THE SURVIVAL OF COHO SALMON (ONCORHYNCHUS KISUTCH) FROM EGG DEPOSITION TO EMERGENCE IN THREE OREGON COASTAL STREAMS

by

K VICTOR KOSKI

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1966

AN ABSTRACT OF THE THESIS OF

K VICTOR KOSKI for the M.S. in Fisheries
(Name) (Degree) (Major)

Date thesis is presented August 12, 1965

Title THE SURVIVAL OF COHO SALMON (ONCORHYNCHUS KISUTCH) FROM EGG DEPOSITION TO EMERGENCE IN THREE OREGON COASTAL STREAMS

Abstract approved James D. Hall
(Major professor)

Survival of coho salmon from egg deposition to emergence was studied in three coastal streams in Oregon from September 1963 until September 1964. Adult coho salmon were captured, tagged, and measured as they entered the streams. Redds of specific females were located and the number of deposited eggs was estimated. A trap that captured the emerging fry was installed on each of these redds and the survival of emerging fry evaluated in terms of gravel composition, gravel permeability, dissolved oxygen, and gravel stability. Size of the parent female and the environmental factors were examined in relation to size and robustness of the emergent fry.

Egg deposition of the spawning coho salmon was estimated from a regression equation based on weight and egg number of coho from a nearby stream. The fry trap, constructed of nylon netting,

was installed as a cap over the redd, and the edges were buried eight inches in the gravel. The concentration of dissolved oxygen in the intragravel water and the gravel permeability were sampled by means of a standpipe placed in each of the redds. Three samples of gravel were obtained from each redd and separated through a series of sieves. The volume retained by each sieve was expressed as a percentage of the total sample. Gravel erosion index stations were established in each of the streams to measure the relative amount of gravel movement.

Mean survival to emergence from 21 redds in the streams was 27. 1 percent. Fry in Deer Creek had the highest survival (54. 4 percent), followed by Needle Branch (25. 1 percent), and Flynn Creek (13. 6 percent). The number of emerging fry ranged from 0 to 2, 061. A mean of 110 days was required for the first emergence from the redds. Mean length of the emergence period for an individual redd was 30, 35. and 39 days for redds on Deer Creek, Needle Branch, and Flynn Creek, respectively. Length of the emergence period appeared to be related to the amount of fine sediments in the redd. Peak emergence from each redd occurred eight to ten days following the first emergence.

The size composition of the gravel was the only factor which showed a statistically significant correlation with survival to emergence. The percentage of fine sediments smaller than 3. 327 millimeters had the highest correlation (correlation coefficient r = -0. 69) of all size groupings tested. In each stream the percentage of fine sediments was inversely related to survival. Both gravel permeability and dissolved oxygen concentration were directly related to survival, but neither correlation coefficient (r = 0.36 and 0. *24*, respectively) was statistically significant at the five percent level, probably because of the interrelationships of several environmental factors affecting survival. Gravel movement was extensive in some areas of the streams.

Size and robustness of the emerging fry decreased throughout the emergence period in each of the redds examined. Both permeability of the gravel and weight of the female parent were directly related to the weight of the emergent fry.

APPROVED:

James D. Hall

Assistant Professor of Fisheries

In Charge of Major

Thomas G. Scott

Head of Department of Fisheries and Wildlife

Dean of Graduate School

Date thesis is presented August 12, 1965

Typed by Eula Weathers

ACKNOWLEDGMENT

Throughout this study, many individuals have given assistance and encouragement for which I am grateful. I particularly want to thank the Research Division of the Oregon State Game Commission under the leadership of Dr. H. J. Rayner for the graduate research assistantship.

It is a pleasure to acknowledge the help of Dr. James D. Hall for his assistance afield and in the preparation of the manuscript. The assistance of Mr. Robert W. Phillips contributed notably to the success of this study. I appreciate the aid of Mr. Wayne L. Hug in the field, as I do the suggestions and help of Mr. Homer J. Campbell. Mr. Dean L. Shumway and others critically reviewed the manuscript. Mr. Otto J. Bodie of the Oregon Fish Commission contributed the coho salmon used in the fecundity study.

Special thanks to my wife, Carol, for her constant help and understanding.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

THE SURVIVAL OF COHO SALMON (ONCORHYNCHUS KISUTCH) FROM EGG DEPOSITION TO EMERGENCE IN THREE OREGON COASTAL STREAMS

INTRODUCTION

Man's land-use activities, particularly logging, are of direct concern to the management of salmon and steelhead trout because of the close relationship between the stream ecosystem and the terrestrial environment. Harvesting of timber without consideration of its effects on the environment cannot only be harmful to fish and other aquatic life, but can also ruin other watershed uses as well. The effects of increased siltation, highly fluctuating streamflow and water temperature, changes in chemical water quality, and removal of streamside vegetation have yet to be determined.

Research into the effects of logging on aquatic resources is one of the objectives of the Alsea Watershed Study located in Lincoln County, Oregon (Chapman *et al.* , 1961). Three small unlogged watersheds, Deer Creek, Flynn Creek, and Needle Branch, have been under study since 1958. Data have been accumulated on physical and biotic factors in the streams, and studies will be continued for several years following logging in 1966. Deer Creek will be cut with staggered settings, Flynn Creek will serve as a control, and Needle Branch will be clear-cut.

The objectives of my study were to determine the survival of coho salmon (*Oncorhynchus kisutch*, Walbaum) from egg deposition to emergence under pre-logging conditions in these streams and to identify and evaluate those factors limiting their survival. Results of this study will later be used as a basis to assess the effects of logging on salmonid embryo and fry survival and on the environmental factors directly related to their survival.

In order to estimate survival to emergence accurately, a trap was used to isolate individual redds and capture the emerging fry. The idea of trapping fry as they emerge is not new, but has met with varying degrees of success in the past. Brasch (1949) used screen cylinders to trap fry from brook trout (*Salvelinus fontinalis*) redds in Wisconsin, but lost the majority of the traps to high water. Heard (1964) used a screen fry trap placed over a portion of the redd to study the phototactic behavior of emerging sockeye salmon (*Oncorhynchus nerka*). Hamilton found that a box-type trap placed over sockeye salmon redds proved quite effective in capturing emerging fry, but the traps were adversely effected by high water.

Many estimates of fry survival have been based on the excavation of redds and the observed survival of the embryos and sac fry. These estimates in many cases may be biased since they do not

R. W. Phillips and K V. Koski. Manuscript in preparation. Oregon Game Commission, Corvallis, Oregon.

J. A. R. Hamilton. Personal communication. Pacific Power and Light Company, Portland, Oregon.

account for the failure of fry (yolk sac absorbed) to emerge from the gravel. High embryonic survival in the redd does not assure high emergent survival due to the inability of some of the fry to escape their natal environment.

Estimates of embryo and fry survival vary considerably because of the different species, areas, and techniques involved. Royce (1959) reviewed the literature on the success of natural spawning in Alaska and British Columbia and stated that on the average, less than ten percent of the eggs of pink (*Oncorhynchus gorbuscha*), chum (O. keta), and sockeye salmon hatch and leave the redd as free-swimming fry. Considerably higher survivals, 60 to 90 percent, for other species of salmonids have been found (Hobbs, 1948 and Briggs, 1953).

Several environmental factors are extremely important in the growth and survival of salmonid embryos and fry. Recent field work by McNeil (1962a) in Alaska, Wickett (1954) in Canada, Gangmark and Bakkala (1960) in California, and Coble (1961) in Oregon has shown that both the quality and rate of exchange of the intragravel water are important to survival. Laboratory work has demonstrated the effects of different concentrations of dissolved oxygen and water velocities on the survival and growth of salmonid embryos and sac fry (Alderdice, Wickett, and Brett, 1958; Silver, Warren, and Doudoroff, 1963; and Shumway, Warren, and Doudoroff, 1964).

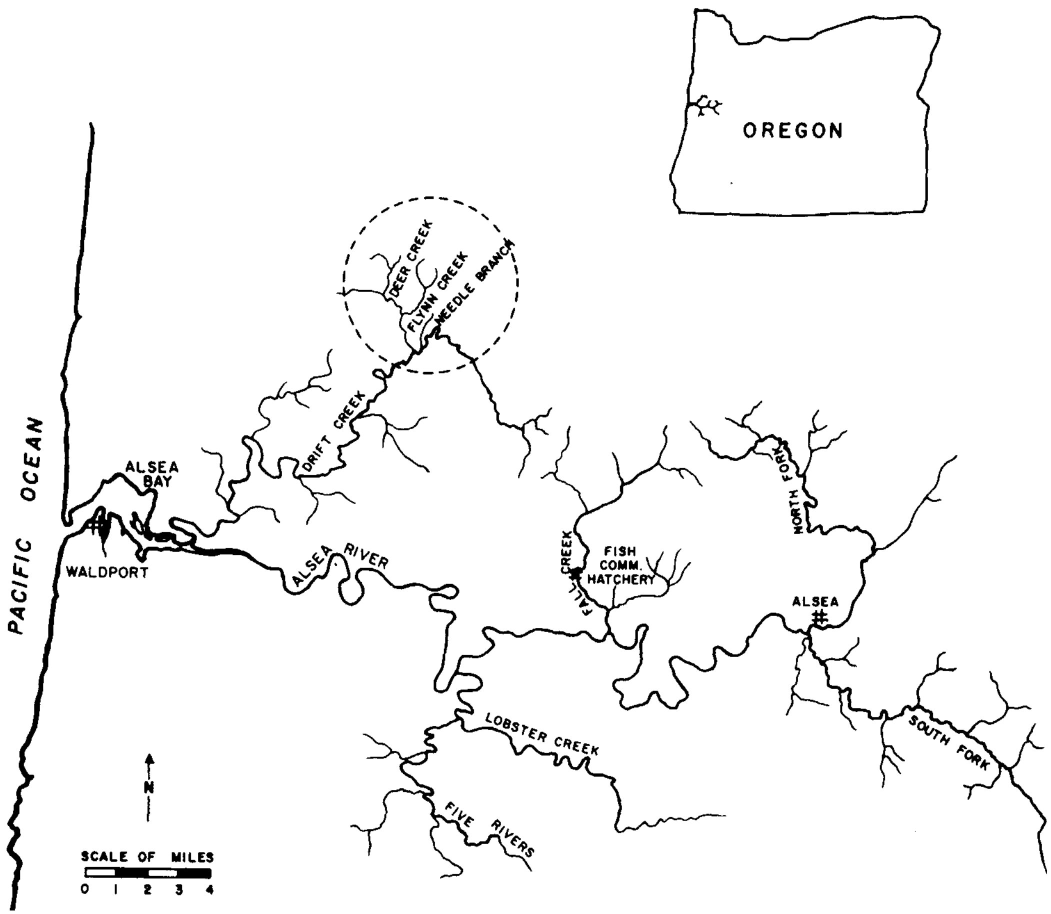
Stability of the redd gravel is a critical factor in survival (Sheridan and McNeil, 1960; Gangmark and Bakkala, 1960; and McNeil, 1962a) The detrimental effects of sedimentation upon salmonid embryos and sac fry have been reported by Harrison (1923), Shapovalov and Berrian (1940), Shaw and Maga (1943), Neave (1947), Stuart (1953), Campbell (1954), Cordone and Kelly (1961), and Bianchi (1963).

DESCRIPTION OF STUDY AREA

This study is located in Lincoln County, about seven miles southeast of Toledo, Oregon. My work was conducted from September 1963 to September 1964 on three small tributaries of Drift Creek, which drains into the Alsea Bay near Waldport, Oregon (Figure 1). The three streams are within about 2. 5 miles of each other and except for size are similar in physical and biotic characteristics (Table 1).

There is considerable seasonal fluctuation in streamflow, but relatively little seasonal variation in stream temperatures (Figure 2). During the study, Deer Creek reached a peak discharge of 96 cubic feet per second (cfs) in January, and had an annual mean discharge of 5.4 cfs; Flynn Creek had a mean flow of 4. 4 cfs and a peak flow of 63 cfs; and Needle Branch a mean flow of 1 . 5 cfs and a peak flow of 28 cfs. Water temperatures during the season ranged from 41 to 58 F with only slight variation among the three streams.

The area receives about 100 inches of rainfall annually, most of which occurs from October to May. Air temperatures generally range from 20 to 90 F. Most of the sediment discharge occurs during the relatively few days of freshet activity. As much as one-fourth of the annual sediment load may occur in one day, and over one-half may occur in the ten days of greatest discharge (Williams,



Alsea River system and Drift Creek study area.

Figure 1. Map of Alsea River system and Drift Creek study area.

Table 1. Physical characteristics of study sections of the three streams.

Characteristics	Deer Creek	Flynn Creek	Needle Branch
LOW WATER			
Total Length (m)	2, 324	1,433	966
Mean Width (m)	1. 80	1.74	1. 10
Mean Depth (cm)	11	13	7
Total Surface Area (m^2)	4, 192	2,480	1, 060
Total Gravel Area (m^2)	1, 541	628	392
Percent Gravel	32.4	25. 5	43. 8
HIGH WATER			
Total Gravel Area (m^2)	7, 351	1, 015	711
Percent Gravel	72.4	24. 0	45. 8
Drainage Area ($mile^2$)	1 . 20	0. 84	0. 32
Gradient (ft/ 100 ft)	2. 8	3.9	5. 5

'From 1959-61 data of Chapman (1961).

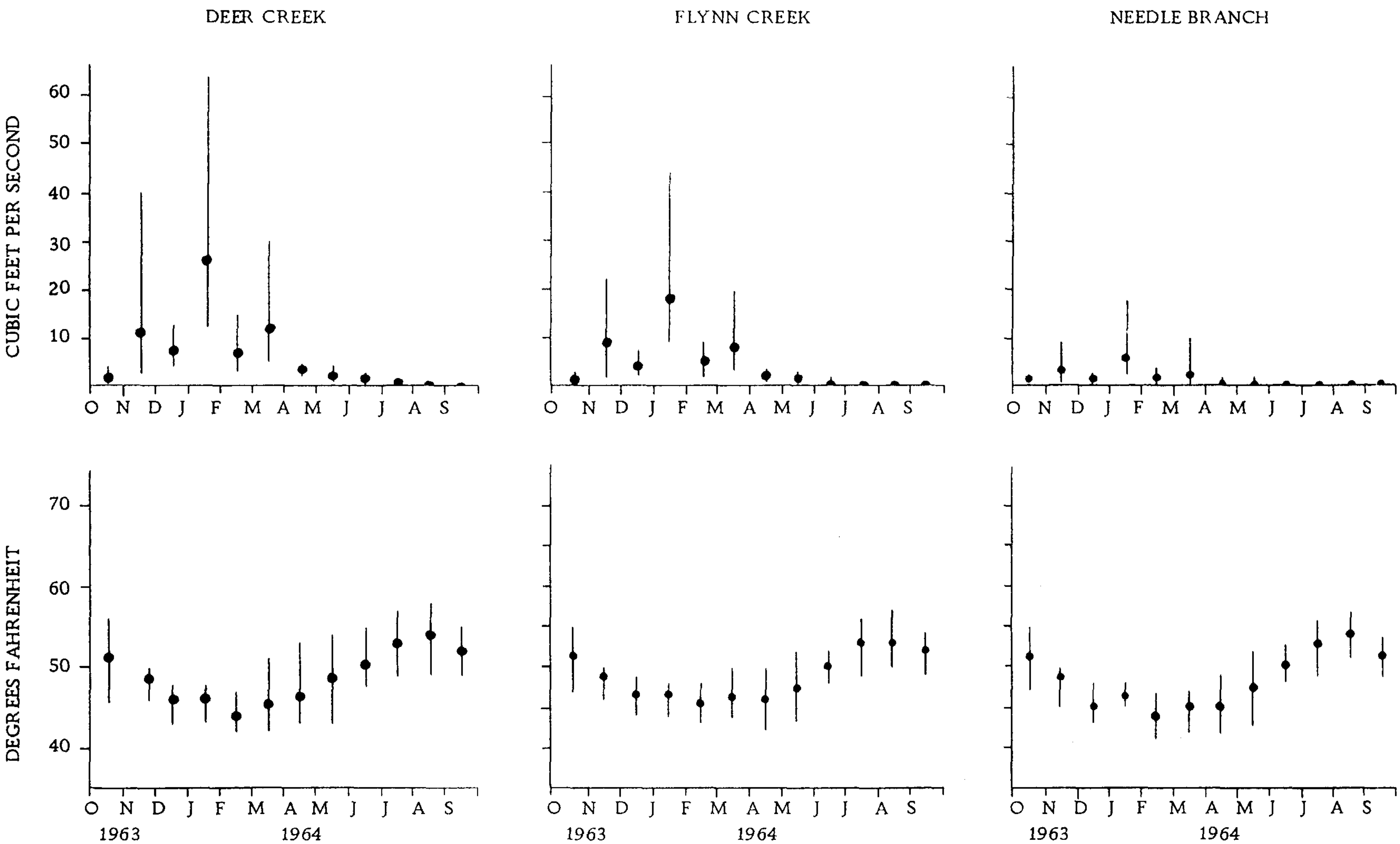


Figure 2. Monthly mean and range of daily discharge and stream temperature in the study streams, October 1963 to September 1964 (U. S. Geological Survey, 1964).

1964).

The watersheds, typical of those of the Coast Range, consist of moderate to steep-sided canyons with a dense understory of salmonberry (*Rubus spectabilis* Pursh.) and vine maple (*Acer circinatum* Pursh.). The overstory is primarily Douglas fir (*Pseudotsuga menziesii* Mirb.) intermixed with red alder (*Alnus rubra* Bong.).

The gravel in the streambed originated from marine sedimentary rock in the Middle Eocene period, and is characterized by micaceous sandstones intermixed with mudstones and siltstones (Vokes, Norbisrath, and Snavely, 1949).

METHODS

Adult and juvenile coho salmon were trapped during their migrations by permanent fish traps located at the downstream end of each of the three study streams. Revolving screens on Deer Creek and Flynn Creek divert downstream migrants into inclined-screen traps. The upstream traps consist of a simple weir entrance leading into a holding section. Only the downstream trap was in operation on Needle Branch.

On Deer and Flynn Creeks, each adult coho was anesthetized \vith chloretone, weighed to the nearest ounce on a spring balance, and measured to the nearest millimeter fork length. Yellow Petersen disc tags, three-fourths inch in diameter and hand lettered with large numbers, were attached to each fish for individual identification. The tagged fish were released upstream. At Needle Branch the spawners were captured in the stream at night, measured, and tagged with a spaghetti tag. The traps were usually checked every morning and more frequently during the peak of migration.

Intensive stream surveys several times a week during the spawning season provided numerous observations on coho spawning and redd sites. The redds were identified as to the specific female, date of spawning, and were marked with flags for later trapping. Spent females were recovered whenever possible.

Fecundity

Literature on coho fecundity for this area was not available, and the small number of females in the three streams precluded sampling them for fecundity determination. Coho for estimates of fecundity were thus obtained from the Oregon Fish Commission Hatchery on Fall Creek in December 1963. Fall Creek, a large tributary to the Alsea River, is about 25 miles upstream from the mouth of Drift Creek. Ninety-two females trapped on their upstream migration \vere used for the study. Fork length for each female was measured to the nearest millimeter and weights were recorded before and after the removal of eggs. The eggs were preserved in ten percent formalin for later volumetric enumeration. The eggs from 17 of these fish were also counted. A comparison between the volumetric method and the actual count indicated a mean difference of only 1.8 percent. A sign test (Li, 1957) revealed that there was no significant difference in the two methods at the five percent level. An estimate of the diameter of the eggs was determined from a sample of about 20 eggs per female.

Linear regression equations of length versus egg number and weight versus egg number were computed on an IBM 1410 computer using the method of least squares (Snedecor, 1956), and the equations used as a means of predicting the egg potential of coho in the study streams.

Fry Emergence Traps

Description

The estimates of survival to emergence of coho were based on the number of emerging fry captured in traps placed over individual coho redds (Figure 3). A nylon net "cap" was placed over the entire redd and buried to a depth of eight inches around the periphery of the redd. The trap consisted simply of a rectangular piece of one-eighth inch mesh netting 8 feet by 15 feet with a 4-foot tapered nylon bag attached about 1 foot from the downstream end (Figure 4). The collection bag resembled the cod end of a small trawl. The majority of emergent fry were removed from the collection bag through a 24-inch nickel zipper. A 60-inch zipper and a 3-foot by 5-foot sleeve were sewn into the center of the trap to facilitate the installation of the trap and aid in the removal of fry. The sleeve could be extended to permit checking of the trap during high water. Some of the traps were left in the stream up to six months and showed little deterioration during this time.

Installation

Two parallel rows of sheet piles (Figure 5) were driven about eight inches apart around the edges of the redd. The gravel between the sheetpiling was removed to a depth of about eight inches,

Figure 3. Fry trap installed on a coho salmon redd.

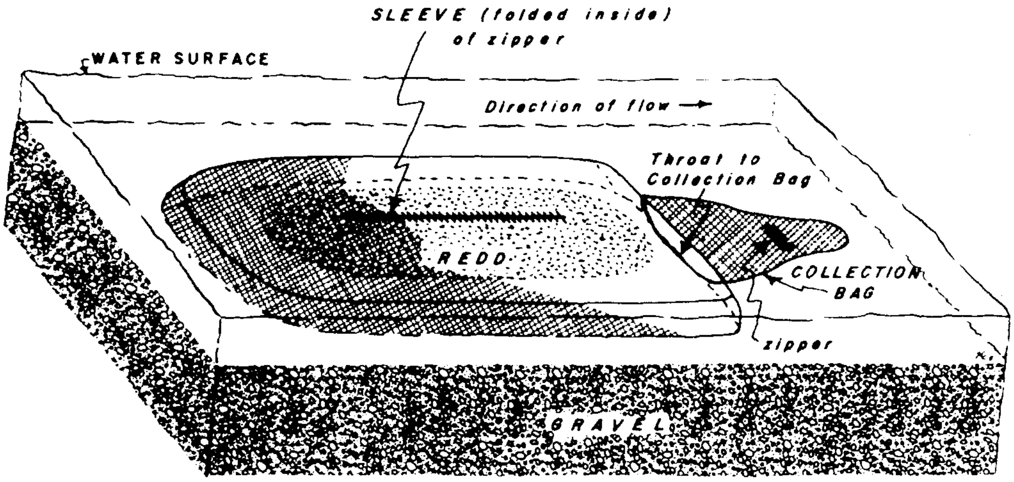


Figure 4. Diagram of the fry emergence trap.

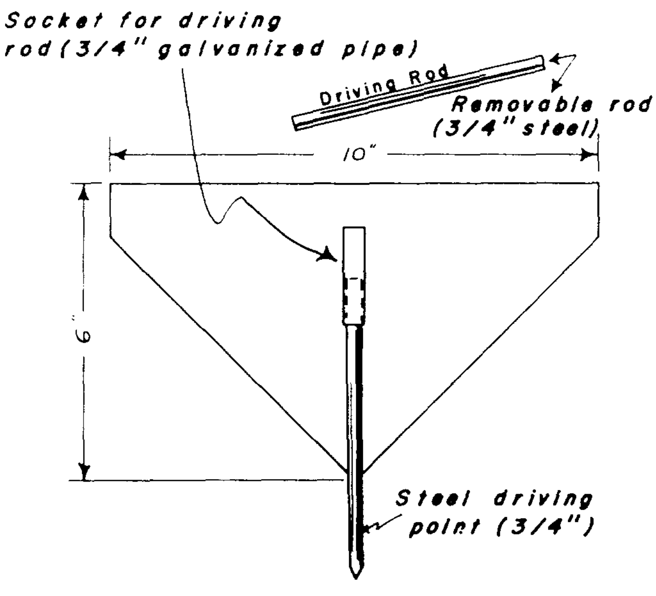


Figure 5. Sheet pile used in installation of the fry trap.

forming a trench. At the front of the redd, a two to three-foot section of the netting was placed in the trench and covered with the gravel that was previously removed. This procedure was repeated until the entire redd was enclosed by the trap. As each section of netting was buried, the piles were carefully removed. The corners of the trap were rounded to make it as streamlined as possible. The streambed surrounding the redd was then rebuilt to its original level to prevent scouring at the edges of the trap. The design and flexibility of the trap offered a minimum of resistance to streamflow. A net was set in the stream behind the site of installation as a check against uncovering fry. Twenty-eight redds were selected for trapping but some were rejected where large numbers of fry were excavated during trap installation. The 22 redds used for the estimates of fry emergence were installed from two to six weeks before expected emergence.

Fry Enumeration

The fry traps were checked about three times a week and all fry removed and enumerated. The collection bag on the trap worked extremely well in concentrating the newly emerged fry for removal (Figure 6). Fry which did not move immediately into the bag were forced into it with a brush and then removed. A small hand net was often used to remove the more elusive fry. At the end of the

Figure 6. Removal of fry from trap.

emergence period an electric shocker was used to remove any remaining fry. A small percentage of the fry from each trap were measured regularly and samples of 10 to 15 fry were preserved in ten percent formalin at the beginning, peak, and end of the emergence period. The wet weight was recorded (two to five months after preservation) to the nearest milligram on a Mettler K7T balance and the fork length recorded to the nearest tenth of a millimeter with calipers. The coefficient of condition was calculated by multiplying the weight in milligrams by 100, 000 and then dividing the product by the cube of the length in millimeters. The weights of the fry were taken after "heavy blotting" with a paper towel (Parker, 1963). A routine was set up so that each specimen was out of formalin for approximately 90 seconds to minimize the error due to evaporation of liquid from the fry.

Environmental Factors Affecting Survival

Several criteria had been previously selected for monitoring throughout the pre- and post-logging period to measure the over-all effects of logging on the environment of salmon embryos (Chapman et al. , 1961). I also used these criteria to evaluate the success of emergence from individual coho salmon redds. The factors examined included the dissolved oxygen content of the intragravel water, gravel permeability and composition in the redds, stream temperature, streamflow, and gravel stability.

Dissolved oxygen and permeability data were obtained throughout the study period from ten redds in each stream, even though all of these redds were not trapped. Intragravel water was sampled with a plastic standpipe driven into a coho redd to a depth of ten inches. The standpipe was similar to the one used by McNeil (1962b) for sampling dissolved oxygen in the streambed. It was constructed of three-fourths inch Kryolite plastic pipe, 24 inches long and perforated with a series of one-eighth inch holes near one end. A special driving rod was used to install the pipe in the redd as close as possible to the site of egg deposition. In three redds, five standpipes were installed to obtain an estimate of the variation of dissolved oxygen and permeability within the redd. Six fish spawned within two to three feet of the Mark VI standpipes (Terhune, 1958) that had been permanently installed in the streams. In three of the trapped redds only the permanent standpipes were used, and these provided a comparison of survival in redds where plastic standpipes were not driven.

Dissolved Oxygen

Samples of water were withdrawn from the standpipes by oral suction (McNeil, 1962b) and analyzed for dissolved oxygen content by a modification of the semi-micro Winkler method (Harper, 1953).

A 25 milliliter aliquant from the 60 milliliter sample was titrated with 0.025 N sodium thiosulfate solution using a microburette graduated to 0. 02 milliliter. Samples were taken from each redd three times a week during the period from mid-February (18 to 56 days after spawning) until early June. However, data on dissolved oxygen from the permanent standpipes were also collected prior to spawning (beginning in mid-December) .

Gravel Permeability

An index of gravel permeability was obtained about every two weeks by lowering the water in the standpipes one inch and measuring the rate of inflow of water from surrounding gravel (Terhune, 1958). The rate of inflow, measured in milliliters for a period of five seconds, was used as the permeability index. The temporary standpipes were not calibrated and hence serve only to indicate comparative permeability in the redds.

Gravel Composition

The gravel sampler described by McNeil and Ahnell (1964) was adopted with some modifications for this study because it successfully retains suspended sediment. The sampler was a large, round, stainless steel basin with a ten-inch tube, four inches in diameter, extending from the bottom. The tube of the sampler was worked manually into the gravel to a depth of ten inches. Contents of the tube were dug by hand and lifted into the basin. Water and fine materials in suspension were trapped by inserting a plunger from a cistern pump into the tube. The sampler was removed from the streambed and the contents poured into one-gallon plastic jars for transporting from the field. Three samples of gravel were taken in the long axis of the redd about 1.5 feet apart.

The volumetric technique employed by McNeil and Ahnell (1964) for analyzing the gravel samples was used. Each sample of gravel was separated into 11-size classes by washing and shaking through a series of 10 standard Tyler sieves having the following square mesh openings (in millimeters) 50.8, 25.4, 12.7, 6.35, 3.327, 1.65, 0.833, 0.417, 0.208, and 0.104. Material passing through the 0.104-millimeter sieve was collected in a 100-milliliter graduated cylinder at the bottom of a settling basin. The cylinder was removed from the basin after the measurement of a sample and the contents allowed to settle overnight before the volume was read directly.

Quantity of the other particle sizes was determined by volume displacement of the material retained by each sieve and expressed as a percentage of the total sample. Before measurement, each sieve was placed on an inclined table and the excess water allowed to drain. Percentage composition of gravel in each of the redds was estimated from the mean of the three samples obtained from each redd.

As a means of measuring the relative amount of gravel movement, 40 gravel erosion index stations were established on the study streams in 1961. These stations are situated in areas used by spawning coho and consist of a vertical column of perforated ping pong balls (McNeil, 1962a). Six balls, each a different color, were buried in a predetermined sequence at each index station. The balls were buried in the fall prior to spawning, and recovered the following summer after emergence. Depth and color of the balls remaining at a site indicate the depth at which erosion and deposition occurred.

Stream Conditions

Stream gages were established in cooperation with the U. S. Geological Survey on each of the study streams in 1958, providing continuous recording of flow and water temperature. Samples of suspended sediment were taken on each stream daily and several times a day during freshets.

RESULTS

Spawning

The first spawning migrants usually reach the study streams early in November and continue arriving on into February. Entry into the study streams is apparently associated with increased streamflows (Figure 7). During the 1963-64 season, the first adult coho salmon entered the Deer Creek trap on November 4, about two weeks after the first significant increase in streamflow. Coho movement and streamflow showed a similar relationship in Flynn Creek.

Two peaks occurred in the spawning migration of coho into the streams during the season (Figure 7). Formation of these two groups may have been due to a delay in migration caused by a decrease in streamflow or temperature. Characteristics of the two groups of spawners are given in Table 2. In general, the early migrants spawned in the lower sections of the streams and the later arrivals utilized the upper sections.

In 1963-64 the fish spawned in approximately the same areas as they had in past years. The redds were dispersed throughout the length of the streams, and superimposition of redds was observed only about two or three times in each stream. While excavating two redds during the trapping period, embryos were uncovered at depths from 7 to 11 inches. The embryos were found in four or five

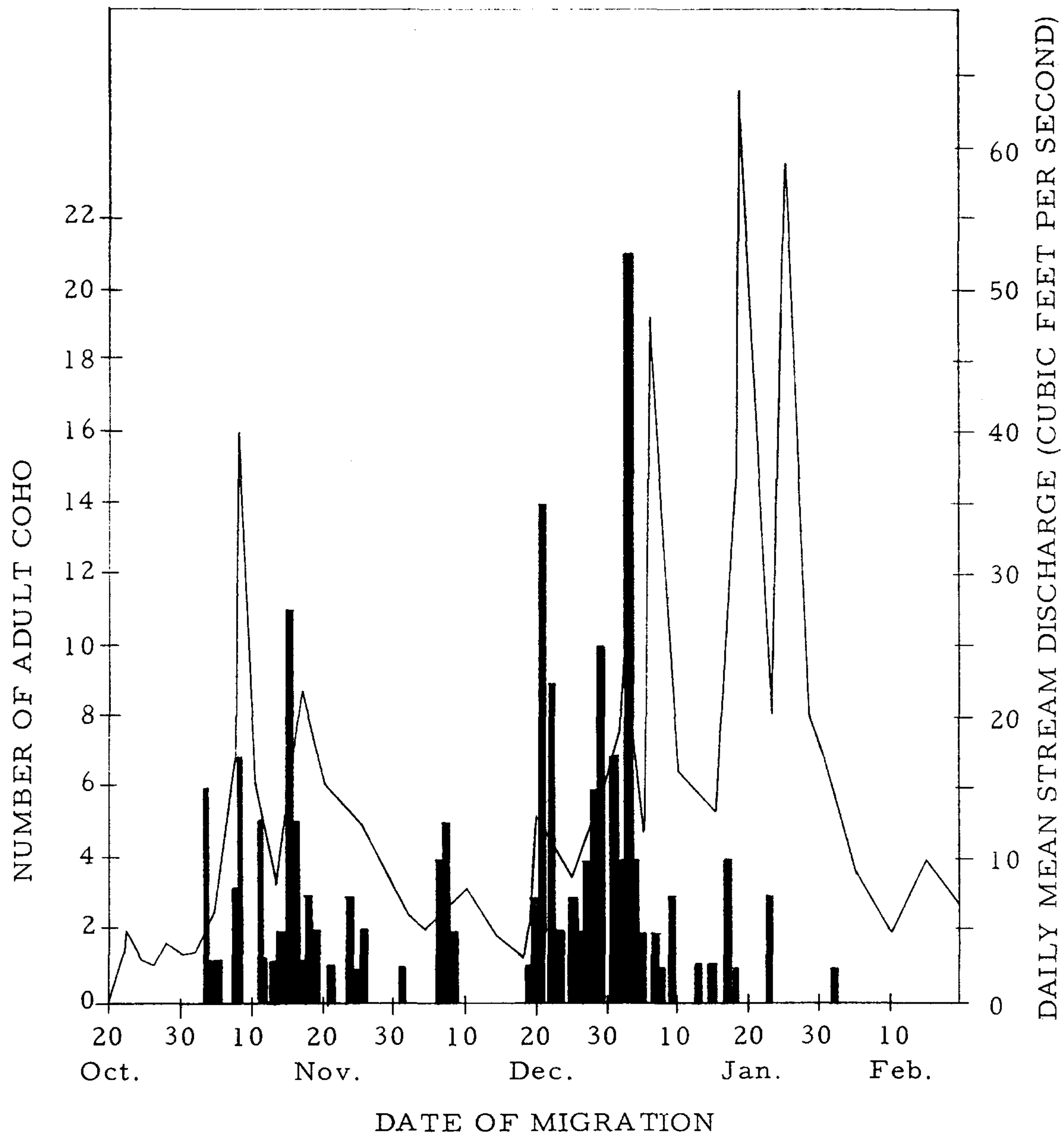


Figure 7. Time of adult coho salmon entry into Deer Creek in relation to daily mean streamflow (1963-64).

Table 2. Characteristics of coho salmon spawning in Deer Creek and Flynn Creek (1963-64).

	Deer Creek		Flynn Creek	
Characteristic	11-4-63 to 12-9-63	12-19-63 to 2-1-64	11-12-63 to 12-21-63	12-21-63 to 1-16-64
Total Number	69	109	21	49
Females	10	19	5	15
Mature Males	43	79	14	33
Immature Males (Jacks)	16	11	2	1
Female Mean Weight (kg)	3. 65	4. 52	3. 89	3. 62
Female Mean Length (mm)	682	728	699	685
Mean Longevity of Females (Days)	13.7		13. 1	

pockets which were orientated in the long axis of the redd and extended a distance of four to five feet. Lateral range of the embryos was approximately two feet. Generally, the embryos were concentrated towards the downstream end of the redd.

Estimated Egg Deposition

Fecundity of echo from Fall Creek was used as the basis for determining egg deposition in the study streams. Both length and weight had relatively good linear correlations (correlation coefficient r = 0. 72 and 0.77, respectively) with egg number (Figures 8 and 9). Weight was assumed to be the best single predictor of fecundity. Because of the high correlation between length and weight (r = 0. 94), a multiple regression equation using both variables was not a significantly better predictor of egg number than weight alone. A curvilinear relationship between length and egg number and weight and egg number was also tested, but found to be insignificant at the five percent level.

At Needle Brach only the length of the females was obtained. Since the coho salmon in Drift Creek was heavier for a given length than the Fall Creek coho, it was thought desirable to adjust the estimated fecundity for Needle Branch fish. The mean difference between the estimates from weight and from length (159 eggs) for all fish in Deer and Flynn Creeks was added to the estimate of fecundity

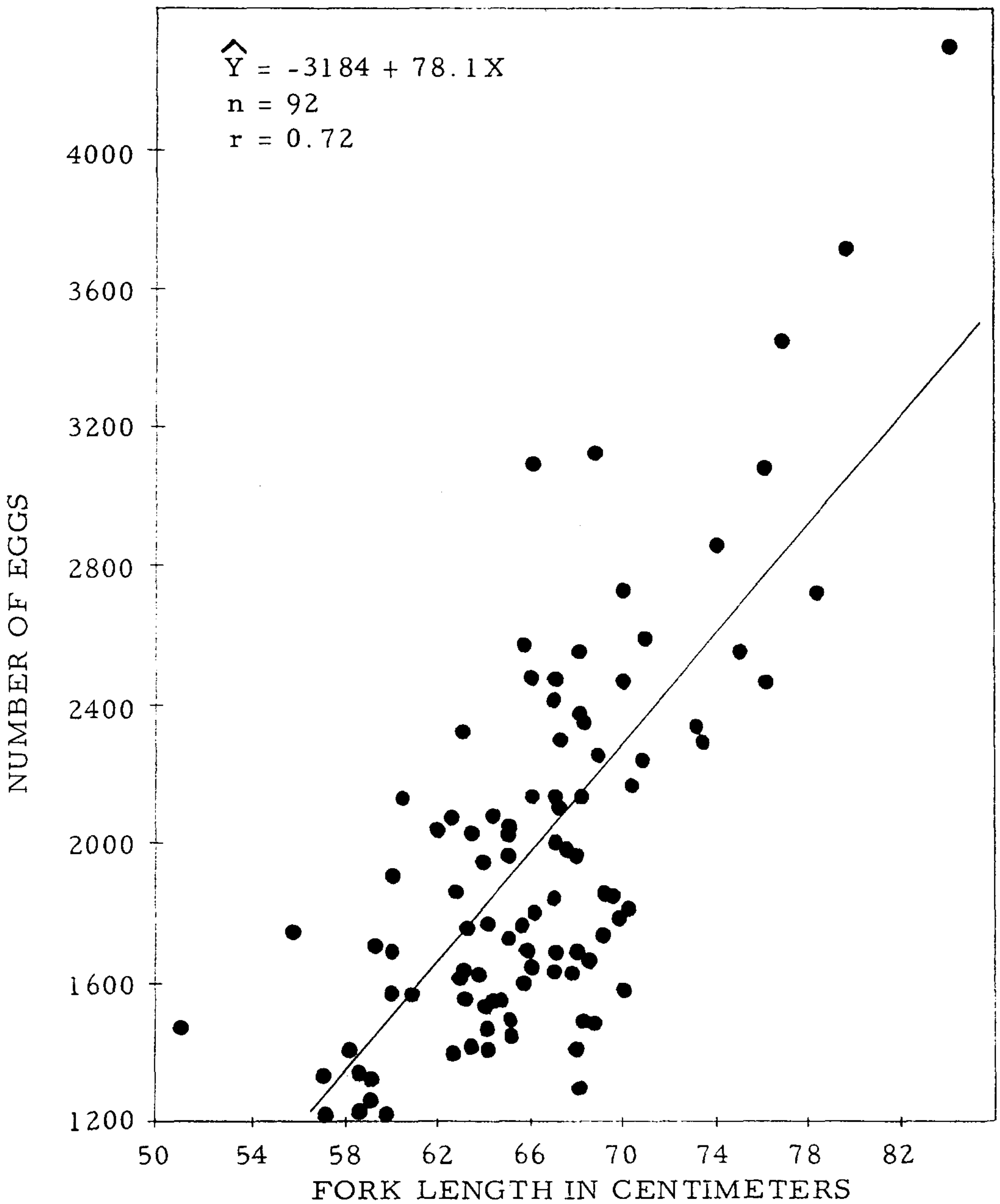


Figure 8. Relationship between length and fecundity for coho salmon at Fall Creek during 1963.

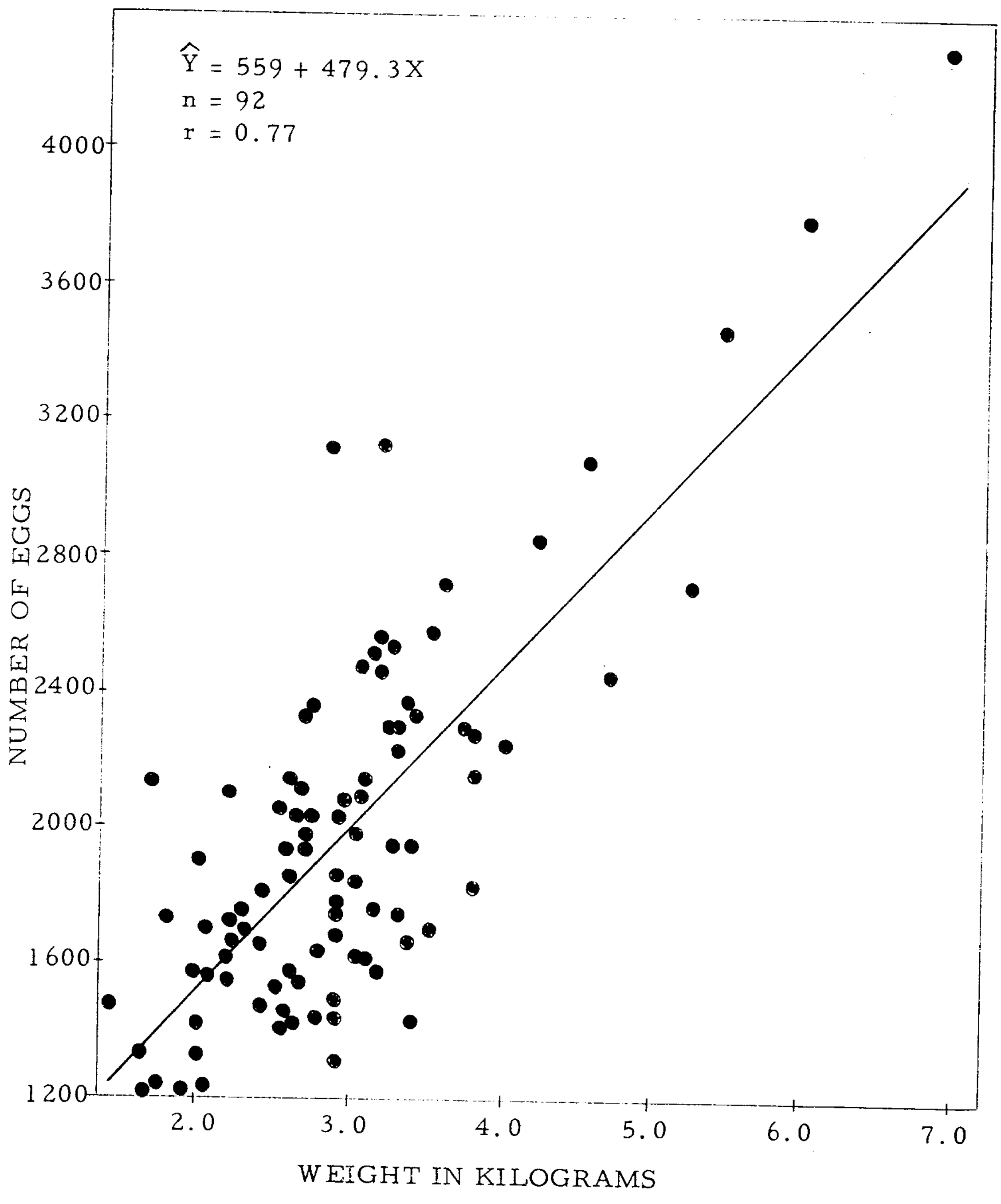


Figure 9. Relationship between weight and fecundity for coho salmon at Fall Creek during 1963.

from length for each female in Needle Branch.

The number of eggs retained by 30 spent females ranged from 0 to 38 with a mean of 4 eggs per female. The mean number of retained eggs was subtracted in cases where specific females were not recovered, even though the number of retained eggs was insignificant when compared to the fecundity. The small number of fry uncovered in some redds while installing the traps was also subtracted from the potential number of eggs deposited.

Survival to Emergence

Estimates of survival from 21 coho redds varied from 0 to 78 percent of the predicted egg deposition. The number of fry emerging from the redds varied from 0 to 2, 061 . The combined mean survival for the three streams was 27. 1 percent. Fry from Deer Creek had a mean survival of 54.4 percent; those from Needle Branch, 25. 1 percent; and those from Flynn Creek, 13.6 percent. The individual redd survivals and the 95 percent confidence limits are shown in Appendix A. In each stream there was at least one trapped redd from which no fry emerged. In one of the redds trapped on Flynn Creek a total of 2, 889 fry or 117 percent of the estimated egg deposition emerged. It is likely that another female, unobserved, deposited her eggs, or a portion of her eggs, in the same area. The number of fry that emerged was outside the 99 percent confidence interval for estimated egg deposition and this redd was excluded from the analysis.

Factors Affecting Survival to Emergence

In an attempt to understand the influence of the environment on the survival to emergence of coho salmon, several factors directly related or associated with the environment of the embryos were examined and analyzed.

Gravel Composition

The amount of fine sediments in the redd had the highest correlation with survival to emergence of all factors examined. By comparing the mean percentages of gravel from the different sieves with the corresponding survival values, it was determined that gravel passing through the 3.327-millimeter sieve had the highest correlation (-0.69) with survival (Figure 10). As the percentage of fine sediments (bottom material < 3. 327-mm) in the redds increased, the success of coho survival to emergence decreased. Fine sediments composed 27 to 51 percent of the gravel in the redds sampled. The inverse relationship between survival and the percentage of fine sediments is revealed more clearly by the mean survivals for each stream (Figure 10). The redds in Deer Creek contained the lowest percentage of fine sediments, followed by Needle Branch and

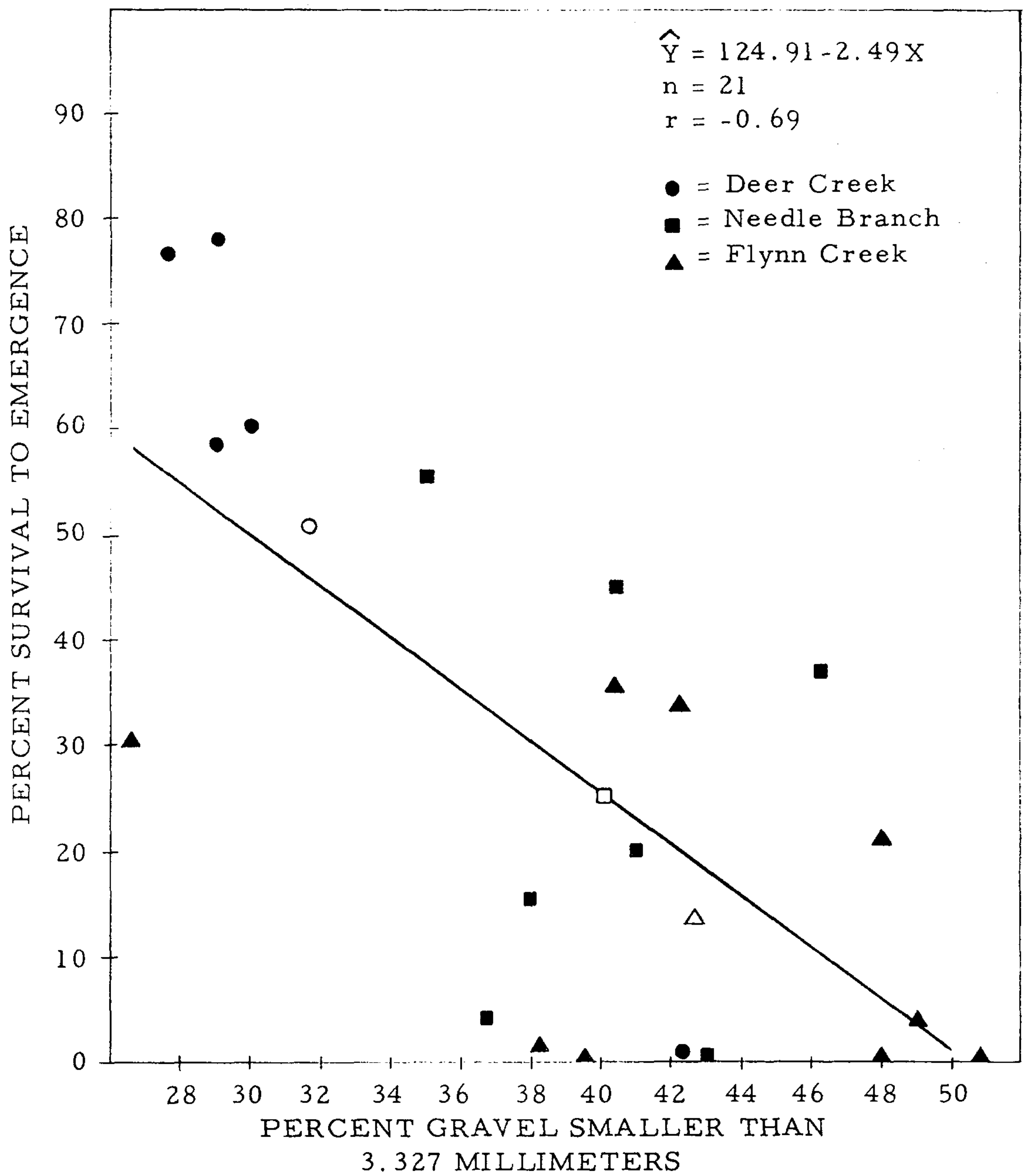


Figure 10. Relationship of gravel size to the survival to emergence of coho salmon. Open figures represent mean for each stream.

then Flynn Creek (Figure 11). The difference in the gravel composition in the three streams is reflected by the respective mean survivals.

An inverse relationship between the percentage of fine sediments in the gravel and its permeability index is evident from Figure 12. The wide variation in values resulted in a low correlation coefficient of -0. 35. There was no apparent relationship between the dissolved oxygen concentration and the composition of the gravel.

Gravel Permeability

An adequate supply of intragravel water is necessary for the survival of developing embryos. Relatively high permeability and sufficient hydraulic gradient assure this supply of water. A comparison between the permeability index values obtained from the redds and the survival indicates a direct relationship and demonstrates the importance of adequate permeability (Figure 13). A confounding of several factors probably accounts for some of the variation. Nine redds had an average permeability index of less than 100 milliliters per five seconds and averaged less than seven percent survival to emergence. A comparison between the dissolved oxygen concentration and permeability ($r = 0.37$) suggested that the concentration of dissolved oxygen increased with

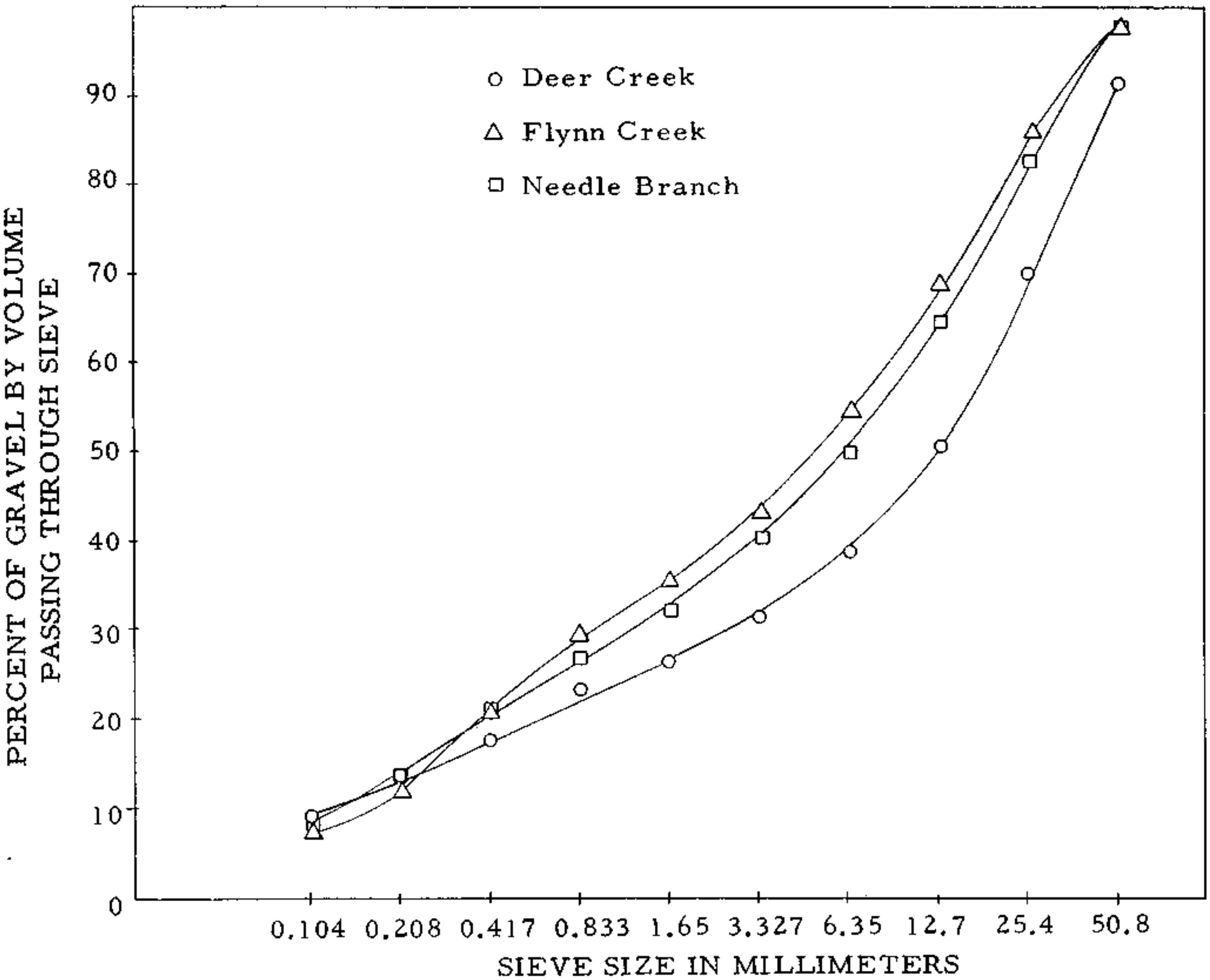


Figure 11. Mean size distribution of the gravel sampled from coho redds in the three study streams.

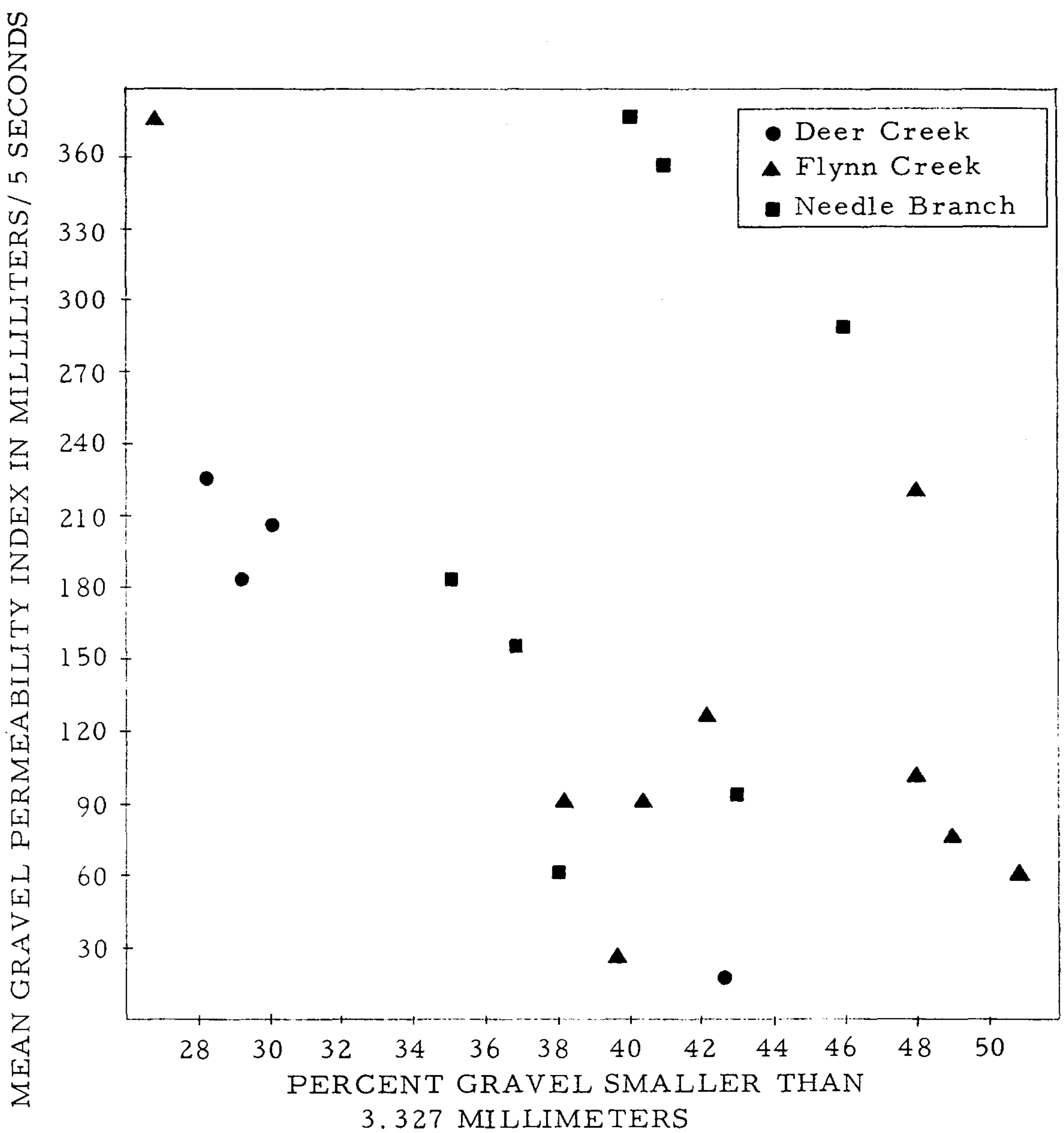


Figure 12. Relation of the percentage of gravel smaller than 3.327 millimeters to the permeability index of the gravel in the trapped redds.

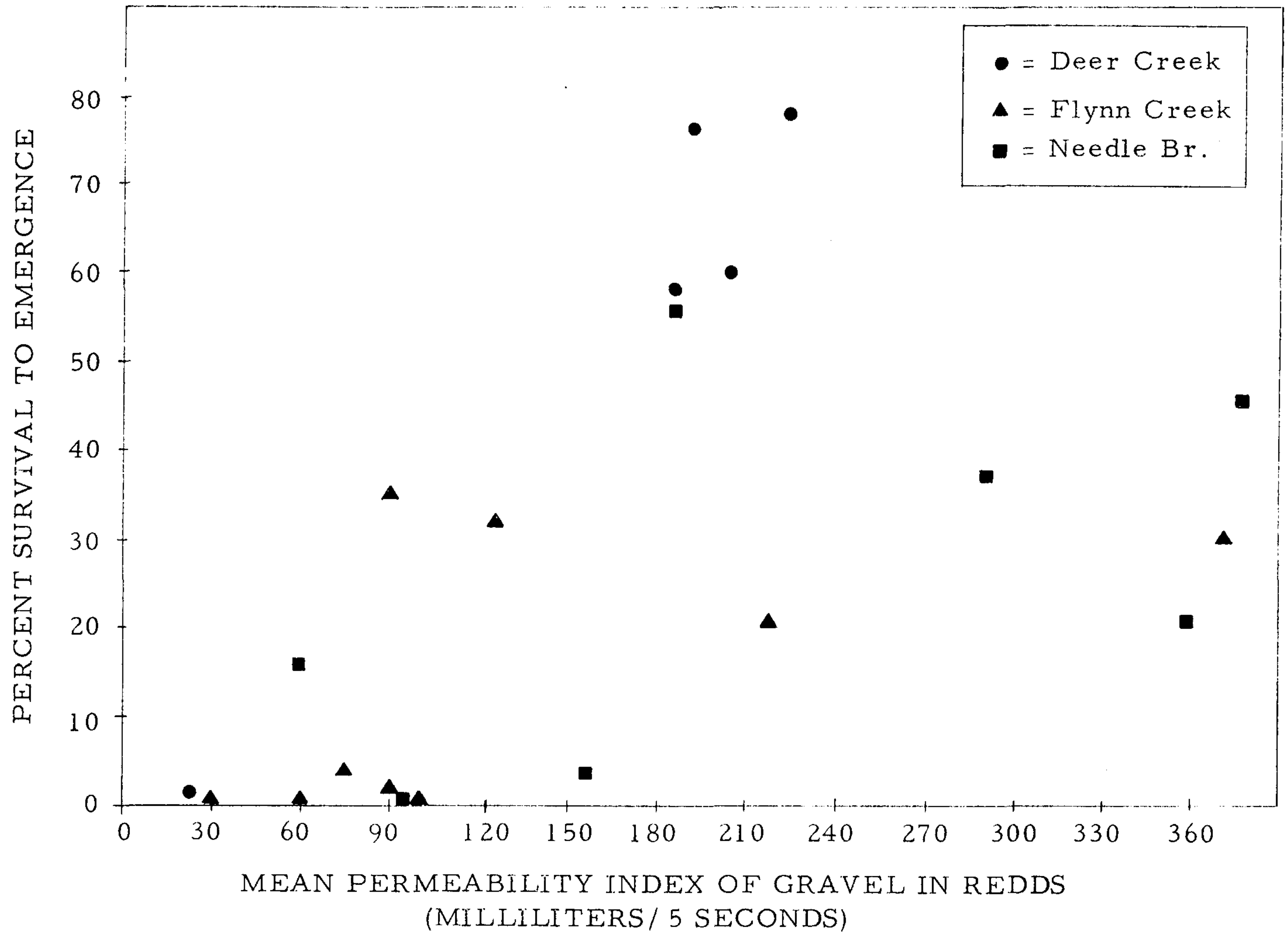


Figure 13. Percent survival to emergence of coho salmon fry in relation to the mean gravel permeability index in trapped redds.

permeability.

Dissolved Oxygen

The concentration of dissolved oxygen in the intragravel water was relatively high; many of the values were near saturation (Appendix B). Only in four redds was the minimum dissolved oxygen concentration below six milligrams per liter. The minimum observed value of dissolved oxygen was presumed the concentration most critical to survival because the lowest levels of dissolved oxygen would be more likely to be lethal than the mean concentration (Figure 14). The composition of the gravel and perhaps other factors affect the relationship of minimum dissolved oxygen and survival to emergence, and may account for the low correlation ($r = 0.24$) between the two. Survival averaged less than four percent in redds having less than six milligrams per liter of dissolved oxygen.

There was considerable lateral variation in the concentration of dissolved oxygen within the redds with multiple standpipes (Appendix B). No significant difference was detected between the values of dissolved oxygen obtained from the plastic standpipes and Mark VI standpipes.

Gravel Stability

Erosion and deposition of gravel occurred throughout each of

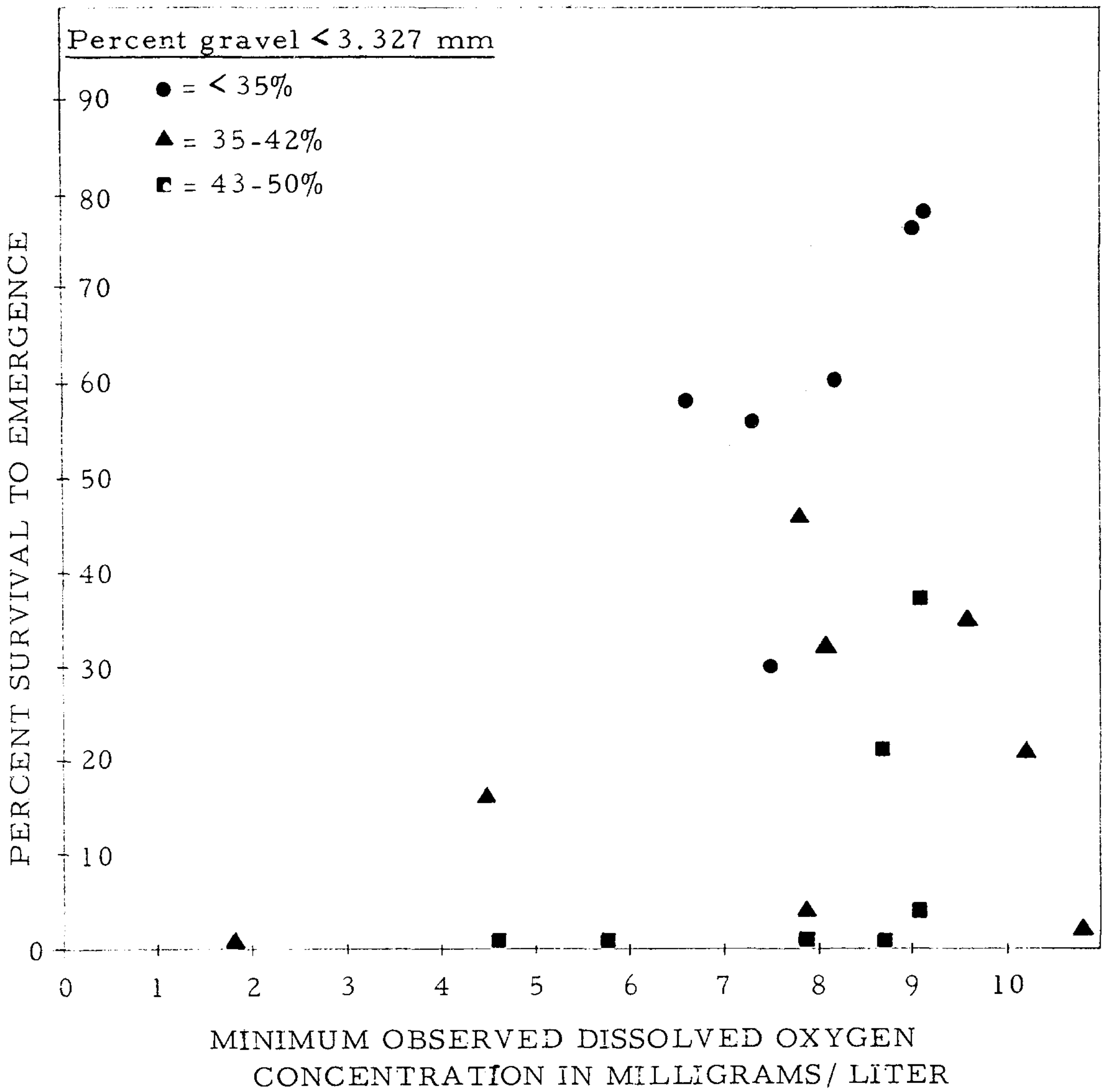


Figure 14. Relationship between minimum observed concentration of dissolved oxygen in trapped redds and percent survival to emergence of coho salmon.

the three streams. Several redds were severely to completely scoured of gravel. Erosion index stations revealed that erosion occurred to a depth of ten inches in some areas, and deposition up to seven inches occurred in others. Erosion was more extensive in 1963-64 than in the previous two seasons (Table 3).

Freshets appear to have had a devastating effect on some of the coho redds. Two groups of redds formed just a few days before the occurrence of the largest freshets of the year had very low survival. It is likely that eggs in the critical period, extremely sensitive to shock, could have been either killed or washed away had they been in redds vulnerable to gravel shifting or scouring.

Emergent Fry

Pattern of Emergence

Spawning took place from mid-November to February with the peak occurring in the latter part of December and early January. Emergence first occurred in Deer Creek on February 10, and within ten days fry had begun emerging in the other two streams. Emergence of fry continued until early June with the peak occurring in the latter part of April. The mean period from egg deposition to the first emergence in the fry traps was 110 days (range 104 to 115 days). The number of days to the first emergence of fry was inversely

Table 3. Gravel erosion and deposition (in inches) at erosion index stations, Drift Creek study streams, 1961-62 to 1963-64.

	Mean depth of erosion	Mean depth of deposition	Mean gain or loss of gravel
Deer Creek			
1961-62	1. 9	- - -	- - -
1962-63	0.6	- - -	- - -
1963-64	3.9	4. 1	+0. 2
Flynn Creek			
1961-62	1 . 7	- - -	- - -
1962-63	0. 0	- - -	- - -
1963-64	2. 8	3. 2	+ 0.4
Needle Branch			
1961-62	1 . 1	- - -	- - -
1962-63	0.3	- - -	- - -
1963-64	4. 2	3. 3	-0. 9

[4] R. W. Phillips. Unpublished data. Oregon Game Commission, Corvallis, Oregon. Dashes indicate no observations.

related to the percentage of fine sediments in the redds (Figure 15).

The temporal pattern of emergence was similar for most of the redds (Figure 16). The peak emergence from each redd occurred about eight to ten days following the first emergence. The length of the emergence period for an individual redd varied from 10 to 47 days with a mean of 35 days. The duration of the emergence period was longer in redds having a high percentage of fine sediments. Mean length of the emergence period in each of the streams was 30, 35, and 39 days for Deer Creek, Needle Branch, and Flynn Creek, respectively. The mean length of time required for 90 percent of the fry to emerge from the redd was 15, 16, and ZO days for Deer, Needle, and Flynn Creeks, respectively. The length of the emergence period seemed to be related to the amount of fine sediments in the redds in each of the streams (Appendix A).

Size and Condition

The size of the emergent fry was evidently related to physical factors in the environment. The mean permeability index appeared to be better related to the weight of the emergent fry than the mean concentration of dissolved oxygen. Redds having comparatively high permeabilities had larger emerging fry than redds with low permeabilities (Figure 17). The fry continually lost weight and condition during the period of emergence. The length of the emergent fry also

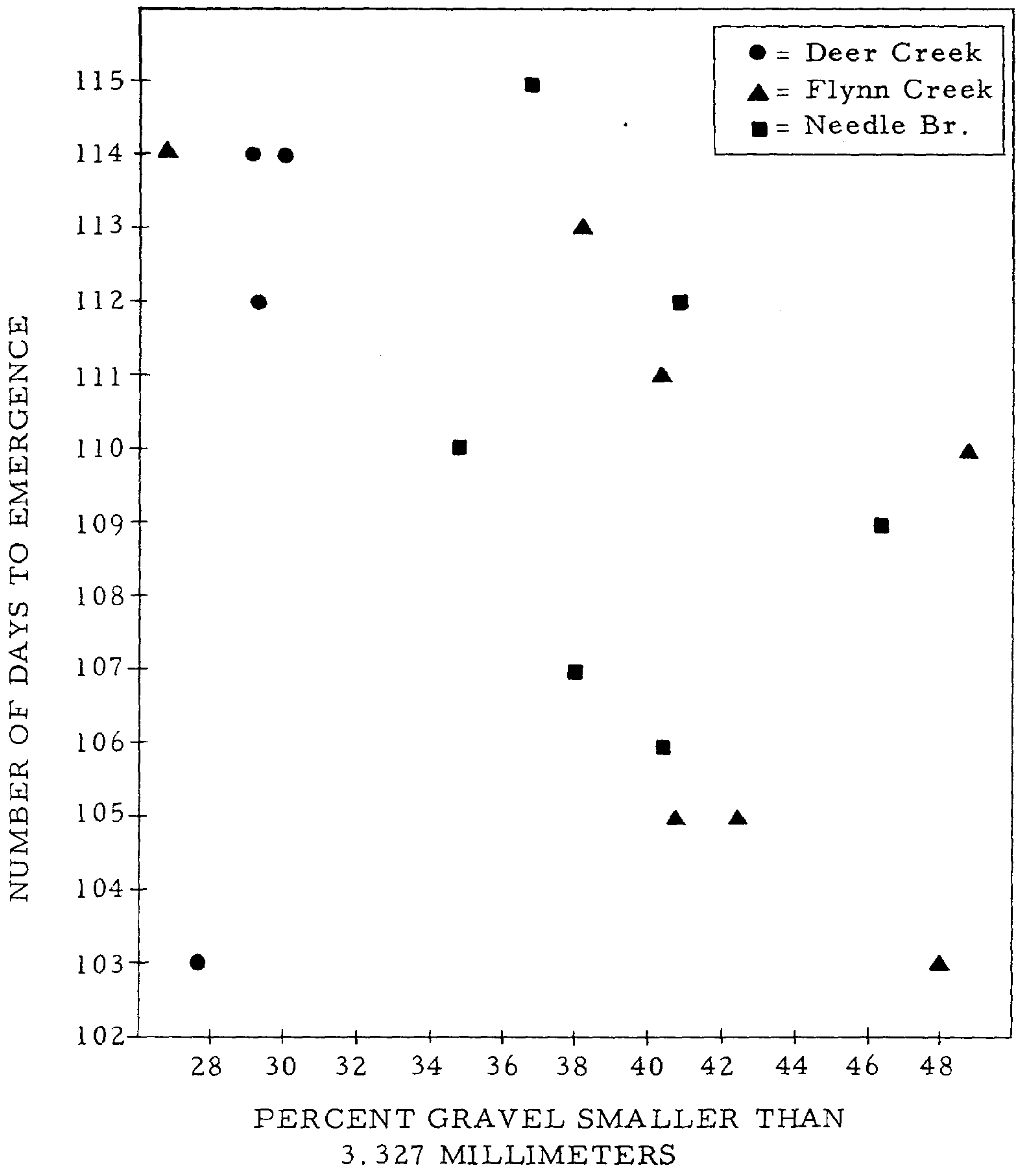


Figure 15. Relation of gravel composition to the time between spawning and first emergence of fry from redds.

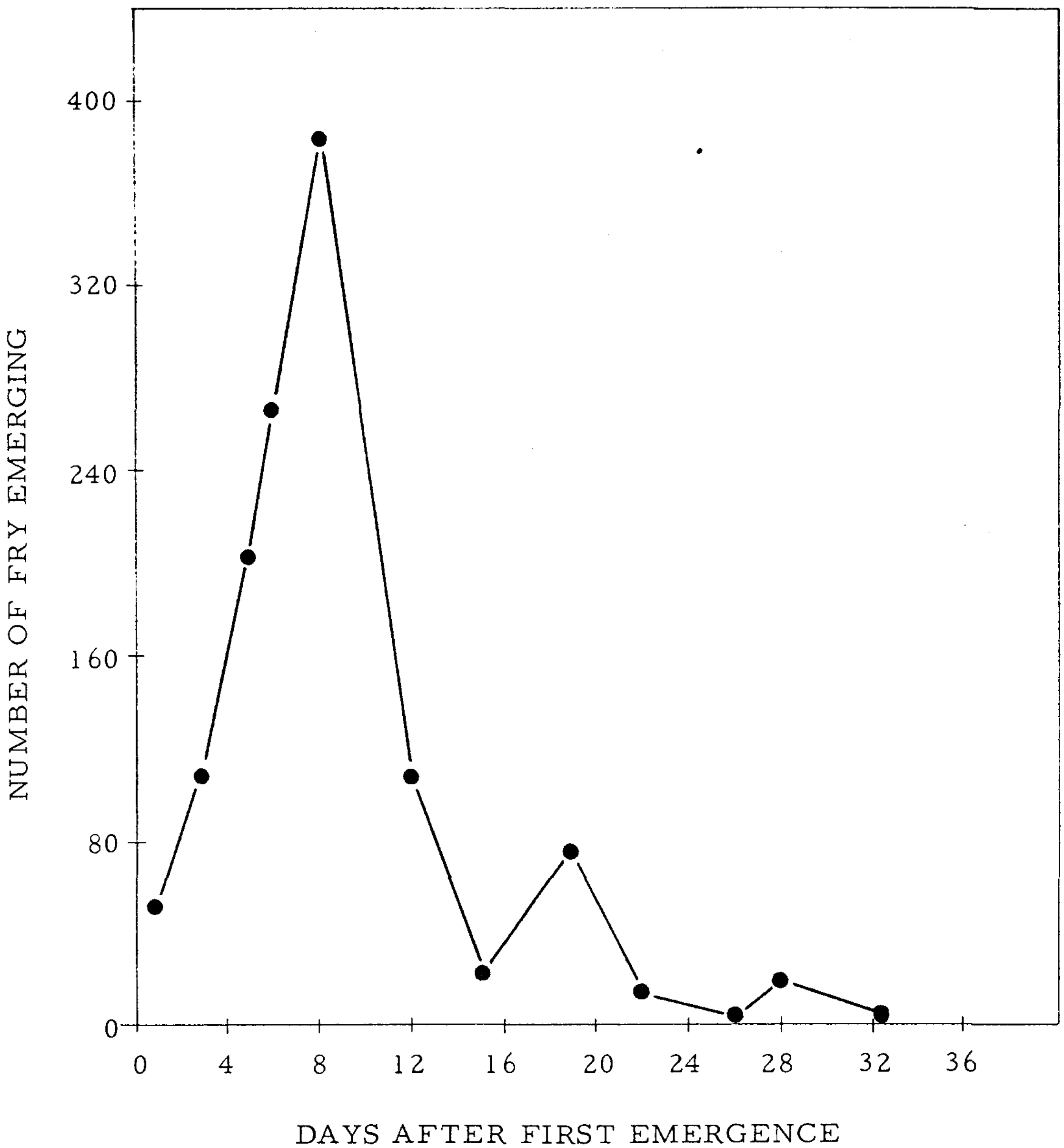


Figure 16. Temporal pattern of fry emergence from a typical redd.

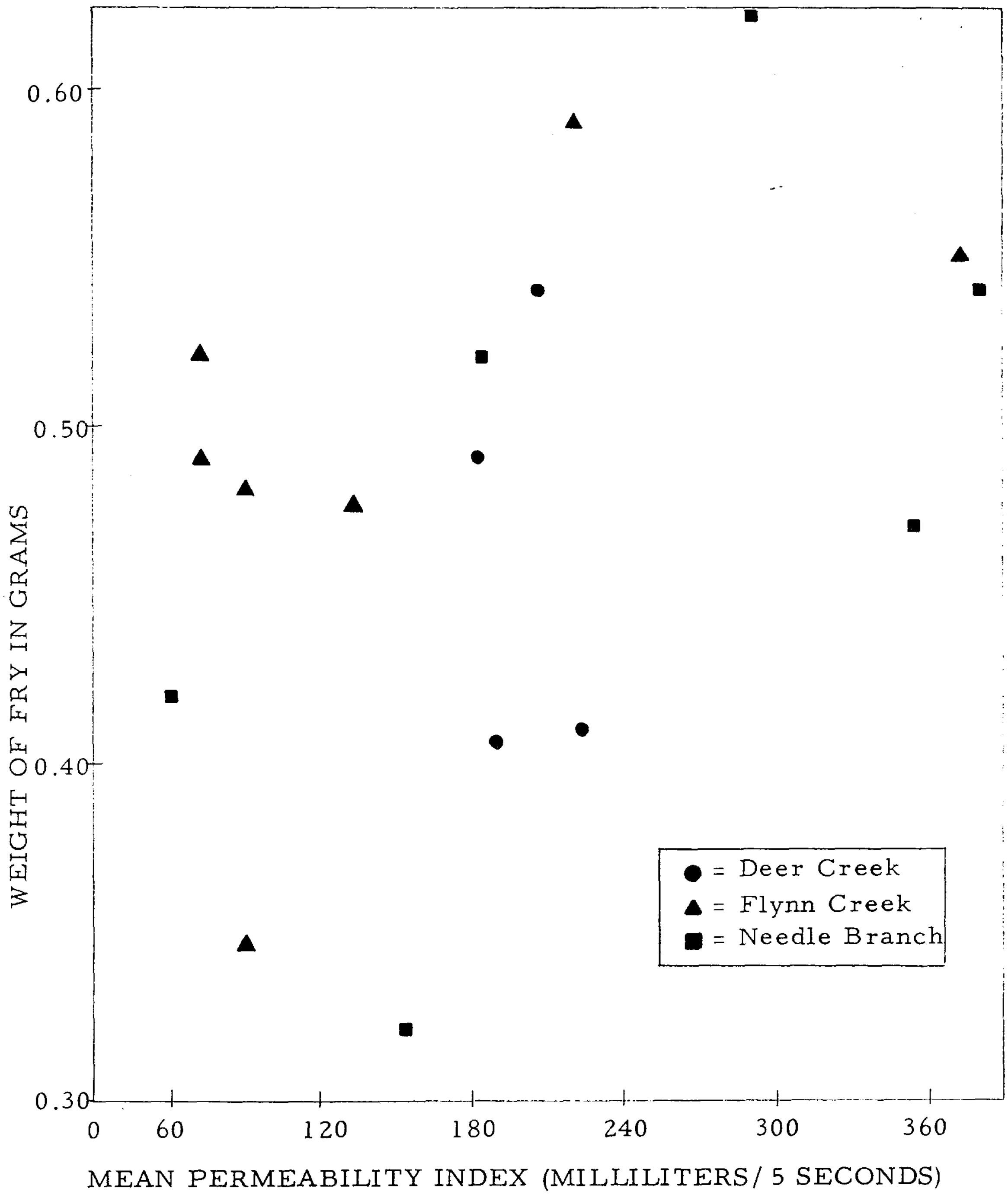


Figure 17. Mean weight of emergent fry from the initial sample in relation to the mean gravel permeability index in the redd.

decreased with time in most of the redds examined. The decrease in weight, length,and condition of the emergent fry as observed in the majority of redds is depicted by a single redd in Figure 18. For the three streams combined, the mean length of the first emerging fry was 37.2 millimeters and the mean weight was 0.48 grams. The mean weight at approximately 50 percent emergence was 0.42 grams.

The size of the fry at emergence was also directly related to the size of the female parent (Figure 19). This relationship is supported by the fact that the size of the egg increases with the size of the female (Allen, 1958).

The over-all analysis has obviously been complicated by the simultaneous operation of several related environmental variables. In an attempt to understand more clearly the relationship of the environmental factors to survival, a multiple regression equation was computed. Percentage of survival to emergence was set as the dependent variable and the composition of the gravel, mean permeability, minimum concentration of dissolved oxygen, and length of the female as the independent variables. The percentage of fine sediments was the variable most closely related to survival. Addition of the other variables did not significantly improve the regression equation. However, the low value of the coefficient of determination (R $=0.52$) indicates that about one-half of the variability

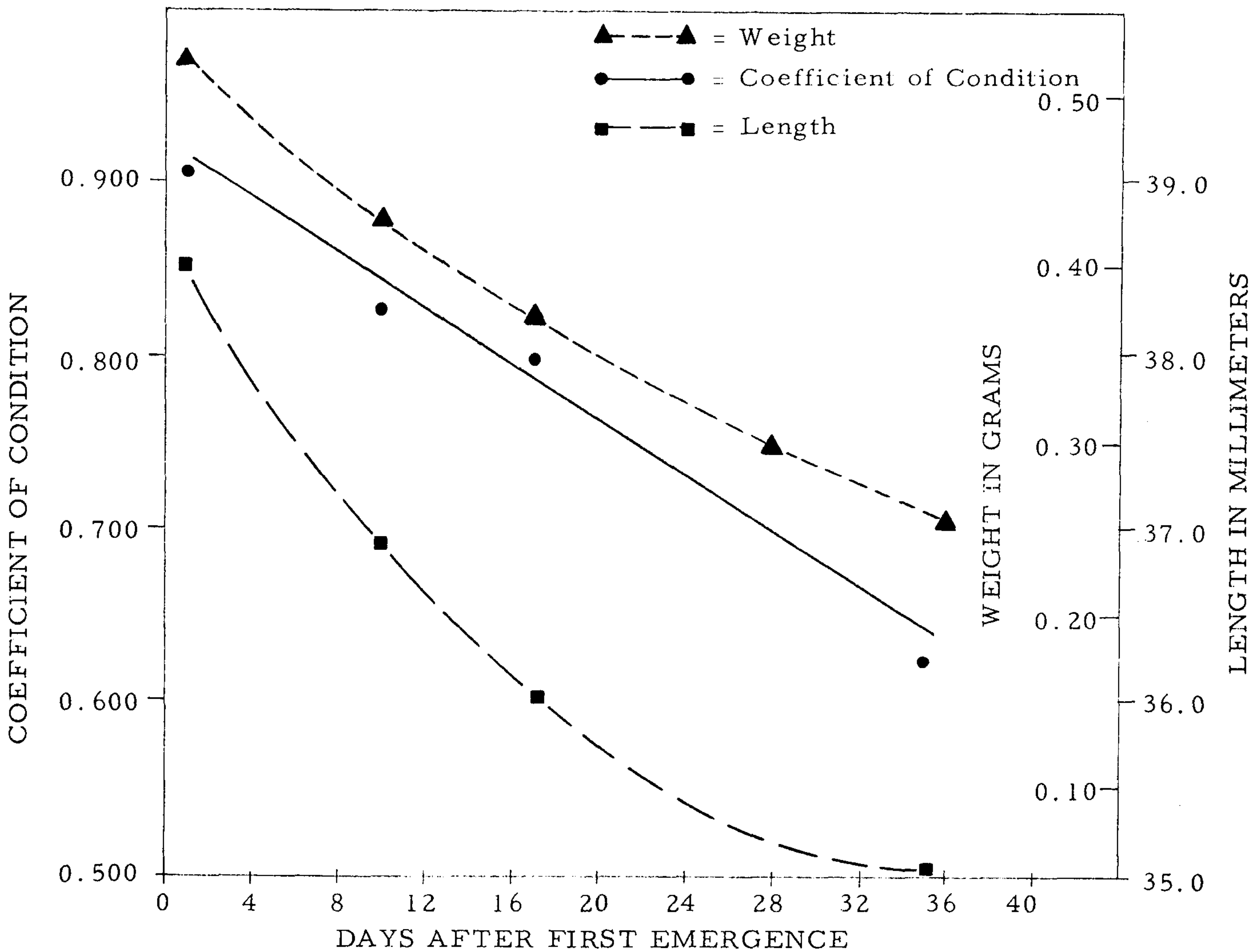


Figure 18. The decrease in weight, length, and coefficient of condition during the emergence period of fry emerging from a typical redd.

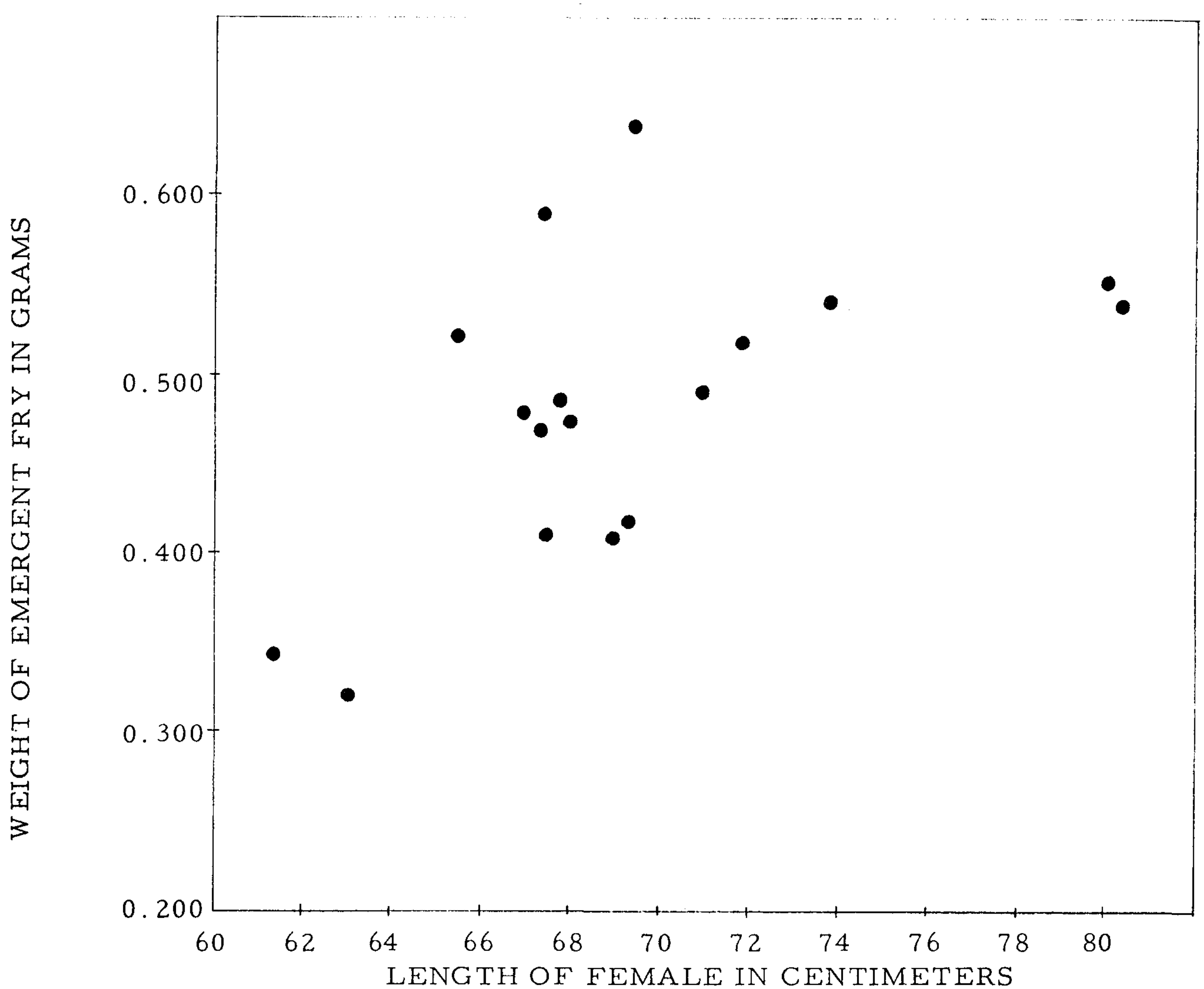


Figure 19. Relationship between the length of the parent female and the mean weight of the emergent fry from the initial sample.

in the estimate of survival has not been taken into account. Gravel erosion, predation, viability of the eggs, and other factors not studied are apparently also important in determining the survival to emergence of coho salmon.

DISCUSSION

Spawning

The characteristics of the observed coho redds agree closely with those of other salmon. Egg depth of 7 to 11 inches in the study streams corresponds with the average of 8 inches determined by Burner (1951) and 10 inches found by Briggs (1953) for coho salmon. However, the depth of burial may vary considerably as shown for a number of species (Burner, 1951; Briggs, 1953; McAfee, I960; and McNeil, 1962a). The depth and location of eggs within a redd undoubtedly affects the time and pattern of emergence, as well as the survival and condition of the fry at emergence.

Fecundity

The accuracy of the estimates of survival to emergence was dependent on the accuracy of the estimated egg deposition for each female. A possible source of error is the large variation in actual egg number for fish of a given weight. There is also a possibility that coho in the Drift Creek area and Fall Creek could differ in egg number, even though both streams are tributaries of the same river. The influence of the hatchery, if any, on fecundity is uncertain; however, the average number of eggs for Fall Creek coho (1, 983) is low as compared to most of the data reported in the literature.

There was a difference in the length-weight relationship for fish from the two areas. Coho from the study streams were slightly heavier for the same length than those from Fall Creek. This was the reason for the larger estimate of egg number from weight as compared with length.

A variety of studies on salmon fecundity are available in the literature but there appears to be no intensive study on any one species. Rounsefell (1957) points out that great differences in fecundity exist between populations of the same species. Aro and Broadhead (1950) have shown that the fecundity of fish of the same length may even differ widely between populations spawning in different portions of the same river.

Allen (1958) gives a comparison of the average fecundity of populations of silver salmon from the Pacific Coast of North America. Because of the wide range of average fecundities reported, it would be unreliable to use data taken from the literature to estimate the egg deposition for a population of coho salmon in a particular stream.

Estimates of Survival to Emergence

The combined survival to emergence of 27.1 percent for coho in the Drift Creek study streams agrees generally with the estimates of salmon survival based on enumeration of fry in streams. My estimate differs, however, from the majority of estimates based on pre-emergent survival, particularly for coho salmon. Extrapolation of pre-emergent survival to estimates of emergent survival may give an unrealistic figure, since a large number of the fry may not be able to emerge from the gravel.

Numerous studies involving several techniques have been conducted on the embryonic survival of salmonids in all stages of development. Hobbs (1948) in New Zealand excavated a total of 711 redds of brown trout (Salmo trutta), rainbow trout (S. gairdneri), and chinook salmon (O. tshawytscha) and found that 92.4 percent of the sac fry were alive. The survival of sockeye salmon to the eyed egg stage was found to be 90 percent (Withler, 1952). Briggs (1953) excavated redds of steelhead trout (S. gairdneri), coho salmon, and chinook salmon in California and found pre-emergent survivals of 64.9 percent, 74.3 percent, and 86.0 percent, respectively. Steelhead eggs buried in Deer Creek, Flynn Creek, and Needle Branch had pre-emergent survivals of 16 to 62 percent (Coble, 1961). Phillips and Campbell (1961) also buried coho and steelhead embryos in the study streams and observed embryo survivals ranging from 0 to 87 percent. In contrast, McNeil (1962a) seldom observed a survival greater than 30 percent and frequently observed survivals less than 10 percent to the pre-emergent fry stage of pink salmon in three streams near Ketchikan, Alaska.

Studies on pink and chum salmon in which the ne-wly emerged migrant fry are counted as they leave the stream may give a more accurate estimate of survival to emergence. In Sashin Creek, Alaska, survival of pink salmon from egg to fry since 1940 ranged from 0.2 to 20 percent and has averaged 2. 4 percent (Merrell, 1962). Pink salmon survival to fry stage during a five year period on Nile Creek varied between 0. 35 and 32. 3 percent (Wickett, 1962). Hunter (1959) made an intensive study of the survival of pink and chum salmon in Hooknose Creek, Canada. Allowing for predation by coho salmon smolts and sculpins, survival from egg deposition to migrating fry over a ten year period ranged from 5.70 to 31.08 percent.

Estimated fry survival for sockeye and chinook salmon also appears low but this could be the result of the difficulty in enumerating fry immediately after emergence. The Fisheries Research Board of Canada (1956) reported that survival of sockeye salmon from eggs to fry in several streams in Canada has ranged from about 2 to 25 percent over a period of several years. Survival of chinook salmon from egg to migrating fry in Fall Creek, California, ranged from 7 to 32 percent during four years studied (Wales and Coots, 1955).

Estimates of the survival to emergence of coho salmon were made by Briggs (1953), Pritchard (1947), and Foerster and Ricker (1953). Briggs (1953) based his estimate of 74. 3 percent on the results of his pre-emergent survival data. Pritchard (1947) summarized the studies in two small streams tributary to the Cowichan River in British Columbia. The efficiency of natural propagation in terms of counted fry was; Oliver Creek, 14,4, 11.8, 30.4, 26.0, *25. 6,* 15. 2, 22. 3, and 22. 2 percent during eight years, and Beadnell Creek, 40. 0, 30.1, 16.3, and 19.5 percent during four years. Foerster and Ricker (1953) found that ratio of coho fry to potential egg deposition during 1929 to 1941 ranged from 0.47 to 6.8 percent.

Much of the mortality in redds in the study streams is thought to be caused by the inability of fry to emerge from the gravel. Numerous dead fry were found at a depth of eight inches in one of the redds with no survival to emergence. The fry were completely buttoned-up but extremely emaciated and apparently unable to penetrate through the intersticies of the gravel. Dead eggs were not recovered in the redd indicating that perhaps a high percentage developed successfully to the fry stage before starving and decomposing. A similar situation was found in a redd which was not trapped. Approximately 260 fry were dead several inches below the surface of the gravel. White (1942) found that where Atlantic salmon had spawned in gravel with an extensive amount of sands, 80 percent of the eggs were dead and 20 percent had produced fry which were unable to emerge through the compact layer. Numerous entombed fry were found in redds even with fairly good emergence.

The five redds having zero survival were completely excavated to determine if eggs had been deposited. Embryos were found in only one of these redds. Though the possibility of false redds existed, I assumed that all trapped redds were true because of the intensive observations of spawners and redd sites. The inability to find any traces of embryos or fry in these redds is most likely the result of scouring. However, decomposition may have accounted for some of the loss. Several workers have found that a loss of from 8 to 97 percent of the embryos may occur in the gravel (Briggs, 1953; Carl, 1940; Shaw and Maga, 1943; and McDonald, I960).

In Alaska and British Columbia it is quite common to find dead salmon eggs in the gravel from the past season. Hunter (1959) stated in some instances dead eggs of pink and chum salmon remained in the gravel up to a year or more. McNeil, Wells, and Brickell (1964) found significant number of dead eggs 18 months after spawning but decomposition had caused them to disintegrate within 12 months of their time of death. Dead sac fry disappeared from the streambed within two months after fry emergence, however.

Environmental Factors Affecting Survival

Composition of the Gravel

In the three streams studied, the composition of the gravel within the redd was the most important single factor affecting the emergence of coho fry. A large amount of sediment in the gravel appears to act in at least two ways to the detriment of fry survival and emergence. Gravel in many cases apparently acts as a barrier, restricting movement and entombing the fry within the redd. Retention of the fry beyond the period of yolk utilization would result in loss of vigor and fitness and thus hinder their ability to emerge. Entombment and extension of the period of emergence was demonstrated in the three streams. The redds in Flynn Creek which had the largest amount of fine sediments exhibited the longest mean period of emergence and the lowest mean survival.

The time to emergence also appears to be influenced by the amount of sediments in the redd. The early initial emergence observed in redds having a high percentage of fine sediments is difficult to explain but may be due to the restricted living space within the interstices of the gravel forcing the fry out. Depth of egg deposition in redds with a large amount of fine sediments may have been less than average and thus permitted some fry to emerge early. Time required for 90 percent fry emergence from the redds indicated that the redds with the largest percentage of fine sediments, redds with early initial emergence, required a longer time to complete emergence and had lower survivals. Early peak emergence attained in redds with a small amount of fine sediments supports the assumption that a large amount of sand and silt would serve as a barrier restricting fry movement. Aquaria observations by Phillips[5] revealed little mortality of coho embryos prior to hatching in fine gravel, but upon hatching the coho sac fry appeared distressed and died a short time later. The restriction of movement was dramatically illustrated by the trail of dead alevins as they struggled towards the surface. The more vigorous died about two inches short of emerging.

Stuart (1953) explains the mechanism by which sediments may directly kill embryos and sac fry. He found that the ova attracted fine particles of silt to the chorion and when subjected for long periods of time died without hatching. Continuous addition of sediments to sac fry resulted in serious inflammation of the gill membranes and eventually caused death.

In view of the relationship between survival and the amount of fine sediment in a redd, it would seem that any increase of silt or sand in the gravel would be detrimental to fry survival. The effects of sedimentation upon the reproduction of salmonids has received a considerable amount of attention, particularly in relation to logging and other land-use activities. After making an extensive review of the literature on the effects of sediment on aquatic life, Cordone

---

[5]R. W. Phillips. Personal communication. Oregon Game Commission, Corvallis, Oregon.

and Kelly (1961) concluded that the effects of sediment upon embryos of salmonids could be, and probably often are, disastrous and that even moderate deposition was detrimental. Bianchi (1963) showed that the suspended sediment load in a stream was one of the important factors determining rainbow trout and cutthroat trout embryo survival. In various laboratory experiments with the burial of coho salmon embryos, it has been shown that siltation greatly reduces the percentage of fry surviving to emergence (Shapovalov and Berrian, 1940 and Shaw and Maga, 1943). Harrison (1923) buried 500 embryos of the sockeye salmon in each of five gravel types and counted the number of fry which emerged. He found that the lowest survival was in the fine gravel with much clay and sand, and the highest occurred in gravel of hickory nut to walnut size. Shelton (1955) buried several lots of chinook salmon embryos in screen boxes under simulated stream conditions. In small gravel of one inch and less (sand and dirt removed), 13 percent emerged. No emergence occurred in 4 of the 12 boxes buried in small gravel. A considerably higher emergence of 87 percent was recorded in the large, one to three inch, gravel. Cooper (1956) stated that deposition of sediments on sockeye spawning areas could reduce the survival rates of embryos and sac fry being reared in the gravel. The reduction in survival is in proportion to the reduction of flow through the gravel, which in turn varies with the concentration of sediment and the sediment particle size.

Gravel samples collected from pink salmon streams in Southeastern Alaska revealed a good inverse relationship between the coefficient of permeability and the percentage by volume of bottom material passing through a 0. 833-mm sieve. Low permeability occurred where bottom materials contained more than 15 percent of sand and silt smaller than 0. 833-mm (McNeil and Ahnell, 1964). An inverse relationship was also found between the percentage of solids passing through a 0. 833-mm sieve and the escapement of pink salmon into six streams. Escapement was very high in Anan Creek where only about six percent of the bottom materials passed through a 0. 833-mm sieve and low in Maybeso Creek where 20 percent of the solids were smaller than 0. 833-mm (McNeil and Ahnell, 1964). Further examination of the gravel samples from the Drift Creek streams shows that the redds in Deer Creek (54.4 percent survival to emergence) had 26.4 percent solids passing through the 0. 833-mm sieve, those in Needle Branch (25. 1 percent survival) had 32. 8 percent solids passing through the 0. 833-mm sieve, and those in Flynn Creek (13.6 percent survival) had 34. 2 percent solids passing through the 0. 833-mm sieve (Appendix C). Redds with zero survival had a minimum of about 35 percent sand and silt passing through the 0. 833-mm sieve.

To test the relationship between streambed gravel composition and salmon fry production, the gravel composition of ten Southeastern Alaska pink salmon spawning areas was measured and compared to the maximum pre-emergent fry survival observed in these areas. The best correlation between pre-emergent survival and gravel composition ($r = 0.80$) was obtained from the fraction of gravel which passed a 0. 833-mm screen (Shapley, 1964). A comparison of the gravel composition from the study streams and those in Southeast Alaska indicates that the study streams have a higher percentage of fine sand and silt, quite possibly due to the degradable nature of the sandstone and siltstone substrate. Considering the gravel composition and the pre-emergent survivals reported by McNeil (1962a), it appears that the over-all survival in the study streams is very good.

The suspended sediments and fine sands accruing to the spawning beds can be expected to increase after logging, with the extent of increase dependent on the harvesting methods and land treatment. Anderson (1930) analyzed suspended sediment discharge in 29 Oregon watersheds and found that recently cutover areas and logging roads together had a highly significant effect on sediment discharge. In Southeast Alaska, McNeil and Ahnell (1964) observed that siltation of spawning beds occurred in association with logging and that the permeability of the spawning beds in the river was reduced considerably. However, freshets in the Alaskan streams removed most if not all of the silt in the spawning beds accumulated from logging.

Permeability

Although the permeability does not affect survival directly, it is a measure of the adequacy of the gravel in the redd to allow for a sufficient supply of water and dissolved oxygen to the embryos and sac fry. According to McNeil and Ahnell (1964), the potential of a salmon spawning bed to produce fry is directly related to its permeability. Wickett (1958) found evidence to indicate that higher survival to emergence of pink and chum salmon was associated with higher gravel permeabilities. Data from this study also indicates that a direct relationship exists, but other factors related to survival cannot be separated and, consequently, they obscure the actual relationship of permeability and survival. Redds with the highest permeabilities tended to have moderate survivals. The gravel in these redds was relatively loose and would have been more susceptible to scouring.

Permeability data collected in other studies conducted on these streams (Coble, 1961; and Phillips and Campbell, 1961) showed no apparent correlation with survival. It is possible that the small size of these streams or their gravel composition could cause a high degree of spatial variation. If this were true, then a single standpipe in a redd may not represent the actual condition. Information obtained by placing five standpipes in three of the redds indicated there was considerable lateral variation in permeability and dissolved oxygen (Appendix D).

Dissolved Oxygen

Although there appeared to be no distinct relationship between my survival to emergence estimates and the concentrations of dissolved oxygen, it is evident from the work of others that the survival and growth of salmonid embryos is dependent on an adequate concentration of dissolved oxygen. Coble (1961), in field experiments with coho and steelhead embryos in the Drift Creek study area, found positive correlations between the apparent velocity of ground water and embryonic survivals, and between the dissolved oxygen levels of the intragravel water and survivals. Dissolved oxygen and apparent velocity were closely related and the effects of these factors could not be separated. Experiments by Phillips and Campbell (1961) in the same area also showed positive correlation between survival of coho and steelhead embryos and mean dissolved oxygen concentrations. Both of the previous studies involved burial of embryos in porous plastic and metal containers. Ziebell and Mills (1963) in a similar experiment with burial of embryos in containers found survival related to dissolved oxygen. Wickett

(1954) found high mortality of chum salmon embryos in a controlled-flow section of Nile Creek, British Columbia, where low concentrations of dissolved oxygen existed. Recent laboratory experiments by Phillips[6] have shown that survival to emergence of coho salmon and steelhead is directly related to the dissolved oxygen concentration of the intragravel water.

In several laboratory studies, low oxygen levels have been shown to cause high embryo mortalities, delayed hatching, and abnormal growth and development (Alderdice, Wickett, and Brett, 1958; Garside, 1959; Silver, Warren, and Doudoroff, 1963; and Shumway, Warren, and Doudoroff, 1964). Studies have shown that the required level of dissolved oxygen for embryos increases from a low level shortly after fertilization to a comparatively high level near the time of hatching (Alderdice, Wickett, and Brett, 1958; and Hayes, Wilmot, and Livingston, 1951). The lethal level of dissolved oxygen was found to be 1.67 mg/1 for chum salmon (Wickett, 1954) and 1.6 mg/1 for chinook salmon and steelhead trout (Silver, Warren, and Doudoroff, 1963).

Phillips and Campbell (1961) found that below about 7.0 mg/1 embryo survival was low. In the trapped redds, all survivals below 6.0 mg/1 were low. However, there was a large number of redds

---

[6]R. W. Phillips. Personal communication.

with low survival at relatively high concentrations of dissolved oxygen. Many of these redds also had a higher percentage of fines that probably accounted for a portion of the mortality. Erosion may also account for some of the low survivals at high oxygen concentrations. Redds having a relatively low percentage of fine sediments had a fairly good relationship between survival and dissolved oxygen.

Salmonid embryos and sac fry in redds depend on the intra-gravel water to supply them with an adequate concentration of dissolved oxygen for survival and normal growth. Reduction in the velocity and oxygen content of the water flowing through the redds because of changes in the composition of gravel may severely affect survival. Even under conditions that are not lethal, there is an increase in the time of hatching and a reduction in the size of fry (Shumway, Warren, and Doudoroff, 1964). This delay in hatching and presumed emergence, as well as the production of smaller fry would undoubtedly contribute to mortality within the redd.

In the study streams, the concentration of dissolved oxygen in the majority of redds appeared to be of sufficient quantity to be non-limiting in terms of survival. The true relationship of dissolved oxygen would be best observed in studies of pre-emergent survival because of the influence of the gravel size on fry emergence. However, dissolved oxygen may have had a pronounced effect on the growth and development of the embryos and sac fry and thus influenced survival indirectly.

Gravel Movement

The erosion of gravel from spawning beds is known to be an important factor in survival of salmonid embryos. Shifting of the gravel can cause scouring of the incubating embryos from the gravel or bring about mortality by merely moving embryos that are in the tender stages following fertilization (Gangmark and Bakkala, 1960). Sheridan and McNeil (1960) observed one situation where an embryo mortality of 95 percent was caused by extensive gravel movement. Reports by Neave and Wickett (1953), Wickett (1958), Skud (1958), and McNeil (1962a) have concluded that gravel erosion in many cases is extremely detrimental to survival.

Peak flows or abnormally high flows which can cause gravel movement can bring about embryo mortality. If the peak flows are increased following logging as Kittredge (1948) and Anderson and Hobba (1959) have shown, then increased gravel shifting could be expected in the study streams. At present, gravel movement in the study area appears to be an important factor in survival. The location of a redd is important since the stability of the gravel varies in different areas of the stream.

Growth and Condition of Emergent Fry

Though there has been considerable work on the effects of the environment on survival, the growth and condition of newly emerged fry has not been given intensive study. Conditions within a redd may allow for survival of embryos and emergence of fry, but their success in the stream is dependent on how well they can compete and how well they can maintain themselves under adverse conditions. Fry which are hindered either by delayed emergence, small size, or poor condition may very well be lost to the stream through emigration or predation. Chapman (1962) studied the behavior of juvenile coho in these same study streams and concluded that aggressive behavior was one factor causing the downstream displacement of newly-emerged fry. The fry moving downstream were smaller than the more aggressive residual fry. Differences as slight as 1 mm were found to be important in the dominance-subordination relationships of coho fry in artificial stream channels. Mason and Chapman (1965) showed that the earliest-emerging fry had an ecological advantage over later-emerging fry, and had a greater tendency to remain in the stream channels.

The decrease in weight and the coefficient of condition during the period of emergence can probably be attributed to retention of the fry in the redd beyond the period of yolk utilization. Because of the restricted movement imposed by the gravel, loss of weight and condition due to lack of sufficient food would result.

Little is known about the intragravel movements of sac fry, but it is reasonable to assume that the distance traveled through the gravel and the time to emerge varies considerably due to depth of egg deposition, gravel composition, and apparent velocity of the intragravel water. Sac fry buried only a few inches deeper in redds having a high percentage of sand and silt would probably require a longer time to emerge and be of poorer condition. Feeding by fry within the gravel of the redd (Disler, 1961) may occur and account for some of the variation in size at emergence.

The ecological significance of the size of fry at emergence has not been completely determined, but differences and changes in size of fry have been noted. In a laboratory experiment by Shapovalov and Berrian (1940), it was noted that the fry exhibited much variation in size. Pink salmon fry in Sashin Creek, Alaska, showed a general decrease in size as migration progressed (Skud, 1955). A size difference in pink salmon fry from one stream between years was indicated by Noerenberg (1963). Sheridan and Noerenberg (1963) concluded that pink salmon fry vary in size within one stream and from one stream to another. Several environmental, physiological, and genetic factors have been postulated for differences in fry size, but their significance has not been established.

In the majority of redds examined, the length of the fry at emergence also decreased with time. Differences in dissolved oxygen and/ or velocity around the eggs could account for the variation in length of the fry during emergence. Daykin (1965) notes that the oxygen content of the microenvironment of the fish embryo is biologically significant, but that only the ambient oxygen content is readily accessible to measurement. The concentration of oxygen in the microenvironment of the developing embryo is always less than the concentration in the supply water. McNeil (1962b) found that spatial differences in dissolved oxygen levels of intragravel water existed, but they were greatest during periods of low discharge and warm weather. Data collected during my study from redds with multiple standpipes also indicated that the dissolved oxygen concentration varied within different parts of the redd. Since the embryos were distributed over a four to five foot area, it is probable that the majority were exposed to a variety of dissolved oxygen concentrations and velocities.

Reductions in either the oxygen concentration or the water velocity at which salmonid embryos are reared tend to reduce the size of newly hatched fry and to increase the length of the incubation period '(Shumway, Warren, and Doudoroff, 1964; and Silver, Warren, and Doudoroff, 1963). Water velocities high enough to assure an adequate supply of oxygen to a redd may vary or change during the incubation period and hence, may not always insure adequate oxygen concentration to the embryos. The decrease in weight and length of the emergent fry with time may reflect the slower development, smaller size, weaker condition, and delayed hatching and emergence caused by inadequate dissolved oxygen and water velocities around the embryos.

The variation in egg size within a female may account for some of the differences in sizes of fry at emergence. Production of larger larvae from bigger eggs has been shown by Toom (1958), Rannak (1958), and Blaxter and Hempel (1963) from their studies on herring. Blaxter and Hempel (1963) state that for herring, larvae from large eggs lived for about 28 days after hatching without food and larvae from small eggs lived only about 15 days. Survival time seemed to depend on the relationship between yolk sac and body weight in the newly hatched larvae. If this is also true in salmonids, then the smaller sac fry would be without food longer than the larger sac fry and possibly have greater difficulty emerging. The significance of the direct relationship between the size of the female and size of the egg as pointed out by Blaxter and Hempel (1963) could lead to a differential larval mortality within a stock of fish if the size of the female affects the viability of the larvae. A mortality selective toward larger fish could have far reaching consequences on the population dynamics and optimum management

Predation

Though no direct observations were made on predation of fry within the redd, observations were made of several organisms associated with the embryos and sac fry in the gravel environment. The reticulate sculpin (Cottus perplexus) was abundant in the streams and many were removed from the fry traps. This species has been observed in the laboratory to prey on sac fry within the gravel. An unidentified oligochaete worm was fairly abundant in the gravel and was found in greater numbers among the dead fry. Briggs (1953) found a high mortality of steelhead trout and coho salmon embryos in redds infested with an oligochaete worm. Tipulid larvae were also found concentrated in redds having a large percentage of dead fry but were probably acting as scavengers. The carnivorous stoneflies, Acroneuria sp., and Alloperla sp., were fairly abundant in the streams and occasionally another carnivorous species, Kathroperla perdita, was found deep in the gravel of the redds. McDonald (I960) found many aquatic forms closely associated with embryo clusters in artificial redds. He attributed the loss of dead embryos to fungus, midge and cranefly larvae, and stonefly nymphs. Dead embryos had been consumed but it was not known if living embryos had been attacked.

Evaluation of the Fry Trap

In order to properly evaluate the fry trap, its effects on the redd environment and its efficiency in capturing emerging fry must be known. Disturbance of the redd gravels may influence the developing embryos, either through direct behaviorial responses or subsequent changes in the intragravel water. A u-test (Li, 1957) indicated that there was no significant difference at the five percent level between the mean dissolved oxygen concentration before and after the traps were installed. A t-test indicated that there was no significant difference at the five percent level between the concentration of dissolved oxygen in redds without traps and those with traps. Though not tested, the permeability data appeared to show the same results as dissolved oxygen. If the quality of the intragravel water can be considered as a criterion of the effect of the fry trap on the environment, then it may be assumed that the trapping did not adversely effect the redds. Some mortality occurred among fry which remained in the collection bag of the trap for an extended period of time; though the average mortality for all redds was less than one and one-half percent. This mortality could be reduced by more frequent checking of the fry traps. The growth of algae was light and actually enhanced the operation of the trap. Minor silt deposition occurred within some of the traps due to the reduction in water velocity. The traps were kept relatively clean of detritus and silt by brushing two to three times a week. Difficulties of installing the traps were encountered in situations where the water depth was greater than two feet and where numerous large rocks precluded the use of sheetpiling.

The efficiency of the fry traps in capturing emerging fry was assumed to be relatively high, though little was known of the intra-gravel movement of the fry. Stuart (1953) found that the sac fry of brown trout migrated upward and outward resulting in a cone-shaped pattern with the apex at the site of egg burial. He also found that the sac fry appeared to be negatively phototatic and negatively rheotatic until complete yolk absorption at which time the responses were reversed. Lateral migration in the study streams was believed to be minimal because of the high percentage of fine sediments in the redds. Experiments by the Oregon Game Commission in gravel-filled troughs have indicated the majority of coho fry emerge within an 18-inch circle placed directly above the location of egg planting.[8]

---

[8] R. W. Phillips. Unpublished data.

Appraisal of Study

The fry emergence trap proved to be a successful tool in determining the survival to emergence of coho salmon. The main contributions of this study are the estimates of survival from time of egg deposition to emergence for individual redds and the assessment of related environmental conditions.

Though it is apparent that there were several factors in the environment which acted as deterrents to survival, the composition of the gravel appeared to be the most important. As a result, I have concluded that the most useful criterion for evaluating the success of survival to emergence in the study streams is the percentage by volume of the redd gravel passing through a 3.327 mm sieve. The significance of the gravel quality is apparent not only in its direct relationship to survival but in its interaction with the other environmental factors. The permeability of the gravel and the concentration of dissolved oxygen in the intragravel water were important to survival indirectly through their effects on growth and size of the emergent fry, and on the time of emergence. The ecological significance of differences in the size and robustness of the emergent fry is in their effect on survival, both in the redd and the stream.

BIBLIOGRAPHY

1. Alderdice, D. F. , W. P. Wickett, and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Research Board of Canada 15(2):229-250.

2. Allen, George H. 1958. Notes on the fecundity of silver salmon (Oncorhynchus kisutch). Progressive Fish Culturist 20(4); 163-169.

3. Anderson, H. W. 1930. Suspended sediment discharge as related to streamflow, topography, soil, and land use. Transactions of the American Geophysical Union 35; 268-281 .

4. Anderson, Henry W. and Robert L. Hobba. 1959- Forests and floods in the northwestern United States. In: Symposium of Hannoversch-Munden, Gentbrugge, Germany, 1959. vol 1. p. 30-39- (International As sociation of Scientific Hydrology publication no. 48)

5. Aro, K. V. and G. C. Broadhead. 1950. Differences between egg counts of sockeye salmon at Lakelse and Babine Lakes. Fisheries Research Board of Canada. Progress Report of the Pacific Coast Station no. 82:17-19.

6. Bianchi, Donald R. 1963. The effects of sedimentation on egg survival of rainbow trout and cutthroat trout. Master's thesis. Bozeman, Montana State College. 28 numb, leaves.

7. Blaxter, J. H. S. and G. Hempel. 1963. The influence of egg size in herring larvae. Journal du Conseil 28(2): 211-240.

8. Brasch, J. 1949. Notes on natural reproduction of the eastern brook trout (Salvelinus fontinalis) with a preliminary report of several experiments on the subject. Madison, 9 p. (Wisconsin. Conservation Department. Investigation Report no. 653)

9. Briggs, John C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. San Pedro, 62 p. (California. Department of Fish and Game. Fish Bulletin no. 94)

10. Burner, Clifford J. 1951. Characteristics of spawning nests of Columbia River salmon. U. S. Fish and Wildlife Service Fishery Bull'et-in 52(61): 97-110.

11. Campbell, H. J. 1954. The effects of siltation from gold dredging on the survival of rainbow trout and eyed eggs in Powder River, Oregon. Portland, Oregon State Game Commission. 3 p. (Processed)

12. Canada. Fisheries Research Board. 1956. Annual report, 1955. Ottawa. 182 p.

13. Carl, G. Clifford 1940. Comparison of coho salmon fry from eggs incubated in gravel and in hatchery baskets. Transactions of the American Fisheries Society 69:132-134.

14. Chapman, Donald W. 1961. Factors determining production of coho salmon, <u>(Oncorhynchus kisutch),</u> in three Oregon streams. Ph.D. thesis. Corvallis, Oregon State University. 192 numb, leaves.

15. ______________. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. Journal of the Fisheries Research Board of Canada 19(6):1047-1080.

16. Chapman, Donald W. et al. 1961. Summary report, Alsea watershed study. Corvallis. 52 p. (Oregon State University. Agricultural Experiment Station. Miscellaneous Paper no. 110)

17. Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society 90:469-474.

18. Cooper, A. C. 1956. A study of the Horsefly River and the effect of placer mining operations on sockeye spawning grounds. New Westminister, International Pacific Salmon Fisheries Commission. 58 p. (Processed)

19. Cordone, Almo J. and Don E. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish and Game 47(2): 189-228.

20. Daykin, P. N. 1965. Application of mass transfer theory to the problem of respiration of fish eggs. Journal of the Fisheries Research Board of Canada 22(1): 159-171.

21. Disler, N. N. 1961. Ecological and morphological characteristics of the development of the Amur autumn chum salmon--Oncorhynchus keta (Walb.) In: Pacific salmon. Jerusalem, Israel Program for Scientific Translations, p. 33-41. (Office of Technical Services publication no. OTS 60-51139; Translated from Akademiya nauk SSSR, Ikhtiologicheskaya Komissiya, Trudy Soveshchanii)

22. Foerster, R. E. and W. Ricker. 1953. The coho salmon of Cultus Lake and Sweltzer Creek. Journal of the Fisheries Research Board of Canada 10(6): 293-319.

23. Gangmark, H. A. and R. G. Bakkala. 1960. A comparative study of unstable and stable (artificial channel) spawning areas for incubating king salmon at Mill Creek. California Fish and Game 46; 151-164.

24. Garside, E. T. 1959. Some effects of oxygen in relation to temperature on the development of lake trout embryos. Canadian Journal of Zoology 37:689-698.

25. Harper, E. L. 1953. Semi-microdetermination of dissolved oxygen. Analytical Chemistry 25:187-188.

26. Harrison, C. W. 1923. Planting eyed salmon and trout eggs. Transactions of the American Fisheries Society 53:191-200.

27. Hayes, F. R., I. R. Wilmot, and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. Journal of Experimental Zoology 116:377-395.

28. Heard, William R. 1964. Phototactic behaviour of emerging sockeye salmon fry. Animal Behaviour 1 2(2-3); 382-388.

29. Hobbs, Derisley F. 1948. Trout fisheries in New Zealand, their development and management. Wellington. 175 p. (New Zealand. Marine Department. Fisheries Bulletin no. 9)

30. Hunter, Jerry G. 1959. Survival and production of pink and chum salmon in a coastal stream. Journal of the Fisheries Research Board of Canada 16(6):835-886.

31. Li, Jerome C. R. 1957. Introduction to statistical inference. Ann Arbor, Mich., Edwards Brothers. 568 p.

32. Kittredge, Joseph.. 1948. Forest influences. New York, McGraw-Hill. 394 p.

33. Mason, J. C. and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. Journal of the Fisheries Research Board of Canada 22(1): 173-190.

34. McAfee, William R. 1960. Redds of the red salmon, Oncorhynchus nerka, in three streams of the Alaska Peninsula. Master's thesis. Ann Arbor, University of Michigan. 39 numb, leaves.

35. McDonald, J. G. 1960. A possible source of error in assessing the survival of Pacific salmon eggs by redd sampling. Canadian Fish Culturist 26:27-30.

36. McNeil, William J. 1962a. Mortality of pink and chum salmon eggs and larvae in Southeast Alaska streams. Ph.D. thesis. Seattle, University of Washington. 270 numb, leaves.

37. _______________. 1962b. Variations in the dissolved oxygen content of intragravel water in four spawning streams of Southeastern Alaska. Washington. 15 p. (U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries no. 402)

38. McNeil, William J. and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. Washington. 15 p. (U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries no. 469)

39. McNeil, William J., Ralph A. Wells, and David C. Brickell. 1964. Disappearance of dead pink salmon eggs and larvae from Sashin Creek, Baranof Island, Alaska. Washington. 13 p. (U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries no. 485)

40. Merrell, Theodore R., Jr. 1962. Freshwater survival of pink salmon at Sashin Creek, Alaska. In: A Symposium on Pink Salmon, ed. by N. J. Wilimovsky. Vancouver, University of British Columbia, 1960. p. 59-72.

41. Neave, Ferris. 1947. Natural propagation of chum salmon in a coastal stream. Fisheries Research Board of Canada. Progress Reports of the Pacific Coast Station no. 104:34-37.

42. Neave, Ferris and W. Percy Wickett. 1953. Factors affecting the fresh-water development of Pacific salmon in British Columbia. In: Proceedings of the Seventh Pacific Science Congress of the Pacific Science Association, Auckland and Christchurch, New Zealand, 1949. vol. 4. Auckland, Wit-combe and Tombs, p. 548-556.

43. Noerenberg, Wallace A. 1963. Salmon forecast studies on 1963 runs in Prince William Sound. Juneau. 28 p. (Alaska. Department of Fish and Game Information Leaflet no. 21)

44. Parker, Robert R. 1963. Effects of formalin on length and weight of fishes. Journal of the Fisheries Research Board of Canada 20(6): 1441 - 1455 .

45. Phillips, Robert W. and Homer J. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. Pacific Marine Fisheries Commission Report no. 14:60-73.

46. Pritchard, Andrew L. 1947. Efficiency of natural propagation of Pacific salmon. Canadian Fish Culturist 1(2): 22-26.

47. Rannak, L. A. 1958. Quantitative study of the Baltic herring eggs and larvae in the northern part of the Gulf of Riga and principle factors determining their survival. St. Andrews, N. B. 15 p. (Fisheries Research Board of Canada, Translation Series no. 238; Translated from Trudy Vsesoiuznovo Nauchno-Issledovatelskovo Instituta Morskovo Rybnovo Khoziaistva i Okeanograffii)

48. Rounsefell, George A. 1957. Fecundity of North American salmonidae. U. S. Fish and Wildlife Service. Fishery Bulletin 57 (1 22): 451-458.

49. Royce, William F. 1959. On the possibilities of improving salmon spawning areas. Transactions of the North American Wildlife Conference 24:356-366.

50. Shapley, Philip S. 1964. Effects of logging on the productivity of pink salmon streams in Alaska. Seattle. 24 p. (University of Washington. Fisheries Research Institute. Alaska salmon studies. Periodic report no. 4)

51. Shapovalov, Leo and William Berrian. 1940. An experiment in hatching silver salmon (Oncorhynchus kisutch) eggs in gravel. Transactions of the American Fisheries Society 69:135-140.

52. Shaw, P. A. and J. A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. California Fish and Game 29: 29-41 .

53. Shelton, Jack M. 1955. The hatching of chinook salmon eggs under simulated stream conditions. Progressive Fish Culturist 17(1):20-35.

54. Sheridan, William L. and William J. McNeil. I960. Effects of logging on the productivity of pink salmon streams in Alaska. University of Washington Fisheries Research Institute. Contribution 77: 16-17.

55. Sheridan, W. L. andW. H. Noerenberg. 1963. Size of pink salmon downstream migrants. Juneau. 20 p. (Alaska. Department of Fish and Game Information leaflet no. 27)

56. Shumway, Dean L. , Charles E. Warren, and Peter Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93(4): 342- 256.

57. Silver, Stuart J. , Charles E. Warren, and Peter Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Transactions of the American Fisheries Society 92(4); 327-343.

59. ______________. 1958. Relation of adult pink salmon size to time of migration and fresh water survival. Copeia no. 3:170-176.

60. Snedecor, George W. 1956. Statistical methods. 5th ed. Ames, Iowa State University Press. 534 p.

61. Stuart, T. A. 1953. Spawning migration, reproduction and young stages of loch trout (Salmo trutta L.). Edinburgh. 39 p. (Gt. Britain. Scottish Home Department. Freshwater and Salmon Fisheries Research no. 5)

62. Terhune, L. D. B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada 15(5): 1027-1063.

63. Toom, M. M. 1958. Experiments in the incubation of Baltic herring eggs. Trudy Vsesoyuznogo nauchno-issledovatelskogo instituta morshogo rybnogo khozyaistva i okeanografii, 34:19-29. (Trans. by the Israel Program for Scientific Translations, Jerusalem, 1962; Office of Technical Services publication no. OTS 61-31040)

64. U. S. Geological Survey. 1964. Surface water records of Oregon. Washington. 397 p.

65. Vokes, H. E., H. Norbisrath, and P. D. Snavely, Jr. 1949. Geology of the Newport-Waldport area, Lincoln County, Oregon. Washington. 1 sheet. (U. S. Geological Survey. Oil and Gas Investigation Preliminary Map om-88)

66. Wales, J. H. and Millard Coots. 1955. Efficiency of chinook salmon spawning in Fall Creek, California. Transactions of the American Fisheries Society 84; 137-149.

67. White, H. C. 1942. Atlantic salmon redds and artificial spawning beds. Journal of the Fisheries Research Board of Canada 6(1): 37-44.

68. Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada 11 (6): 933-953.

69. ______________. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. Journal of the Fisheries Research Board of Canada 15(5): 1103-1126.

70. ______________. 1962. Environmental variability and reproduction potentials of pink salmon in British Columbia. In: A Symposium on Pink Salmon, ed. by N. J. Wilimovsky. Vancouver, University of British Columbia. p. 73-86.

71. Williams, R. C. 1964. Sedimentation in three small forested drainage basins in the Alsea River Basin, Oregon. Washington. 16 p. (U. S. Geological Survey. Circular no. 490)

72. Withler, F. C. 1952. Sockeye reproduction in a tributary of Babine Lake, 1950-51. Fisheries Research Board of Canada. Progress Reports of the Pacific Station no. 91:13-17.

73. Ziebell, C. D. and A. D. Mills. 1963. An investigation of certain water quality and biological conditions in Boise Creek-Enumclaw, Washington. Washington Pollution Control Commission. Research Bulletin no. 63-1:1-33.

APPENDICES

APPENDIX A

SUMMARY OF DATA COLLECTED ON THE SURVIVAL TO EMERGENCE OF COHO SALMON FROM THE DRIFT CREEK STUDY STREAMS (1963-64)

Redd Location [a]	Female Length (mm)	Female Weight (kg)	Estimated Fecundity	Estimated Egg Deposition	Date of Spawning	Days to first Emergence	Period of Emergence (days)	Number Fry Emerged	Perce Surviv to Emerge
Deer Creek									
5690	678	3.57	2257	2257	Jan. 1	114	30	1311	58.1
5070	803	6.07	3444	3441	Jan. 3	114	38	2061	59.9
575 E. Fork	689	3.77	2352	2351	Jan. 2	—	--	0	0.0
125 E. Fork	675	3.40	2177	2172	Jan. 28	112	24	1684	77.5
3490	689	3.60	2271	2268	Jan. 12	103	39	1736	76.5
Flynn Creek									
800	615	2.55	1772	1761	Dec. 31	113	28	20	1.1
500	800	6.12	3471	3469	Jan. 12	114	40	1025	29.5
38S[b]	718	3.99	2460	2453	Jan. 14	105	46	2889	117.8
380	668	3.03	2001	1997	Jan. 5	111	33	710	35.6
350	675	3.57	2257	2253	Dec. 26	—	--	0	0.0
200 E. Fork	710	4.08	2500	2498	Jan. 3	—	--	0	0.0
100 E. Fork	680	3.69	2311	2304	Dec. 25	—	--	0	0.0
-50	728	4.34	2621	2621	Dec. 23	103	40	554	21.1
-225	660	2.75	1867	1860	Dec. 28	110	38	69	3.7
-375	686	3.80	2365	2364	Dec. 28	105	47	743	31.4
Needle Branch									
2280	675	—	2247	2243	Jan. 20	112	32	455	20.3
1580	655	—	2091	1943	Jan. 8	110	37	1066	54.9
1220	694	—	2471	2466	Dec. 21	109	42	887	36.0
1050	694	—	2471	2.447	Jan. 20	107	39	375	15.3
1000	648	—	2036	2030	Dec. 29	—	--	0	0.0
590	735	—	2715	2715	Jan. 2	106	47	1225	45.1
425	630	—	1895	1889	Jan. 21	115	10	71	3.8

[a] Distance in feet above or below weir

Redd excluded from survival analysis

Range in Survival (95% confidence limit)	Fry Length at initial Emergence (mm)	Fry Weight at initial Emergence (g)	Fry Weight at 50% Emergence (g)	Minimum Dissolved Oxygen (mg/1)	Mean Dissolved Oxygen (mg/1)	Mean Permeability Index (ml/ 5 sec.)	Percent Gravel Passing 3.327 mm Sieve
55.9-60.5	38.2	0.489	0.433	6.6	9.2	184	29.2
55.6-64.9	38.2	0.536	0.525	8.2	10.5	206	30.0
----	----	----	----	7.9	10.3	22	42.5
74.7-80.6	36.4	0.412	0.412	9.1	10.9	224	29.3
73.6-79.7	35.9	0.409	0.344	9.0	10.9	191	27.7
1.1- 1.2	34.7	0.345	0.313	10.8	11.8	90	38.2
27.4-32. 1	38.5	0.551	0.500	7.5	10. 1	373	26.7
----	38.6	0.519	0.373	7.7	9.4	72	40.7
34.x - 6.9	37.6	0.482	0.440	9.6	11.3	90	40.4
----	----	----	----	1.8	3.9	27	39.6
----	----	----	----	4.6	7.7	100	48.0
----	----	----	----	5.8	8.8	60	50.8
20.1-22.3	37.3	0.590	0.563	8.7	10.4	219	48.1
3.6- 3.9	37.4	0.493	0.440	9. 1	10. 6	75	48.9
30.1-32.8	36.0	0.475	0.454	8.1	10.9	125	42.3
19.3-21.1	37.2	0.469	0.454	10.2	11.5	357	40.9
52.7-57.3	38.4	0.522	0.512	7.3	10.8	183	34.9
34.6-37.4	39.1	0.637	0.605	9.1	10.6	290	46.3
14.8-15.9	36.2	0.417	0.400	4.5	8.7	60	38.0
				8.7	10.5	92	43.0
42.9-47.6	38.4	0.540	0.540	7.8	9.9	377	40.4
3.6- 4.0	34.2	0.320	0.320	7.9	10.5	156	36.8

APPENDIX B

DISSOLVED OXYGEN DATA FROM REDDS IN STUDY STREAMS (1963-64)

Flynn Creek

Redd Location	No. Samples	Milligrams per Liter Mean Concentration	Minimum Concentration	Maximum Concentration
800	35	11.8	10.8	13.3
500	34	10.1	7.5	11.6
385	34	9.4	7.7	10.8
380	35	11.3	9.6	13.4
350	34	3.9	1.8	6.5
200 EF	35	7.7	4.6	10.4
100 EF	35	8.8	5.8	11.8
-50	35	10.4	8.7	11.8
-225	34	10.6	9.1	12.1
-375	35	10.9	8.1	12.5
Surface	35	12.0	10.6	13.1

Deer Creek

Redd Location	No. Samples	Mean Concentration	Minimum Concentration	Maximum Concentration
5690	34	9.2	6.6	11.2
5070	34	10.5	8.2	12.6
575 EF	34	10.3	7.9	11.6
125 EF	34	10.9	9.1	12.5
4770	34	10.4	8.4	12.5
3490	32	10.9	9.0	12.4
1840	33	9.3	6.1	11.4
390	16	8.8	5.8	10.8
100	32	8.6	4.8	11.8
-150	32	11.2	8.8	12.8
Surface	34	12.2	11.0	13.4

APPENDIX B (continued)

Needle Branch

Redd Location	No. Samples	Milligrams per Liter Mean Concentration	Minimum Concentration	Maximum Concentration
2545	33	11.7	10.6	13.4
2490	17	11.6	10.7	13.1
2280	33	11.5	10.2	12.9
1990	33	11.2	9-8	12.9
1580[a]				
(1)	33	10.8	9.2	12.6
(2)	33	9.9	8.6	11.3
(3)	33	8.9	3.3	11.5
(4)	33	10.5	7.8	11.9
(5)	33	9.6	7.4	12.2
1220	33	10.6	9.1	12.3
1050[a]				
(1)	33	8.7	5.2	10.8
(2)	33	8.7	6.2	11.1
(3)	33	3.0	0.6	9.1
(4)	33	7.8	4.8	10.9
(5)	33	8.7	5.8	10.1
1000	33	10.5	8.7	12.3
590	33	9.9	7.8	12.3
425[a]				
(1)	33	10.5	8.7	12.3
(2)	33	10.4	8.7	12.5
(3)	33	9.8	7.8	11.3
(4)	33	8.4	6.1	11.4
(5)	33	9.6	8.4	11.4
275	32	10.8	9.4	12.6
Surface	33	11.6	10.1	13.5

Redds with multiple standpipes

APPENDIX C

MEAN COMPOSITION OF GRAVEL FROM REDDS IN STUDY STREAMS (1963-64)

	Deer Creek		Needle Branch		Flynn Creek	
Sieve Size (mm)	Percent Retained	Percent Passing	Percent Retained	Percent Passing	Percent Retained	Percent Passing
50.8	7.8	91.8	2.1	97.8	2.7	97.3
25.4	21.3	70.5	14.5	83.3	12.6	84.7
12.7	19.4	51.1	17.8	65.5	16.5	68.2
6.35	12.0	39.1	15.0	50.5	14.6	53.6
3.327	7.4	31.7	10.5	40.0	11.2	42.4
1.65	5.3	26.4	7.3	32.7	8.2	34.2
0.833	3.7	22.7	5.0	27.7	5.8	28.4
0.417	5.0	17.7	6.7	21.0	7.4	21.0
0.208	4.9	12.8	7.8	13.2	9.0	12.0
0.104	5.0	7.8	4.8	8.4	5.3	6.7
<0.104	7.8	---	8.4	---	6.7	---

APPENDIX D

PERMEABILITY INDEX DATA FROM REDDS IN STUDY STREAMS (1963-64)

Flynn Creek

Redd Location	No. Samples	Milliliters per 5 Seconds Mean Value.	Minimum Value	Maximum Value
810	7	90	60	125
500	9	373	170	465
385	9	72	25	130
380	7	90	75	110
350	9	27	5	45
200 EF	9	100	55	130
100 EF	9	60	30	95
-50	9	219	80	350
-225	9	75	40	160
-375	9	125	50	325

Deer Creek

Redd Location	No. Samples	Mean Value	Minimum Value	Maximum Value
5690	8	179	80	240
5070	8	203	165	250
525 EF	8	23	15	30
125 EF	8	215	95	300
4770	8	286	90	375
3490	7	208	55	325
1840	8	46	30	65
390	4	16	10	20
100	7	81	40	110
-150	7	111	80	135

APPENDIX D (continued)

Needle Branch

Redd Location	No. Samples	Milliliters per 5 Seconds Mean Value	Minimum Value	Maximum Value
2545	8	290	220	405
2490	4	59	40	80
2280	8	363	265	490
1990	8	336	275	460
1580[a]				
(D	8	218	160	260
(2)	8	222	130	290
(3)	8	44	30	60
(4)	8	317	235	420
(5)	8	104	70	150
1220	8	284	135	370
I050[a]				
(D	8	164	115	200
(2)	8	16	5	20
(3)	8	41	20	55
(4)	8	67	30	95
(5)	8	11	5	15
1000	8	89	50	115
590	8	377	315	450
425[a]				
(D	8	409	360	505
(2)	8	134	30	220
(3)	8	15	5	20
(4)	8	23	10	40
(5)	8	197	80	290
275	8	319	220	485

Redds with multiple standpipes