INTERTIDAL SPAWNING OF PINK SALMON

BY MITCHELL G. HANAVAN AND BERNARD EINAR SKUD

FISHERY BULLETIN 95

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*

FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

ABSTRACT

Extensive spawning of the pink salmon (*Oncorhynchus gorbuscha*) in the parts of streams subject to tidal action has been observed in Southeastern Alaska. A series of experiments at Lover's Cove stream on Baranof Island was set up to determine the success of this spawning in terms of numbers of fry produced from eggs deposited in the intertidal zone. The experiments used rectangular wire-mesh pens whose lower parts were buried in the stream gravel. Adult salmon were confined in these pens and allowed to spawn; pens remained in the gravel during the incubation period, and fry were counted as they emerged.

Survival rates, calculated as number of fry produced in relation to estimated number of eggs contained in the females, were 20.9, 3.2, and 19.8 percent for 1949, 1950, and 1951, respectively, at the 8- to 9-foot tidal level. Somewhat higher survival rates were noted at the intermediate tidal levels in 1950 than at the extremes, and this was attributed to the winter-tempering effect of water of moderate salinity and temperature.

The effect of crowding was studied by pairing pens at identical tidal levels and doubling the number of females placed in one of the members of the pair. Observations of survival rates and of the adult fish after completion of spawning indicated that the chief effect of crowding was increased egg retention by the more crowded females.

Detailed observations were made of salinities prevailing in the spawning gravels during the tidal cycle. Water was pumped from a pipe driven into the gravel, and its salinity measured with a hydrometer. Salinity was found to increase with each increase in depth of tidal inundation, until a salinity similar to that of open coastal water was reached. Accuracy of hydrometer observations was verified by comparison with titration and conductance measurements.

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SURVIVAL OF PINK-SALMON SPAWN IN AN INTERTIDAL AREA WITH SPECIAL REFERENCE TO INFLUENCE OF CROWDING

By MITCHELL G. HANAVAN, *Fishery Research Biologist*

Pink salmon (*Oncorhynchus gorbuscha*) are taken commercially from Puget Sound to Western Alaska but occur in greatest abundance in Southeastern Alaska, the approximate midpoint of their geographical distribution on the west coast of North America. Collectively, the hundreds of streams of the Alexander Archipelago and of the mainland provide a great expanse of spawning gravel suitable for pink salmon. Individually, many of these streams are short with steep gradients that provide few or no accessible spawning areas above the high-tide level. As a consequence the pink salmon, which spawn in large numbers in streams of the latter type, are limited to riffles within the intertidal zone, i. e., the stream sections between the lower low-tide and higher high-tide levels. Many of the nests made in the gravels of the intertidal zone are covered with salt water for a substantial part of the fall and winter incubation period.

The survival and contribution to the pink-salmon populations of spawn deposited in intertidal areas are of current interest because of the damage to these areas that may result from logging operations. Development of the woodpulp industry in Southeastern Alaska will result in increased logging in the near future and experience proves that logging can be detrimental to salmon-producing streams. Unstable streams are particularly vulnerable to such damage, as a change in the equilibrium of the stream channel at one point may be followed by the shifting of riffles and channels farther downstream with a resulting loss of eggs or alevins in the gravels. Intertidal-stream sections, flowing over barren alluvial deposits, frequently are less stable than stream channels above high-tide level, and consequently are likely to sustain the greater damage from an upset in the equilibrium of the stream.

Presented in this report are measurements of the survival of pink-salmon spawn in an intertidal area as determined by impounding spawners within screened pens and counting the fry produced. Measurements obtained by this method are compared with survival rates in a natural stream, the latter measured by the upstream-downstream counting weir used since 1940 to determine annual fresh-water survival rates in Sashin Creek at Little Port Walter (fig. 1).

A comparison of survival rates under two levels of spawning density is presented as a secondary subject of this report, in part because the pens used in the intertidal study presented an opportunity to obtain a direct comparison under otherwise similar conditions. The technique is better suited to provide information on the manner in which crowding affects survival than to define the most productive distribution of spawners under natural conditions.

Bernard Skud and Willard Brewington of the Seattle Laboratory staff and Jerrold Olson, foreman of the Little Port Walter Station, assisted with the experiments.

THE INTERTIDAL STUDY AREA

We selected Lover's Cove stream near the Little Port Walter field station for our intertidal-zone spawning study. It is typical of many small streams in the southern part of Baranof Island: steep, flood-washed, and unstable. The average annual precipitation at the Little Port Walter station from 1940 to 1951 was 214.07 inches. Undoubtedly, the Cove stream, 2½ miles distant and lying deeper in the mountains, receives even greater rainfall. Frequent floods produce sharp fluctuations in stream level, particularly during the fall months, and result in a shifting of gravel bars and stream channels, and undoubtedly they destroy many eggs deposited in the less stable parts of the stream.

The intertidal zone of the study stream extends approximately 1,500 feet—from high-tide level to

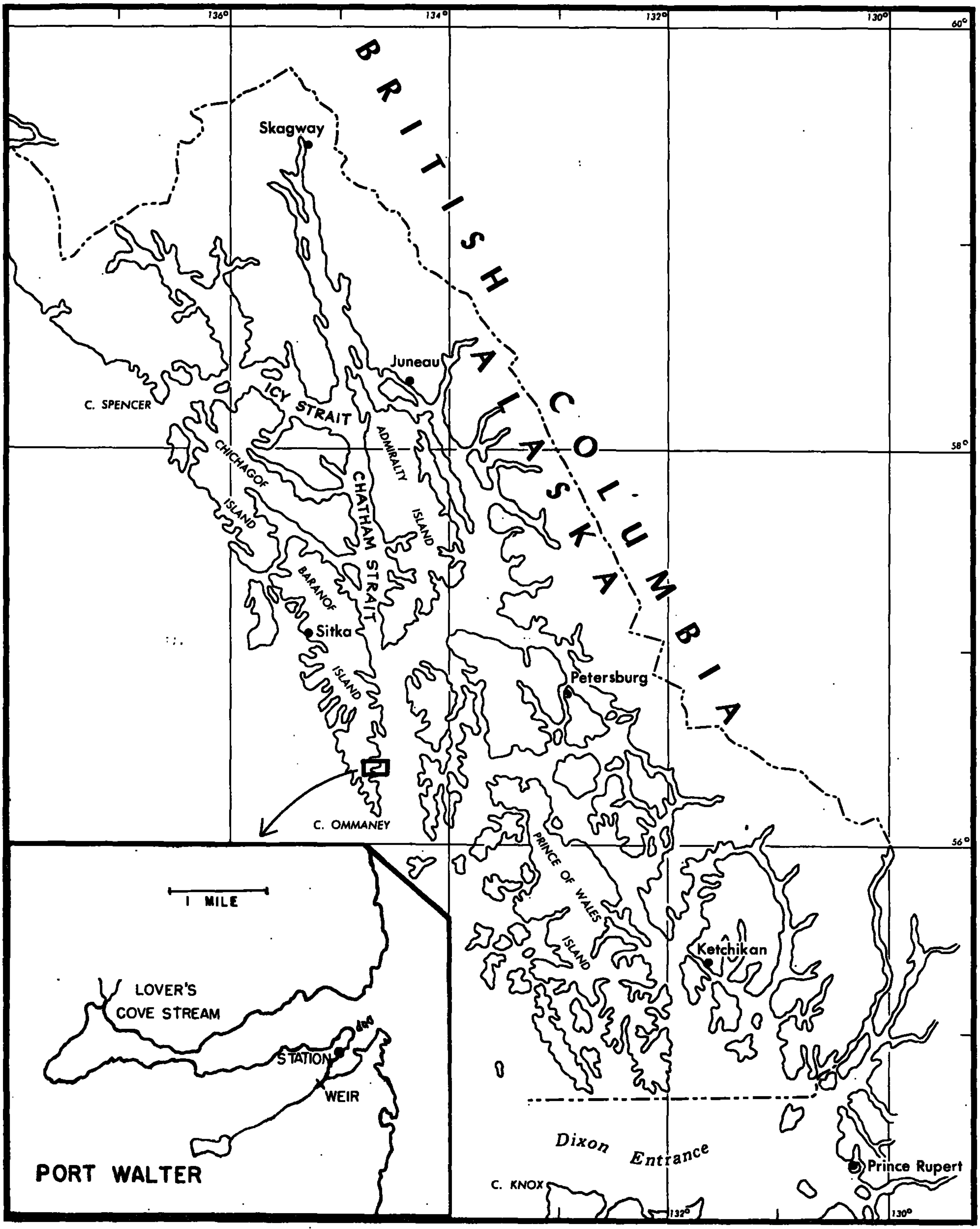

FIGURE 1.—Southeastern Alaska, with insert showing Port Walter.

mean low tide. Through virtually all of this distance the stream traverses a delta which drops abruptly to depths of 20 fathoms and more a short distance below mean low tide. The intertidal zone provides a stream section of moderate gradient with extensive gravel riffles. It is within the upper portion of this section that most of the pink salmon are observed to spawn—roughly, from the plus-4-foot tide level to the higher high-tide mark, plus-11.5 feet.

MEASUREMENT OF SURVIVAL

To measure survival rates in the intertidal zone at Lover's Cove, screened pens were designed to enclose both spawners and fry. A pen constructed for this purpose (shown in fig. 2) measured 8 feet in length and 4 feet in width, and was 2 feet deep. The bottom of the pen was open since the sides extended to a depth of 18 inches in the gravel—10 inches below the level of the deposited eggs. Materials used were 3/16-inch angle iron, 1/8-inch strap iron, and 18-gage 6-mesh-per-inch galvanized wire cloth. Corner bolts held the removable lid in place. Heavy construction provided weight and strength to resist damage from flood, ice flow, and the inquisitive Alaska brown bear. A clearance of 6 to 10 inches between the enclosed gravel and the lid of the pen provided a low profile and minimum resistance to the current. Figure 3 shows pens in position in the stream.

Calculation of survival rates in the pens conformed to the method used at Sashin Creek weir (U. S. Fish and Wildlife Service 1941). This method describes the success of a pink-salmon brood from the count of spawners as they enter the stream in the fall to the count of fry as they enter the sea in the spring. Each mature female, on the basis of repeated sampling contains approximately 2,000 eggs. The 1951 sample, for example, included 77 females, average fork length 21.50 inches, average egg count 2,074.2, standard deviation 239.28 eggs. With 2,000 eggs per female as the basis of calculation, the estimate of the survival rate is determined by the following equation:

$$\text{Survival rate} = \frac{\text{number of fry} \times 100}{\text{number of females} \times 2{,}000}$$

THE 1949 IMPOUNDMENTS

Lover's Cove stream enters the intertidal zone in two main branches which join in a large pool at the plus-4-foot tide level. Four pens were used in the 1949 experiment, two in each branch of the stream at the plus-8-foot tide level, the approximate midpoint of the intertidal area used by spawning salmon.

The pink-salmon populations of lower Chatham Strait, including those of the Cove stream and Sashin Creek, are "late" races that spawn in September and October. Small numbers of pink salmon are observed near the mouth of the Cove stream early in August, but few enter the stream to spawn until mid-September after which spawning activity increases rapidly and declines to completion early in October.

During the second week in September, a movement into the stream with the rising tide and a retreat to the bay with the receding tide characterized the behavior of the pink-salmon schools. Meanwhile the number of active spawners steadily increased, particularly in the upper section of the intertidal zone. On September 11 the behavior pattern changed and a large school of fish remained in the pool at the 4-foot level. We seined these fish, examined them, and selected individuals that appeared to be unspawned. These were measured and placed in the pens. The average fork length of the 18 females used in the experiment was 21.25 inches, standard deviation 1.06 inches.

To determine the effects of crowding on the survival rate, 1 of each pair of pens received 3 females and the other, 6. Pens with 3 females provided approximately 1 square yard for each female while 6 females doubled this concentration. We released 2 males in the pens with 3 females, 5 males in the pens with 6 females, and secured the lids. Fewer males than females, we believed, might reduce the competition between males for partners but later observations indicated that this was an unnecessary precaution. In one instance the impounded males appeared particularly battered about the snout and an additional male was added to the pen to ensure attendance of a male to the end of the spawning period.

In the following history of the impoundment pens those in the west branch of the stream are referred to as 3a and 6a, in the east branch 3b and 6b, in accordance with the number of females held. All pens were stocked on September 11 and table 1 lists the dates on which the dead fish were removed.

TABLE 1.—*Removal of pink salmon from the impoundment pens, 1949*

[M=male; F=female]

Date	Number of adults removed from pen No. —							
	3a		6a		3b		6b	
	M	F	M	F	M	F	M	F
Sept. 26	0	1	0	1	0	2	0	1
29	0	0	0	0	1	0	0	0
Oct. 6	2	2	3	4	2	1	5	5
11	0	0	2	1	0	0	0	0

Ice covered the cove and adjacent inner bay of Port Walter from late November until the latter part of April. The pens were not visited during this period but the first inspection on May 1 revealed them to be in good condition. Fifteen visits were made in May and June to remove and count the fry as they emerged from the gravel (table 2).

Visits to the pens were too infrequent to completely define the periods of spawning and of emergence of the fry from the gravel. Tables 1 and 2 indicate that while the spawning period did not exceed 20 days, the period of emergence was more than 45 days. Later-than-average spawning occurred in pen 6a, possibly accounting for a delay in time of emergence in this pen. The 50-percent-of-emergence date fell on May 19 in pen 6a and on May 8 in 3a. May 12 was the 50-percent-of-emergence date in both 3b and 6b. The later time of emergence in pen 6a is in conformity with the general rule that late-spawning fish produce late-emerging fry.

TABLE 2.—*Removal of pink-salmon fry from impoundment pens, spring 1950*

Date	Number of fry removed from pen No.—			
	3a	6a	3b	6b
May 1	221	95	35	133
3	85	22	6	116
8	195	0	309	122
10	175	0	237	158
12	(1)	18	277	270
15	26	48	135	148
17	14	187	43	100
19	59	373	15	38
22	23	212	45	62
24	21	115	23	63
29	3	9	5	14
June 4	8	16	58	48
10	5	9	49	40
18	(1)	(1)	11	24
30	(1)	0	4	6
Total	835	1,104	1,252	1,342

[1] High water prevented removal of fry.

Summarized results of the 1949 impoundments, with survival rates, are presented in table 3.

Table 3 describes (1) the degree of spawning success achieved by the individual females in each pen, (2) the count and estimated percentage of eggs retained, (3) an estimate of the number of eggs loose in the pens at the conclusion of spawning, (4) the number of fry produced in each pen, and (5) the resulting survival rates.

Comparison of the number of eggs loose in the pens with the number retained in the spent females shows that retention was by far the more important factor in reducing the survival rates. The greater egg retention in the more crowded pens, 6a and 6b, is highly significant by chi-square test but the number of eggs loose in the pens was not clearly related to crowding.

Survival rates were significantly higher in the less-crowded pens, 3a and 3b, although the higher survival in 3b coincided with the largest accountable loss of eggs. The death of a female in 3b shortly after the pens were stocked left only 2 females during the spawning period. This reduction in the effect of crowding apparently favored survival and more than compensated for the larger accountable loss of eggs. Lack of a direct ratio between the accountable loss of eggs and survival rates suggests that crowding may adversely affect survival in some obscure manner—possibly as a result of repeated disturbance of the gravels after they have received the initial deposit of eggs.

TABLE 3.—*Lover's Cove impoundment pens, 1949–50*

Item	Pen No.—			
	3a	6a	3b	6b
Females:				
With 1,800 eggs or more (unspawned)	0	0	1	0
With fewer than 1,800 eggs but more than 100	1	4	1	3
With 100 eggs or less (spent)	2	2	1	3
Eggs:				
Total number	6,000	12,000	6,000	12,000
Number retained by females	174	4,224	3,212	3,455
Retained (percent)	2	35	54	29
Loose in pens	15	300	300	125
Fry:				
Number removed from pens	835	1,104	1,252	1,342
Survival (percent)	13.9	9.2	20.9	11.2

THE 1950 IMPOUNDMENTS

To explore variations in survival related to levels in the intertidal zone, and to obtain additional data on the effect of crowding on survival, we added 6 pens to the experiment in 1950 and

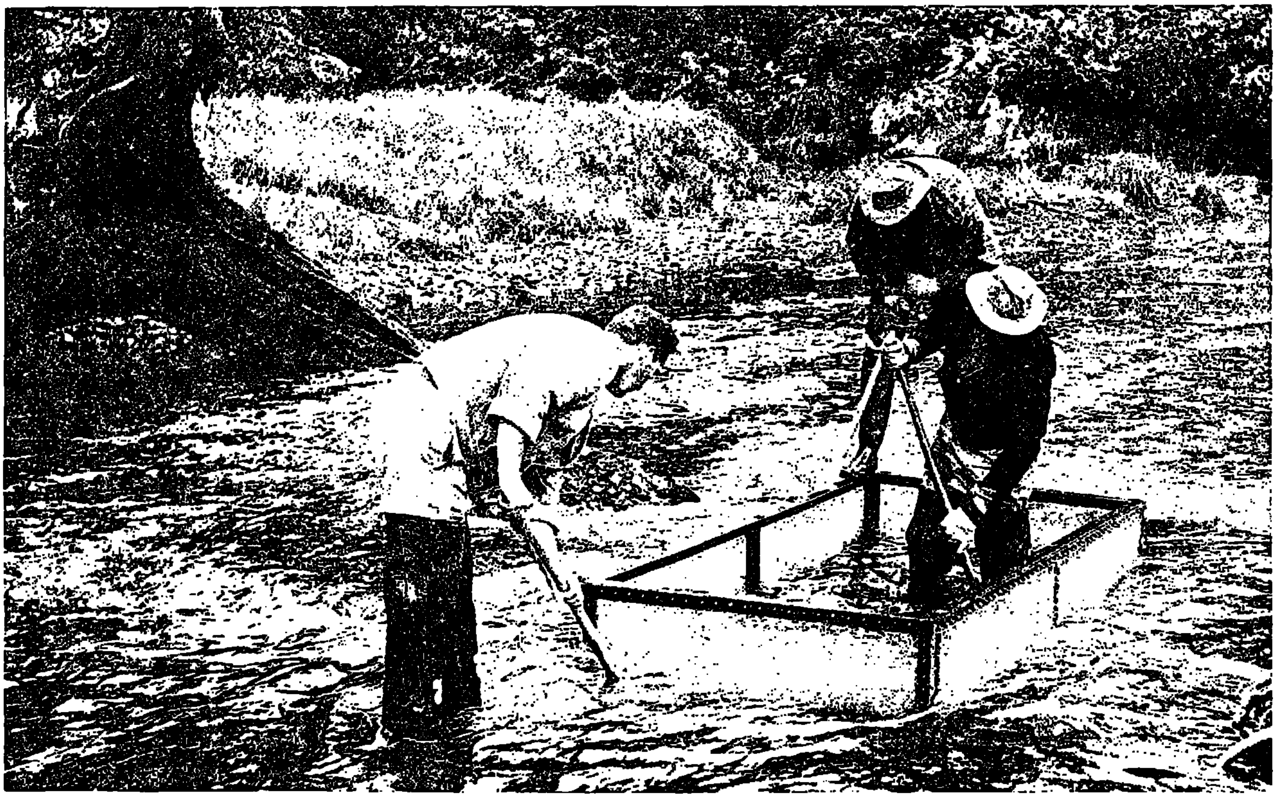

FIGURE 2.—Impoundment pen; setting pen in the gravel of Lover's Cove stream.

FIGURE 3.—Impoundment pens; in place in stream with tops closed.

placed them in pairs at the plus-4-, plus-7-, and plus-11-foot tide levels, while retaining pens 3b and 6b at the plus-8-foot level.

The behavior pattern of the pink salmon in 1950 was similar to that of the previous year, and on the ebb tide of September 13 a large school of salmon remained in the pool at the plus-4-foot tide level. We seined these fish, selected and measured the females to be used in the experiment, and placed them in those pens located between the 4- and 8-foot levels. The fish placed in pens at the plus-11-foot tide level were caught in small pools in the upper intertidal zone. The average fork length of the 35 females used was 21.97 inches, standard deviation 1.12 inches.

Three pairs of pink salmon were placed in 1 of each of the paired pens and 6 pairs in the other. In the following tables each pen is described by 2 numbers, the first indicating elevation above mean low tide (0-foot tide level) and the second the number of female pink salmon held in it; for example, 7–6, 7–3, designate pens at the 7-foot tide level, one of which contains 6 females and the other 3.

Table 4 gives the schedule of removal of dead fish from the pens listed in their upstream order. High water on September 20 and October 2 prevented inspection of pens 4–5 and 4–3 on those dates. On October 8, following a week of continuous rainfall, we found the lids of 4–5, 4–3, and 7–6 dislodged, and the pens empty. High waters obscured conditions in the other pens on this date. In view of the subsequent history of 7–6 it is probable that all three of these pens received a fairly complete deposition of eggs. As a general rule, in any well-defined spawning area, there is a downstream progression of spawning activity during the course of the season—a tendency for early arrivals to spawn in the upper and late arrivals in the lower reaches of the spawning gravels. This is true even in a relatively short intertidal-zone stream section, and, as a result, the fish seined in the upper part of the intertidal zone and held in pens 11–6 and 11–3 spawned shortly before those in the other pens.

TABLE 4.—*Removal of pink salmon from the impoundment pens, 1950*

[M = male; F = female]

Date	Number of adults removed from pen No.—															
	4–5		4–3		7–3		7–6		8–3		8–6		11–6		11–3	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Sept. 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	(1)	(1)	(1)	(1)	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Oct. 2	(1)	(1)	(1)	(1)	0	2	1	4	1	1	1	2	5	5	2	2
8	(2)	(2)	(2)	(2)	(1)	(1)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
14	(2)	(2)	(2)	(2)	3	1	(2)	(2)	2	2	5	4	0	0	0	0

[1] Obscured by high water.
[2] Pen cover dislodged by high water.

TABLE 5.—*Removal of pink-salmon fry from impoundment pens, 1951*

Date	Number of fry removed from pen No.—							
	4–5	4–3	7–3	7–6	8–3	8–6	11–6	11–3
Apr. 29	0	0	24	85	123	114	0	0
May 7	0	0	243	480	34	98	(1)	181
9	0	0	114	196	23	27	(1)	52
14	(1)	0	0	0	5	(1)	(1)	(1)
16	0	0	83	191	4	(1)	(1)	(1)
25	0	1	10	13	0	(1)	(1)	(1)
28	1	0	1	2	0	33	(1)	31
31	0	0	0	1	0	3	(1)	3
June 4	0	0	0	0	0	2	(1)	0
8	0	0	1	0	0	(1)	(1)	(1)
Total	1	1	476	968	189	277	0	267

[1] High water prevented removal of fry.

Ice covered Big Port Walter Bay, preventing access to the pens from November 15 until April 28. Between April 28 and June 8 the pens were visited 10 times to remove and count the fry as shown in table 5.

In general, the periods of spawning and emergence in 1950–51 were similar to those of 1949–50. A notable difference, seen by comparing tables 2 and 5, was the rapid decline in the numbers of emerging fry in the spring of 1951, after what appeared to be a productive start, in contrast with the more prolonged period of emergence in 1950.

The cause of the failure of pen 11–6 to produce fry was not determined. High water submerged the pen through the entire period of the emergence of the fry and, although visibility through the screen was believed adequate to permit observation of fry, were any present, none was observed nor was any means of escape detected.

Results of the 1950 impoundment are summarized in table 6. Fifty percent of the females removed from the pens in 1950 were completely spawned, a slight increase over the 1949 percentage, and one entirely attributable to the spawning success of the more mature females placed in the pens at the 11-foot tide level.

Retention of eggs resulted in a substantial loss during the spawning period and, as in 1949, it was

TABLE 6.—*Lover's Cove impoundment pens, 1950–51*

Item	Pen No.—							
	4-5	4-3	7-3	7-6	8-3	8-6	11-6	11-3
Females:								
With 1,800 eggs or more (unspawned)	(1)	(1)	0	....	0	0	1	0
With fewer than 1,800 eggs but more than 100	....	....	2	3	1	4	1	0
With 100 eggs or less (spent)	....	....	1	1	2	2	4	3
Eggs:								
Total number	10,000	6,000	6,000	12,000	6,000	12,000	12,000	6,000
Number retained by females	....	....	1,624	4,658	1,116	2,646	2,846	16
Retained (percent)	....	....	27	39	19	22	24	0
Loose in pens	....	....	100	125	1,000	1,000	425	150
Fry:								
Number removed from pens	1	1	476	968	189	277	(2)	267
Survival (percent)	....	....	7.9	8.1	3.2	2.3	....	4.5
Percentage of time covered by tide	65	65	35	35	25	25	2	2
Maximum salinity in gravel (‰)	30.7	30.7	29.7	29.7	7.6	7.6	.0	.0

[1] Record incomplete as noted in table 4.
[2] Record incomplete as noted in table 5.

significantly greater in the more crowded pens. The estimate of eggs loose in impoundment pens at the conclusion of the spawning period again indicated that this source of loss not only was less than the loss of eggs by retention, but it also was less clearly related to crowding than was egg retention.

The level of survival in the impoundment pens during the winter of 1950–51 was well below that of the previous year. In 1949–50, survival rates in pens 3b and 6b were 20.9 and 11.2 percent. The same pens, identified as 8–3 and 8–6 in 1950–51, had survivals of 3.2 and 2.3 percent.

Table 6 includes two categories of measurements not contained in table 3. These are (1) percentage of the incubation period during which nests were exposed to tidal inundation, and (2) maximum salinities measured at high tide at a point 8 inches deep in the stream gravel. The methods used in obtaining these measurements and the hydrodynamics of the intertidal zone are discussed in Salinity gradients in the intertidal zone of an Alaskan pink-salmon stream, page 177.

THE 1951 IMPOUNDMENTS

In 1951, the pen locations remained as they were in 1950 with the exception that pens at the 11-foot level were moved to more stable and accessible locations at the 9-foot level. Pens at the 4-foot level were washed several hundred feet downstream by heavy rains September 8 and 9, and as further shifting of the stream channel appeared imminent they were not replaced.

Flood damage to the stream channel and continuing high water prevented effective use of the seine; however, on September 15, fish were taken to stock all pens with the exception of one at the 9-foot level. Average fork length of the 21 females was 21.79 inches, standard deviation 0.99 inches.

Big Port Walter remained frozen from mid-December until mid-April and on April 28 the first fry were counted from the pens. Production was well below expectations in the pens at the 7- and 8-foot levels, and when water levels permitted, a close inspection revealed holes in the screens caused by corrosion and abrasive action of sand. An unknown number of fry escaped through these openings, and as a result data were incomplete from 4 of the 5 pens.

Results of the 1951 impoundments follow in table 7.

Table 7 shows fewer females in the completely spawned category than occurred in previous impoundment trials, but the percentages of eggs retained were similar to those of previous experiments—a significantly greater retention of eggs occurring in the more crowded pens.

Contrary to previous experience, the number of eggs loose in the pens at the conclusion of spawning

TABLE 7.—*Lover's Cove impoundment pens, 1951–52*

Item	Pen No.—				
	7-3	7-6	8-6	8-3	9-3
Females:					
With 1,800 eggs or more (unspawned)	0	1	1	0	0
With fewer than 1,800 eggs but more than 100	1	3	5	2	2
With 100 eggs or less (spent)	2	2	0	1	1
Eggs:					
Total number	6,000	12,000	12,000	6,000	6,000
Number retained by females	843	4,228	6,127	1,678	672
Retained (percent)	14	35	51	28	11
Loose in pens	43	500	225	10	7
Fry:					
Number removed from pens	(1)	(1)	(1)	(1)	1,185
Survival (percent)	(1)	(1)	(1)	(1)	19.8

[1] Corroded screens allowed fry to escape.

was positively and significantly correlated with the number of females held ($r=0.883$, $P<.05$). This loss of eggs again was of minor significance compared with the loss by retention.

Fortunately, one of the 5 pens (9–3) survived the rigors of the winter and produced 1,185 fry from the spawning of 3 females. The high survival rate, 19.8 percent, was similar to the 20.9 percent survival of pen 3b at the 8-foot tide level, during the successful winter of 1949–50.

DISCUSSION

The use of screened enclosures in the intertidal experiments imposed limitations on the interpretation of results. Measurements obtained by this method are not directly comparable to those obtained by weir counts in a natural stream area, such as Sashin Creek (fig. 4), nor do they measure spawning success and survival in intertidal areas other than those within the pens. The handling of adult fish and the restricted space available for them within the pens were factors that did not favor spawning success or the survival rate. On the other hand, both adults and fry were protected from predators, a condition favoring survival.

The interplay of natural and imposed conditions on the intertidal experiments for the years 1949, 1950, and 1951 resulted in survival rates of 20.9, 3.2, and 19.8 percent in pens that contained 3 females located at the 8- and 9-foot tide levels. Survival rates in Sashin Creek for these years were 3.7, 0.1, and 9.3 percent. The average for the 12-year period 1940–51 was 2.54 percent. The similarity in the years of occurrence of the high- and low-survival rates in the intertidal and fresh-water areas suggests a response to common environmental factors and specifically to those factors related to the fresh-water environment.

It may be significant in this regard that the winter of 1950–51 was unusually cold with the greatest departure from normal temperatures occurring in November. In the 12-year period 1940–51, the four lowest survival rates in Sashin Creek coincided with the four coldest Novembers suggesting that abnormally low stream temperatures occurring early in the incubation period (between the 6th and 10th weeks) may be particularly damaging to the developing eggs. The average Sashin Creek stream temperature for November in 1949 was 43.3° F., in 1950 it was 36.9° F., and in 1951 it was 39.4° F.

If the abnormal drop in stream temperatures in November 1950 was, in fact, the cause of low survival rates in the pens and in Sashin Creek, and if low temperatures proved particularly damaging to eggs deposited during the latter part of the spawning period (those in an early stage of development), this factor could account for both the low survival rates and the brief period of emergence shown in table 5.

Differences in the survival rate related to the 4-, 7-, 8-, and 11-foot tide levels are shown in table 6. Pens 4–5 and 4–3, located near the lower limit of the intertidal area used by spawning pink salmon, produced one fry each. Similarities in the histories of these pens and of pen 7–6 during the spawning period indicate that seeding occurred at the 4-foot level. It may therefore be inferred that the low survival resulted from exposure of eggs to salinities which reached concentrations approaching those of open coastal sea water, 30.7 p. p. th. Thus, during periods of tidal inundation, which totaled 65 percent of the October–April incubation period, eggs at the 4-foot level were subjected to high salinities for extended periods of time.

The eggs in pens 7–3 and 7–6 were exposed to maximum salinities (only slightly lower than those at the 4-foot level) but with much shorter intervals of exposure; periods of tidal inundation totaled 35 percent of the incubation period. Apparently this was an optimum level during the adverse winter of 1950–51, as the pens at the 7-foot level were more productive than those at higher elevations.

Frequency of exposure to salt water of moderate temperature may have favored survival at the 7-foot level, as all high tides of November and December exceeded 7 feet, although several successive lower high tides failed to reach the 8-foot level. Thus the 8-foot level and those above it were exposed to more prolonged periods of untempered stream flow. The tempering effect of the tides continues through the incubation period, as marine temperatures exceed stream temperatures from October through April. In November 1950, the mean Sashin Creek temperature was 36.9° F., while the marine temperature at Sitka was 44.5° F. (U. S. Coast Geodetic Survey 1952). April 1951 temperatures were 34.2° and 41.4° F., respectively. Temperatures measured in the bay at Little Port Walter in February 1951 are probably more indicative of differences existing in water temperatures at the Cove and in the sea. Bay tem-

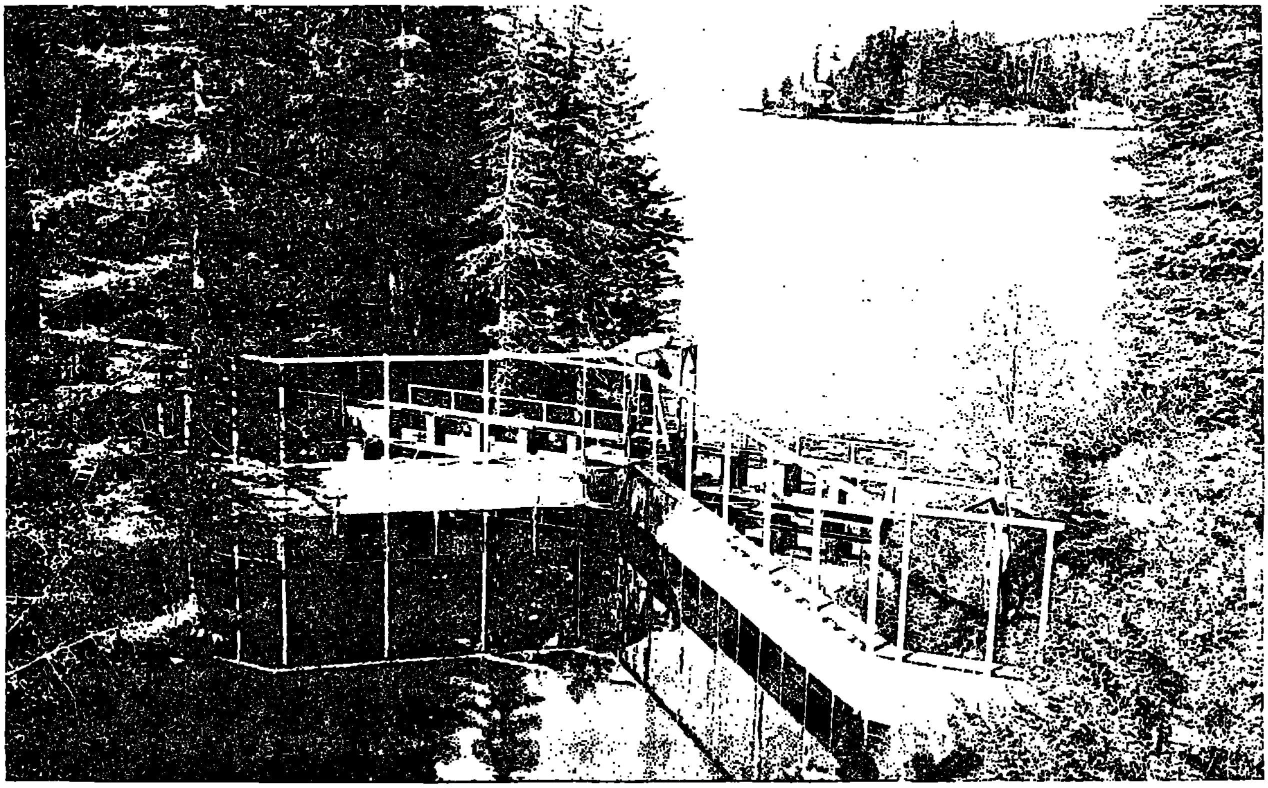

FIGURE 4.—Sashin Creek weir, Little Port Walter, Alaska.

peratures averaged 34.6° F. in the brackish surface layer and 39.1° F., 20 feet below the surface. Appendix table B–1, p. 185, shows the warming in the stream gravel that accompanied a rising tide in August 1951.

While the periods of immersion in salt water at the 7-foot level favored survival they did not favor earlier emergence of the fry from the gravel which, as table 5 shows, occurred at the 8-foot level. As previously noted, low-survival rates during the 1950–51 season apparently were related to an unfavorable fall stream-temperature gradient. In contrast, emergence and downstream migration of the fry are related more closely to the spring stream-temperature gradient. On the basis of 10 annual measurements, the time of the seaward migration of fry in Sashin Creek shows a correlation of $r = -0.215$ with the November–December stream temperatures; while the correlation with March–April stream temperatures is $r = -0.881$, a highly significant correlation.

Crowding, as an influence on successful spawning and survival, was measured by the device of pairing the pens and stocking one with twice as many females as the other. The levels of crowding arbitrarily selected approximated 1 and 2 females per square yard. There is evidence in past escapement records that under natural conditions crowding may be an influence in reducing the survival rate. Egg retention, failure to deposit in the gravel, and mechanical shock caused by repeated stirring of the gravel may all result from crowding and contribute to this loss. The first of these, increased egg retention, was the only factor consistently in evidence in pen experiments.

SUMMARY

Pink salmon spawn in large numbers in many of the intertidal areas of Southeastern Alaska streams. To obtain information on the productivity of intertidal spawning, a series of experiments using wire-screen enclosures was undertaken in an intertidal area near the Little Port Walter station during the years 1949, 1950, and 1951. The experiments were designed to show differences in the survival rate, from spawning to the emergence of fry, related to periods of inundation at various tidal levels.

Crowding as an influence on successful spawning and survival was measured by the device of pairing the pens and stocking one with twice as many females as the other. The levels of crowding arbitrarily selected approximated 1 and 2 females per square yard. Results of the experiments indicated the following:

1. The lower limit of the intertidal area in which pink salmon spawn, approximately 4 feet above mean low tide, may be unproductive but above this level the survival of spawn is comparable to if not greater than survival in fresh-water stream areas.
2. Abnormally cold stream temperatures, resulting in a low fresh-water survival rate, may be modified by warmer tidewater to create conditions most favorable for survival at some intermediate level in the intertidal zone.
3. Crowding reduces the survival rate by increasing the retention of eggs and possibly by increasing the incidence of mechanical shock to eggs previously deposited in the gravel. The loss of eggs by failure to deposit in the gravel was secondary to retention as a cause for lower survival rates and was less clearly related to crowding.

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SALINITY GRADIENTS IN THE INTERTIDAL ZONE OF AN ALASKAN PINK SALMON STREAM

By BERNARD EINAR SKUD, *Fishery Research Biologist*

This study[1] was carried out to supplement fresh-water survival data which have been gathered in Southeastern Alaska on the pink salmon (*Oncorhynchus gorbuscha*), a species known to utilize spawning areas in the intertidal zone of some streams. Environmental differences between intertidal and fresh-water zones of a stream have led fishery biologists to question whether intertidal spawning by pink salmon is detrimental to the survival of their eggs and fry. To interpret the effects of tidal inundation on survival of spawn, it is necessary to understand the physical characteristics of the intertidal zone. The purpose of this investigation was to determine the degree of salinity in the water within the gravel beds of known intertidal spawning grounds.

In recent years, the physical and biotic characteristics of waters in the intertidal zone have drawn the attention of numerous ecologists and oceanographers. Whether their studies dealt with the hydrobiology of organisms or hydrological features in relation to pollution, the investigations have readily exhibited the complexity of the factors involved.

In the literature there is a noted discrepancy in the interpretation of different types of saline waters and it is, therefore, appropriate to qualify and define the estuarine area referred to in this paper. It is not the intent to evaluate previously proposed definitions, but only to present, for the sake of clarity, descriptions best suited for the study. Rochford (1951) distinguishes estuarine from brackish waters on a principle of variability based on time; that is, estuarine suggests a daily as well as a seasonal fluctuation in salinity, whereas brackish implies only a seasonal salinity change. It is necessary to submit only two divisions of the estuarine waters—those of the inlet up to the mouth of the stream and those of the intertidal zone from the mouth to the farthest reaches of the highest tide. The mouth, in this instance, is considered as the equivalent of the zero tide level. Further classification is not necessary for the purposes of this paper.

SAMPLING PROCEDURES

In conjunction with a series of experimental spawning pens at Lover's Cove stream sampling of the water within the stream bed was initiated during the summer of 1951 (see fig. 1, p. 168). The spawning pens were set at selected distances upstream from the mouth to subject them to varying degrees of inundation by tidal waters. The pens were stocked each fall with a given number of male and female pink salmon and the fry were counted out each spring so that the survival could be determined. A sampling station for measuring salinity was set up at four of the pen locations so that salinity sampling results could be correlated with fry survival (see p. 173).

At each location, a galvanized pipe with an outside diameter of 1 inch was set in the gravel of the stream bed to a depth of 6 to 8 inches, corresponding to the average depth of pink-salmon nests. A 10-foot length of pipe was used at the set of pens closest to the creek mouth (station A) to permit sampling at flood tide, and a 5-foot section of pipe was placed beside it at the same depth, to facilitate sampling at ebb tide. The pipe was open at both ends and the pipe end in the gravel was perforated with 12 ⅜-inch holes to ensure maximum exchange of water within the pipe and in the area immediately surrounding the pipe.

Actual sampling was accomplished by using a hand pump and a length of ½-inch rubber tubing which could be inserted into the pipe. Water was pumped into sampling jars at the approximate rate of 1 quart in 15 seconds, and each sample was held for density determinations with a hydrometer. This method was devised to obtain preliminary information on the changes that take place under the influence of tidal inundation. Though neces-

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[1] The author was assisted by Jerrold Olson and Willard Brewington, of the Fish and Wildlife Service.

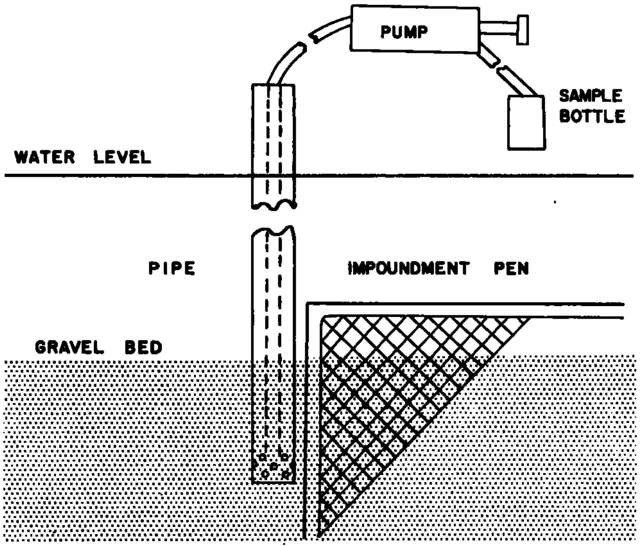


Figure 1.—Diagrammatic section of sampling station at high tide.

sarily crude, this initial procedure for taking samples from within the gravel of the stream bed was carried on at the other stations (fig. 1). Table 1 gives the location of the stations and their relation to the tides (based on astronomical predictions from mean lower-low water).

Table 1.—*Location of stations and tidal influence*

Approximate distance upstream from zero tide level	Tidal level at station, from mean lower-low water	Approximate time covered by the tide in a 7-month period
	Feet	*Percent*
Station A: 400 feet	4	65
Station B: 800 feet	7	35
Station C: 950 feet	8	25
Station D: 1,300 feet	11	2

The pipes used at each station were wired to the steel impoundment pens so that they would not be subject to any movement that might disturb the gravel surrounding the openings at the bottom of the pipe. These permanent stations could be sampled repeatedly during various tidal cycles. When the height of the water permitted, sampling was done by standing on top of the pens which were approximately level with the normal stream height. When the incoming tide raised the water level too high, samples were taken from a small skiff. The following data were recorded: Time sample was drawn, height of water, air and water temperatures, and maximum tidal height.

To facilitate recording the progressive rise of tidal waters at each station, the sampling pipes were marked in inches, the zero mark being equivalent to the level of the impoundment pen cover. Samples were originally drawn at 1-foot and ½-foot intervals, but in an effort to determine more accurately the stage at time of the change from fresh to salt water, samples were drawn at 1-inch and 2-inch intervals. Samples were drawn at a number of different stations during the same tidal cycle to compare the resulting salinities as the tidal water progressed upstream. Continuous sampling sequences were attempted at two of the stations during both flood and ebb tides; however, it was not possible to attain complete sequences on different days with similar tidal cycles.

SALINITY DETERMINATIONS

The positions of the pens were such that station A was reached at a tidal level of 4 feet, station B at 7 feet, and station C at 8 feet. The depth of tidal water at which a given degree of salinity occurred within the gravel bed varied at these three stations during the same tidal cycle, and also varied at any one of the stations during different tidal cycles (fig. 2). Stations B and C, located on the left-hand tributary of the stream, were exposed to an equal volume of fresh-water discharge. During a particular tidal cycle, under 25 inches of tidal inundation, station B reached a saline content of 27 parts per thousand, whereas, at the same depth station C registered a salinity of less than 5 parts per thousand. This progressive salinity decrease upstream represents the

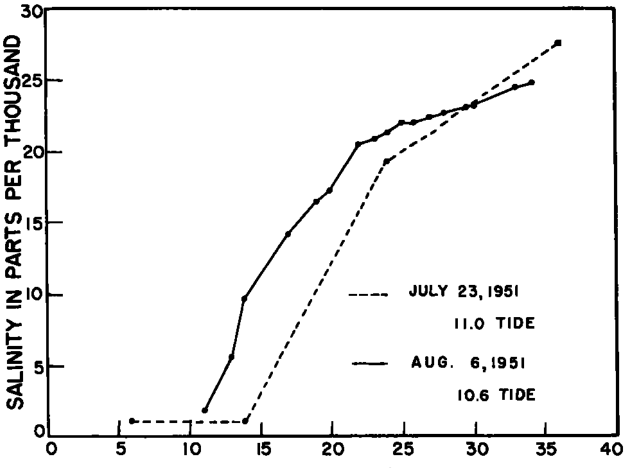


Figure 2.—Samples from station A on days with comparable tidal heights.

longitudinal salinity gradient, and is brought about by the continual dilution and mixing of fresh and sea water. Station A, which was located below both the left and right branches of the stream, was subject to washing by a greater volume of fresh water than the other stations. This fact introduced a variable which prevented an exact comparison among all of the stations during a tidal cycle.

Station D was reached by only the highest tidal waters which were subject to continuous mixing and hence to the greatest dilution. Sampling was soon discontinued at this station, since no substantial increase in salinity was recorded.

The method of testing for salinity, by use of a set of hydrometers, necessitated drawing off as much as a quart of water for each sample. At the outset of the work, the amount of water sampled was considered a means of ensuring complete circulation of the ambient water with that in the pipe. At a later date it was suggested that such quantities for each sample might tend to draw water, by suction, from areas above the gravel of the stream bed. This possibility, later tested and compared by the conductivity method, is discussed in appendix A, p. 182. Salinity determinations in the tidal zone required the use of three hydrometers to provide density readings for the entire range—one with a scale ranging from 0.996 to 1.011, a second with a scale 1.010 to 1.021, and a third with a scale from 1.020 to 1.031. The hydrometers were floated in the sample water contained in quart mason jars (the best available containers). The temperature of each sample was taken to correct for differences of density arising from reading the hydrometer at temperatures other than its calibration temperature of 15° C.; such corrections and the conversion of density to salinity were made from tables in the Manual of Tide Observations (U. S. Coast and Geodetic Survey 1941). These data are recorded in appendix B, p. 183.

Specific conductance determinations were made on the model RC–1B conductivity bridge manufactured by Industrial Instruments, Inc. The conductivity cell was a dipcell, type Cel–1A, supplied by the same manufacturer. The accuracy of this a.-c. unit is somewhat limited, depending on the scale used and the ability and care exercised in using the instrument. Personal error may be present either in reading the scale or in setting the null indicator. Compensation for differences in conductance due to temperature was necessary. Before use, the conductivity cell was replatinized, and the cell constant was determined and checked after each series of observations.

The table presented by Thomas, Thompson, and Utterback (1934) was used to determine chlorinity and the established empirical relation (salinity equals 0.03 plus 1.805 [chlorinity]) between salinity and chlorinity provided the salinity readings in parts per thousand. Redfield (1948) points out that the concentration of various constituents of sea water mixed with river water cannot be precisely estimated from chlorinity because of the relatively richer composition of dissolved solids in river water. For this reason, salinity is not exactly proportional to chlorinity.

Approximately 200 samples were taken from the creek at Lover's Cove. Some 40 of these were retested at the Seattle laboratory of the Fish and Wildlife Service by the conductivity method of determining salinity. As a further check of the accuracy of the determinations, the salinity of a number of the samples was tested by the titration method at the oceanographic laboratories of the University of Washington. The results of the three methods were compared and the hydrometer, or density, method found sufficiently accurate for the purposes of this work.

The conductance method was also used in the field for testing the sampling method and warrants further explanation and discussion of the procedure followed. Comparisons of the accuracy of the three methods showed that the original values obtained with the hydrometer differ by less than 10 percent from the values found by titration and conductance (table 2). This method

TABLE 2.—*Comparison of salinity determinations by 3 methods of samples from Lover's Cove stream, 1951*

Sample	Salinity (°/$_{oo}$) determined by—		
	Titration	Conductance	Hydrometer
No. 698	2.8	2.9	2.9
No. 702	12.6	11.8	12.9
No. 703	10.7	10.0	10.8
No. 704	8.7	8.5	8.8
No. 713	5.4	5.1	5.1
No. 714	26.8	25.7	27.7
No. 716	4.0	3.8	3.9
No. 718	3.6	3.3	3.4
No. 3268	17.8	17.2	17.5
No. 3273	21.9	20.8	22.6
No. 3283	18.9	19.0	20.9
No. 3285	22.3	21.7	22.7

also has many distinct advantages in the field. In areas of comparatively small ranges of density, the common form of stem hydrometer is generally not sufficiently accurate but it is applicable in estuarine waters, where greater ranges in density are encountered.

HYDROLOGY OF THE INTERTIDAL ZONE

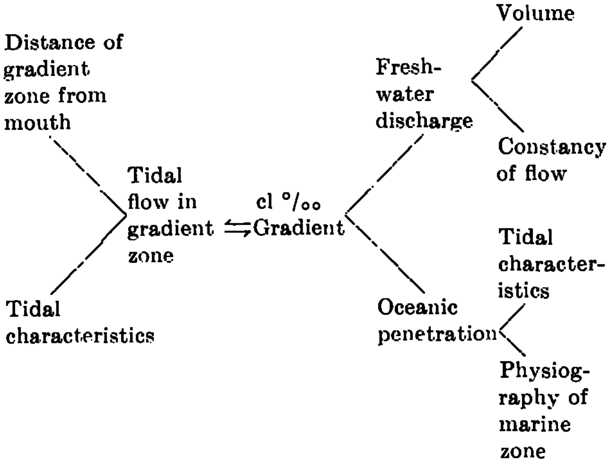
Consideration of the physical changes in the intertidal zone, brought about by the mixing of fresh and salt waters, is essential in an analysis of the sampling results. The variables most significant in this study include density, salinity, tidal forces, stream discharge, and turbulence. The density of inshore sea water is, for the most part, dependent on salinity. Density and salinity gradients may, therefore, be regarded as essentially the same. The forces exerted by tidal waters and stream discharge produce the turbulence and, in effect, the mixing of the fresh and saline waters. These components and their relation to density contribute to the production of the three zones of oceanographic structure of a water mass described by Tully (1949). The upper zone is formed by fresh water entering the tidal body and mixing with the underlying sea water, and its lower limit is marked by an inflexion in the salinity gradient. The seaward movement of fresh water and the reciprocal movement of the tide produce a middle, or circulatory, zone bounded by a threshold, which separates it from the third, or deep, zone.

For the most part, Tully's work was limited to that area of an inlet up to the creek mouth. The results obtained in sampling the Lover's Cove stream during tidal inundation showed that the phenomena of salinity gradients continue upstream. Some distinction should be made, however, between the differences encountered in a restricted channel of a stream and in the wider scope of an inlet or bay. A stream of fresh water entering the inlet has a tendency to spread, more or less fan shaped, over the underlying saline water. In this process, some mixing of fresh and salt waters is in evidence and results in the formation of lateral salinity gradients, the water becoming more saline as the distance from the mouth increases. On the other hand, when tidal waters have progressed upstream into a comparatively small channel, fresh water entering the system is limited to the same channel and lateral gradients are less significant.

The dispersion of fresh-water runoff as it enters estuarine waters during flood tide is described concisely by Tully:

> It is reasoned from the principle of isostacy that when fresh water is being supplied continually in one part of the system and sea water is supplied in another there will be a constant isostatic head inducing a surface seaward flow. It is remarked that both the upper and middle zones become more saline to seaward, from which it is reasoned that all the fresh, and at least some of the sea water leaves the inlet through the upper zone . . . any fresh water accumulating in the middle zone would tend to join with the upper zone, and a compensatory inflow of sea water in the middle zone would result.

It follows, then, that the mixing process is largely a horizontal exchange across the salinity gradients, and the extent and manner of mixing largely determine the degree of zonation in estuarine waters. A composite picture of the components and their contribution to the development of the salinity gradient is found in the following diagram (after Rochford 1951):



During an ebbing tide, the tidal flow decreases and eventually reverses its movement so as to be flowing in the same direction as the overlying fresh water. As the estuarine waters in the intertidal zone decrease in depth to include only the upper zone of density stratification, the process of recovery begins as the churning fresh water enters the system uninhibited by an incoming tide.

During the early stages or at the upper limits of an incoming tide, the depth of tidal inundation in the stream is not great enough to establish the three zones of density stratification. Depending on the depth of the tidal waters, either the lower zone or both lower and middle zones may be lacking. Nevertheless, where the depth of sea water is sufficient, the upper and middle zones in the open waters of the inlet should appear in the stream. Sampling data from the surface to the stream bottom confirmed that this was true for Lover's Cove stream. Furthermore, the same stratification was present when sampling was done from the surface to varying depths within the gravel. By sampling at short intervals, it was possible to follow the progress from the upper zone to the presence of the inflected boundary and then to the middle, or circulatory, zone (fig. 3). There is also adequate evidence of the longitudinal stratification which was present in the intertidal zone. As mentioned before, this stratification proceeds to an approximate nil salinity at or near the tidal limit for any given instant.

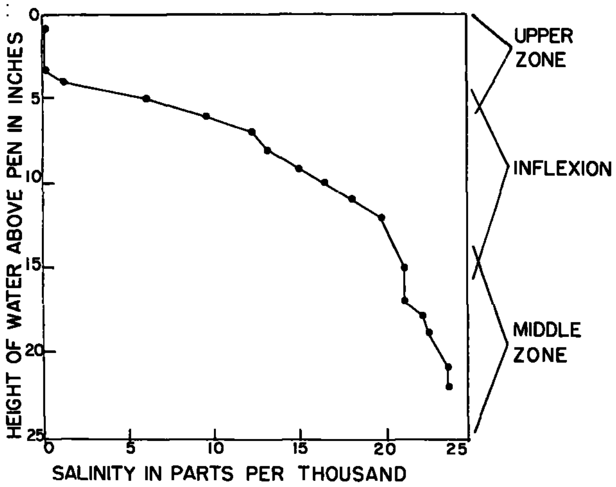


FIGURE 3.—Lover's Cove, station B, depicting oceanographic structure of the salinity gradient, August 7, 1951.

The stratification revealed by sampling indicates that the gravel bottom did not essentially impede either the exchange of fresh and sea water or the forces exerted by an incoming tide. This brings to light an interesting comparison of bottom types and their tendency to obstruct the transfer of fluids of varying density. The texture, shape, and sorting of the materials composing the stream bottom are important factors to be considered in the porosity, hence the water content, of a particular deposit. Permeability of a sediment which is related to porosity, is of particular concern and is a measure of the ability of water to circulate through the sediment.

Reid (1930) and W. B. Alexander et al. (1932) found considerable retention of saline water in intertidal sand after the tide had receded. A gravel bottom undoubtedly has similar tendencies toward retention, but is more permeable than sand and permits thorough washing by fresh water. In a few instances, a lag occurred in the recovery to fresh water and also in the establishment of saline water within the gravel. This tendency, possibly effected by interstitial water, occurred in areas of less-coarse gravel. In general, however, the recovery to fresh water within the stream bed at Lover's Cove during an ebb flow exhibited a very slight distinction, if any, from the recovery in the layer of water just above the stream bed (table 3).

To predict the threshold of change from the upper to the middle zone during any tidal cycle, stream discharge, local runoff, wind, and seasonal salinity changes must be considered. Stream discharge and runoff are of particular concern in this part of Southeastern Alaska which annually records over 200 inches of rainfall. Wind can bring about changes in the degree of mixing in estuarine waters, in addition to influencing the tidal cycle itself. Seasonal changes in salinity are likewise of some consequence. The salinities of these waters are the highest in the months preceding the spring thaw and the lowest in the summer months.

TABLE 3.—*Data sheet showing recovery to fresh water during an ebbing tide at station B, July 31, 1951*

[High water—8.7 feet at 1323; low water—3.9 feet at 1829]

Sample	Height of water above pen	Time	Tide height	Temperature	Hydrometer reading	Density corrected to 15° C.	Salinity
	Inches		*Feet*	° *C.*			‰
No. 6	12	1401	8.5	15.5	1.0114	1.0115	16.1
No. 8	11	1409		15.5	1.0100	1.0101	14.2
No. 10	10	1418		15.5	1.0100	1.0101	14.2
No. 12	9	1425		15.5	1.0094	1.0095	13.5
No. 13	8	1430		15.5	1.0090	1.0091	12.9
No. 14	7	1437		15.5	1.0074	1.0075	10.8
No. 15	6	1442	8.0	15.5	1.0058	1.0059	8.8
No. 16	5	1448		15.5	1.0034	1.0034	5.5
No. 17	4	1452		15.5	1.0018	1.0018	3.4
No. 18	3	1456		15.5	1.0008	1.0008	2.1
No. 19	2	1500		15.5	1.0002	1.0002	1.3
No. 20	1	1505		15.5	1.0000	1.0000	1.1
No. 21	0	1509	7.5	15.5	<1.0000	<1.0000	<1.0
No. 22	0	1514		15.5	<1.0000	<1.0000	<1.0

CONCLUSIONS

Pink salmon utilize spawning areas in the intertidal zone of some streams in Southeastern Alaska.

To evaluate the survival of spawn in an intertidal area it is necessary to ascertain and understand the physical components of such an environment. The purpose of this study was to determine the degree of salinity reached in the water within the gravel bed of a known pink-salmon spawning area. The conclusions are as follows:

1. The three zones of oceanographic structure of waters in the inlet are found in the intertidal zone of the stream when exposed to tidal inundation.
2. The saline content of the water within the gravel of the spawning beds is dependent on the salinity of the overlying waters.
3. When tidal waters have increased the water depth of the stream to include the middle zone of the salinity gradients, the water within the gravel is of a salinity similar to that of the coastal waters open to the ocean.
4. The coarse gravel of the spawning bed showed no appreciable tendency to hold the denser saline water and allowed thorough washing by fresh water during ebb tide.

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APPENDIX A

TEST OF SALINITY-SAMPLING METHOD

A means of testing the original sampling method was devised to determine the possibility of drawing water from areas of lesser or greater density than that in which the sampling pipe was situated. This work was done in the State of Washington on a small stream which enters Puget Sound a few miles south of Three Tree Point. The method made use of a conductivity cell and required a source of electricity which was supplied by a property owner in the vicinity. Essentially, the procedure used at Lover's Cove was repeated. The sampling pipe, however, was larger—of 2-inch outside diameter—to enable use of the conductivity unit. Procedure of pumping the samples was the same, except that the cell was lowered in the pipe first and was then followed by the tube for pumping. The sensitivity of the instrument could distinguish changes of approximately 0.5 of a unit of salinity at constant temperature, and therefore, any amount of water drawn into the pipe at the sampling level which was of different density than that which existed originally could be noted on the conductivity bridge scale.

Repeated tests failed to show any change in salinity due to pumping. That is to say, while pumping was in progress, no noticeable change in conductance was recorded, indicating that any ambient water drawn into the pipe at sampling level was of the same characteristics as that already in the pipe. This may be explained on a purely physical basis, as water of less density forced downward into a region of greater density would tend to return to its original position, and vice versa. Undoubtedly, enough suction could be applied to counteract this tendency, but the opening of the tubing was less than one-half inch in diameter and even extremely rapid pumping did not result in changes that could be detected on the conductance bridge. With such evidence, it was assumed that the method of pumping water samples from within the gravel of the stream bed provided a substantially accurate means of sampling. If any contamination occurred from areas of different densities, it could be regarded as negligible in view of the large range of density and the comparatively rapid changes.

APPENDIX B

TABLE OF OBSERVATIONS

July 17: Experimental sampling was carried on to design a system for future sampling. Samples 2 and 3 were taken in the open water of the stream to test differences of the water at the surface and at the stream bottom.

July 19: Experimental sampling; samples 4 and 6 were taken in open water rather than from within the pipe.

July 23: The procedure used to obtain the data presented under this date was used for all samples taken subsequently.

July 26 and 28: Two sections of pipe, station A(1) and station A(2), were set in the gravel to depths of 12 and 4 inches, respectively, and pipe A remained at the 6- to 8-inch depth. This experiment was designed to show the progressive change of salinity at various depths within the gravel bed of the stream.

August 20: Samples 1, 2, 3, and 4 were drawn from the top 6 inches of water within the pipe to determine any difference in samples drawn from the bottom of the pipe in the gravel. On the same date, samples 6, 7, and 8 were drawn in open water at varying distances below the surface.

The salinity-sampling results at Lover's Cove stream, Alaska, from all stations are presented in appendix table B-1. The temperatures recorded in the table were measured for density correction and do not represent field conditions.

APPENDIX TABLE B-1.—*Salinities recorded at all stations, Lover's Cove stream, Alaska, 1951*

Date and sample	Station	Height of water above pen	Time	Tide height	Temperature	Hydrometer reading	Density corrected to 15° C.	Salinity
July 17 (High water, 12.5 feet at 0018):				*Feet*	° *C.*			‰
No. 1	A		2345	12.5	14.5	1.0222	1.0221	29.9
No. 2	A	Surface sample			14.5	1.0000	<1.0000	<1.0
No. 3	A	Stream bottom			14.5	1.0222	1.0221	29.9
No. 4	A		0030		14.5	1.0220	1.0219	29.7
July 19 (High water, 10.5 feet at 1436):								
No. 1	A		1400	10.5	14.5	1.0212	1.0211	38.6
No. 2	B				14.5	1.0212	1.0211	28.6
No. 3	B				14.5	1.0212	1.0211	28.6
No. 4	B	Surface sample			13.5	1.0000	<1.0000	<1.0
No. 5	D	0 inch	1530		13.0	<1.0000	<1.0000	<1.0
No. 6	B	Stream bottom			14.0	1.0212	1.0210	28.5
July 23 (High water, 11.0 feet at 1717):								
No. 1	A	6 inches	1400		16.0	<1.0000	<1.0000	<1.0
No. 2	A	14 inches	1415		16.0	<1.0000	<1.0000	<1.0
No. 3	A	24 inches	1435	6.5	16.0	1.0136	1.0138	19.1
No. 4	B	0 inch	1450		16.0	<1.0000	<1.0000	<1.0
No. 5	A	36 inches	1456		15.5	1.0200	1.0201	27.3
No. 6	C	0 inch	1510	8.0	15.5	<1.0000	<1.0000	<1.0
No. 7	B	12 inches	1517		16.0	<1.0000	<1.0000	<1.0
No. 8	A	48 inches	1521		16.0	1.0212	1.0214	29.0
No. 9	C	12 inches	1539	9.0	16.0	<1.0000	<1.0000	<1.0
No. 10	A	59 inches	1545		16.0	1.0216	1.0218	29.5
No. 11	B	26 inches	1549		15.5	1.0200	1.0201	27.3
No. 12	C	24 inches	1614	10.0	15.5	1.0016	1.0016	3.2
No. 13	B	37 inches	1619		15.5	1.0210	1.0211	28.6
No. 14	A	72 inches	1626		15.5	1.0226	1.0227	30.7
No. 15	D	4 inches	1717	11.0	16.0	<1.0000	<1.0000	<1.0
No. 16	C	36 inches	1725		16.0	1.0048	1.0050	7.6
July 26 (High water, 9.7 feet at 1931):								
No. 1	A(1)	12 inches	1536	5.5	14.5	1.0132	1.0131	18.2
No. 2	A(2)	12 inches			14.5	1.0156	1.0155	21.3
No. 3	A(1)	13 inches	1539		14.5	1.0132	1.0131	18.2
No. 4	A(2)	13 inches			14.5	1.0158	1.0157	21.6
No. 5	A(2)	14 inches	1542		14.5	1.0162	1.0161	22.1
No. 6	A(1)	14 inches			14.5	1.0144	1.0143	19.7
No. 7	A(2)	15 inches	1545		14.5	1.0162	1.0161	22.1
No. 8	A(1)	15 inches			14.5	1.0144	1.0143	19.7
No. 9	A	17 inches	1550		14.5	1.0148	1.0147	20.3
No. 10	A	18 inches	1557	6.0	14.5	1.0150	1.0149	20.5
No. 11	A	19 inches	1600		14.5	1.0150	1.0149	20.5
No. 12	A	20 inches	1604		14.5	1.0150	1.0149	20.5
No. 13	A	21 inches	1606		14.5	1.0152	1.0151	20.8
No. 14	A	22 inches	1609		14.5	1.0152	1.0151	20.8
No. 15	A	23 inches	1612		14.5	1.0152	1.0151	20.8
No. 16	A	24 inches	1617	6.5	14.5	1.0152	1.0151	20.8

APPENDIX TABLE B–1.—*Salinities recorded at all stations, Lover's Cove stream, Alaska, 1951*—Continued

Date and sample	Station	Height of water above pen	Time	Tide height	Temperature	Hydrometer reading	Density corrected to 15° C.	Salinity
				Feet	° *C.*			‰
July 28 (High water, 9.8 feet at 2129):								
No. 1	A	15 inches	1400	5.8	15.0	1.0224	1.0224	30.3
No. 2	A	13 inches	1415		15.0	1.0224	1.0224	30.3
No. 3	A	12 inches	1424		15.0	1.0222	1.0222	30.0
No. 4	A(1)	12 inches	1435		15.0	1.0212	1.0212	28.8
No. 5	A(2)	12 inches	1437	5.5	15.0	1.0212	1.0212	28.8
No. 6	A	11 inches	1442		15.0	1.0214	1.0214	29.0
No. 7	A	10 inches	1500		15.0	1.0210	1.0210	28.5
No. 8	A(2)	10 inches	1506		15.0	1.0210	1.0210	28.5
No. 9	A(1)	10 inches	1509		15.0	1.0208	1.0208	28.2
No. 10	A	9 inches	1515	5.2	15.0	1.0204	1.0204	27.7
No. 11	A(1)	9 inches	1520		15.0	1.0210	1.0210	28.5
No. 12	A(2)	9 inches	1523		15.0	1.0208	1.0208	28.2
No. 13	A	9 inches	1535		15.0	1.0196	1.0196	26.7
No. 14	A(1)	9 inches	1543		15.0	1.0206	1.0206	28.0
No. 15	A(2)	9 inches	1545		15.0	1.0202	1.0202	27.4
No. 16	A	9 inches	1600		15.0	1.0184	1.0184	25.1
July 30 (High water, 8.2 feet at 1239):								
No. 1	A	45 inches	1239		20.5	1.0192	1.0204	27.7
No. 2	B	11 inches	1245	8.5	20.5	1.0148	1.0159	21.8
No. 3	C	2 inches	1249		19.5	<1.0000	<1.0000	<1.0
No. 4	B	10 inches	1320		19.5	1.0112	1.0120	16.7
No. 5	C	0 inch	1326		19.5	<1.0000	<1.0000	<1.0
No. 6	C	0 inch	1339		19.5	<1.0000	<1.0000	<1.0
No. 7	B	7 inches	1344		19.5	1.0130	1.0139	19.2
No. 8	C	0 inch	1347		21.0	<1.0000	<1.0000	<1.0
No. 9	B	6 inches	1351	8.0	19.5	1.0014	1.0021	3.8
No. 10	C	0 inch	1355		20.5	<1.0000	<1.0000	<1.0
No. 11	B	5 inches	1400		19.5	1.0000	1.0007	2.0
No. 12	C	0 inch	1404		19.5	<1.0000	<1.0000	<1.0
No. 13	B	3 inches	1408		19.5	<1.0000	<1.0000	1.0
No. 14	B	2 inches	1417		19.5	<1.0000	<1.0000	<1.0
No. 15	B	1 inch	1422		19.5	<1.0000	<1.0000	<1.0
No. 16	B	0 inch	1428	7.5	20.5	<1.0000	<1.0000	<1.0
No. 17	B	Creek bottom	1430		20.5	<1.0000	<1.0000	<1.0
No. 18	B	0 inch	1435		20.5	<1.0000	<1.0000	<1.0
No. 19	B	0 inch	1440		21.0	<1.0000	<1.0000	<1.0
No. 20	B	0 inch	1445		21.0	<1.0000	<1.0000	<1.0
No. 21	B	0 inch	1450		21.0	<1.0000	<1.0000	<1.0
No. 22	B	0 inch	1457		21.0	<1.0000	<1.0000	<1.0
No. 23	A	25 inches	1504		21.0	1.0192	1.0205	27.8
July 31 (High water, 8.7 feet at 1313):								
No. 1	C	5 inches	1330		15.5	<1.0000	<1.0000	<1.0
No. 2	B	14 inches	1337		15.5	1.0104	1.0105	14.8
No. 3	C	4 inches	1341		15.5	<1.0000	<1.0000	<1.0
No. 4	B	13 inches	1355		15.5	1.0102	1.0103	14.5
No. 5	C	3 inches	1358		15.5	<1.0000	<1.0000	<1.0
No. 6	B	12 inches	1401	8.5	15.5	1.0114	1.0115	16.1
No. 7	C	2 inches	1405		15.5	<1.0000	<1.0000	<1.0
No. 8	B	11 inches	1409		15.5	1.0100	1.0101	14.2
No. 9	C	1 inch	1413		15.5	<1.0000	<1.0000	<1.0
No. 10	B	10 inches	1418		15.5	1.0100	1.0101	14.2
No. 11	C	0 inch	1421		15.5	<1.0000	<1.0000	<1.0
No. 12	B	9 inches	1425		15.5	1.0094	1.0095	13.5
No. 13	B	8 inches	1430		15.5	1.0090	1.0091	12.9
No. 14	B	7 inches	1437		15.5	1.0074	1.0075	10.8
No. 15	B	6 inches	1442	8.0	15.5	1.0058	1.0059	8.8
No. 16	B	5 inches	1448		15.5	1.0034	1.0034	5.5
No. 17	B	4 inches	1452		15.5	1.0018	1.0018	3.4
No. 18	B	3 inches	1456		15.5	1.0008	1.0008	2.1
No. 19	B	2 inches	1500		15.5	1.0002	1.0002	1.3
No. 20	B	1 inch	1505		15.5	1.0000	1.0000	1.1
No. 21	B	0 inch	1509		15.5	<1.0000	<1.0000	<1.0
No. 22	B	0 inch	1514	7.5	15.5	<1.0000	<1.0000	<1.0
No. 23	A	30 inches	1520		15.5	1.0212	1.0213	28.9
Aug. 2 (High water, 9.6 feet at 1413):								
No. 1	C	18 inches	1415		16.5	1.0008	1.0010	2.4
No. 2	B	27 inches	1423	9.5	16.0	1.0194	1.0196	26.7
No. 3	C	17 inches	1435		16.0	1.0022	1.0023	4.1
No. 4	C	16 inches	1453		16.0	1.0030	1.0031	5.1
No. 5	B	25 inches	1457		16.0	1.0202	1.0204	27.7
No. 6	C	14 inches	1502		16.0	1.0030	1.0031	5.1
No. 7	C	13 inches	1511		16.0	1.0030	1.0031	5.1
No. 8	C	12 inches	1515	9.0	16.0	1.0030	1.0031	5.1
No. 9	C	11 inches	1519		16.0	1.0030	1.0031	5.1
No. 10	C	10 inches	1524		16.0	1.0030	1.0031	5.1
No. 11	B	19 inches	1526		16.0	1.0202	1.0204	27.7
No. 12	C	9 inches	1530		16.0	1.0030	1.0031	5.1
No. 13	C	8 inches	1535		16.0	1.0030	1.0031	5.1
No. 14	C	7 inches	1538		16.0	1.0028	1.0029	4.8
No. 15	C	6 inches	1542	8.5	15.5	1.0028	1.0028	4.7
No. 16	C	5 inches	1545		15.5	1.0028	1.0028	4.7
No. 17	B	13 inches	1550		16.0	1.0202	1.0204	27.7
No. 18	C	3 inches	1555		15.5	1.0022	1.0022	3.9
No. 19	C	2 inches	1559		15.5	1.0018	1.0018	3.4
No. 20	C	1 inch	1602		15.5	1.0018	1.0018	3.4
No. 21	C	0 inch	1605	8.0	15.5	1.0016	1.0016	3.2
No. 22	C	0 inch	1609		15.5	1.0014	1.0014	2.9
No. 23	B	6 inches	1615		16.0	1.0136	1.0138	19.1

APPENDIX TABLE B-1.—*Salinities recorded at all stations, Lover's Cove stream, Alaska, 1951*—Continued

Date and sample	Station	Height of water above pen	Time	Tide height	Temperature	Hydrometer reading	Density corrected to 15° C.	Salinity
Aug. 6 (High water, 10.6 feet at 1559):				*Feet*	° *C.*			‰
No. 1	A	11 inches	1300	5.2	11.5	1.0010	1.0006	1.8
No. 2	A	13 inches	1305		11.5	1.0040	1.0036	5.6
No. 3	A	14 inches	1306		11.5	1.0072	1.0067	9.8
No. 4	A	15 inches	1308		11.5	1.0084	1.0079	11.4
No. 5	A	16 inches	1310	5.7	11.5	1.0096	1.0091	12.9
No. 6	A	17 inches	1312		11.5	1.0108	1.0103	14.5
No. 7	A	18 inches	1315		12.0	1.0114	1.0110	15.4
No. 8	A	19 inches	1316		12.0	1.0122	1.0118	16.5
No. 9	A	20 inches	1318		12.0	1.0130	1.0126	17.5
No. 10	A	21 inches	1320		12.0	1.0144	1.0140	19.4
No. 11	A	22 inches	1321		14.5	1.0150	1.0149	20.5
No. 12	A	23 inches	1323	6.2	14.5	1.0152	1.0151	20.8
No. 13	A	24 inches	1326		14.5	1.0156	1.0155	21.3
No. 14	A	25 inches	1328		14.5	1.0162	1.0161	22.1
No. 15	A	26 inches	1330		13.0	1.0164	1.0161	22.1
No. 16	A	27 inches	1332		13.0	1.0166	1.0163	22.4
No. 17	A	28 inches	1334		13.0	1.0168	1.0165	22.6
No. 18	A	29 inches	1336	6.7	14.0	1.0170	1.0168	23.0
No. 19	A	30 inches	1338		14.0	1.0172	1.0170	23.3
No. 20	A	31 inches	1340		14.0	1.0174	1.0172	23.5
No. 21	A	33 inches	1344		14.0	1.0180	0.0178	24.3
No. 22	A	34 inches	1346		14.0	1.0182	1.0180	24.6
Aug. 7 (High water, 10.7 feet at 1626):								
No. 1	B	1 inch	1411	4.5	16.0	<1.0000	<1.0000	<1.0
No. 2	B	2 inches	1412		16.0	<1.0000	<1.0000	<1.0
No. 3	B	3 inches	1414		16.0	<1.0000	<1.0000	<1.0
No. 4	B	4 inches	1416		16.0	1.0000	1.0001	1.2
No. 5	B	5 inches	1418		16.0	1.0038	1.0039	6.2
No. 6	B	6 inches	1420	5.0	16.0	1.0064	1.0066	9.7
No. 7	B	7 inches	1422		16.0	1.0080	1.0082	11.8
No. 8	B	8 inches	1424		16.0	1.0092	1.0094	13.3
No. 9	B	9 inches	1426		16.0	1.0106	1.0108	15.2
No. 10	B	10 inches	1430		16.0	1.0120	1.0122	17.0
No. 11	B	11 inches	1432		16.0	1.0126	1.0128	17.8
No. 12	B	12 inches	1434	5.5	16.0	1.0138	1.0140	19.4
No. 13	B	13 inches	1436		16.0	1.0144	1.0146	20.1
No. 14	B	14 inches	1438		16.0	1.0148	1.0150	20.6
No. 15	B	15 inches	1440		16.0	1.0150	1.0152	20.9
No. 16	B	16 inches	1442		16.0	1.0150	1.0152	20.9
No. 17	B	17 inches	1444		16.0	1.0150	1.0152	20.9
No. 18	B	18 inches	1446	6.0	16.0	1.0158	1.0160	22.0
No. 19	B	19 inches	1448		16.0	1.0160	1.0162	22.2
No. 20	B	20 inches	1451		16.0	1.0164	1.0166	22.7
No. 21	B	21 inches	1455		16.0	1.0170	1.0172	23.5
No. 22	B	22 inches	1457		16.0	1.0170	1.0172	23.5
Aug. 20 (High water, 11.7 feet at 1554):								
No. 1	C	34 inches	1455	10.9	15.0	1.0002	1.0002	1.3
No. 2	C	35 inches	1459		15.0	1.0006	1.0006	1.8
No. 3	C	36 inches	1501		15.0	1.0014	1.0014	2.9
No. 4	C	37 inches	1503		15.0	1.0018	1.0018	3.4
No. 5	C	38 inches	1506	11.1	15.0	1.0026	1.0026	4.5
No. 6	C	2 inches below surface			15.0	<1.0000	<1.0000	<1.0
No. 7	C	12 inches below surface			15.0	<1.0000	<1.0000	<1.0
No. 8	C	24 inches below surface			15.0	1.0002	1.0002	1.3

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