PRODUCTION OF FRY AND ADULTS OF THE 1972 BROOD OF PINK SALMON, *ONCORHYNCHUS GORBUSCHA*, FROM GRAVEL INCUBATORS AND NATURAL SPAWNING AT AUKE CREEK, ALASKA

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ABSTRACT

Production of fry and adults of the 1972 brood of pink salmon, *Oncorhynchus gorbuscha*, at Auke Creek, Alaska, was compared between a gravel incubator hatchery and natural spawning. Natural production in the creek above the hatchery weir (estimated from hydraulic sampling) was 73,900 fry (SE: 32,800) from an estimated initial seeding of 934,065 eggs (SE: 42,811) for a survival rate of 0.079 (SE: 0.035). An estimated total of 579,000 unfed fry (SE: 25,296) were released from the hatchery for a comparable survival rate of 0.743 (SE: 0.047). Exactly 84,000 of the hatchery fry and 5,500 of the creek fry were released after being marked by clipping fins. All adults returning to the weir were examined for marks, and some additional marks were recovered from sport and commercial fishermen; 667 marked hatchery fish and 74 marked creek fish were recovered. Estimated survival of hatchery fry to returning adult was only 0.0079 (SE: 0.0003) equal to 0.59 (SE: 0.071) the corresponding estimate of 0.0135 (SE: 0.0016) for creek fry, which suggests that hatchery fry were inferior to creek fry in the marine environment; however, hatchery fry emigrated seaward 2 wk earlier than creek fry and may have encountered less favorable marine conditions. Survival from eggs to returning adult stage was 5.50 times (SE: 2.59) higher for hatchery fry than for creek fry because of much greater survival from egg to fry in the hatchery; the difference is not statistically significant. Hatchery fry were generally shorter but heavier than creek fry and emigrated seaward at a slightly earlier stage of development. No differences in size or time of return of adults could be traced to the incubation environment from which they came.

The level of harvest of pink salmon, *Oncorhynchus gorbuscha*, in Alaska in the 1970's (Seibel and Meacham 1975) has been about one-ninth the level of the 1930's (Kasahara 1963). This decline, in view of recent advances in salmon hatchery systems (Bams 1972), might be countered by large-scale artificial propagation of salmon fry to supplement natural spawning. As a first step toward developing systems for enhancing or rehabilitating the depleted stocks, the National Marine Fisheries Service, Northwest Fisheries Center Auke Bay Fisheries Laboratory and the Alaska Department of Fish and Game agreed in August 1971 to begin testing a gravel incubator hatchery on Auke Creek near Juneau in southeastern Alaska.

Auke Creek was selected because it is accessible and has a fish weir and a dependable water supply from nearby Auke Lake. Lake water is especially desirable for hatcheries in Alaska because the water temperature generally remains above freezing (3°-4°C). However, lake water has at least one disadvantage–it has a different seasonal temperature pattern than most of the streambed waters where pink salmon eggs normally incubate. Bams (1972) avoided the problem of temperature differences by collecting hatchery water from beneath the streambed, but this is not always feasible in Alaska because of the severe freezing conditions encountered at many potential hatchery sites. This report on the 1972 brood pink salmon at Auke Creek compares hatchery production and natural production in regard to 1) survival from eggs to emergent fry, fry to returning adults, and eggs to returning adults; 2) size, stage of development, and emergence timing of fry; and 3) size and time of return of adults returning to Auke Creek from hatchery and creek fry.

MATERIALS AND METHODS

A heated building (7.3 by 13.4 m) provided space for a water filter and ultraviolet purifier; incubators; instruments for measuring temperature and oxygen; equipment for censusing, sampling, and marking fry; and instruments for measuring and counting adult salmon. The building was located on Auke Creek near a fish-counting weir at the head of tide where eggs could be collected from

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returning adult salmon. The hatchery water supply came from nearby Auke Lake. The eggs were incubated to the eyed stage in Heath[2] incubators and then transferred to gravel incubators to complete development.

Water Filter and Purifier

The water filter and ultraviolet purifier system supplied treated water to one-half of the hatchery incubators; the rest were supplied with untreated water. The filter was rated to remove particles 10 μm in diameter or larger. The purifier was designed to give a minimum dosage of 35,000 μW·s/cm^2 at 2,537 Å. The water treatment had no apparent beneficial effect.

Natural Spawning

From 4 August to 21 September 1972, 1,768 adult pink salmon entered the fish counting weir. About 55%, 459 females and 527 males, were released to spawn above the weir. The rest were kept for fecundity counts and hatchery spawn source. Ten females from which we obtained fecundity counts were treated as a simple random sample in later analysis, although no serious effort was made to assure randomness of selection. Average fecundity in this sample was 2,035 eggs/female (SE: 93.27). This estimate agreed closely with 2,023 eggs/female from an inventory of eggs obtained from the 386 females used as the hatchery spawn source after a rough correction for eggs retained. Most pink salmon released above the weir spawned in a 297-m section of stream between the weir and Auke Lake. Fewer than 20 adults spawned in Lake creek above Auke Lake. The alevin population of Auke Creek was estimated 20-21 March 1973 with a hydraulic pump census (McNeil 1964).

Collection and Eyeing of Eggs

Eggs for seeding incubators were obtained from the Auke Creek pink salmon run 8 August through 22 September 1972. These dates cover nearly the entire run, thereby assuring representation of all parts of the run in the next generation. Eggs were collected from 386 females (about 45% of the females in the spawning run) in the manner described by Bailey and Taylor (1974). Malachite green treatments, 15 ppm. for 1 h, were used at weekly intervals between 17 August and 19 October to control fungus growth until eyed eggs were removed from the Heath trays.

Raising Eyed Eggs to Fry Stage

The eyed eggs were raised to the fry stage in four gravel incubators (Bams 1970) designated A, B, C, D (Table 1). The incubators measured 1.2 by 1.2 by 1.2 m and used a system of perforated pipes and horizontal layers of graded gravel to achieve uniformity of upwelling flow through the eggs and gravel. Flow to A, B, and C was initially set at 75 liters/min and to D at 79 liters/min. Incubators A, B, and C were loaded with an estimated 150,000 eggs (SE: 1,030) each and incubator D with an estimated 158,000 eggs (SE: 1,085) (Table 1). Therefore each incubator initially contained 2,000 eggs per liter/min.

Iron bacteria sheaths and a flocculent iron precipitate accumulated in the incubators. The material seemed to accumulate as rapidly in incubators receiving filtered and irradiated water as in those receiving untreated water. The intended water flow through the incubators receiving treated water could not be maintained. Flow through incubator C had dropped from the desired 1.26 liters/s to 0.88 liter/s 18 December 1972, and flow through incubator B had dropped to 0.95 liter/s 3 January 1973. Flow through these incubators was maintained at 0.63-1.07 liters/s for the rest of the incubation period. The full 1.26 liters/s was maintained at all times in the two incubators receiving untreated water, probably because the hydraulic head on the untreated water supply was about twice the head on the treated water.

The estimates of numbers of eggs seeded in each incubator were determined by the method of Burrows (1951). Through an oversight, records of

TABLE 1.—Operating conditions in four gravel incubators seeded with eyed pink salmon eggs, Auke Creek, 1972. For each incubator the volume of substrate and eggs was 1.246 m^3.

Incubator	Number eggs	Water flow (liters/min)	Type of water treatment
A	150,000	75	Untreated
B	150,000	75	Filtered and ultraviolet treated
C	150,000	75	Filtered and ultraviolet treated
D	158,000	79	Untreated

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[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

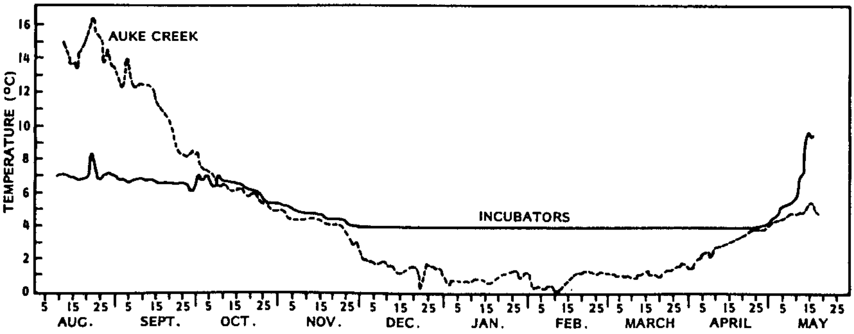

FIGURE 1.—Temperatures in gravel incubators and in surface water of Auke Creek, 8 August 1972 through 17 May 1973.

the procedure were of insufficient detail to estimate the precision of the initial seedings. Variances of these initial seedings were estimated from data obtained in recent years, 1974 and 1975. This source of error was determined to be negligible in later calculations.

Eggs were fertilized on the following schedule: incubator A, 4-31 August; B, 4 August to 8 September; C, 11-17 September; and D, 17-21 September.

Water Temperatures

We measured temperatures daily with a mercury thermometer (to the nearest 0.1°C) in Auke Creek and in the incubators from the time the first eggs were collected until the fry left the creek. While eggs were being collected (8 August to 22 September 1972), water in Auke Creek was warmer than water in the incubators (Figure 1). The creek water was cooler than the incubator water from 9 October throughout the rest of the incubation period, which ended when the fry emerged.

Oxygen Levels

Oxygen concentrations in the water supply to the hatchery and in effluents from the incubators were measured to the nearest 0.01 mg/liter by the Winkler method. Oxygen was measured at weekly intervals from shortly after eyed eggs were seeded (9 November 1972) until the fry began to emerge (23 March 1973). Oxygen content of the water supplied to the incubators decreased steadily—from 9.6 mg/liter (73% saturation) on 22 November 1972 to 7.8 mg/liter (59% saturation) on 23 March 1973 (Figure 2). Oxygen in effluents from gravel incubators decreased from 9.3 mg/liter (71% saturation) to 6.7 mg/liter (51% saturation) during the same period.

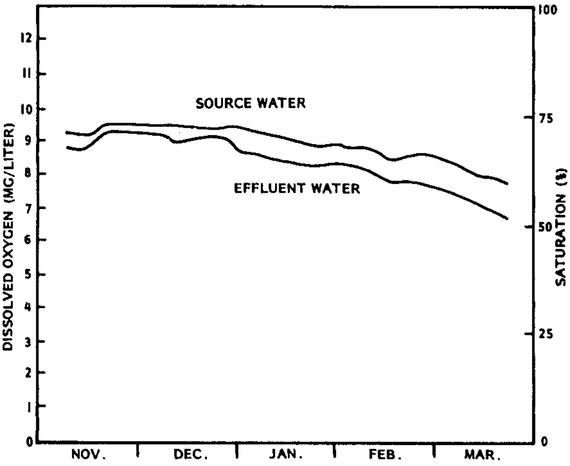

FIGURE 2.—Dissolved oxygen levels in source water and effluent water of gravel incubators at Auke Creek Hatchery, 9 November 1972 through 23 March 1973.

Counting and Processing Fry

We collected emigrating creek fry and hatchery fry to measure and mark, to determine time of migration, and to estimate abundance of hatchery fry. Two 0.91- by 0.91-m fyke nets with floating live-boxes were used to index the daily emigration of creek fry and to collect fry for a mark and recovery experiment. The daily counting of fry as they emerged from gravel incubators and the collection of fry for fin clipping and measuring was expedited by passing the incubator effluents over a cone-shaped sampling device[3] and then through a second sampling device consisting of a set of five parallel troughs. The first device provided small subsamples of fry from which total numbers emerging could be estimated; the second

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[3] A blueprint for the cone-shaped fish sampler was supplied by the Washington Department of Fisheries.

device separated a larger subsample from the total numbers for marking.

We calibrated the cone device as a sampler with which to estimate total numbers of emerging fry from the incubators. Inspection of the relationship of total fry emigrating from an incubator (y) plotted against fry retained by the sampler (x) on 24 occasions indicated a constant ratio (straight line through the origin) with increasing variation at higher subsampler counts (Figure 3). Consequently, the average of the 24 ratios (y/x) available from the calibration study is taken as the slope estimate (Snedecor 1956: 153-156) and was calculated as 24.537 (SE: 1.072). The major portion of the fry passed the cone sampler and were then routed through the parallel troughs, one of which emptied into a holding tank and four of which emptied into the hatchery drain and then into Auke Creek. With these two devices we captured about one-fourth of the gravel incubator fry each day without impeding the seward migration of the other three-fourths.

Twice weekly, samples of 50 fry from each gravel incubator and the fyke nets were preserved in 5% Formalin. The preserved fry were allowed to stand for 6 wk before lengths were measured to the nearest millimeter and wet weights to the nearest milligram. An index to stage of development (Bams 1970) of the fry was computed from the formula

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

This index is used only on unfed fry to indicate the relative yolk content. It is not a condition factor.

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 developmental index as follows:

$$\bar{Y}_W = \Sigma W_i \bar{Y}_i$$

where $\bar{Y}_W$ = weighted mean
$\bar{Y}_i$ = observed mean measurement in ith period
W_i = proportion of run leaving in ith period from index sampling, and

$$V(\bar{Y}_W) = \sum_{i=1}^{n} W_i^2 V(\bar{Y}_i)$$

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

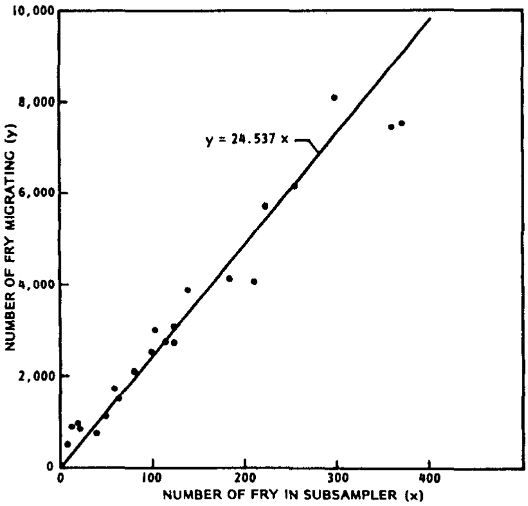

FIGURE 3.—Relation of number of fry migrating to number of fry in subsampler. Each point represents one sample.

Technicians marked hatchery fry by clipping the adipose and left ventral fins and creek fry by clipping the adipose and right ventral fins. Before marking, the fry were anesthetized in a solution of 1:7,500 MS-222 (Tricaine methanesulfonate) buffered with sodium bicarbonate to pH 6.1-6.4; the solution was kept cool in a water table and recirculated to keep the oxygen content high. Surgical iris scissors were used to excise fins under a 3× magnifying lens. Technicians marked an average of about 200 fry/h on this study, whereas technicians marked about 400 fry/h on a similar study in Canada (R. A. Bams pers. commun.). Samples of fry from each technician were examined several times daily to ensure that the correct fins were excised as close to the body as possible. All marked fry were released at 1130 h the same day they were marked; most of the unmarked fry that had left the incubator or the stream at the same time had migrated seaward 24 h earlier. Dead fry remaining in the release tank were counted each morning. The immediate mortality from marking was less than 0.1% for both hatchery and creek fry. Totals of marked fry released were 84,000 from the hatchery and 5,500 from the creek. The daily numbers of marked fry released from the hatchery and the creek were roughly proportional to the respective migrations of fry from these two sources. There was a slight bias toward marking too few fry during the first half of the migration, but the bias was in the same direction and magnitude on both types of fry.

Less than 1% of the creek fry died in the fyke net and floating live-box, indicating slightly greater physical abuse for marked creek fry than marked hatchery fry.

Recovery of Marked Adults

Returning 1972 brood adults were counted at the weir in Auke Creek in the summer of 1974; some adult salmon were anesthetized and measured. Mideye-to-tail-fork lengths were measured to the nearest millimeter and weights to the nearest 0.01 kg.

Analysis of Survival

Survival probabilities from egg to fry and fry to returning adult are estimated from estimates of initial number of eggs, fry produced, and returning adults. Ratios of these survival estimates are used to compare survival of hatchery and creek salmon. Variances of survival and estimates of ratios of these survival estimates were approximated by the delta method (Deming 1943; Paulik and Robson 1969). Finite population correction factors were ignored in variance calculations; changes in variance estimates would have been insignificant.

Estimation of survival from marking requires special argument. The expected total unmarked returns from hatchery and creek fry combined is

$$T = Us + U's'$$

where U and U' are initial numbers of unmarked fry from the creek and hatchery respectively, and s and s' are the probabilities of survival of the two unmarked groups at sea. Marking increases mortality. If the probability of survival from marking is τ and identical for both groups, the probabilities of survival from both causes are $s\tau$ and $s'\tau$ for creek and hatchery fry respectively. The expected total return of the unmarked fry had they been marked, T', is

$$T' = Us\tau + U's'\tau.$$

The ratio of T' to T is τ. Therefore, we estimate survival from marking from estimates of T and T' as

$$\hat{\tau} = \hat{T}'/\hat{T}.$$

The expectation T is estimated by the total unmarked recoveries to the weir. The expectation T' is estimated from appropriate combinations of estimates of numbers of unmarked creek and hatchery fry and estimates of marine survival of marked fry of both groups.

Total variation among incubators in estimated survival from egg to fry is divided into three sources: 1) Underlying variation due to heterogeneity of genetic composition of pink salmon and environmental conditions among incubators, 2) binomial variation within incubators, and 3) sampling error in estimation of numbers of eggs and fry. We imagine an unobserved universe of survival probabilities s with mean $\bar{s}$ has been sampled randomly by our study; four members were drawn, each applying to one of our incubators. Actual survival within an incubator varies from its associated probability of survival due to binomial variation; instead of a fraction s surviving, the actual fraction is $\hat{s}$. This actual rate was not observed; rather, we estimated $\hat{s}$ by $\hat{\hat{s}}$, the ratio of estimated fry to estimated eggs.

Total variance of estimated survival among incubators, σ_t^2, is defined by

$$\sigma_t^2 = \underset{3}{E}(\hat{\hat{s}} - \bar{s})^2$$

where $\underset{3}{E}$ denotes the expectation operation over the three sources of variation.

This expression may be rewritten as

$$\sigma_t^2 = \underset{3}{E}[(\hat{\hat{s}} - \hat{s}) + (\hat{s} - s) + (s - \bar{s})]^2.$$

After completing the square and evaluating the expectations of the terms, we find

$$\sigma_t^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2$$

where $\sigma_1^2 = \underset{1}{E}\,(s - \bar{s})^2$, the variance of underlying survival probabilities among incubators; $\sigma_2^2 = \underset{2}{E}\,(\hat{s} - s)^2$, the average binomial variance; $\sigma_3^2 = \underset{3}{E}\,(\hat{\hat{s}} - \hat{s})^2$, the average variance due to errors in estimates of fry and eggs; $\underset{1}{E}$ denotes the expectation operation over the first source of variation; and $\underset{2}{E}$ denotes the expectaton operation over the first two sources of variation.

Our experiment provides four unobserved selections from the underlying probabilities of survival, four estimates of binomial variation, and four estimates of variance in estimated survival due to errors in estimates of eggs and fry. Averages of the four estimates for the second and third sources are used to estimate σ_2^2 and σ_3^2. The sample variance of $\hat{s}$ is used to estimate σ_t^2. The estimate of σ_1^2 is obtained by subtraction.

RESULTS

First, we evaluate the effectiveness of the Auke Creek Hatchery by comparing survival of hatchery and creek fishes at different life stages: egg to emergent fry, fry to returning adult, and egg to returning adult. Next we estimate survival from marking. Then we compare size, stage of development, and emergence timing of hatchery fry with creek fry. Finally, we compare size and time of return of hatchery fish and creek fish as adults.

Survival from Egg to Fry

We estimated survival from potential egg deposition to fry for creek fry as the ratio of an estimate of the alevins in the spawning area of the creek above the weir in the spring of 1973 (just before emergence) to an estimate of the potential egg deposition. Because 459 females spawned in the stream above the weir, we estimate potential egg deposition as (459)(2,035) = 934,065 [SE: (459)(93.27) = 42,811 eggs].

On 20 and 21 March 1973, we determined the number of live alevins in each of 86 0.1-m^2 units of a simple random sample from the 8,600 such units making up the spawning area above the weir. The average number of alevins per unit was 8.593 (SE: 3.814). Hence, total live alevins in the spawning area was estimated to be (8,600)(8.593) = 73,900 alevins [SE: (8,600)(3.814) = 32,800 alevins].

Survival to time of sampling is estimated as the ratio of estimated total alevins to estimated potential egg deposition or 73,900/934,065 = 0.079 (SE: 0.035).

In the gravel incubators, estimated survival from live egg to fry was calculated as the ratio of estimated total emigrants to initial numbers of live eggs. The sums of the daily numbers of fry in subsamples from the four incubators were as follows: (A) 5,960; (B) 5,792; (C) 5,153; and (D) 6,692. Total emigrations from the incubators and corresponding standard errors were estimated using the calibration results: (A) (5,960)(24.537) = 146,240 fry [SE: (5,960)(1.072) = 6,389 fry]; (B) 142,118 (SE: 6,209); (C) 126,439 (SE: 5,524); and (D) 164,202 (SE: 7,174). The grand total of fry emigrating was 579,000 (SE: 25,296).

Estimates of survival from live eyed eggs to fry and the standard errors of these estimates were as follows: (A) 146,240/150,000 = 0.975 (SE: 0.043); (B) 0.947 (SE: 0.041); (C) 0.843 (SE: 0.037); and (D) 1.039 (SE: 0.045). The estimate for incubator D is not feasible, but since it lies within a standard error of the feasible range, we do not suspect errors in data recording or calculations. The mean of the survival estmates was 0.951, and the sample variance of the estimates was 0.00667.

This variance estimate is divided into three components—$\hat{\sigma}_1^2$, $\hat{\sigma}_2^2$, $\hat{\sigma}_3^2$—representing variation in underlying survival probabilities, binomial variation, and variation due to errors in estimating eggs and fry respectively. The estimates are as follows: $\hat{\sigma}_1^2 = 0.00493$, $\hat{\sigma}_2^2$ is negligible, and $\hat{\sigma}_3^2 = 0.00174$. Therefore, most of the total variance of survival estimates among the four incubators seems due to variation in underlying survival within the incubators rather than binomial variation or variation in egg or fry counts.

The incubator survival rates are from live eyed egg to fry. The creek survival rate is from potential egg deposition to fry. To make the survival rates comparable, we adjust the incubator survival to that from potential egg deposition to fry. The proportion of potential egg deposition which develops to the eyed stage in the hatchery is estimated as the ratio of total estimated eyed eggs obtained from the 386 females artificially spawned to estimated potential egg deposition by the females, or 614,000/785,510 = 0.782 (SE: 0.036). The adjusted incubator survival rate from potential egg deposition to fry is (0.782)(0.951) = 0.743 (SE: 0.047).

Survival from Fry to Returning Adult

Although most of the marked returning adults were recovered at the weir in Auke Creek below their point of origin, some were recovered from sport and commercial fishermen and from the intertidal spawning area of Auke Creek (Table 2). Total recoveries from all sources were used to estimate relative survival from fry to returning adult: 667 of the marked hatchery fish and 74 of the marked creek fish were recovered. Estimated survival of hatchery fry to returning adults is

$667/84{,}000 = 0.0079$ (SE: 0.0003). Estimated survival of creek fry for the same period is $74/5{,}500 = 0.0135$ (SE: 0.0016). Therefore, our estimate of relative survival of hatchery fish as compared to creek fish is $0.0079/0.0135 = 0.59$ (SE: 0.071).

TABLE 2.–Source of recoveries of marked pink salmon adults originating from fry marked at Auke Creek in 1973.

Source of recovery	Origin of marks	
	Hatchery	Creek
Commercial fishery	4	1
Sport fishery	8	0
Intertidal area of Auke Creek	11	2
Auke Creek weir	644	71
Total	667	74

Survival from Egg to Returning Adult

While hatchery fry suffered greater losses than creek fry in the marine environment, their increased survival under the artificial conditions during incubation was compensating. Overall relative survival from potential egg deposition to returning adult can be estimated as the ratio of the products of survival from potential egg deposition to alevin and from fry to returning adult for hatchery and creek fry. The survival of hatchery fish relative to creek fish is

$$(0.743)(0.0079)/(0.079)(0.0135) = 5.50 \text{ (SE: 2.59)}.$$

Production of adults by the hatchery is estimated to be 5 to 6 times that of natural production, although the precision of that estimate is extremely low, as indicated by the standard error–a rough 95% confidence interval would include the possibility that survival from potential egg deposition to adult was smaller for hatchery operations than for natural spawning.

Survival from Marking Effects

Estimates of the initial numbers of unmarked creek and hatchery fry are 68,400 and 495,000, respectively. Unmarked recoveries to the weir totaled 5,545. Survival of marked fry to return at the weir is estimated by the ratios of marked recoveries at the weir (Table 2) to numbers of marked fry released, or $71/5{,}500 = 0.01291$ for creek fry and $644/84{,}000 = 0.00767$ for hatchery fry. Then survival from marking is estimated to be

$$[(68{,}400)(0.01291) + (495{,}000)(0.00767)]/5{,}545 = 0.84.$$

Determination of the precision of the marking mortality estimate was not attempted because of the apparent complexity of the problem.

Fry Size and Developmental Index

Most of the fry from gravel incubators were shorter (Figure 4) but heavier (Figure 5) than creek fry, although there were two exceptions: fry from incubator A had an average weight of 260.0 mg, which was not significantly different from the average weight for creek fry–260.2 mg (Table 3);

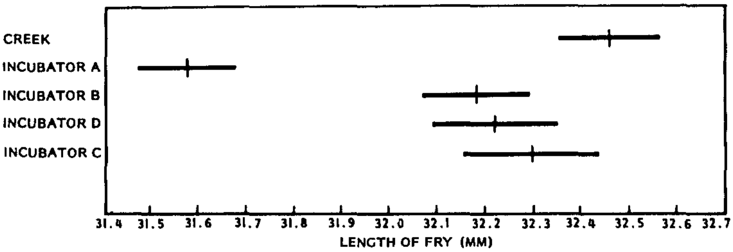

FIGURE 4.–Weighted means and 95% confidence intervals for these means of lengths of preserved fry from Auke Creek and four gravel incubators.

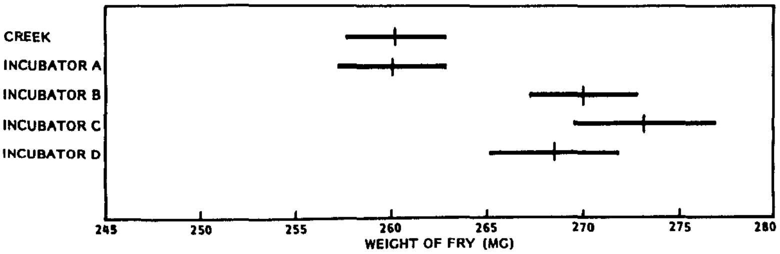

FIGURE 5.–Weighted means and 95% confidence intervals for these means of weights of preserved fry from Auke Creek and four gravel incubators.

TABLE 3.—Pooled means and variances of means for lengths, weights, and development index, K_D, of pink salmon fry (50 fry/sample) at Auke Creek in spring of 1973.

Source	Number of samples	Length (mm)		Weight (mg)		K_D index	
		Mean	Variance	Mean	Variance	Mean	Variance
Creek	13	32.45	0.00272	260.2	1.630	1.964	5.36×10^{-6}
Incubator:							
A	8	31.57	0.00252	260.0	1.917	2.008	5.50×10^{-6}
B	8	32.17	0.00276	269.9	1.856	2.009	5.54×10^{-6}
C	4	32.21	0.00412	273.2	3.352	2.012	9.61×10^{-6}
D	5	32.29	0.00483	268.6	2.714	1.987	9.92×10^{-6}

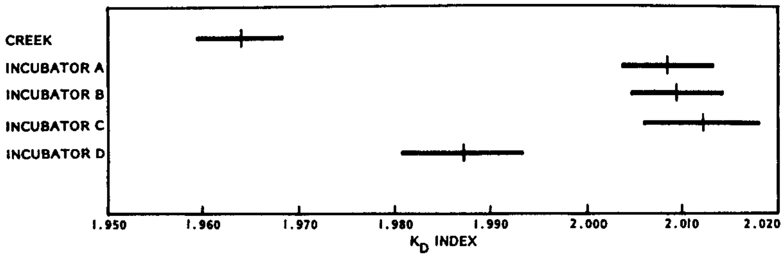

FIGURE 6.—Weighted means and 95% confidence intervals of these means of indices of development, K_D, of preserved fry from Auke Creek and four gravel incubators.

and fry from incubator D had an average length of 32.29 mm, which was not significantly different from the average length for creek fry—32.45 mm.

Indices of development were higher for fry from all the gravel incubators than for creek fry (Figure 6). The mean indices of development for gravel incubator fry ranged from 1.987 to 2.012, whereas the mean for creek fry was only 1.964 (Table 3). In an earlier test (Bailey and Taylor 1974) the average K_D index decreased about 0.005 unit/day in the final stages of alevin development. Since the average K_D index for incubator fry was 0.016 unit higher than the index for creek fry, incubator fry apparently emerged about 3 days earlier in their development.

Time of Emergence and Seaward Migration

Fry of the 1972 brood from the gravel incubators migrated voluntarily between 15 March and 23 May 1973; the median date was 14 April (Figure 7). Creek fry emigrated between 16 March and 15 May; the median date was 27 April (Figure 7).

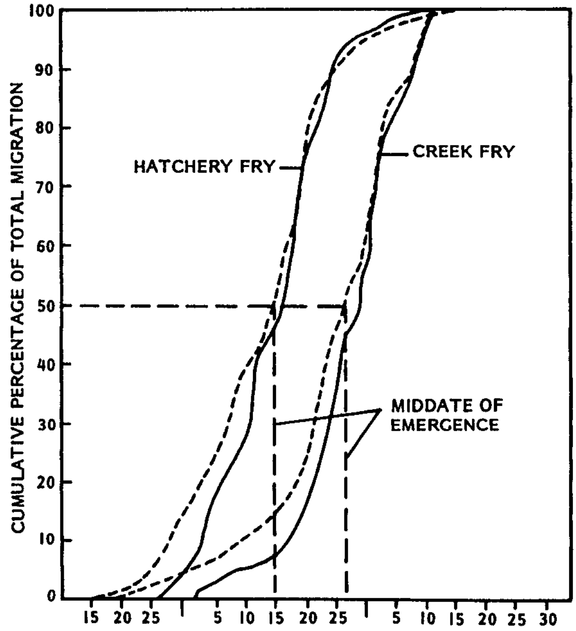

FIGURE 7.—Daily cumulative percentage of pink salmon fry migrations of creek fry and hatchery fry from Auke Creek in 1973; solid lines represent fin-marked fry and dashed lines represent total fry in the respective migrations.

Size of Returning Adults

Length measurements of adults from the 1972 brood that returned to the weir in 1974 are classified by sex, origin (whether creek or hatchery), and time of return (either early or late run). Mean lengths and sample sizes (Table 4) were used as basic observations with which to perform an analysis of variance (Scheffé 1959: 362-363) to search for differences in size among the classifications. Analyses were performed separately for each sex because underlying variances of hatchery fish differed significantly between sexes. Spawning males typically vary more in length than spawning females. The corresponding tests for creek fish did not indicate inequality of vari-

TABLE 4.—Average lengths of adult pink salmon returning to Auke Creek weir, early and late runs; the figures in parentheses represent the number of fish in the samples.

		Average lengths (mm)			
		Early run		Late run	
Mark	Origin	Male	Female	Male	Female
Unmarked	Hatchery and creek	493.1 (117)	495.2 (92)	512.4 (58)	500.8 (137)
Ad-LV[1]	Hatchery	500.2 (126)	499.6 (70)	510.0 (44)	495.6 (44)
Ad-RV[2]	Creek	505.6 (19)	515.9 (7)	515.7 (3)	497.3 (3)

[1] Ad-LV = adipose and left ventral fins.
[2] Ad-RV = adipose and right ventral fins.

ances, probably because of the small sample sizes.

Differences in length due to origin, time of return, or interaction were not detectable at the 95% level of testing for either sex (Table 5). Only time of return for females approached statistical significance (the test would have been significant at the 90% level). Mean lengths of samples of creek fish exceeded those of hatchery fish in all cases (Table 4). While our data suggest that creek fish were larger than hatchery fish upon return, the observed differences could be due to chance when samples were drawn. Larger samples would have been needed to resolve the issue.

TABLE 5.—Analysis of variance of size of returning adult male and female pink salmon classified by origin (creek or hatchery) and time of return (early or late).

Source	Degrees of freedom	Mean square	F
Males:			
Origin, A	1	30.8025	<1
Timing, B	1	99.0025	<1
AB	1	0.0225	<1
Error	188	161.543	—
Females:			
Origin, A	1	81.000	2.09
Timing, B	1	127.690	3.30
AB	1	53.290	1.38
Error	120	38.739	—

Timing of Adult Return

Marked hatchery fish entered the weir between 6 August and 25 September and marked creek fish entered between 16 August and 20 September (Figure 8). For 644 marked hatchery fish the median date of return was 13 September 1974; for 71 marked creek fish the median date was 10 September.

DISCUSSION

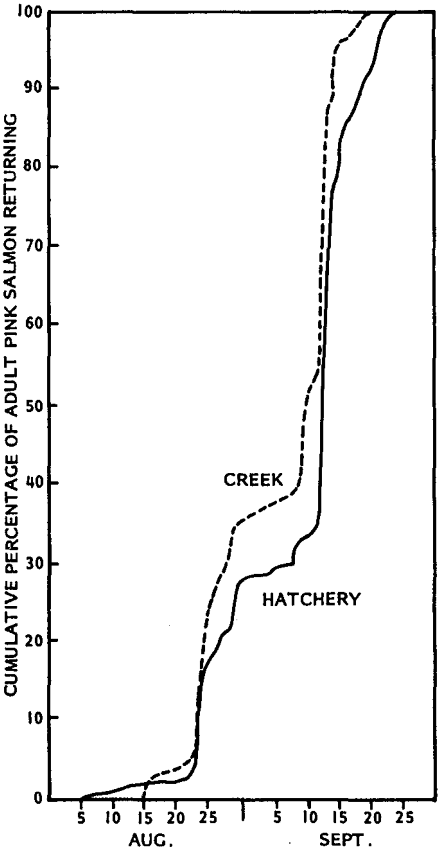

FIGURE 8.—Daily cumulative percentage recovery of marked adult pink salmon at Auke Creek weir, 1974.

Gravel incubation of eggs and release of unfed fry increased the survival from potential egg deposition to returning adult an estimated 5 to 6 times over natural spawning for 1972 brood year pink salmon at Auke Creek. The estimate lacks precision, however, and a rough 95% confidence statement includes the possibility that egg-to-returning-adult survival was less for incubator fry than for naturally produced fry. Further, the estimate of relative survival is potentially biased unless marine mortality due to marking and fishing was similar for both groups of marked fry. The similarity of timing of adult returns from both groups gives no reason to suspect differential fishing mortality. The low mortality of creek fry in the fyke net and live-box suggests only slightly greater physical abuse occurred to marked creek fry than hatchery fry. The difference in survival from potential egg deposition to returning adult, if real, was accomplished in spite of certain deficiences in the quality of environment provided for eggs and alevins in the hatchery and in spite of a lower ocean survival for hatchery fry than for creek fry.

There is a notable difference in survival from marking in the tests at Auke Creek and the tests by Bams (1972, 1974) at Headquarters Creek, Vancouver Island. The estimate of survival from marking at Auke Creek, 84%, is much greater than the 17% and 36% survival we estimated from Bams' data on Headquarters Creek. Intertidal alevin production in Auke Creek below the weir was estimated by hydraulic pump survey to be 16% of that above the weir. Possible straying of these intertidal fish above the weir upon return would only bias our estimate below actual survival from marking. The slower rate at which our technicians clipped fins may be the cause of better survival from marking at Auke Creek.

Our estimates of fry releases and survivals imply that an increase in numbers of returning spawners at Auke Creek in 1974 was largely due to operation of the hatchery. If this is true, then hatcheries can be built on lake-water sources with a reasonable expectation of successfully enhancing salmon numbers. Projections of our data must be considered tentative because of the lack of precision. However, the magnitude of the Auke Creek escapement in relation to escapements to other streams in northern southeastern Alaska supports our conclusion that operation of the Auke Creek Hatchery did in fact enhance the return of adult salmon. For example, marked hatchery fry had a recovery rate of 0.767%. Survival from marking was 84%. The release of 579,000 hatchery fry would project to (579,000)(0.00767)/0.84 = 5,287 adults. The projected return of creek fry would be (84,000)(0.01291)/0.84 = 1,291 adults. In 1974, 6,260 adults returned to the Auke Creek weir from a parent escapement of 1,768 adults. This 3.5-fold increase occurred in the face of a general scarcity of pink salmon in this part of Alaska. According to Kingsbury (1975) the lowest escapement for pink salmon streams of northern southeastern Alaska since 1960 occurred in 1974.

The yolk content of 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, may not be able to osmoregulate in seawater, and are more vulnerable to predators. On the other hand, fry that have little or no yolk are losing weight and soon become weakened and emaciated and again are more vulnerable to predators. Naturally produced fry emerge volitionally from the stream gravel, presumably at the stage of development that ensures maximum survival. Our analysis of the developmental index showed our gravel incubator fry emerged prematurely in comparison to creek fry.

Earlier (in the temporal sense) emergence of fry produced in gravel incubators at Auke Creek also suggests that the Auke Creek Hatchery environment was inferior to the natural streambed environment. Hatchery fry emerged and migrated seaward 2 wk earlier than creek fry. This could place them in the estuary before the spring bloom of zooplankton on which they feed and before spring warming of estuarine surface water. The resulting slow growth rate could mean an excessively long period of high vulnerability to predators. Experiments by others (Levanidov 1964; Bams 1967; Kanid'yev et al. 1970; Parker 1971) show that small juvenile salmon suffer higher mortality from predation than large juvenile salmon.

The earlier time of migration and size of hatchery fry at Auke Creek were probably caused by one or more of the following: the higher average winter temperature of Auke Lake water (4°C) as compared to the temperature in natural redds in Auke Creek (0°-2°C); the low oxygen content of 60-70% saturation in lake water supplied to incubators; and the brown organic material from iron bacteria which accumulated in the gravel incubators and impeded the flow of water.

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