Cr. 1966	May 5-9	3	21	35.9	0.27
	May 16	12	14	37.6	0.34

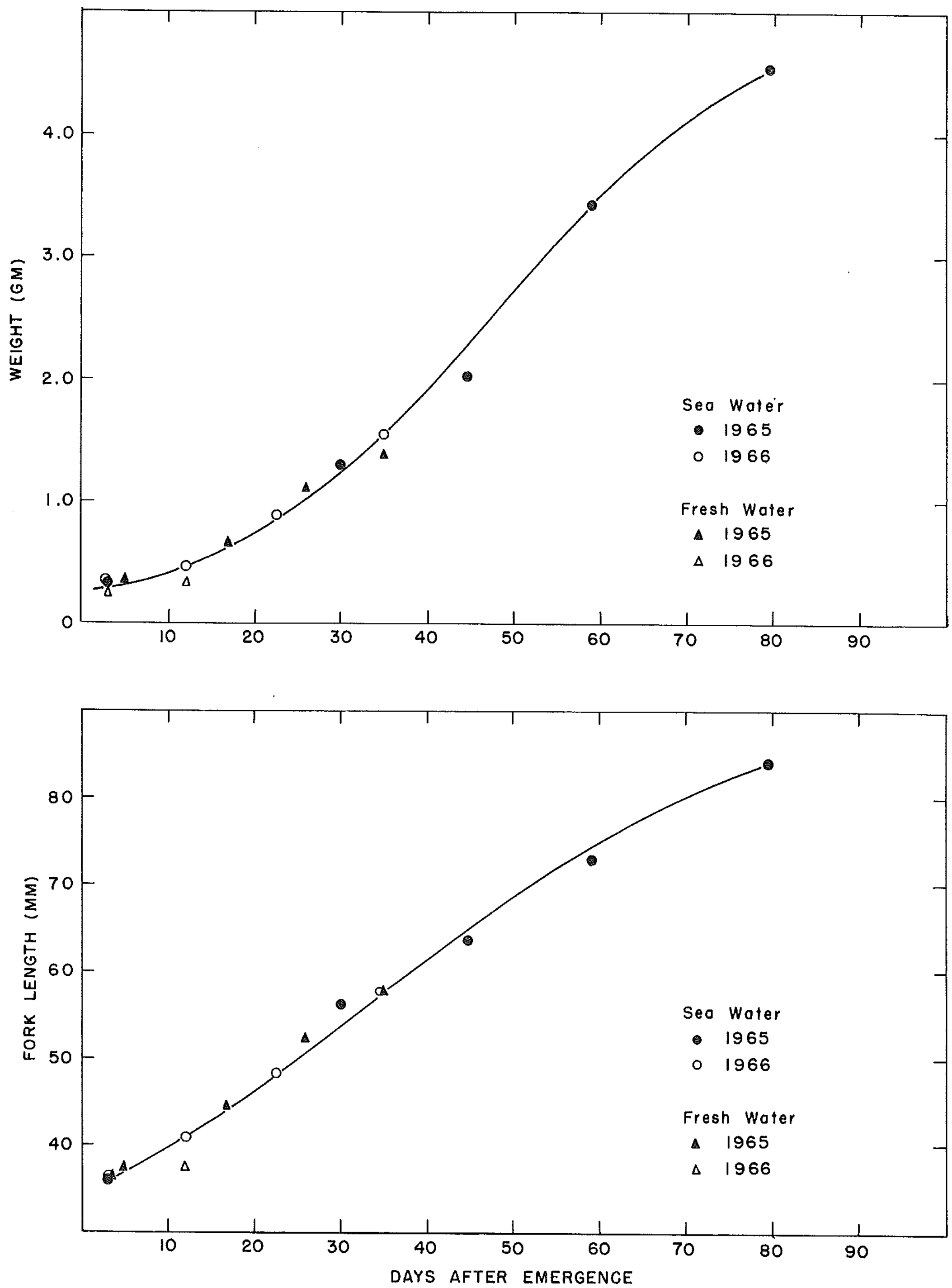

FIGURE 5 - Growth of pink salmon fry held continuously in sea water (29 to 31 $^{o}/oo$) and in fresh water, 1965 and 1966.

Average lengths and weights of samples from these three stocks are shown in TABLE 7. Initially, newly emerged early and peak stocks of fry averaged approximately 35 mm in length and weighed 0.3 gm. The late stock included a few larger fry which had remained to feed in the channel for a few days following emergence, prior to the date the stock was obtained at the channel outlet. Lengths of the late group ranged from 31 to 45 mm, in contrast to early and peak fry which varied between 31 and 38 mm in length. It is estimated from length distributions of the samples taken that larger fry formed at least 15 per cent of the late stock.

Early fry reached an average size of 83 mm and 4.5 gm when the experiment terminated after 87 days of holding. After 70 days, the peak stock reached 76 mm and 3.6 gm. The late stock grew to an average of 71 mm and 3.2 gm after 59 days in the holding area.

Growth rates of the three stocks of fry were examined in relation to date and to number of days after emergence, and were found to be essentially similar in both length (FIGURE 6) and weight (FIGURE 7). Toward the end of the holding period growth rates appeared to decline somewhat, possibly brought about by the reduction in food supplied when zooplankton became less available. However, prior to this decline, the rate of growth was approximately 0.6 mm and 0.05 gm per day and was very similar to the growth rate recorded in sea water in 1965.

Comparison with Wild Fry

Results of this investigation are to be used in the consideration of factors affecting the distribution and survival of pink salmon fry after they leave the Fraser River. It is therefore necessary to compare the experimentally raised fish with those fry found in the wild state. Any significant deviation in growth rate or condition between the two groups of fish would reduce the applicability of the experimental results to the natural populations.

TABLE 7 - Length and weight measurements of three stocks of Sweltzer Creek pink salmon fry held in increasing salinities, 1966.

Stock	Date Sampled	Mean No. Days After Emergence	No. Fry Sampled	Average Fork Length mm	Average Weight gm
Early	April 15-21	4	60	35.3	0.29
	April 25-May 2	14.5	60	42.0	0.55
	May 5-13	25	60	49.9	1.01
	May 16-23	35.5	55	56.5	1.50
	May 26-June 7	48	60	64.1	2.22
	June 9-17	60	59	69.8	3.03
	June 20-27	70.5	57	76.0	3.76
	July 10	87	(20)	(83.0)	(4.51)
Peak	May 4-9	3.5	60	35.5	0.26
	May 13-19	13	59	42.5	0.59
	May 23-June 2	25	65	50.4	1.00
	June 7-17	40	74	59.1	1.81
	June 20-27	51.5	60	67.6	2.63
	July 12	70	(14)	(75.7)	(3.64)
Late	May 13-19	3	55	36.7	0.34
	May 23-30	13.5	45	42.6	0.61
	June 3-9	24	50	50.7	1.06
	June 13-20	34.5	60	58.9	1.80
	June 23-27	43	40	64.5	2.30
	July 11	59	(14)	(71.4)	(3.15)

( ) Small samples, held on reduced feed from July 1-12.

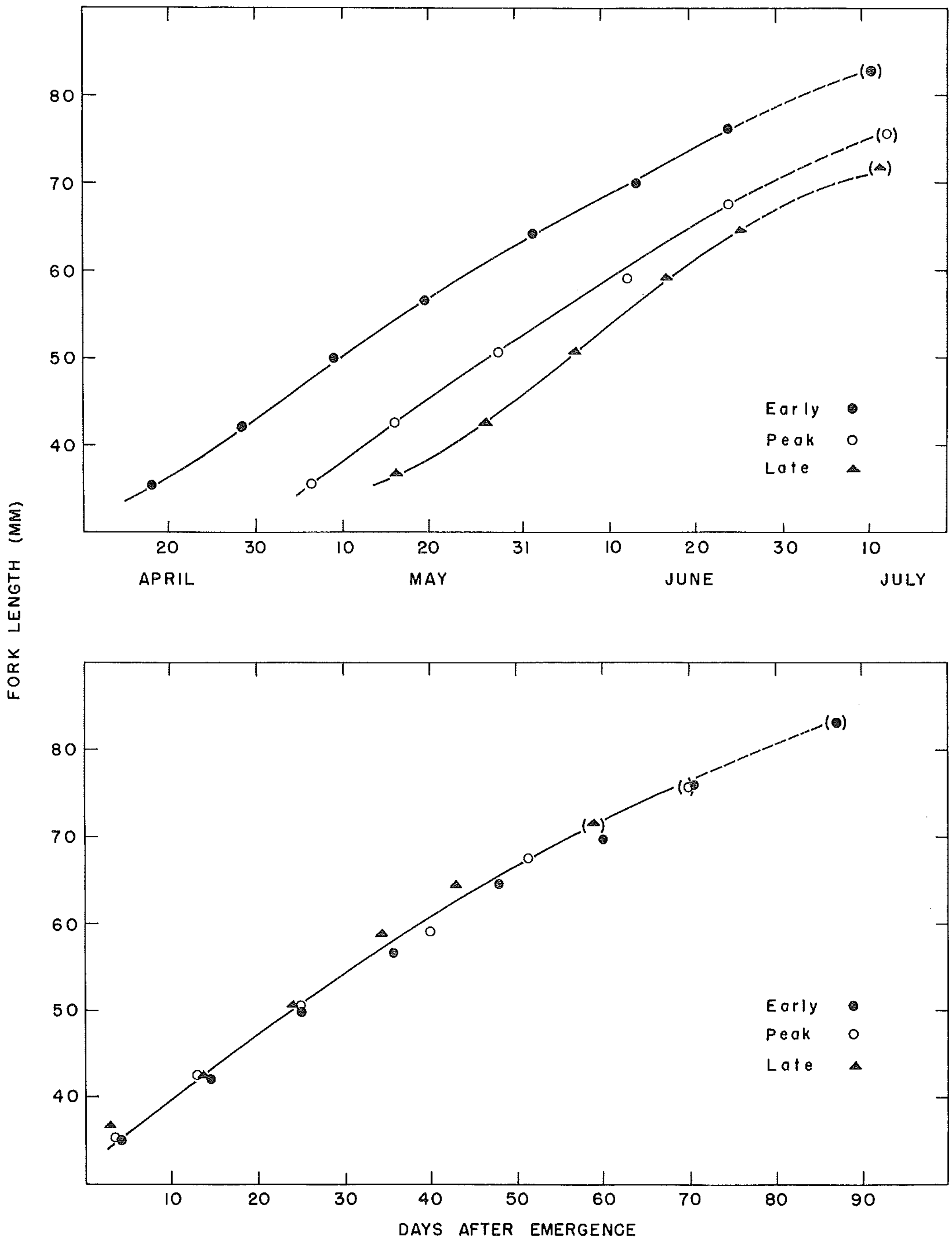

FIGURE 6 - Growth in length of pink salmon fry from three segments of emergence held in increasing salinities, 1966. Final sample of each stock held on reduced diet after July 1.

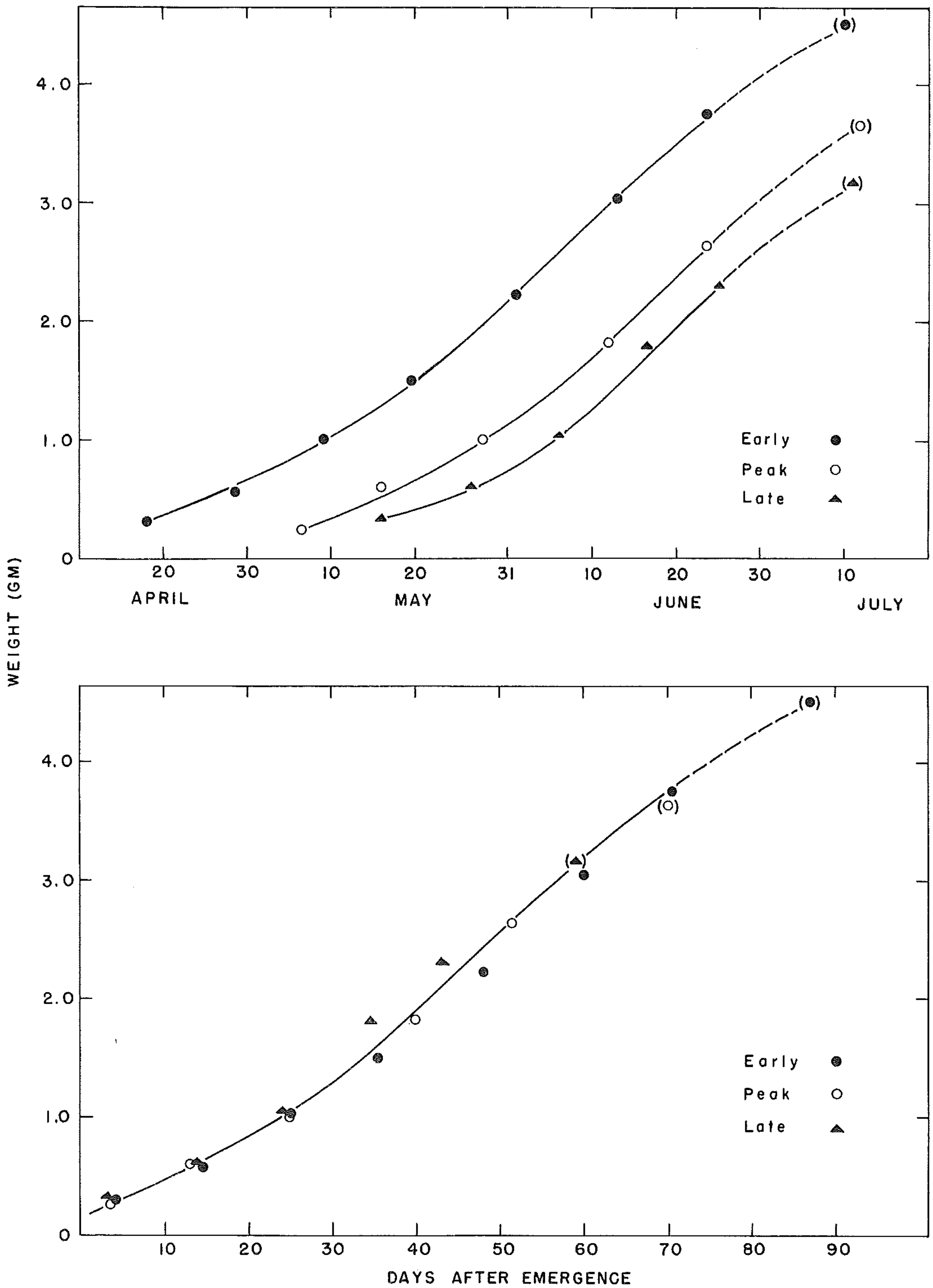

FIGURE 7 - Growth in weight of pink salmon fry from three segments of emergence held in increasing salinities, 1966. Final sample of each stock held on reduced diet after July 1.

In the Fraser system, seaward migration of newly emerged pink salmon fry occurs between March 24 and May 20, as determined at Mission, 50 miles upstream from the Fraser River mouth (Vernon, 1966). The fry passing this point average 32 to 35 mm in fork length. Within days after the migration begins, small schools of pink salmon fry may be observed in shallow areas near the rocky shores of the Gulf and San Juan Islands at distances ranging from 5 to 30 miles from the mouth of the Fraser River. Samples from these schools yield average fork lengths and variances comparable to newly emerged fry sampled at Mission.

As part of its overall investigation into the biology of the pink salmon, the Commission has conducted extensive sampling in the Gulf and San Juan Islands during the period of pink salmon fry abundance. With the aid of samples taken in 1966 by the Fisheries Research Institute, the period of coverage extends from April to September. Average fork lengths of the fry sampled are presented in FIGURE 8 where each point represents a sample of at least 45 fish (average sample size of 125). The continued arrival of small fish to both the Gulf and San Juan Islands is demonstrated by the low average fork lengths from samples well into May. The occasional capture of larger fish during this period indicates that growth is occurring, but the low mean lengths indicate that very few of the larger fish are incorporated into the sample. Field observations indicate that the larger fish move offshore and the inshore area is replenished with new arrivals. By late May, associated with the end of downstream migration, samples indicate a general increase in fork length.

Because of the extended period of arrival of new fry and the lack of knowledge concerning the degree of mixing of early and late arrivals, precise determination of a population growth rate does not appear practical. However, a line representing an increase in fork length of 1 mm/day has been presented in FIGURE 8 for purposes of illustration. Considering the variability of the data, the agreement of the data with the line appears reasonable. More detailed analysis of observations made by field personnel

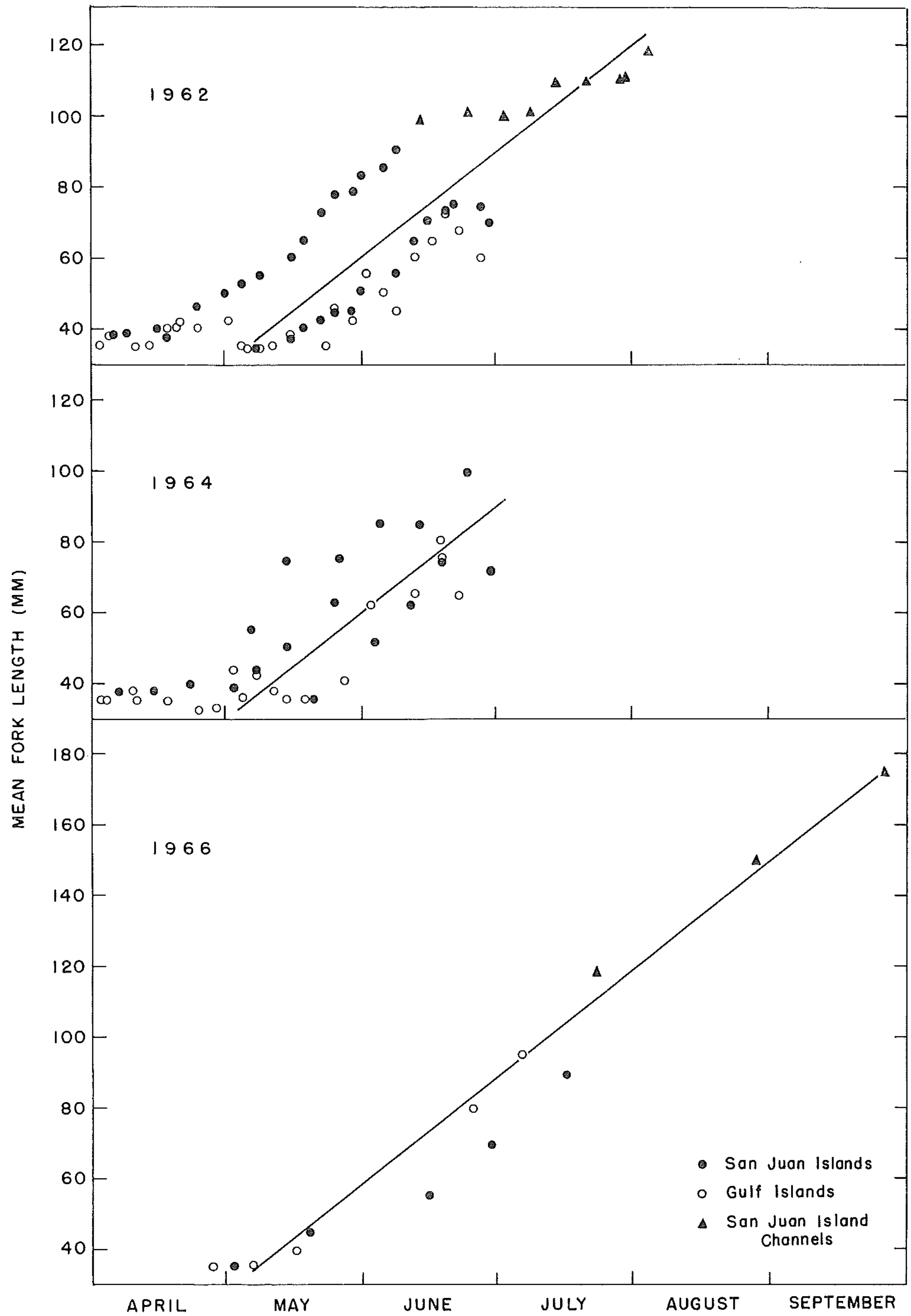

FIGURE 8 - Average fork lengths of pink salmon fry sampled in the San Juan and Gulf Islands, 1962, 1964 and 1966. (Samples from San Juan Island channels in 1966 courtesy of the Fisheries Research Institute, University of Washington.)

during the sampling operations, as well as reports of the changing abundance of fry moving downstream past Mission, provide estimates for shorter periods of time ranging from 0.7 to 1.2 mm/day. These values are comparable to the 0.87 mm/ day derived from the data of LeBrasseur and Parker (1964) for the first 30 days of estuarial growth of Bella Coola pink salmon fry.

The data presented above would seem to indicate that the growth rate of the experimental stocks, 0.6 mm/day, is lower than that estimated for the wild stocks. This difference may be more apparent than real. The growth rate of experimental fish was measured from the time of emergence, while that of the wild stocks was determined after fry had reached the offshore islands, at an undetermined time after emergence. The lower growth rate of the experimental fish during the first week would tend to lower the average rate over the entire period. Whatever the cause, this period of slow growth demonstrates the variability of growth under various conditions, and might in fact be a natural occurrence in the first weeks of marine life for wild stocks.

Condition of experimental stocks was also examined by comparing the length-weight relationships of experimental fish with wild pink salmon fry. This method of examination allows comparisons between groups of fish without regard to age.

Regression equations calculated for each of the experimental stocks indicated considerable variability in slope between fry held in fresh and sea water in 1965 and 1966 (TABLE 8). The relatively few samples in these groups may be responsible for the variation. For the groups of fry held in increasing salinity, however, length-weight relationships were similar. Slopes of these equations ranged from 3.21 to 3.27 and were almost identical to the values of 3.10 to 3.25 calculated for wild pink salmon fry captured in the San Juan Islands (TABLE 8 and FIGURE 9).

It has been concluded that the growth rate of fry held experimentally may have been less than that of wild fish but that their condition, as indicated by length-weight relationships, compared favorably with wild fry. In general, results obtained from these experimental stocks should be applicable to wild stocks.

TABLE 8 - Length-weight regressions of experimental and wild stocks of pink salmon fry based on sample means, where X = length in mm and Y = weight in grams.

Stock and Date of Emergence	No. Samples	Regression Equation
EXPERIMENTAL STOCKS IN SEA WATER		
Atnarko River April 1, 1965	9	Log Y = 2.9887 Log X -5.0771
Sweltzer Creek May 4, 1966	5	Log Y = 3.5525 Log X -6.0460
EXPERIMENTAL STOCKS IN FRESH WATER		
Bear Creek April 20, 1965	4	Log Y = 2.7712 Log X -4.7191
EXPERIMENTAL STOCKS IN INCREASING SALINITY		
Sweltzer Creek April 14, 1966	20	Log Y = 3.2441 Log X -5.4837
Sweltzer Creek May 3, 1966	15	Log Y = 3.2719 Log X -5.5652
Sweltzer Creek May 13, 1966	12	Log Y = 3.2089 Log X -5.4401
Three Groups Combined	47	Log Y = 3.2203 Log X -5.4721
WILD STOCKS		
San Juan Islands, 1962	27	Log Y = 3.1787 Log X -5.3064
San Juan Islands, 1964	13	Log Y = 3.2267 Log X -5.4620
San Juan Islands, 1966	5	Log Y = 3.1015 Log X -5.2006
Three Years Combined	45	Log Y = 3.1703 Log X -5.3469

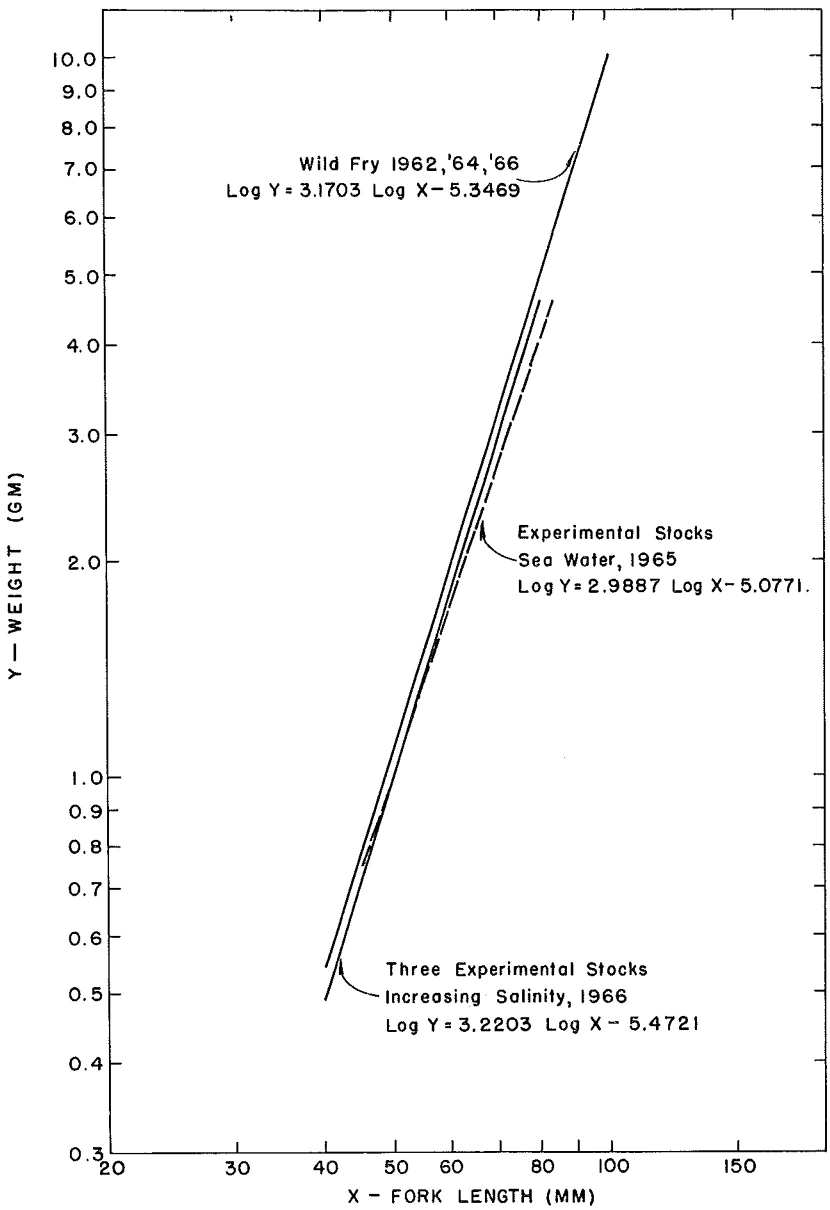

FIGURE 9 - Length-weight regressions of experimental stocks compared with wild pink salmon fry captured in the San Juan Islands.

BEHAVIOR OF PINK SALMON FRY IN A VERTICAL TEMPERATURE GRADIENT

Poikilothermic animals when exposed to a gradient of temperatures select a particular narrow range of thermal environment and spend most of their time in this region. The mean temperature of this region has been called the selected or preferred temperature. Brett (1952) studied young fish (40 to 50 mm long) of the genus Oncorhynchus in fresh water and found the region of greatest preference lay in the 12° to 14°C (53.6° to 57.2°F) stratum.

Presumably the preferred temperature is related to some average optimum level of physiological condition for growth and activity at the time and thus may influence survival of the fish. Martin (1966) noted different growth rates among pink salmon fry held at different constant temperatures. Vernon (1958) found an apparent inverse correlation between seawater temperature in the estuarial life of the pink salmon and their subsequent abundance as adults. Thus it appears that some optimum temperature for growth and, ultimately, survival may exist during this phase of the life cycle.

In an experimental temperature gradient, young pink salmon should select the temperature most suitable to their requirements which should, in turn, be the temperature they would select in the natural environment. In the present experiments, fry from three segments of emergence were tested to examine their behavior in a temperature gradient at frequent intervals during their first three months after emergence.

Temperature Selection by Fry from Three Segments of Emergence

Early, peak and late emerging fry from the Sweltzer Creek channel were tested in temperature gradients between April 19 and July 12, 1966. The gradients provided ranged from approximately 60°F at 0.5 ft below the surface to 36°F at the 5.5 ft level. A variety of gradients were tested during the season (TABLE 9) and the effects of these different gradients will be

TABLE 9 - Average temperature at upper and lower levels of gradient throughout each test period - early, peak and late stocks of pink salmon fry, 1966. All tests carried out in sea water of approximately 30 °/oo salinity except where noted.

STOCK	DATE TESTED	MEAN TEMPERATURE (°F) AT:		
		Surface	0.5 ft	5.5 ft
Early	April 19*	-	60.0	48.6
	May 4	62.9	54.9	43.2
	10	61.2	56.6	46.9
	23	62.6	57.2	45.4
	27	59.7	56.3	45.6
	June 7	58.1	55.7	42.9
	24	57.8	55.9	40.1
	July 10	62.3	59.3	41.2
Peak	May 12**	62.8	59.0	44.5
	20	58.1	56.4	43.6
	25	60.3	56.8	46.3
	28	63.1	56.8	48.2
	31	60.1	47.1	44.7
	June 6	60.7	59.4	50.2
	13	-	59.4	53.7
	23	53.8	52.0	36.1
	July 12	59.4	57.3	42.5
Late	June 2	61.7	58.5	45.2
	10	62.1	58.5	45.7
	24	55.6	53.5	45.1
	July 11	56.9	55.8	39.6

* April 19 - 12.4 °/oo salinity.

** May 12 - 24.4 °/oo salinity.

discussed in more detail later. All but two tests (see TABLE 9) were carried out using sea water of approximately 30 ‰ salinity.

Several sharp changes in the level of temperature selected in the gradient were noted for the early fry obtained from the channel on April 14. Initially, a large drop in selected temperature from 55.7° to 51.2°F occurred in the interval between April 19 and May 4 (FIGURE 10). In subsequent tests, the average temperature selected varied from 49.2° to 53.2°F, but a general downward trend was evident during the period from May to July.

Peak fry were taken from fresh water on May 3 and tested in a temperature gradient on several occasions during May, June and July. As seen in FIGURE 10, these fry behaved in a relatively uniform manner during tests in May and early June. From May 12 to May 31, the temperature selected in the gradient varied between 53.3° and 52.6°F. In early June, fry were located in slightly warmer temperatures from 54.2° to 54.8°F. Between June 13 and June 23 the temperature selected changed sharply to 48.7°F, a drop of 5.5°F, but in the last test on July 12, fish were again located in a somewhat warmer temperature level (50.6°F).

Late emerging fry obtained on May 13 also underwent a marked and progressive fall in selected temperature as the season progressed. From the first test on June 2 until the final test on July 11 the average temperature selected in the gradient dropped from 54.8° to 49.7°F (FIGURE 10).

In general, all three groups of fry initially selected temperatures from about 53° to 56°F and later selected temperatures from about 49° to 51°F. The general downward trend in the level of selected temperature was observed in all stocks but was most evident in the peak and late groups.

Effect of Holding Temperatures

Temperatures in raceways holding the three groups of experimental fry were determined by the temperature of the water supply and varied from 48° to 55°F during the season (FIGURE 10). In most cases, tests in the

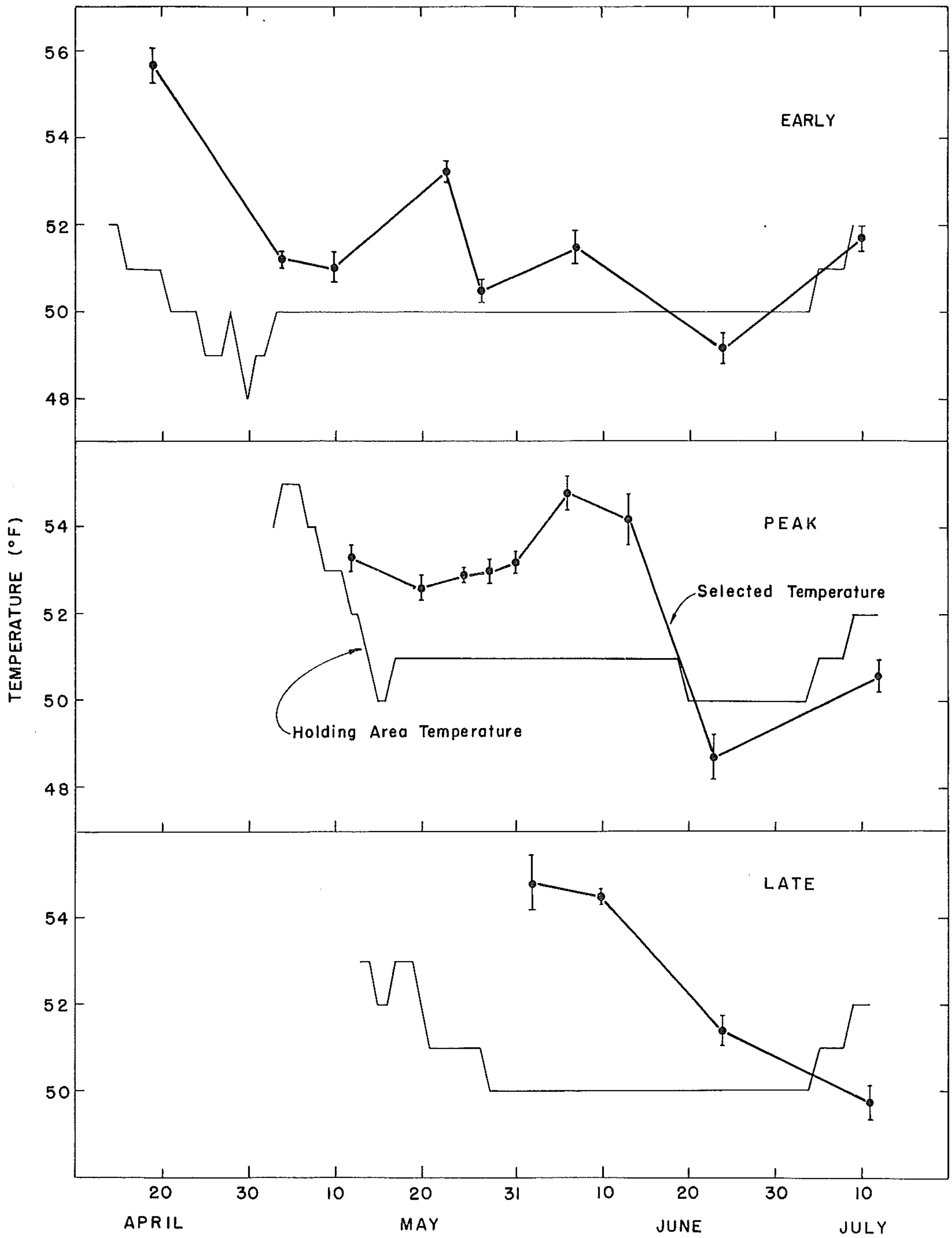

FIGURE 10 - Average temperatures (± SEM) selected by early, peak and late fry in a temperature gradient, 1966.

temperature gradient indicated that fry selected temperatures 3° or 4°F above the holding temperature. The fact that fry were held at one temperature and selected a different temperature in the gradient seems to be well established by these results. However, the selected temperatures tended to approach the holding temperatures toward the end of the season. Relatively little data are availàble concerning the effect of acclimation temperature on temperature selection by pink salmon. Brett (1952) observed that pink salmon fry held for three weeks at 50°F selected a temperature of about 52°F indicating that acclimation did not cause fry to select a temperature to coincide with the acclimation temperature. However, at higher acclimation temperatures, some upward shift in selected temperature occurred. In the present experiments, some of the downward change in selected temperature could have resulted from the low holding temperature, however, the relatively long period of time before any change was noted, especially in the case of peak migrants, argues against acclimation being the major controlling factor.

Effect of Time of Emergence and Size

The effect of time after emergence on the level of temperature selected in the gradient was examined for all three groups of fry, using as a common basis the number of days after emergence (FIGURE 11). From these curves it appeared that the selected temperature declined at approximately the same time among each group of fry, between 30 and 40 days after emergence. The early fry, as noted above, were more variable in their response than the later groups. Temperatures selected by peak fry dropped rapidly approximately 40 days after emergence; late fry showed a more gradual decrease in selected temperature that began 30 days after emergence.

This drop in selected temperature occurred in peak and late stocks when fry reached a length of approximately 54 to 60 mm and weighed from 1.3 to 2.3 gm. The variability in response of early fry obscured the particular size at which a definite drop in selected temperature occurred.

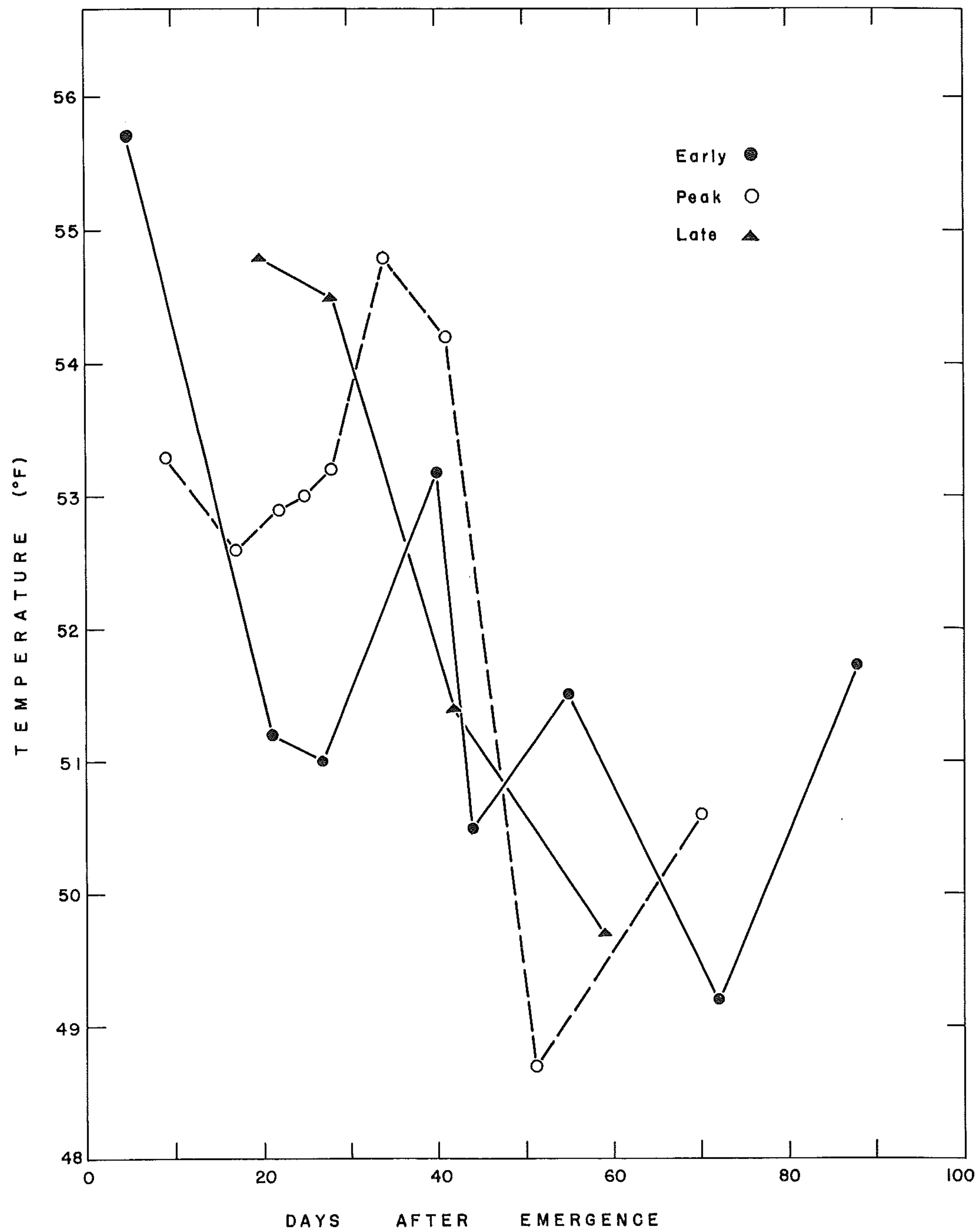

FIGURE 11 - Average temperatures selected by early, peak and late fry in a temperature gradient in relation to number of days after emergence.

Effect of the Vertical Gradient on Results of Temperature Tests

Tests in a Uniform Temperature

Numerous tests were conducted in which the distribution of fry in a uniform temperature was compared with fry distribution in a temperature gradient. Early fry tested on April 15 within one day of emergence tended to remain in the middle of the chamber when no gradient was present (FIGURE 12). In a temperature gradient, as on April 19, there was a tendency for fry to become somewhat more concentrated near the middle of the tank at a temperature of approximately 56°F. In later tests, fry remained near the bottom when no gradient was present but moved off the bottom of the chamber in response to a temperature gradient.

Similarly, fry from the peak and end of emergence tended to remain close to the bottom of the chamber in a uniform temperature but moved up toward the middle of the chamber in response to a temperature gradient (FIGURE 12). In almost every case, the distribution of fry in the presence of a temperature gradient differed from that observed in the control chamber. In addition, the location of fry changed from test to test in relation to the different temperature gradients.

From these tests, it was concluded that the presence of a temperature gradient caused a shift in the location of fry compared with their distribution in the control chamber under uniform temperature conditions.

Tests in a Moving Gradient

On several occasions, the temperature gradient was moved either up or down the chamber during a test period and the response of fry recorded. Several tests showed that fry moved to follow the changing level of temperature. A test on May 4 using the early group of fry showed this response. In the first series of observations, most fry were located

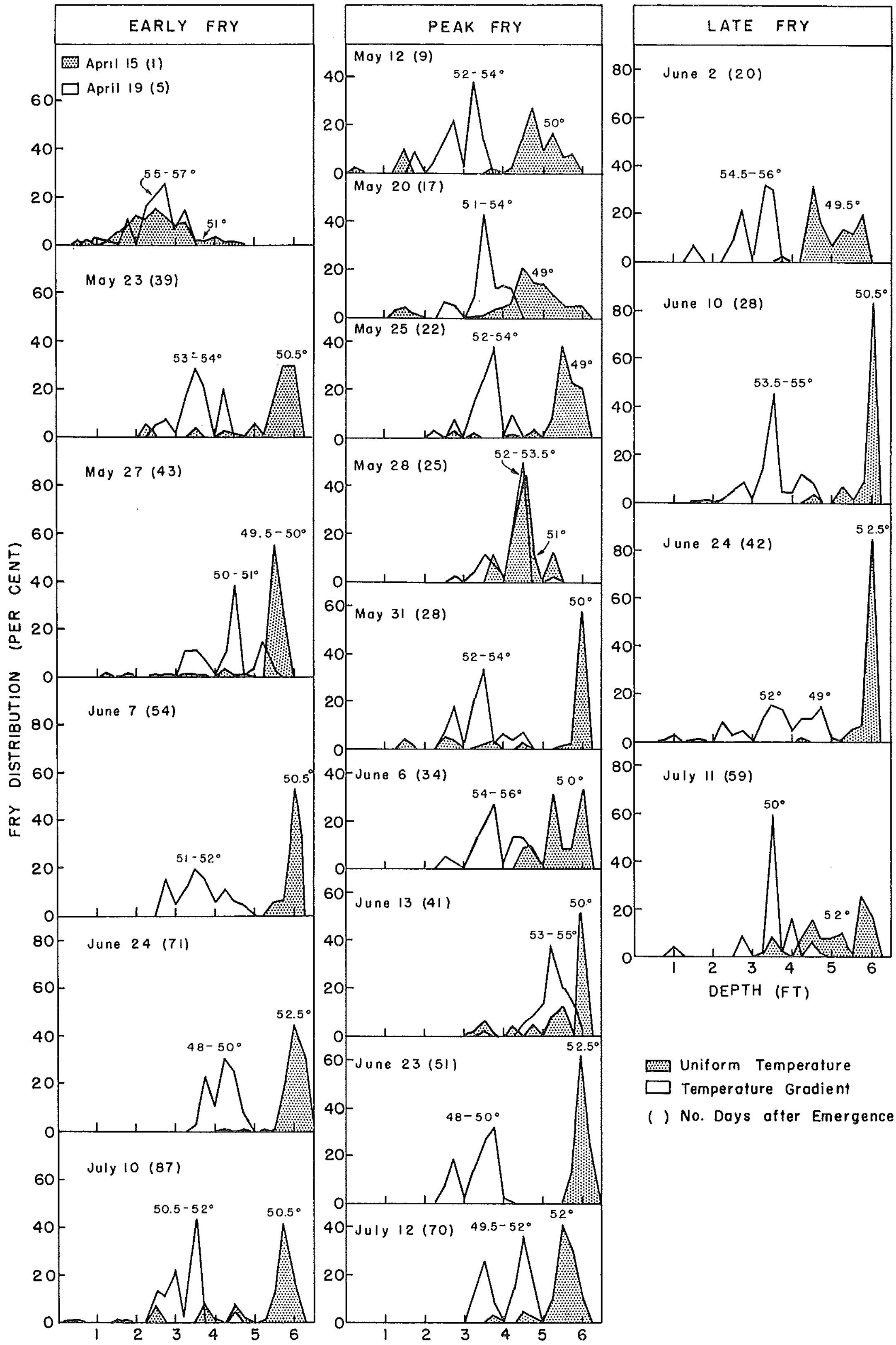

FIGURE 12 - Distribution of fry in a control tank with uniform temperature and in a temperature gradient - early, peak and late stocks, 1966. Temperatures (°F) throughout control tank and in gradient (for peak numbers of fry only) shown for each test.

at a depth of 2.5 ft where the temperature was approximately 51.5°F. Later in the same day, the entire gradient was warmed and 51.5°F was shifted to a depth of 3.5 ft. Fry appeared to follow this temperature level and most were later observed at the 3.5 ft depth. Similar shifts in distribution of fry were observed on numerous occasions. In general, fry moved deeper in the chamber as the temperature gradient warmed and selected approximately the same temperature in a new location.

The location of fry within the chamber also changed when the gradient was allowed to cool during the test period. When fry from the peak of emergence were tested on June 23, the majority were observed at the 3.5 ft level, at a temperature of 48.7°F. When the gradient was cooled, fry followed the change and were again found at this temperature at the 2.5 ft level.

It should be noted that the temperature of 48.7°F selected by peak fry in the test on June 23 (FIGURE 10) occurred within a relatively cold gradient of 36° to 54°F (TABLE 9) and dropped sharply from the 54.2°F temperature selected during the previous test in a warmer (54° to 59°F) gradient on June 13, indicating that the colder gradient influenced test results. A subsequent test on July 12 in an intermediate gradient (43° to 59°F) indicated that the level of temperature selected increased slightly to approximately 51°F. Therefore, although there was evidence of a general downward trend in selected temperature as the season progressed, the sharp drop noted between June 13 and June 23 was evidently exaggerated because of the change in gradients.

It was concluded that, in general, fry responded to a changing temperature gradient by moving up or down the chamber to select the same temperature at a new depth. However, an extreme change in gradient between tests apparently influenced temperature selection on one occasion when fry moved into a cooler temperature level rather than remain too close to the surface.

BEHAVIOR OF PINK SALMON FRY IN A VERTICAL SALINITY GRADIENT

Pink salmon fry migrate to the sea immediately after emergence from the gravel. The period of time before fry encounter sea water depends in part upon the distance of the spawning ground from the estuary and on the river velocity at the time of migration. In the Fraser River system, fry may be required to make the transition from fresh to sea water rather rapidly. Small pink salmon fry, of a size comparable to newly emerged fry caught in fresh water, have been captured in the Gulf Islands some 15 mi from the Fraser River mouth in salinities ranging from 25 to 31 $^{o}/oo$. In addition, there is evidence of a relationship, although possibly indirect, that pink salmon survival rates are greater when salinities of the estuary are higher during the April to August period (Vernon, 1958). Thus the tolerance of juvenile pink salmon to rapid entry into sea water and the sequence of salinity concentrations normally selected during the transition to sea water are of importance in understanding behavior and survival during this phase of pink salmon development.

The transition to sea water of juvenile pink salmon was studied under laboratory conditions by following the salinities selected by groups of fry at intervals up to 10 weeks after emergence. The effect of immediate conversion to 30 $^{o}/oo$ sea water and retention in fresh water was also examined. In addition, fry from early, peak and late segments of an emergence curve were studied to determine the effect of timing on the transition to sea water.

Effect of Holding Salinities

The effect of continuous exposure to either fresh water or sea water on the development of sequential changes in salinity selection was examined in the present study. In the course of these tests, the rapid conversion of pink salmon fry to sea water was carried out on several occasions.

Frequent tests of the tolerance of newly emerged pink salmon fry to sea water showed that healthy fry could survive when moved instantaneously from fresh water to 30 $^{\circ}/oo$ salinity. Pink fry were even returned to fresh water after a few days in sea water and lived for many days. In application of this finding to the present study, it can be said that fry can move from one level of salinity to another in the test chamber with relative impunity. Therefore, when fry appear to avoid certain seawater concentrations, it is probably incorrect to imply that a potentially lethal condition is directly responsible for this behavior.

Non-Fraser Stocks, 1965

Preparatory to the more complete tests of salinity selection made in 1966, a preliminary series of experiments was performed on non-Fraser stocks of pink salmon fry in 1965. In one instance, fertilized eggs from Atnarko River were incubated at the Sweltzer Creek Field Station and the fry were transferred to Bowman's Bay on April 1, immediately after emergence. These fry were converted from fresh water to 30 $^{\circ}/oo$ sea water in a period of a few hours and were held in this concentration without mortality throughout the 83-day holding period.

The first test of these fish in the salinity gradient was not made until April 23, 22 days after emergence. At this time sea water of 30 $^{\circ}/oo$ was avoided, but several intermediate salinity levels were utilized, the greatest number of fry being observed at salinities of 7 to 25 $^{\circ}/oo$ (TABLE 10). By April 26 the fish no longer avoided 30 $^{\circ}/oo$ salinity, and from April 29 until May 18 the selection of this concentration was quite obvious with at least 74 per cent of the fry recorded in 30 $^{\circ}/oo$ sea water.

The second group of pink salmon fry used in these experiments was obtained from Vancouver Island. Eggs from a spawning population at Bear Creek were incubated to the "eyed" stage and planted in the Robertson Creek channel for incubation. A sample of about 2,000 fry was taken from fresh water on the day of emergence (April 20), moved to Bowman's Bay, and held continuously in fresh water. Observations in the test chamber showed that these fry were going through changes in salinity selection even though confined to fresh water in the holding area (TABLE 11). In the first test

TABLE 10 - Per cent distribution of Atnarko River pink salmon fry tested in salinity gradients at intervals between 22 and 48 days ( ) after emergence, 1965. Fry held continuously in sea water prior to testing.

DEPTH ft	APRIL 23 (22)		APRIL 26 (25)		APRIL 29 (28)		MAY 3 (32)	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.9	4.6	2.6	5.8	3.6	.6	2.9	-
1-2	7.3	17.7	7.3	-	6.4	11.9	9.2	-
2-3	13.4	23.1	12.7	11.7	13.9	7.5	14.6	-
3-4	21.9	30.0	20.6	20.8	19.0	-	22.2	-
4-5	25.3	23.8	26.0	16.7	26.2	-	26.0	3.2
5-6.5	30.2	.8	30.0	45.0	30.0	80.0	30.7	96.8

DEPTH ft	MAY 10 (39)		MAY 18 (47)		MAY 19 (48)	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	3.4	-	3.5	-	15.2	-
1-2	4.9	7.1	7.8	-	20.8	-
2-3	13.6	8.4	13.8	-	26.7	-
3-4	22.2	6.5	21.3	7.4	30.7	100.0
4-5	26.0	4.5	23.5	14.7	30.7	-
5-6.5	30.5	73.6	30.0	77.9	30.7	-

TABLE 11 - Per cent distribution of Bear Creek pink salmon fry tested in salinity gradients at intervals up to 23 days ( ) after emergence, 1965. Fry held continuously in fresh water prior to testing.

DEPTH ft	APRIL 28 (8)		APRIL 30 (10)		MAY 13 (23)	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.7	-	2.6	2.5	3.3	-
1-2	5.5	17.5	7.3	2.5	5.8	2.8
2-3	13.8	36.5	15.4	21.5	14.1	6.1
3-4	21.2	44.0	21.3	73.5	21.3	37.2
4-5	25.3	2.0	26.0	-	25.3	53.9
5-6.5	30.5	-	30.4	-	30.0	-

on April 28, eight days after emergence, most fry were observed in salinities ranging from 5 to 21 $^{o}/oo$. Subsequent tests on April 30 and May 13 showed an avoidance of the lower salinity concentrations and selection of progressively greater salinities, up to 25 $^{o}/oo$, although sea water of 30 $^{o}/oo$ was avoided in all three tests.

Fry held in fresh water fed and grew well only until mid-May, hence no further tests were attempted after May 13. By the last week in May, fry began to die in large numbers and all were dead by May 30.

Fraser Stocks, 1966

In the spring of 1966, pink salmon of Fraser River origin were readily available from the experimental channel at the Sweltzer Creek Field Station and were used exclusively for testing.

Before obtaining the three large groups of fry that were to comprise the major samples for experimental work, several small groups of about 200 fry were captured very early in the season. These fish were tested in the salinity gradient chamber for a few days and then released. Results from these preliminary tests form a basis for examining some variability seen among the later samples.

Approximately 200 newly emerged pink salmon fry were captured on March 29 and moved to Bowman's Bay the same day. They were held in fresh water and a salinity test was made the next day, March 30. As shown in TABLE 12, most fry were found in a salinity of 7 $^{o}/oo$. Fry appeared to avoid salinities over 12 $^{o}/oo$, indicating that they were only beginning to adapt to a marine environment within one day of emergence.

A second group of about 200 fry was obtained on April 5 and moved immediately to Bowman's Bay. Within 3 hr after sampling, 100 fry were placed in 30 $^{o}/oo$ sea water; the remaining 100 fry were held in fresh water. The group held in sea water was tested the next day and showed a definite selection of dilute sea water of 2 and 7 $^{o}/oo$, while salinities of 13 $^{o}/oo$ and above were avoided (TABLE 12). Although these fish had

TABLE 12 - Per cent distribution of Sweltzer Creek pink salmon fry in salinity gradients within one and two days ( ) after emergence, 1966. Very early emerging fry held in fresh water and sea water prior to testing, as indicated.

A. Fry emerged March 29.

	FRESH WATER	
	March 30 (1)	
DEPTH ft	Salinity °/oo	Fry %
0-1	2.7	9.3
1-2	7.2	82.2
2-3	12.5	8.5
3-4	20.6	-
4-5	25.3	-
5-6.5	30.4	-

B. Fry emerged April 5.

	FRESH WATER				SEA WATER	
	April 7 (2)				April 6 (1)	
DEPTH ft	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.0	49.2	2.7	12.5	1.8	62.5
1-2	7.8	25.8	7.1	5.8	7.4	37.5
2-3	13.0	25.0	13.4	45.9	12.7	-
3-4	19.9	-	19.7	35.8	19.9	-
4-5	26.0	-	25.8	-	26.0	-
5-6.5	28.9	-	30.5	-	29.1	-

C. Fry emerged April 11.

	FRESH WATER							
	April 12 (1)				April 13 (2)			
DEPTH ft	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.0	13.6	2.7	21.4	2.2	28.6	2.6	-
1-2	7.2	35.0	6.7	45.6	8.5	52.9	5.8	18.6
2-3	11.9	35.7	12.7	14.3	13.6	18.6	13.0	17.1
3-4	17.7	14.3	19.9	8.6	19.3	-	19.5	57.1
4-5	24.4	.7	24.8	10.0	24.9	-	25.3	7.1
5-6.5	28.9	.7	29.8	-	28.2	-	29.6	-

been held in sea water of 30 ‰ for 24 hr and were not suffering any apparent ill-effects, they clearly "preferred" less concentrated salinities. Fry of the same group, but held in fresh water, were tested twice on April 7. One sample was found to remain in lower salinities than the other but both avoided salinities greater than 25 ‰ (TABLE 12).

Finally, a third sample of fry was taken on April 11, moved to Bowman's Bay and held in fresh water. Two salinity tests on April 12 showed that these fry also selected dilute sea water with most observations recorded in salinities of less than 20 ‰ (TABLE 12). In two additional tests performed April 13, the majority of fry were observed in salinities of either 8.5 or 19.5 ‰. In both tests, however, higher salinity concentrations were almost completely avoided.

Results of these preliminary tests indicated the early stages of adaptation to sea water and showed a fairly rapid transition of fry to intermediate salinities even though most fry had been held continuously in fresh water prior to testing. Results also showed considerable variation in the salinity levels at which most fry were located, even in tests of the same stock on the same day. For this reason, use of calculated average "preferred" salinities has generally been avoided since fry showed a considerable range in distribution within the salinity gradient.

In 1966, further experiments were conducted in which fry were held continuously in fresh water or 30 ‰ sea water until tested in the chamber, in order to compare results with those recorded under similar conditions in 1965. Fry for these tests were obtained from the peak of emergence from Sweltzer Creek channel on May 4. The group held in fresh water became obviously distressed within 10 days and only one salinity preference test was attempted. A second group of fry placed in sea water of 30 ‰ on May 4 survived without mortality until released on June 9.

The salinities selected by fry held in fresh water and in sea water were very similar when tested on May 9, five days after emergence (TABLE 13). Both groups of fry were observed most frequently in salinities of 21 to 26 $^{o}/oo$ and tended to avoid more concentrated sea water. The fry held in fresh water had all died by May 16. When those held in sea water were tested again on May 17, their selection of sea water (29 $^{o}/oo$) was well established and dilute salinities were avoided. Similar results were noted in a final test of these fry on June 9.

Comparison of the above results with tests on fry sampled one day earlier (May 3) and held in increasing salinities (to be described in more detail later) showed a similar pattern of selection and avoidance for various salinity concentrations (TABLE 13). By two weeks after emergence, most fry had moved from intermediate salinities into the more concentrated salinity levels available in the test chamber, whether they had been held in an environment of increasing salinity or continuously in sea water of approximately 30 $^{o}/oo$.

These results, together with those of earlier experiments in 1965, indicated that fry which had been exposed to 30 $^{o}/oo$ sea water within one day after emergence still selected intermediate salinities in the gradient for a considerable time thereafter. The groups of fry held continuously in fresh water showed fairly regular changes in their choice of salinities in the gradient even though they had never been exposed to sea water. These results indicate that the sequence of salinity concentrations selected and avoided by pink salmon fry developed independently of the salinity of the holding environment.

Salinity Selection by Fry from Three Segments of Emergence

Large samples of fry from the early, peak, and late segments of the 1966 emergence from the Sweltzer Creek channel were captured and held separately at Bowman's Bay to observe the effect of time of emergence on the development of salinity selection.

TABLE 13 - Per cent distribution of Sweltzer Creek pink salmon fry tested in salinity gradients at intervals between 4 and 16 days ( ) after emergence, 1966. Fry held in fresh water, sea water or increasing salinity prior to testing, as indicated.

A. Fry emerged May 4.

	FRESH WATER		SEA WATER			
	May 9 (5)		May 9 (5)		May 17 (13)	
DEPTH ft	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.9	12.0	2.6	-	2.6	-
1-2	7.6	7.3	8.7	11.9	8.0	-
2-3	13.7	10.0	13.7	-	12.7	2.1
3-4	21.0	22.7	21.0	18.8	19.2	7.9
4-5	26.7	48.0	26.4	55.0	25.3	13.6
5-6.5	31.1	-	29.6	14.4	28.9	76.5

B. Fry emerged May 3.

	INCREASING SALINITY							
	May 7 (4)		May 10 (7)		May 13 (10)		May 19 (16)	
DEPTH ft	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.2	19.2	2.2	-	8.3	-	2.6	-
1-2	8.3	3.8	8.7	-	13.8	-	8.3	-
2-3	13.4	7.7	13.0	5.7	18.1	4.0	13.8	-
3-4	20.6	37.7	20.2	15.7	27.1	8.7	20.6	25.3
4-5	26.7	27.7	25.7	10.7	30.7	9.3	25.7	21.3
5-6.5	29.6	3.8	28.9	67.9	35.4	78.0	29.3	53.4

Early Fry

A sample of about 3,000 early emerging pink fry from the Sweltzer Creek channel was moved to Bowman's Bay on April 14, 1966. Fry were held in water of increasing salinity as determined by frequent tests in the salinity gradient during the weeks following emergence. Results of tests conducted on subsamples from this group of fry are given in TABLE 14.

In the first test on April 15, almost all fry remained in a very dilute salinity of approximately 2 $^{o}/oo$. One test on April 16 gave the same result, although in duplicate tests on both April 15 and 16, many fry were observed in salinities of up to 21 $^{o}/oo$ rather than the more dilute sea water. Of greater importance than the particular salinity selected is the fact that, in each case, more concentrated salinities of 26 to 30 $^{o}/oo$ were avoided.

Tests from April 18 through April 22 showed that, in general, most fry remained in salinities between approximately 13 and 26 $^{o}/oo$. Concentrations of sea water above and below these values were generally avoided. Duplicate tests on April 21 and 22 gave similar results on both days. From April 25 until April 28, a fairly consistent selection of more concentrated sea water became evident. However, tests between April 29 and May 7 showed the fry to be widely dispersed in the gradient with the majority located at salinities ranging from 13 to 27 $^{o}/oo$. By May 12, fry had moved back into the highest salinities available and dilute sea water was almost completely avoided. Similarly, a final test on June 22 showed a distinct selection of the highest salinity concentration in the gradient.

In a few of these tests, the salinity present in the chamber was increased from 30 $^{o}/oo$ to about 36 $^{o}/oo$ by adding evaporated sea salt to the water. In the first test on April 20, fry entirely avoided the increased salinity of 36.8 $^{o}/oo$ at the bottom of the chamber. By April 25, fry had moved into the deepest level of the chamber in a standard gradient (maximum salinity 30 $^{o}/oo$), and also were found at this level in one test

TABLE 14 - Per cent distribution of EARLY fry tested in salinity gradients at intervals up to 69 days ( ) after emergence, 1966. Salinity of holding area prior to each test also noted.

DEPTH ft	APRIL 15 (1) 0 °/oo				APRIL 16 (2) 7.3 °/oo			
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.2	86.5	2.6	7.9	1.8	100.0	2.9	12.0
1-2	8.3	13.5	6.1	35.0	8.9	-	7.6	13.3
2-3	12.1	-	12.6	12.8	14.3	-	11.9	74.7
3-4	18.3	-	20.8	44.3	20.8	-	19.2	-
4-5	24.6	-	26.4	-	26.6	-	24.6	-
5-6.5	27.5	-	29.9	-	29.8	-	30.0	-

DEPTH ft	APRIL 18 (4) 7.3 °/oo		APRIL 19 (5) 15.7 °/oo		APRIL 20 (6) 15.7 °/oo			
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.9	-	1.8	.7	2.6	-	8.5	13.3
1-2	6.5	6.0	9.1	14.0	8.3	6.5	13.7	6.7
2-3	12.7	17.3	13.4	-	13.4	22.2	19.8	6.7
3-4	21.0	69.4	21.0	16.0	20.2	60.2	26.5	46.7
4-5	23.5	7.3	26.7	66.0	26.0	11.1	31.5	26.7
5-6.5	25.3	-	30.0	3.3	28.9	-	36.8	-

DEPTH ft.	APRIL 21 (7) 18.8 °/oo				APRIL 22 (8) 20.8 °/oo			
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.6	-	1.8	-	2.6	1.7	2.9	-
1-2	6.5	-	8.0	-	8.0	31.7	6.5	5.0
2-3	12.7	2.7	13.4	13.3	14.8	25.0	14.1	20.0
3-4	21.0	85.3	20.2	80.0	20.2	41.7	21.0	50.0
4-5	24.6	12.0	24.2	6.7	23.9	-	25.3	25.0
5-6.5	30.7	-	28.9	-	28.8	-	31.1	-

TABLE 14 - (Cont.)

DEPTH ft	APRIL 25 (11) 20.8 °/oo		APRIL 27 (13) 23.9 °/oo				APRIL 28 (14) 25.7 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.2	.7	2.6	-	8.7	-	1.8	-
1-2	6.5	3.3	8.0	6.7	14.5	7.3	1.8	-
2-3	13.7	-	16.6	6.7	20.2	12.7	12.7	20.0
3-4	20.6	14.0	20.2	66.7	26.7	6.7	14.5	-
4-5	26.4	13.3	27.1	6.7	31.1	.7	14.5	.7
5-6.5	29.6	68.7	29.3	13.3	35.4	72.7	31.1	79.3

DEPTH ft	APRIL 29 (15) 25.7 °/oo		APRIL 30 (16) 29.6 °/oo		MAY 3 (19) 30-31.5 °/oo		MAY 5 (21) 30-31.5 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	18.1	4.0	2.9	-	8.3	2.6	2.2	-
1-2	18.1	34.7	7.3	2.0	14.5	10.5	8.3	15.8
2-3	30.4	30.0	13.4	16.7	19.5	32.2	13.4	20.9
3-4	30.4	18.0	20.2	50.0	26.4	40.1	21.0	12.7
4-5	30.4	5.3	25.3	18.0	32.2	7.9	26.7	12.7
5-6.5	36.1	8.0	31.1	13.3	36.1	6.6	30.4	38.0

DEPTH ft	MAY 7 (23) 30-31.5 °/oo		MAY 12 (28) 30-31.5 °/oo		JUNE 22 (69) 30-31.5 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	8.3	-	9.1	-	2.9	-
1-2	13.7	1.7	14.5	-	7.3	-
2-3	20.2	45.8	22.8	1.3	13.7	-
3-4	27.5	47.5	27.1	4.0	21.3	-
4-5	31.8	5.0	32.5	1.3	27.8	7.5
5-6.5	36.1	-	35.4	93.4	30.7	92.5

on April 27 when an increased salinity of 35.4 °/oo was present. From April 29 to May 7, most fry reverted to intermediate salinity levels, as previously noted. During this period, however, when salinities in the deepest level were increased to 36 °/oo, less fry were observed in this region than when salinities were in the 30 °/oo range. By May 12, almost all fry were recorded at the 35 °/oo salinity level. Although results were somewhat variable, these tests suggested a slower movement of fry into high salinities of 36 °/oo than into the salinities of approximately 30 °/oo characteristic of the estuarial and coastal environment.

Peak Fry

A group of about 5,000 pink fry was captured on May 3 during the peak of emergence from the Sweltzer Creek channel and moved to Bowman's Bay. These fry were treated similarly to those from the early segment of emergence, being held in water of increasing salinity as indicated by regular tests in the vertical salinity gradient.

In the first salinity test on the day of emergence, May 3, fry chose intermediate salinities ranging from 9 to 21 °/oo (TABLE 15). Higher concentrations of sea water were avoided. On May 4 fry moved into higher salinity concentrations (up to 30 °/oo) but reverted again to intermediate salinity levels on May 5 and 7. It was not until tests on or after May 10 that fry consistently chose salinities of 30 °/oo or higher. In addition, from May 10 until tests ended on June 20, concentrations of about 8 °/oo salinity or less were completely avoided.

A few of the above tests included artificially concentrated sea water up to 36 °/oo salinity. On May 13, most fry selected 35 °/oo salinity (TABLE 15). However, in a later test on May 19 under the same conditions, the fry remained in 31 °/oo salinity and clearly avoided the 35 °/oo concentration. By June 8, fry again moved into 36 °/oo and, in the final test on June 16, fry obviously selected 36 °/oo salinity and avoided concentrations less than about 20 °/oo. The variable response of fry to these increased salt concentrations was similar to that noted for the early emerging fry.

TABLE 15 - Per cent distribution of PEAK fry tested in salinity gradients at intervals up to 48 days ( ) after-emergence, 1966.

DEPTH ft	MAY 3 (0) 0 °/oo Salinity °/oo	Fry %	MAY 4 (1) 13.9 °/oo Salinity °/oo	Fry %	MAY 5 (2) 13.9 °/oo Salinity °/oo	Fry %
0-1	2.2	2.8	1.9	1.3	2.6	4.0
1-2	8.7	20.6	7.7	2.0	11.2	4.7
2-3	13.8	34.0	13.5	9.3	13.0	20.8
3-4	20.6	42.6	21.0	22.0	21.0	62.4
4-5	26.7	-	27.2	31.3	26.4	6.0
5-6.5	30.4	-	29.8	34.0	31.4	2.0

DEPTH ft	MAY 7 (4) 13.9 °/oo Salinity °/oo	Fry %	MAY 10 (7) 20.6 °/oo Salinity °/oo	Fry %	MAY 11 (8) 25.8 °/oo Salinity °/oo	Fry %
0-1	2.2	19.2	2.2	-	2.2	-
1-2	8.3	3.8	8.7	-	8.3	-
2-3	13.4	7.7	13.0	5.7	13.8	17.8
3-4	20.6	37.7	20.2	15.7	20.6	7.9
4-5	26.7	27.7	25.7	10.7	26.7	17.1
5-6.5	29.6	3.8	28.9	67.9	30.4	57.1

DEPTH ft	MAY 13 (10) 26.2 °/oo Salinity °/oo	Fry %	MAY 19 (16) 26.2 °/oo Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	8.3	-	2.6	-	14.5	-
1-2	13.8	-	8.3	-	19.5	3.3
2-3	18.1	4.0	13.8	-	26.0	8.7
3-4	27.1	8.7	20.6	25.3	31.7	80.6
4-5	30.7	9.3	25.7	21.3	35.4	6.7
5-6.5	35.4	78.0	29.3	53.4	35.4	.7

TABLE 15 - (Cont.)

DEPTH ft	JUNE 8 (36) 30.5-31.5 °/oo			
	Salinity °/oo	Fry* %	Salinity °/oo	Fry %
0-1	7.8	-	30.9	-
1-2	14.1	-	30.9	-
2-3	19.9	24.0	30.9	-
3-4	27.1	26.0	30.9	6.7
4-5	31.3	19.0	31.9	.7
5-6.5	36.2	31.0	35.9	92.7

* Fry restless - only first 10 observations used.

DEPTH ft	JUNE 16 (44) 30.5-31.5 °/oo		JUNE 20 (48) 30.5-31.5 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	11.6	-	2.9	-
1-2	13.8	-	7.3	-
2-3	19.9	.7	12.3	-
3-4	27.8	16.7	20.2	2.7
4-5	31.4	24.0	26.4	21.3
5-6.5	36.1	58.6	30.4	76.0

Late Fry

A final sample of about 3,000 pink salmon fry captured on May 13 represented the late segment of emergence from Sweltzer Creek channel. Fry were moved to Bowman's Bay the same day and placed in a raceway in fresh water. A salinity test was begun immediately and the salinity of the water in the raceway was adjusted to correspond to the salinity selected by fry in the test gradient.

The seasonal change in salinity levels selected by this group of late emerging fry showed a clear progression from intermediate salinities to 30 $^{o}/oo$ sea water. In the first test on the date of emergence, most fry were found in intermediate salinities up to 21 $^{o}/oo$; higher salinity concentrations were avoided (TABLE 16). Similar results were noted three days later on May 16. By May 18, there was a distinct movement into 30 $^{o}/oo$ salinity, as was also observed again on May 20. On May 24, artificially concentrated sea water up to 36 $^{o}/oo$ salinity was available in the gradient. However, most fry avoided this strong concentration and remained in the 25 and 31 $^{o}/oo$ salinity levels. In this case, salinities of about 19 $^{o}/oo$ and less were avoided. Finally, in a test on June 15 in which similarly concentrated sea water was used, more than 90 per cent of the fry selected the 36 $^{o}/oo$ salinity level and avoided all salinities of 26 $^{o}/oo$ or less.

Effect of Age and Size on the Transition to Sea Water

The preceding tests on various stocks of pink salmon all indicated a progressive movement of fry into increasing salinities. However, the rate of transition to sea water was not the same for all stocks, as is evident when results are examined in relation to age and size of the fry.

As noted previously, there was considerable variation in the distribution of fry in the salinity gradients, even in duplicate tests of the same stock on the same day. This is also evident in FIGURE 13 where the average salinity calculated for each test has been plotted against the age of the fry (indicated by the number of days after emergence). Thus

TABLE 16 - Per cent distribution of LATE fry tested in salinity gradients at intervals up to 33 days ( ) after emergence, 1966.

DEPTH ft.	MAY 13 (0) 0 °/oo		MAY 16 (3) 13.7 °/oo		MAY 18 (5) 16.3 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.2	2.5	1.8	.7	2.2	-
1-2	8.3	7.4	6.2	.7	8.7	6.7
2-3	13.0	33.9	12.3	16.7	13.0	8.0
3-4	20.6	55.4	20.2	82.0	20.2	6.7
4-5	25.3	-	25.7	-	25.7	9.3
5-6.5	28.2	.8	30.4	-	29.6	69.4

DEPTH ft	MAY 20 (7) 26.4 °/oo		MAY 24 (11) 28.0 °/oo		JUNE 15 (33) 30.5-31.5 °/oo	
	Salinity °/oo	Fry %	Salinity °/oo	Fry %	Salinity °/oo	Fry %
0-1	2.6	-	9.4	-	8.3	-
1-2	7.3	-	13.0	-	13.7	-
2-3	12.7	4.7	18.8	.7	19.9	-
3-4	20.2	10.0	25.3	64.6	26.4	-
4-5	26.0	17.3	31.1	22.6	31.1	9.3
5-6.5	29.3	68.0	35.8	12.0	36.1	90.7

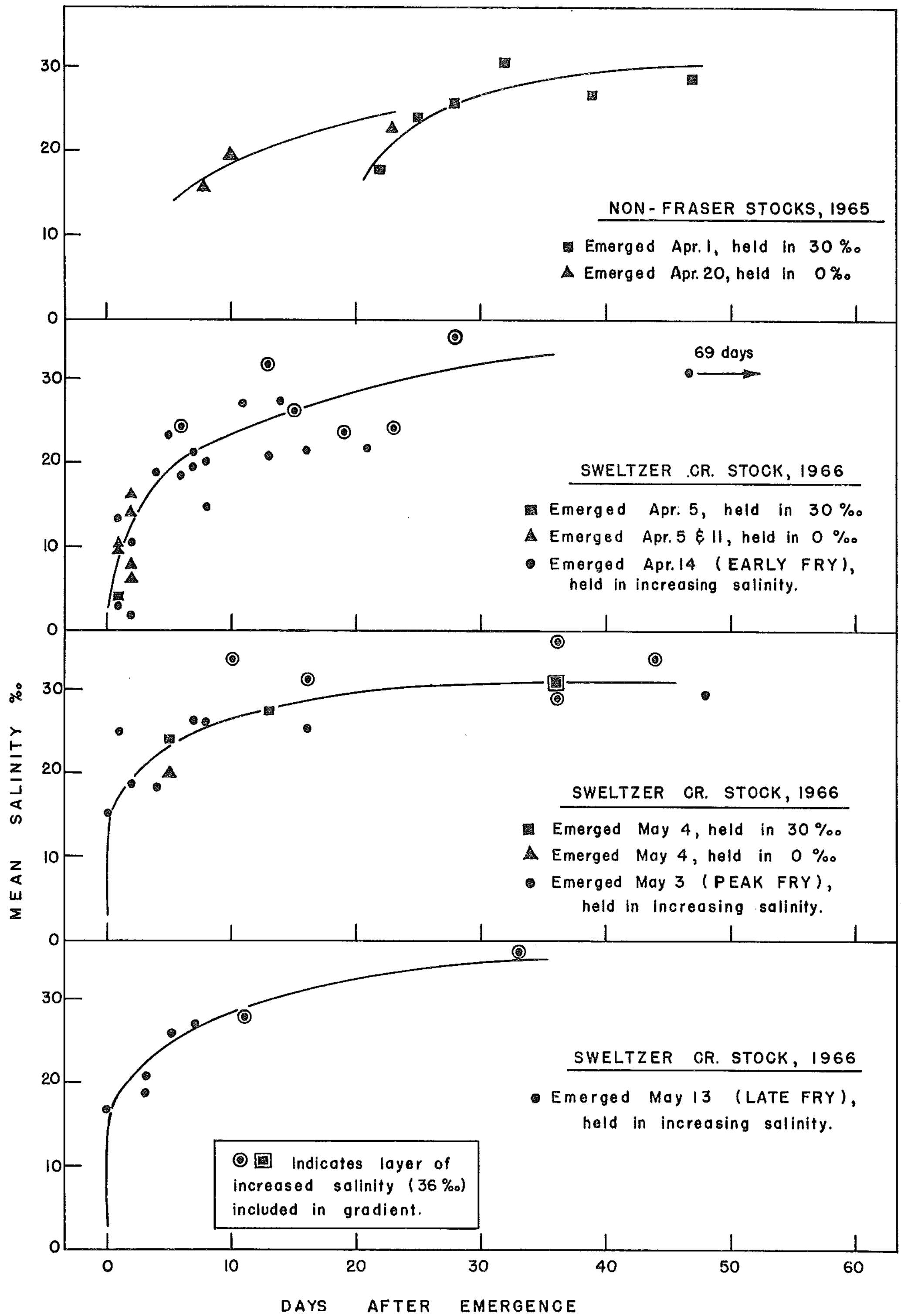

FIGURE 13 - Average salinity levels selected by pink salmon fry in relation to number of days after emergence, 1965 and 1966.

although determination of an average salinity for each day appears inappropriate, a trend line indicating the rate of transition from fresh water to sea water has been approximated for each series of tests.

The 1965 tests on non-Fraser stocks indicated a relatively slow transition to sea water (FIGURE 13). In the first test in the gradient, three weeks after emergence, the earlier stock (emerged April 1) selected salinity levels averaging 17 ‰. Although transition to intermediate salinities may have been more rapid than indicated by this single initial test, subsequent tests showed that the fry apparently required a period of 25 to 28 days to move into salinities averaging 25 ‰. The stock which emerged April 20 was found in salinities averaging 16 ‰ in the first test eight days after emergence and appeared to require nearly two weeks to move into salinities averaging 20 ‰.

Examination of the 1966 results indicated a progressively more rapid transition to sea water of the later emerging stocks (FIGURE 13). Very early fry (emerged April 5 and 11) tested within one and two days of emergence were found in dilute salinities averaging 4 to 16 ‰. Tests of the early stock (emerged April 14) again indicated a considerable variation in distribution, with average salinities ranging from 2 to 13 ‰ during the first two days after emergence. Subsequent tests of the early stock continued to show extensive variability but indicated that salinities selected in the gradient averaged 20 ‰ within approximately one week after emergence and averaged 25 ‰ within two weeks after emergence.

In contrast, peak fry (emerged May 3 and 4) and late fry (emerged May 13) made the transition to sea water much more rapidly. The first tests on the day of emergence showed fry in salinities averaging 15 to 17 ‰. Within two to three days after emergence these fish had moved into salinities averaging 20 ‰ and within one week were in average salinities of 25 ‰.

As noted previously, salinity of the holding area appeared to have little influence on the salinity level selected in the gradient. Data in FIGURE 13 (see early and peak fry, 1966) indicate that the mean salinity selected in the gradient followed a similar trend, regardless of previous holding conditions.

Response of fry to extremes of salinity in the gradient, i.e., more than 28 $^{o}/oo$ or less than 10 $^{o}/oo$, also varied between stocks. In 1966, none of the early fry (emerged April 14) were found in salinities over 28 $^{o}/oo$ until five days after emergence and at this time the proportion was very low - 3.3 per cent. Early fry were not found consistently in high salinities until tests on or after the eleventh day and even then the proportion varied widely between 5 and 90 per cent during the next three weeks of testing. Furthermore, small numbers of early fry were still found in low salinities as late as three weeks after emergence whereas peak and late fry entirely avoided salinities below 10 $^{o}/oo$ within one week. Peak fry (emerged May 3) selected sea water of 30 to 31 $^{o}/oo$ and consistently avoided dilute salinities within seven days after emergence. Similarly, the late fry (emerged May 13) moved rapidly into 30 $^{o}/oo$ sea water on the fifth day after emergence.

Because of the similarity in growth rates of all experimental stocks, the relationship of size to seawater transition was essentially the same as the relationship to age. The 1965 stocks were older, and thus larger, than the 1966 stocks at certain comparable stages in the transition to sea water. When salinities selected in the gradient averaged 20 $^{o}/oo$, the earlier fry (emerged April 1, 1965) were approximately three weeks old and averaged 48 mm in length; the second group (emerged April 20) were two weeks old and 42 mm in length.

In contrast, the 1966 stocks made the transition to 20 $^{o}/oo$ sea water at a somewhat smaller size; early fry took approximately one week, peak and late fry required only two to three days. Because of the relatively slow initial growth rate of all 1966 stocks, fry from all three groups averaged 35-36 mm in length at this time. By the time of transition to 25 $^{o}/oo$ sea water, early fry (14 days after emergence) averaged 42 mm in length, peak and late fry (7 days after emergence) averaged only 37-38 mm in length. The 1965 stock of fry (25-28 days after emergence) were even larger and averaged 52 mm in length at this stage in transition to sea water.

It is therefore apparent that the transition from fresh water to sea water was not rigidly controlled by age or size of the fry. However, the data indicate that avoidance of dilute salinities and movement into 30 ‰ sea water was more rapid among the later emerging stocks.

Effect of the Vertical Gradient on Results of Salinity Tests

Tests in a Uniform Salinity

The distribution of fish when a uniform salinity was present throughout the entire chamber was examined to determine the influence of depth *per se* on the position of fry. The control tests were compared with results observed in the salinity gradient in order to evaluate the relative importance of depth on the levels chosen by fry in the presence of a salinity gradient.

The stock of Bella Coola fry held continuously in sea water was tested four times during the 1965 season (FIGURE 14). Results indicated that fry placed in the chamber without a gradient of temperature or salinity generally were widely dispersed throughout the tank, with the exception of one test on May 23 when 80 per cent of the observations were recorded at a depth of 2.5 ft. As the season progressed, fry tested in the control chamber tended to move from the middle of the chamber to deeper levels.

The 1966 tests of the changing depth distribution of pink salmon fry within a uniform salinity are plotted in FIGURE 15. Distribution of fry from the same groups tested at approximately the same time in a salinity gradient has been plotted in the same graph. Early tests on March 30 and April 15 showed that fry were widely dispersed in the middle of the control chamber. When a salinity gradient was present, fry were found in the upper section of the chamber where the lowest salinities were located.

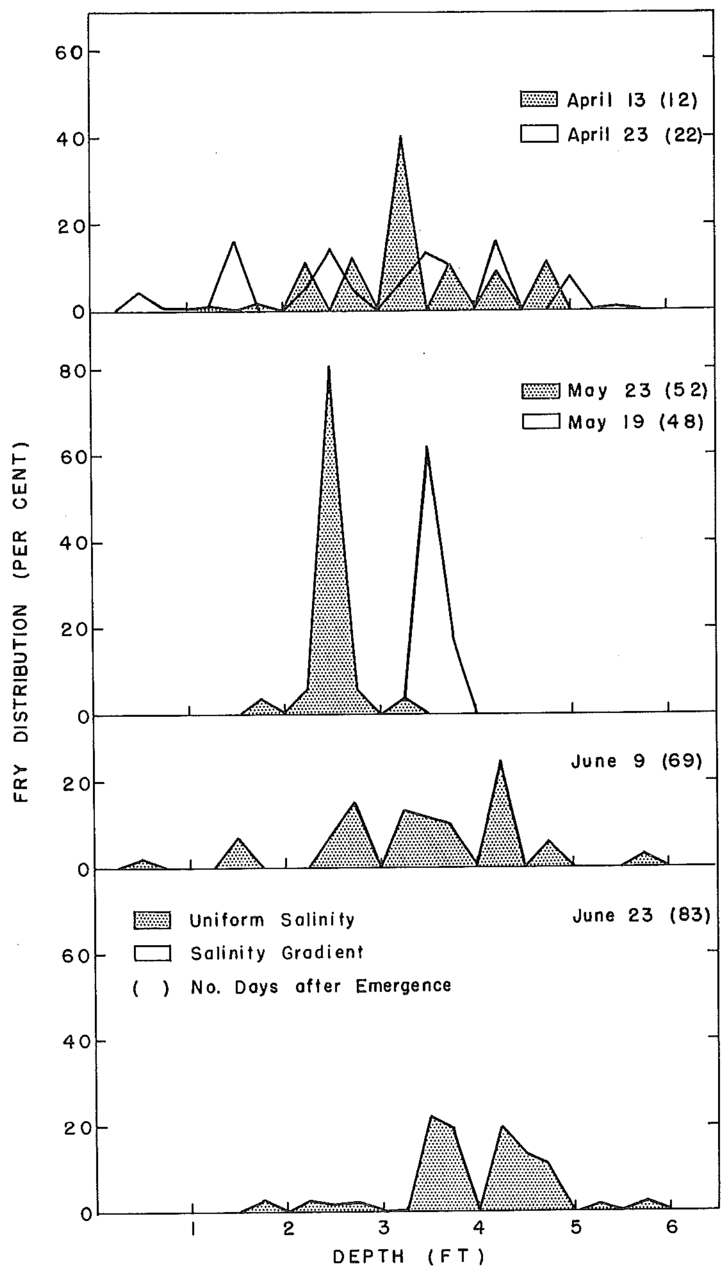

FIGURE 14 - Distribution of fry in a control tank with uniform salinity (31 $^{o}/oo$) and in a salinity gradient - seawater held stock emerged April 1, 1965.

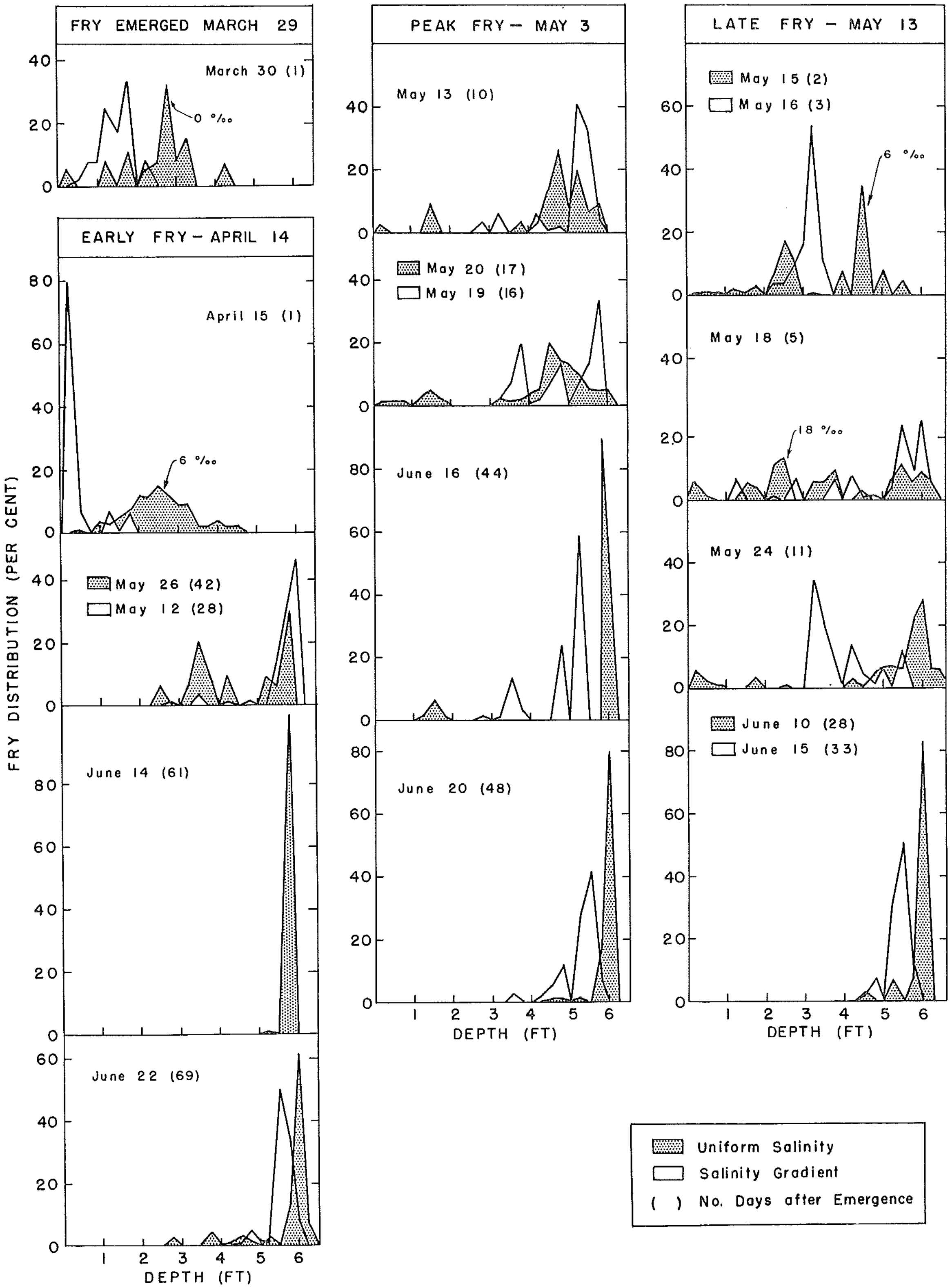

FIGURE 15 - Distribution of fry in a control tank with uniform salinity (30 to 31 ‰ except where noted) and in a salinity gradient - four stocks of fry, emerged on dates indicated, 1966.

By May 26, fry from the early portion of the migration were still observed in the middle and lower section of the chamber, although in a salinity gradient, fry from the same group had moved to the bottom of the chamber where the 30 $^{o}/oo$ sea water was located. By June 22, fry were concentrated near the bottom of the chamber in both the gradient and control tests.

When peak fry were tested in a uniform salinity on May 13, 10 days after emergence, most fry were found near the bottom of the chamber (FIGURE 15). Similar results were noted in subsequent control tests on May 20, June 16 and June 20. Peak fry selected 30 $^{o}/oo$ sea water as early as May 13, and in both the gradient and control tests were found near the bottom of the chamber. The salinity gradient, however, appeared to concentrate the fry to a greater extent than when no gradient was present.

Fry from the end of the migration were also tested in a uniform salinity (FIGURE 15). On May 15 and May 18, these fry were found to be spread fairly evenly throughout the chamber. In later tests on May 24 and June 10, almost all fry were observed in deeper water near the bottom of the chamber. When a salinity gradient was present, fry were generally found in a more restricted segment of the chamber. On May 15, fry were centered around a depth of 3.25 ft when a gradient was present. On May 18, they were found primarily at depths of 5 to 6 ft in response to the gradient. On May 24, fry in a uniform salinity were concentrated near the bottom of the chamber; however, when the selected salinity of the fry was placed near the middle of the chamber in another test on the same day, fry were located in that position. In the final test on June 15, fry in the gradient were found near the bottom of the chamber, as was the case in a control test on June 10 in a uniform salinity.

These tests showing distribution of fry in the absence of a salinity gradient indicated that depth of water was a factor of the environment to which fry orientated in the chamber. Except for the earliest tests of each group, fry were generally found near the bottom of the chamber. It remained, therefore, to demonstrate the relative effect of salinity selection in reference to depth selection in order to validate the results of tests in the salinity gradient.

Tests in a Moving Gradient

Once a group of fry had selected a particular salinity, it was possible to place this salinity at a different depth in the chamber. The distribution of another sample of fry from the same group was then recorded. If salinity were the major factor determining distribution, fry should be found at the new depth at which their selected salinity was located. This procedure was carried out on several occasions and it was found that the fry did, in general, move in accordance with their "preference" for particular salinity concentrations rather than remain at the same depths.

One such test on May 18, 1965, showed most fry to be in the 29.8 $^{o}/oo$ salinity layer located between 5 and 6 ft below the surface. The next day, approximately the same salinity was extended from 3 to 6 ft in the chamber; fry again selected this salinity but were located between the 3.25 and 3.5 ft depths (FIGURE 16).

Several tests on Fraser stocks in 1966 also indicated that particular salinities were chosen even when the levels of those salinities were changed in the chamber (FIGURE 16). In each case, fry moved higher in the chamber and selected approximately the same salinity. The fry appeared to avoid the higher concentrations of sea water present in the deeper levels.

The tests all showed that once a salinity gradient had been established in the experimental chamber, fry orientated with respect to their selection of particular salinities. Salinity gradients apparently overcame the preference for particular depths of water evident in the control tests.

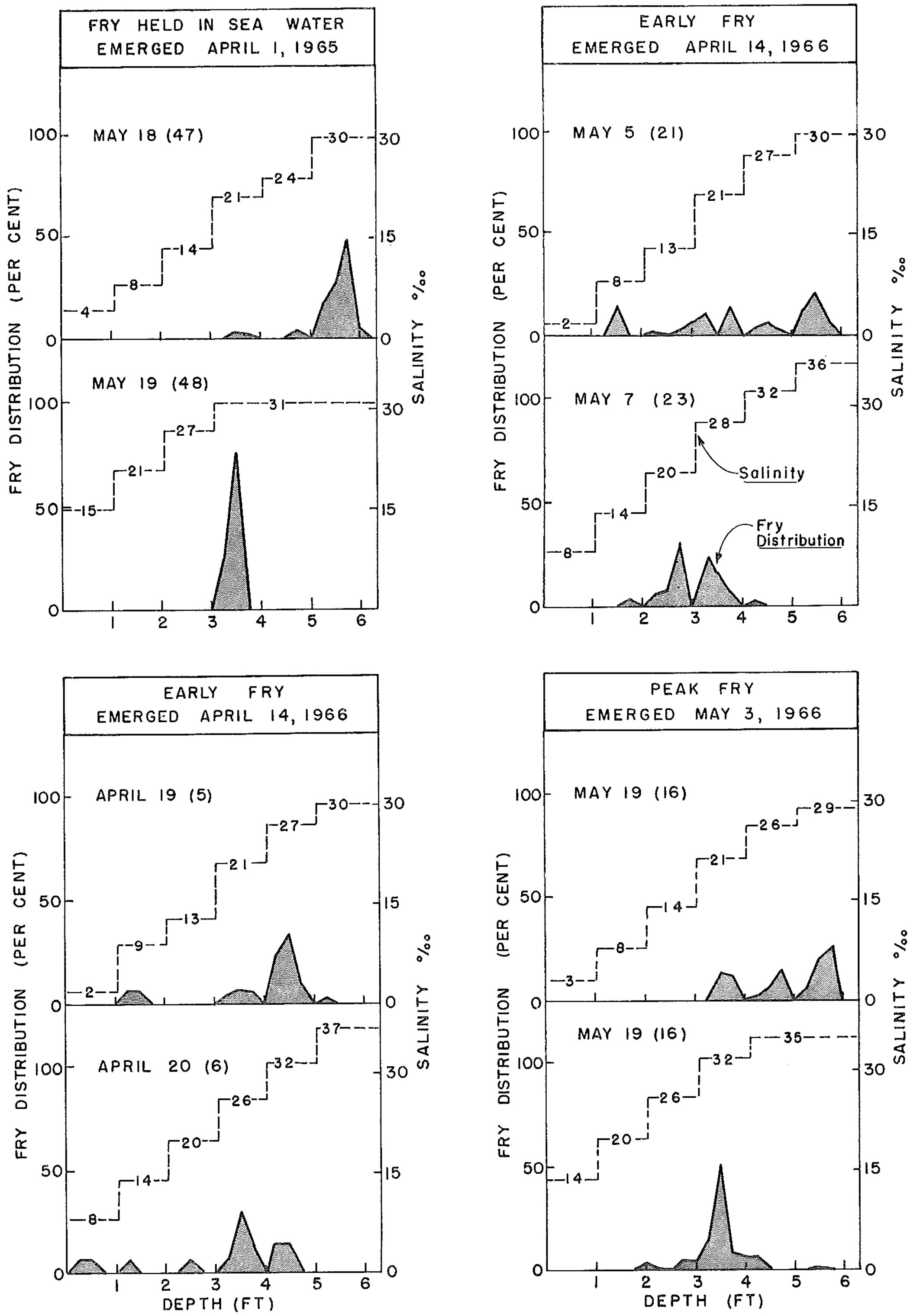

FIGURE 16 - Change in distribution of pink salmon fry following a shift in the salinity gradient. Date and number of days after emergence ( ) shown for each test, 1965 and 1966.

DISCUSSION

An attempt has been made to define the normal behavior of pink salmon fry with respect to temperature and salinity gradients which they may encounter during the first few months following migration to the sea. Groups of pink salmon fry have been raised experimentally so that their environment and growth has approximated the natural state during this period. The levels of temperature and salinity selected by samples of these fry have been observed at frequent intervals and certain patterns of behavior have been noted. In the following sections, the ecological significance of the selected levels of temperature and salinity are discussed in relation to behavior and survival of young pink salmon in the natural environment.

Temperature

In the present study, young pink salmon reared in sea water until they reached approximately 80 mm in length continued to select a fairly narrow range of temperatures in a vertical gradient. Since temperature gradients are present in natural waters in both vertical and horizontal directions, temperature selection may serve to direct young fish to favorable environments. In this regard, Norris (1963) recently suggested that the California opaleye, Girella nigricans, was able to use naturally occurring gradients to direct its movements to suitable environments. Presumably, temperature-directed movements lead fish into specific locations that provide optimum conditions for feeding, growth, and protection from predators.

The present experiments also indicated that the level of temperature selected by young pink salmon was not constant but decreased as fry grew larger. Sullivan and Fisher (1953) noted that the temperature selected by brook trout (Salvelinus fontinalis) held at essentially constant temperatures rose in the spring and fell in the fall suggesting that these changes were of a seasonal nature. Norris (1963) also indicated that the level of temperature selected may change at certain stages of fish development.

Among juvenile pink salmon, temperature selection and the changing level of temperature selected may assist in explaining their distribution in coastal waters. Soon after migration from fresh water, fry initially move into shallow areas close to the beaches and later move away from shore to deeper water. In the present experiments, fry up to about 60 mm in length selected temperatures of 53° to 56°F in the gradient while larger fry selected slightly colder temperatures in the 49° to 51°F range. It is possible that the change from onshore to offshore location recorded in nature is triggered by a change in selected temperature forcing the larger fish to seek colder water farther from shore.

This behavior pattern of young pink salmon is undoubtedly related to survival. Their small size presumably exposes the youngest fry to heavy predation and inshore location may provide protection from larger fish. At a larger size young pink salmon presumably are better able to avoid predators and also are able to range farther in their search for food. The continuous recruitment of pink salmon fry over a period of several weeks might also make it important for the larger individuals to move away from shore to reduce the competition for food with newly arriving fish. In general, the net movement away from shore serves to dilute the population in the relatively restricted onshore locations.

Depth selection may also exert an influence in directing movement of pink salmon fry. Tests in a uniform temperature and salinity indicated that smaller fish tended to select shallow and intermediate depths while larger fish selected deep water and were usually found concentrated in the bottom of the chamber. Under natural conditions, it is possible that this same behavior would assist in directing smaller fish to shallow water onshore and larger fish to deeper water offshore. This behavior would then reinforce the effect of temperature in directing the movements of fry.

The mechanism ultimately responsible for the observed movements of fry during this period is not known. It can be postulated that the initial response of small fish to seek shallow water may be inherent and that temperature and depth selection only assist in directing fish to these locations. In this case, fry would initially move close to shore in spite of adverse temperatures in these locations. On the other hand, the movement of fry may be entirely directed by temperature selection. In this case, fry would avoid onshore locations if temperatures exceeded the preferred range. It frequently has been noted that fry avoid areas of flat beach on rising tides when the water temperatures are excessively high. In this case, it is possible that in years of late fry emergence or above average temperatures, even the smallest fry would be forced to remain offshore where predation may be higher or the food supply reduced. At the present time, the relative influence of inherent behavior and environment in directing the movements of fry has not been determined.

A very large mortality of young pink salmon fry has been shown to occur during the early period of marine life (Parker, 1965) which may vary considerably from year to year (Vernon, 1966; Parker, 1964). Although Vernon (1958) presented evidence of an inverse correlation of seawater temperatures during estuarial residence of young pink salmon with survival rate to adults, the precise manner in which temperature may act to affect survival is not known. In isolated locations it is possible that rapid warming of shallow beaches may result in lethal temperatures and cause mortality among the fry. However, for the overall population this effect may be relatively minor unless a possibly inherent behavior pattern forces the fry into these locations.

The fact that growth rates of young pink salmon vary in relation to temperature may be a more important factor in survival. Recent growth studies of young pink salmon held under controlled temperature conditions indicated that during the first 22 days after emergence, rapid growth occurred between 11° and 16°C (51.8° and 60.8°F) with maximum growth occurring between 13° and 14°C (55.4° and 57.2°F) (Martin, 1966). In the present experiments, young fry initially selected temperatures from about 53° to 56°F, a range slightly colder than the temperatures of maximum growth found by Martin, but included in the region of rapid growth. This would imply that the selected temperature zone provides an environment for rapid growth of young fry and may lead to increased survival.

In an associated study, Martin (1966) found that young pink salmon held in pens in sea water in a natural temperature regime showed a definite fall in rate of growth in mid-June, at a time when fish would normally be leaving inshore areas for the colder water offshore. The decreased rate of growth was attributed by Martin to the rising seawater temperatures in mid-June and not to size and age of the fish which ranged from 50 to 63 mm in length and from 4 to 11 weeks of age. However, a re-examination of his data indicates that the larger fish which had emerged first underwent a considerably more pronounced drop in rate of growth than did the smaller fish. This evidence would be consistent with the hypothesis that selection of colder temperatures by larger fry is related to their maintaining a rapid growth rate. Since growth and survival are intimately associated, the ability of fry to find, in the natural environment, the correct sequence of selected temperatures which results in rapid growth may be an important feature in survival.

The timing of the selection behavior observed among pink salmon fry is presumably set long before the fry enter sea water. Freshwater temperatures during incubation from spawning to emergence will largely govern the timing of fry migration to salt water. Depending upon the timing of this migration, suitable temperatures may or may not be available for fry in the estuary. Climatic conditions will also affect the water temperatures available, particularly in the very shallow waters near shore utilized by pink salmon fry during the early period of marine residence. Correlation between temperature and survival may therefore reflect the availability of naturally occurring temperatures at the levels "preferred" or required by fry for rapid growth.

Salinity

Pink salmon fry migrate to the sea shortly after they emerge from the freshwater nursery area and are required to make the transition to sea water at a relatively rapid rate. In the present study, the natural behavior of fry in moving from fresh to sea water was followed in an experimental situation. It was found that fry selected a regular, orderly sequence of low salinities initially and high salinities later, corresponding to those observed in the natural estuarial environment. This behavior was apparently independent of the salinity of the previous holding environment and suggests that an endogenous mechanism regulates salinity selection, probably controlled by the endocrine system. It was also recorded that newly emerged fry were able to withstand immediate conversion from fresh to sea water (31 $^{o}/oo$ salinity) without apparent harmful effect. In this environment, the fry grew normally during the next three months. On the other hand, fry held in fresh water suffered heavy losses beginning a few weeks after emergence and all died within five weeks, or less.

The present study showed that the timing of emergence was a factor determining the rate of transition from fresh to sea water. In general, early emerging fry required a longer time to select increasing concentrations of sea water compared with fry from the peak, or later, in an emergence curve. Similarly, early fry did not avoid dilute sea water as quickly after migration as did the peak or late fry. However, among all stocks of fry tested, movement into sea water of 31 $^{o}/oo$ salinity was essentially completed in a maximum period of one month.

The transition from fresh to sea water in natural populations of pink salmon fry can be examined with reference to these experimental results. During their seaward migration, pink salmon fry have been observed concentrated along the edge of the plume of fresh water that projects into Georgia Strait from the Fraser River (E. Barraclough, personal communication). Fry were also seen in pockets of cloudy water which had become separated from the plume. It is believed that these pockets of brackish water quickly find their way to the region of the Gulf Islands. Presumably, this period when fry are exposed to brackish water may roughly correspond to the intervals noted when gradually increasing concentrations of sea water were being selected in the salinity gradient. Since higher salinities are available outside this plume, it is probable that fry remain in the lower salinities because they prefer to do so. The possibility also exists that this behavior provides some protection since, in the cloudy water, the small fry would be less noticed by predators.

In addition, the experimental evidence indicates that all stocks of fry avoided salinities over approximately 29 $^{o}/oo$ for the first four days after emergence. If the same situation prevails under natural conditions, it is postulated that pink salmon fry would avoid high salinities during the first few days of estuarial migration. However, it is doubtful that sea water would be lethal in itself since the experimental stocks of fry tolerated 30 $^{o}/oo$ salinity almost immediately after emergence. Once fry have grown beyond the stage of avoiding higher salinities, a gradual avoidance of dilute sea water develops. This behavior would ensure the gradual dispersion of pink salmon fry.

Pink salmon fry are found actively migrating in the Fraser River from late February to late May in even-numbered years. The timing of migration is determined by temperatures during the incubation period. If these temperatures have been warmer than average, fry migration will be early; and similarly if they have been colder than average, the migration will be late. Since time of seaward migration appears to influence the behavior of fry with respect to salinity, differences in timing may influence survival. It was found that earliest migrants required the longest time to develop avoidance of dilute sea water, peak migrants were intermediate and late migrants required the least time for this behavior to develop. The result of this behavior under natural circumstances would be to influence the rate of migration into concentrated sea water. The early and late segments of the migration would be brought closer to the peak migrants in their reaction to various salinities. Presumably, the peak of the migration has through evolution become most closely synchronized with the average long-term environment and therefore is most suited to the requirements of the fry. The different behavior patterns noted within the extremes of migration would tend to restrict the migration to this long-term optimum period.

Slight variations in timing of fry emergence and migration may expose fry to markedly different conditions in the Fraser River and in the rate of transition to salt water. Changes in the freshwater environment that may alter conditions for incubation and influence time of migration should therefore be prevented wherever possible. In addition, the transition from fresh to sea water occurs quickly among pink salmon fry so that the route of emigrating fry must not be blocked. Large impoundments of water in the migration route could prolong migration and disorientate the fry. If entry to sea water were delayed, the sequence of behavioral changes might occur out of phase with the environment. Since late segments of a migration make the most rapid transition to sea water, any delay of these fish would probably be more detrimental than to earlier migrants. Similarly, if the whole emergence and migration were later than normal, a delay might be particularly harmful. In any event, variations in survival resulting from relatively small changes in timing and environment may be large. Efforts must be made to ensure that changes do not unfavorably influence the direction of the survival curve.

SUMMARY AND CONCLUSIONS

1. Large variations in the number of returning adult pink salmon have been recorded in the Fraser River system in the fall of odd-numbered years. Variations in marine survival are evidently largely responsible for the observed fluctuations in adult runs and apparently occur during the initial period of estuarial residence when mortality rates are high. The temperature and salinity conditions encountered by pink salmon fry during this period are implicated as factors involved in this variable survival.

2. The critical nature of this period in the life cycle requires definition of the normal sequence of behavior of young pink salmon in relation to temperature and salinity during early marine life. In this way, the behavior and distribution of pink salmon fry under natural conditions in the estuary can be examined and reasons for variations in survival can be postulated.

3. Pink salmon fry from the Bella Coola system, from Bear Creek on Vancouver Island, and from Sweltzer Creek in the Fraser River watershed were used during tests in 1965 and 1966. Fry from three segments of emergence from the Sweltzer Creek incubation channel were also tested separately. Fry were held in one of three salinity conditions (fresh water, increasing salinities, or continuously in 29 to 31 °/oo sea water) for periods up to three months after emergence.

4. Fresh or frozen zooplankton was used exclusively as the diet of the young fish. Growth rates of experimental stocks appeared slightly below those estimated for wild fry of the same age, but their condition, as indicated by length-weight relationships, was almost identical to wild pink salmon fry. No mortalities were recorded among fry held in sea water. In fresh water, all fry died within approximately five weeks.

5. An apparatus was designed to maintain a vertical temperature or salinity gradient for a period of many hours. Groups of fry were tested in both gradients at frequent intervals for the first three months after emergence. Fish were tested only once and then released.

6. Pink salmon fry selected certain restricted ranges of temperatures when exposed to a temperature gradient. Youngest and smallest fry generally selected temperatures between 53° and 56°F, older and larger fry selected temperatures between 49° and 51°F. The early emerging fry showed the most variable response in a temperature gradient; peak and late fry exhibited a more regular transition toward cooler temperatures. The change in selected temperature from warmer to colder levels occurred at lengths from 53 to 60 mm for the peak and late fry and occurred between 30 and 40 days after emergence.

7. Pink salmon fry in a salinity gradient selected progressively greater salinities in an orderly sequence after emergence. This sequence was essentially unaffected by the salinity of the holding environment. However, the rate of transition to sea water was apparently dependent upon the time of fry emergence and migration. Early fry required the longest time to enter 30 to 31 °/oo sea water, peak fry were intermediate in their timing, and late fry required the shortest time to enter high salinities. Fry also avoided dilute sea water once they began to select

higher salinities. Early fry took a longer period of time to avoid dilute sea water compared with peak and late fry, but all stocks had essentially completed the transition to sea water within one month.

8. Temperature selection by pink salmon fry may be important in directing their movements during the initial few months of estuarial residence. The initial selection of warmer temperatures may direct fry to onshore locations, while later selection of colder temperatures may direct fish offshore to colder and deeper water. The movement of larger fry into deeper water, as observed experimentally, possibly reinforces the effect of temperature selection. This behavior would help to restrict the numbers of fry located in the limited onshore areas.

9. The growth of young pink salmon as influenced by temperature may be related to survival. Growth has been reported to be rapid in the temperature zone corresponding to the initial temperature selected by fry in the present experiments. However, fry restricted to warmer water onshore have been reported to undergo a fall in rate of growth as they reached larger sizes. The fall in selected temperature seen among larger fry, and possibly associated with offshore migration, may therefore be associated with maintenance of rapid growth. Survival of young pink salmon may be related to their ability to find, in the natural environment, a sequence of temperatures which results in rapid growth.

10. Differences were noted in the sequence of salinities selected and avoided by different segments of an emergence which would result in bringing early and late fry closer to the peak fry in their transition to sea water. This behavior would draw the extremes of the migration to the more central portion which presumably is most suitably timed with the long-term environment.

11. Alterations in the freshwater environment can influence the timing of fry emergence and migration. If timing of migration is restricted to the period most advantageous for the transition to the marine environment, any change in the freshwater environment that alters migration time could be harmful to fry. Similarly, delays in the migration route caused by large impoundments of water behind dams or other obstacles could upset the timing of migration and be detrimental to survival.

LITERATURE CITED

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

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. J. Fish. Res. Bd. Canada, 9(6): 265-323.

Burrows, R.E. and H.H. Chenoweth. 1955. Evaluation of three types of fish rearing ponds. U.S. Fish and Wildl. Serv., Res. Rept. 39: 1-29.

Ford, P. 1958. Studies on the development of the kidney of the Pacific pink salmon (Oncorhynchus gorbuscha (Walbaum)). II. Variation in glomerular count of the kidney of the Pacific pink salmon. Canadian J. Zool. 36: 45-47.

Hoar, W.S. 1960. Environmental physiology of animals. 2nd ed. Scholars Library, New York. 98 pp.

LeBrasseur, R.J. and R.R. Parker. 1964. Growth rates of central British Columbia pink salmon (Oncorhynchus gorbuscha). J. Fish. Res. Bd. Canada, 21(5): 1101-1128.

Martin, J.W. 1966. Early sea life of pink salmon. Proc. 1966 Northeast Pacific Pink Salmon Workshop, Alaska Dept. Fish and Game, Inf. Leaflet 87: 111-125.

Norris, K.S. 1963. The functions of temperature in the ecology of the percoid fish Girella nigricans (Ayers). Ecol. Monographs, 33(1): 23-62.

Parker, R.R. 1964. Estimation of sea mortality rates for the 1960 brood-year pink salmon of Hook Nose Creek, British Columbia. J. Fish. Res. Bd. Canada, 21(5): 1019-1034.

1965. Estimation of sea mortality rates for the 1961 brood-year pink salmon of the Bella Coola area, British Columbia. J. Fish. Res. Bd. Canada, 22(6): 1523-1554.

Sullivan, C.M. and K.C. Fisher. 1953. Seasonal fluctuations in the selected temperature of speckled trout, Salvelinus fontinalis (Mitchill). J. Fish. Res. Bd. Canada, 10(4): 187-195.

Threadgold, L.T. and A.H. Houston. 1964. An electron microscope study of the "chloride cell" of Salmo salar L. Exptl. Cell Research, 34: 1-23.

Vernon, E.H. 1958. An examination of factors affecting the abundance of pink salmon in the Fraser River. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 5, 49 pp.

1966. Enumeration of migrant pink salmon fry in the Fraser River estuary. Internat. Pacific Salmon Fish. Comm., Bull. 19, 83 pp.

Whitmore, C.M., C.E. Warren and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Amer. Fish. Soc., 89(1): 17-26.

Wickett, W.P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Bd. Canada, 15(5): 1103-1126.