INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

PROGRESS REPORT

No. 20

COMPARISON OF SOCKEYE SALMON FRY PRODUCED BY HATCHERIES, ARTIFICIAL CHANNELS AND NATURAL SPAWNING AREAS

BY

R. W. MEAD and W. L. WOODALL

NEW WESTMINSTER, B. C.

CANADA

1968

INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

Appointed under a Convention
Between Canada and the United States for the
Protection, Preservation and Extension of
the Sockeye and Pink Salmon Fisheries
in the Fraser River System

PROGRESS REPORT

No. 20

COMPARISON OF SOCKEYE SALMON FRY PRODUCED BY HATCHERIES, ARTIFICIAL CHANNELS AND NATURAL SPAWNING AREAS

By

R.W. Mead and W.L. Woodall

New Westminster, B.C.
Canada
1968

ABSTRACT

Several characteristics thought to influence potential survival of fry from hatcheries, artificial channels, and natural areas were examined for three Fraser River races of sockeye salmon (*Oncorhynchus nerka*). Fry from the three incubation environments were evaluated with regard to emergence timing, physical characteristics and behavior. Although hatchery fry were found to be inferior to natural fry in many characteristics, channel fry were judged to be equivalent to the natural fish in nearly all areas of consideration. Hatchery fry emerged considerably earlier, weighed significantly less, and showed less avoidance of light than either channel or natural fry. Channel fry also emerged 5 to 11 days earlier than natural fry, but in all other aspects were equivalent to fry produced from natural spawning areas. The three types of incubation environment apparently produced no major differences in body lipid content at emergence or in extent of predation loss. The significance of these findings with regard to fry survival is discussed and certain recommendations for channel management are presented.

TABLE OF CONTENTS

COMPARISON OF SOCKEYE SALMON FRY PRODUCED BY HATCHERIES, ARTIFICIAL CHANNELS AND NATURAL SPAWNING AREAS

INTRODUCTION

Although the Fraser River system has historically been one of the world's foremost producers of sockeye salmon (Oncorhynchus nerka), the pressures of encroaching civilization are causing deteriorative changes in the natural environment of some salmon spawning streams. Unstable flow and altered water temperatures, resulting from extensive logging, are the chief reasons for the declining productivity of the affected spawning areas. Since continued development within the watershed can only increase the adverse effects on the fisheries resource, more reliance must be placed on artificial aids to salmon production.

For these aids to be successful, the sockeye fry produced must at least approach the capability of survival of those from natural spawning areas. In past years, hatchery production of Fraser River sockeye proved to be no more successful than natural propagation (Foerster, 1938) in spite of greatly increased egg-to-fry survival in the hatchery environment. Although not evident at the time, these hatchery fry were inferior to naturally produced sockeye fry in certain characteristics essential for subsequent survival.

It is now recognized that the environment imposed by the hatchery is responsible for imparting the inferior characteristics to such artificially produced fry. Water velocities, light intensities and dissolved oxygen concentrations characteristic of standard hatchery operations produce sockeye fry which differ significantly from fish produced under more natural conditions (Brannon, 1965). Differences in size, time of emergence and behavior indicate that sockeye fry produced under these conditions would be less apt to survive than wild fry. Various inferiorities of trout fry and other species of salmon fry produced by hatcheries have also been noted (Miller, 1954; Salo and Bayliff, 1958; Bams, 1967).

Fortunately, recent developments in artificial aids to salmon propagation appear considerably more promising than those of the past.

Preliminary investigation by the Commission indicated that the adverse differences between hatchery-raised and naturally incubated sockeye fry could be minimized if eggs were spawned naturally or artificially planted into channels containing a porous gravel medium, graded to remove fine materials, with controlled water flows. Such channels, it was believed, would greatly increase egg-to-fry survival by giving control over and protection from the hazards and imperfections of the natural environment. At the same time, the desirable features necessary for good fry survival would be retained. On the basis of these preliminary studies, the Commission established several prototype artificial spawning and incubation channels in areas where sockeye (and pink salmon) runs were in danger of extinction.

In this investigation, the quality of sockeye fry produced from artificial channels is assessed in comparison with standard hatchery and natural fry from comparable genetic backgrounds. Time of emergence, physical characteristics, and behavior of the three types of fry are examined to establish if the differences between hatchery and natural fry have been eliminated by incubation in a channel environment.

AREAS AND METHODS OF INVESTIGATION

Three areas in the lower Fraser watershed, Upper Pitt River, Weaver Creek and Cultus Lake (FIGURE 1), were chosen for study because of the availability of prototype artificial channels as well as nearby areas of natural spawning. In addition, small experimental hatcheries were established at each location. Replication of the experiment at each of the three streams provided a comparison of three races of sockeye as well as a check upon the reliability of results obtained from each area.

While minor differences in method were necessary because of variations in facilities at the different streams, the general procedures were the same for all areas. At each stream, eggs and spawners were obtained during the peak of the spawning period (TABLE 1). Spawners were measured from snout to tail fork (fork length) and only those fish near the estimated average

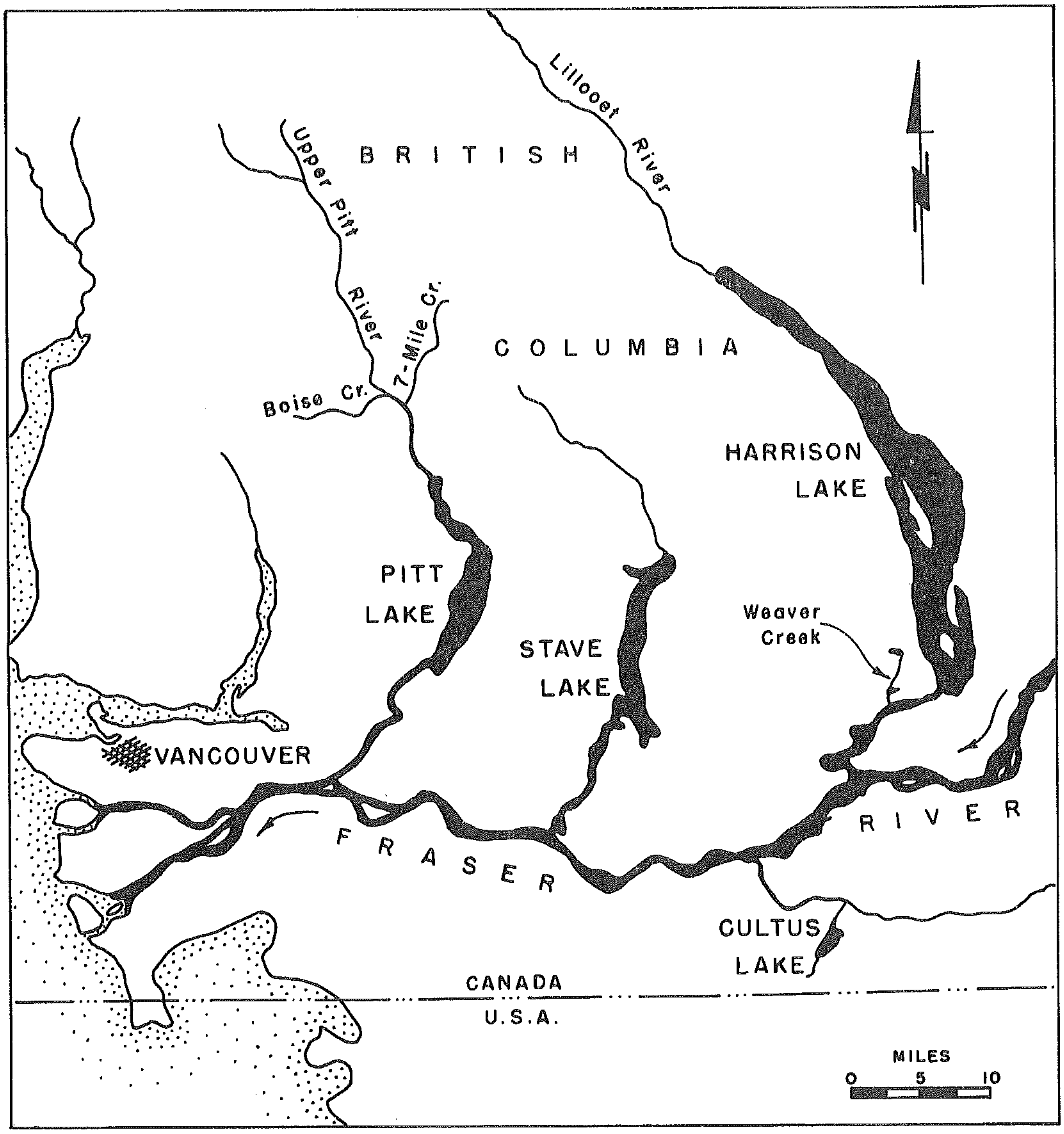

FIGURE 1 - Location of Upper Pitt River, Weaver Creek and Cultus Lake in the lower Fraser River watershed.

TABLE 1 - Measurements of parent sockeye spawners and eggs at each experimental incubation site.

AREA AND INCUBATION SITE	DATE EGGS FERTILIZED, 1966		PARENT FORK LENGTH (cm)						DRY EGG WEIGHT (mg)
			MALES			FEMALES			
	Range	Peak	Range	Mean	$S\bar{x}$	Range	Mean	$S\bar{x}$	
Upper Pitt River									
Hatchery	Sept. 8	Sept. 8	71-76	*		64-69	*		64.68
Channel	Sept. 8	Sept. 8	71-76	*		64-69	*		64.68
Natural	Sept. 7-11	Sept. 9	71-76	73.8	1.24	64-69	66.5	1.04	**
Weaver Creek									
Hatchery	Oct. 18	Oct. 18	65-72	*		58-65	*		57.13
Channel	Oct. 17-23	Oct. 20	65-71	67.6	1.42	58-64	61.5	1.13	**
Natural	Oct. 17-24	Oct. 20	65-72.5	68.7	1.05	60-65.5	63.0	1.20	**
Cultus Lake									
Hatchery	Nov. 18	Nov. 18	60-67	*		56-60	*		36.38
Channel	Nov. 18	Nov. 18	60-67	*		56-60	*		36.38
Natural	Nov. 17-24	Nov. 20	60-67	63.2	1.45	56-60	57.5	0.53	**

* Individual lengths not recorded, however only fish within stated ranges were spawned artificially.

** Egg samples not obtained from naturally spawned groups.

length of the spawning population were used. The range was kept as narrow as possible to provide similar parent stocks for the three incubation sites - hatchery, channel and natural - at each stream. Artificially fertilized eggs for hatcheries and incubation channels were obtained on a day which coincided closely with peak of spawning in the sites where natural spawning was required.

Upper Pitt River Incubation Sites

In the Upper Pitt River watershed, sockeye referred to as the Pitt race spawn in Upper Pitt River and in two tributary streams, Boise Creek and 7-Mile Creek (FIGURE 1). The three experimental incubation sites were set up within the hatchery, in the incubation channel adjacent to 7-Mile Creek, and in an area of natural spawning ground penned off within the creek itself (FIGURE 2).

The experimental hatchery environment was set up within the hatchery building in sections of shallow 16-ft troughs exposed to diffuse natural light. The experimental area was enclosed with 6 mil black plastic film to prevent light from reaching other troughs in the building containing eggs for the incubation channel.

On September 8, 1966, approximately 161,000 eggs were obtained from ripe sockeye spawners in 7-Mile Creek. The eggs from 40 females were fertilized with milt from 20 males. After water hardening, approximately 33,000 eggs were placed in each of two hatchery baskets (25 x 11 x 5 in.) and water flow through the troughs was set at 10 U.S. gal/min. After hatching, the alevins were removed from the baskets and kept in two shallow 10-ft troughs at the same flow of 10 gal/min. Water for the hatchery was taken from 7-Mile Creek through a settling basin and air equilibrating tower. Water temperatures during the incubation period averaged 40.8°F and varied from a high daily mean of 50.0°F to a low daily mean of 36.0°F.

The experimental incubation channel site was located in the most upstream leg of the prototype incubation channel (FIGURE 2). Approximately 95,000 eggs were taken from the same group of spawners used for the hatchery

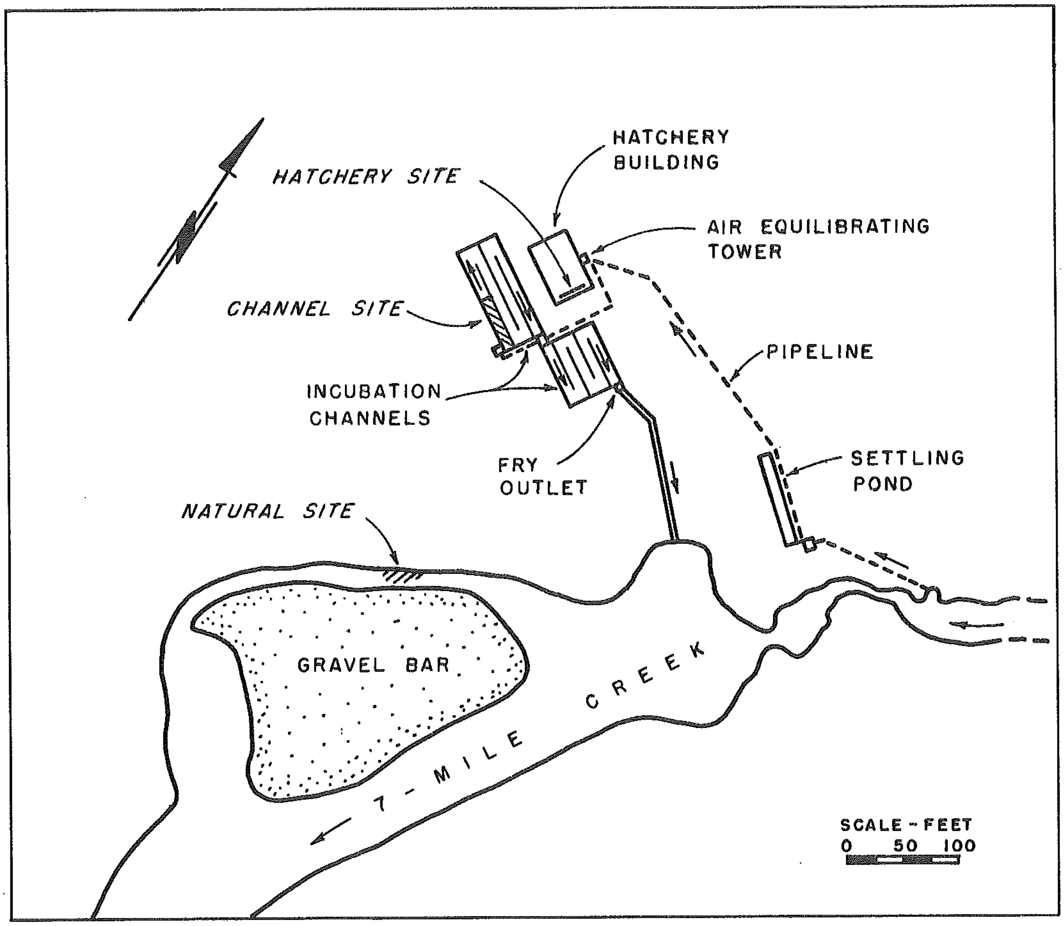

FIGURE 2 - Experimental hatchery, channel, and natural incubation sites at 7-Mile Creek, tributary to Upper Pitt River.

portion of the experiment. Eggs were incubated under the same conditions of flow and temperature as the hatchery eggs, but were held in the darkened portion of the hatchery.

When the eggs reached the "eyed" stage shortly before hatching, they were planted in the assigned area of the channel under 8 in. of gravel at a density of approximately 720 eggs per sq ft. Gravel in the channel area was graded from 0.375 to 0.75 in. and the water supply was the same as that of the hatchery. During most of the incubation period a flow of 466 U.S. gal/min provided an upwelling velocity of 0.5 mm/sec from perforated pipes buried beneath the gravel. About a month before fry emergence the water supply was changed to half upwelling, half surface (stream) flow, and at emergence the entire water supply was changed to surface flow.

To prevent movement of the alevins downstream through the gravel, a screen barrier was installed across the channel at the downstream end of the experimental section. During the last stages of incubation, a screen fry trap was attached to the barrier. Lateral movement of fry to the adjacent leg of the channel, or intrusion of fry from other areas, was prevented by the plywood partitions which divide the channel.

Water temperatures at the channel site were the same as in the hatchery as ascertained by frequent measurements with a 12-in. laboratory thermometer.

The experimental natural spawning site was located in a side channel of 7-Mile Creek (FIGURE 2) in an area used in previous years by sockeye spawners. An area next to the bank was equipped with a 2-in. mesh wire pen designed to hold 20 pair of spawning sockeye and provide 1.5 sq yd of spawning gravel per pair. This area is considered the minimum for successful egg-to-fry survival in natural spawning areas (Internat. Pacific Salmon Fish. Comm., 1964). The ends of the pen were tapered toward the bank to offer minimum resistance to water flow and outside passage of other fish. Wire screen extended 18 in. below the gravel surface and was lined with fine plastic screening to prevent movement of alevins in or out of the area. Prior to fry emergence, the pen was lined with 10 mesh/in. wire cloth from the gravel surface to above the water level. A fyke net was attached to an opening in the screen at the downstream end of the pen leading to a screened V-throat trap.

The interval and peak of the spawning period within the pen were recorded (TABLE 1) and all females were checked when dead for per cent of egg deposition. During the winter incubation period, steps were taken when necessary to maintain the integrity of the pen during flood conditions. A trash rack was constructed upstream to divert logs and other large debris; leaves and other fine material were cleaned from the screen whenever necessary. In times of low water conditions, water was diverted into the area by shear logs and rock barriers.

During the incubation period, water depth over the gravel ranged from approximately 5 in. to 3.5 ft. Temperatures were checked frequently and were found to be identical to those of the channel and hatchery sites.

Weaver Creek Incubation Sites

At Weaver Creek, three experimental incubation sites were stocked with eggs of the Weaver Creek race. The <u>experimental hatchery environment</u> was constructed by positioning three 8-ft hatchery troughs above the water surface in one of the legs of the prototype artificial spawning channel (FIGURE 3). Water was supplied through a 4-in. pipe and head-box from an adjacent leg of the channel at a higher elevation. The troughs were covered with green translucent plastic that permitted daylight to reach the eggs without the lethal effects of direct sunlight.

On October 18, 1966, approximately 67,000 eggs were spawned artificially using 27 females and 15 males taken from Weaver Creek below the spawning channel. After water hardening, the eggs were placed 22,000 to a standard hatchery basket (18 x 11 x 4.5 in.) in each of the three troughs. Water flows were set at 8 U.S. gal/min. Dead eggs and alevins were removed when necessary and the alevins were allowed the full length of the trough after hatching. Daily mean temperatures during incubation ranged from a high of 54.5°F to a low of 38.0°F and averaged 42.5°F.

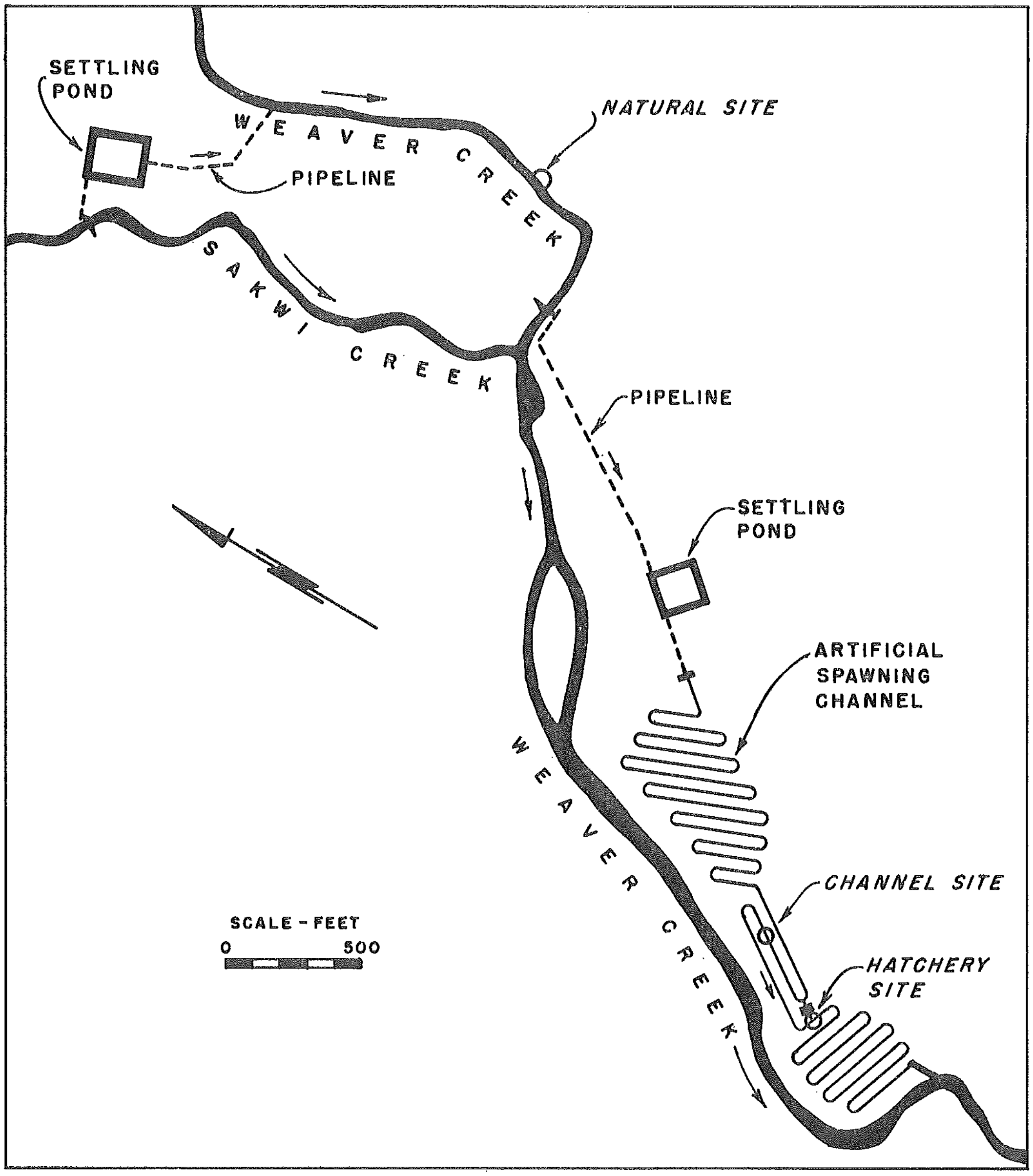

FIGURE 3 - Experimental hatchery, channel, and natural incubation sites at Weaver Creek.

The experimental spawning channel site was located adjacent to the hatchery troughs in one leg of the prototype channel (FIGURE 3). A pen similar to that described for the Upper Pitt River natural site was constructed of 2-in.-mesh wire. The wire extended 18 in. below the gravel surface and was attached to 2-by 4-in. lumber laid on the bottom of the channel. Fine plastic screen lined the pen below the gravel surface to prevent movement of alevins in or out of the area.

Twenty pair of ripe spawners were placed in the penned area on October 17, 1966, with an area of 1.5 sq yd available for each spawning pair. Duration and peak of spawning were noted and dead females were checked for per cent of spawn.

Water flow through the area was maintained at approximately 1.25 to 1.5 ft/sec with water depths of 1.5 to 2 ft. The graded gravel size in the area ranged from 0.5 to 4 in. and temperatures were the same as those given for the hatchery troughs. Throughout the study period the wire pen was kept free of debris. At fry emergence, fine screening was added above the gravel surface and a fry trap installed as described for the Upper Pitt natural spawning site.

The experimental natural spawning site was located in Weaver Creek above the channel, but below the diversion of water from Sakwi Creek to insure that the natural area received the same water supply as the channel (FIGURE 3). A pen providing 1.5 sq yd of gravel per pair was constructed, operated, and protected in the same manner as the one in 7-Mile Creek. Twenty pair of ripe spawners were placed in the creek pen on the same day as the channel pen and observed for duration, peak and per cent of spawning.

Water depth over the gravel ranged from 3 in. to 4.5 ft during the incubation period. Temperatures during incubation were checked frequently and found to be very similar to those of the channel and hatchery sites. Water in the exposed channel warmed and cooled more than the creek, depending on weather conditions, but over the entire incubation period the accumulated thermal units to emergence were calculated to be the same at both sites.

Cultus Lake Incubation Sites

At Cultus Lake, the experimental hatchery environment was set up in two uncovered 8-ft shallow hatchery troughs in the laboratory building at Sweltzer Creek Field Station (FIGURE 4). Natural light from nearby windows and from overhead lights in the building reached the troughs during daylight hours. The bulbs were removed from the light fixture directly over the troughs to prevent direct light from reaching the eggs.

Eggs were obtained from the beach-spawning sockeye population at the south end of Cultus Lake on November 18, 1966. Twenty-five females and 14 males were used to obtain 70,000 eggs. After water hardening, 60,000 of these eggs were divided between two hatchery baskets (18 x 11 x 4.5 in.). Each basket occupied the upstream compartment of an 8-ft hatchery trough. Maintenance during the incubation period was the same as at the other two hatchery locations. The water for incubation was obtained from Cultus Lake and the flow set at 8 U.S. gal/min. Temperatures were maintained at a constant 46.5°F, the temperature of the spring-fed natural spawning ground which ranged from 46.0° to 47.0°F and averaged 46.5°F.

A small temporary incubation channel was constructed for the purpose of this study adjacent to the Sweltzer Creek Field Station (FIGURE 4). The channel consisted of an excavation 3 ft deep, 3 ft wide and 6 ft long lined with 6 mil plastic film and filled with the same gravel as the Weaver Creek channel (0.5 to 4 in.). A water flow of 6 U.S. gal/min supplied four perforated pipes in the floor of the channel to provide an upwelling velocity of 0.5 mm/sec through the gravel. Ten thousand eyed eggs obtained from the same parents as the Cultus hatchery eggs were planted at a density of 720 eggs/sq ft under 8 to 10 in. of gravel.

These eggs had been incubated prior to planting in the same troughs as the hatchery eggs, except that covers were placed over the baskets to eliminate light. Just prior to fry emergence, the upwelling water flow was reduced and most of the water was diverted to a surface flow to facilitate trapping the fry at the downstream end of the channel. Temperatures throughout incubation were controlled at 46.5°F in the same manner as the hatchery.

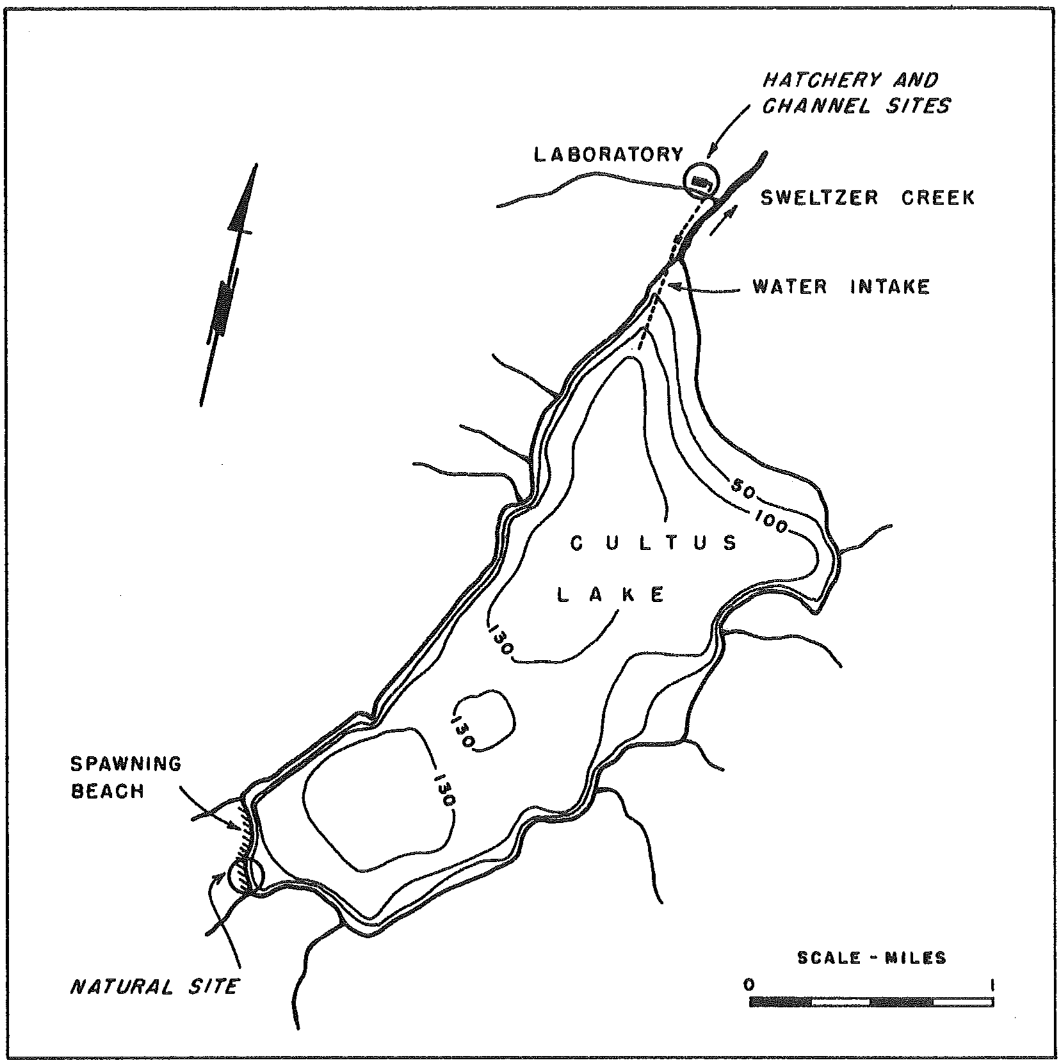

FIGURE 4 - Experimental hatchery, channel, and natural incubation sites at Cultus Lake.

The natural spawning site differed from other areas since Cultus Lake fish spawn in spring-fed beach areas rather than in a stream. The Cultus experimental site was a 10-ft by 20-ft penned area extending from the beach out to a depth of 4 ft of water. On November 17, 1966, 20 pairs of sockeye were placed in the pen and observed as described for other penned areas. Approximately 1.5 sq yd of suitable gravel was available per pair of spawners. During the spawning period, the pen was covered with net to prevent fish escaping over the fence. The pen was lined above and below the gravel with fry-proof nylon bobbinet, rather than wire screen, and during emergence the area was seined daily in lieu of trapping the fry.

As mentioned previously, the spring-fed water temperatures remained at about 46.5°F throughout the incubatory period as checked frequently by thermistor probe.

Growth and Timing Studies

At each experimental site, the young fish were sampled periodically during the incubation and emergence period to determine rate of development and size at emergence. Description of these samples requires definition of the terms used to describe the various stages of development. In the present paper, "alevin" refers to that stage between hatching and closing of the ventral abdominal muscles along the median raphe in hatchery fish, or, in the case of channel and natural fish, the stage from hatching to emergence from the gravel. Beyond this point, the fish are defined as "fry", even though in many cases yolk absorption was not complete and a small quantity of yolk remained in the body cavity. Fish that emerged from the gravel in channels and wild areas with a large amount of external yolk, visible laterally, have been classified as "premature fry". The term "body" refers to all parts of the fish except yolk.

At hatchery sites, dead eggs and alevins were removed from the hatchery baskets regularly and mortalities recorded throughout the incubation period. The hatchery samples selected for comparison with peak emerging channel and natural fry were sampled at the time when 75 per cent of the population had completed absorption of external yolk. On the growth curves this represented the time of maximum sample weight. Alevins were sampled weekly for establishing yolk absorption and growth curves. These samples of approximately 100 fish were taken by dip net from the most dense concentration of fish to minimize sampling bias.

The alevins from channel and natural areas (except Cultus channel) were sampled by digging up samples of approximately 100 fish at least once during their gravel residence. During emergence, the fry were enumerated daily to establish survival rates and emergence curves, and samples of 100 fry were taken regularly for body and yolk measurements throughout the emergence period.

All samples were preserved in 10 per cent formalin for at least 48 hr before the measurements were taken. From each of the alevin and fry samples, 20 or more individuals were weighed separately on an analytical balance after oven drying for 24 hr at 98°C. The bodies were dissected from the yolk for drying and weighing. Lengths were measured to the nearest tenth of a millimeter using metal calipers. Justification for the use of 20 individuals was obtained by weighing as many as five groups of 20 fish from the same sample and comparing the mean weights by the statistic "t". It was found that there were no significant differences between groups of 20 individuals from the same fry sample.

Lipid Analysis

Since sockeye fry migrate to their rearing lake very shortly after emergence from the gravel, body energy sources must be adequate for successful transfer to the new environment. As an indication of these energy reserves, fry from each incubation site were tested for total lipid content. At the peak of emergence, 100 fry from each site were quick-frozen with a small quantity of water. Each sample was later divided into two 50-fish lots and total lipids were determined by a chloroform-methanol extraction (Folch, Lees and Stanley, 1957). Lipids were expressed as percentage wet weight, the latter determined from fish sampled on the same day and preserved in formalin.

Behavior Tests

Of the many behavior patterns which might influence the relative survival rates of fry incubated in various environments, the two selected for the present study were (1) vulnerability to predation, and (2) response to light. It has previously been shown that predation is a major source of mortality in the early life history of sockeye fry (Ricker, 1941; Roos, 1960). If the artificial incubation environment has had a detrimental effect upon the fry's behavior or condition, it may be evident in increased fry mortality upon exposure to known predators. A deviation from the natural response to light could also result in high losses of artificially incubated fry upon release into a stream. Sockeye fry emerge at night and normally show a preference for low light intensities for some time after emergence (Hoar, Keenleyside and Goodall, 1957; Brannon, 1967). In the present study, tests were conducted to measure any differences in reaction to light between recently emerged fry from different incubation environments.

Nearly 3,000 fry from the peak of emergence from each incubation site were transported to Sweltzer Creek Field Station for behavior tests. These fish were moved in milk cans containing aerated water and required a trip of 3 hr by speedboat and truck from the Upper Pitt River, 1 hr by truck from Weaver Creek and 15 min by truck from the natural spawning site at Cultus Lake. Most fish were tested within two days after emergence, but in the interim were held in troughs supplied with Cultus Lake water at temperatures of 44° to 46°F and maintained on freshwater zooplankton also collected from Cultus Lake. Stocks of fish from channel and natural sites were held in darkness, except for feeding and counting out samples, while the hatchery stocks were kept in uncovered troughs.

Predation

Vulnerability to predation was tested by exposing sockeye fry from each incubation site to groups of two known predators, sculpins (*Cottus sp.*) and juvenile coho salmon (*O. kisutch*). Tests were carried out in three 300-gal circular fiberglass tanks supplied with Cultus Lake water at a rate of 5 gal/min. Water levels were maintained at 18 in. and temperatures ranged from 44° to 46°F. Rocks were placed in the bottom of the tanks to provide hiding places for both predators and fry. Tests were begun at 4:30 p.m. each day and the surviving fry counted out and removed at 3:30 p.m. the following day. All tanks were out of doors and exposed to natural lighting.

Three groups of sculpins and three groups of coho were maintained, each group containing five fish 3 to 5 in. long. Sculpins and coho were used on alternate days so that each group of predators was starved for 24 hr before each test. Sockeye fry from each incubation site, in groups of 50 at a time, were exposed to each of the six groups of predators. Reactions of fry to the predator fish were noted at the beginning and end of each test period.

Light

The response of sockeye fry to light was tested in two modified 16-ft by 1-ft hatchery troughs. The troughs were set level and each was equipped with a series of hinged screen dividers which could be raised from a horizontal to a vertical position by pulling a wire handle to which the dividers were attached (FIGURE 5). In the horizontal position, the dividers were flat on the bottom of the trough to allow free passage of fry. When in the vertical position, the dividers partitioned the trough into eight equal compartments. The water level was maintained at a depth of 3.5 in., about 0.5 in. below the top of the dividers.

A 25-watt incandescent light bulb was installed at each end of both troughs and operated so that for four successive tests, alternate ends of either trough would be illuminated. A 6-mil black plastic sheet covered the troughs to eliminate all other light during testing. The light intensity varied down the length of the trough from 5.0 foot candles (ft-c) at the lighted end to 0.6 ft-c at the dark end, as measured at the surface of the water using an incident ray photographic light meter. The trough which did not have a light on during a test was considered the control. Approximately

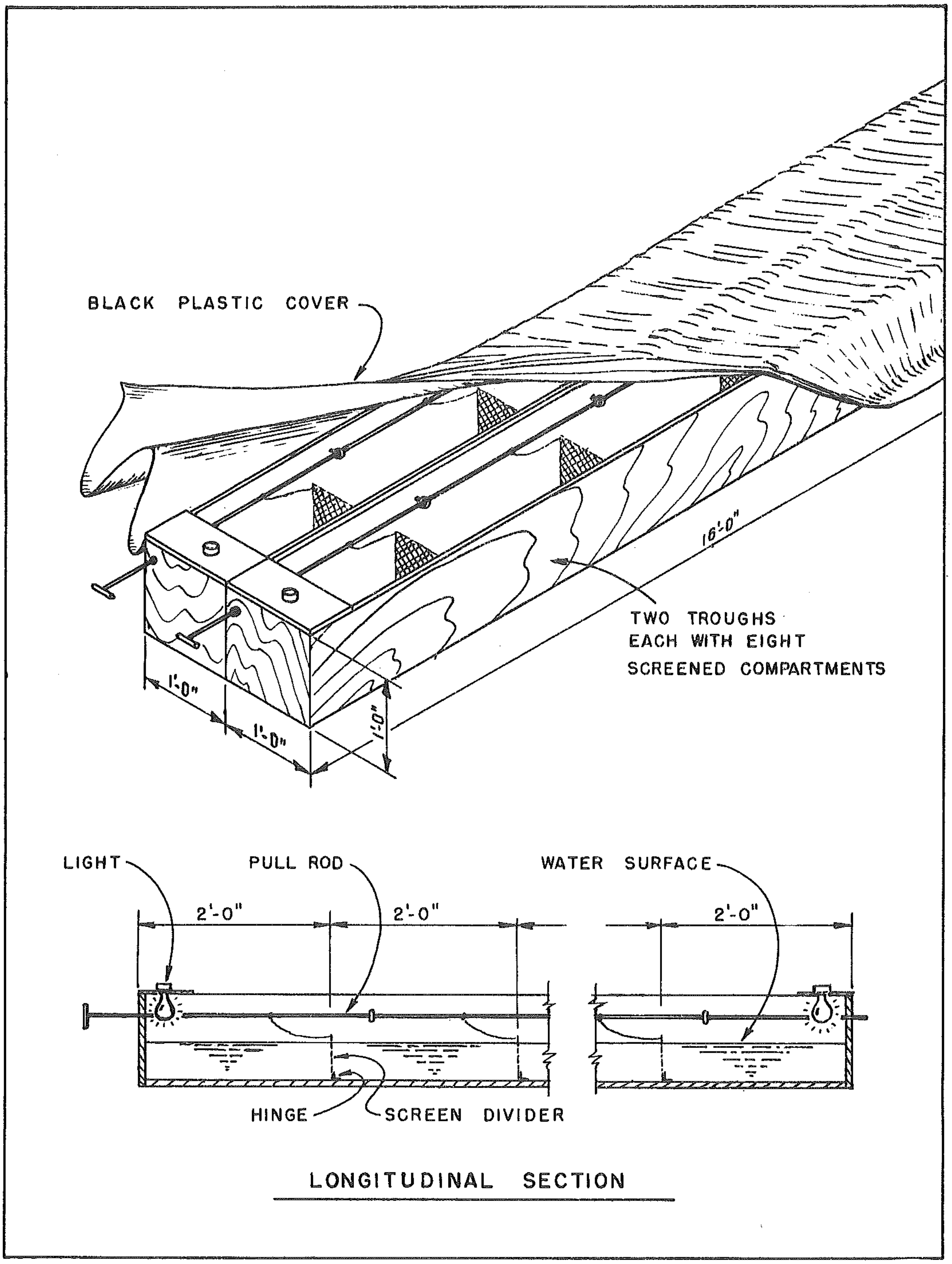

FIGURE 5 - Light intensity troughs.

50 fry were released at the center of each trough at the start of the test. After 1.5 hr the dividers were quickly raised to the vertical position to trap the fry within the various compartments. The numbers in each compartment were counted and the percentage distribution calculated. Duplicate tests were run for each of the two light positions in each trough, making a total of eight tests in varying light intensity (and eight controls in total darkness) of fry from each incubation site.

RESULTS

Survival During Incubation

At the three hatchery sites, mortalities were not excessive and in all areas survival was close to 90 per cent (TABLE 2). Since the eggs were not disturbed after the first day past fertilization, or prior to blastopore closure, most losses were due to fungus formation around blank (unfertilized) eggs which spread to surrounding normal eggs. This type of mortality was most severe among the Cultus eggs where the higher incubation temperature was probably a contributing factor. At all hatchery sites, additional mortalities occurred just after hatching from the nonspecific condition "white spot disease". The cause was not determined, although at Cultus the large numbers of hydras in the troughs were probably responsible. Densities of 5 to 40 hydras per sq in. have been observed in hatchery baskets and as many as six hydras have been observed attached to a single egg shortly before hatching.

Recent studies at Cultus have shown newly hatched sockeye alevins subjected to concentrations of *Hydra oligactis* of 2.5 per sq in. of aquarium bottom (in still water at 40°F) showed white yolk spots after 8 hr and all were dead within 24 to 48 hr. At a lower concentration of 0.5 hydras per sq in., white spots appeared in the yolk of all alevins within 48 hr but no mortalities occurred. At 0.25 organisms per sq in., no white spots were found after one week's exposure. Alevins in control aquaria without hydras were unaffected.

TABLE 2 - Survival from egg deposition to fry emergence at hatchery, channel and natural incubation sites.

RACE AND INCUBATION SITE	NUMBER OF EGGS TAKEN	NUMBER OF FRY EMERGED	PER CENT SURVIVAL		
			Fertilization to Eyeing	Eyeing to Emergence	Total
Upper Pitt River					
Hatchery	66,000	62,000	94.7	99.2	93.9
Channel	95,000	86,450	94.7	96.0	91.0
Natural	80,000*	8,850	-	-	11.1
Total Channel	3,658,000	2,868,000	89.1	88.0	78.4
Weaver Creek					
Hatchery	67,000	60,500+	96.0	94.1	90.3
Channel	75,800*	29,000	-	-	38.3
Natural	80,000*	15,450	-	-	19.3
Total Channel	13,120,000x	10,758,000	-	-	82.0
Cultus Lake					
Hatchery	60,000	52,000	91.7	94.5	86.7
Channel	10,900	9,950	91.7	99.5	91.3
Natural	73,800*	15,500	-	-	21.0

* Estimated egg deposition by 20 female spawners.

x Estimated egg deposition by 3,424 female spawners.

+ Includes 2,250 premature fry.

A similar "white spot" condition and mortality was noted among recently hatched chinook (O. tshawytscha) and coho (O. kisutch) salmon alevins exposed to Hydra oligactis (Eisler and Simon, 1961).

In the experimental sites at Pitt and Cultus incubation channels, survival was 91.0 and 91.3 per cent, respectively (TABLE 2). However, at the experimental site in the Weaver spawning channel, only 38.3 per cent survived, as opposed to an over-all survival in the entire channel of 82.0 per cent. The lower survival in the experimental site is believed due to the sampling procedures which were necessary to obtain alevins prior to emergence. In the large gravel used at Weaver channel, movement of alevins was possible, making it difficult to obtain adequate samples without considerable disturbance of the redd site.

Survival in the natural sites appeared relatively high at Weaver Creek (19.3 per cent) and Cultus Lake (21.0 per cent), but was only 11.1 per cent at 7-Mile Creek. Various factors may have contributed to the lower survival in 7-Mile Creek, but since velocity of flow through the gravel was not measured at natural sites, it is difficult to determine which factor was most important. Sampling at these natural sites prior to fry emergence disturbed the over-all area less than sampling in the channels since the alevins within the gravel of the natural area tended to stay closer to the original redds.

Duration of Incubation

Among all three races, the hatchery fish reached the fry stage (closure of the ventral abdominal slit) well in advance of the peak (50 per cent) of fry emergence from the other two environments. In some cases to be described later, the hatchery fry at this stage contained slightly more yolk than fry from the peak of emergence from channel and natural sites. This occurred because a random sample was taken from the entire hatchery population, whereas only the emerging fry were sampled from channel and natural sites. Furthermore, if hatchery fry had not been considered emerged at this stage (75 per cent "buttoned up"), many would have begun to lose weight due to starvation (Hurley and Brannon, MS, 1968). Thus the "peak emergence" dates selected for hatchery fish are considered realistic. After adjustment for the one- to two-day difference in time of fertilization (TABLE 1), the hatchery fry showed an advancement, as compared with fry from natural sites, of 12 days at Pitt, 9 days at Weaver and 26 days at Cultus (TABLE 3).

The three races of channel fry also emerged a few days earlier than their counterparts in the natural environment. However, the advancement in timing (also corrected for time of fertilization) was less than that of the hatchery fry. At Pitt, the channel emergence preceded the natural emergence by about 9 days, at Weaver 5 days and at Cultus 11 days (TABLE 3). Since the temperature cycles within each area were essentially the same at all experimental sites, the advancement in timing is reflected in the reduced number of temperature units (degree-days above 32°F) accumulated by hatchery and channel fry at emergence as compared with natural fry.

While the significance of the timing variation is most important when the experimental areas are compared, it is also of value to compare the emergence from each experimental channel site with emergence from the channel as a whole. At Weaver, emergence from the channel pen coincided exactly with that from the rest of the channel, indicating that emergence timing from the experimental site was in no way abnormal when compared with the channel as a whole. At Pitt channel, however, peak emergence from the experimental section preceded that of the remainder of the channel by four days, possibly because egg-taking for the test section had been completed approximately five days before 50 per cent of the eggs for the rest of the channel had been obtained.

At Weaver the difference in timing between channel and natural fry emergence was only five days, the least among the three races examined. Since this five-day difference represents about 60 temperature units, it is possible that small differences in temperature between the creek and channel (too slight to be detected consistently) could have caused the difference noted in emergence timing. However, thermograph records of channel temperatures in 1967-68 showed that while there were differences in monthly

TABLE 3 - Duration of incubation at each experimental site.

Race and Incubation Site	Mean Water Temperature (°F) During Incubation	No. Days to Peak Emergence	Temperature Units to Peak Emergence
Upper Pitt River			
Hatchery	40.8	221	1,940
Channel	40.8	224	1,970
Natural	40.8	233	2,050
Weaver Creek			
Hatchery	42.5	169	1,770
Channel	42.5	173	1,810
Natural	42.5	178	1,870
Cultus Lake			
Hatchery	46.5	128	1,860
Channel	46.5	143	2,070
Natural	46.5	154	2,230

mean temperatures down the length of the two-mile channel, these differences averaged out so that there was no difference in accumulated temperature units between the upper and lower portions of the channel by the end of the incubation period. It is felt that these same thermal relationships apply between the experimental natural and channel sites. Therefore, although the difference in emergence timing was less at Weaver than at Pitt or Cultus, the advanced emergence at Weaver is believed to be a developmental advancement rather than caused by a temperature difference between the two incubation sites.

Prior to the emergence of normal fry from the pen in Weaver channel, in late March, premature fry with a large quantity of external yolk began to appear in the trap as early as February 15. These fry predominated in the catches until the second week in March and accounted for approximately 8 per cent of the total emergence from the pen area. These fry were trapped primarily on dark nights and might have re-entered the gravel further downstream if they had not been caught in the trap. However, traps at the outlet end of the channel did show that a small percentage of premature fry were leaving the channel entirely.

Traps in the corresponding natural area of Weaver Creek failed to produce any significant numbers of premature fry. Thus in this case, early emergence from the channel into the creek may be considered abnormal, and because of this, losses among these fry are probably very high. However, in some areas the emergence of fry with large yolk reserves appears to be normal. McCart (1967) noted the presence of "yolk-sac" sockeye fry in various percentages in the Upper Babine River throughout the entire 1964 and 1965 migration periods. He also noted several increases in the proportion of "yolk-sac" fry following temperature surges. At Weaver channel, the occurrence of such fry seemed to be associated only with dark nights. There was no premature emergence from the Cultus incubation channel and that from the Pitt channel site was insignificant (less than 100 fry).

Growth During Incubation

Size of fry produced at the peak of emergence from each incubation site was evaluated by comparing dry weights, lengths and efficiency of yolk conversion. Measurements of dry yolk remaining at emergence showed that Weaver Creek and Cultus Lake fry emerged at complete yolk absorption, while at Pitt River, fry from channel and natural areas still had 2.3 to 3.5 mg of dry yolk material remaining at emergence (TABLE 4). Similarly, the Pitt hatchery fry also contained considerable internal yolk (2.8 mg) upon reaching their maximum size.

In making the weight comparisons between various groups of fry, it was assumed that at the time of emergence maximum body weight had been achieved and without subsequent feeding a loss of body weight would soon take place. Therefore, although slightly different amounts of residual yolk remained at emergence, such yolk material would not significantly increase the body weight at complete yolk absorption. In all cases the body growth rate of hatchery fish slowed to almost zero near the end of yolk absorption. Furthermore, total weights (body plus yolk) at this time did not significantly change the weight relationships of the three types of fry.

On this basis, then, dry body weights of fry at peak emergence were compared directly. At all three streams, channel and naturally incubated fry were found to be superior to hatchery fry in weight and in efficiency of yolk conversion (TABLE 4). Statistical analysis of dry body weights, compared by using the statistic "t", indicated that hatchery fry were very significantly lighter ($P < 0.001$) than the other groups of fry (TABLE 5).

In comparing channel fry with natural fry, the results are not as definitive. At Cultus Lake, the channel and natural fry were virtually identical in size, while at Weaver Creek, fry from the peak channel emergence were significantly heavier than natural fry. At Pitt River the opposite was true with natural fry somewhat heavier than the channel fry. Because of these differences in results, the data were re-examined by expanding the sample to include the peak fry plus all samples within one standard deviation from the mean on the emergence curves. Since emergence approximates a normal curve, these samples would represent approximately

TABLE 4 - Mean length, dry weight and yolk conversion efficiency of sockeye fry (N=20) from peak of emergence at each experimental incubation site.

RACE AND INCUBATION SITE	MEAN FORK LENGTH (mm)	DRY BODY WEIGHT (mg)		DRY YOLK WEIGHT (mg)		YOLK CONVERSION EFFICIENCY* Per Cent
		Mean	Standard Error	Mean	Standard Error	
Upper Pitt River						
Hatchery	31.3	30.42	± .63	2.77	± .31	47.0
Channel	31.3	37.35	± .80	3.45	± .32	57.7
Natural	32.3	39.97	± .56	2.34	± .24	61.8
Weaver Creek						
Hatchery	29.6	24.98	± .54	1.64	± .26	43.7
Channel	30.3	34.71	± .91	0	-	60.8
Natural	31.0	30.43	± .58	0	-	53.3
Cultus Lake						
Hatchery	26.4	17.68	± .37	0.97	± .19	48.6
Channel	28.3	22.80	± .42	0	-	62.7
Natural	28.2	22.73	± .48	0.46	± .12	62.5

* Percentage of original yolk (egg weights in TABLE 2) converted to body weight.

TABLE 5 - Statistical evaluation ("t" test) of dry body weights of sockeye fry from each experimental incubation site.

RACE AND INCUBATION SITE	PEAK EMERGENCE			PEAK EMERGENCE ± 1 STD. DEV.		
	N	$\bar{X}$	P	N	$\bar{X}$	P
Upper Pitt River						
Hatchery	20	30.42				
Channel	20	37.35	<0.001	60	37.00	<0.500
Natural	20	39.97	<0.050	60	36.24	
Hatchery	20	30.42	<0.001			
Weaver Creek						
Hatchery	20	24.98				
Channel	20	34.71	<0.001	60	32.21	<0.050
Natural	20	30.43	<0.001	60	30.71	
Hatchery	20	24.98	<0.001			
Cultus Lake						
Hatchery	20	17.68				
Channel	20	22.80	<0.001	60	23.22	>0.900
Natural	20	22.73	>0.900	60	23.08	
Hatchery	20	17.68	<0.001			

68 per cent of the total population. When the values of "t" were recalculated using these data, it was found that the differences between the dry body weights of channel and natural fry were not significant at Pitt River ($P < 0.50$) or at Cultus Lake ($P > 0.90$). At Weaver Creek the difference in weight was in the inconclusive range ($P < 0.05$) (TABLE 5). It would appear that there were no significant differences between the dry body weights of channel and wild fry.

Lipid Content at Emergence

The lipid content of peak fry from all incubation sites ranged from approximately 3 to 4 per cent of total wet weight (TABLE 6). Among all three races, channel and hatchery fry were not deficient in lipid stores when compared with natural fry at the corresponding stage of development, i.e., peak emergence. However, had the hatchery fish been held without food until the date of natural site emergence (to achieve natural timing before release to the lake), starvation would probably have been evident. The same could occur if fry failed to leave the channels immediately after emergence to find an area of more abundant food supply.

TABLE 6 - Lipid content of peak emerging fry from each experimental site, expressed in per cent of wet weight.

RACE AND INCUBATION SITE	PER CENT LIPID CONTENT*	
	Mean	Range
Upper Pitt River		
Hatchery	4.33	4.19-4.45
Channel	4.23	3.96-4.49
Natural	3.41	3.20-3.62
Weaver Creek		
Hatchery	4.20	4.14-4.26
Channel	3.69	3.59-3.79
Natural	3.18	3.11-3.24
Cultus Lake		
Hatchery	4.33	4.09-4.58
Channel	3.90	3.84-3.97
Natural	4.05	3.85-4.27

* Calculated from two 50-fish samples from each site.

Response of Fry to Predators

Groups of sockeye fry exposed to predators suffered mortalities averaging 3 to 42 per cent (TABLE 7). In these experiments, juvenile coho salmon were more efficient predators than sculpins as the latter did not venture far from the bottom of the tank in pursuit of fry. There was a tendency for higher average mortality among groups of hatchery fry, particularly when exposed to coho, but variations between tests were too great to establish statistically significant differences between fry of one race from different incubation sites. However, tests did show a great difference in mortality between the smaller Cultus fry (26 to 28 mm long) and the slightly larger fry (30 to 32 mm) from Weaver Creek and Upper Pitt River.

TABLE 7 - Average percentage mortality of sockeye fry (N=50) after 23-hr exposure to three groups* each of sculpins and juvenile coho salmon.

RACE AND INCUBATION SITE	PER CENT MORTALITY CAUSED BY:							
	Sculpins				Coho			
	Test 1	Test 2	Test 3	Mean	Test 1	Test 2	Test 3	Mean
Upper Pitt River								
Hatchery	10	2	2	4.7	16	14	16	15.3
Channel	8	18	2	9.3	6	14	20	13.3
Natural	2	0	8	3.2	8	18	14	13.3
Weaver Creek								
Hatchery	8	0	0	2.7	18	20	22	20.0
Channel	10	0	10	6.7	20	12	18	16.7
Natural	4	0	2	2.0	12	10	14	12.0
Cultus Lake								
Hatchery	36	42	14	30.7	30	40	56	42.0
Channel	34	18	22	24.7	28	40	42	36.7
Natural	18	38	28	28.0	36	32	44	37.3

* Each group of predators contained five individuals.

All groups of fry showed essentially the same behavior patterns during the test period. When first released into the tank the fry would scatter among the rocks throughout the bottom of the tanks. It was at this time that most of the predation by sculpins took place. After one hour the fry would be organized into schools and swimming against the current. Sculpins were never observed attacking these schools. The coho, however, continued to attack such schools periodically. At this time, the only observable defense against attack was a burst of swimming speed. Sudden movement by the observer during the first hour would again scatter the fry to the bottom of the tank. After the 23-hr test period, however, in tests with sculpins all remaining fry were found to be schooled very near the water surface. Sudden movements from above would cause the school to turn and flee with the current, but rarely did any fry go to the bottom of the tanks. At the end of the tests using coho salmon, quite a different situation existed. Never were any schools of fry seen after the 23-hr period and all fry were invariably found under the rocks in the bottom of the tanks. Groups of fry held in similar tanks without predators did not show this response, but continued to swim randomly throughout the tanks.

It is evident, then, that the predator attacks upon the fry forced the survivors to the areas of the tanks where they would be less vulnerable to predation. Thus the avoidance of dangerous areas eventually became the primary defense mechanism, as opposed simply to swimming ability as seen earlier in the tests. After the initial test period, a few groups of fry were left with the same predators for up to four days without further mortalities taking place.

Response of Fry to Light

The response to light was tested on peak emerging fry from each of the nine experimental sites. To analyse results of each test, the percentage of fry in each of the eight sections of the trough, weighted to their distance from the central release point, was used to calculate the extent of movement toward either end of the trough, designated as positive toward end A and negative toward end B. The sum of these values provided a single measure of the response of fry in each test and control.

In the control trough, where all light was excluded, many of the tests showed the fry had a predilection to move toward the end of the trough designated as A (FIGURE 6). The factor or factors causing this behavior are unknown, and the same response occurred regardless of which of the two troughs served as the control. For this reason, the results were separated into two groups; the four tests (and four controls) with the light on at A were averaged and examined separately from those with the light on at end B.

In the test trough, channel and natural fry showed similar negative responses to the light (FIGURE 6). When the light was on at A, these fry moved toward end B of the trough. With the light on at B, these fry moved toward end A more strongly than the respective controls. Hatchery fry from Cultus and Weaver showed considerably less avoidance of light than the corresponding channel and natural fry. However, Pitt hatchery fry responded more negatively than might be expected, particularly with the light on in the A position. On the other hand, when the light was on at the B position, they did not move toward end A as strongly as the controls. No explanation for the different behavior of Pitt hatchery fry can be offered other than the fact that the Pitt hatchery environment tended to be considerably darker than the other hatcheries in spite of light from one window and from low wattage incandescent lights. Also, the Pitt fry experienced the longest transportation to Cultus for testing which may have interfered with the results.

DISCUSSION

Differences in incubation environment may cause differences in the fry produced. In the present study, fry were incubated under as similar conditions as possible with regard to origin of eggs, date of spawning, water supply, and thermal conditions. The only major variable was the substrate in which the eggs were incubated which varied from none in the

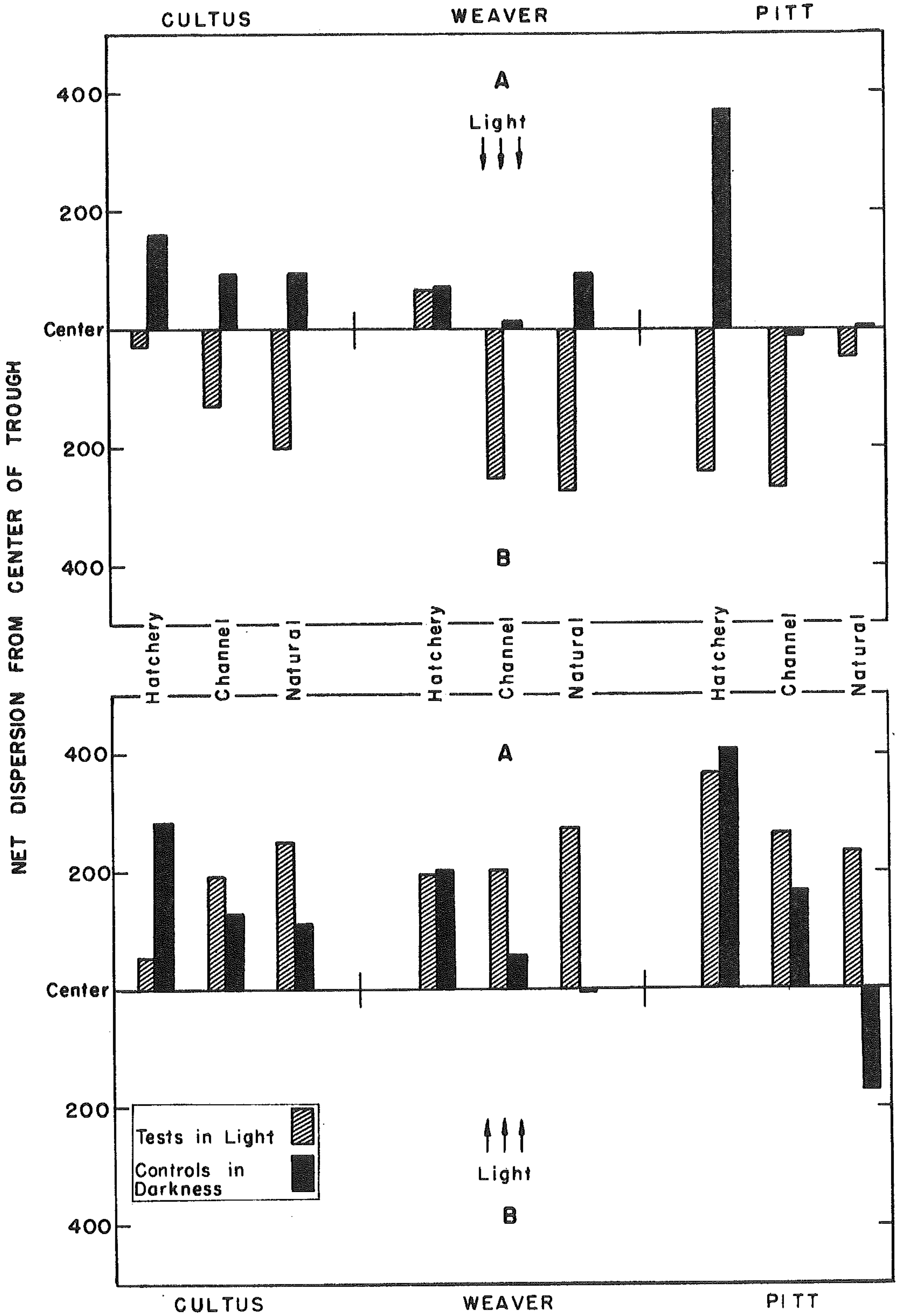

FIGURE 6 - Response of fry to light.

hatchery environment to the wide range of gravel size found in sockeye natural spawning areas. Spawning and incubation channels are intermediate in that very small particles are not present. The channels investigated in this study contained gravel ranging in size from 0.375 to 0.75 in. at Pitt River and 0.5 to 4 in. at Weaver and Cultus. In contrast, gravel in sockeye natural spawning grounds may consist of as much as 40 per cent fine particles which pass a 0.5-in. screen (Andrew and Geen, 1960; Chambers, 1956). These differences in substrate cause differences in other parameters, notably velocity, light and oxygen supply. These, in turn, can impart differences to the fry produced.

Incubation in high water velocities produces sockeye fry weighing significantly less than those incubated in low velocities. For example, hatchery incubation at calculated actual velocities of 25 and 75 mm/sec has been found to produce sockeye fry weighing significantly less than those incubated at velocities of 15 mm/sec or less (Brannon, 1965). In the present experiment, hatchery eggs and alevins were incubated in apparent velocities of 23 to 28 mm/sec. Thus the relatively high water velocity together with the lack of spatial confinement may have been the primary factors in producing hatchery fry which were significantly smaller at emergence than comparable channel or natural fry. Since the quantity of yolk to be utilized is fixed, growth is necessarily sacrificed to satisfy the energy demand of the increased activity in hatchery-incubated alevins. The presence of substrate in channels and natural incubation areas reduces the velocities to which the alevins are exposed, as well as providing spatial confinement. Therefore, energy demands for maintaining position are reduced to a minimum.

However, the elimination of fine material from the gravel could conceivably allow higher intergravel velocities in channels than in natural areas which would then result in smaller fry from channels. In the present experiment this did not occur. In fact, at Weaver Creek channel where the gravel size is largest, the channel fry had a dry weight even greater than that of the natural fry. Probably it is the support and confinement that makes incubation in a substrate superior to the unconfining hatchery baskets and troughs. Hence, the incubation of alevins in a gravel substrate, be it natural or channel composition, produces fry which presumably reach their genetic potential in size with a better chance for survival.

Exposure to light during incubation may also contribute to production of smaller fry. Brannon (1965) found that, at hatching, sockeye eggs exposed to light showed a poorer efficiency in yolk conversion and body weights were significantly less than those held in darkness. Furthermore, this initial difference in weight was maintained until yolk absorption was complete. In the present study, it was not possible to obtain comparable samples from natural and channel areas exactly at hatching for comparison with hatchery alevins. However, the exposure of hatchery eggs to light, while the channel and natural eggs were incubated in total darkness, may also have contributed to the smaller final body weight and length of hatchery fish.

By removing fine material from the gravel and controlling water flow, the potential egg-to-fry survival in channels is greater than in natural areas, partly because the areas of poor water exchange through groups of eggs are reduced. However, at the same time, the oxygen conditions to which the eggs and alevins are exposed may be more like the hatchery than the natural environment, or at least somewhere in between. It is this increased availability of dissolved oxygen that may have caused the emergence of channel fry to precede the emergence of natural fry at all locations examined.

Oxygen studies by Brannon (1965) suggest that the factor most responsible for accelerated development of alevins is the difference in oxygen levels between the hatchery, where the water is essentially saturated at all times, and the natural environment where oxygen concentrations are moderately low. Garside (1966) also found that lower levels of oxygen caused reduction in the developmental rate of brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*) embryos. In the present study, this relationship was most evident in the oxygen levels and emergence dates recorded at Cultus Lake. Oxygen in the hatchery water supply was 11 mg/l, whereas dissolved oxygen levels from the spring-fed spawning areas of Cultus Lake have been measured as low as 3.0 mg/l (Brannon, 1965). As a result, the difference in emergence dates between the hatchery and natural areas at Cultus Lake was 26 days, twice as great as the other two races tested. At Pitt and Weaver, oxygen levels in the natural areas are probably greater (because of the stream flow conditions) than in the beach seepage at Cultus and differences in time of emergence were therefore considerably less.

The advancement of hatchery fry over channel and natural areas may also have been due in part to their exposure to light, in addition to the possible differences in oxygen level. Brannon's work showed that there was less yolk remaining at hatching in groups of sockeye eggs exposed to light, and yolk absorption of these alevins was completed three days sooner than among sockeye incubated in darkness.

In summary, then, the combined deficiencies in weight, length, and emergence timing appear to place the hatchery sockeye fry at an extreme disadvantage when released into the lake environment upon emergence. The artificial channel fry, however, approximate quite closely the physical characteristics of the natural fish and presumably would have an equal chance for survival on this basis. The effects of the few days advancement of channel fry cannot be assessed without further studies of fry during their early lake residence. The specific tolerance limits probably vary from one lake environment to the next. In fact, the few days advancement at Pitt and Weaver might be found to be more critical than the greater difference in timing at Cultus.

Biochemical analysis showed that body reserves of lipid were very similar at emergence for fry from all incubation sites. Any depletion of these reserves would have occurred after the normal emergence time and therefore could be prevented by feeding either artificially or naturally at the proper time. Hatchery fry that were held until natural release dates, a period ranging from 9 to 26 days for the races studied, would certainly need to be fed to prevent starvation. It is well known that fry which do not obtain food immediately after yolk absorption are permanently stunted (Palmer et al., 1951).

The characteristics imprinted into the newly emerged fry by the incubation environment may determine whether fry will survive their early lake residence. Because the deficiencies in weight and emergence timing place the hatchery sockeye fry at an extreme disadvantage when released directly into the lake environment, it is not surprising that previous sockeye hatchery operations in

British Columbia failed to provide clear evidence of "any beneficial results in any of the areas where they [hatcheries] were located ..." (Foerster, 1968). Based on tests of natural and artificial sockeye propagation at Cultus Lake, Foerster (1938) concluded that "artificial propagation exhibits no significantly increased efficiency, in point of seaward-migrating young sockeye, over natural spawning." However, if fry are fed for some period prior to release, their origin (hatchery, channel, natural) may not be as critical as when fry are released immediately upon emergence. Modern hatchery diets may now be able to produce sockeye smolts that return at a satisfactory rate regardless of the origin of the fry. The recent spectacular success of hatchery operation and artificial rearing in producing runs of coho and chinook salmon in the northwest United States, and experiments on rearing sockeye by the International Pacific Salmon Fisheries Commission at Cultus Lake (Internat. Pacific Salmon Fish. Comm., 1968) lend hope in this regard.

A reduced photonegative response, as noted here for Weaver Creek and Cultus Lake hatchery fry, may be one of the factors responsible for the generally poor survival following release of hatchery-incubated fry. As noted previously, the release of hatchery fry into Cultus Lake did not increase the efficiency of smolt production, even though egg-to-fry survival in the hatchery ranged from 58 to 68 per cent of the total eggs available (Foerster, 1968). Since egg-to-fry survival was presumably much lower in the natural spawning grounds, this implies considerably better lake survival of natural fry than of fry released from the hatchery. Similarly, Salo and Bayliff (1958) presented data showing freshwater survival from natural spawning of coho salmon (_O. kisutch_) exceeded 9 per cent from egg to seaward migrant, whereas only 4 per cent of 500,000 hatchery-produced coho fry survived after release to reach the migrant stage. If released directly into a stream upon emergence, a reduced photonegative response could render hatchery-incubated sockeye fry much easier prey than their wild counterparts who migrate mainly at night and tend to seek less lighted areas during the day. Masking of these natural responses by the conditioning of the hatchery environment could conceivably affect the ability of such fry to cope successfully with the dangers of their early freshwater existence. Deviations of fry from natural condition, both in behavior and in physical characteristics, must certainly put such fry at a disadvantage in terms of survival.

The predation tests in this study did not indicate an increased mortality among those fry with an abnormal response to light. However, these tests were not designed to correlate the photo response with predation since no choice of lighting was available to the fry (i.e., all tests began in daylight). Furthermore, the predation losses within each group of fry were highly variable and therefore inconclusive in showing differences between fry of one race from different incubation sites. However, body length appears to be a major factor in the survival potential of migrating fry. Bams (1967) found that length of sockeye fry was an important factor in both swimming performance and predation tests. He found differing ranks of swimming performance between groups of fry with length differentials of 2 to 4 mm. The present tests also showed a greatly increased predation upon the smaller Cultus fry.

The fish appearing to be most fit for survival are those from the peak of the emergence. For example, in most cases the fry which left the gravel during the peak of emergence had the greatest body weight. This evidence supports the concept that individuals which deviate from the norm are less adapted for survival in an environment which has, through natural selection, produced each genetic stock of sockeye. This is not to say that individuals which deviate from the population average never survive, but that the odds are less in their favor. This applies not only to emergent fry populations, but to all other stages of the sockeye life cycle as well. Royal (1953) applied this concept to the relationship between the peak of the adult migration and maximum reproduction.

In addition to the differences noted between the types of fry from each race, it is important to note the differences observed between races. Pitt River fry emerged with several milligrams of yolk remaining, while at the other areas the yolk material was exhausted at emergence. The benefit of this trait cannot be fully assessed without a full knowledge of the rearing environment at Pitt Lake. Perhaps the areas of abundant food supply are farther from the spawning areas than at Cultus and Weaver. Similar yolk reserves have been found in emergent Chilko Lake fry, but in this case the yolk supply is believed related to the upstream migration which Chilko fry must accomplish to reach their nursery lake (Brannon, 1967).

These differences between the races point out that each race has evolved characteristics which provide for the best survival in its own particular environment. Thus the advantage of superior physical characteristics is relevant only within a race and not necessarily between races. Hence, caution must be exercised in drawing generalized conclusions on data from only one race of sockeye.

Caution may also be necessary in applying results from one channel to another, as indicated by information released recently by the Department of Fisheries of Canada and the Fisheries Research Board of Canada (Anonymous, 1968). These agencies report that fry from Fulton Spawning Channel were inferior to Fulton River natural fry in terms of weight, stamina and resistance to starvation, although the channel fry appeared to survive as well in Babine Lake as did their counterparts from the river. It is also stated that the river fry migrated considerably earlier than those from the channel. Data from the Fulton Channel then seem to contradict the findings in the present investigation. However, the report also indicates that the Fulton River fry migrated with more yolk than channel fry and were likely being scoured from the river gravel by high water velocities. This fact, plus variation in genetic stocks, channel design, thermal history and other intrinsic environmental conditions might well produce the different results found in the two investigations.

IMPLICATIONS FOR CHANNEL MANAGEMENT

If emergence must be precisely correlated with the environmental cycle of the rearing lake to which the fry migrate, major deviations in emergence timing could exceed the environmental tolerance limits of the race involved. It is not known whether the earlier emergence from channels noted in this experiment is detrimental to the survival of channel fry. However, the timing of the natural population has been selected through evolution and must be considered most favorable for survival. Any survival less than that of the naturally produced fry will be reflected in losses to the fishery because of the relatively low percentage returns from even the best surviving natural fry.

Thus it may be advantageous to take appropriate action to ensure that the time of channel emergence is close to that of the natural areas. There appear to be two possible management procedures which can be manipulated to achieve this ideal: (1) the thermal cycle during incubation within the channel, and (2) the relative spawning times between the channel and the natural populations.

Since most channels require supplemental water during periods of low flow in winter, it may be possible to supply cooler or warmer water than that of the natural areas for part of the incubation period. The inherent nature of channels with their relatively shallow water depths, slow flow, and exposure may produce enough decrease in temperature during winter to compensate for a faster developmental rate, without additional temperature regulation. Based on the present experiments, the use of water which is significantly warmer than that of the natural incubation areas, either because of warming along the length of the channel in warm weather or from a supplementary source at a higher temperature, should be avoided. Certainly, accurate and detailed temperature records are essential for all channel operations to indicate the thermal unit accumulations of both channel and natural areas.

Since the effects of imposing a somewhat foreign temperature cycle on developing sockeye eggs and alevins is not precisely known, an alternative method of adjusting the emergence of channel fish (closer to that of the natural) would be to adjust the spawning date in the channel. In the case of advanced development in a channel, it may be advantageous to use the peak and later part of the run, rather than allowing the first part of the spawning run to enter the channel. If management practices in this regard were kept standard each year, the small differences in emergence timing imposed by channels might be overcome by the gradual adaptation of the spawning population to the new environment. Unfortunately, however, most of the races selected for channels are relatively small compared to the Fraser River sockeye run as a whole. Therefore the part of the run which escapes to the channel spawning grounds varies from year to year, depending on the regulations designed for the major races which contribute most to the Fraser River sockeye fishery.

Because of variations in temperature and spawning time from year to year at any one channel, it may be advantageous to sample both the channel and natural areas periodically during incubation to obtain average yolk weights. Based on the results of such sampling, measures could be initiated to adjust the rate of development of the channel alevins by temperature regulation if a suitable water source were available.

It is also important in the design of artificial channels that newly emergent fry are not delayed in leaving the channel once they emerge from the gravel. Problems have been encountered in the past at Pitt and Cultus channels in this respect, and fry have had to be forced manually from the channels. Steps taken to increase surface velocities during emergence have helped alleviate the problem.

Since each present channel and all future channels will have their own sets of special conditions and environments, management procedures for each must be determined individually, using the results from previous experiments as guidelines. In husbandry of all animals, and in salmon culture specifically, success emerges as a result of a sensitive blend of art and science.

SUMMARY

1. Sockeye salmon fry from Upper Pitt River, Weaver Creek and Cultus Lake races produced by hatcheries, artificial channels, and natural spawning areas were studied. Comparisons were made of fry which were as equivalent as possible in genetic background, time of fertilization and thermal history. The fry were examined with regard to growth, timing, per cent lipid, susceptibility to predation, and photo response.

2. Hatchery fry were found to reach developmental stages equivalent to emergence considerably sooner than the corresponding natural fry. Channel fry showed some advancement of development, but it was not established whether the deviation from the natural emergence timing was great enough to be harmful.

3. Fry produced by conventional hatchery methods were found to weigh less at emergence than artificial channel and natural fry of the same race. Channel fry, conversely, were found to approximate the natural fry in size.

4. Analysis for per cent lipid in the newly emerging fry failed to show any deficiencies in hatchery or channel fry as compared with wild fry at normal emergence, but any delay in releasing hatchery or channel fry without feeding could result in depletion of body reserves.

5. Behavior tests showed that hatchery fry from Weaver Creek and Cultus Lake were less photonegative than the channel and natural fry at the time tested. This reaction, which is considered abnormal for newly emerged sockeye fry, could result in loss of such fry when released into the natural environment.

6. Predation tests were not sensitive enough to detect significant differences in predation rates between fry of one race incubated under different conditions. However, differences between the races were significant, the predation upon the smaller Cultus fry being considerably greater than upon the larger fry of Pitt and Weaver races.

7. Differences between the three races of sockeye were noted in egg size, final body weight and amounts of residual yolk upon emergence. These differences between races (and possible differences between channels) indicate the need for individual studies of each race wherever artificial aids to propagation are contemplated.

8. Management practices suggested to control time of fry emergence from channels include selection of suitably timed spawners, adjustment of incubation temperatures and prevention of any delay in fry migration.

LITERATURE CITED

Andrew, F.J. and G.H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Internat. Pacific Salmon Fish. Comm., Bull. 11. 259 p.

Anonymous. 1968. The Babine Lake development program. Progress report to March 31, 1968. Dept. Fish. Canada and Fish. Res. Bd. Canada, Vancouver, B.C. 75 p.

Bams, R.A. 1967. Differences in performance of naturally and artificially propagated sockeye salmon migrant fry, as measured with swimming and predation tests. J. Fish. Res. Bd. Canada 24(5): 1117-1153.

Brannon, E.L. 1965. The influence of physical factors on the development and weight of sockeye salmon embryos and alevins. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 12. 26 p.

1967. Genetic control of migrating behavior of newly emerged sockeye salmon fry. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 16. 31 p.

Chambers, J.S. 1956. Research relating to study of spawning grounds in natural areas. U.S. Army Corps of Engineers, North Pacific Div., Fish. Eng. Res. Program, Prog. Rept. p. 88-94.

Eisler, R. and R.C. Simon. 1961. Destruction of salmon larvae by Hydra oligactis. Trans. Amer. Fish. Soc. 90(3): 329-332.

Foerster, R.E. 1938. An investigation of the relative efficiencies of natural and artificial propagation of sockeye salmon (Oncorhynchus nerka) at Cultus Lake, British Columbia. J. Fish. Res. Bd. Canada 4(3): 151-161.

1968. The sockeye salmon, Oncorhynchus nerka. Fish. Res. Bd. Canada, Bull. 162. 422 p.

Folch, J., M. Lees and G.H. Sloan Stanley. 1957. A simple method for the isolation and purification of total lipides from animal tissues. J. Biol. Chem. 226: 497-509.

Garside, E.T. 1966. Effects of oxygen in relation to temperature on the development of embryos of brook trout and rainbow trout. J. Fish. Res. Bd. Canada 23(8): 1121-1134.

Hoar, W.S., M.H.A. Keenleyside and R.G. Goodall. 1957. Reactions of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada 14(6): 815-830.

Hurley, D.A. and E.L. Brannon. MS, 1968. Effect of feeding before and after yolk absorption on the growth of sockeye salmon. Internat. Pacific Salmon Fish. Comm.

International Pacific Salmon Fisheries Commission. 1964. Proposed artificial spawning channel for Weaver Creek sockeye. Admin. Rept. 61 p.

1968. Annual report for 1967. 51 p.

McCart, P. 1967. Behavior and ecology of sockeye salmon fry in the Babine River. J. Fish. Res. Bd. Canada 24(2): 375-428.

Miller, R.B. 1954. Comparative survival of wild and hatchery-reared cutthroat trout in a stream. Trans. Amer. Fish. Soc.(1953) 83: 120-130.

Palmer, D.D., H.E. Johnson, L.A. Robinson and R.E. Burrows. 1951. The effect of retardation of the initial feeding on the growth and survival of salmon fingerlings. Progr. Fish-Cult. 13(2): 55-62.

Ricker, W.E. 1941. The consumption of young sockeye salmon by predacious fish. J. Fish. Res. Bd. Canada 5(3): 293-313.

Roos, J.F. 1960. Predation of young coho salmon on sockeye salmon fry at Chignik, Alaska. Trans. Amer. Fish. Soc. 89(4): 377-379.

Royal, L.A. 1953. The effects of regulatory selectivity on the productivity of Fraser River sockeye. Canadian Fish Cult. 14: 1-12.

Salo, E.O. and W.H. Bayliff. 1958. Artificial and natural production of silver salmon, Oncorhynchus kisutch, at Minter Creek, Washington. Wash. State Dept. Fish., Res. Bull. 4. 76 p.