Distribution of Spawning Pink Salmon in Sashin Creek, Southeastern Alaska, and Survival of Their Progeny

By William J. McNeil

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CONTENTS

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By

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ABSTRACT

The escapement of pink salmon (Oncorhynchus gorbuscha) to Sashin Creek, southeastern Alaska, in 1963 was 16,757 fish, and fresh-water survival calculated from potential egg deposition and number of outmigrant fry was 20 percent. The spawning ground was divided into three areas--upper, middle, and lower--for the study of density of spawners and survival of progeny. The density of spawners was highest in the middle area. Survival during spawning was low in each area; survival between the end of spawning and the beginning of fry emergence was variable among the three areas; and survival during fry emergence was high in each area. From egg deposition to fry emergence, survival was estimated to be 31 percent in the upper area, 16 percent in the middle area, and 15 percent in the lower area.

Although the upper area was highly productive of pink salmon fry, it has had intensive spawning only in years when the density of spawners was high. When the density was low, spawners tended to concentrate in the lower area. The validity of the supposition that only highly productive spawning beds are used when escapements are small is questioned. The observations at Sashin Creek indicate that relatively large escapements help ensure complete use of productive spawning beds.

INTRODUCTION

The production of fry of pink salmon (Oncorhynchus gorbuscha) can vary greatly among areas within a stream (Merrell, 1962; McNeil, 1966). Much of this variation may be due to the distribution of spawners. Frequently, small runs spawn in restricted areas in a stream, whereas large runs spawn throughout a stream (Kaganovskii, 1949; Hunter, 1959; Merrell, 1962; Vasilenko-Lukina, 1962). It has been postulated that areas not used when runs are small have relatively poor conditions for eggs and alevins (Neave, 1953 and 1958; Pritchard, 1948; Semko, 1954; Ward and Larkin, 1964).

Recent evidence from studies on Sashin Creek, a small stream on Baranof Island, southeastern Alaska, is not in full agreement with this hypothesis. Merrell (1962) demonstrated that a spawning area used little in a year of low escapement was used intensively in a year of high escapement; in the year of high escapement this intermittently used area had a high survival of eggs and alevins and produced an exceptionally large number of fry.

To clarify the relations among the distribution of spawners, survival of eggs and alevins, and production of fry in Sashin Creek, I studied a relatively large run of pink salmon that spawned there in the latter half of August and in September 1963. Survival from deposition of eggs to emergence and migration of fry was determined in three areas that together included 97 percent of the area used by spawners in years of large escapements. In this paper, estimates of survival of embryos and alevins are compared with the density of spawners in the three study areas, and survivorship curves are described for each area. Also discussed is the concept that large numbers of spawners are required to ensure complete use of all productive spawning areas within a stream.

Only a small portion of Sashin Creek can be used by salmon spawners. Although the creek is about 4,000 m. long, a waterfall 1,200 m. from the head of tide prevents further upstream movement of spawners. Little spawning occurs in a narrow canyon that extends 300 m. downstream from the waterfall or in the intertidal zone, where the gradient is steep and the bottom is mostly bedrock. The main spawning ground--13,629 m.^{2}--lies between the intertidal zone and the canyon. This study considered a 13,084 m.^{2} area, which was divided into three areas--upper (2,945 m.^{2}), middle (4,067 m.^{2}), and lower (6,072 m.^{2}). The upper area has a relatively steep gradient and coarse materials in the bed; the middle area has an intermediate gradient and medium-sized materials; and the lower area has a shallow gradient and fine materials (table 1).

Table 1.--Size composition of bottom materials[1] and average gradient in three areas in Sashin Creek

Area	Average gradient	Bottom materials composed of--		
		Cobbles[2]	Pebbles and granules[3]	Sands and silts[4]
	Percent	Percent	Percent	Percent
Upper..	0.7	81	16	3
Middle.	0.3	61	26	13
Lower..	0.1	47	36	17

[1] Procedures for sampling bed materials to measure size composition are described by McNeil and Ahnell (1964). Materials >15.2 mm. diameter are excluded.

[2] Cobbles are >12.7 mm. diameter.

[3] Pebbles and granules are 1.68 to 12.7 mm. diameter.

[4] Sands and silts are <1.68 mm. diameter.

NUMBER, DENSITY, AND DISTRIBUTION OF SPAWNERS

Distribution and density of female spawners were studied to provide answers to three questions: (1) Does the density of females differ among the three study areas? (2) Are any differences in distribution of females related to size of the spawners? (3) Are any differences in distribution of females related to time of spawning? The observations were limited to females because potential egg deposition is determined by the number and average egg content of females. Other observations at Sashin Creek (unpublished) have established that a female remains in the vicinity of her redd from beginning of spawning to death.

Adult male and female salmon were counted as they entered the Sashin Creek weir at the head of tidewater.[1] The first salmon was counted August 10 and the last September 6.

One hundred females were tagged August 20 and 21. (It was later found that 30 percent of the total females had passed the weir by August 21 and that 10 percent of the total had occupied the spawning ground.) A Petersen plastic disk, 5/8-inch diameter, was attached to each female on each side of the origin of the dorsal fin. Disks of different colors were used to identify females longer or shorter than average. The average mideye-fork length--49.9 cm.--was determined from measurements of 50 females. Fifty females longer than average were tagged with pink disks, and 50 shorter than average with green disks. Females 49.9 cm. long were not tagged.

The females (tagged and untagged) were counted in the three study areas by observers on foot who made surveys on the following weekly schedule: observer A[2]--Monday and Thursday; observer B--Tuesday and Friday; and observer C--Wednesday and Saturday. The location of each tagged female was determined during each survey and plotted on a detailed map of Sashin Creek.

The total number of females spawning in each area was estimated by the following formula:

$$\text{Number spawning} = \frac{\Sigma \text{ Daily number on spawning ground}}{\text{Average redd life}}$$

Daily numbers were summed by fitting a curve to the number of females counted each date surveys were made and measuring the area under the curve (the area under the curve is given as female-days). Average redd life (the estimated number of days each female spent on the spawning ground) was determined from the daily observations of tagged females. The method has been further illustrated by McNeil (1964a and 1964b).

Number and Density of Spawners

Agreement was good between the estimates of spawning females based on counts during the surveys on foot (9,030) and the counts at the weir (8,740). The estimate for the surveys was the average of the following counts by the observers: A, 9,640; B, 7,510; and C, 9,950.

Agreement among the observers on the estimates of relative densities of spawners in the study areas also was good.[3] The density was about 50 percent higher in the middle area than in the upper and lower areas (table 2).

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[1] Males and females can be separated easily by well-developed secondary sexual characteristics (Davidson, Vaughan, Hutchinson, and Pritchard, 1943).

[2] Two persons made observations on Monday and Thursday--the first through September 16 and the second after September 16.

[3] Density was estimated by dividing the square meters of spawning ground into the estimated number of females spawning.

Table 2.--Estimates of density of female pink salmon spawning in three areas in Sashin Creek

Area	Estimated females per square meter based on counts of observer--			Mean of estimates
	A	B	C	
	Number	Number	Number	Number
Upper.....	0.7	0.4	0.7	0.6
Middle....	1.0	.7	1.0	.9
Lower.....	.6	.5	.7	.6

Distribution of the tagged females further demonstrated the higher density in the middle area. The numbers of tagged females spawning in each area would be directly proportional to the area of spawning bed if the females occurred in equal density. The expected number of tagged females per area, based on the hypothesis that density was equal, is given in table 3 with the observed number. A chi-square test yielded χ^2(2 d.f.) = 5.22 (probability = 0.07). This result combined with the fact that observers consistently found greater densities of untagged females in the middle area than in the upper and lower areas causes me to conclude that the density of spawners was not uniform among the three study areas.

Table 3.--Numbers of tagged female pink salmon observed in three areas in Sashin Creek and the expected number, on the basis of the null hypothesis of equal density

[χ^2(2 d.f.) = 5.22 (probability = 0.07)]

Area	Females expected	Females observed
	Number	Number
Upper..................	19	13
Middle..................	27	36
Lower..................	40	37

Distribution of Large and Small Females

Large and small females were distributed equally on the spawning ground. Of 86 tagged female pink salmon observed to spawn, half were shorter than average length (49.9 cm.) and half were longer. The hypothesis that large and small females spawned with equal frequency was tested for each study area.

Table 4.--Numbers of large and small tagged female pink salmon that spawned in three areas in Sashin Creek, and associated probabilities, assuming the distribution of spawners was unrelated to size

Area	Large females	Small females	Probability
	Number	Number	
Upper.......	6	7	1.00
Middle......	19	17	.865
Lower.......	18	19	1.00

Table 4 gives the observed numbers of large and small females in the study areas and the 2-tailed probabilities of occurrence of the observed values, assuming the hypothesis to be correct. The results clearly demonstrate that distribution was unrelated to length.

Distribution of Early- and Late-Spawning Females

I wish to consider two questions on the distribution of early and late spawners: (1) Do large and small females spawn early or late with equal frequency? (2) Are early and late spawners distributed similarly among the study areas? Pink salmon began to spawn August 10, and spawning was completed by September 30. About 50 percent of the females spawned before September 3. Forty-four tagged females that spawned before September 3 were classified as "early"; 42 that spawned September 3 and later were classified as "late."

The binomial test was used to examine the first question. Of the 44 early-spawning tagged females, 26 were large and 18 were small. The null hypothesis that large and small females spawned early and late with equal frequency was tested with the normal approximation of the binomial distribution. A value $\underline{z} = |1.06|$ was obtained. If the hypothesis is true, a value $\underline{z} = > |1.06|$ would be expected in 29 percent of similar experiments; I conclude that large and small females tagged August 20 and 21 spawned early or late with equal or nearly equal frequency.

The chi-square test was used to examine the second question. The expected numbers of tagged females in the study areas (based on the null hypothesis that early- and late-spawning females exhibited no difference in their distribution) and the numbers of early- and late-spawning females observed in each study area are given in table 5. The value χ^2(2 d.f.) = 7.87 (probability = 0.02) was obtained. I conclude that early-spawning females favored the upstream area and late-spawning

Table 5.--Expected and observed numbers of early- and late-spawning female pink salmon in three areas in Sashin Creek

[χ^2(2 d.f.) = 7.87 (probability = 0.02)]

Area	Early spawners		Late spawners	
	Expected	Observed	Expected	Observed
	Number	Number	Number	Number
Upper..	6.7	10	6.3	3
Middle.	18.4	21	17.6	15
Lower..	18.9	13	18.1	24

females the downstream area. The downstream "shift" in distribution of tagged females during September was not related to date of entry into the stream because all tagged females entered Sashin Creek on August 20 and 21. The shift may have been caused by unusual weather in 1963.

The weather was exceptionally dry before September 3 (average daily rainfall, August 10-September 2, 0.25 cm.) and exceptionally wet thereafter (daily average, September 3-29, 4.52 cm.). The early period was the third driest and the late period the wettest in 26 years of record.

DENSITY, DISTRIBUTION AND SURVIVAL OF EGGS, ALEVINS, AND FRY

Eggs and alevins were sampled periodically within the three study areas, and fry migrating to sea were counted at a weir at the head of tidewater. Eggs were collected after spawning (late September); and eggs and alevins were collected during hatching (mid-December), before emergence (late March), and during emergence (early and late May). All eggs collected in March and May were dead. The sampling locations, each representing 0.1 $m.^2$ of the streambed, were selected at random within the study areas with the aid of tables of random numbers. Hydraulic sampling equipment used for collecting eggs and alevins was described by McNeil (1964b). The downstream migration of fry started in late March and lasted until early June.

Density and Distribution of Deposited Eggs

The number of eggs recruited to a spawning bed approaches an upper limit as the density of spawners increases and the percentage of potential egg deposition recruited to the spawning bed decreases (McNeil, 1964a). The present study indicated that the percentage of potential egg deposition recruited to the spawning bed is also related to the size of materials in the spawning bed. On the basis of the density of spawners, the density of eggs at the end of spawning should have been highest in the middle spawning area but actually was highest in the upper area (the area with coarse bottom materials and steep gradient). Furthermore, the estimated potential egg deposition was equal in the upper and lower areas, but at the end of spawning the number of eggs per square meter was twice as great in the upper area as in the lower (table 6).

Other evidence indicates that the percentage of the spawning ground used for egg deposition depends on the density of spawners and is independent of the size of materials in the spawning bed. To index the percentage of area used by spawners, I combined sampling units (0.1 $m.^2$) where more than three eggs were collected at the end of spawning; units that had three or fewer eggs per 0.1 $m.^2$ were considered to be unused. My selection of more than three eggs per 0.1 $m.^2$ to index use is arbitrary, but some small value greater than zero is required to help correct for eggs that drift to points not used by spawners. A test of hypothesis that more than three eggs per sample would be obtained with equal frequency among the three study areas yielded a value χ^2(2 d.f.) = 14.1 (probability = 0.001). The percentage of samples that contained more than three eggs was highest for the middle area (table 7)--the same area that had the highest density of spawners.

The percentage of the spawning ground used for egg deposition appeared to be related to the average density of spawners; but the efficiency of egg deposition was related to both the size composition of materials in the spawning bed and the average density of spawners. Under conditions of streamflow prevailing in 1963, the relatively coarse materials in the upper area provided for more efficient recruitment of

Table 6.--Potential and observed density of eggs of pink salmon in three areas in Sashin Creek at the end of spawning

Area	Potential eggs per square meter	Observed eggs per square meter	
		Mean	90-percent confidence limits of the mean
	Number	Number	Number
Upper....	1,140	885	± 160
Middle...	1,710	538	± 120
Lower....	1,140	433	± 80

Table 7.--Percentage of 0.1-m.^{2} sampling units with more than three eggs of pink salmon in three areas in Sashin Creek

Area	Sampling units	Sampling units with more than three eggs	
		Mean	Approximate 90-percent confidence limits of the mean[1]
	Number	Percent	
Upper......	81	80	± 7.3
Middle.....	81	89	± 5.4
Lower......	181	76	± 5.2

[1] Confidence limits were calculated from normal approximation of the binomial distribution.

eggs than the finer materials in the middle and lower areas.

Survival of Embryos and Alevins

The technique of randomly sampling 0.1-m.^{2} areas of streambed provides an estimate of survival from the time of spawning to the time of sampling. Survival ($\underline{S}$) is estimated from number of live embryos and alevins in spawning beds and potential egg deposition. An estimate of total survival for any selected period is calculated from:

$$\hat{\underline{S}}_{\underline{j}} = \frac{\frac{1}{\underline{k}} \sum_{\underline{i}=1}^{\underline{k}} (\text{live})_{\underline{ij}}}{(\text{potential deposition})_{\underline{j}}} \qquad (1)$$

where $\underline{i}$ designates an individual sampling point ($\underline{i}$ = 1 to $\underline{k}$) and $\underline{j}$ designates an individual study area ($\underline{j}$ = 1 to 3).

In calculating $\hat{\underline{S}}_{\underline{j}}$, I assumed the number of eggs and alevins collected at the $\underline{i}$th point to be 93 percent of the total number present at the time of sampling (McNeil, 1964b). Potential egg deposition was calculated from the estimated average number of females that spawned per square meter, multiplied by their average fecundity (1,900 eggs).

Survival was estimated by use of equation (1) in the three areas for the three periods: (1) beginning to end of spawning (through spawning), (2) beginning of spawning to end of hatching (through hatching), and (3) beginning of spawning to beginning of fry emergence (to emergence) (table 8). Survival to the end of spawning was estimated from samples collected in late September; survival to hatching and survival to fry emergence were estimated from the samples collected in late March. The number hatching was estimated by summing live and dead alevins. Dead alevins that disappeared before late March would cause overestimation of survival through the hatching stage, but there was evidence that the error from this source was small. Average density of live-plus-dead eggs and alevins in the middle and lower areas did not change significantly between late September and late March or in the

Table 8.--Estimates of number and percentage survival of eggs and alevins from potential egg deposition of 1963 brood year pink salmon in Sashin Creek

Area	Potential egg deposition per square meter	Time period	Live eggs and alevins per square meter		Estimated mean survival
			Mean	90-percent confidence limits of the mean	
	Number		Number	Number	Percent
Upper......	1,140	Through spawning......	760	±157	67
		Through hatching......	374	±113	33
		To emergence..........	370	±112	32
Middle.....	1,710	Through spawning......	344	±117	20
		Through hatching......	283	± 94	17
		To emergence..........	276	± 93	16
Lower......	1,140	Through spawning......	316	± 82	28
		Through hatching......	319	± 82	28
		To emergence..........	179	± 93	16

Table 9.--Estimated percentage of eggs and alevins from the 1963 brood year of pink salmon that disappeared from three areas in Sashin Creek during and after spawning

Area	Potential egg deposition per square meter	Time period	Live plus dead eggs and alevins per square meter: Mean	Live plus dead eggs and alevins per square meter: 90-percent confidence limits of the mean	Estimated disappearance
	Number		Number	Number	Percent
Upper......	1,140	Through spawning..... To emergence.........	885 459	±162 ±127	22 60
Middle.....	1,710	Through spawning..... To emergence.........	538 508	±122 ±138	69 70
Lower......	1,140	Through spawning..... to emergence.........	433 446	± 84 ± 98	62 61

upper area between mid-December and late March. (Late March was a good time to estimate survival because large numbers of fry emerged in early April.)

The disappearance of dead eggs and alevins from the spawning bed was also studied to help identify possible causes of mortality. The percentage of dead eggs and alevins that disappeared was estimated by:

$$\left(1 - \frac{\text{Live + dead eggs and alevins in spawning bed}}{\text{Potential egg deposition}}\right)(100)$$

The percentage of eggs that disappeared during the spawning period was about 3 times greater in the middle and lower areas than in the upper (table 9). Most of this loss was from eggs discharged during spawning; post mortem examination of 435 females showed that only about 4 percent of their potential egg deposition was retained in the body cavity, and loss of unspawned females to predators was minor. Brown bears occur on the Sashin Creek watershed, but we found no evidence that they frequented the lower section of stream before October--after pink salmon had spawned.

Disappearance of large numbers of eggs during spawning occurs commonly with pink salmon. Superimposition of redds, which results in the dislodgment of eggs previously deposited, is one factor that causes eggs to disappear during spawning (McNeil, 1964a). Coarse bottom materials may reduce the magnitude of mortality from superimposition of redds because the females cannot dislodge large cobbles while digging, and the eggs merely drift into the large interstices. This may be a reason for the decreased loss of eggs in the upper area during spawning.

Although evidence failed to indicate that eggs and alevins disappeared from the middle and lower areas between the end of spawning and the beginning of fry emergence, the percentage that had disappeared from the upper area increased from 22 to 60 during that period (table 9). An estimated 58 percent had disappeared from the upper area in autumn before the mid-December sampling; this figure was very close to the estimated 60 percent that had disappeared by late March.

The specific factors that caused eggs and alevins to disappear from the upper area in autumn have not been identified, but predators or scavengers may have been important. McDonald (1960) and McLarney (1964) found that scavengers and predators feed more heavily on salmon eggs where bottom materials are coarse than where they are fine. If scavengers or predators ate eggs and alevins in the upper area, their rate of feeding would probably be high in autumn when water temperatures are relatively warm (2° to 7° C.) and low in winter when they are relatively cool (0° to 2° C.)

I do not believe that disturbance of bed materials from flooding caused eggs and alevins to disappear from spawning beds, because the flow of Sashin Creek is well regulated. A regulated flow is provided by lakes on the watershed which provide temporary storage for water during periods of high runoff. The maximum discharge over a 12-year period (1952-64) was estimated to be 21 $m.^3$ ($1\ m.^3 = 35.314$ cu. ft.) per second. Maximum discharge affecting the 1963 brood year was estimated to be 15 $m.^3$/sec., and there was no evidence of dislodgment of materials in the spawning bed or of debris in the high-flow channel.

Patterns of Fresh-water Mortality

Before I describe the temporal patterns of fresh-water mortality, I shall review the chronological events pertaining to Sashin Creek pink salmon of the 1963 brood year.[4] Spawners first occupied the spawning ground August 10, and the die-off of spawned fish had nearly ended by September 29. About 85 percent of viable eggs had hatched before December 12. Fry migrated between March 25 and June 1.

Estimates of survival and mortality are given for the following periods in fresh water:

	Months
1. Egg deposition (mid-August to late September)	1.5
2. Egg deposition to hatching (late September to mid-December)	2.5
3. Hatching to fry emergence (mid-December to late March)	3.5
4. Fry emergence and migration (late March to late May)	2.0
Total	9.5

Survival within the nth period is calculated from the equation:

$$S_1 \cdot S_2 \cdot \cdot \cdot S_n = S \quad \text{or} \tag{2}$$

$$S_n = \frac{S}{S_1 \cdot S_2 \cdot \cdot \cdot S_{(n-1)}} \tag{3}$$

The estimates of survival shown in table 8 are used to compute survival during periods 1, 2, and 3. An example from data for the upper area will illustrate how the computations are made. Survival in period 1 is estimated by $\hat{S}$ to end of spawning, giving $\hat{S}_1 = 67$ percent for the upper area. Survival in period 2 is:

$$\hat{S}_2 = \frac{0.33}{0.67} = 0.49.$$

Survival in period 3 is:

$$\hat{S}_3 = \frac{0.32}{(0.67)\ (0.49)} = 0.97.$$

Survival during period 4 (fry emergence and migration) was high. The total abundance of alevins was determined from samples collected at the beginning of fry emergence (early March). An estimated 3,342,000 alevins were in the streambed; 3,256,000 (97 percent of the estimate) were subsequently counted at the weir when they were migrating to sea as fry. Samples collected on May 2 in all three areas and May 24 in the middle area also indicated that mortality in spawning beds was low during fry emergence. Survival was assumed to equal 97 percent throughout the stream during period 4.

The estimates of survival in each of the four periods and the total for all four periods are summarized in table 10. The estimates of total survival (from potential egg deposition to migrating fry) weighted by size of the study areas are used to compute total survival for pink salmon of the 1963 brood year for the stream as a whole. The estimate obtained--19 percent--agrees closely with the estimate of 20 percent obtained from potential egg deposition and number of fry counted at the weir.

Instantaneous mortality coefficients corresponding to the survival percentages given in table 10 were also calculated. The mortality coefficients provide direct comparisons of rate of mortality among the areas and periods considered.

In computing mortality coefficients, I assumed that the rate of change in numbers of live eggs and alevins with respect to time, $\frac{dN}{dt}$, was constant within each time period and area. Thus, for the jth area and the nth period:

$$\frac{dN_{jn}}{dt} = -MN_{jn} \tag{4}$$

where M is the mortality coefficient.

The exponential equation:

$$\frac{N_{jn}}{N'_{jn}} = e^{-Mt} \tag{5}$$

is obtained by integrating equation (4). In equation (5), the denominator (N'_{jn}) is the number of live eggs and alevins present at the beginning of period n, and the numerator (N_{jn}) is the number at the end. Hence, the following relation holds:

$$\frac{N_{jn}}{N'_{jn}} = S_{jn} = e^{-Mt} \tag{6}$$

The equation:

$$M = \frac{-\ln(S_{jn})}{t} \tag{7}$$

is obtained by conversion to natural logarithms.

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[4] The term "brood year" describes the year of spawning and is not necessarily synonymous with the term "year class," which applies to either the year of hatching or the year of emergence of the fry.

Table 10.--Estimates of survival of pink salmon of the 1963 brood year during four periods in three areas in Sashin Creek

Area	Survival in period				Total survival
	1	2	3	4	
	Percent	Percent	Percent	Percent	Percent
Upper...........	67	49	97	97	31
Middle..........	20	85	94	97	16
Lower...........	28	100	57	97	15

In computing values of M, the unit of time is taken as 1 month. Thus, t = 1.5 for period 1; 2.5 for period 2; 3.5 for period 3; and 2.0 for period 4. Values of $\bar{S}jn$ used to compute M (equation 7) are taken directly from table 10. The computed values of M for each area and time period are given in table 11.

Table 11.--Estimated instantaneous mortality coefficients during four periods[1] in the life of pink salmon of the 1963 brood year in three areas in Sashin Creek

Area	Instantaneous mortality coefficient in period--			
	1	2	3	4
Upper........	0.27	0.29	0.01	0.02
Middle.......	1.07	0.06	0.02	0.02
Lower........	0.85	0	0.16	0.02

[1] The periods are: (1) Egg deposition (mid-August to late September , (2) egg deposition to hatching (late September to mid-December), (3) hatching to fry emergence (mid-December to late March), and (4) fry emergence and migration (late March to late May).

Changes in the number of live eggs and alevins within each area and in the entire stream are shown in figure 1. For the entire stream, numbers declined most during spawning and least during emergence and migration of the fry. The sequence of mortality before the fry emerged differed among the three areas. The decline in numbers in the upper area was less pronounced than in the middle and lower areas during period 1 but more pronounced during period 2. The only distinct decline in numbers during period 3 was in the lower area.

The differences in the density of fry in the three areas were marked. The number of fry per square meter was 360 in the upper area, 268 in the middle area, and 174 in the lower area. Because of the differences in size of the areas, each area produced about the same total number of fry.

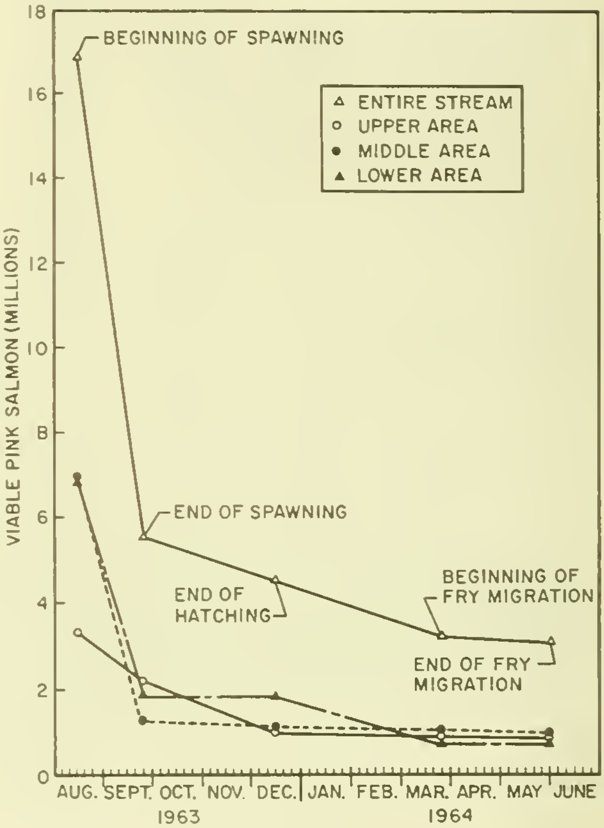

Figure 1--Number of viable pink salmon of the 1963 brood year in three areas of Sashin Creek and in the entire stream, at beginning and end of four periods in fresh water.

SUMMARY AND CONCLUSIONS

In 1963, spawning pink salmon in Sashin Creek failed to concentrate in the upper area of the spawning ground, which appeared to afford excellent habitat for embryos and alevins. The steep gradient and coarse materials in the upper area suggest that intragravel waterflow and oxygen supply are favorable (Vaux, 1962; McNeil and Ahnell, 1964). The dissolved-oxygen levels of intragravel water remained relatively high in the upper area throughout the period of spawning in both 1962 and 1963, whereas in the middle and lower areas they were relatively low in August (table 12).

The existence of an environment favorable for embryos in the upper area was also indicated by a high percentage of live eggs in the samples collected September 25. In the upper area, 86 percent of the eggs were alive--significantly more than the 64 percent in the middle area or the 73 percent in the lower. The better survival could have resulted from the higher dissolved-oxygen levels in the intragravel water in the upper area (higher than 64-percent saturation). Phillips and Campbell (1962) observed less than 25-percent survival to hatching of embryos of coho salmon (O. kisutch) and rainbow trout (Salmo gairdneri) which had been buried in streambed gravels and subjected to dissolved oxygen levels averaging less than 7 mg./l. (lower than 65-percent saturation).

Although the density of spawners was highest in the middle area, the density of eggs was highest in the upper area; 78 percent of the potential egg deposition was estimated to be in the upper area, as compared with 31 percent in the middle and 38 percent in the lower area. Since the spawners retained only 4 percent of their eggs, it appeared that losses from redd superimposition and other factors that cause eggs discharged by females to disappear from the spawning bed were low in the upper area and high in the middle and lower areas. I believe that the percentage of potential egg deposition present in the spawning bed at the end of spawning was highest in the upper area because of the coarser bottom materials there.

Survival in period 1 (egg deposition) was much higher in the upper area (67 percent) than in the middle area (20 percent) or the lower area (28 percent). The calculated instantaneous mortality coefficients were 3 to 4 times higher in the lower and middle areas than in the upper area during period 1.

In period 2 (deposition to hatching), survival was high in the middle and lower areas but low in the upper area, where large numbers of eggs and alevins disappeared. Factors causing eggs and alevins to disappear from the upper area were not identified, but scavengers or predators may have played an important role.

In period 3 (hatching to fry emergence) survival was high in the upper and middle areas but low in the lower area, where dead alevins were considerably more abundant in samples collected in late March than they were in the other two areas. The low survival in the lower area was not due to predation

Table 12.--Dissolved-oxygen content of intragravel water in three areas in Sashin Creek, 1962 and 1963[1]

Area and date	Water temperature	Concentration of dissolved oxygen		Saturation
		Mean	90-percent confidence limits of the mean	
	° C.	Mg./l.	Mg./l.	Percent
Upper				
August 23, 1962	13	6.9	±0.8	65
August 7, 1963	13	7.3	±.6	69
September 13, 1963	12	8.8	±.6	81
September 27, 1963	9	8.2	±.6	71
Middle				
August 23, 1962	13	5.0	±1.0	47
August 7, 1963	13	5.1	±.5	48
September 13, 1963	12	8.4	±.6	78
September 27, 1963	9	9.2	±.4	79
Lower				
August 23, 1962	13	5.2	±.7	49
August 7, 1963	13	5.9	±.6	56
September 13, 1963	12	8.3	±.6	77
September 27, 1963	9	8.7	±.6	75

[1] Methods of sampling were described by McNeil (1962).

or dislodgment from the gravel by high water--the dead alevins were still present. Poor water circulation within the spawning bed in the lower area, which has a low gradient and relatively fine particles, may have produced weak alevins that had a lowered survival rate during winter.

The high survival throughout the stream in period 4 (fry emergence and migration) indicates that predation was not severe during this period.

The number of viable pink salmon eggs of the 1963 brood year declined from about 16.8 million to about 5.6 million between the beginning and the end of spawning. Mortality in autumn, winter, and spring further reduced the number to 3.2 million fry migrating to sea. Total fresh-water survival was estimated to be 31 percent in the upper area, 16 percent in the middle area, and 15 percent in the lower area (table 10). The number of fry in spring 1964 was about 360/m.^{2} in the upper area, 268/m.^{2} in the middle area, and 174/m.^{2} in the lower area. Merrell (1962) also observed a considerably higher density of fry of the 1959 brood year in the upper area (about 325/m.^{2}) than in the lower (about 135/m.^{2}).

In 2 years of high abundance (1959 and 1963), spawning pink salmon were concentrated in the middle area, whereas in 2 years of low abundance (1958 and 1964), they were concentrated in the lower area. In 1959 when 35,391 fish migrated upstream, the density of spawners was at least twice as high in the middle area as in the other two areas. In 1958 when only 217 spawning fish entered the creek, they concentrated in the lower and middle areas (Merrell, 1962); in 1964 when 2,200 fish were counted, I observed the highest density of spawners in the lower area and almost no spawners in the upper area.

Little is known of the factors that cause pink salmon to select particular sites for spawning. Fabricius and Gustafson (1954) found that char demonstrated a preference for material of certain sizes in the spawning bed. In

Table 13.--Survival of pink salmon from potential egg deposition to migrant fry in Sashin Creek for the 11 larger and 11 smaller of 22 escapements, 1940-63[1]

Comparative size of escapement and brood year	Potential egg deposition	Fry migrating to estuary	Survival from egg to fry
	Number	Number	Percent
Large escapements			
1940	52,858,000	3,400,000	6.4
1941	58,678,000	1,024,000	1.2
1942	78,894,000	674,000	.8
1943	14,980,000	228,000	1.5
1945	5,062,000	43,000	.8
1949	4,800,000	176,000	3.7
1951	4,062,000	413,000	10.2
1955	10,286,000	1,266,000	12.3
1959	40,379,000	5,332,000	13.2
1961	29,425,000	5,940,000	20.2
1963	16,640,000	3,256,000	19.6
Mean	--	--	8.2
Small escapements			
1944	3,904,000	106,000	2.7
1946	736,000	1,200	.2
1947	1,330,000	28,000	2.1
1948	516,000	9,100	1.8
1950	86,000	50	.1
1953	1,284,000	95,000	7.4
1954	12,000	660	5.5
1956	1,018,000	5,000	.5
1957	2,588,000	563,000	21.8
1958	174,000	10,000	6.1
1962	8,000	100	1.2
Mean	--	--	4.5

[1] No fish were allowed to spawn in 1952 and 1960.

the present study the size of females did not strongly influence their distribution. Females tagged August 20 and 21 demonstrated a downstream "shift" in their distribution on the spawning ground in the latter half of the spawning period in 1963. This change in distribution occurred after stream discharge increased from 0.3 to 3.0 m.^{3}/sec. or more; hence, the increased turbulence of the water in the upper area, which has a steep gradient, could have caused late spawners to seek the less turbulent water in downstream low-gradient areas.

If density of spawners is high in the upper area of Sashin Creek only when the escapement is large, it could be the result of crowding in the middle and lower areas, which might cause the spawners to "overflow" into the upper area. This behavior could contribute to relatively low survival of the population in years when spawners are scarce and to relatively high survival in years when spawners are abundant. Data for 22 broods of pink salmon in Sashin Creek show survival of fry from the 11 smaller broods to average 4.5 percent of the potential egg deposition and survival from the 11 larger broods to average 8.2 percent (table 13). Although these data demonstrate that low abundance of spawners offers no advantage in terms of an increased percentage survival, the average survival of the progeny of the 11 larger escapements was not significantly greater than that of the 11 smaller ones (t = 1.27; 20 degrees of freedom).

The supposition that only highly productive spawning beds are used in years in which escapements are small is to be questioned; when escapements are small, the more productive spawning areas of Sashin Creek are not always used. This behavior cannot be explained fully at this time. Yet if predation is an important cause of mortality in the upper area, mortality could increase in that area as the size of the population decreases. If so, it could be beneficial for small escapements to spawn in the downstream areas even though physical characteristics for growth of embryos and alevins might be less favorable. Additional research on this problem is needed.

Behavior traits that affect distribution of spawners should receive consideration in the management of pink salmon. Because of possible unequal distribution of spawners, it might be desirable or necessary to provide escapements in excess of those which would be required if spawners were distributed uniformly. Crowding on certain spawning beds may cause some spawners to leave and use spawning beds that are more favorable for developing embryos and alevins.

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