THE EMBRYONIC SURVIVAL OF COHO SALMON AND STEELHEAD TROUT AS INFLUENCED BY SOME ENVIRONMENTAL CONDITIONS IN GRAVEL BEDS

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Introduction

Hundreds of miles of stream environment are being physically altered each year by logging activities in Oregon.

The removal of watershed cover by logging and accompanying road building is responsible for large amounts of silt entering the stream. Some of the silt is carried downstream, especially in periods of high flow, and much of it settles for a time on the gravel beds used by spawning salmon and trout.

The purpose of the investigation, of which a segment is reported upon here, is to determine the effect of logging on the survival to emergence of salmon and trout. It is part of a more comprehensive study of the effect of logging on aquatic resources. Before the effect of logging on survival to emergence can be determined, the influence of the environmental factors in the gravel must be assessed. Changes in these environmental factors caused by logging can then be evaluated as they affect survival.

The study of survival to emergence is divided into two segments; 1) the determination of the effect of environmental factors in the gravel on survival, and 2) the determination of the effect of logging on the environmental factors in the gravel.

Only the first part, the effect of the environmental factors in the gravel on survival will be dealt with here. The second part, the effect of logging on the environmental factors in the gravel, must await logging when the "before", "during", and "after" values of two environmental factors, gravel permeability and dissolved oxygen concentration of the intragravel water, will be compared. This report includes the results of two field studies designed to determine the effect of three environmental factors on embryonic survival of steelhead trout and coho salmon. The environmental factors are; the dissolved oxygen concentration of the intragravel water, the apparent velocity[1] or seepage rate of the intragravel water, and the permeability of the gravel[2]. Each of the factors is compared to the number of embryos surviving to hatchings.

The steelhead embryo survival study was done on Deer Creek. It is an unlogged tributary of Drift Creek, tributary of the Alsea River on the Oregon coast. The drainage area is approximately 800 acres. Needle Branch, the site of the coho embryo survival study, also is an unlogged tributary of Drift Creek. Its drainage area is about 250 acres.

Review of Literature

Dissolved Oxygen

In laboratory experiments by other investigators designed to measure the effect of dissolved oxygen on embryonic survival, two criteria were used in evaluating the results. They were 1) lethal level, which is the highest concentration at which all embryos were killed; and 2) critical level which is the concentration necessary to just meet the demand of the embryo.

1) Lethal level

Wickett (1954) working with chum salmon *(Oncorhynchus keta)* found 1.67 ppm of dissolved oxygen to be lethal. Silver[3] found 1.6 milligrams per liter of dissolved oxygen to be lethal to chinook salmon *(O. tshawytscha)* and steelhead trout *(Salmo gairdneri)* embryos. He reported embryos surviving at concentration as low as 2.5 milligrams per liter. Shumway[4] working with coho salmon *(O. kisutch)* embryos did not determine a lethal level but found survival occurred at 2.5 milligrams per liter.

2) Critical level

Alderdice, Wickett, and Brett (1958) reported the critical level of dissolved oxygen for chum salmon embryos to be 0.72 ppm shortly after fertilization. The value increased during the incubation period to 7.19 shortly before hatching.

Wickett (op. cit.) reports that Lindroth (1942) working in the laboratory with Atlantic salmon, *S. salar* Linnaeus, embryos found the critical level of dissolved oxygen to increase from 0.76 ppm in early stages of development to 5.8 ppm near the time of hatching. The temperature was 5 and 5.5° C. respectively. The critical level at hatching at 17° C. was 10 ppm.

Hayes, Wilmot and Livingston (1951) conducting laboratory experiments with Atlantic salmon embryos at Halifax, Nova Scotia, found the critical dissolved oxygen level to be 2.8 ppm 20 days after fertilization and 7.1 ppm just before hatching. The embryos were incubated at 10° C.

Silver[3] did not determine a critical level but found significant size differences in chinook salmon alevins when the embryos were developed at 2.5, 3.9, 5.6, 8.0, and 11.7 milligrams per liter of dissolved oxygen. In addition there were significant size differences in steelhead alevins when the embryos were developed at 2.6, 4.2, 5.7, 7.9 and 11.2 milligrams per liter of dissolved oxygen.

Shumway[4] did not determine a critical level for dissolved oxygen but found significant size differences in coho salmon alevins when the embryos were reared at 2.5, 4.0 and 10.3 milligrams per liter.

Wickett (1954) found high mortality in chum salmon embryos in a controlled-flow section of Nile Creek, British Columbia. Low concentrations of dissolved oxygen were found in the intragravel water which Wickett suggests could have caused the mortality.

Coble[7] in field experiments with coho and steelhead in the Drift Creek area found an equally good correlation between survival and dissolved oxygen and between survival and apparent velocity. He found both factors to be closely associated in the gravel bed, i.e., high disolved oxygen and high apparent velocity usually occurred together.

1 Apparent velocity is the rate of seepage thru an area of solids plus voids normal to direction of flow. It varies with gravel permeability and hydraulic gradient. True velocity is the actual velocity of flow thru the interstitial spaces. It differs from pore to pore and is impossible to measure.

2 Gravel permeability is the capacity of gravel to transmit water. It depends on composition and degree of compactness of the gravel.

3 Silver, Stuart S. 1960. The influence of water velocity and dissolved oxygen on the development of salmonid embryos. M. S. Thesis, Oregon State University, Corvallis, June 1960. 50 pp. (Unpublished).

4 Shumway, Dean L. 1960. The influence of water velocity on the development of salmonid embryos at low oxygen levels. M.S. Thesis, Oregon State University, Corvallis. June 1960. 44 pp. (Unpublished).

7 Coble, Daniel W. 1960. The influence of environment conditions in redds on the survival of salmonid embryos. M.S. Thesis, Oregon State University, Corvallis, June 1960. 37 pp. (Unpublished).

Apparent Velocity

Wickett (op. cit.) showed that an apparent velocity of about 5 millimeters per hour is sufficient to supply oxygen to a single chum salmon embryo when the oxygen concentration is 3 ppm. At 2 ppm the apparent velocity necessary to supply the embryos increases to about 15 millimeters per hour.

Silver[3] found an approximate true velocity[5] of 6.1 centimeters per hour at an oxygen concentration of 2.5 milligrams per liter to be sufficient for survival of chinook salmon and steelhead trout embryos in the laboratory. It was apparent that lower velocities produced smaller alevins at oxygen concentrations as high as 8 milligrams per liter.

Shumway[4] found coho salmon embryos surviving at an approximate true velocity of 3 centimeters per hour at a dissolved oxygen concentration of 2.5 milligram per liter. He found small but significant size differences in the velocities tested (3, 10, 16 and 750 centimeters per hour).

Cooper[6] reports laboratory experiments by Pyper in New Westminster, B.C., as demonstrating that a reduction in apparent velocity[2] decreased the number of sockeye salmon *O. nerka* (Walbaum) alevins emerging from the gravel.

Gangmark and Bakkala (1960) found the survival of chinook salmon *O. tshawytscha* (Walbaum) to be much higher in a controlled-flow section of Mill Creek, California, than in the stream itself. Fines had been removed from the gravel in the controlled section. The authors attribute the greater survival to the higher seepage rate or apparent velocity of intragravel water in the channel.

The investigations cited above did not test the value of gravel permeability in embryonic survival. Gravel permeability would influence survival to hatching indirectly by providing for, but not insuring, intragravel water containing sufficient oxygen and having sufficient velocity.

Wickett (1958) has found some evidence to indicate that higher survival to emergence of chum salmon and pink salmon was associated with higher gravel permeabilities. He compared survival and gravel permeabilities on four streams in British Columbia.

Methods and Materials

Environmental conditions in the gravel were sampled by means of a standpipe, one end of which was buried in gravel while the other end extended above the water surface. Steelhead embryos were held in a small perforated container in the gravel near the end of the pipe.

The device used to obtain observations from gravel beds was a modification of the Mark VI standpipe. The method was developed by Wickett (op. cit.), improved by Pollard (1955), and improved still further in the Mark VI model by Terhune (1958). Calibration figures given by Terhune (ibid.) were used to determine gravel permeability and apparent velocity.

5 True velocity was approximated under laboratory conditions.

6 Cooper, A. C. 1956. A study of the Horsefly River and the effect of placer mining operations on sockeye spawning grounds. Intern. Pac. Salmon Fish. Comm. 58 pp. (Processed).

Briefly, the standpipe is a piece of 1¼ inch standard aluminum pipe 34¼ inches long with a pointed steel head for driving into the gravel. In the 2-inch section just above the driving head are 48 perforations ⅛ inch in diameter. The pipe is driven into the gravel until the perforated section is located at the desired depth. In the experiments, all embryos were buried 10 inches in the gravel. The depth was selected because it was close to the average depth which coho and steelhead bury their eggs. The open end of the pipe extends above the surface of the water. Dissolved oxygen content and apparent velocity of the intragravel water, and the gravel permeability are measured by means of the pipe.

The standpipe was modified by cutting it in two (Gangmark and Bakkala, 1958, and Coble[7]). The portion having the perforations was referred to as the "standpipe" while the upper end was the "extension." Because the standpipes were of the same dimensions, only one extension was needed for all the pipes.

The standpipe was equipped with a flat base rather than a point on the lower end to increase stability (Gangmark and Bakkala, op. cit., and Coble[7]). When the perforated chamber was buried in the gravel to a depth of 10 inches, the pipe protruded several inches above the gravel surface. The extension was fastened by a coupling to the standpipe.

After observations were taken, the extension was detached and a cap fitted over the pipe to keep out foreign objects.

In earlier work by Gangmark and Bakkala (op. cit.) and by Coble[7] plastic mesh bags were used to hold the embryos in the gravel. In both experiments the bags were buried in the vicinity of, but not around, the standpipes.

By means of the standpipes, the environmental conditions measured approximate those in the gravel immediately surrounding the perforated section. The farther the embryos are from the perforations, the more erroneous the sample figures are likely to be in describing environmental conditions at the embryos. Therefore, a porous container was needed to hold the embryos close to the standpipe perforations. The embryo container had to be: (1) high permeable; (2) suitable for holding embryos to hatching; (3) non-toic; (4) rigid; and (5) shaped to provide for the distribution of embryos at similar distances around the pipe.

A perforated stainless steel box, 4 inches square and 1 inch deep was developed to slip over the pipe, holding the embryos close to the perforations. One hundred embryos were used to determine survival at a particular test site. Sterilized glass beads, 6 millimeters in diameter, were added to each box to provide uniform permeability about the embryos.

Steelhead Embryo Survival

From previous sampling of dissolved oxygen concentrations in the intragravel water of Deer Creek, a range of oxygen concentrations was selected and the locations were marked. On March 21, 1960, fourteen experimental groups of 100 steelhead embryos each were placed in the gravel at the 10-inch depth.

Steelhead eggs were taken from several females, fertilized by sperm from several males and water-hardened for one to two hours at the Alsea Hatchery. The embryos were placed in quart jars filled with water and transported 65 miles by automobile and 1 mile by trail to the stream. There the perforated boxes were filled half full of glass beads. The embryos were counted into boxes and more glass beads added to fill the box. After securing the lid with small stainless steel bolts, the box was fitted over the standpipe and slipped into position around the perforations. The pipe was buried in the gravel.

A 16-foot hatchery trough was established on a small tributary of Flynn Creek to determine the time of hatching in the experimental group.

Sampling at the standpipes was done at intervals of about 10 days. While the water samples were being taken for the determination of dissolved oxygen, the cap was removed and an aluminum rod-sponge rubber stopper was slowly lifted until the end of the rod cleared the stream surface.

The stopper was used to prevent contamination of the water in the perforated section of the standpipe by the surface water. Between sampling periods, the stopper was stored in the standpipe with the sponge rubber stopping the perforations to keep fines from entering.

With the rod lifted, a rubber tube was inserted through the rod and, by means of oral suction, a water sample was drawn into a 37 millimeter vial. The "semi-micro" technique of oxygen determination described by Harper (1953) was used. Reagents were added following the Alsterberg (sodium azide) modification of the Winkler method (American Public Health Association et al., 1946).

On the day following the dissolved oxygen sampling, the cap was again removed from the standpipe. The stopper was slowly removed and the extension affixed. The velocity liner was inserted and the change in dilution of a color solution[8] was determined as described by Terhune (op. cit.).

Once a velocity determination was made, the velocity liner was removed and the gravel permeability determined, again following the procedure given by Terhune (op. cit.).

The experiment was terminated on May 25, twenty-three days after hatching began in the baskets at Flynn Creek. The perforated boxes[9] were removed from the gravel and survival determined by the number of live alevins present. All identifiable alevins were alive while those embryos which had not hatched were all dead.

Not all embryos could be accounted for. Some had disintegrated and were not recognizable as individual eggs.

Fungus in four experimental groups (two with survival and two without) and in all control groups made the distinction of individual embryos difficult.

All alevins were preserved in Bouins fluid. Samples of the dead embryos were examined the next day. No disease was found.

The water temperature did not fluctuate markedly during the incubation period. The range was 45° to 52° F., and the mean was 48° F.

There was survival in six of the fourteen experimental groups, ranging from 22 to 63 percent.

When survival percentages of the experimental lots were plotted against the mean dissolved oxygen concentrations, it was found that the higher survival occurred at higher levels of dissolved oxygen (Figure 1.) No survival occurred where embryos were exposed to mean oxygen concentration of 7.2 milligrams per liter or less.

8 The assumption is made that the color solution has no effect on developing embryos in the concentrations used.

9 The assumption is made that the stainless steel perforated boxes have no effect upon the developing embryos.

In the incubation period variability was found in the oxygen concentration at most of the standpipes. Table I presents the mean and range of the dissolved oxygen determinations for each standpipe.

The comparison of the size of the surviving alevins with the dissolved oxygen sample means showed that those alevins from embryos that had received higher concentrations of oxygen were larger than alevins from embryos reared at the lower concentrations (Figure 2). Size was compared by excision of the yolk sac from a sample of 20 of each lot and displacement in a graduate cylinder.

In comparison of survival with mean apparent velocity, the higher velocities were correlated with higher survivals, with a few exceptions (Figure 3.) Considerable variation in apparent velocity was found at each standpipe. The mean and range of the observation are presented in Table 1.

There was no correlation of survival with gravel permeability. The permeabilities tested were high, the means ranging from 6,425 to 30,000 centimeters per hour. If values approaching zero had been included in the experiment, probably there would have been a relationship.

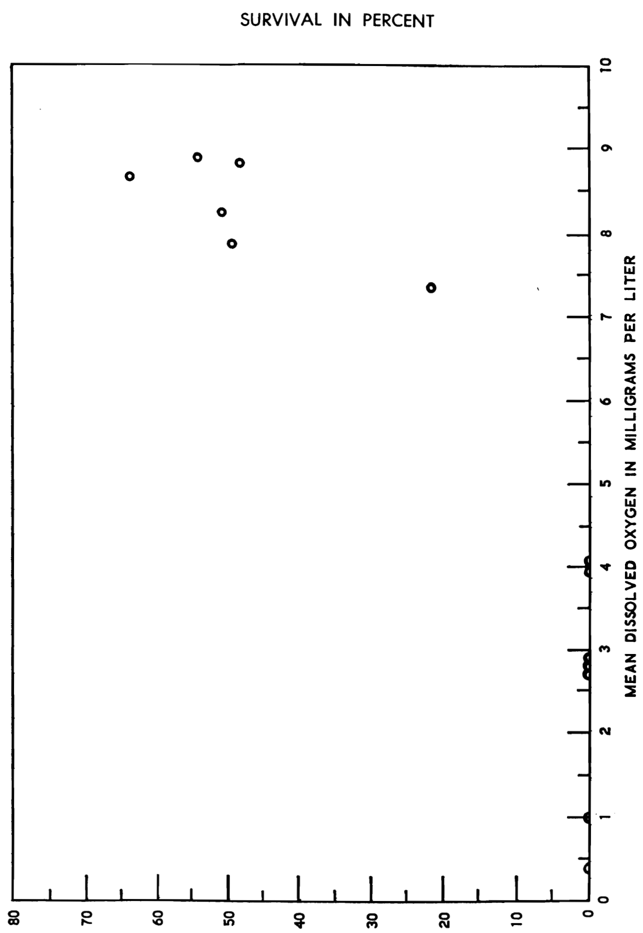

Figure 1.--A comparison of the survival of steelhead embryos with the mean oxygen content of intra-gravel water.

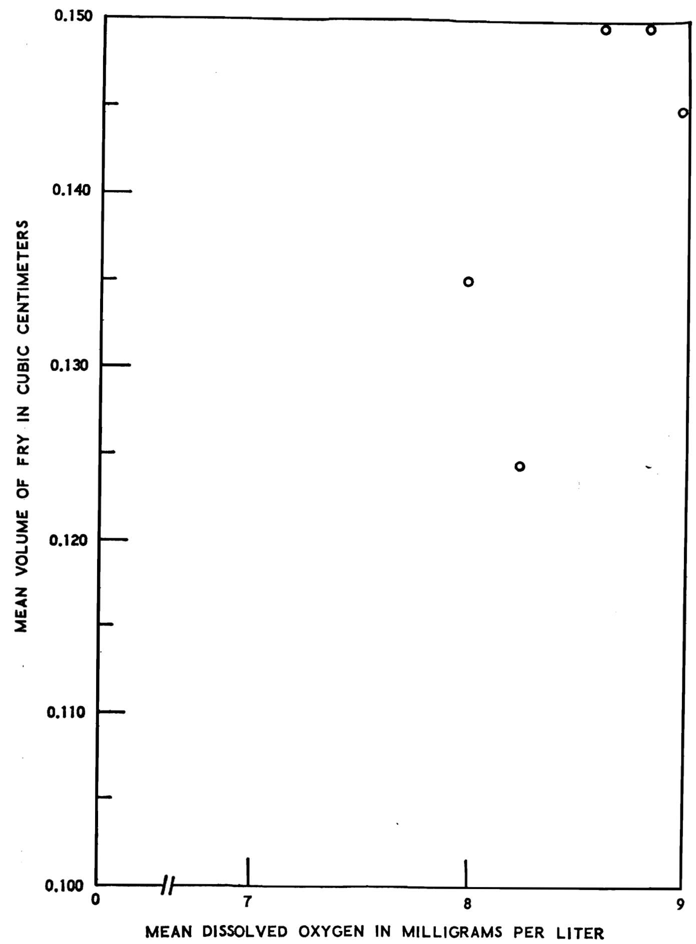

Figure 2.--The relationship of the size of steelhead fry with the mean oxygen content of intra-gravel water.

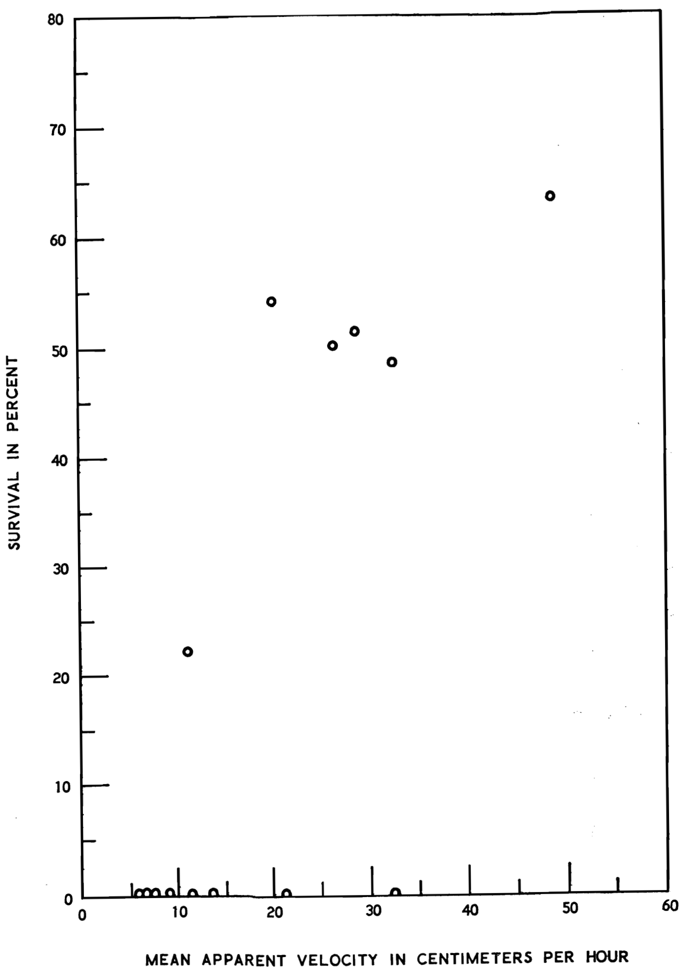

Figure 3.--The relationship of survival with the mean apparent velocity of intra-gravel water through spawning gravel.

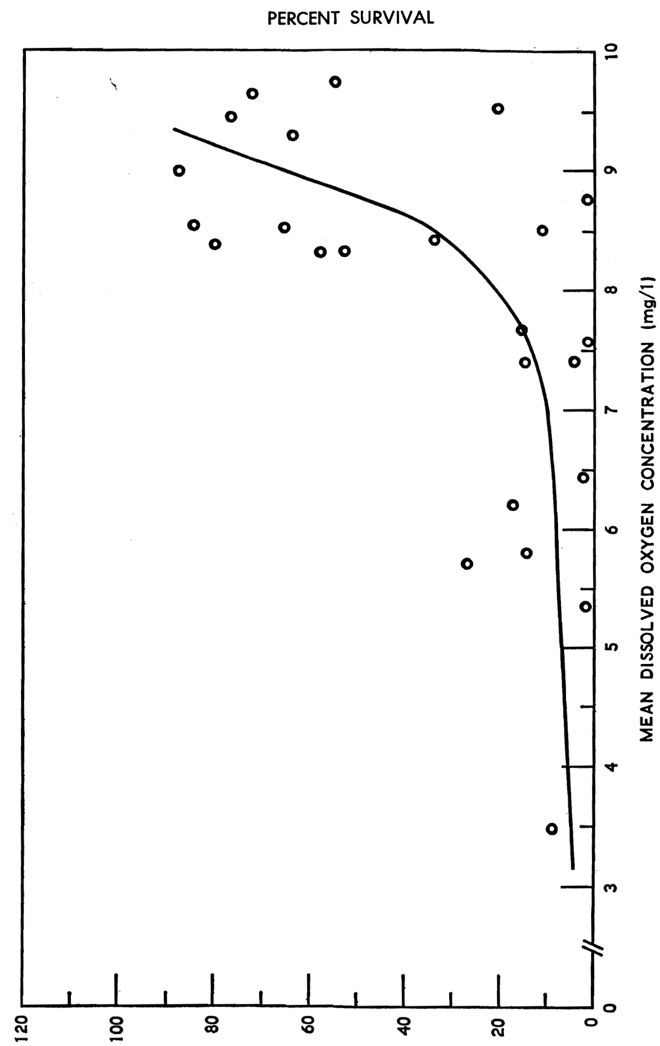

Figure 4.—Relationship of mean dissolved oxygen to survival of coho embryos Needle Branch, Dec. 20,1960 - Feb. 28, 1961

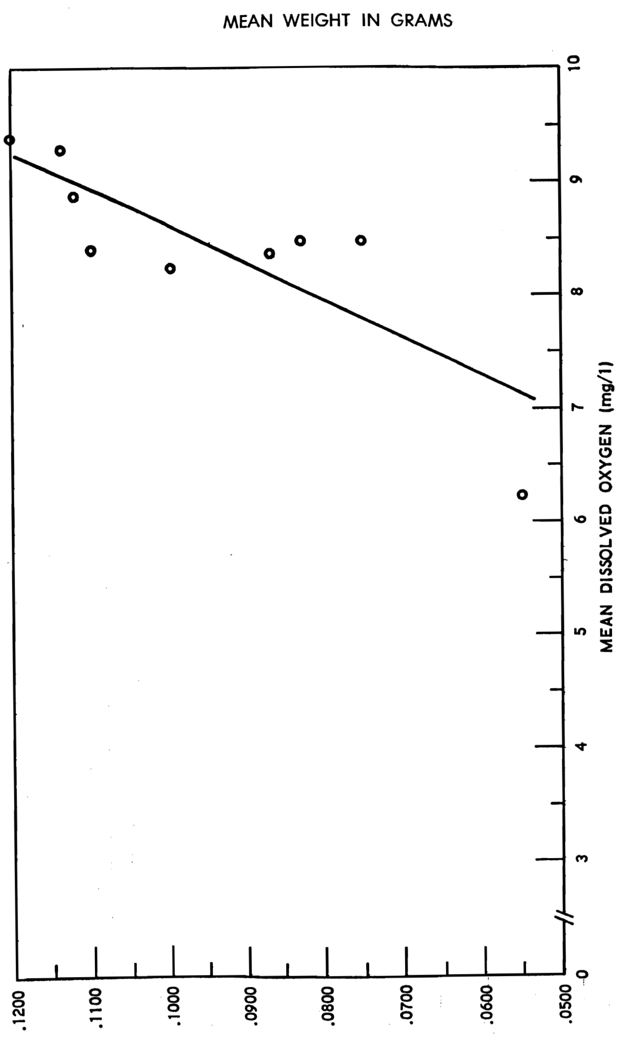

Figure 5.--The relationship of weight of coho alevin, without yolk sac, and dissolved oxygen concentration of intra - gravel water.

TABLE 1

Dissolved Oxygen Concentration, Apparent Velocity and Survival of Steelhead Embryos in Deer Creek, 1960.

Experi-mental lots	Dissolved oxygen concentration (milligrams per liter)		Apparent velocity (centimeters per hour)		Survival (percent)
	Mean	Range[1]	Mean	Range[2]	
1	4.0	1.2-6.9	6	4-8	0
2	2.9	0.6-7.1	9	6-14	0
3	1.0	0.0-2.8	11	8-20	0
4	8.9	8.2-9.7	32	25-42	49
5	7.2	3.8-9.7	7	6-11	0
6	8.7	7.4-9.5	48	40-55	63
7	2.8	0.8-7.6	13	5-43	0
8	0.4	0.0-1.4	32	28-36	0
9	2.9	0.2-6.1	21	7-55	0
10	4.0	0.7-7.9	7	6-10	0
11	8.3	6.9-9.5	28	10-70	51
12	9.1	7.3-10.0	20	15-27	54
13	8.0	6.1-9.8	26	15-37	50
14	7.5	6.2-9.5	11	5-24	22

[1] Derived from 6 observations at 10-day intervals.
[2] Derived from 4, 5, or 6 observations.

Coho Embryo Survival

The methods used in the 1961 field study with coho embryos were the same as those employed in the steelhead embryos study with a few minor exceptions.

The coho eggs were taken from several females and fertilized by several males at the Fish Commission of Oregon Alsea Hatchery on Fall Creek (Alsea River). The eggs were allowed to water-harden for 1 to 2 hours before being transported by automobile some 65 miles to Needle Branch. A total of 24 experimental groups of 100 embryos each were buried at predetermined locations in Needle Branch.

Sampling at the standpipes was done at intervals of about 5 days for dissolved oxygen, and at 10-day intervals, approximately, for apparent velocity and gravel permeability. The experiment was terminated February 28, 1961. Hatching was nearly completed (95 percent). Similarly, in the coho study as in the steelhead study, not all dead embryos could be accounted for because of decomposition. All embryos were preserved in Bouins fluid.

The live alevins appeared to be healthy. There was no reason to expect disease in any of the experimental groups.

The water temperature fluctuated within narrow limits. The range was 44° to 48° F. The mean was 46° F.

Of the 24 experimental lots, survival occurred in 22.

In comparing percentage of survival with the mean dissolved oxygen concentration there was an apparent positive correlation (Figure 4 and Table 2). Only in those groups where the mean concentration of oxygen was greater than 8 milligrams per liter did the survival exceed 30 percent.

The size of the alevins was compared with the mean dissolved oxygen concentration (Figure 5.) Larger alevins were found where the embryos had been reared at the high concentrations.

Survival precentages were compared with the mean apparent velocities. There was no correlation.

The survival percentages were also compared with mean gravel permeabilities. There was no correlation in the ranges tested. The mean gravel permeability ranged from 2,110 to 25,400 centimeters per hour.

TABLE 2

Dissolved Oxygen Concentration and Embryonic Survival of Coho Salmon in Needle Branch, December 20, 1960 to February 28, 1961

Experimental lot number	Dissolved oxygen concentration (milligrams per liter) Mean	95% confidence interval	Survival (percent)
1	8.5	7.8-9.2	64
2	9.4	8.7-10.1	78
3	6.2	5.9-6.6	18
4	8.5	7.4-9.5	82
5	9.7	8.5-10.9	55
6	8.4	7.3-9.5	80
7	5.7	4.1-7.3	26
8	9.0	7.8-10.2	87
9	5.8	4.1-7.5	14
10	3.5	1.9-5.0	7
11	7.4	5.1-9.7	3
12	8.5	7.6-9.3	33
13	6.4	4.7-8.1	1
14	5.4	3.3-7.5	0
15	7.6	6.4-8.8	1
16	8.3	7.4-9.2	59
17	8.3	7.6-9.0	52
18	8.8	8.2-9.4	0
19	7.4	5.8-9.0	15
20	9.5	8.8-10.2	20
21	9.6	8.7-10.5	71
22	8.5	7.4-9.5	11
23	7.7	6.7-8.7	16
24	9.3	8.4-10.2	62

Conclusions

Under the assumptions listed, the following conclusions are:

1. That there is a positive correlation between the survival of coho and steelhead embryos and mean dissolved oxygen concentration in the gravel beds of two small coastal streams.
2. That the dissolved oxygen concentration necessary for the embryonic survival of coho and steelhead in coastal stream gravel beds is greater than has been previously suspected. Results of field experiments indicate that mean oxygen concentrations in gravel necessary for a high survival of coho and steelhead embryos may exceed 8 mg/liter.

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FOR THE YEAR 1961

To the Congress of the United States and the Governors and Legislatures of the Three Compacting States, Washington, Oregon, and California, by the Commissioners of the Pacific Marine Fisheries Commission in Compliance with the State Enabling Acts Creating the Commission and Public Law 232 of the 80th Congress of the United States Assenting Thereto.

Respectfully submitted,
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