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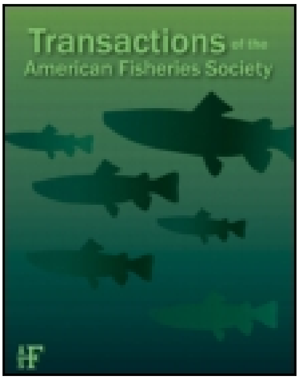

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Influence of Water Exchange and Dissolved Oxygen in Redds on Survival of Steelhead Trout Embryos[1]

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ABSTRACT

A field study of spawning gravel conditions affecting the survival of steelhead trout (*Salmo gairdneri* Richardson) embryos was conducted in two small streams in the Alsea River Basin in Lincoln County, Oregon, from February to June 1959. Holes 10 inches deep, approximating natural redds, were dug in arbitrarily selected spawning locations. Plastic mesh sacks containing gravel and 100 fertilized trout eggs were placed in the upstream end of each hole. A standpipe was placed in the lower end of each excavation about 10 inches away from the eggs, and the hole was filled with gravel to the streambed level. Periodically, determinations were made of gravel permeability and of the apparent velocity and dissolved-oxygen content of the intra-gravel water. A month after calculated hatching times, the bags were removed from the streambed, and the fry contained in them were counted and preserved. The permeability of the spawning gravel fluctuated while embryos were in the gravel. During this period mean gravel permeabilities ranged from 80 to 400 meters per hour; apparent velocities from 5 to almost 110 centimeters per hour; and dissolved-oxygen concentrations from 2.6 to 9.25 milligrams per liter. Embryonic survival percentages ranged from 16 to 62. There was positive correlation between the apparent velocity of ground water and embryonic survivals, and between the dissolved-oxygen levels of the gravel water and survivals. Apparent velocities and dissolved-oxygen concentrations were closely related in the intra-gravel water, and effects of these factors could not be separated.

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INTRODUCTION

In 1958 the Oregon Cooperative Wildlife Research Unit[3] and the Governor's Committee on Natural Resources[4] initiated studies on the effects of logging practices upon various watershed values in Lincoln County, Oregon. One study included several years of investigation of salmonid production in three streams of the Alsea River Basin, Needle Branch, Flynn Creek, and Deer Creek, which drain areas of uncut Douglas fir forest. The phase of the study reported here was designed to provide information on conditions in spawning gravels before the streambeds become altered as a result of logging. Most of the work was done on Needle Branch. A few experiments were conducted in Horse Creek, a small stream which drains a logged area. Gravel in the streambeds is mostly sandstone. In sections of the streams used by salmonids for spawning, there are few rocks larger than 4 inches in diameter. Redds are dug in bottoms which range from silt to particles 3 inches in diameter.

This coastal area receives an annual rainfall of about 100 inches per year, most of which falls between October and May. Water levels in the streams fluctuate greatly during this 8-month period, and considerable movement of streambed gravels occurs, especially during peak flows. Water temperature and discharge data for Needle Branch are presented in Table 1. The temperature of the water below the surface of the streambed was virtually the same as that above it.

The term "embryo" is used herein to specify all stages of development from fertilization to the time of fry emergence from the gravel. Some conditions in spawning beds that affect the fate of embryos within them are gravel permeability, a characteristic of the gravel itself, and apparent velocity and dissolved oxygen, characteristics of the water flowing through the gravel. "The *apparent velocity* sometimes called the superficial or macroscopic velocity, is the rate of seepage expressed as the volume of liquid flowing per unit time through a unit area (of solids plus voids) normal to the direction of flow. The *true*, or *pore velocity* is the actual velocity of flow through the interstitial spaces, and differs from pore to pore" (Pollard, 1955). For

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[3] Oregon State College Agricultural Research Foundation, Wildlife Management Institute, U. S. Fish and Wildlife Service, and Oregon State Game Commission cooperating.

[4] Comprised of representatives of various State agencies that are concerned with the conservation of Oregon's natural resources.

TABLE 1.—*Maximum and minimum discharges and water temperatures of Needle Branch, Lincoln County, Oregon, 1959*[1]

Month	Discharge (cubic feet per second)	Temperature (degrees Fahrenheit)
January		
Maximum	14.0	48
Minimum	1.7	41
February		
Maximum	7.8	48
Minimum	1.3	42
March		
Maximum	4.8	48
Minimum	0.7	44
April		
Maximum	3.7	51
Minimum	0.3	45
May		
Maximum	3.7	51
Minimum	0.4	46
June		
Maximum	1.0	54
Minimum	0.3	48

[1] Obtained from a stream gauge operated by the U. S. Geological Survey.

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present purposes, permeability is defined as the capacity of the gravel to transmit water. Spawning gravels, depending on their nature, transmit water at various rates, and in this paper the capacity to transmit water is expressed in meters per hour.

Wickett (1954) found low dissolved-oxygen concentrations attributed to low water flow in portions of a study stream and thought they may have caused the observed high mortalities of chum salmon (*Oncorhynchus keta*) embryos. He also described a standpipe (later improved by Terhune, 1958) which was used to estimate the apparent velocity of the intra-gravel water, and which provided access to water for dissolved-oxygen determinations. Alderdice, Wickett, and Brett (1958) exposed chum salmon embryos to low dissolved-oxygen levels for 7-day periods and then held the embryos at saturation levels for the remainder of development. Various concentrations at different developmental stages resulted in delays in hatching, abnormal development, and increased mortalities. Silver[5] held steelhead trout (*Salmo gairdneri*) embryos and chinook salmon (*Oncorhynchus tshawytscha*) embryos from fertilization to hatching at various concentrations of dissolved oxygen and at known velocities of water current. Reduced levels of dissolved oxygen or velocity caused delays in hatching, and the fry produced at the low levels were smaller in length and volume at hatch than those reared at higher levels of dissolved oxygen or water velocity. Shumway[6] also found that the production of embryonic tissue was reduced with decreased levels of dissolved oxygen or water velocity.

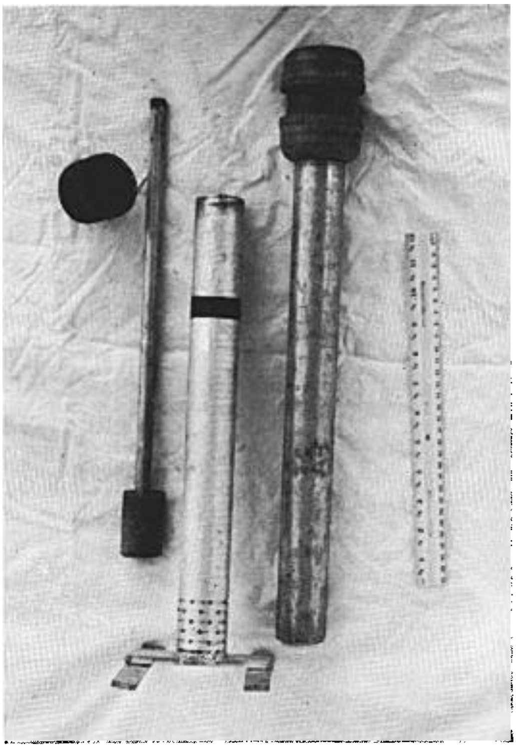

FIGURE 1.—The standpipe assembly showing extension, stopper, and cap.

MATERIALS AND METHODS

Standpipes, which have been used for studies of water flowing through gravel, are pieces of pipe perforated at one end which, when placed vertically in a streambed, permit ground water to flow through the lower end. The top of the pipe extending above the surface of the stream provides access to the intragravel water. Standpipes used in this study (Figure 1) were 15-inch lengths of 1¼-inch aluminum pipe perforated in the lower 2 inches by 48 ⅛-inch, evenly spaced holes. The

[5] Silver, S. J. (1960) The influence of water velocity and dissolved oxygen on the development of salmonid embryos. M.S. thesis, Oregon State College, Corvallis. 50 pp.

[6] Shumway, D. L. (1960) The influence of water velocity on the development of salmonid embryos at low oxygen levels. M.S. thesis, Oregon State College, Corvallis. 49 pp.

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lower end was sealed by a small plate, and two flat metal bars attached here served to hold it more firmly in the gravel. Horizontal grooves one-sixteenth inch wide and one-sixteenth inch deep extended between the holes on the outer surface of the pipe and reduced the chance of pebbles blocking the openings. A piece of sponge rubber on a handle could be placed in the standpipe to prevent water from flowing through the pipe when it was not in use. When the pipe with top capped was buried 10 inches in the gravel with the stopper in place, it could be considered a part of the streambed. When measurements of intra-gravel conditions were being made, the cap and stopper were removed, and a 2-foot extension was fitted to the top of the pipe.

This standpipe incorporates some of the features of the pipe developed by Gangmark and Bakkala (1958) and the one designed by Terhune (1958). In these two papers and the paper of Pollard (1955), there are complete discussions of the theories behind and the limitations involved in the design, calibration, and use of standpipes.

Gravel permeability can be estimated through its relationship to the rate at which water can be removed from a standpipe by pumping. When water is pumped from a standpipe into a graduated cylinder and the time taken to remove it is recorded, an amount of water per unit of time is obtained, and this is a function of the permeability of the gravel surrounding the pipe. The relationship between the rate of water removal and the permeability of the gravel has been shown by Terhune (1958).

The apparent velocity of the ground-water flow can be estimated from the relationship between the rate of flow in the lower end of a standpipe and water velocity in the streambed. When a color solution is injected into a standpipe, the color of the water in the pipe becomes lighter with time as it is diluted by exchange with water from the streambed. By periodic sampling of water in the pipe, the rate of dilution may be measured. Apparent velocity of the water flowing through the streambed can then be estimated from the relationship of dilution rate to ground-water flow (Terhune, 1958).

Dissolved-oxygen determinations were made on 37-milliliter samples of water taken from the pipes (Harper, 1953).

On February 10, 1959, fertilized steelhead trout eggs were obtained from the Oregon Fish Commission hatchery on Fall Creek, a tributary of the Alsea River, and transported directly to the study area, a distance of 65 miles. Holes 10 inches deep and about 14 inches long were dug in spawning gravel at arbitrarily selected locations.[7] Gravel and water-hardened eggs (100 per sack) were placed in plastic mesh sacks having 19 meshes per inch, and the tops of the bags were secured with nylon cord. A standpipe was placed in the downstream end of each hole, and a sack of fertilized eggs and gravel was put in the upper end about 10 inches away from the pipe. The hole was then filled with gravel to the level of the streambed. Determinations of gravel permeability and of apparent velocity and dissolved-oxygen content of ground water were made at intervals throughout the incubation period. One month after calculated hatching times, the sacks and pipes were removed and fry in the sacks counted and preserved in Bouin's solution. Silt was deposited to various degrees on the mesh of many of the sacks. The effect of it on water circulation through the bags was not determined but was thought to be of little importance to the survival of the embryos.

RESULTS

The first measurements from the standpipes were taken 2 days after the study redds were prepared. A permeability measurement was made each week (except one) for the next 12 weeks, and 10 apparent velocity determinations were obtained in this period. Various numbers of dissolved-oxygen determinations were made at different stations. The permeability of the gravel surrounding the standpipes continually changed during the incubation period (Table 2). The environment of the embryos is by no means stable.

From more complete data in two study redds in Horse Creek and eight in Needle Branch (Table 3), it can be noted that conditions were quite different in the various redds. Mean permeabilities ranged from 80 to 400 meters per hour, mean apparent velocities from 5 to 108.5 centimeters per hour, and mean dissolved-oxygen concentrations from 2.6 to 9.2 milligrams per liter. Survival percentages ranged from 16 to 62. The relationships between these environmental conditions and the survival of the embryos is more clearly illustrated in Figures 2 and 3. In these figures the regression lines are drawn

[7] Subsequently wild fish dug redds in some of the chosen areas.

TABLE 2.—*Permeability measurements in meters per hour from Horse Creek and Needle Branch, 1959*

Date	Horse Creek 1	Horse Creek 2	Needle Branch 1	Needle Branch 2	Needle Branch 3	Needle Branch 4	Needle Branch 5	Needle Branch 6	Needle Branch 7	Needle Branch 8
February										
12	100	350	150	60	350	200	350	350	90	350
19	100	200	200	100	500	150	450	450	100	500
26	150	150	150	60	450	200	300	450	150	300
March										
5	60	100	150	100	350	100	300	200	60	300
12	60	150	150	60	300	100	200	200	100	150
20	100	150	150	100	150	100	150	150	60	150
28	60	100	150	100	150	60	200	200	60	150
April										
2	100	150	150	60	100	90	150	100	60	150
16	60	150	150	60	200	60	500	500	100	200
23	60	150	150	100	150	60	450	500	60	200
May										
1 or 13	70	90	150	200	150	70	550	350	40	300
1 or 13	70	200	100	90	100	80	700	800	50	350

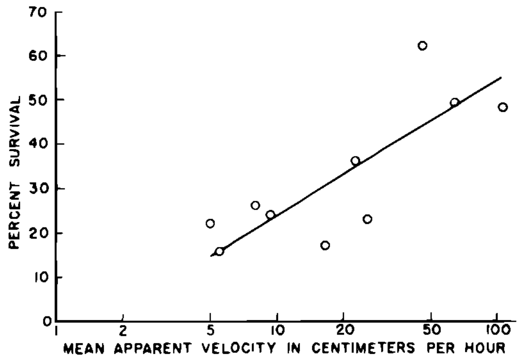

FIGURE 2.—The relationship between apparent velocity and embryonic survival.

between the means of the five highest and the five lowest observations. In Figure 2 percentages of survival are plotted against the mean apparent velocities. In general low embryonic survivals are associated with low mean velocities, and higher survivals with higher velocities. In Figure 3 the percentages of survival are plotted against the mean dissolved-oxygen concentrations. Here, low survivals are shown to be associated with low mean dissolved-oxygen levels, and higher survivals with higher oxygen concentrations. No relationship between permeability and survival was found.

DISCUSSION

In this study the determinations of apparent velocity and of dissolved oxygen were of similar value for appraising the environment of the embryos. In Figure 4 the relationship between the apparent velocity of ground water and embryonic survival has been removed by adjusting the percentages of survival to what they might have been at 31 centimeters per hour, the mean value of all apparent velocity determinations. This is essentially a graphic method of multiple regression analysis. The adjusted percentages of survival are plotted against the 10 mean dissolved-oxygen values, and no definite relationship is apparent. If a positive correlation were shown here, the dissolved-oxygen data would be accounting for more effects of the environment on the embryos than were the velocity measurements. In Figure 5 the relationship between dissolved oxygen and survival has been removed by adjusting the percentages of survival to what they might have been at 6 milligrams per liter of oxygen, the mean value of all dissolved-oxygen measurements. These adjusted percentages of survival are plotted against the 10 mean apparent velocity figures. Since a positive correlation is not obvious here, the velocity determinations account for no environmental effects not already accounted for by the measurements of dissolved oxygen.

The relationship between dissolved-oxygen concentration and apparent velocity in the

TABLE 3.—*Permeabilities, apparent velocities and oxygen concentrations of water, and percentages of survival of steelhead trout embryos in 10 study redds in Horse Creek and Needle Branch*

Station[1]	Permeability (meters per hour)		Apparent velocity (centimeters per hour)			Oxygen (milligrams per liter)			Percentage survival
	Mean	Range	Mean	Minimum	S.D.	Mean	Minimum	S.D.	
H.C. 1	82.5	60–150	26.0	12.5	10.3	5.7	3.9	1.9	23
H.C. 2	160	90–350	9.5	2.5	6.1	6.5	4.1	2.1	24
N.B. 1	150	100–200	8.0	5.0	2.9	5.2	4.1	1.2	26
N.B. 2	90	60–200	16.8	10.0	4.4	6.4	4.0	1.7	17
N.B. 3	245	100–500	65.0	30.0	32.2	6.4	3.8	2.0	49
N.B. 4	105	60–200	5.5	2.5	1.9	2.6	1.0	1.9	16
N.B. 5	400	150–700	23.0	17.5	12.8	8.3	3.6	2.6	36
N.B. 6	355	150–800	5.0	2.5	2.7	2.7	0.8	1.8	22
N.B. 7	80	40–150	46.5	15.0	17.8	9.2	7.4	1.9	62
N.B. 8	300	150–500	108.5	85.0	21.1	6.6	4.1	3.4	48

[1] H.C. = Horse Creek; N.B. = Needle Branch.

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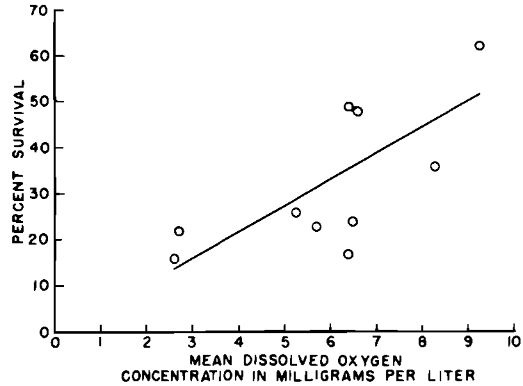

FIGURE 3.—The relationship between dissolved-oxygen concentration and embryonic survival.

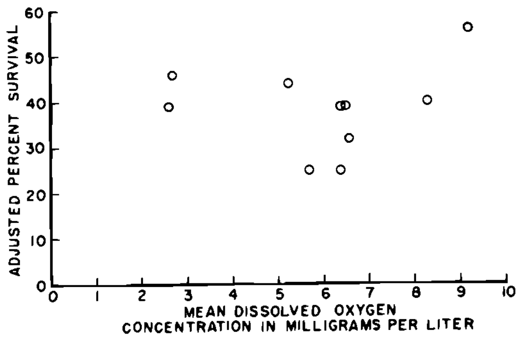

FIGURE 4.—The relationship between dissolved-oxygen concentration and the percentage of survival adjusted to 31 centimeters per hour apparent velocity to remove velocity relationship.

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streambed is indicated in Figure 6, in which the regression line is drawn by eye. It is apparent that when velocities are low, oxygen concentrations may be expected to be low; and when they are higher, oxygen levels may be expected to be higher.

The apparent similarity in the value of oxygen concentration and apparent velocity for indicating the suitability of the embryonic environment can be misleading. It is oxygen that is essential to the embryo, and the function of water movement is mainly to deliver oxygen to the embryo and to carry away metabolic waste products. Shumway[8] found that the embryo's oxygen requirements can be met by very low water velocities when oxygen concentrations are adequate and that the influence of different velocities ranging from 3 to 750 centimeters per hour on embryonic growth is slight compared to the influence of oxygen levels ranging from 2.5 to 10.3 milligrams per liter.

In the streams studied, determinations of the oxygen content of water flowing through the redd apparently provide the information necessary for a satisfactory evaluation of the environment of the embryos. Situations may occur where oxygen levels are low while velocities are high because of the flow pattern in the gravel or because there are large amounts of organic matter or large numbers of embryos in the gravel. In these instances oxygen determinations would be the only satisfactory means of evaluating the environment. In two redds receiving waters flowing at different velocities but having the same concentration of dissolved oxygen, conditions for embryonic development may be better in the area with the higher exchange rate of water.

It was found during the study that gravel 6 inches away from a standpipe had little effect on the permeability measurement obtained at the pipe, and that gravel permeability varied greatly from point to point. Sometimes standpipes half a foot apart yielded different readings, even though measurements taken one after another at either pipe were the same. The velocity of subsurface flow is mostly a function of the hydraulic head and the permeability of the gravel. Therefore, a closer relationship between velocity and survival than between permeability and survival and the observed lack of apparent relationship between gravel permeability and survival would be expected. Over a relatively large area, however, a positive correlation between permeability and survival may generally be ex-

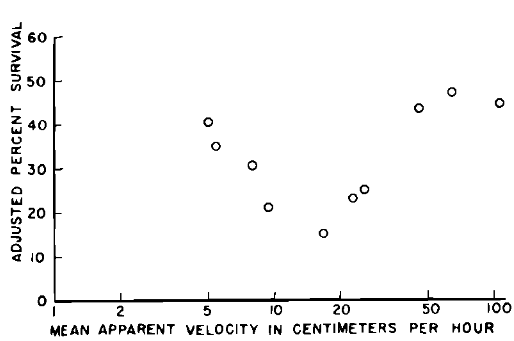

FIGURE 5.—The relationship between apparent velocity and percentage of survival adjusted to 6 milligrams per liter of dissolved oxygen to remove oxygen relationship.

[8] See footnote 6.

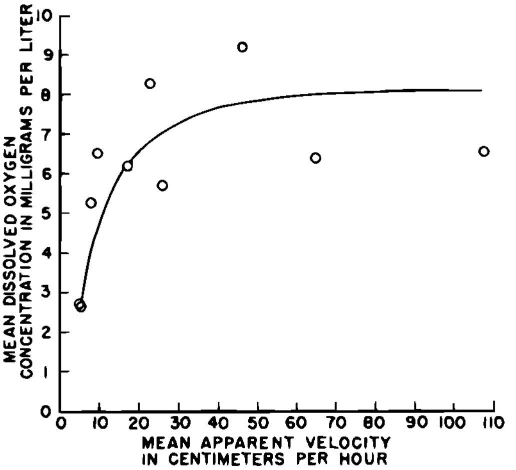

FIGURE 6.—The relationship between apparent velocity and dissolved-oxygen concentration.

pected. Wickett (1958) states that "the density of spawners that produces the greatest numbers of fry is related to the average permeability of the stream bottom."

Indications were found that considerable gravel movement occurs at least 10 inches below the streambed during the period that salmonid eggs are in the gravel. This shifting gravel as well as insufficient oxygen may be a cause of egg losses. Gangmark and Broad (1956) found early mortalities corresponding with freshets. No information pertaining to this question was acquired in this study.

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