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NOAA Technical Memorandum NMFS ABFL-3

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National Marine Fisheries Service

Salmon Fry Production in a Gravel Incubator Hatchery, Auke Creek, Alaska, 1971-72

JACK E. BAILEY and SIDNEY G. TAYLOR

SEATTLE, WA
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NMFS ABFL-1. An improved incubator for salmonids and results of preliminary tests of its use. By Jack E. Bailey and William R. Heard.

NMFS ABFL-2. A Guide to the Collection and Identification of Presmolt Pacific Salmon in Alaska with an Illustrated Key. By Milton B. Trautman.

NMFS ABFL-3. Salmon Fry Production in a Gravel Incubator Hatchery, Auke Creek, Alaska, 1971-72. By Jack E. Bailey and Sidney G. Taylor.

U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Survival and physical characteristics of pink salmon fry, *Oncorhynchus gorbuscha*, incubated in two types of boxes, each box containing about 1 m^3 of gravel, and a Heath incubator were compared with fry from natural spawning to evaluate the use of boxes to produce fry. The gravel incubators were seeded at densities of 74,200 to 198,000 eyed eggs/m^3. Survival from eyed eggs to emergent fry ranged from 79 to 97% in artificial incubation, but the number of incubators tested was too small to define any relationships between survival and incubator type or egg density. With artificial incubation in gravel, survival from potential eggs in females to emergent fry was 69%, whereas with natural spawning and incubation in the creek, survival was about 12%.

Fry emerged from gravel incubators about 3 days earlier than from the streambed. The gravel incubator fry were larger than tray fry but smaller than creek fry. The smaller size of the gravel incubator fry could not be explained entirely on the basis of early emergence.

Further studies were recommended to determine whether the muskeg sediment that accumulated in the incubators, the low oxygen level (57 to 69% saturation), or the substrate particle size and composition inhibited growth of the embryos.

INTRODUCTION

Scientists of the National Marine Fisheries Service (NMFS) have conducted research in Alaska for over 10 yr to evaluate the environmental requirements of salmonid eggs, alevins, and fry in the natural streambed. To refine the studies of embryo ecology, the scientists at the Auke Bay Fisheries Laboratory developed a system of incubating salmonid eggs in boxes of gravel similar to the system developed by Bams (1970). Biological, chemical, and physical factors such as egg density, oxygen levels, and water velocities could be controlled or monitored more precisely in the boxes than in a natural streambed. The boxes required a minimum of space and water in which substantial numbers of robust fry could be produced. In a laboratory test, 1-cubic-foot boxes seeded with 10,000 eggs of pink salmon, *Oncorhynchus gorbuscha*, produced 8,300 viable fry per box—a fivefold to tenfold increase in survival over that expected in natural redds (Bailey and Heard, 1973). Water flow in the boxes was about 2.0 liters/min. The fry from 1-cubic-foot boxes could not be distinguished from wild fry on the basis of size and ability to resist starvation in seawater. Similar incubators developed in British Columbia yielded a sixfold advantage, in numbers of returning adults, over natural reproduction of pink salmon (Bams, 1972). Thus, the concept of incubating salmon eggs in a carefully controlled gravel environment appears to have good potential as a method to increase fry production.

Auke Creek was selected as the site for the test of the incubator boxes because it is near the Auke Bay Fisheries Laboratory and because an existing pipeline provides an adequate water supply with adequate protection against freezing from nearby Auke Lake (Fig. 1). Construction of the pilot production facility began in July 1971, and the incubation of pink salmon eggs began in the fall of that year. Although the incubator box concept may evolve into a technique for low-cost mass production of salmon fry in remote areas of Alaska, some preliminary field experiments (Bailey and Heard, 1973) have ended in catastrophic losses of eggs and alevins. These losses were due principally to mechanical difficulties in maintaining a continuous flow of water at remote locations during severe cold weather. We felt that the biological feasibility of the incubator concept could be evaluated

[1]Northwest Fisheries Center Auke Bay Fisheries Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, AK 99821. Taylor was employed by the Alaska Department of Fish and Game during most of the first year of this cooperative study with the National Marine Fisheries Service. The project also involves a third agency, Territorial Sportsmen, Inc. of Juneau, Alaska. The pilot gravel incubation facility was assembled on property owned by Territorial Sportsmen, Inc.

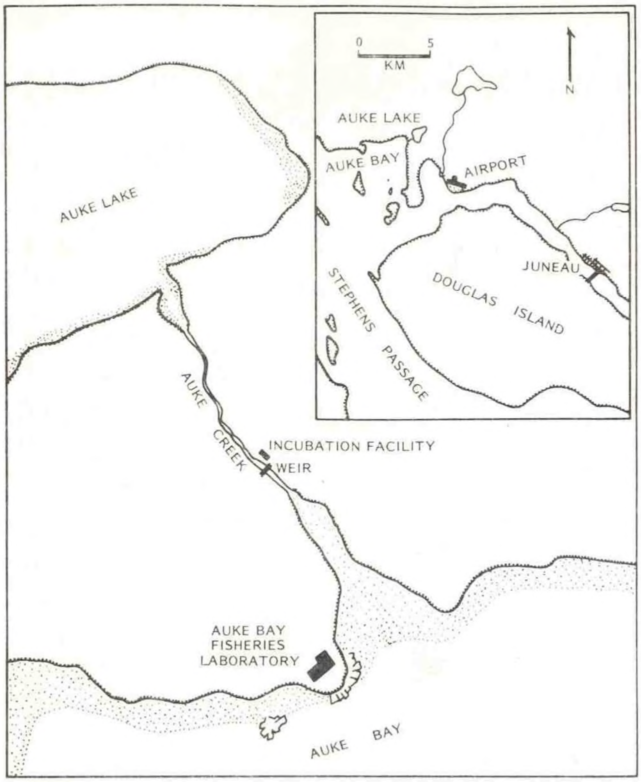

Figure 1.—Site of incubation facility on Auke Creek, southeastern Alaska, where the National Marine Fisheries Service, NOAA, and Alaska Department of Fish and Game are experimenting in a cooperative effort to rear salmon fry in gravel incubators.

on a reliable water supply such as was available at the Auke Creek site.

This report of the first 12 mo of progress (July 1971 through June 1972) describes the Auke Creek incubation facility, the techniques used in collection of eggs and operation of the gravel and tray incubators, the water quality in the incubators, and the differences between incubator fry and creek fry. The immediate objectives for the first year of operation were (1) to use boxes of gravel (gravel incubators) to produce a substantial number of pink salmon fry, (2) to compare survival and physical characteristics of fry from the gravel incubators with fry from Auke Creek and with fry produced on flat screened trays (tray incubators), and (3) to supplement the natural production of fry in Auke Creek by releasing fry of Auke Creek parentage from the gravel incubators.

BUILDING AND WATER SYSTEM

A 7.3- by 13.4-m (24- by 44-foot) heated building (Fig. 2) provided space for gravel incubators containing at least 1 million eggs, four stacks of tray incubators, a 567-liter/min water filter and ultraviolet purifier system, equipment for fry censusing and sampling, and a storage room. The building was built on the bank of Auke Creek near a fish-counting weir (Fig.1) where eggs could be collected from returning adult salmon.

Water was supplied from Auke Lake through a buried 10.2-cm (4-inch) polyvinyl chloride (PVC) pipe connected to a 35.6-cm (14-inch) wood stave pipeline; the intake was about 7.6 m beneath the surface and 1.5 m off the bottom of Auke Lake. The water was discharged into an elevated 1,000-liter fiber glass head tank inside the building, which ensured a constant 3.6 m of hydraulic head above the floor of the building. The head tank could be bypassed to supply untreated water to the incubators; the 10.2-cm bypass had about 7.9 m of hydraulic head at floor level. Because the filter-purifier system was not installed until February 1972, the bypass was not used for the 1971-72 incubation period.

One advantage of the Auke Lake water source was the relatively small risk of loss of flow because of freezing. A disadvantage of the lake water was the difference in temperature compared with Auke Creek: the lake water was comparatively cool in autumn and stable at about 4°C all winter, whereas the creek temperature was near freezing all winter. Oxygen levels were also a point of concern. Previous studies with incubating eggs in water from Auke Lake had shown that oxygen levels might drop to 8 mg/liter or lower (Bailey and Evans, 1971).

EXPERIMENTAL DESIGN

The plan of the experiment was to incubate pink salmon eggs at two different densities in four boxes of gravel and to compare the emergent fry with fry migrating seaward from natural redds in Auke Creek and with fry produced on flat trays of a Heath incubator. The evaluation of the incubator test was based on survival from eyed egg to emergent fry, fork length of preserved fry, wet weight of preserved fry, timing of emergence, and stage of development at emergence.

WATER QUALITY

Five parameters of water quality were monitored during the test of gravel incubation; viz temperature, oxygen, ammonia, carbon dioxide, and pH.

Water temperatures of Auke Creek surface flow and the incubator effluent were read once daily to the nearest 0.1°C with a mercury thermometer.

Dissolved oxygen values of samples collected at weekly intervals from the water supply and from the incubator effluents were measured to the nearest 0.01 mg/liter by the Winkler method.

Water samples were collected at least once weekly from the incoming water supply and from the incubator effluents to analyze for ammonia, carbon dioxide, and pH. The samples were analyzed in connection with a laboratory bioassay (to be reported separately) of ammonia toxicity to salmonid eggs and alevins.

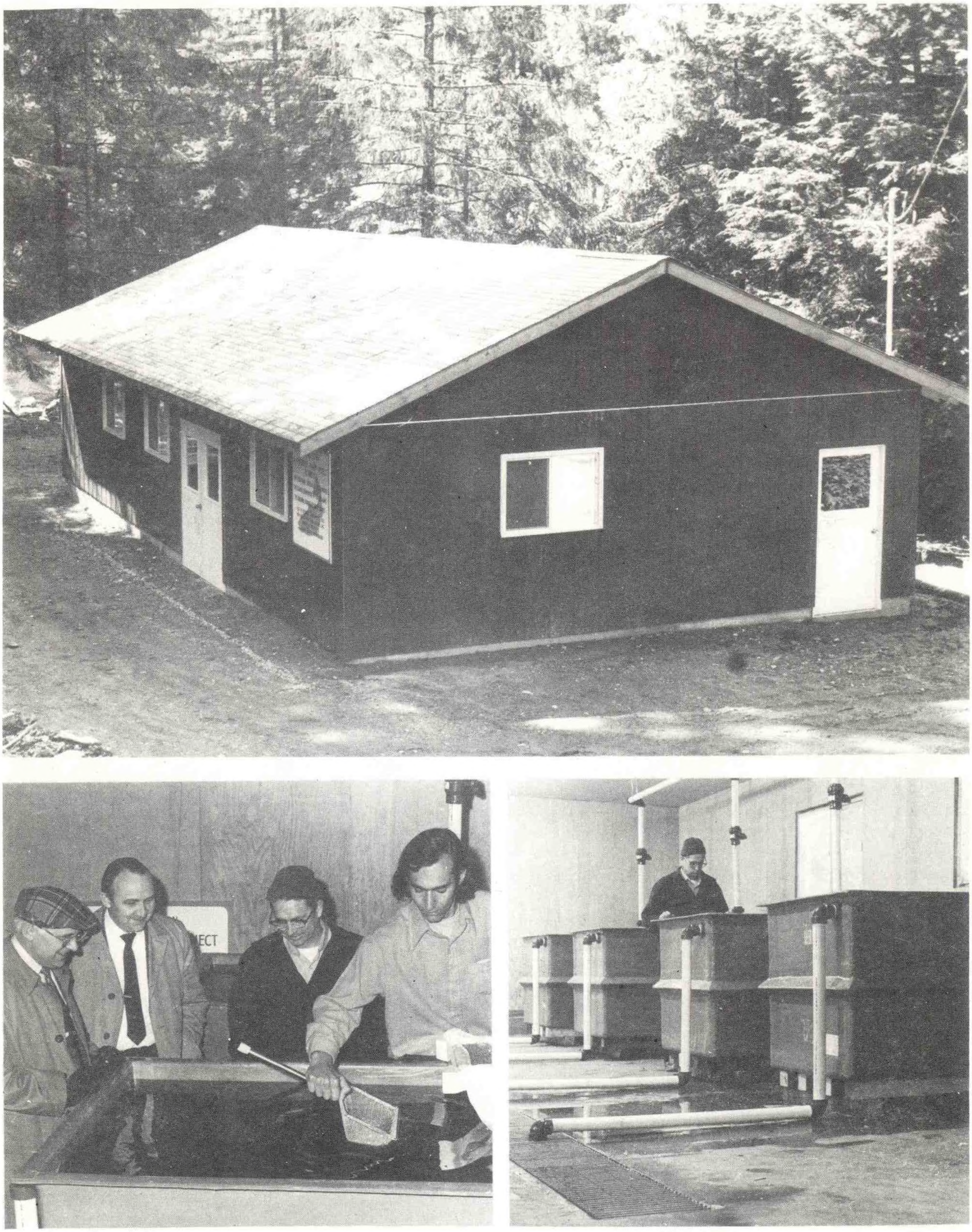

Figure 2.—Incubation facility housing gravel incubators and other equipment needed to rear salmon fry. Four incubators are shown at the lower left, and one incubator is being seeded with pink salmon eggs.

COLLECTION AND PRETREATMENT OF EGGS

Pink salmon eggs from two sources, Auke Creek and Sashin Creek, were incubated in the eyed stage in flat trays and baskets so that eggs taken on different days could be mixed before they were seeded into test incubators. Eggs from Sashin Creek were used to fulfill the numbers needed for the experimental design. To prevent genetic contamination, no fry from Sashin Creek eggs were released at Auke Creek.

Auke Creek Eggs

Eggs for three of the four boxes were obtained from Auke Creek pink salmon. Adult pink salmon began entering the stream 12 August, and the run continued until 5 October. Eggs were collected from 159 females between 19 August and 15 September. We assumed an average egg content of 1,700 eggs per female. Females generally had to be held in a pen for about 5 days to allow their eggs to ripen enough so that they could be spawned artificially. The eggs were taken by incision after the females were killed by a blow on the head and bled by cutting the caudal artery; care was taken to avoid contamination of the eggs with blood, slime, or water. Three to five females were spawned into a plastic pail, and sperm from an equal number of males was added. The eggs and sperm were then gently mixed and washed with fresh water. The flat trays and baskets in which the eggs were incubated to the eyed stage were covered to exclude light. Malachite green treatments (15 ppm for 1 h at 10-day intervals) were used to control fungus growth.

All live eggs were eyed by 28 October at which time dead eggs were removed. The live eggs were seeded into the boxes of gravel 10 November (Fig. 2). Sample counts of eggs at the time they were buried in the gravel boxes indicated less than 1% were dead or not fertilized (opaque white or contained no embryo). Drip-drained Auke Creek eggs had an average count of 606 eggs/100 ml of displaced water. The displacement method of counting eggs is accurate to about ±5% (Burrows, 1951).

Sashin Creek Eggs

Eggs for the fourth box and the Heath incubator were obtained from Sashin Creek. The Sashin Creek eggs were taken 13-19 September by the same techniques described for the Auke Creek eggs, and were incubated to the eyed stage at Little Port Walter. They were transported to Auke Bay the first week of November. Dead eggs, 10.1% of the original total, were removed after eyeing. Sample counts of eyed eggs at the time they were buried in the gravel boxes indicated only 1.2% were dead or not fertilized. Drip-drained Sashin Creek eggs had an average count of 619 eggs/100 ml of displaced water.

INCUBATOR DESIGN AND OPERATION

The boxes were 1.2 by 0.91 by 0.91 m (4 by 3 by 3 feet) deep. The surface area of gravel was 1.1 m^2, but each box occupied almost 1.5 m^2 of floor space. The incubators containing gravel were of two types—Bams box and NMFS box—which differed only in the method of achieving uniform upwelling flow of water through the eggs and gravel. The method of dispersing water in the NMFS box required less space, and therefore more space was available for incubation of eggs and alevins in NMFS boxes than in Bams boxes.

The two types of gravel incubators and the Heath incubator are designated in this report as Bams boxes A and C, NMFS boxes B and D, and tray incubator.

Bams Boxes

Water was introduced into the Bams box through a grid of pipes laid on the bottom inside the box. The grid of pipes in the Bams box (Figs. 3, 4) comprised a manifold pipe and eight pairs of cross pipes. The manifold pipe was 5.1-cm (2-inch) PVC, and the cross pipes were 42.5 cm long, 1.9-cm (¾-inch) PVC placed on 15-cm centers. The cross pipes had 80 pairs of 2-mm ($\frac{5}{64}$- inch) holes drilled 90° apart and were placed holes up on 8-cm (3-inch) centers. The coarse gravel substrate in which the grid of pipes was buried and which was used as support for the eggs was river

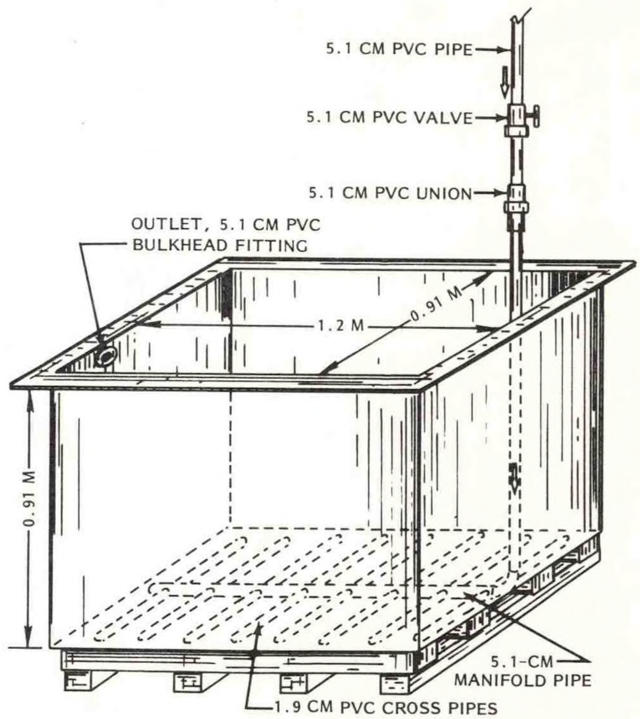

Figure 3.—Bams box used for incubating pink salmon eggs in a gravel substrate. Grid of perforated pipes on bottom of box provides uniform distribution of upwelling flow.

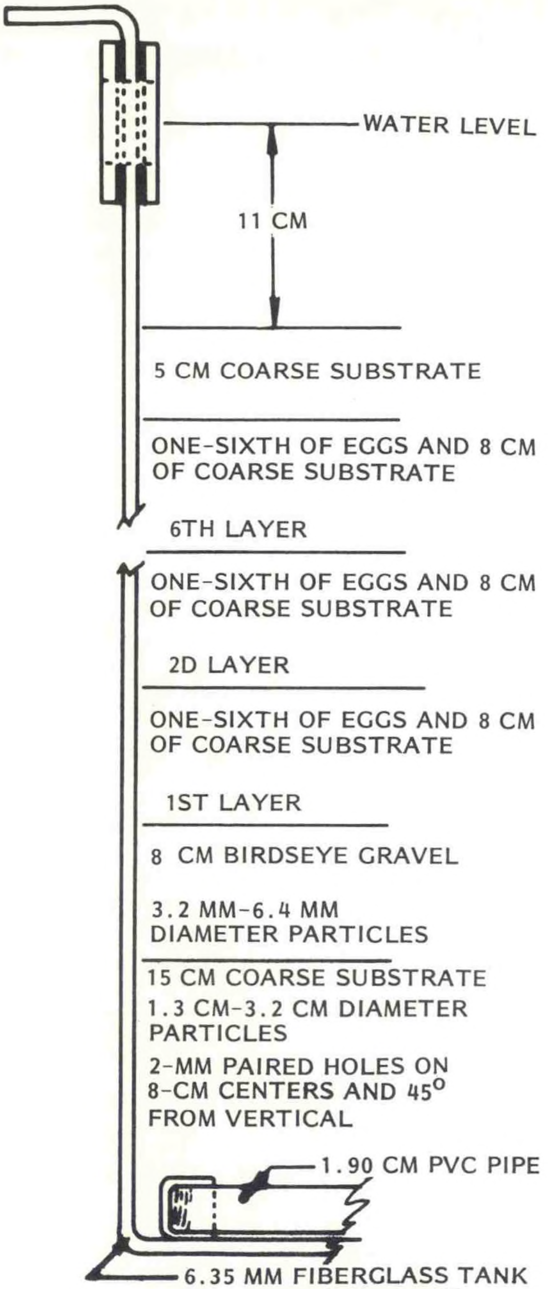

Figure 4.—Cross-section detail of Bams box used for incubating pink salmon eggs in gravel substrate (see Fig. 3).

gravel that had been washed and graded to remove all particles under 1.3 cm (½ inch) and over 3.2 cm (2¼ inch) in diameter. Crushed rock of 1.9- to 3.8-cm (¾- to 1½-inch) particle size is recommended but was not available. An 8-cm layer of bird's-eye gravel, 3.2- to 6.4-mm (⅛- to ¼-inch) particle diameter, acted as a pressure plate to achieve uniform water velocities in all parts of the box. The layer of bird's-eye gravel was also river gravel washed and graded to remove all particles under 3.2 mm and over 6.4 mm in diameter. The boxes were loaded by placing the pipe grid on the bottom and packing a 15-cm layer of coarse substrate around and on top of it; this was followed by the 8-cm layer of bird's-eye gravel. Six 8-cm layers of coarse substrate were then placed in the box, and one-sixth of the total number of eggs was placed on top of each layer. The last layer of eggs was covered with 5 cm of coarse substrate. About 11 cm of open water was left at the top so that emergent fry could swim to the outlet on the side of the box. With this method of loading the box, about 0.57 m^3 of coarse substrate habitat was accessible to the incubating alevins.

Bams box A was loaded with 112,200 Sashin Creek eggs and box C with 53,600 Auke Creek eggs (Table 1). Water flow to the high-egg-density box (A) was 56 liters/min and to the low-density box (C) was 28 liters/min.

Table 1.—Density of eggs, water flow, and apparent velocity of NMFS boxes B and D and Bams box C (Auke Creek pink salmon eggs) and Bams box A (Sashin Creek eggs).

	Bams boxes		NMFS boxes	
	A	C	B	D
Density:				
Eggs/box	112,200	53,600	56,100	112,100
Eggs/m^2	100,600	50,300	50,300	100,600
Eggs/m^3	198,000	94,700	74,200	148,400
Waterflow:				
Liters/min	56	28	28	56
Liters/min/10,000 eggs	5.0	5.2	5.0	5.0
Apparent velocity ($cm^3/h/cm^2$)	302	151	151	302

NMFS Boxes

In the NMFS box, water was introduced through a false bottom of perforated plastic sheet stock (Figs. 5, 6). The false bottom was a sheet of perforated polypropylene plastic 3.2 mm (⅛ inch) thick with 2.4-mm ($\frac{3}{32}$-inch) holes drilled on 12-mm ($\frac{15}{32}$-inch) staggered centers. The perforated plate was supported on 19-mm (¾-inch) diameter by 3-cm (1 $\frac{3}{16}$- inch) long PVC rods on 7.6-cm centers. A 2.5-cm (1-inch) layer of bird's-eye gravel was placed on top of the perforated plate to promote even distribution of water flow through the eggs and gravel. The bird's-eye gravel was covered with 15 cm (6 inches) of coarse substrate; then followed six 8-cm (3-inch) layers of coarse substrate. As with the Bams box, one-sixth of the total number of eggs was placed on top of each layer. The last layer of eggs and gravel was covered with 7 cm of coarse substrate. About 11 cm of open water was left at the top so that fry could swim to the outlet on the side of the box. Because the perforated plate system of flow dispersal occupied less space than the perforated grid system, the NMFS boxes had about 0.76 m^3 of space available for incubating

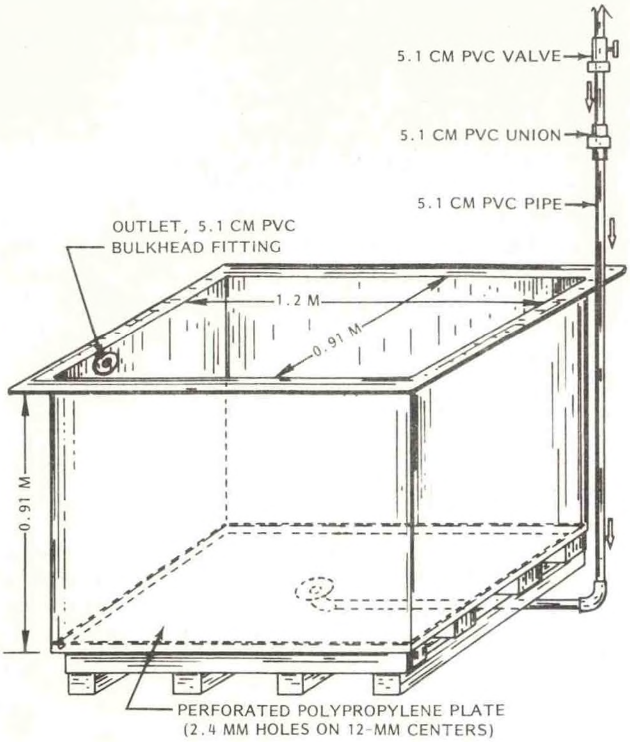

Figure 5.—NMFS box used for incubating pink salmon eggs in a gravel substrate. Perforated false bottom provides a uniform distribution of upwelling water.

alevins, compared with about 0.57 m^3 in the Bams box.

NMFS box B was loaded with 56,100 and box D with 112,100 Auke Creek eggs (Table 1). Water flow to the low-density box (B) was 28 liters/min and to the high-density box (D) was 56 liters/min.

Tray Incubator

The tray incubator (Heath) was seeded with 8,000 Sashin Creek eggs in each of two trays. The density was reduced to about 2,000 alevins per tray after hatching. Water flow was set at 19 liters/min. The fry produced on the flat screen trays without gravel were compared with fry from the gravel incubators and from the creek. The tray incubator also provided a source of fry to establish the basic parameters of an index to stage of development (Bams, 1970).

NATURAL SPAWNING IN AUKE CREEK

In 1971, 737 females and 1,035 males were placed above the weir and most spawned in the 297-m section of stream between the weir and Auke Lake, but a few spawned in Lake Creek above Auke Lake. The Auke Creek streambed above the weir has approximately 859 m^2 suitable for spawning. A few pink salmon also spawned in the intertidal zone below the weir, but we did not estimate their number.

ENUMERATION OF FRY

Fry that emerged from the three boxes seeded with Auke Creek eggs (Table 1) were allowed to swim through parallel troughs that divided them into four groups. Three of the groups were allowed to escape immediately into Auke Creek, and the fourth group from each box was released the following night after enumeration and collection of samples of fry for size measurements. Total counts of fry that swam through each of the four partitioned passages on 12 successive

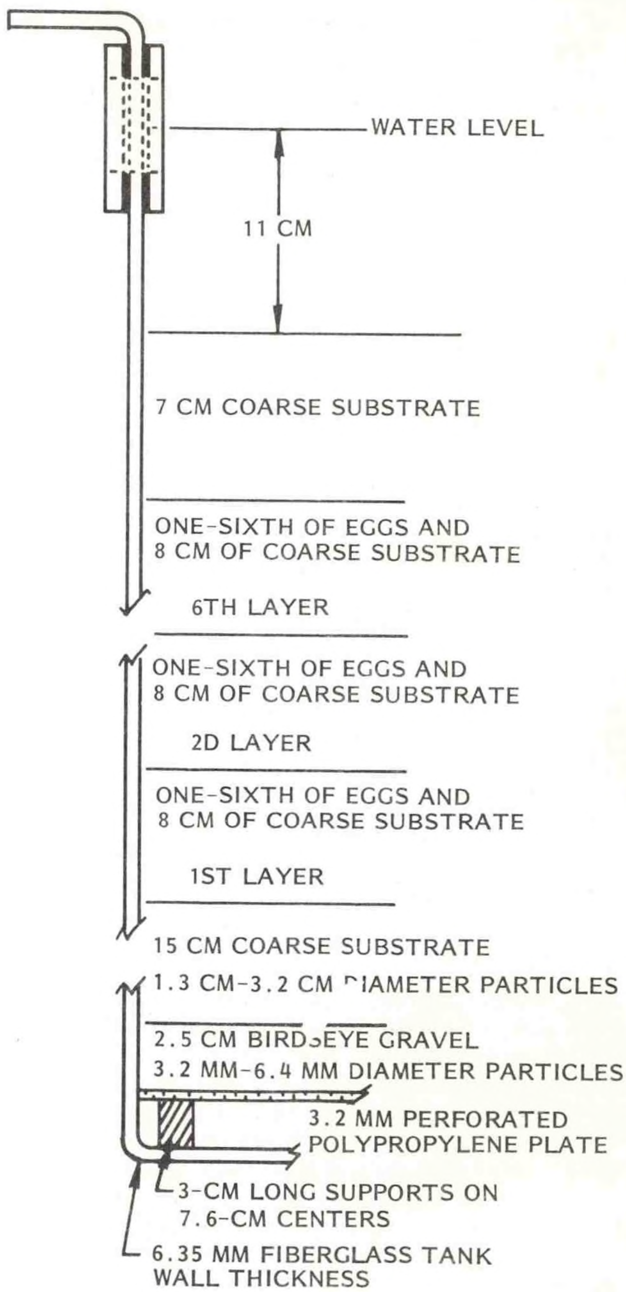

Figure 6.—Cross-section detail of NMFS box used for incubating pink salmon eggs in gravel substrate (see Fig. 5).

nights were treated statistically as a two-way analysis of variance with one observation per cell. The calculated F value for passages (4.77) was significant at the 1% level with 3 and 33 df. Therefore, we concluded the four partitioned passages did not divide the migrating fry equally. We compensated for the apparent bias by retaining the fry from a different passage each night on a rotating basis. At the end of the migration, we calculated the total number of fry by two methods: first by assuming the nightly counts represented 25% of the migrating fry, and second by applying the estimates of sampler bias to the nightly counts. The two methods yielded estimates that agreed within 1%.

Fry that emerged from the box seeded with Sashin Creek eggs (Table 1) were counted daily and destroyed after the samples were obtained for size measurements.

The population of creek fry resulting from natural spawning was estimated by a hydraulic pump census (McNeil, 1964) of the streambed above and below the weir. We used a 0.1 m^2 sampling frame. Sampling was physically difficult because of the presence of many boulders and outcroppings of bedrock. Standard error of mean was 45% of the value of the mean fry density.

COLLECTING AND PROCESSING SAMPLES OF FRY

To compare the size of fry from each type of incubation environment, samples of 50 fry were collected and preserved in 5% Formalin daily from each gravel incubator and as available from a migrant fry trap on Auke Creek. Samples of fry from the incubator tray were preserved weekly 21 March to 4 May 1972. Samples were kept in the preservative for 6 wk or more. The fry were then measured to the nearest millimeter of fork length and weighed to the nearest milligram of wet weight. The stage of development of emergent fry was described by Bams (1970) developmental index:

$$K_D = \frac{10 \sqrt[3]{\text{weight in milligrams}}}{\text{length in millimeters}}$$

Because it was not practical to measure all of the preserved fry, representative samples from each incubator and from Auke Creek were selected about once each week. Weighted means and variances of pooled data were computed on the basis of the fraction of the migrant fry represented by each sample. Statistical comparisons were made of lengths, wet weights, and Bams (1970) developmental index as follows:

$$\overline{Y}_w = \Sigma W_i \overline{Y}_i ,$$

where $\overline{Y}_w$ = weighted mean,
$\overline{Y}_i$ = observed mean measurement in ith period,
W_i = proportion of run leaving in ith period.

$$\widehat{V(\overline{Y}_w)} = \sum_{i=1}^{n} W_i^{\,2} \widehat{V(\overline{Y}_i)} ,$$

where $V(\overline{Y}_w)$ = estimate of weighted variance,
$V(\overline{Y}_i)$ = sample variance of estimated mean in ith period,
n = number of periods sampled.

RESULTS

The results of this study can be conveniently divided into those that measured and compared various parameters of the artificial and natural incubation environments and those that measured and compared emergence and morphometric features of the artificially and naturally produced pink salmon fry.

Water Quality

Water temperatures in the incubators and in the stream were recorded daily during the entire incubation period. Dissolved oxygen, ammonia, carbon dioxide, and pH of the influent (incoming water supply) and the effluents from the incubators were recorded at approximately weekly intervals from the beginning of hatching of the eggs until most of the fry had emerged.

Temperature.—During the time the eggs were collected and fertilized (21 August to 15 September 1971), Auke Creek water temperature dropped from 17° to 12°C (63° to 54°F), and the incubator temperature dropped from 8.3° to 7.2°C (47° to 45°F) (Fig. 7). The incubator temperatures were lower than the creek because the water for the incubators came from below the surface of the lake and the creek water came from the surface of the lake. The incubator temperature remained near 7°C (45°F) until 18 October and then gradually dropped to 3.5° to 3.8°C (38° to 39°F), where it remained from 16 November 1971 through 15 May 1972. Auke Creek temperature was higher in the fall and lower in the winter than incubator temperature. Auke Creek temperature dropped from 17°C at the beginning of the spawning season to the winter level of 0° to 1°C (32° to 34°F) in late November.

Oxygen.—The oxygen level of the incubation effluents (Fig. 8) never dropped below 7.5 mg/liter (57% saturation) even though the incoming water supply was only 61 to 69% saturated with oxygen. Oxygen consumption rates were computed on the basis of numbers of fry emerging—about 0.02 mg of oxygen per fry per hour (Table 2). These estimates of oxygen comsumption rates are actually higher than the true rate for live alevins because dead eggs and alevins

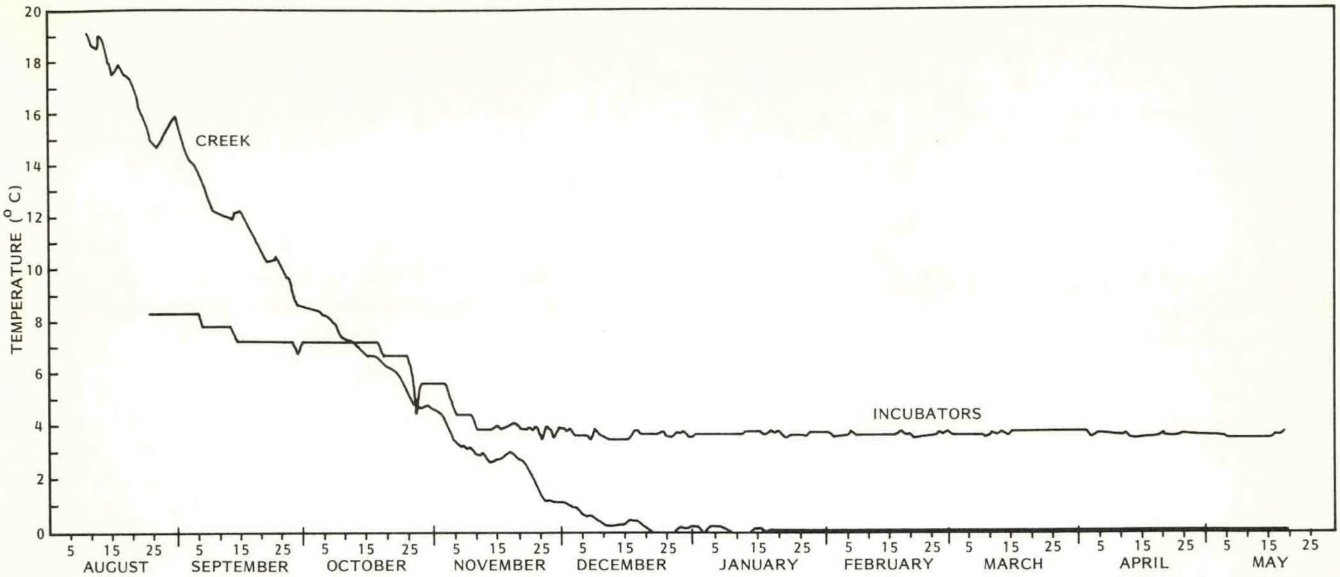

Figure 7.—Temperatures of water in gravel incubators and of surface water in Auke Creek, 21 August 1971 to 15 May 1972.

comsume oxygen (Brickell, 1971) and were not accounted for in the estimates.

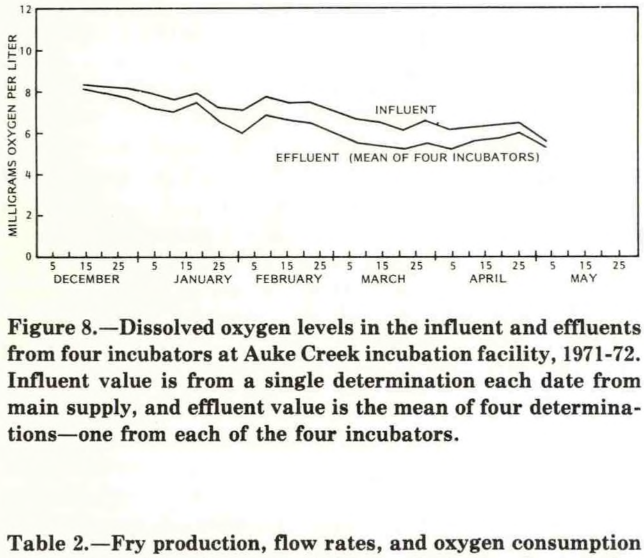

Figure 8.—Dissolved oxygen levels in the influent and effluents from four incubators at Auke Creek incubation facility, 1971-72. Influent value is from a single determination each date from main supply, and effluent value is the mean of four determinations—one from each of the four incubators.

Table 2.—Fry production, flow rates, and oxygen consumption in four gravel incubators at Auke Creek during the period 1 February through 4 April 1972.

Incubator	Number of emergent fry	Water flow (liter/h)	Total oxygen consumed (mg/h)	Oxygen consumed per fry (mg/h)
Bams box				
A	109,100	3,360	1,633	0.0150
C	48,300	1,680	842	0.0174
NMFS box				
B	50,500	1,680	1,039	0.0206
D	88,800	3,360	1,426	0.0161

Sediment.—A brown filamentous sediment accumulated in all of the incubators during the incubation period. The sediment was identified as precipitated iron compounds on and among the sheaths of iron bacteria.

Fry Production and Quality

The number of fry produced from Auke Creek eggs in our incubators was about equal to the production of fry from natural spawning in Auke Creek. We collected random samples of migrant fry from the incubators and from the creek to compare length, weight, and stage of development. Practically all of the fry migrated from the stream and from the incubators in April 1972. Except for fry needed to evaluate size and stage of development, fry from the Auke Creek eggs were released to enhance the natural run of pink salmon in Auke Creek.

Survival from egg to fry.—We spawned 159 females and obtained 234,000 eggs or 86% of their estimated contents of 270,000 (Table 3). Loss of eggs in this operation was attributed to attempts to take eggs

Table 3.—Number of pink salmon eggs or fry at different life stages and survival between stages for Auke Creek eggs incubated in gravel incubators.

Life stage	Number present	Percent survival	
Eggs in females	270,300	—	
Green eggs	234,000	86	-69
Eyed eggs	221,800	95	
Emergent fry	187,600	84	

from females that were not ripe (i.e. eggs still attached to the ovarian membranes) and to shedding of eggs by females that had become overripe in the holding pen. Survival from newly fertilized eggs (green eggs) to eyed eggs was 95%. Losses during this interval depend on several factors: the ripeness of the fish; the care taken in handling the females, eggs, and sperm; and the growth of fungus among the incubating eggs. Typically, spawn takers expect 94 to 98% of the eggs they collect to survive to the eyed stage. Survival from the eyed egg to the emergent fry stage was 84%.

A census of 36 random points with a hydraulic pump in April indicated that only 157,200 fry resulted from natural spawning in Auke Creek above the weir. The potential egg deposition (PED) of the 737 females was 1,252,900, so the survival was about 12.5% from PED to fry.

No attempt was made to compare survival of fry from the tray incubator with survival of those from the gravel incubators.

Effects of density on survival from egg to fry.—The density of eggs in the boxes ranged from 74,200 to 198,000 eggs/m^3 of gravel and survival from eyed eggs to fry ranged from 79 to 97% (Table 4). Although the average survival in the gravel incubator was 89%, the inaccuracies inherent in the displacement method used to count eggs could amount to ±5% and only four incubators were tested. With this degree of accuracy and only two incubators in each test, only differences of more than 10% could be considered significant. The cause of low survival in NMFS box D was not identified and could not be attributed entirely to the high density of eggs because Bams box A yielded good survival at the same density.

Table 4.—Numbers of eyed pink salmon eggs and survival to emergent fry in individual incubators.

Incubator	Number of eyed eggs	Numbr of emergent fry	Percentage survival
Bams box A	112,200	109,100	97
NMFS box B	56,100	50,500	90
Bams box C	53,600	48,300	90
NMFS box D	112,100	88,800	79

Effects of genetics and box design on survival from egg to fry.—Differences in survival due to genetic characters of parents or box design could not be conclusively demonstrated in this test because of the small number of samples. The one box of Sashin Creek eggs, Bams box A, had an eyed-egg-to-fry survival of 90%, whereas three boxes of Auke Creek eggs had an average survival of 89% (range 79 to 97%). Average survival from eyed egg to emergent fry was 90 to 97% in the two Bams boxes compared to 79 and 90% in the two NMFS boxes. The comparatively low survival in NMFS boxes may have been only a chance occurrence, and further tests should be conducted with this type of box.

Effects of conditions in the incubators on size and stage of development of fry.—The completeness of absorption of the yolk by fry when they leave the incubating bed, either natural or artificial, bears directly on the survival of the fry in the wild. Fry with a large amount of yolk have not attained their maximum potential size, are relatively poor swimmers, and are unnecessarily vulnerable to predators. On the other hand, fry that have absorbed all of their yolk are losing weight and soon become weakened and emaciated and again unnecessarily vulnerable to predators. Fry emerge from gravel on their own volition and presumably do so at the stage of development that ensures maximum survival. With tray incubators, the fry are locked in with screen covers until released.

The hatchery operator must examine his tray fry and decide when to release them. In our experiment, the tray fry were not released, but based on measurements of samples preserved 21 March to 11 April 1972, they could logically have been released on about 21-28 March, when the tray fry had a mean K_D value of 1.97 (Table 5) which corresponded to the mean K_D value of 1.97 of emergent fry from three of the four gravel incubators. Tray fry reached maximum weight about 28 March. By 4 April, the tray fry were obviously becoming emaciated and losing vigor. Therefore, if maximum survival at sea had been the aim, they would have been released when they reached maximum weight, or a developmental index of about 1.97. Samples of tray fry collected 21 and 28 March had best pooled mean lengths, weights, and indices of development (Figs. 9, 10, 11); and we used these as a base to compare these factors in fry from the creek and gravel incubators.

The source of eggs and incubation environment influenced the size of fry, but the density of eggs did not. In gravel incubators, the Sashin Creek eggs yielded significantly longer fry than Auke Creek eggs (Fig. 9). With one exception, Sashin Creek eggs in gravel yielded significantly heavier fry (Fig. 10) than the Auke Creek eggs in gravel. Sashin Creek eggs incubated in gravel boxes yielded significantly longer and heavier fry than Sashin Creek eggs incubated in the trays. Creek fry were significantly longer than either gravel fry or tray fry regardless of egg source. Moreover, with the exception of Sashin Creek fry from Bams box A, creek fry were heavier than fry from incubators. Fry of Auke Creek parentage from the gravel incubators were significantly longer than fry of Sashin Creek parentage from the tray incubator, but in only one gravel incubator (Bams box C) were fry of Auke Creek

Table 5.—Mean and variance of lengths, weights, and developmental indices of pink salmon fry from Auke Creek, gravel incubators (Bams and NMFS boxes), and tray incubators.

Incubation site and date	Number	Length (mm) Mean	Length (mm) Variance	Weight (mg) Mean	Weight (mg) Variance	Index K_D Mean	Index K_D Variance
Auke Creek							
11 April	50	32.00	0.9796	257.3	664.7	1.986	0.00166
18 April	49	32.55	1.6692	247.7	831.2	1.927	0.00265
22 April	49	32.96	0.8316	252.3	507.2	1.916	0.00169
26 April	49	32.65	0.9813	250.5	446.2	1.930	0.00190
5 May	50	32.08	1.7894	254.6	1,107.9	1.973	0.00300
17 May	50	32.44	0.6596	260.9	434.1	1.969	0.00272
Bams box A							
30 March	50	31.56	1.3943	244.0	690.9	1.978	0.00266
5 April	50	32.06	0.8739	256.1	598.8	1.979	0.00198
11 April	50	32.18	1.1710	249.7	755.6	1.954	0.00156
18 April	50	32.08	0.5649	254.8	562.3	1.974	0.00190
22 April	48	31.98	0.9570	255.9	631.9	1.984	0.00188
26 April	50	31.82	0.9669	252.0	570.1	1.983	0.00130
5 May	50	32.04	0.8555	245.1	451.5	1.952	0.00284
Bams box C							
30 March	50	31.40	1.3469	234.6	829.0	1.961	0.00186
5 April	50	31.32	1.2833	240.0	822.0	1.981	0.00214
11 April	50	32.00	0.9388	250.0	525.3	1.967	0.00157
18 April	50	31.86	1.2249	246.8	707.8	1.967	0.00167
22 April	50	31.84	1.0351	255.3	708.7	1.990	0.00196
26 April	49	32.06	0.6003	255.9	414.0	1.979	0.00164
5 May	50	31.86	0.6126	251.0	500.6	1.978	0.00263
NMFS box B							
30 March	50	31.28	0.9812	235.2	643.6	1.971	0.00188
5 April	50	31.38	1.0159	236.6	512.4	1.969	0.00157
11 April	50	31.90	1.1531	247.2	514.6	1.966	0.00151
18 April	50	31.76	0.6759	243.4	508.2	1.964	0.00153
22 April	50	32.10	0.8265	254.2	367.5	1.973	0.00194
26 April	50	32.06	1.3228	252.8	601.9	1.971	0.00238
5 May	50	31.94	0.6698	245.0	415.0	1.958	0.00173
NMFS box D							
30 March	50	31.44	1.1494	228.6	701.0	1.942	0.00149
5 April	50	31.60	1.0612	243.4	696.2	1.973	0.00170
11 April	50	31.80	1.0204	232.7	591.0	1.932	0.00154
18 April	50	32.20	0.8571	249.4	484.5	1.954	0.00164
22 April	49	32.04	0.7483	254.7	397.0	1.977	0.00185
26 April	50	31.98	0.5914	243.9	381.7	1.952	0.00130
5 May	50	32.26	0.6045	250.5	373.7	1.953	0.00225
Tray							
21 March	49	31.13	1.2801	233.7	824.0	1.976	0.00231
21 March	50	31.30	1.4388	234.1	772.8	1.966	0.00141
28 March	50	31.70	0.8309	246.0	626.3	1.974	0.00205
28 March	50	31.64	1.5004	241.4	996.0	1.964	0.00212
4 April	50	32.03	1.7698	234.8	1,165.9	1.921	0.00257
4 April	50	32.10	2.2551	235.8	1,242.3	1.921	0.00628
11 April	50	32.06	1.1175	227.7	941.3	1.901	0.00391
11 April	50	31.98	1.2853	227.7	941.3	1.906	0.00397

parentage heavier than fry of Sashin Creek parentage from the tray incubator. The gravel incubator fry, with the exception of fry from box D, had significantly higher K_D indices (average 1.970 K_D units) (Fig. 11) than creek fry (average 1.954 K_D units). Fry from the two high-density boxes, Bams box A and NMFS box D, were as long as or longer than fry from the two low-density boxes, NMFS box B and Bams box C. The comparatively lighter weight of fry from high-density NMFS box D was probably relatable to the uniden-

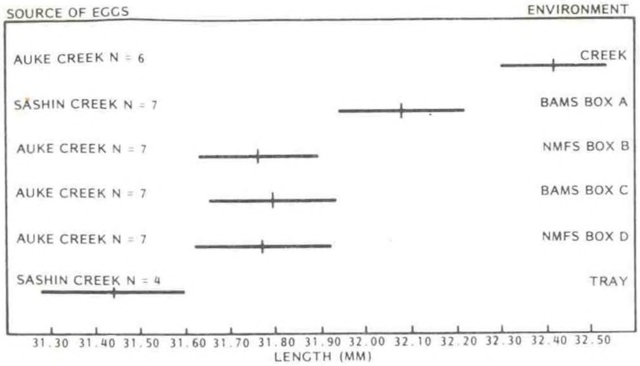

Figure 9.—Lengths of preserved fry in relation to source of eggs and incubation environment; the length of each horizontal line equals two times the standard deviation of pooled means from N samples of 50 fry per sample.

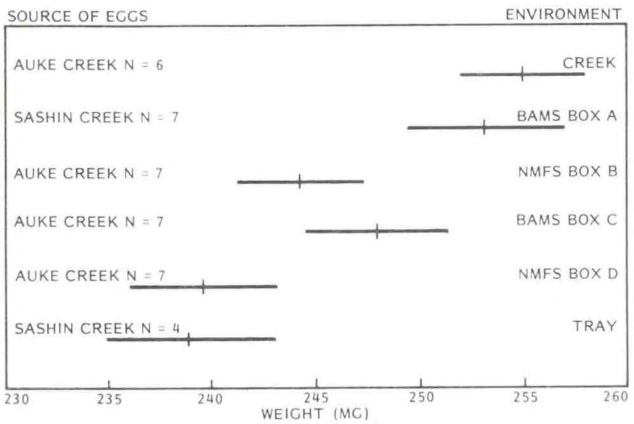

Figure 10.—Weights of preserved fry in relation to source of eggs and incubation environment; the length of each horizontal line equals two times the standard deviation of pooled means from N samples of 50 fry per sample.

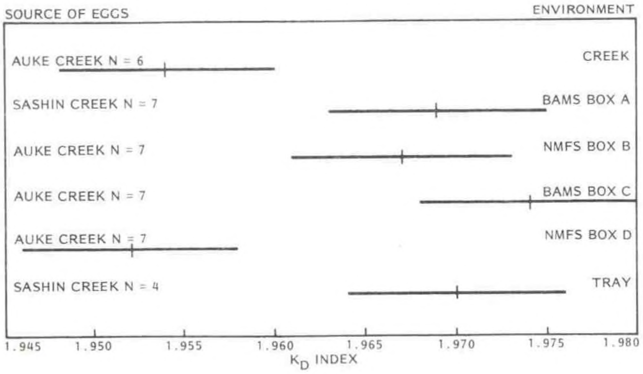

Figure 11.—Indices of development, K_D, of preserved fry in relation to source of eggs and incubation environment; the length of each horizontal line equals two times the standard deviation of pooled means from N samples of 50 fry per sample.

tified factor or factors that caused low survival in this box.

The K_D index of alevins on trays decreased at a rate of 0.005 K_D units per day during the last month before hypothetical release of fry. If the K_D factor of alevins in gravel decreased at the same rate, then the gravel incubator fry migrated to sea at a developmental stage 3 days younger than the creek fry.

The alevins on trays were increasing in length at the rate of 0.08 mm/day during the last month before hypothetical release. If alevins in gravel were growing at a similar rate, 3 days additional growth would have increased their mean length from the observed 31.77 mm to 32.01 mm, which is still shorter than the 32.42-mm observed mean length of creek fry. Bams (1970 and 1972) produced gravel incubator fry that emerged prematurely and were slightly shorter than creek fry, but if the above correction was made for stage of development, Bams' incubator fry had the potential to equal creek fry in length.

Time of emergence of incubator-reared and wild fry.—Fry emerged from the gravel incubators and migrated to Auke Bay between 23 March and 14 May; over 98% of them left the incubators during the 34-day period between 30 March and 3 May. The midpoint of emergence occurred 10 April for NMFS box D, 14 April for NMFS box B, and 16 April for Bams boxes A and C (Fig. 12). These dates of emergence contrast sharply with the 21-28 March hypothetical best release dates for tray fry.

The timing of migration of creek fry from Auke Creek could not be accurately determined because deep snow and ice delayed installation of a fry-counting trap. High streamflows resulting from rain and melting snow made it impossible to operate the trap continuously. The greatest trap count (680 fry) was recorded 11 April (Table 6), the first morning after the trap was in operation. By that time, 40% of the incubator fry had left the gravel boxes. A few creek fry were still leaving Auke Creek on 14 June, but heavy precipitation and high streamflows prevented further trapping. The trap catches suggest that timing of creek fry migrations was generally similar to timing of incubator fry migrations but that creek fry continued to migrate over a much longer span of time.

DISCUSSION

This first attempt at mass production of high-quality pink salmon fry from gravel incubators at Auke Creek yielded 187,600 fry. The gravel incubators were evaluated on the basis of egg-to-fry survivals, size and stage of development in relation to conditions in the incubators, and time of emergence and seaward migration in relation to conditions in the estuary.

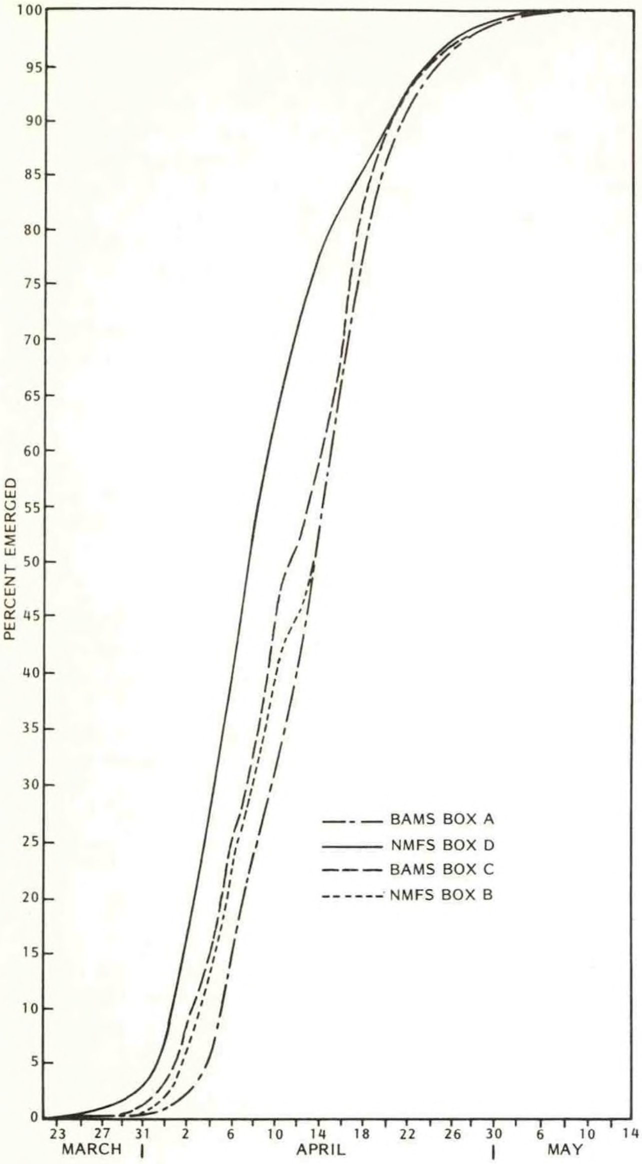

Figure 12.—Daily cumulative percentage of emergence of pink salmon fry from each gravel incubator at Auke Creek incubation facility between 23 March and 14 May 1972.

Survival

Survival from PED to emergent fry was 69% for artificial incubation compared to 12.5% for natural spawning in the creek; a gain ratio (gain ratio = survival in hatchery ÷ survival in creek) of 5.5. Gain ratios of 1.8 to 6.04 have been reported by Bams (1970, 1972, 1973) for pink salmon incubated in boxes of gravel in British Columbia. Approximately 181,000 incubator fry were released alive to migrate seaward with the 157,200 wild fry from Auke Creek. The remaining incubator fry, about 6,600, were used for size measurements.

Eyed-egg-to-fry survival in the gravel incubators at Auke Creek was 84% compared to 82 to 95% survivals reported by Bams (1970, p. 1438; 1973, p. 4). This was encouraging because the water supply was not filtered at Auke Creek as it was in the British Columbia tests. The use of gravel incubators will be more practical if filtration of the water is not required.

Size and Stage of Development

Fry from the gravel incubators were intermediate in size between the larger creek fry and the smaller tray fry. Pink salmon fry emerged from the gravel incubators at an earlier stage of development, about 3 days, than from the Auke Creek streambed. We postulate that salmon fry actually find it easier to emerge from deep-gravel incubators which contain no sand than from streambeds which do contain sand. An additional 3-day development would not have

Table 6.—Index trap catches of creek-incubated pink salmon fry migrating from Auke Creek, 11 April to 14 June 1972.

Date	Hours fished	Number caught	Date	Hours fished	Number caught
April			May		
11	2000-2400	680	14	—	—
12	2000-2400	250	15	—	—
13	—	—	16	—	—
14	2000-2400	266	17	1630-0800	312
15	—	—	18	1630-0800	322
16	—	—	19	1630-0800	532
17	—	—	20	—	—
18	2030-2400	173	21	—	—
19	2000-2400	321	22	—	—
20	2000-2400	404	23	—	—
21	2000-2400	205	24	—	—
22	2000-2400	148	25	1630-0800	73
23	—	—	26	1630-0800	26
24	2000-2400	203	27	—	—
25	2000-2400	335	28	—	—
26	2000-2400	244	29	—	—
27	2000-2400	67	30	—	—
28	2000-2400	130	31	—	—
29	2000-2400	91			
30	—	—	June		
May			1	—	—
1	2100-0830	47	2	—	—
2	2100-0800	58	3	—	—
3	2100-0800	81	4	—	—
4	2100-0800	122	5	—	—
5	2100-0800	226	6	—	—
6	2100-0800	147	7	—	—
7	—	—	8	—	—
8	—	—	9	—	—
9	—	—	10	—	—
10	—	—	11	—	—
11	—	—	12	—	—
12	—	—	13	1630-0800	89
13	—	—	14	1630-0800	33

made up for the difference in size between incubator fry and creek fry. The comparatively small size of fry from gravel incubators at Auke Creek must be attributable to our failure to provide a completely optimum environment. At least three factors warrant further investigation and improvement at the Auke Creek Station: (1) substrate particle size and shape, (2) accumulation of brown sediment in the incubators, and (3) dissolved oxygen.

Crushed rock was used by Bams (1970 and 1972) as the substrate for incubation of salmon eggs, whereas we used river gravel. The relative paucity of flat surfaces of river gravel may have minimized the number of suitable interstices where alevins could find the physical support and undisturbed rest necessary for maximum growth.

The brown sediment produced by iron bacteria in the incubators may have interfered with the uniform flow of water through the gravel interstices and physically restricted respiratory movements of gill opercula. Further study is needed to determine whether the brown sediment has a growth-inhibiting effect on salmon embryos.

Dissolved oxygen in the effluents from the incubators exceeded 7.5 mg/liter, which is generally considered adequate for salmon. Percent of saturation values for oxygen in the influent ranged from 61 to 69% while percent of saturation values in the incubator effluents ranged from 57 to 68%. Higher oxygen levels might have resulted in larger fry. Itazawa (1971) found that rainbow trout 30 to 35 cm long in water at 2° to 9°C could not maintain normal arterial oxygen levels when oxygen concentration in the surrounding water dropped below 63% of saturation. He called this the "critical level of saturation" for rainbow trout. Less oxygen would presumably constitute a stress which could suppress growth. Salmon alevins might have a critical level similar to rainbow trout. If this is true, then growth of alevins may have been inhibited by low oxygen concentrations in this test of gravel incubation.

Time of Emergence

The time of emergence of fry from the gravel may be crucial to their survival. Survival in the estuary may depend on the arrival of fry coinciding with seasonal phytoplankton blooms, which could offer a measure of concealment from predators, or with seasonal zooplankton blooms, which are the major source of food. First spring phytoplankton blooms occur in Auke Bay each year between mid-March and early April, and zooplankton blooms soon follow (Wing and Reid, 1972). In 1972, zooplankton increased from scarce to relatively abundant sometime between 10 April 1972 and 18 May 1972 (B. L. Wing, Northwest Fisheries Center, Auke Bay Fish. Lab, NMFS, NOAA, Auke Bay, AK 99821, pers. commun.). Most of the incubator fry left Auke Creek to enter the estuary in April when zooplankton populations were increasing. Many of the creek fry migrated in April with the incubator fry, but some creek fry continued to migrate in May.

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