SUCCESS OF PINK SALMON SPAWNING RELATIVE TO SIZE OF SPAWNING BED MATERIALS

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[Contribution No. 157, College of Fisheries, University of Washington]

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ABSTRACT

The potential of a salmon spawning bed to produce fry is directly related to its permeability. The relationship between the coefficient of permeability and the fraction of bottom materials consisting of fine particles is inverse.

Field methods for measuring size composition of bottom materials in salmon spawning beds are described, and an empirical relationship between the fraction (by volume) of solids less than 0.833 mm. minimum dimension and the coefficient of permeability of stream bottom materials is given. Size of bottom materials in streams utilized for spawning by pink salmon *(Oncorhynchus gorbuscha)* varied considerably. The more productive spawning streams had the more permeable spawning beds. Adult pink salmon caused the removal of finer particles from bottom materials during spawning. The evidence indicates that the fine particles removed consist largely of organic matter. Logging caused fine sands and silts to accrue to spawning beds. Flooding caused the removal of fine particles from spawning beds.

INTRODUCTION

Pink salmon *(Oncorhynchus gorbuscha)* are the most abundant of the Pacific salmon and in most years provide a larger commercial catch than the other species. In the eastern Pacific, pink salmon are of commercial importance from Bristol Bay, Alaska, to Puget Sound, Wash. They are of greatest importance in Southeastern Alaska where there are about 1,100 spawning streams (Martin, 1959).

A critical period in the life history of pink salmon occurs between the time eggs are deposited in spawning beds of streams and the time fry emerge several months later. Adult females excavate pockets in gravel beds and cover their eggs with 3 to 15 inches of gravel. This action affords eggs and larvae protection against predators, mechanical injury, and displacement by flowing water. Other environmental stresses are encountered, however, and mortality within the streambed commonly exceeds 75 percent.

The growth, development, and survival of salmon eggs and larvae are dependent on physical and chemical characteristics of the surrounding water. These properties include

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temperature, dissolved oxygen content, velocity, mineral and waste metabolite content, and osmotic pressure. Osmotic pressure is especially important where spawning occurs in intertidal areas of streams.

To prosper, an embryo or larva must receive an ample supply of oxygenated water of suitable temperature and free of toxic substances. Thus, the quality of water within a spawning bed may limit the number of salmon produced. Size composition of bottom materials greatly influences water quality by affecting rates of flow within spawning beds and rates of exchange between intragravel[1] and stream water.

The presence of fine particles in spawning beds (viz, sands and silts) increases egg and larval mortality of several salmonid species (Harrison, 1923; Shapovalov, 1937; Shaw and Maga, 1943; Shelton, 1955; Lucas, 1960; Andrew and Geen, 1960; Cordone and Kelley, 1961). The presence of fine materials in spawning beds reduces their permeability, and according to Wickett (1958), survival of pink and chum *(O. keta)* salmon eggs and larvae is related directly to permeability.

Equipment has been developed to measure permeability of salmon spawning beds in situ (Terhune, 1958). There is a possibility that the size composition of bottom materials in spawning beds affords an equally satisfactory index of streambed quality as it relates to egg and larval survival. It is the purpose of this report to (1) describe a method for measuring size composition of bottom materials in salmon spawning beds, (2) show a relationship between content of fine materials and permeability of spawning beds, (3) describe differences in size composition and permeability of spawning beds in streams supporting low to high densities of spawning adult pink salmon, and (4) demonstrate the occurrence of temporal variations in size composition associated with spawning, logging, and flooding.

The size composition of bottom materials was studied as part of an investigation of the effects of logging on pink salmon streams in Alaska. Observations were made mostly in streams located near Hollis on Prince of Wales Island. Financial suport for these studies was provided by the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, with Saltonstall-Kennedy Act funds. Assistance with field sampling studies was given by the Northern Forest Experiment Station, U.S. Forest Service, Juneau.

FIELD MEASUREMENT OF SIZE COMPOSITION

Perhaps the simplest technique for determining size composition of spawning bed materials was employed by Burner (1951), who approximated visually the relative amounts of large, medium, and small gravel in redds. A more analytical classification of gravels in Pacific salmon redds was undertaken by Chambers, Allen, and Pressey (1955), who isolated small areas of stream bottom from the influence of current with open cylinders. Gravel was removed from within the cylinders with a scoop, washed through a series of sieves, and weighed. Hatch (1957) collected bottom materials with a spade that had a hood enclosing the upper section of blade. In a laboratory, he analyzed bottom materials for sand, silt, and clay content.

Collecting Samples

We developed a bottom sampler suitable for use in shallow water and in gravel after several types of samplers were tried and found to have a common deficiency--none retained silt going into suspension. Furthermore, samplers with mechanically operated closures did not function successfully at all times in coarse gravel and rubble, and certain sampling techniques required the collection of large quantities of bottom materials that could not be sorted and classified quickly.

Samples of bottom materials were removed from the streambed with the sampler (fig. 1). The sampler is stainless steel and is round in cross section. The tube of the sampler was worked manually to a depth of 6 inches. Contents of the tube were dug by hand and lifted

[1] The term "intragravel water" is used to describe water occupying interstitial spaces within the streambed.

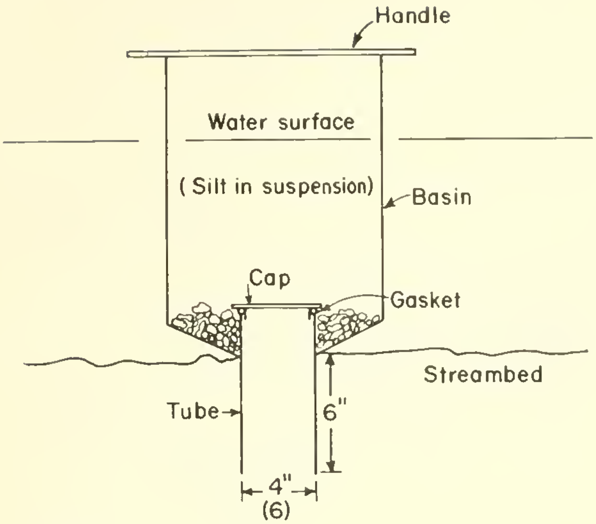

Figure 1.--Sampler for collecting bottom materials.

into the basin. Because the water was continuously agitated, the finest materials passed into and remained in suspension as the sample was collected. After solids were removed from the tube and placed in the basin, a watertight cap was inserted in the tube to retain water and suspended solids in the basin.

This technique possibly introduced some bias because of the loss of silt in suspension within the tube as the sampler was lifted from the stream. Samples collected during low stream discharge no doubt contained a greater absolute quantity of solids in suspension within the tube, on the average, than samples collected during periods of high stream discharge. To minimize this source of error, sampling was restricted to periods of low discharge.

The diameter of the tube used at a particular location depended on the size of the gravel. A 4-inch-diameter tube was used in most streams sampled. In a stream with coarse gravel it was necessary to use a 6-inch-diameter tube. After a sample was removed from the streambed, it was transferred to 10-quart plastic buckets to facilitate handling. After at least 10 minutes had elapsed to allow suspended materials to settle, excess water was decanted from the buckets.

Sorting and Measuring Samples

In Southeastern Alaska, where it rains frequently, the problem of drying samples before sorting is almost insuperable unless covered facilities are provided. For sorting samples in the field, it was necessary therefore to adopt "wet" techniques, and the samples were not dried for analysis.

Bottom samples were separated into 10 size classes by washing and shaking them through nine standard Tyler sieves having the following square mesh openings (in mm.): 26.26, 13.33, 6.68, 3.33, 1.65, 0.833, 0.417, 0.208, and 0.104. Silt passing the finest screen was collected in a vessel.

Washing samples through sieves is efficient and affords nearly complete separation of size groups. One problem with very fine sieves, however, is their tendency to become clogged and to retain water. The finest sieve used (0.104 mm.) was found to be the smallest that would allow water and suspended materials to pass through without seriously clogging the sieve.

After passing through the finest screen, water and suspended materials were placed in a large funnel (fig. 2) and allowed to settle for 10 minutes. The volume of settled solids was then measured. Solids remaining in suspension were discarded. More than 90 percent of the suspended solids settled within 10 minutes.

The volume of solids retained by each sieve was measured after the excess water drained off. The contents of each of the larger sieves (26.26 through 0.417 mm.) were placed in the device shown in figure 3, and the water displaced by solids was collected in a graduated cylinder and measured. Solids retained by the small diameter sieves (0.208 and 0.104 mm.) were sometimes carefully washed into a graduate with a measured volume of water, and the increase in volume was read directly. In these instances, the fines were transferred to the graduate through a 6-inch plastic funnel.

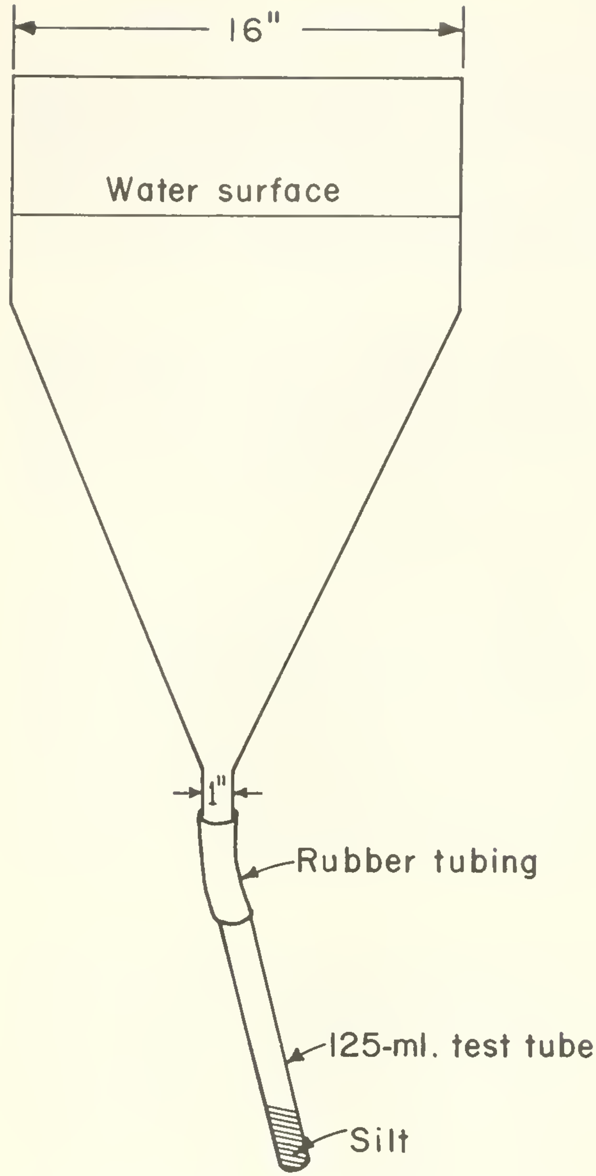

Figure 2.--Settling funnel for collecting silt fraction in bottom materials.

Two men could sort a sample and measure the volume of solids retained on each sieve in about 10 minutes.

The volume of individual samples collected with the bottom sampler varied somewhat from point to point but was generally within 10 percent of the mean. Variation in sample volumes was caused by variation in porosity and core depth. All sample fractions are expressed as a percentage of the sample.

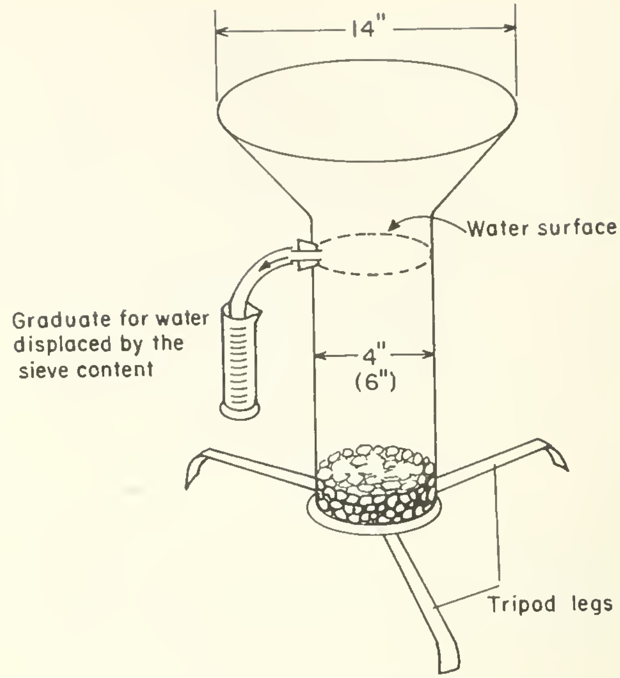

Figure 3.--Device for measuring the volume of water displaced by solids retained by sieves.

PERMEABILITY AND ITS RELATION TO COMPOSITION

The permeability of spawning bed materials depends on the density and viscosity of the water, the porosity of the streambed, and the size, shape, and arrangement of solids. There is a direct relationship between permeability and porosity (Franzini, 1951) and between permeability and average particle size in mixtures of nonuniform sizes (Krochin, 1955; Childs, Collis-George, and Holmes, 1957). A decrease of temperature and porosity and an alteration of particle shape from spherical to angular produce marked reductions in permeability of sands (Fair and Hatch, 1933).

A standpipe for measuring permeability of salmon spawning beds has been tested and calibrated (Pollard, 1955; Terhune, 1958). Wickett (1958) used this permeability standpipe to measure permeability of spawning beds in British Columbia streams where total fresh-water survival had been measured over a number of years. Wickett observed a relationship between average permeability of the beds and survival of salmon (fig. 4).

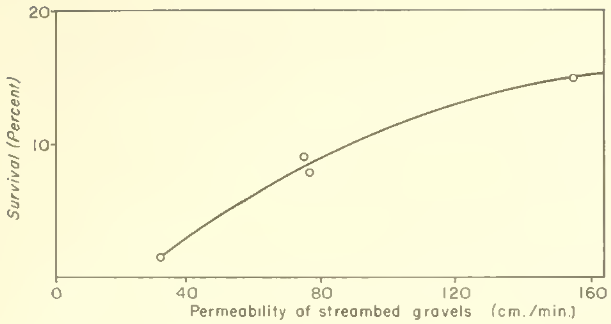

Figure 4.--Observed relationships reported by Wickett (1958) between permeability of spawning beds and survival of pink and chum salmon to the migrant fry stage.

Method of Measuring Permeability

The coefficient of permeability describes the facility with which a liquid can flow through permeable materials. Since viscosity affects the rate at which a liquid flows, it is common practice to express permeability at a temperature selected as a standard (68^{0} F. was selected in these studies).

The coefficient of permeability (k) is defined as

$$k = \frac{Q}{Ai},$$

where Q is the volume of water flowing per unit of time through a gravel bed having a hydraulic gradient i and a cross-sectional area A. Since i is dimensionless, the dimensions of k are

$$\frac{\text{length}}{\text{time}}.$$

Samples of bottom materials were collected from two streams. Each sample consisted of two 6-inch-diameter cores that were removed from adjacent points in important pink salmon spawning areas. Size composition was determined, and each sample was thoroughly remixed and divided into 12 fractions. The fractions were added one at a time to a constant-head permeameter (fig. 5).

To attain a relatively uniform degree of compaction (and porosity), gravel was neither

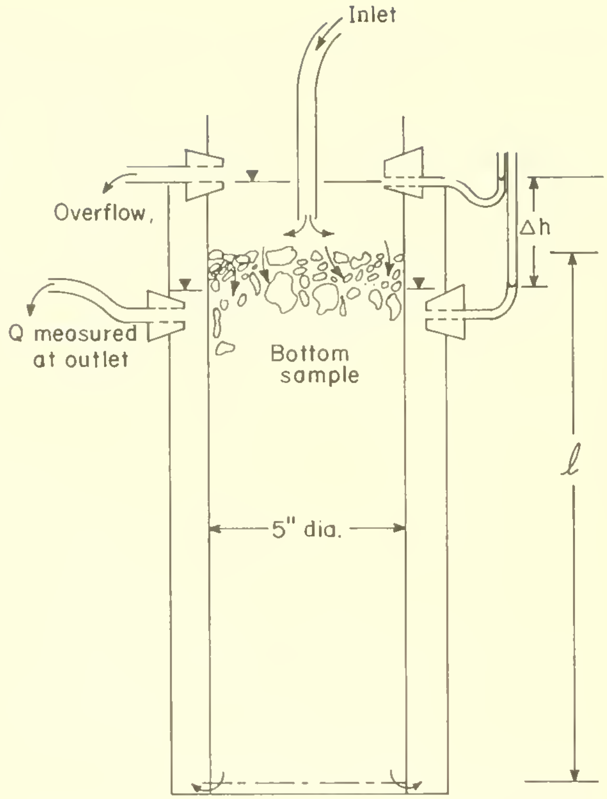

Figure 5.--Constant-head permeameter used to measure permeability of spawning bed materials. Hydraulic gradient (i) = $\Delta h/l$.

tamped nor shaken after being placed in a permeameter. Hence, the permeabilities measured were most likely representative of loose, unconsolidated spawning bed materials.

The coefficient of permeability was measured for 19 bottom samples. Water was allowed to pass through each sample continuously over the period August 25-30, 1960. Permeability of each sample was measured August 26, 29, and 30. Water temperature varied from 49^{0} to 56^{0} F. at the times measurements were made, and all permeability readings were corrected for standard viscosity of 1.0 centipoise at 68^{0} F.[2]

Results of Permeability Tests

A good inverse relationship was found between the coefficient of permeability and the

[2] Each observed value of permeability was multiplied by water viscosity (in centipoises) at the temperature a measurement was made to obtain permeability at 68^{0} F. (see Frevert and Kirkham, 1948).

Table 1.--Percentage of bottom materials passing through 0.833-mm. sieve and coefficient of permeability of 19 bottom samples measured on three dates

[Permeability readings corrected for standard viscosity of 1.0 centipoise at 68° F.]

Percentage passing through 0.833-mm. sieve	August 26	August 29	August 30	Mean
	Cm./min.	*Cm./min.*	*Cm./min.*	*Cm./min.*
4.5	461	556	512	510
5.0	363	381	460	401
5.5	544	476	538	519
5.6	291	290	283	288
5.6	370	281	288	313
6.1	252	278	280	270
6.2	288	363	344	332
6.3	305	243	315	288
8.1	159	229	158	182
9.3	150	194	196	180
9.7	144	188	156	163
10.1	152	256	172	195
10.3	168	223	141	177
10.9	53	60	61	58
12.2	131	128	134	131
12.7	42	45	43	43
12.7	87	105	104	99
14.7	25	21	41	29
15.6	24	26	23	24

percentage by volume of a bottom sample passing through an 0.833-mm. sieve. Percentage of materials passing through an 0.833-mm. sieve are given in table 1 along with the observed values of the permeability coefficient. Mean permeability is plotted against percentage of materials passing through an 0.833-mm. sieve in figure 6.

It is apparent that permeability is high where bottom materials contain less than 5 percent by volume of sands and silts passing through an 0.833-mm. sieve. Low permeability occurs where bottom materials contain more than 15 percent by volume of sands and silts passing through an 0.833-mm. sieve.

SIZE COMPOSITION AND SPAWNING SUCCESS

Bottom samples were obtained from sampling areas in six streams. Most of the effort was expended in five streams near Hollis (Old Tom, Maybeso, Indian, and Twelvemile Creeks, and Harris River). Samples also were collected from Anan Creek, which is located about 75 miles northeast of Hollis and is one of the most productive pink salmon streams in Southeastern Alaska.[3]

All six streams were sampled in summer 1959 shortly before spawning began. Table 2 gives the mean percent by volume of solids retained by sieves and settling from suspension in 10 minutes. Pronounced differences were found in volumes of fine sands and silts in the various spawning beds (fig. 7).

[3] For estimates of spawning escapements see "Stream Catalog of Southeastern Alaska Regulatory District No. 2" (Special Scientific Report--Fisheries No. 453) and "Stream Catalog of Southeastern Alaska, Regulatory Districts Nos. 5, 6, 7, and 8" (in preparation at the Fisheries Research Institute for publication as Special Scientific Report--Fisheries).

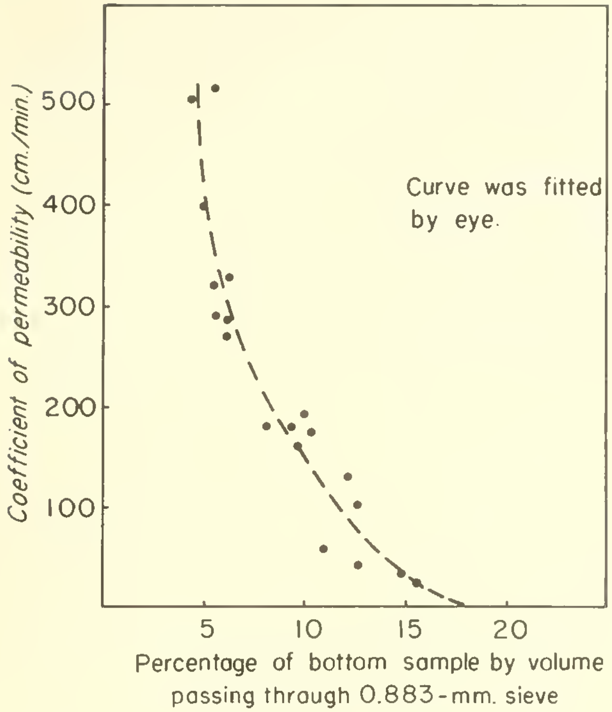

Figure 6.--Relationship observed between coefficient of permeability and the fraction of the total volume of stream bottom materials passing through an 0.833-mm. sieve. (Curve fitted by eye.)

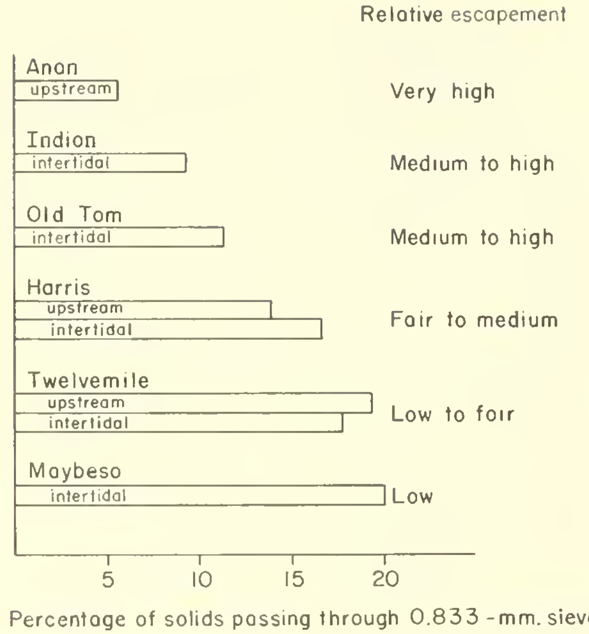

Figure 7.--Percentage of the total volume of bottom materials in six Southeastern Alaska pink salmon streams passing an 0.833-mm. sieve. Samples were collected in summer 1959. The streams have been ranked in accordance with approximate levels of pink salmon escapements weighted by available spawning area.

According to unpublished data on weir counts and visual estimates, the number of adult pink salmon spawning in Anan Creek on occasion has exceeded 1 million, and in most years exceeds 100,000. Five random samples were obtained from a large spawning riffle in Anan Creek about 3 miles upstream from the estuary. Even with this small number of samples, it was apparent that virtually no silt and little fine sand were present and that bottom materials were highly permeable.

Estimated escapements of pink salmon have been lower in Maybeso Creek than in any of the other streams sampled. A few hundred pink salmon spawn some years in the intertidal zone of Maybeso Creek, where 20 percent of the total volume of solids present in an intertidal riffle were found to pass through an 0.833-mm. sieve, indicating extremely low permeability.

Escapement estimates indicated that in the most years Twelvemile Creek was considered to be a marginal spawning stream, although it supported larger runs of pink salmon than Maybeso Creek. Although Twelvemile Creek comprises several miles of spawning ground, pink salmon escapements rarely exceed a few thousand adults. Size composition of bottom samples shows that intertidal and upstream spawning grounds in Twelvemile Creek contain large volumes of fine sands and silts and have low permeability.

Estimates of pink salmon escapements into Harris River, Indian Creek, and Old Tom Creek have varied greatly, but sizable runs have been recorded for each of these streams in some years. Runs into Harris River and Old Tom Creek commonly include tens of thousands of adult pink salmon and may exceed 50,000 on occasion. Both streams have extensive spawning grounds, with Harris River being larger. Spawning grounds in Indian Creek are limited by comparison, but escapements of thousands of adult pink salmon commonly

Table 2.--Mean percent by volume of solids retained by sieves (openings in mm.) and settling from suspension in 10 minutes. (All rocks larger than 4 inches minimum dimension excluded.)

Stream and sampling area	Samples	Area sampled	Percent of total volume of solids retained by sieve with opening of--									Percent total volume of solids settling from suspension
			26.26	13.33	6.68	3.33	1.65	0.833	0.417	0.208	0.104	
	Number	*Square feet*										
Anan Creek												
Upstream	5	[1]25,000	41.5	10.4	10.3	10.1	9.6	10.6	3.9	1.3	0.3	0.2
Indian Creek												
Intertidal	50	36,560	35.2	15.3	12.9	11.3	7.3	8.6	4.9	1.3	0.4	2.7
Old Tom Creek												
Intertidal	15	[1]36,000	26.5	17.8	15.7	12.4	7.4	8.6	6.3	2.4	0.7	2.2
Harris River												
Upstream	25	83,750	24.0	16.2	14.1	11.8	8.4	11.8	9.2	2.4	0.4	1.9
Harris River												
Intertidal	37	62,640	25.1	14.6	13.2	11.0	7.9	11.5	10.5	2.7	0.4	3.1
Twelvemile Creek												
Intertidal	50	60,080	21.2	15.1	13.9	12.5	8.8	10.7	8.4	2.5	0.9	5.9
Twelvemile Creek												
Upstream	50	66,400	19.7	13.9	13.0	12.9	9.6	11.6	9.5	3.6	1.2	5.0
Maybeso Creek												
Intertidal	16	[1]15,000	19.4	11.3	12.6	13.4	11.0	12.3	10.1	4.7	1.4	3.8

[1] Area estimated.

occur nevertheless, with peak escapements approaching 10,000. Harris River and Indian and Old Tom Creeks may be somewhat representative of numerous Southeastern Alaska pink salmon streams which, when taken as a whole, contribute significantly to the total catch. Although the volume of fine sands and silts in these streams varied, it was apparent that each contained considerably larger volumes of fine materials and was less permeable than the area of Anan Creek sampled.

SILT REMOVAL BY SPAWNERS

In view of the nearly conclusive evidence that silt is harmful to salmon eggs and larvae (see the review by Cordone and Kelley, 1961), it is likely that redd digging benefits progeny through removal of fine particles and organic detritus from spawning beds. Changes occurring in the composition of bottom materials during the spawning period were studied.

Volumes Removed

The intertidal Harris River sampling area was sampled randomly before and after spawning in 1959 and 1960. The number of females spawning between the sampling dates was estimated to be 2.4 per 100 square feet in 1959 and 4.6 per 100 square feet in 1960. It was found that the percentage of solids passing through an 0.833-mm. sieve decreased significantly over the spawning period in both years (table 3). The greatest decrease occurred among settleable solids passing through a 0.104-mm. sieve and classified as "pan" in these studies. Other studies suggested that a considerable portion of fine particles removed by spawners consisted of light organic material.

Organic Content

The organic content of pan materials was determined for samples collected before spawning in the summer of 1958. Nine samples from spawning riffles in Harris River and Indian and Twelvemile Creeks were dried and sorted. Materials passing through a 0.104-mm. sieve (pan) were divided into two groups before being weighed--those retained by a 0.074-mm. sieve and those passing through a 0.074-mm. sieve. The organic fraction of each group was burned off, and the samples reweighed. Solids retained by the 0.074-mm. sieve had an average organic content of 3.9 percent (range, 1.7 - 7.2 percent); whereas the average organic content of solids passing a 0.074-mm. sieve was 12.4 percent (range, 7.9 - 19.0 percent).

Specific gravity of materials retained by and passing through the 0.074-mm. sieve was also determined. Mean values of four samples were 2.68 g./cc. for materials retained by the 0.074-mm. sieve and 2.38 g./cc. for materials passing through the 0.074-mm. sieve. Thus it appeared that the highest organic fraction was in the finest size groups, which were also most susceptible to complete removal from spawning beds.

SPAWNING BED SILTATION

During our studies, we observed one instance where siltation of spawning beds occurred in association with logging. We also observed that flooding removed most if not all of the silt accumulating from logging.

Silt Pollution from Logging

Land areas contiguous to the upstream sampling area of Harris River were logged in late summer and autumn 1959. From personal observation, it was apparent that tributary streams draining the logged areas carried unusually heavy silt loads during freshets. Water samples collected from three tributary streams during freshets contained, on the average, two to four times more inorganic sediment after logging then before. The average amount of organic sediment in samples collected after logging was only fractionally more than the amount in samples collected before logging. Because of the high variability observed in the amount of sediment carried by the tributary streams and the small numbers of samples collected, it is not possible to show conclusively that the content of inorganic sediment increased because of logging. However, the data, which are summarized in table 4, lend support to this conclusion.

Table 3.--Mean percent by volume of fine sands and silts in samples from intertidal spawning bed of Harris River before and after spawning of pink salmon in 1959 and 1960

Year and time samples collected	Females spawning per 100 sq. ft.	Samples	Total volume of solids retained by sieve with opening of-- 0.417 mm.	0.208 mm.	0.104 mm.	Pan	Solids passing through 0.833-mm. sieve
	Number	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1959							
Before spawning (August 13)	2.4	37	10.5	2.7	0.4	3.1	16.7
After spawning (October 6)		17	9.4	2.1	0.4	1.3	13.2
Difference			1.1	0.6	0.0	1.8[1]	3.5[2]
1960							
Before spawning (August 4)	4.6	32	7.9	1.7	0.9	4.3	14.8
After spawning (September 26)		23	8.0	1.8	0.2	1.5	11.5
Difference			0.1	0.1	0.7[1]	2.8[1]	3.3[2]

[1] Difference significant at 0.5-percent level.
[2] Difference significant at 5.0-percent level.

Table 4.--Suspended sediment content of three small tributaries of Harris River before logging (1956) and after (1959)

Stage of logging and date	Hour of day	Water depth	Sediment content	
			Organic	Inorganic
TRIBUTARY A				
Before logging		*Feet*	*Mg./l.*	*Mg./l.*
August 30	1600	1.2	32	1
September 25		0.4	53	10
September 30	1230	0.5	56	15
November 20	1245	1.1	9	14
Mean			38	10
After logging				
September 11	1200	0.6	62	20
September 25	1145	0.8	56	23
October 11	1345	0.8	59	85
Mean			59	43
TRIBUTARY B				
Before logging				
August 30	1432	0.6	69	16
September 25	1600	0.5	60	16
September 30		0.6	52	62
November 20	1307	0.9	39	15
Mean			55	27
After logging				
September 25	1200	0.5	35	46
September 25	1200	0.4	61	49
October 11	1130	0.7	53	49
October 11	1350	0.5	85	155
October 16	1645	0.5	96	20
October 17	0830	0.9	113	73
Mean			74	65
TRIBUTARY C				
Before logging				
August 30	1400		82	3
September 25	1614	0.4	35	1
September 30	1315	0.7	61	40
November 20	1350	1.0	23	14
Mean			50	14
After logging				
October 11	0800	0.6	30	20
October 11	1030	0.8	44	70
October 11	1100	0.8	84	181
October 13	1100	1.3	68	51
October 16	1200	0.6	48	13
October 16	1700	0.9	82	0
Mean			57	56

Silt content of spawning beds.--Bottom samples obtained from upstream in Harris River in August and October 1959 revealed that the volume of silts and fine sands in spawning beds increased significantly during periods when tributary streams appeared to carry increased amounts of inorganic sediments. Similar increases did not occur in intertidal Harris River, suggesting that settleable solids were not transported downstream in significant amounts, or in Indian Creek, which was unlogged. Instead, the volume of fine particles in intertidal Harris River and Indian Creek declined significantly between late summer and midautumn, possibly because of spawning activity. Mean percentages of materials passing through an 0.833-mm. sieve were:

Harris River (upstream):
- August 16, 1959--13.9 percent
- October 27, 1959--17.4 percent

Harris River (intertidal):
- August 13, 1959--16.7 percent
- October 20, 1959--13.8 percent

Indian Creek (intertidal):
- August 11, 1959--9.3 percent
- November 10, 1959--7.4 percent

For each area, differences between sampling dates were tested with a t-test and were found to be significant at the 5-percent level.

The decrease in percentage of materials passing through an 0.833-mm. sieve in intertidal Harris River was thought to be caused by redd digging (refer to table 3). Because the density of female spawners in Indian Creek was nearly twice that observed in intertidal Harris River in 1959 (4.3 versus 2.4 per 100 square feet), a decrease in the volume of fine particles was to be expected here, too. By comparison, spawning females were scarce in upstream Harris River in 1959 (0.6 female per 100 square feet), and redd digging must have reduced the silt content of upstream Harris River only slightly. Hence, logging silt probably did not replace a deficit created by redd digging, but simply added an amount additional to what was already present in August 1959.

Effect of silt on permeability.--According to the curve relating content of fine particles to permeability (fig. 6), permeability of spawning beds in upstream Harris River was reduced considerably by settleable solids added in autumn 1959. This was confirmed by a laboratory study.

After size composition was determined, gravel samples from intertidal Harris River and Indian Creek were placed in constant-head permeameters (fig. 5). A mixture of fine particles (5 parts retained by 0.208-mm. sieve; 3, by 0.104-mm. sieve; and 12, by pan) was added to each permeameter. The amount of fine materials added varied from 2.4 to 2.8 percent of the total volume of each sample tested. (The estimated increase in volume of fine particles in upstream Harris River during autumn 1959 was 3.5 percent.) Permeability of each sample before and after addition of fine particles is given in table 5. Addition of fine particles reduced permeability an average of 2.5 times (range was 1.4 to 4.3 times).

Silt Removal by Flooding

The deposition of fine materials in the upstream Harris River sampling area was found to be temporary. Flooding occurred in the periods November 5-7 (5.32 inches of rain in 72 hours) and December 5-7 (7.02 inches of rain in 72 hours).[4] In samples of bottom materials obtained from upstream Harris River after flooding (February 23, 1960). the content of fine materials had returned to the level observed in summer 1959 before logging.

Observations on individual size groups passing through an 0.833-mm. sieve revealed that sizes retained by 0.208-mm. and 0.104-mm. sieves and passing through a 0.104-mm. sieve (pan) were most affected by logging and flooding. Mean percentages of the total volume of bottom material in upstream Harris River in these four size groupings plus those retained by a 0.417-mm. sieve show changes in volumes of fine particles occurring in association with siltation and flooding (table 6).

[4] Rainfall was recorded at Hollis by the U.S. Forest Service.

Table 5.--Decrease in permeability of bottom materials from salmon spawning beds with addition of fine particles[1]

[Permeability readings corrected for standard viscosity of 1.0 centipoise at 68° F.]

No fine particles added		Fine particles added	
Percent passing through 0.833-mm. sieve	Permeability	Percent passing through 0.833-mm. sieve	Permeability
	Cm./min.		*Cm./min.*
6.1	270	8.8	80
4.5	510	7.3	362
14.7	29	17.1	14
10.3	177	12.8	99
10.9	58	13.4	40
9.7	163	12.4	57
12.7	43	15.3	10
5.6	313	8.1	173

[1] Fine particles added consisted of materials retained by a 0.208-mm. (5 parts) and a 0.104-mm. (3 parts) sieve and passing through a 0.104-mm. sieve (12 parts).

Table 6.--Mean percentage of total volume of bottom materials in five size classes of fine particles from upstream Harris River before siltation from logging, after siltation, and after siltation and flooding

Condition of stream	Size group				
	Passing through 0.833-mm. seive	Retained by 0.417-mm. sieve	Retained by 0.208-mm. sieve	Retained by 0.104-mm. sieve	Passing through 0.104-mm. sieve
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Before siltation (August 10, 1959)	13.9	9.2	2.4	0.4	1.9
After siltation (October 27, 1959)[1]	17.4	9.7	4.2	0.6	2.9
After siltation and flooding (February 23, 1960)[2]	14.0	9.2	2.7	0.3	1.8

[1]Harris River was observed to carry heavy silt loads on October 12 and 17, 1959.

[2]Flooding occurred on about November 6 and December 6, 1959.

Differences between mean values of August 16 and October 27 and of October 27 and February 23 were evaluated with a t-test. Except for the fraction retained by the 0.417-mm. sieve, all differences were significant at the 10-percent level at least.

SUMMARY

Permeability of bottom materials is probably an important factor limiting fry production in spawning beds. It has been shown how permeability is related to size composition of bottom materials, and it is possible to compare relative permeability of spawning beds by determining average size composition. Hence, a simple and direct method of measuring physical properties of spawning beds pertaining directly to their capacity to produce fry has been provided through developing techniques for measuring size composition of bottom materials.

Pronounced differences in size composition of bottom materials were observed among several pink salmon spawning streams. The more productive spawning streams had the highest permeability coefficients.

The volume of fine materials within particular spawning beds changes with time. A reduction in volumes is caused primarily by forces that produce gravel movement (e.g., redd digging and flooding). Silts and fine sands accruing to spawning beds and reducing their permeability are transported in part from watersheds into spawning streams. Logging increases the amount of transported materials.

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