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ABSTRACT

Prince William Sound is unique among major pink salmon-producing areas in that a significant portion of the spawning takes place in the intertidal zones of streams. Olsen Creek is one of the major spawning streams in the sound.

The percentage of fines (solids passing through an 0.833-mm. sieve) in spawning-bed materials increased progressively from higher to lower intertidal levels, i.e., higher intertidal levels contained coarser spawning gravel than lower levels.

Although less than one-third of the spawning area available in the Olsen Creek drainage is subject to tidal influence, 70 percent of the total pink salmon spawners occupied this area in 1962 and 30 percent in 1963. Late-run fish of the even-year line spawned only in the intertidal area; fish of both the early and late runs of the odd-year line spawned in both the intertidal and fresh-water areas. The size of the spawning populations was estimated by a repetitive stream survey technique, which is described and compared with the three methods used in 1960 and 1961.

The length of pink salmon was compared between sexes, between spawning areas, and between times of spawning. Fish in the even-year line that spawned in the small intertidal creeks tended to be smaller than those that used the main stream, but in the odd-year line this difference was confined to females. The mean lengths of females were about the same in 1962 and 1963, but females from the odd-year line were more fecund. In both years a significant positive correlation was shown between lengths of females and numbers of eggs.

INTRODUCTION

Prince William Sound annually produces runs of pink salmon, Oncorhynchus gorbuscha, worth millions of dollars. The runs have had 0.6 to 8.8 million fish from 1956 to 1963.[1] The pink salmon of the sound differ from those of other areas in that a significant portion spawn in the intertidal zones of streams. Noerenberg[2] estimated that in 1952-61, 35 to 57 percent of the pink salmon in the odd-year lines[3] and 72 to 77 percent in the even-year lines spawned within the stream intertidal zones.

It is clear that spawning populations in the intertidal zones of streams contribute significantly to the production of pink salmon and chum salmon, O. keta; yet little is known of the environment itself or of the biology of the salmon in this area. Studies at Olsen Bay have shown that the action of the tide causes changes in the flow, temperature, salinity, and dissolved oxygen of the intragravel water that would affect the biology of the fish in the intertidal environment. The effects of most of these

[1] Robert S. Roys and Wallace H. Noerenberg. 1965. Forecast of the 1965 Prince William Sound pink and chum runs. In Forecast research on 1965 central Alaska pink salmon fisheries, pp. 4-19. Alaska Dep. Fish Game, Inform. Leafl. 65.

[2] Wallace H. Noerenberg. 1963. Salmon forecast studies on 1963 runs in Prince William Sound. Alaska Dep. Fish Game, Inform. Leafl. 21, 29 pp.

[3] Pink salmon spawn and die when they are 2 years old; therefore, spawners from consecutive years do not interbreed and the odd and even years constitute separate genetic lines.

factors have been studied rather extensively in the fresh-water environment but comparatively little in the intertidal zone. Kirkwood (1962) and Tait and Kirkwood (1962) described methods of assessing production of salmon fry in the intertidal zones of streams in Prince William Sound; Kirkwood (1962) showed that survival of pink and chum salmon was higher in the 8- to 12-foot (2.4- to 3.7-m.) tide levels than in the 4- to 8-foot (1.2- to 2.4-m.) levels and was negligible below the 4-foot (1.2-m.) tide mark. Hanavan and Skud (1954) found that the lower limit of survival was about 4 feet (1.2 m.) above mean low tide in Lovers Cove Creek in southeastern Alaska.

In 1960 the BCF (Bureau of Commercial Fisheries) began studying the ecology of the pink and chum salmon in the intertidal zones of streams in Olsen Bay, Prince William Sound, to determine the factors that limit abundance of pink and chum salmon in the intertidal zones. Olsen Creek is one of the major spawning streams for pink and chum salmon in Prince William Sound. Helle, Williamson, and Bailey (1964) reported the results of the first 2 years of investigations.

The present paper describes the quality of the intertidal streambed and the abundance, timing, distribution, length, and fecundity of the pink salmon spawning populations in the fresh-water and intertidal areas of Olsen Creek in 1962 and 1963. These features are compared between habitats and between years to determine possible causes of observed differences. The quality of the streambed and the length of adult pink salmon were determined also in two small nearby intertidal streams, Middle Slough and Little Creek, for comparison with the data from Olsen Creek.

DESCRIPTION OF STUDY AREA

Olsen Creek is in Olsen Bay, which is in Port Gravina on the eastern side of Prince William Sound, Alaska. Olsen Creek is at the head of the bay and has two branches, East Fork and West Fork; the branches converge at the 11-foot (3.4-m.) tide level to form the main channel in the intertidal zone (fig. 1). Middle Slough and Little Creek drain the east side of the tideflat parallel to Olsen Creek. Salmon can go up each fork of Olsen Creek about 2.5 km., but this study mainly concerns the area below the 12-foot (3.7-m.) tide level (about mean high tide), which is considered to be the boundary between the intertidal and the fresh-water zones. The spawning grounds in Middle Slough and Little Creek are entirely intertidal.

Olsen Creek was divided into five study sections on the basis of ecological differences: upper intertidal, holding pool, low gradient, middle intertidal, and lower intertidal (fig. 1). Middle Slough and Little Creek are so small that they were not divided into study sections.

STREAMFLOW AND PRECIPITATION

Because of the importance of streamflow in the ecology of the spawning areas, we collected data on flow and its related factor, precipitation. The volume of streamflow is very closely related to rainfall at Olsen Creek because the watershed is steep and contains no lakes for water storage.

Beginning in 1961, BCF maintained gages to record the level of the stream on both forks of Olsen Creek in the 3 summer months, and used a Price[4] current meter to measure stream discharge at various stream heights. Because a long drought in 1962 resulted in streamflows so low that the recorder on the West Fork did not operate properly, only the data for the East Fork for 1962-63 are considered here (fig. 2). Because concurrent measurements in the two forks at all water levels above the minimum flow for 1961-63 showed that the fluctuations were practically identical in the forks, I believe the data for the East Fork represent stream level fluctuations adequately for all of Olsen Creek. The concurrent data for the two forks of Olsen Creek in 1961 were given by Helle et al. (1964).

Precipitation at Olsen Creek in 1960-63 was measured only in July to September, but the daily observations for these 3 months (table 1) were similar to those for Cordova (U.S. Weather Bureau, 1961-64), which is about 48 km. from the bay. Therefore the figures for the annual precipitation for Cordova are probably indicative of the annual precipitation at Olsen Creek.

QUALITY OF STREAMBED

I based my evaluation of the quality of the streambed in Olsen Creek on the sizes of bottom materials in the spawning areas. An analysis in 1961 had shown an increase in materials less than 1 mm. in size from higher to lower tide levels in the intertidal zone (Helle et al., 1964). In 1962 this relation was investigated in more detail.

McNeil and Ahnell (1964) found an inverse relation between streambed permeability and the proportion of silt and fine sands in the bottom materials. They also found that the pink salmon spawning streams that contained relatively low percentages of silt and fine sand produced more salmon than streams containing higher percentages of these materials.

[4] Trade names referred to in this publication do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

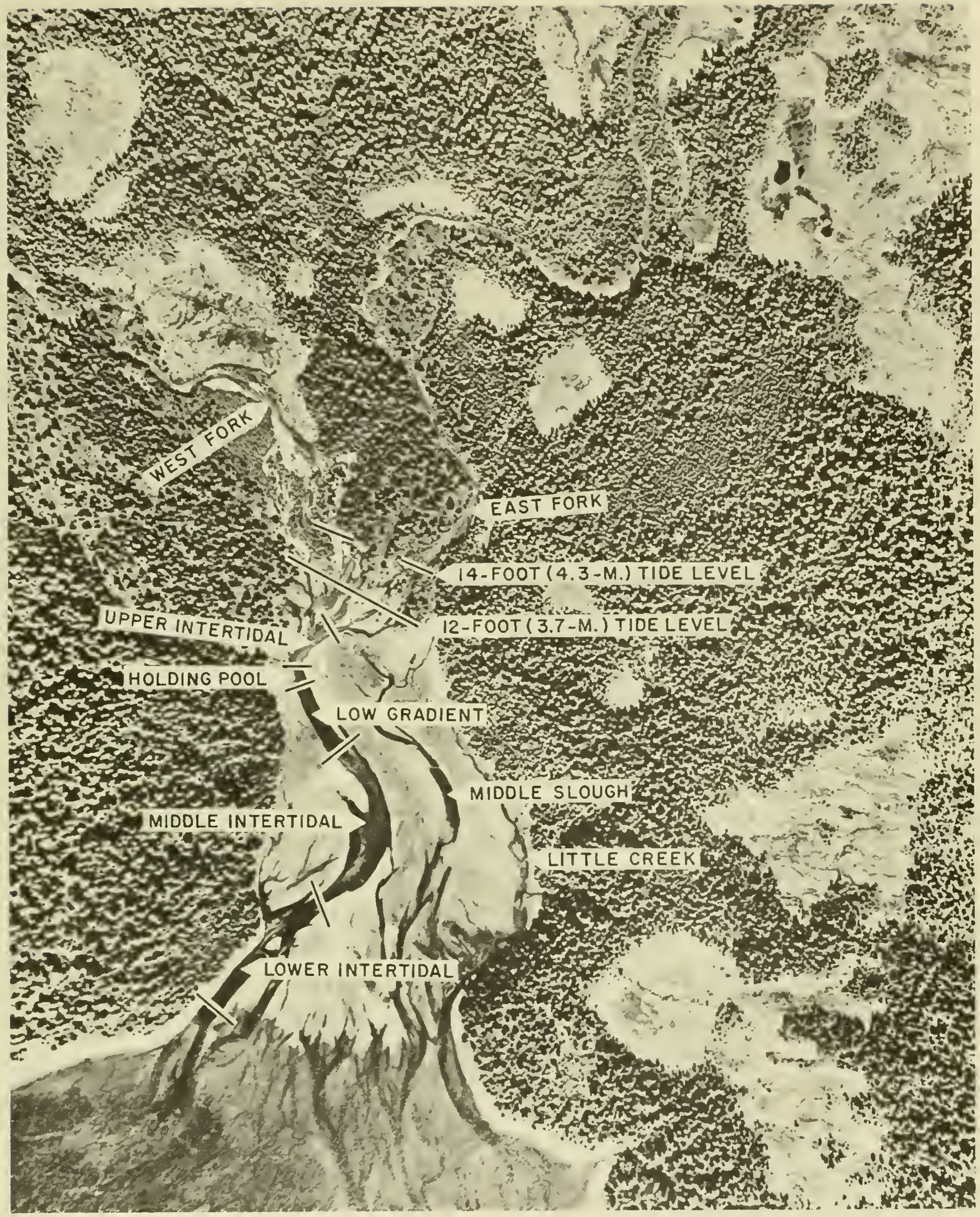

Figure 1.--Vertical aerial photograph of intertidal zone of Olsen Creek, Olsen Bay, Alaska, site of studies on pink salmon spawning populations, 1960-63.

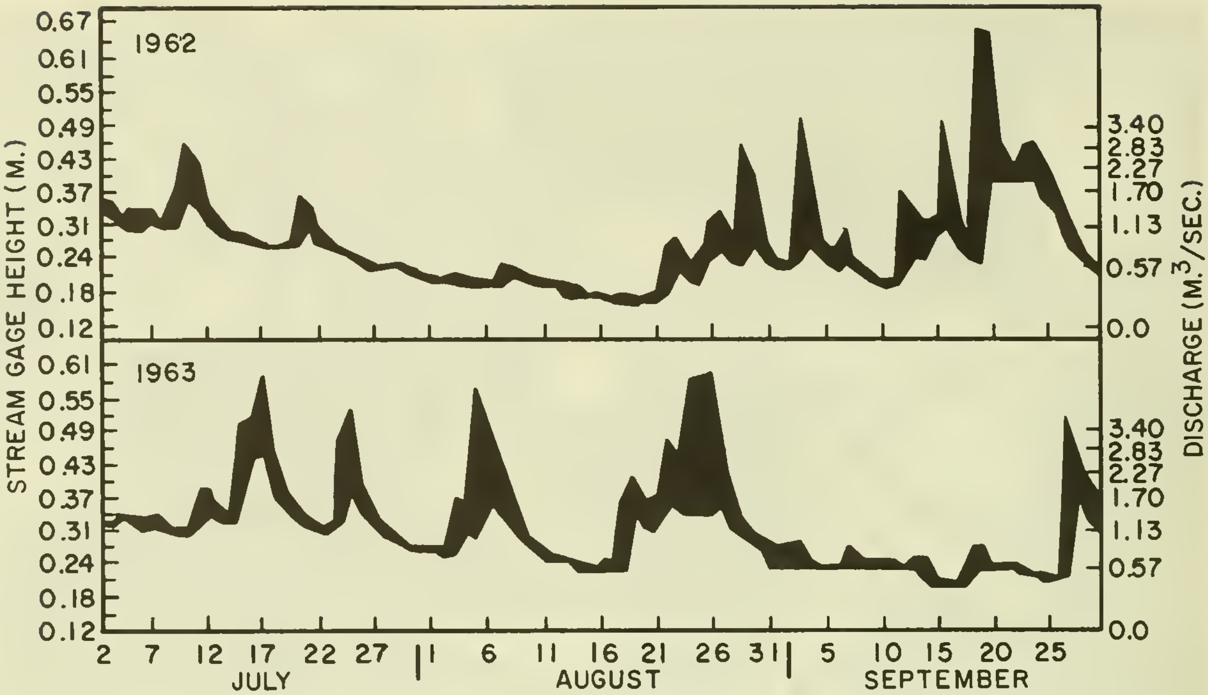

Figure 2.--Daily maximum and minimum stream levels and discharge, July to September 1962-63, East Fork of Olsen Creek.

Table 1.--Precipitation at Olsen Creek and Cordova,[1] Prince William Sound, July to September 1960-63

Year	July				August				September			
	Olsen Bay		Cordova		Olsen Bay		Cordova		Olsen Bay		Cordova	
	In.	Cm.	In.	Cm.	In.	Cm.	In.	Cm.	In.	Cm.	In.	Cm.
1960	8.19	20.80	9.10	23.11	8.49	21.56	7.98	20.27	15.47	39.29	19.40	49.28
1961	[2]3.88	9.86	[2]4.92	12.50	13.20	33.53	15.43	39.19	12.75	32.39	13.51	34.32
1962	2.59	6.58	3.96	10.06	3.98	10.11	4.85	12.32	12.61	32.03	12.45	31.62
1963	5.55	14.10	9.17	23.29	7.30	18.54	7.50	19.05	7.05	17.91	7.57	19.23

[1] Cordova data from "Climatological data, Alaska," U.S. Weather Bureau (1961-64).
[2] Beginning July 10.

We used the gravel sampling equipment and procedures described by McNeil and Ahnell (1964) to collect and determine the size of the bottom materials. The choice of individual plots to be sampled in each area was made by drawing paired numbers from a table of random numbers (Snedecor, 1956) and plotting the coordinates on a map of the stream. Sample plots were located in the stream by pacing the distance from a baseline set up along the stream. Samples of gravel were taken from the upper intertidal area before and after spawning to learn if spawning activity reduced the amount of fines (silt and fine sand passing through 0.833-mm. sieve) in the streambed. The other areas in Olsen Creek were sampled only after spawning and served as a basis for comparing the areas. Middle Slough and Little Creek were both sampled before spawning. Samples were randomly chosen within the 4- to 10-foot (1.2- to 3.0-m.) tide levels because there is no spawning below or above these levels in these two streams.

The mean percentage of fines in the upper intertidal area was significantly higher before spawning (11.0) than after spawning (7.4--see table 2),[5] but the reduction may have been caused by flooding rather than spawning. McNeil and Ahnell (1964) demonstrated that both flooding and spawning activity reduced the percentage of fine materials in a stream--and several freshets occurred during September in Olsen Creek (fig. 2).

The area where Olsen Creek meets tide water serves as a settling basin, and in general the percentage of fines increased from the higher to the lower tide levels (table 2). An exception to this progression was the low-gradient area, where the stream is deeper and has less gradient than in the two adjoining sections.

The percentage of live eggs in the stream in the fall and the survival of larvae over the winter decrease from higher to lower tide levels in Olsen Creek (Helle et al., 1964). This trend in mortality is probably caused not only by lower streambed permeability but also by the increasingly severe effects of tide-associated changes in salinity, dissolved oxygen, and temperature in the lower intertidal zone.

[5] The respective variances were 20.8 and 4.7. A comparison of the two means was made with the t-test. Because the sample sizes were different and the variances were unequal, the degrees of freedom were calculated by the formula given by Paulik. The t-value of 3.13 (26 d.f.) was significant at the 99-percent level. (Gerald Paulik. 1961. Two-sample statistical tests. Univ. Wash., Seattle, Fish. Res. Inst., Circ. 155, 7 pp.)

ESTIMATING ABUNDANCE OF SPAWNERS

An estimate of the number of spawners is a basic statistic in studies on the life history of pink salmon. Such estimates are often made by counting salmon at weirs as they pass upstream to the spawning grounds. The use of weirs to study intertidal spawners at Olsen Creek is impractical, however, because of the width of the intertidal spawning area; more-

Table 2.--Mean percentage by volume of bottom materials that were retained by various sieves and settled from suspension in 10 minutes, from four areas of Olsen Creek, Middle Slough, and Little Creek, 1962

Sample area	Samples	Total volume retained by sieves with square mesh openings (in mm.) of--										Total volume of solids settling from suspension	Fines (amount passing through 0.833-mm. sieve)
		50.8[1]	25.4	12.7	6.35	3.36	1.68	0.833	0.417	0.208	0.104		
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Olsen Creek intertidal zone													
Upper intertidal[2]	22	9.3	17.5	16.3	14.8	13.0	9.5	8.5	5.0	2.2	0.7	3.1	11.0
Upper intertidal[3]	12	6.1	16.2	18.9	18.0	15.1	9.9	8.5	4.1	1.3	0.7	1.3	7.4
Low gradient	10	4.8	20.7	21.1	16.0	11.4	7.2	8.6	5.0	2.9	1.3	1.2	10.4
Middle intertidal	43	5.7	18.4	19.7	16.2	13.6	9.3	7.8	4.0	2.0	0.8	2.4	9.2
Lower intertidal	29	3.5	15.4	19.1	16.1	13.5	10.2	8.9	5.2	2.3	1.1	4.5	13.1
Middle Slough	25	2.6	11.2	17.6	19.3	16.2	10.0	8.9	4.9	2.4	1.4	5.5	14.2
Little Creek	25	1.8	18.5	23.8	21.7	16.1	5.5	3.3	2.1	1.6	1.0	4.5	9.2

[1] Rocks larger than 10 cm. minimum dimension excluded.
[2] Sample taken before spawning.
[3] Sample taken after spawning.

over, weirs do not provide information on the distribution of spawners in the stream.

In 1960 and 1961 several different methods of estimating the number of spawners were used including periodic counts made on foot surveys to determine distribution. A method of estimating the total number of fish that spawned during the season based on periodic foot survey counts was evaluated by comparing the results with estimates made by other methods.

Description of Methods

In 1960 and 1961, several methods were used to estimate the number of spawners in the fresh-water and intertidal stream areas. Fresh-water spawners were counted as they passed weirs at the mean high tide line of Olsen Creek (Helle et al., 1964). Frequent floods made maintenance of the weirs too costly. In 1960 a "peak count" method was used to estimate the number of intertidal spawners. In this method observers walking along the streambank counted live and dead fish. The peak count estimate was made by adding the maximum count of live fish to the accumulated count of carcasses on any one day. In 1961 the number of intertidal spawners was estimated by a tag ratio method. In this method live pink salmon were tagged in the bay with Petersen disk tags, and the ratio of tagged to untagged carcasses on the spawning grounds was used to estimate the size of the population.

Because the combination of methods tried was not satisfactory, we needed to develop a single, more efficient method for estimating the populations of both intertidal and fresh-water spawners. McNeil (1962) had been successful in estimating total spawning populations of pink salmon in southeastern Alaska by periodically walking along a stream and counting the fish on the spawning grounds (so-called foot survey). We had counted pink salmon during periodic foot surveys of Olsen Creek in 1960-61 to determine the time of spawning and distribution of fish in fresh-water and intertidal areas. I therefore decided to try this method for estimating the populations of intertidal and fresh-water spawners.

Evaluation of the Foot Survey Method

To evaluate the foot survey method, I used data collected during the studies in 1960-61, when foot surveys were used to estimate the numbers and distribution of spawners in the entire stream every 7 to 10 days. Two biologists counted salmon separately on each survey, and although the counts were similar, those of the more experienced observer were used in all calculations. Sheridan (1962) and Willis (1964) compared spawning ground (foot survey) counts of different observers made under ideal field conditions and found no significant differences. Variability increased, however, when counts of salmon in pools were included and also when numbers of fish were large (Sheridan, 1962).

Methods of estimating the total number of spawners from repeated foot surveys were suggested by Gangmark and Fulton (1952) and Sheridan (1962), and described in detail by McNeil (1962, 1964, 1966a, and 1966b). McNeil (1964) plotted daily counts, drew a curve by inspection, and divided the area under the curve (fish days) by the average redd life (the estimated number of days each fish spent on the spawning ground) to obtain an estimate of the number of pink salmon that spawned. Estimates made by this method were within 6 percent of the actual number of fish present (counted through a weir).[6]

The foot survey counts for 1960 and 1961 were plotted (figs. 3 and 4), and the area under the curve for each year (fish days) was calculated and divided by the average stream life (number of days each fish spends in the stream) to obtain estimates of the intertidal and fresh-water spawning populations. Stream life was used in the calculations instead of redd life because all of the pink salmon in the stream were counted whether they were spawning or not. In 1961 the average stream life of intertidal spawners was shorter for the late run (8.5 days) than the early run (15.3 days)--see Helle et al. (1964). The estimated stream life of fresh-water spawners was the difference in days between the highest daily count of live fish and the highest daily count of carcasses that had drifted downstream and accumulated at the weirs. This difference was 9 days for the East Fork and 16 days for the West Fork in 1960 and 9 days for the East Fork and 13 days for the West Fork in 1961. It is not clear why stream life was longer in the West Fork. Perhaps the large pool on the West Fork allowed spawned out fish to remain in the stream longer before they died and were conveyed downstream to the weir.

Estimates of the populations of adult pink salmon in the three areas made by the foot survey method are compared with estimates by other methods in table 3. The greatest difference between estimates (6 and 22 percent) was for the fresh-water population in the East Fork. The number of fresh-water spawners estimated by the foot survey method was larger than the number counted at the weir for all areas except the West Fork in 1961. The weir counts were known to be low because sections of the weirs were removed several times during

[6] William J. McNeil, William O. McLarney, Clark T. Fontaine, Robert Coates, David Brickell, and Ralph Wells. 1964. Pink salmon studies at Little Port Walter, summer and autumn, 1963. Manuscript on file, Bur. Commer. Fish. Biol. Lab., Auke Bay, Alaska.

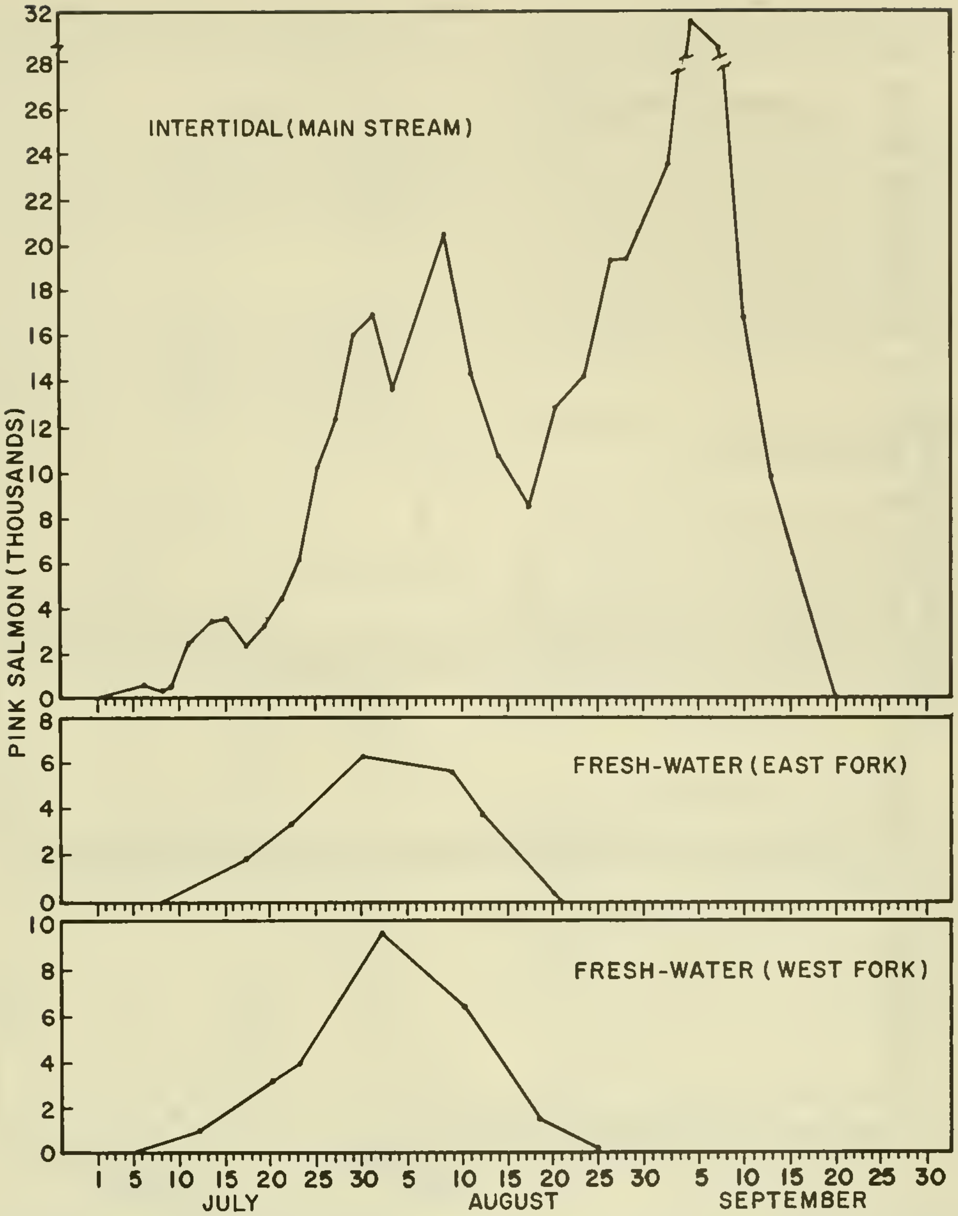

Figure 3.--Seasonal abundance of adult pink salmon in the intertidal (main stream) and fresh-water (East and West Forks) areas of Olsen Creek, based on counts made during periodic foot surveys--July through September 1960.

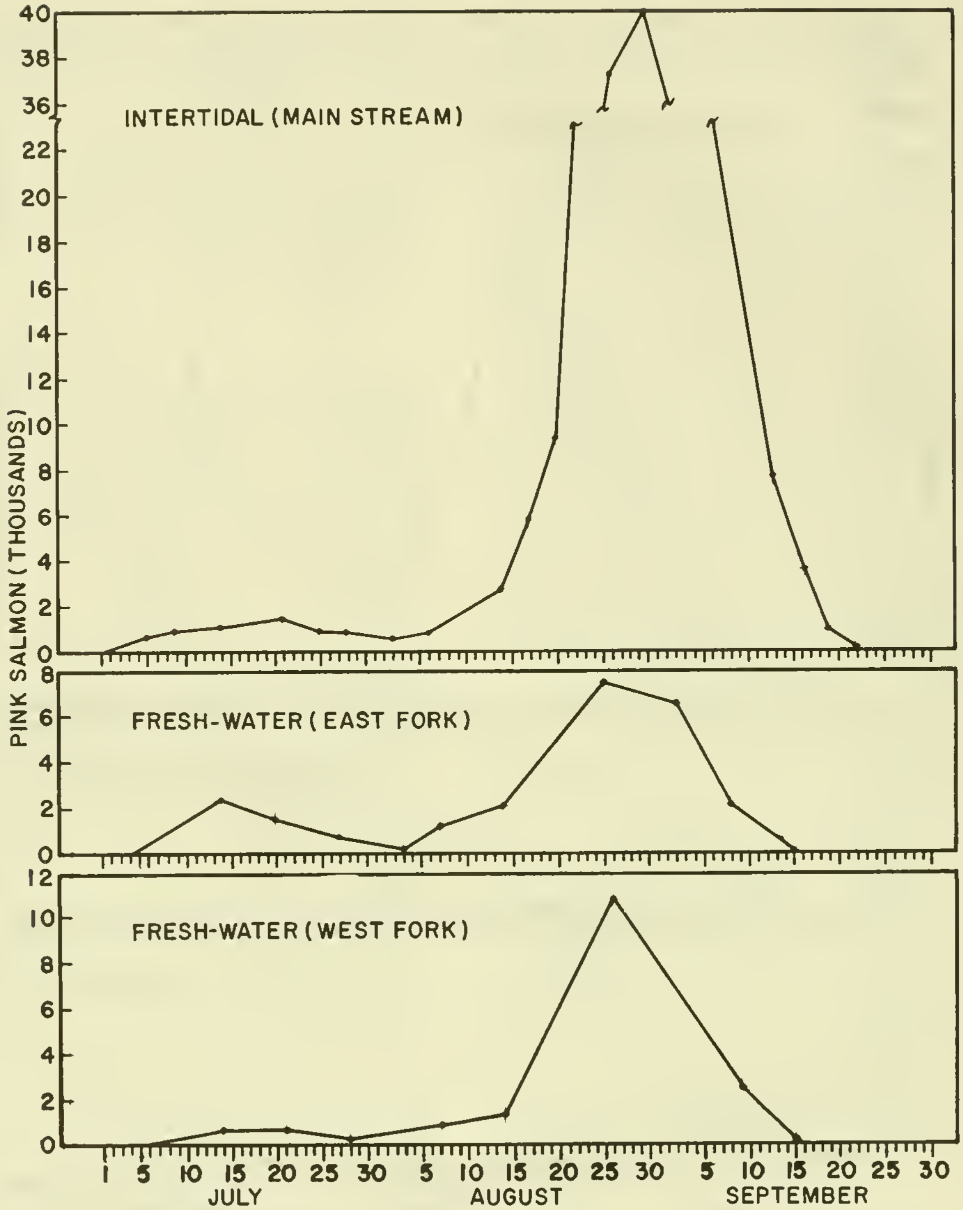

Figure 4.--Seasonal abundance of adult pink salmon in the intertidal (main stream) and fresh-water (East and West Forks) areas of Olsen Creek, based on counts made during periodic foot surveys--July through September 1961.

floods in 1960 and 1961 and unknown numbers of fish passed upstream without being counted (Helle et al., 1964).

The estimate of the intertidal spawning population by the peak count method in 1960 was less than the estimate by the foot survey method (table 3). This peak count estimate would be low because freshets, tidal action, and bears probably removed many of the carcasses before they could be counted.

Table 3.--Number of spawners in intertidal and fresh-water areas estimated by foot survey method compared with number estimated at weirs in the fresh-water area and by two other methods (peak count in 1960 and tag ratio in 1961) in the intertidal area of Olsen Creek, 1960-61

Year and spawning area	Spawners estimated from--		Difference
	Foot survey method	Other methods	
	Number	Number	Percent
1960			
Intertidal....	89,989	72,617	19
Fresh-water:			
East Fork...	15,856	12,392	22
West Fork...	14,546	13,565	7
Total.....	120,391	98,574	18
1961			
Intertidal....	83,168	100,147	20
Fresh-water:			
East Fork...	20,044	18,870	6
West Fork...	14,877	16,888	14
Total.....	118,089	135,905	15

The tag ratio method gave a larger estimate of the number of pink salmon spawning in the intertidal area in 1961 than did the foot survey method. Fish for tagging were captured in the bay near the mouth of the stream, and carcasses were counted daily (Helle et al., 1964). Studies on the Lakelse River, British Columbia, have shown that the tag ratio method of determining the size of spawning populations of pink salmon overestimated the actual runs by 41.5 percent in one year and 26.6 percent in another (Fisheries Research Board of Canada, 1962). Whether or not the tag ratio method overestimated the intertidal run at Olsen Creek in 1961 is not known. Helle et al. (1964), who compared the estimates by this method with weir estimates in the upstream areas of Olsen Creek in 1961, found that the two estimates were similar for the West Fork (the tag ratio method overestimated the minimal weir count by only 5 percent) but that the tag ratio estimate was 41 percent larger than the weir count in the East Fork.

Population estimates by the foot survey method were larger (four out of five times) than estimates by other methods that were known to be minimal and smaller than a tag ratio estimate that was suspected of being high (table 3). I therefore conclude that the foot survey method gives reasonable estimates of the spawning populations at Olsen Creek. An annual estimate of stream life or redd life is desirable, however, because these may change from year to year.

ABUNDANCE, TIMING, AND DISTRIBUTION OF SPAWNERS

The pink salmon run to Olsen Creek has four recognized segments based on season and spawning ground used: an early and a late run that spawn in the intertidal zone and an early and a late run that spawn in fresh water. The relative numbers of fish in these groups are distinctly different in odd and even years (Helle et al., 1964). These four segments were present in both 1962 and 1963.

The 1962 Spawning Population

The number of pink salmon counted on periodic foot surveys of the intertidal zone of Olsen Creek and the fresh-water spawning areas (East and West Forks) from June through September 1962 are shown in figure 5. The estimates of stream life made by Helle et al. (1964) for fish of the 1961 escapement were used in the calculations of the total number of spawners by the foot survey method. Table 4 presents the population estimates for the various parts of the run.

Most of the even-year line of pink salmon in Prince William Sound spawn in the intertidal area of streams. In 1962, 70 percent of the total run of pink salmon in Olsen Creek spawned in the intertidal area, and in 1960 (the parent year) 75 percent used this area (table 4). Of the total pink salmon escapement in Prince William Sound, 70 percent spawned in the intertidal zone in 1962[7] and 77 percent in 1960 (see footnote 2). Olsen Creek received 7 percent of the total pink salmon escapement in Prince William Sound in 1960 and 3 percent in 1962.[8]

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[7] Wallace Noerenberg. 1964. Prince William Sound pink and chum salmon forecast studies. In Forecast research on 1964 Alaskan pink salmon fisheries, pp. 18-35. Alaska Dep. Fish Game, Inform. Leafl. 36.

[8] Wallace Noerenberg. 1961. Observations on spawning and subsequent survival of fry of the 1960 salmon runs in Prince William Sound, Alaska. Alaska Dep. Fish Game, Mem. 5. (See also footnote 7.)

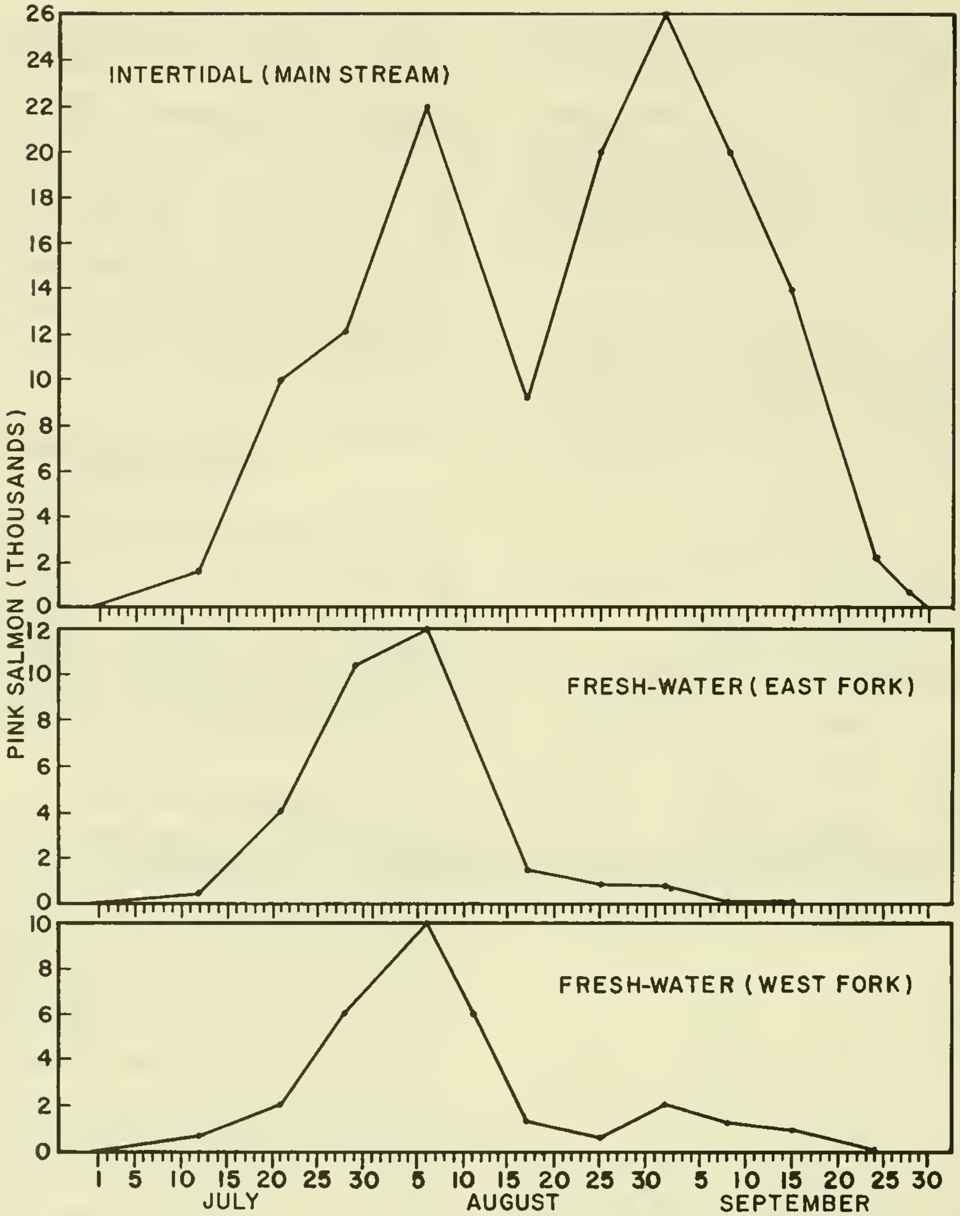

Figure 5.--Seasonal abundance of adult pink salmon in the intertidal (main stream) and fresh-water (East and West Forks) areas of Olsen Creek, based on counts made during periodic foot surveys--July through September 1962.

Table 4.--Foot survey estimates of pink salmon in intertidal and fresh-water areas of Olsen Creek, 1960-63

Year	Intertidal spawners			Fresh-water spawners						Total spawners	Intertidal spawners
				East Fork			West Fork				
	Early	Late	Total	Early	Late	Total	Early	Late	Total		
	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Percent
1960	24,647	65,342	89,989	15,856	([1])	15,856	14,546	([1])	14,546	120,391	75
1961	3,144	80,024	83,168	3,974	16,070	20,044	1,530	13,347	14,877	118,089	70
1962	29,536	74,459	103,995	27,800	([1])	27,800	15,762	([1])	15,762	147,557	70
1963	3,697	16,387	20,084	5,674	12,113	17,787	3,562	17,387	20,949	58,820	34

[1] Late-run pink salmon of the even-year line do not spawn above the 14-foot (4.3-m.) tide level (see fig. 1); therefore, the few fish that spawn between the 12-foot (3.7-m.) level (arbitrary division between intertidal and fresh-water areas) and the 14-foot (4.3-m.) level are considered intertidal spawners.

The timing and distribution of the pink salmon runs in Olsen Creek in 1962 were nearly identical to the parent runs in 1960--the runs in both years were bimodal in time of appearance in the stream.[9] The early run spawned in both the fresh-water and intertidal areas, and the late run spawned only in the intertidal area. In 1960, 45 percent of the early run spawned in the intertidal area, and in 1962, 41 percent spawned there (table 4). The few fish of the late run that selected the fresh-water area (fig. 5) spawned between the mean high and extreme high tide levels--the 12- to 14-foot (4.0- to 4.3-m.) tide zone, which is contiguous to the arbitrarily established upper limit of the intertidal zone.

In July and August 1962 (peak of spawning for the early run), pink salmon could not get to some spawning areas in Olsen Bay because of extremely low water caused by a drought. Little Creek (fig. 1), for example, had so little water that by July 27 all the water in the lower half of the stream seeped through the gravel (the surface of the bed was dry); between August 10 and 21 the upper half of the stream was also dry. Foot surveys of Little Creek revealed 22 male pink salmon and one female on July 27 and seven males and two females on August 6. These fish, which were in the intertidal portion of the stream, were isolated in small shallow pools when the tide was out and were particularly vulnerable to predation by black bears, Ursus americanus, and glaucous-winged gulls, Larus glaucescens. The first rainfall of any consequence was on August 21, when the stream returned to its normal flow.

The effect of the drought was also evident in Olsen Creek. The West Fork has two falls--the first about 1 km. and the second about 2.5 km. above the confluence with the East Fork. Pink salmon can usually negotiate the first falls but never the second. As the stream level fell during the drought, however, the first falls became a barrier. On July 27, 5,924 pink salmon were counted in the West Fork between the confluence of the two forks and the first falls; an additional 4,000 to 5,000 were crowded in the pool below the falls; only 404 were between the two falls. On August 6 the count was still about 11,000 below the first falls but only 179 above. The effects of the low water on the migration of pink salmon spawners in Olsen Creek in 1962 were discussed by Helle (1966).

[9] Fish of the first mode are termed the early run (or the early escapement) and fish of the second mode the late run. In the stream the two runs may overlap, but the fish are easily recognized as early or late by their degree of physical degeneration.

The 1963 Spawning Population

Figure 6 shows the results of the foot survey counts of pink salmon in the intertidal and fresh-water spawning areas in 1963. Because these counts did not include fish in the pools, the area under the curve was divided by the mean redd life instead of mean stream life to estimate the total spawning populations. I assumed for these calculations that redd life for males and females was the same and that the sex ratio was 1:1.

Redd life was determined by daily observations of 340 tagged female pink salmon that had been captured off the mouth of Olsen Creek with a beach seine and tagged with a Petersen disk tag 1-1/4 inches (3.17 cm.) in diameter. The numbers or letters on the tags were large enough so that individual fish could be readily identified from the bank of the stream (Hobart, 1964). The location of each tagged female was recorded daily after she entered the stream. Redd life was recorded as the time in days from the first day that redd digging and defense were observed until the female was no longer near her redd. One day was added to each estimate of redd life because females were assumed to be present one-half

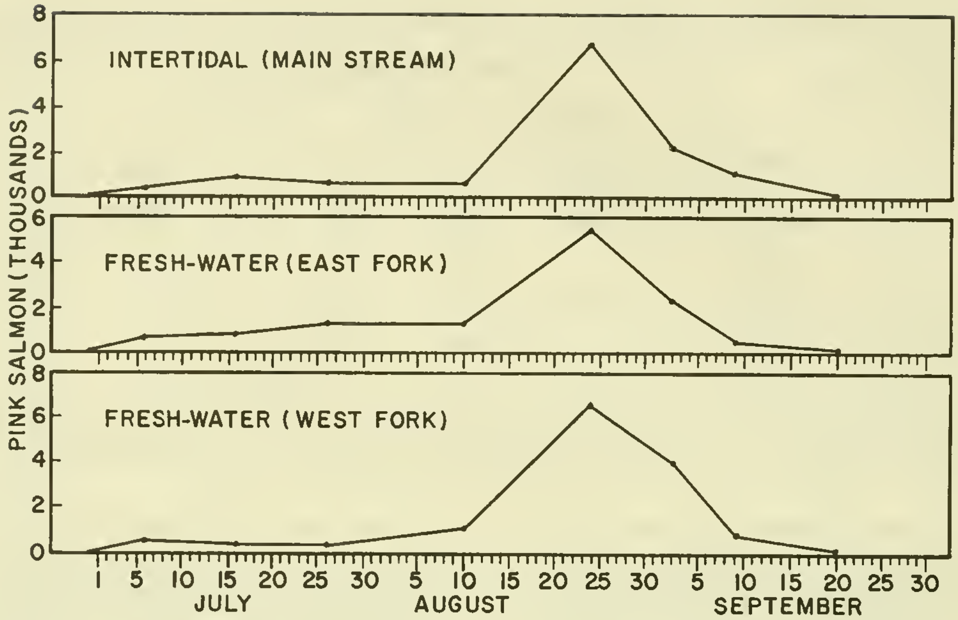

Figure 6.--Seasonal abundance of adult pink salmon in intertidal (main stream) and fresh-water (East and West Forks) areas of Olsen Creek (excluding pools), based on counts made during periodic foot surveys--July through September 1963.

day before the first observation and one-half day after the last (McNeil, 1964). For the total early run (fresh-water and intertidal runs combined) the mean redd life for 16 females was 8.9 days (range 5-17 days); for the total late run the average for 26 females was 6.2 days (range 4-8 days).

To estimate the total number of spawners (table 4) I divided by 8.9 the total number of fish days (area under the curves in fig. 4) before August 9 (early run) and by 6.2 after August 9 (late run).

The number of pink salmon in the early run in 1963 was nearly the same as in 1961, but the late run was considerably larger in 1961 (table 4). Only 34 percent of the total run in Olsen Creek spawned in the intertidal zone in 1963, but 70 percent of the parent run had spawned there in 1961. In all of Prince William Sound, 46 percent of the pink salmon spawned in the intertidal area in 1963 (see footnote 7) and 35 percent in 1963 (see footnote 1). Olsen Creek received 2 percent of the total pink salmon escapement in Prince William Sound in 1961 and 1 percent in 1963 (see footnotes 1 and 2).

Pink salmon appeared on the spawning ground in 1963 about the same time as they had in 1961, and in both years the small early and large late runs spawned throughout the stream (figs. 4 and 6). A drought occurred in September 1963, but it was so near the end of spawning that the resultant low streamflow did not affect the abundance or distribution of the spawners.

LENGTHS OF FRESH-WATER AND INTERTIDAL SPAWNERS

Spawning dates and relative numbers in the early and late runs were consistently different between pink salmon that spawned in fresh water and those that spawned in intertidal areas, both in odd and in even years. This relation suggested that the fresh-water and intertidal spawners are discrete populations in the Olsen Bay drainage (Helle et al., 1964). As one test of this hypothesis, I compared the MEHP (mideye to posterior end of hypural plate) lengths of dead spawned-out fish from the various suspected populations. Only spawned-out fish were used because the "home area" could not be determined until the fish had spawned. Elongation of the jaws of males and erosion of the caudal fin of females during spawning precluded use of the more common measurement from mideye to fork of tail. The relation between the two types of lengths was determined also to facilitate comparison of data from Olsen Creek with data from other areas.

The MEHP lengths of carcasses of both sexes were measured with a caliper to the nearest millimeter. Bias in selecting fish was avoided by measuring all of the carcasses within a previously designated section of the stream on each sampling day. Most of the carcasses of the fresh-water spawners accumulated in pools or against log jams close to the spawning riffles and were probably eventually eaten by scavengers, although a few may have drifted down into the intertidal area and been included in the measurements of intertidal spawners.

Comparisons of Lengths of Pink Salmon from Various Segments of the Run

Comparisons were made of the lengths of males and females from the early and late runs in 1962 to the fresh-water and intertidal spawning areas. In 1963 comparisons were limited to areas in the intertidal zone.

1962.--In 1962 the MEHP length was determined for 984 adult pink salmon from early and late runs to one fresh-water area (East Fork) and three intertidal areas (main stream of Olsen Creek, Little Creek, and Middle Slough). A modification of the graphic method of Dice and Leraas (1936) suggested by Simpson, Roe, and Lewontin (1960) was used to compare the lengths of males and females from early and late runs (fig. 7). The amount of vertical overlap of the black bars (95-percent confidence interval on each side of the mean) indicates a statistical significance. If the black bars are about the same size and

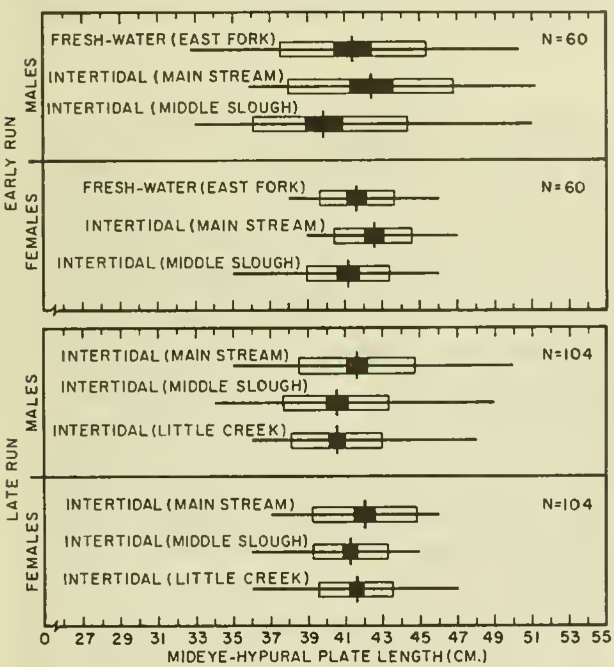

Figure 7.--Comparison of MEHP length of pink salmon from the early and late runs in one fresh-water area (East Fork) and three intertidal areas (main stream of Olsen Creek, Little Creek, and Middle Slough), 1962. Horizontal lines represent range in length; black bar indicates 95-percent confidence interval on each side of the mean (vertical line). One-half of the black bar plus the white bar at either end is one standard deviation. N equals the number of specimens in each sample. All except East Fork are in intertidal area.

do not overlap, the two samples are nearly certain to be significantly different.

Measurements of males and females from the same areas demonstrate that the lengths of males were more widely dispersed around the mean (fig. 7), as evidenced by ranges and standard deviations. The mean lengths of males and females from the early run in Middle Slough were significantly less than those of other early-run intertidal spawners (t-tests; $P < 0.01$).

For males and females (considered separately by sex) the average lengths of late-run fish in Middle Slough and Little Creek in 1962 were significantly less than those of late-run fish in the main stream of Olsen Creek (t-tests; $P < 0.01$ for all except the difference between females from Little Creek and the main stream, which was at $P < 0.10$). This tendency for fish in the small intertidal creeks, Middle Slough and Little Creek, to be shorter was also noted in the parent year, 1960 (Helle et al., 1964). Two possibilities are suggested to account for this size difference: Stocks that are genetically different may home to specific portions of the Olsen Creek tideflat, or behavioral patterns may cause segregation of large and small fish. Large adults might find it difficult to spawn in the smaller channels, or large adults might drive small adults away from "preferred" redd locations in the main stream of Olsen Creek.

The mean lengths of females from the early run in the East Fork were significantly less ($P < 0.05$) than those of early-run females from the main stream, but the mean lengths of the males from the two areas were not significantly different (fig. 7). The mean lengths of males and females in the early run were greater (but not significantly so) than the mean lengths of males and females in the late run from corresponding areas; this relation also held in 1960 (Helle et al., 1964).

1963.--In 1963 the MEHP length was determined for 622 adult pink salmon from the early and late runs to the main stream of Olsen Creek and the late run to Little Creek. Sampling was restricted to these two intertidal areas because the parent year (1961) showed no intraseasonal differences in mean lengths between fish from the main stream and the two forks of Olsen Creek or between those from Middle Slough and Little Creek (Helle et al., 1964).

In 1963 length differences of late- and early-run fish of the same sex were not significant (fig. 8)--in contrast to 1961, when late-run fish were significantly longer than early-run fish.

Only late-run pink salmon spawned in Little Creek in 1963. Males from Little Creek did not differ in mean length from late spawners in the main stream, but females in Little

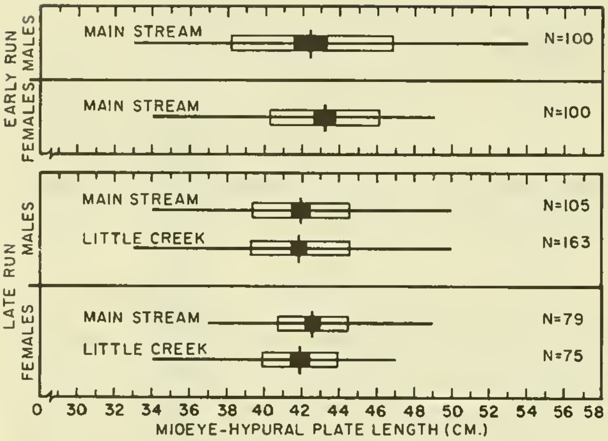

Figure 8.--Comparison of MEHP lengths of pink salmon from the early and late runs in two intertidal areas (main stream of Olsen Creek and Little Creek), 1963. (See legend of figure 7 for explanation.)

Creek were significantly shorter ($P < 0.05$) than females in the main stream (fig. 8). In the parent year (1961) the mean length of pink salmon spawning in Little Creek was shorter than of those spawning in the main stream, but the difference was not significant (Helle et al., 1964).

Relation of MEHP Length to Length from Mideye to Fork of Tail

Although the MEHP measurement is most appropriate in Olsen Creek because of the advanced maturity of fish sampled on the spawning grounds, other investigators commonly use the MEFT (mideye to fork of tail) measurement. To relate the two values, in 1962 and 1963 we collected 97 unspawned females at the mouth of Olsen Creek and measured both the MEHP and MEFT lengths on each fish with a caliper rule to the nearest millimeter. The relation is $\hat{Y} = 4.7 + 1.01X$, where $\hat{Y}$ is the expected MEFT length in centimeters and X is the MEHP length in centimeters (fig. 9).

FECUNDITY

Female pink salmon were collected for fecundity determinations from the early and late segments of the runs to Olsen Creek in 1962 and 1963, without reference to spawning area. The intertidal and fresh-water portions of the runs cannot be sampled separately because many females expel some of their eggs before they reach their "home" spawning area. The females in my sample, which were captured in a beach seine at the mouth of Olsen Creek, were identified as early or late on the basis of the time of their appearance at the mouth of the creek. The ovaries were removed from the fish, placed in a cloth bag, and boiled in water until the ova had hardened and could be easily separated from the membranous connective tissues. The eggs were counted by use of counting boards (see Helle et al., 1964). The MEHP length of each fish was measured.

I determined the relation between number of eggs and length. In 1963 the eggs in each ovary were counted separately so that a comparison of number of eggs in the right and left ovaries could be made. The number of eggs retained in the body cavity after spawning was determined by a periodic examination of carcasses on the spawning grounds.

Relation between Fecundity and Length

In 1962 fecundity was determined for both the early and late runs. Females were collected periodically in 1963 and combined without regard to early or late runs because the data collected in 1961 indicated no difference in the fecundity of the two runs (Helle et al., 1964).

1962.--In 1962 the mean fecundity of 49 females from the early run was 1,815 eggs, and the mean length was 43.0 cm.; the means for 41 females from the late run were 1,846 eggs and 43.5 cm. (table 5). The relation between the number of eggs and the mean length was low but significant for early-run females ($r = 0.347$) but not significant for late-run females ($r = 0.294$). The smaller range in length of late-run females may account for this lack of correlation for the late run. Foerster and Pritchard (1941), who compared the relation between number of eggs and length in pink and sockeye salmon, *Oncorhynchus nerka*, found that the correlation coefficients were significant for both length and weight but were much lower for pink than for sockeye salmon. They suggested that the difference was due partly to the narrower range in size of pink salmon.

The relation between length and number of eggs for the females from the early and late runs combined in 1962 is shown in figure 10. The mean length of the 90 females was 43.2 cm., and the mean fecundity was 1,829 (table 5). The relation between number of eggs and length was highly significant ($r = 0.335$). The mean length of 50 females (early and late runs combined) sampled in the parent year (1960) was 43.0 cm., and the mean egg content was 1,815 (Helle et al., 1964). The relation between number of eggs and length for the 50 fish in 1960, however, was not significant ($r = 0.210$).

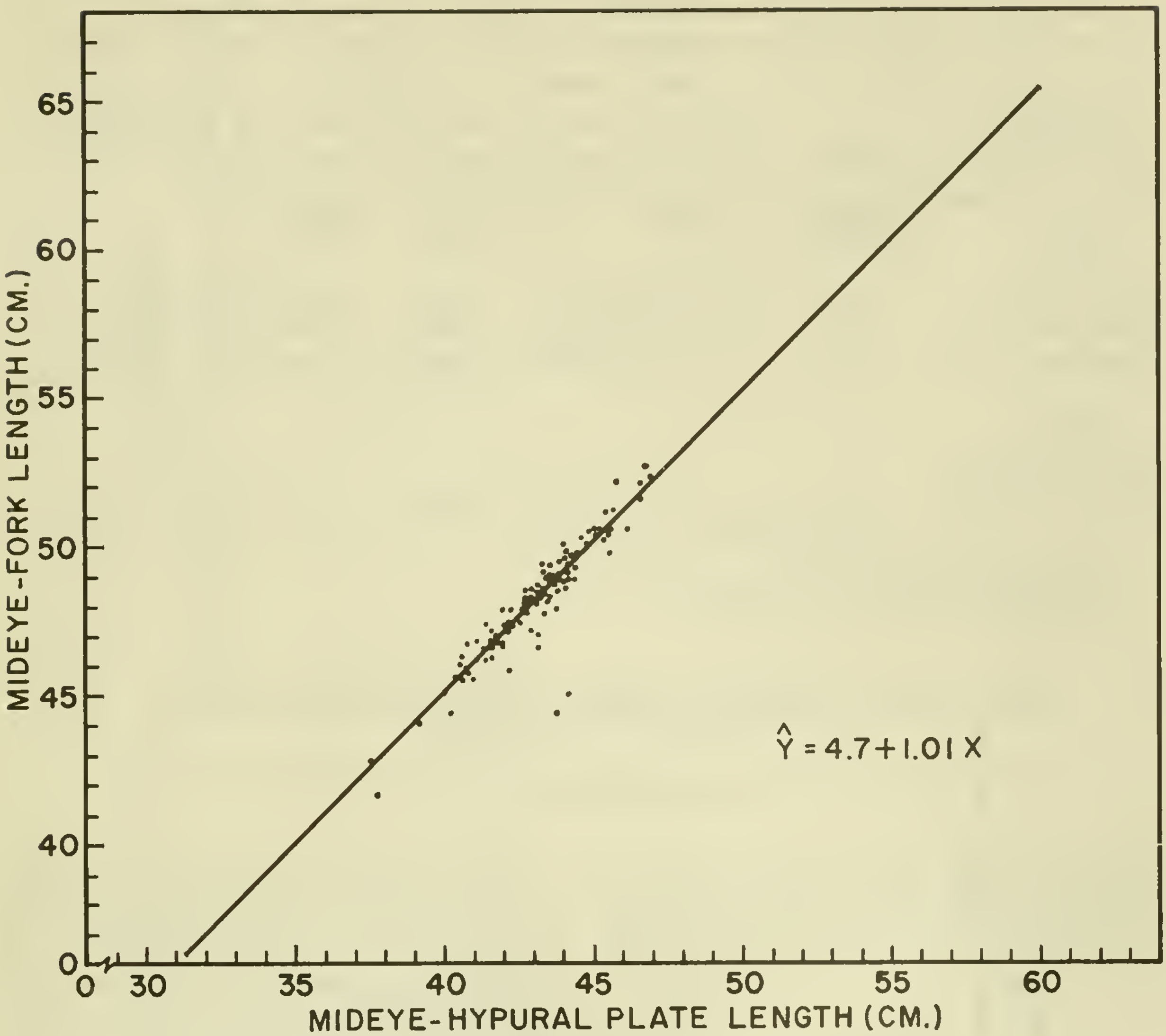

Figure 9.--Relation of MEHP length to MEFT length of 97 female pink salmon at Olsen Creek, 1962-63.

1963.--In 1963, the fecundity of 52 females was determined from samples collected periodically and combined without regard to early or late runs because the data collected in 1961 indicated no difference in the fecundity of the two runs (Helle et al., 1964) and those for 1962 indicated a similar relation. The mean length of females sampled in 1963 was 43.1 cm., and the mean egg content was 1,929 (table 5). Although the mean lengths of females were about the same in 1962 as in 1963, the mean number of eggs per female was greater (by 100 eggs) in 1963. Females collected in 1961 also had a greater mean egg content (by 279 eggs) than females collected in 1960, but they were, on the average, also slightly longer in 1961 (Helle et al., 1964).

The relation between number of eggs and length in 1963 for females from the early and late runs combined is shown in figure 11. The relation was highly significant ($r = 0.634$). The range in lengths of females and number of eggs was smaller in 1963 than in 1962, and yet the correlation coefficient was higher in 1963. A partial explanation for the lower correlation in 1962 is the presence of five average to large females with considerably fewer than the average number of eggs (fig. 10).

Comparison of Right and Left Ovaries, 1963

Several workers have found differences in the average number of eggs in the right and left ovaries of salmon. Rounsefell (1957) in

Table 5.--Numbers of eggs and lengths of female pink salmon from early and late runs, Olsen Creek, 1962-63

Year and spawning group	Females	MEHP length		Eggs		Correlation coefficients
		Mean	Range	Mean	Range	
	Number	Mm.	Mm.	Number	Number	r
1962						
Early run........	49	430	355-476	1,815	714-2,714	[1]0.347
Late run.........	41	435	404-486	1,846	1,273-2,376	0.294
Combined	90	432	355-486	[2]1,829±66	714-2,714	[3]0.335
1963						
Early and late runs combined..	52	431	367-468	[2]1,929±68	1,433-2,509	[3]0.634

[1] Significant at $P < 0.05$.
[2] Confidence interval at 95-percent level.
[3] Significant at $P < 0.01$.

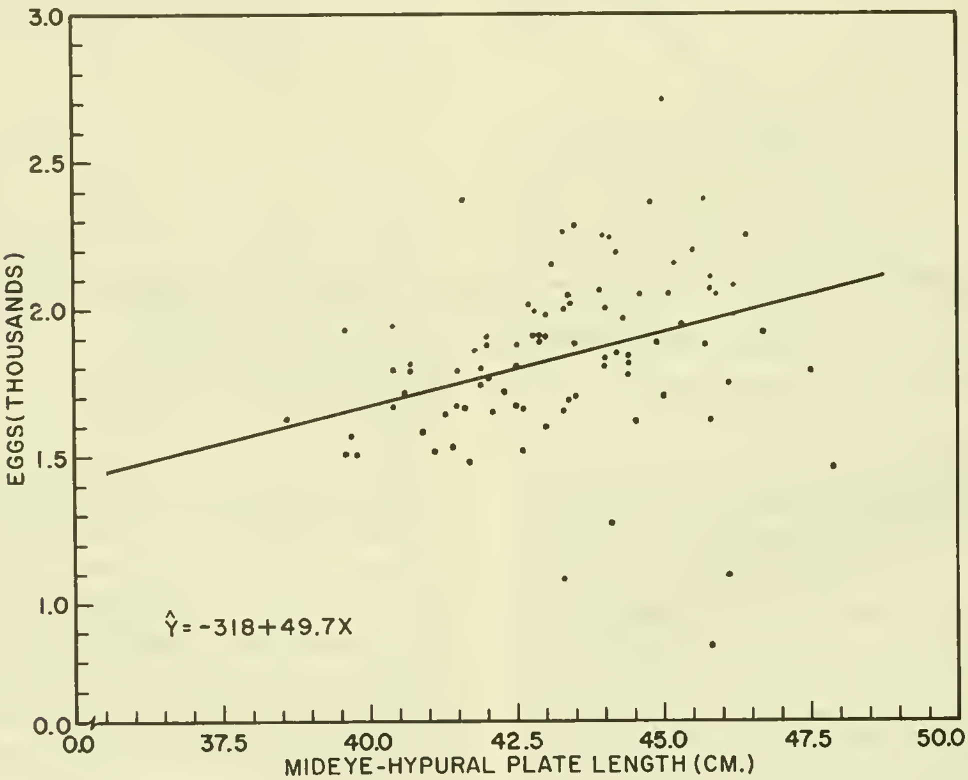

Figure 10.--Relation of number of eggs to MEHP length for 90 pink salmon, early and late runs combined, Olsen Creek, 1962.

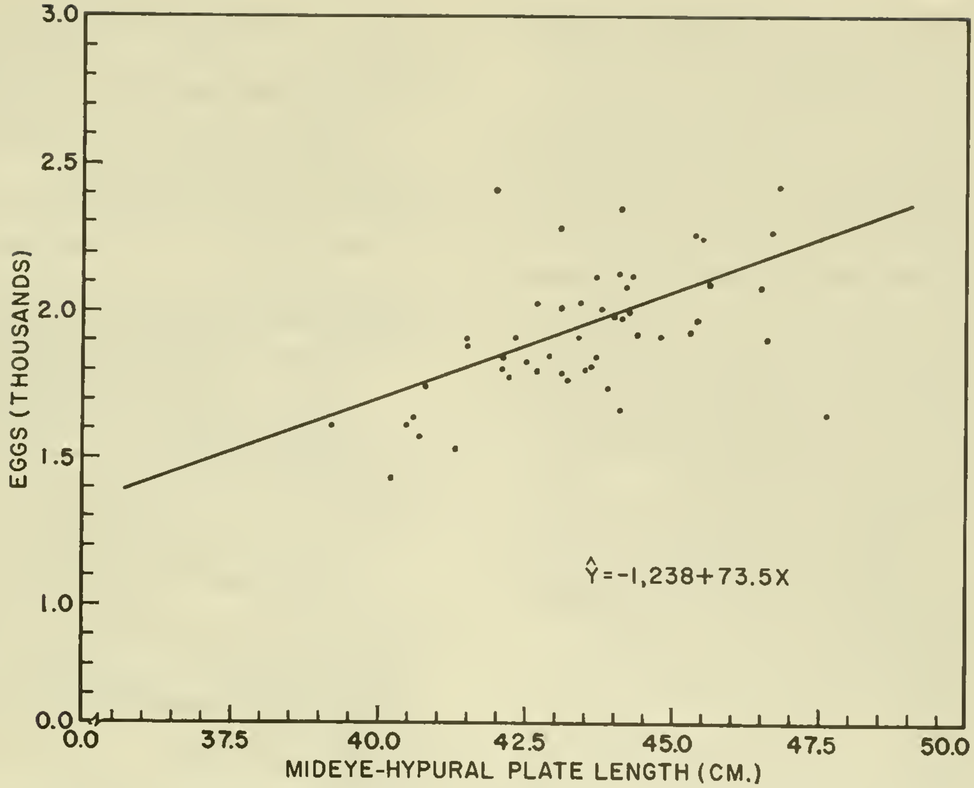

Figure 11.--Relation of number of eggs to MEHP length for 52 pink salmon, early and late runs combined, Olsen Creek, 1963.

reference to sockeye salmon from the Karluk system on Kodiak Island, Alaska, noted that both ovaries maintain the same rate of maturation even though the number of eggs in each ovary is different. Hartman and Conkle (1960) found that about 90 percent of the left ovaries contained more eggs than the right in sockeye salmon from Brooks Lake, Alaska, in 1957 and 1958. Nelson (1959) reported that the right ovary usually contained more eggs than the left in sockeye salmon from Bare Lake, Alaska.

The number of eggs was recorded for the right and left ovaries of 50 pink salmon from Olsen Creek in 1963. The mean number of eggs in the left ovaries was 954, and the mean for the right ovaries was 978; the difference was not significant. The left ovary contained more eggs than the right in 21 fish (42 percent) and fewer in 29 (58 percent).

Egg Retention, 1962 and 1963

Intermittently in 1962 and 1963 we examined carcasses of spawned-out female pink salmon to determine egg retention (the number of eggs remaining in the carcass). The egg retention at Olsen Creek in 1962 and 1963 was about 10 percent. During the late run in 1961 it reached 41 percent (Helle et al., 1964). The high egg retention in 1961 was associated with a high density of spawners. The retention was only 7 percent in 1960, when the density of spawners was similar to that observed in 1962 and 1963.

SUMMARY

Studies on the ecology of pink salmon in the intertidal and fresh-water areas of Olsen Creek began in 1960. Following is a summary of observations on the quality of the streambed and the abundance, timing, distribution, length, and fecundity of pink salmon in 1962 and 1963.

1. The percentage of fines (materials passing through an 0.833-mm. sieve) in samples of material from the streambed increased from higher to lower tide levels. In streambed materials taken in the upper intertidal area before and after spawning, fines were significantly lower in the postspawning sample. Whether this difference was caused by spawning activity or flooding, or both was not determined.

2. The numbers of pink salmon spawning in 1962 and 1963 were estimated by repetitive stream surveys. The estimates by this method

were compared with data from 1960 and 1961 weir counts, tag ratio estimates, and a peak count method. Differences among the estimates ranged from 6 to 22 percent.

3. Seventy percent of the pink salmon in Olsen Creek spawned in the intertidal zone in 1962. The run was bimodal; the early portion spawned in both the fresh-water and intertidal areas of the stream, whereas the late run spawned only in the intertidal zone. This distribution was identical to that of the parent year, 1960.

4. Only 34 percent of the total run spawned in the intertidal area in 1963. The timing of the run in 1963 was identical to that of the parent year (1961), but unlike the even-year run, early and late pink salmon both spawned in the upstream and intertidal portions of the stream.

5. In 1962, pink salmon that spawned in the two small intertidal creeks close to Olsen Creek--Middle Slough and Little Creek--were significantly smaller than intertidal spawners in Olsen Creek. This relation also existed in the parent year (1960).

6. In 1963 late-run females in Little Creek were significantly smaller than late-run females in Olsen Creek.

7. A graph of the relation between two lengths--mideye to hypural plate and mideye to fork of tail--is presented for ready comparison of the two measurements.

8. Although the mean length of females taken for fecundity samples was about the same in both years, the mean fecundity was 1,829 eggs in 1962 and 1,929 in 1963.

9. The relation between number of eggs and length in 1962 was significant for early-run fish but not for late-run fish. The combined sample showed a highly significant ($r = 0.335$, $n = 90$) relation between number of eggs and length.

10. The relation between number of eggs and length for early and late runs combined in 1963 was highly significant ($r = 0.634$, $n = 52$).

11. The mean number of eggs per ovary was 954 for the left ovary and 978 for the right. The right ovary held more eggs than the left in 58 percent of 50 females examined, but the difference was not statistically significant.

12. About 10 percent of the eggs were retained in the carcasses of females in both 1962 and 1963.

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