Effect of Quality of the Spawning Bed on Growth and Development of Pink Salmon Embryos and Alevins

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ABSTRACT

Among three segments of the spawning ground in Sashin Creek, southeastern Alaska, the largest and fastest developing embryos and alevins of pink salmon, Oncorhynchus gorbuscha, came from spawning gravels characterized by high levels of dissolved oxygen in intragravel water. The high oxygen levels occurred in a stream segment which has a relatively steep grade and coarse materials in the bed. No differences in water temperature were observed among the three segments.

INTRODUCTION

Pacific salmon bury their eggs in gravel beds of streams where the developing embryos and alevins are protected from exposure to predation, light, and turbulent water. Unfortunately, conditions in the spawning beds are not always adequate for optimum growth and development.

Effects of environmental stresses on growth and development of eggs and alevins have been studied in the field, in the laboratory, and with artificial populations in streams. The studies of natural populations have yielded information on environmental factors that sometimes limit survival in spawning beds, but aside from observations on the body size of newly emerged fry, little attention has been given in field studies to the effects of stress on growth and development.

This paper describes the growth and development of embryos and alevins of pink salmon, Oncorhynchus gorbuscha, in natural spawning beds of different quality in Sashin Creek, a small stream in southeastern Alaska.

STUDY AREA

BCF (Bureau of Commercial Fisheries) is studying the ecology of salmon spawning beds in Sashin Creek between the ocean and an impassable falls about 1,000 m. upstream. The creek drains a small (13.5-km.^{2}) watershed on Baranof Island about 100 km. south of Sitka. The ecological studies have been concentrated in three segments that together include about 96 percent of the total spawning ground. In this report the three segments, which are continuous over 890 m. of stream channel, are designated as "upper" (220 m. long), "middle" (270 m.), and "lower" (400 m.). The upper segment has a relatively steep grade (0.7 percent) and coarse materials in the bed; the middle segment has an intermediate grade (0.3 percent) and medium-sized materials; and the lower segment has a relatively shallow grade (0.1 percent) and fine materials. The contrasting ecological conditions resulting from these different grades and streambed materials make Sashin Creek an excellent stream for a comparative study of populations of salmon eggs and alevins in a natural environment.

Dissolved oxygen and temperature of the intragravel water are two of the principal criteria used to assess the quality of a spawning bed. These two criteria were measured in Sashin Creek with standpipes driven at many random locations within three segments of the spawning bed (table 1). The upper segment, where the grade is steep and the bed materials are coarse, often had a higher content of dissolved oxygen in the intragravel water than did the middle and lower segments (table 1). These differences were particularly evident when waterflows were low and water temperatures

Table 1.--Dissolved oxygen content of intragravel water in Sashin Creek in the summers of 1962, 1963, and 1965[1]

Date	Water temperature	Dissolved oxygen					
		Upper segment		Middle segment		Lower segment	
		Mean	90-percent confidence limit of mean	Mean	90-percent confidence limit of mean	Mean	90-percent confidence limit of mean
	° C.	Mg./l.	Mg./l.	Mg./l.	Mg./l.	Mg./l.	Mg./l.
1962							
August 23	13	6.9	±0.8	5.0	±1.0	5.2	±0.7
1963							
August 7	13	7.3	±0.6	5.1	±0.5	5.0	±0.6
September 13	12	8.8	±0.6	8.4	±0.6	8.3	±0.6
1965							
August 16	12	9.7	±0.7	8.9	±0.8	8.5	±1.1
September 13	11	6.2	±0.9	3.8	±0.8	2.3	±0.3
September 22	12	7.6	±0.8	4.3	±0.6	2.9	±0.6
Average	--	7.8	--	5.9	--	5.4	--

[1] No samples were collected in the summer of 1964.

high. Repeated measurements of the temperature of the intragravel water in the three segments consistently failed to reveal statistically significant differences in the mean values. Thus, we presumed that any differences in growth and development of embryos and alevins that we might observe would result from factors other than water temperature.

GROWTH AND DEVELOPMENT OF EMBRYOS AND ALEVINS

In Sashin Creek, pink salmon spawn in August and September; the eggs hatch in November and December; the alevins remain in the streambed during winter; and the fry emerge and migrate to sea in April and May.

The present study pertains to eggs and alevins of the 1961, 1963, and 1965 brood years. Because pink salmon live only 2 years from fertilization of the egg to maturity and death of the adults, the odd- and even-numbered brood years are genetically separate. It is not unusual in populations of pink salmon for one of the two lines to be much more abundant than the other. Over the period of this study, the odd-year line was dominant in Sashin Creek. In fact, fish were too scarce in the even-year line to permit comparisons of the growth and development of eggs and alevins similar to those we made for the odd-year lines.

Eggs and alevins were collected from random points on the spawning ground with the aid of a hydraulic sampler (McNeil, 1964), and the samples were preserved in Stockard's solution (six parts Formalin, five parts glycerine, four parts acetic acid, and 85 parts water).

1961 and 1963 Brood Years

The studies of the 1961 and 1963 brood years were preliminary and concerned alevins collected in March shortly before fry began to leave the gravel; the alevins were weighed only. They were taken from the Stockard's solution and blotted with paper towels to remove excessive moisture. The first indication of possible differences in the average weight of alevins from the three segments of the Sashin Creek spawning ground came in March 1962 (1961 brood year); the alevins from the upper segment were significantly heavier ($P>0.05$) than those from the middle and lower segments. The same relation held in March 1964 (1963 brood year).

The average wieghts for the two brood years were as follows:

Stream segment	1961	1963
	Mg.	Mg.
Upper	222	223
Middle	202	201
Lower	205	207

Before differences in body weight of the alevins among the three segments of the spawning ground can be ascribed to differences in environmental conditions, it is necessary to consider the time of spawning; the alevins from the upper segment may have been larger because spawning was earlier. The average dates of spawning and density of spawners in 1961 from the three segments of the spawning ground were not well documented, but detailed observations had been made on time and density of spawning in 1963 (McNeil, 1966a).

In August and September 1963, Sashin Creek had 16,757 pink salmon spawners. We estimated the average density of spawners to be about 0.9 female per square meter in the middle segment and 0.6 in the upper and lower segments. Although the size of a female apparently had not bearing on the selection of a spawning area, the time of spawning did--early females tended to concentrate in the upper segment and late females in the lower. The nonuniform distribution of spawners supported the contention that eggs were deposited earlier in the upper segment than in the middle or lower segment. The larger alevins in the upper segment may, therefore, have resulted from an earlier date of egg deposition rather than from differences in growth due to differences in environmental conditions.

It seems unlikely that the larger alevins in the upper segment could have been the result of a genetically superior stock, because the total available spawning area (13,629 $m.^2$) in the stream is confined to a channel only 1,000 m. long. Furthermore, the study segments are continuous and no permanent tributary streams enter Sashin Creek over the length of the study area.

1965 Brood Year

We studied the distribution of spawners in 1965 the same way as in 1963 but sampled eggs and alevins (the 1965 brood) more intensively. The eggs and alevins were sampled in three periods: late September, at the end of spawning; late November, during hatching; and late March, before the fry emerged. The escapement to Sashin Creek in 1965 (14,813 pink salmon) included 7,109 females. The densities of females were about 0.6 per square meter in the upper and middle segments and 0.4 in the lower. Average dates of spawning differed little in the upper and middle segments (see table 10 of McNeil, 1968), but the lower segment seemed to attract mostly late spawners.

Hence, in 1965 we had an excellent opportunity to compare differences in growth and development of embryos and alevins, especially between the upper and middle segments, where fish were at almost the same density and spawned about the same time. About 75 percent of live eggs and alevins in the streambed in late September 1965 had died by late March 1966; the total number of live specimens in the samples also decreased.

The potential for differences in growth and development in the three segments was enhanced by pronounced differences in water quality brought about by a drought in 1965. Oxygen values were high in August and low in September (table 1); on September 22, after most fish had completed spawning, the dissolved oxygen content of intragravel water was low--only 71 percent of saturation in the upper segment, 40 percent in the middle, and 27 percent in the lower.

Because spawning was considerably later in the lower segment than in the upper and middle segments, comparisons of the size of body parts and stages of development are restricted to embryos and alevins from the upper and middle segments.

September samples.--The September samples contained only embryos because development had not proceeded to the alevin stage. Embryos were examined for the presence of pigmented eyes, diameter of eye, and length of pectoral fin (table 2). The samples were taken September 25-29; an equal number of points were sampled in each area on each

Table 2.--Development and size of pink salmon embryos in upper and middle segments of Sashin Creek, September 25-29, 1965 (Mean values and 90-percent confidence limits are given)

Segment	Live specimens in sample	Embryos with pigmented eyes	Diameter of eye[1]	Length of pectoral fin[1]
	Number	Percent	Mm.	Mm.
Upper	7,514	0.62	0.86±0.04	0.46±0.03
Middle	11,964	0.56	0.82±0.04	0.43±0.03

[1] Estimated from random subsample of 150.

date to insure that the average stage of development of embryos in the samples was not influenced materially by the sampling procedure. To determine the percentage with pigmented eyes, we examined a subsample of 150 randomly selected eggs under low magnification (35X). Embryos with pigmented eyes were dissected and examined under higher magnification (100X). The microscope had a micrometer eyepiece to measure diameter of the eye and length of the pectoral fin. The eye was pigmented in 62 percent of the embryos from the upper segment and 56 percent from the middle. Also, embryos from the upper segment had the larger eye diameter and the longer pectoral fin (table 2).

November samples.--Embryos and alevins were sampled on November 19-21 for measurements of length of body and pectoral fin and diameter of eye. Indications in September that growth was more rapid in the upper segment than in the middle were reinforced in November (table 3). Furthermore, 77 percent of the surviving eggs had hatched in the upper segment compared with only 30 percent in the middle. (By contrast, only 11 percent of the eggs had hatched in the lower segment; the tendency of late females to spawn in the lower segment undoubtedly contributed to the delayed hatching there.)

March samples.--By March, all the live embryos had hatched to alevins. Subsamples of alevins were examined for external yolk and weighed, and body length, diameter of the eye, and length of the pectoral fin were measured (table 4). Alevins from the upper stream segment continued to be larger and more advanced in development.

SOME EFFECTS OF WATER QUALITY ON GROWTH AND DEVELOPMENT

In all 3 years of the study, embryos and alevins grew faster and developed more rapidly in the upper segment of the Sashin Creek spawning ground than in the middle and lower segments. This favorable growth may have been due to the relatively better quality of the intragravel water in the upper segment, as indicated by the higher levels of dissolved oxygen (table 1).

The content of dissolved oxygen in intragravel water is controlled both by biological

Table 3.--Development and size of pink salmon embryos and alevins in upper and middle segments of Sashin Creek, November 19-21, 1965 (Mean values and 90-percent confidence limits are given)

Segment	Live specimens in sample	Eggs hatched	Length of body[1]	Diameter of eye[2]	Length of pectoral fin[2]
	Number	Percent	Mm.	Mm.	Mm.
Upper	4,584	0.77	23±0.03	1.61±0.02	1.14±0.05
Middle	4,615	0.30	22±0.04	1.50±0.02	1.00±0.11

[1] Alevins only; estimated from random subsample of 150.
[2] Alevins and embryos combined, estimated from random subsample of 150.

Table 4.--Development and size of pink salmon alevins in upper and middle segments of Sashin Creek, March 21-26, 1966 (Mean values and 90-percent confidence limits are given)

Segment	Live specimens in sample	Alevins with external yolk	Length of body[1]	Wet weight (with yolk)[1]	Diameter of eye[1]	Length of pectoral fin[1]
	Number	Percent	Mm.	Mg.	Mm.	Mm.
Upper	1,864	0.53	32±0.5	263±4	2.50±0.02	2.43±0.06
Middle	2,231	0.54	31±0.5	257±4	2.43±0.02	2.22±0.06

[1] Estimated from random subsample of 150.

and physical factors. It is reduced by oxidation of organic detritus and respiration of organisms, and replenished (primarily) by stream water entering the streambed. Interchange between stream and intragravel water is affected by streamflow, gradient, curvature of the streambed, and coarseness and permeability of bed materials (Vaux, 1968).

The supply of dissolved oxygen in a spawning bed is continually renewed by the flowing stream water. If the velocity of the flowing water is reduced because the hydraulic gradient or the permeability of the streambed is low, the amount of dissolved oxygen may not be sufficient to maintain optimum growth and development of embryos and alevins or the waste products of metabolism may accumulate. Low velocity also increases the time that water is exposed to the biochemical oxygen demand of the streambed, causing a further reduction in the availability of dissolved oxygen to eggs and alevins and a further buildup of waste metabolites, especially in summer when the water is warm. Wickett (1958) and McNeil (1966b and 1968) reported high mortality in salmon eggs and alevins that had been deprived of dissolved oxygen because of low permeability of bed materials and limited interchange between stream and intragravel water. Coble (1961) and Phillips and Campbell (1962) showed that low dissolved oxygen in intragravel water (as a result of low velocity) retarded growth and limited survival of coho salmon, O. kisutch, and rainbow trout, Salmo gairdnerii. Low dissolved oxygen levels induced experimentally also caused substantial reduction in the size of newly hatched alevins and a high percentage of abnormalities: Shumway, Warren, and Doudoroff (1964) reared embryos of coho salmon at a water velocity of 3 cm./hr. and an oxygen level of 2.4 mg./l.; the alevins at hatching were only one-third the size of control samples. Silver, Warren, and Doudoroff (1963) had similar results in a study of chinook salmon, O. tshawytscha, and rainbow trout.

Although low levels of dissolved oxygen retard development up to hatching, the rate of growth of the alevin appears to compensate partly for such retarded growth, provided adequate oxygen and waterflow are available. Hamdorf (1961) found that rainbow trout embryos exposed to hypoxial conditions were much smaller at hatching than a control group. He found, however, that if he reared the alevins of these same embryos in water saturated with dissolved oxygen, they soon approached the size of the fry from the control group. Brannon (1965) reported similar results from eggs of sockeye salmon, O. nerka, that had been reared under hypoxial conditions; the alevins produced from such eggs were one-half the weight of those reared at oxygen saturation. Brannon observed little difference in body weight at yolk absorption for the embryos, but for the fry reared under hypoxial conditions, yolk absorption was delayed about 3 weeks. Neither Hamdorf nor Brannon measured anatomical features such as eye diameter or length of pectoral fin. The possibility that such measurements may be better indicators of environmental stresses in early development than measurements of body length or weight is supported by the present study.

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