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INSTREAM FLOW AND THE REPRODUCTIVE EFFICIENCY OF SOCKEYE SALMON

by

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1.0 ABSTRACT

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Substrate scouring due to a flood (249.3 m^3/sec) reduced egg/alevin densities by 50.6 and 96.6 percent on two reach types sampled. The presmolt-to-spawner ratio ranged from 5.8 following the flood to 20.2 following augmented low flow and no flood. Fry production in 1976 and 1977 was 1.76×10^6 and 22.8×10^6, respectively, representing survival rates of 0.81 and 8.1 percent. A sustained flood loss of 42 percent of the spawning habitat coupled with a 22 percent increase in escapement appears to have increased the density-dependent mortality and reduced the contribution of the early spawners to the total fry production. These results should help to establish an efficient escapement goal for the Cedar River sockeye and find application on salmon streams affected by hydroelectric or diversion projects where stream discharge can be managed to maximize spawning area to benefit fish production.

Key words: instream flow, water diversion, sockeye salmon, density-dependent mortality, fry production, flood effects, egg densities, hydraulic samples, fish management, environmental effects, stream habitat.

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3.0 INTRODUCTION

The Cedar River is the major spawning ground for the Lake Washington sockeye salmon, one of the largest runs of this species in the contiguous 48 states. The Cedar River watershed is managed by the City of Seattle Water Department as the primary source of municipal and industrial water supply for the Seattle metropolitan area. Management of the water resource must take into consideration, not only the municipal and industrial needs, but also the instream flow requirements of the sockeye and less abundant coho and chinook salmon and steelhead and cutthroat trout. Regulation of the river discharge has a direct effect on the anadromous salmonids in the river below the city water supply diversion. During periods of low runoff, the demands placed on the system by the fishery resource, public use and the municipal and industrial needs can be in conflict.

Previous studies on the Cedar River by Collings et al. (1972) and Stober and Graybill (1974) have dealt with the effects of minimum discharge on the available spawning area for Cedar River sockeye salmon. Miller (1976) investigated the relationships between discharge, fish production, and water supply in the Cedar River while the biological production of Lake Washington sockeye was modeled by Bryant (1976). The latter two studies pointed out the need for additional information on the early life history of sockeye salmon in the Cedar River. The production of Lake Washington sockeye salmon was largely controlled by the conditions encountered during reproduction and early development in the Cedar River. The controlling factors included the environmental effects of fall droughts, winter floods, as well as density-dependent mortality, a direct function of population size on the area of available spawning substrate. The fall spawning discharge was partially controlled to maximize spawning area and egg deposition throughout an extended spawning period while flood discharges were uncontrolled. Redd density, egg deposition and survival were investigated on spawning reaches with contrasting hydraulic characteristics. Environmental conditions during the 2 years studied ranged from extreme flooding to extreme drought. River discharge during the latter period was mitigated from upstream storage during the sockeye salmon spawning season. Specific objectives of this study were to:

1) monitor the sockeye spawner distribution, abundance, redd density, and timing of the escapement to the spawning reaches;

2) determine egg-alevin densities and survival following successive increases in spawner density during the season;

3) determine the effects of controlled spawning discharge and winter flood discharge on preemergent fry survival and condition;

4) determine embryonic development rates and emergence timing from early, middle and late portions of the escapement; and

5) estimate the production of sockeye fry during 2 years at two levels of escapement and instream flow regimes.

Anadromous sockeye salmon from Baker Lake, Washington, were first introduced into the Lake Washington watershed in 1935 (Woodey 1966). Adult returns were insignificant from brood years prior to 1960 (Kolb 1971). There were substantial increases in escapements from the 1960-1967 brood years, resulting in the maximum return of 540,000 in 1971. The run now is of economic and biological importance to the State of Washington and the Seattle metropolitan area.

Woodey (1966, 1972) described the life cycle of the Lake Washington sockeye. The adults return each year to the lake from June to August, peaking around July 4, and remain in the lake for 1-4 months before spawning. Over 90 percent of the escapement spawns in the Cedar River from early September through mid-December. Fry emergence from the spawning gravel occurs from January through late May. Fry emigration to Lake Washington occurs from January-June. The primary growing period is from June through October in the limnetic zone of the lake. Zooplankton forms the principal food source. After 12-15 months rearing in the limnetic zone, the juveniles smoltify and migrate to sea during the spring.

Determination of sockeye salmon egg-alevin densities and survival rates have been recently investigated by the IPSFC (Woodey, personal communication). Mathisen (1962) reported on the effect of altered sex ratios on the spawning of red salmon in Southeast Alaska. McNeil (1962)

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Considerable information on the behavior of juvenile sockeye salmon is available. Extensive field observations have been reported by McDonald (1960), Hartman et al. (1962 and 1967), and Heard (1964). Estimates of downstream migrant fry in British Columbia systems have been obtained by Clarke and Smith (1972) for sockeye fry. Sockeye smolts have been enumerated by Burgner (1962) and Schroeder (1972) in Alaska and Tyler and Wright (1974) in Washington.

We anticipate that the results of this study will be useful to the Cedar River Ad Hoc Water Resource Management Committee, which includes, in addition to the local sponsors of this project, the Washington State Departments of Ecology, Fisheries, and Game (WDE, WDF, WDG); U.S. Army Corps of Engineers (USACE); and City of Seattle Department of Lighting. Lake Washington sockeye are presently utilized by an intensive lake sport fishery as well as by the Muckleshoot and Suquamish Indian tribes.

4.0 DESCRIPTION OF STUDY AREA

The Cedar River drainage encompasses a 487-km^2 area. The river heads on the west slope of the Cascade Mountains, flows across the lowlands of the Puget Sound area, and empties into the south end of Lake Washington (Fig. 1). Average annual precipitation ranges from 250 cm near the head (primarily as snow) to 80 cm near the mouth (generally as rain). Hydrographic analysis of river discharge indicated high flows during winter and low flows during late summer, a pattern typical of lowland streams. Runoff may occasionally increase during spring snowmelt.

The discharge of the Cedar River presently is regulated both by operation of the Cedar Falls hydroelectric station (30 MWe at 21.3 m^3/sec) below Chester Morse Lake (Seattle City Light) and by an average annual diversion of about 4.8 m^3/sec at Landsburg by the Seattle Water Department. Only the lower 34.8 km of the river are available to anadromous salmonids such as sockeye, chinook, and coho salmon and steelhead and cutthroat trout due to obstruction of the river by the Landsburg diversion dam.

Eleven reaches were selected as sites for intensive hydraulic and biological investigations in an effort to represent the different spawning areas utilized by sockeye in the river. Reaches 1 to 11 were located at RKm 31.6, 28.0, 25.3, 22.0, 21.6, 20.9, 20.1, 18.5, 13.5, 8.5, and 2.4, respectively (Fig. 1). For the sake of continuity with previous investigations by Stober and Graybill (1974), during the 1975 spawning season all reaches were identical to those of the previous study, with the exception of Station 8, which had been located approximately 200 m downstream. A 715-m^2 area was added to the downstream section of Station 5. This additional area included a riffle where the water velocity accelerated, and was added to investigate spawner utilization and substrate stability. Stations at RKm 22.0 and 8.5 corresponded to Stations A and C, respectively, of Collings et al. (1970).

Due to drastic channel changes in certain parts of the river following the December 1975 flood, new study reaches in 1976 were selected to relocate Stations 2, 7, and 10 and were designated 2B, 7A, and 10A, respectively. Station 2B was established immediately upstream from Station 2 (RKm 28.0). Station 7A was relocated 0.8 km downstream of

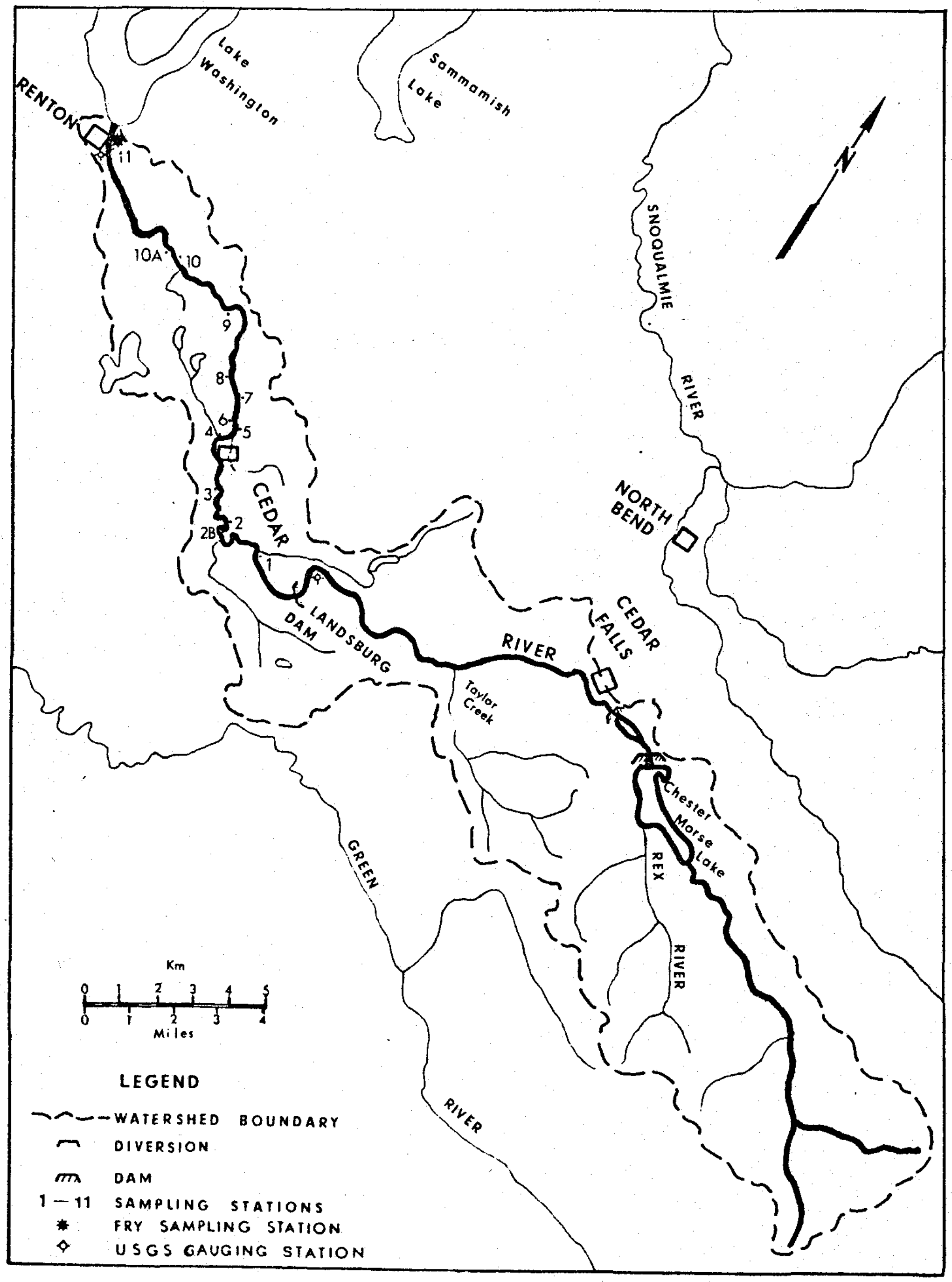


Fig. 1. Map of Cedar River watershed, showing location of study reaches, stream gauges and fry sampling station.

Station 7 at RKm 20.1. Station 10A was reestablished about 400 m downstream of the site of Station 10 which had been above the lower Jones Bridge.

The effects of instream flow and spawner density on egg/alevin density and survival were intensively studied at Stations 1 and 5 during 1975 and at Stations 2B and 5 during 1976.

Fry sampling was conducted near the mouth of the Cedar River (Fig. 1) at RKm 1.0. The site was selected because it was below all major spawning areas in the river and was restricted to the general public. The channel at this site was straight with a coarse gravel substrate. A cross-sectional contour (Fig. 2) indicated a bar along the east side of the channel and maximum depth along the west bank. The river width was 40.3 m. During the first season, the average depth varied from 0.6 to 0.8 m and in 1977, it ranged between 0.3 and 0.8 m. Midchannel current velocities ranged from 0.5 to 0.9 m/sec and 0.3 to 0.8 m/sec in 1976 and 1977, respectively. In general, the discharge pattern decreased from major flood flows during the first part of the 1976 fry sampling season while augmented low discharge during severe drought conditions characterized the 1977 season.

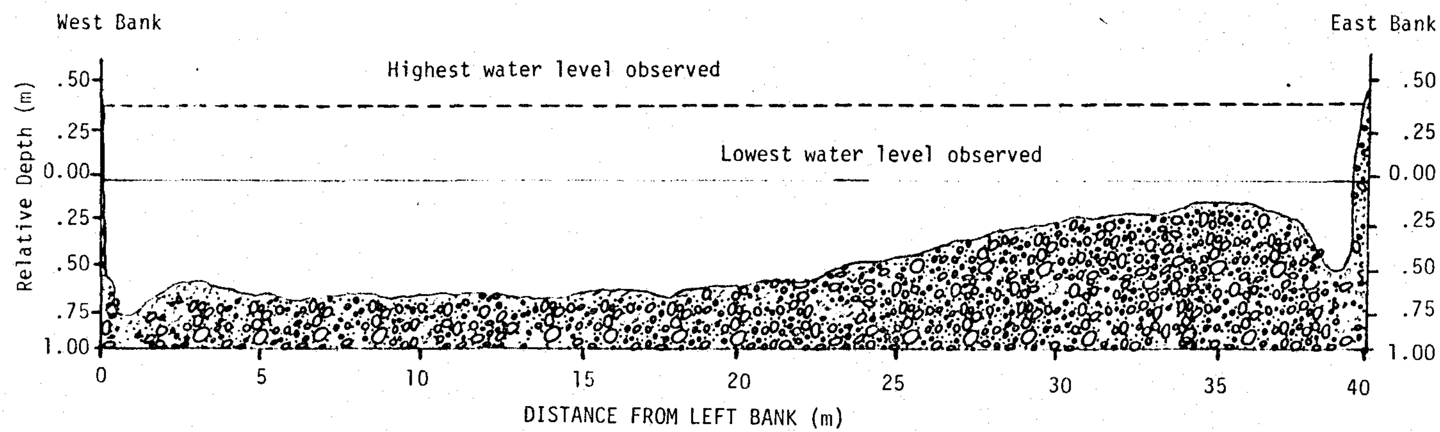


Fig. 2. Cross-section of the Cedar River at the fyke net sampling site.

5.0 MATERIALS AND METHODS

5.1 Hydraulic Measurements

Systematic measurements of depth and velocity along four or more transects at each sample reach were recorded at several discharges as described by Collings et al. (1972), and Stober and Graybill (1974). Over 30 readings were taken along each transect. Velocities were measured at a depth of 12 cm ("fish depth") with a Marsh-McBirney electronic current meter (Model 201). These measurements were analyzed with the contouring computer program FRB726 (SYMAP) which produced a map of the preferred spawning area within each reach on the basis of a modal analysis of the 80 percent range of preferred depth (15.2 to 54.9 cm) and velocity (28.4 to 78.9 cm/sec) reported by Stober and Graybill (1974). Hydraulic surveys were conducted during several discharges through the fall spawning season to determine suitable spawning areas at each reach based on depth and velocity criteria. Additional surveys were conducted at Stations 1 and 5 in 1975 and Stations 2B and 5 in 1976, because these reaches were sampled to determine egg and preemergent fry densities in the gravel.

5.2 Spawner Counts

The escapement of spawning sockeye to the Cedar River was estimated as in the past by WDF from tower counts made at RKm 8.5. The distribution and abundance of spawning sockeye in the Cedar River were monitored in 1975 and 1976 for comparison with previous years (1972-1974). Active spawners within each of the 11 reaches were counted each week. The number of redds and wetted perimeter was mapped using plane table methods each week. The area actually spawned and the total wetted area were determined by planimeter measurement of the plane table maps.

5.3 Float Surveys

The river below Landsburg (RKm 34.8 to 6.0) was floated each week to determine the spawner distribution and utilization. Area spawned each week was recorded on photocopies of aerial photographs of the river channel. The photos used in 1975 were taken in August 1973; however, the river was photographed again in August 1976, following the December

1975 flood. The later aerial photos were utilized during the 1976 spawning season. Landmarks (i.e., trees, logs, boulders, etc.) served as reference points in outlining actual spawning areas. The area spawned each week was determined from the photocopy by using a "square" grid (each square = 10 mm^2 = 0.1 cm^2) method.

5.4 Egg and Preemergent Fry Sampling

Hydraulic sampling was conducted to investigate the distribution, density, and survival of sockeye eggs and alevins in the gravel at Stations 1 and 5 from October 1975 to March 1976. Similar samples were taken at Stations 2B and 5 from October 1976 to March 1977. Both reaches were chosen for study each year due to utilization by sockeye spawners and because the reaches contrasted physically and hydraulically, which provided an opportunity for biological comparison.

Egg and alevin sampling during each series was conducted along four transects at Stations 1 and 2B, and five transects at Station 5. All transects were randomly selected and established perpendicular to the flow of water. Each transect was sampled only once during each year. When low flow conditions permitted wading, samples were collected at 0.76-m intervals, using a hydraulic sampler as described by McNeil (1964). Samples were taken along each transect through the observed spawned area. Additional digs were made into the unspawned area to insure definition of the limits of the spawned area. Each sample covered an area of 465 cm^2 (0.5 ft^2) to a depth in the substrate of about 30 cm, depending on the size and permeability of the gravel.

High winter discharge during 1975-1976 required modification of the hydraulic sampler so that it could be operated from a 3.7-m flat-bottom boat (Fig. 3). A rope attached to two pulleys secured to the bow of the boat was anchored to each bank of the river. The boat was maneuvered along this rope, which was tightened or slackened to position the sampler at 1.5-m intervals along each transect. Once positioned, a large iron bar was lowered vertically through the bow frame into the streambed to hold the boat in position. Two steel rods were similarly lowered to the bottom along each side of the boat for added stability. The sampling

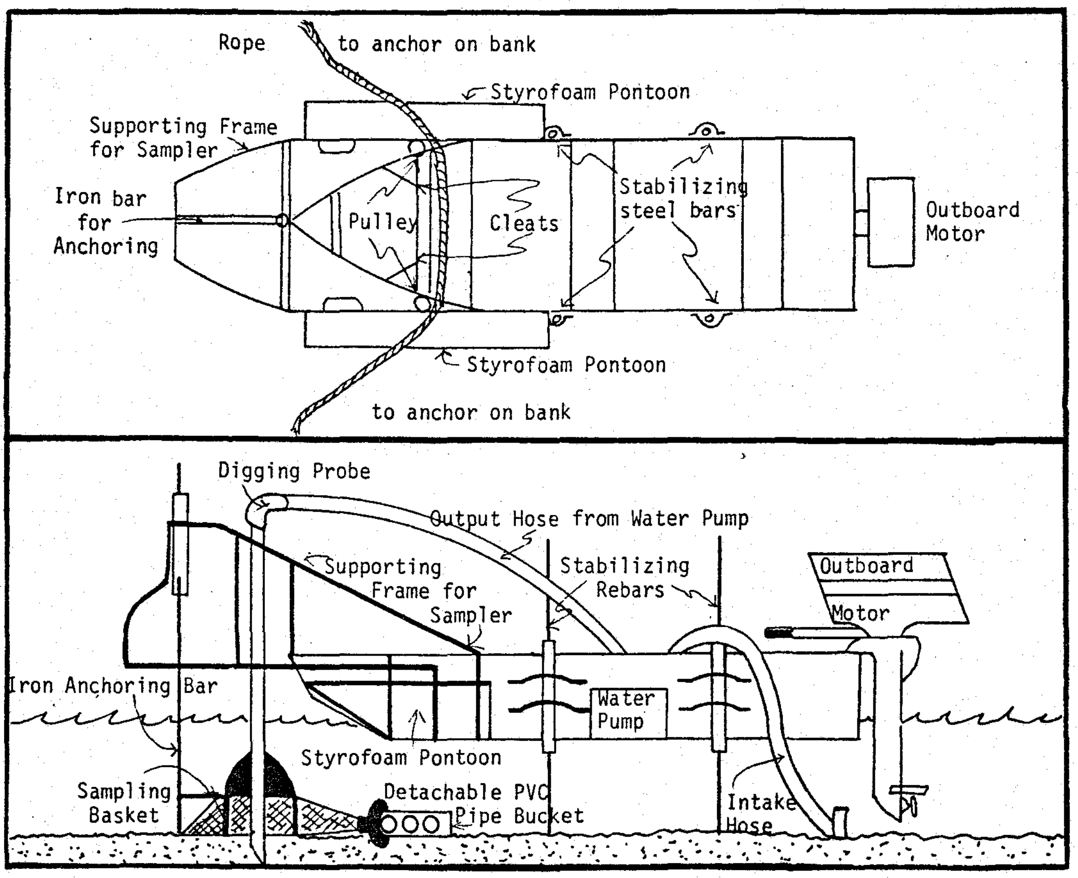


Fig. 3. Preemergent egg and fry sampling equipment, for use during high river discharge.

basket was streamlined to reduce resistance at high water velocities; however, the sample area remained at 465 cm^2. The sampler was guided down the large iron bar to the streambed. The nozzle end of the probe was inserted through a collar in the canvas-covered basket top. The basket was retrieved and contents removed from the bucket. Eggs were separated from the gravel and preserved in Stockard's solution. Alevin samples were preserved in 10 percent Formalin.

5.5 Potential Egg Densities

The expected potential egg densities in the gravel were calculated by estimating the number of contributing female spawners at the sampling stations in two ways:

1) by assuming 58 percent of all spawners observed on the reaches were females; and

2) by enumerating the recorded redds, assuming each redd corresponded to a single female.

The use of the former method is the primary alternative in years when the spawner density is so great that differentiating single redds is not possible. During the 1975 and 1976 seasons, map records of individual redd locations afforded an opportunity for a comparison of the two methods. Both procedures utilized maps of recorded redds to determine the total area spawned.

The area of a redd was assumed to be oval in shape including an area of 1.8 m^2 (Burner 1951). A limited number of redds measured in the Cedar River produced a similar area. Each week an elliptical area of 1.8 m^2 was drawn at a scale of 1:240 around each recorded redd and all encircled areas were totaled. Overlapping areas were measured only once. New, previously unspawned areas were measured weekly and added to the cumulative total area spawned.

Estimates of the potential egg densities at Stations 1, 2B, and 5 were based on the following assumptions: 1) the average redd life for sockeye in the Cedar River was 7.0 days (Fraser 1970); 2) the female-to-male ratio was 58:42; and 3) the average egg deposition of each female was 3,500 eggs. The percentages of female sockeye salmon reported for the 1964 (Woodey 1966) and 1969 (Fraser 1970) runs were 59.1 percent and

60.3 percent, respectively. Purse seine test fishing (Jewell et al. 1969) and the 1976 WDF sockeye enhancement project near the river mouth found a 58:42 female-to-male ratio. The latter ratio was utilized to determine the number of females on the reaches from total spawner counts. The total number of females was divided into the total cumulative area spawned on each reach to estimate the mean densities.

The average Cedar River sockeye fecundity was determined by Heiser (1969) for 1968 and 1969 at 3,545 (± 1,120; 95 percent C.I.) and 3,639 (± 1,016; 95 percent C.I.) eggs/female, respectively. Bryant (1976) determined the mean fecundity was 3,575 (± 1,166; 95 percent C.I.) for the 1973 run. The WDF estimated fecundity from 32 females collected from the 1976 run at about 3,900 eggs/female (Allen and Cowan, personal communication). The average egg retention of spawned-out Cedar River sockeye females ranged from 150 to 200 eggs in 1969 (WDF 1969). The average egg deposition per female was estimated at 3,500 eggs which accounted for egg retention (Bryant 1976).

5.6 Egg/Alevin Classification

Each sample was preserved in Stockard's solution (four parts Formalin, five parts glycerine, six parts acetic acid, and 85 parts water). This preservative caused the embryo to become visible, contrasting with the yolk material and facilitating identification of the developmental stage. Eggs were classified as live or dead according to the following criteria. Live eggs were transparent reddish-orange, exhibiting normal embryonic development. All normal transparent eggs in the initial part of the sampling season were categorized as live. Dead eggs were opaque, translucent, off-color, or exhibited abnormal embryonic development. Following the spawning season, all transparent eggs without embryonic development were classified as dead. Broken shells or shell fragments could not be classified as dead with certainty and therefore were not included.

Alevins, or sac fry, were classified as live or dead in the field before preservation. Dead alevins were not commonly encountered and special note of their presence was recorded.

5.7 Tests for Intragravel Egg Mortality

Tests of proportionate frequencies, employed to determine the occurrence of mortality, are based on the assumption that after spawning is completed the proportion of samples taken from a spawning bed which includes eggs and alevins will vary with the actual total mortality level. These statistical tests have been described by Bliss and Calhoun (1954), and Snedecor (1956), and employed by McNeil (1962) in his analysis of pink salmon egg mortality.

The basic premise of the tests assumes that if no additional mortality has occurred, the following conditions would be expected:

a) The proportion of the samples including any eggs or alevins, live or dead, would not decrease.

b) The proportion of samples, including any live eggs or alevins, would not decrease.

c) The proportion of samples including any dead eggs would not increase.

For each sampling date, the number of samples (k_o) and the proportions of the total number of samples (p_o) falling into three categories are given. These three categories included those samples with: 1) no eggs or alevins at all; 2) no live eggs or alevins; and 3) no dead eggs or alevins. Two kinds of trends of the changing proportions indicated mortality. First, the increasing proportions (p_o) during the season in categories 1 and 2 would suggest that eggs and alevins have been removed from the gravel. During the September-December spawning period, this removal is assumed to represent mortality of eggs and alevins which disappear from the spawning bed prior to their complete development and natural emergence. Throughout the following postspawning emergence period, fry emergence could be a factor in decreasing the number of samples in these two categories. Secondly, significant decreases during the season in the proportions of the third category would indicate a smaller fraction of the samples on later dates did not include dead eggs or alevins, and that a greater proportion of the samples collected on later dates did include dead eggs or alevins, indicating mortality had occurred.

Samples with only one egg or alevin were jointly classified with points which were totally devoid of eggs or alevins. The choice to categorize samples with single specimens was arbitrary.

A chi-square test of independence was used to determine if significant change in the fraction of samples (p_o) had occurred within each category over the September-December spawning season of 1976 at Stations 2B and 5. The postspawning data were similarly analyzed to detect significant mortality following the completion of egg deposition. For this reason, the December data were included with this latter group to represent the final spawning season values to be compared with those of the postspawning period.

The k_o and p_o values of the zero or one dead egg/alevin category were again presented for Stations 2B and 5, with their 95 percent confidence limits to identify the specific periods of significant mortality during the spawning season. The following equation was utilized in setting 95 percent confidence limits to the number of samples with zero or one dead egg/alevin, using the normal approximation of the binomial distribution:

$$(\bar{k}_o, \underline{k}_o) = kp_o \pm 2.0[kp_o \ (1-p_o)]^{1/2}.$$

The 95 percent confidence limits of the fraction of samples that had zero or one dead egg/alevin were calculated by dividing the limits of k_o by the total number of samples.

5.8 Estimated Mortality Ratios from Dead-to-Total Eggs/Alevins

In contrast to the tests of proportionate frequencies, the mortality ratios, referred to as M_r by McNeil (1962), indicate different levels of mortality in the gravel by comparing the average percentages of dead-to-total eggs/alevins in samples for each sampling date. Significant increases in these percentages indicate the occurrence of mortality of eggs and alevins remaining in the gravel at the time of sampling, and unlike the previous tests, do not measure mortality caused by their direct removal by scouring, predation, or superimposition. Likewise, the disappearance of dead specimens due to scavenging and decomposition is not taken into account. Therefore, M_r ratios should be considered estimations of minimum mortality levels.

However, during the postspawning period the emergence of fry will also add bias to the sample counts, increasing the dead-to-total ratio of the samples, and leading to a possible underestimation of survival.

The average dead-total ratio of samples for each date was calculated according to the following equation:

$$M_r = \frac{\Sigma^k \frac{\text{dead}}{\text{dead + live}}}{k}$$

where k is equal to the number of samples with eggs or alevins collected from a reach on a given date.

Prior to calculating this average dead-to-total ratio, M_r, it was necessary to determine how much of the total variation in the individual sample counts was due to binomial variation. When the total numbers of eggs and alevins counted in individual samples vary over a wide range, binomial variation can be responsible for a significant part of the total variation. In this case, weighting of counts may be warranted.

Cochran (1943) states that the ratio of binomial variance-to-total variance is:

$$\bar{f}\,\frac{(100 - \bar{f})}{s^2\,\bar{n}_h},$$

where

$\bar{f}$ = the grand mean of all dead-total percentages;
s^2 = the mean square error of these mortality percentages; and
$\bar{n}_h$ = the harmonic mean of the observation.

According to Cochran, when most variation appears to be extraneous and not binomial, equal weighing of the observations is advised. McNeil (1962), upon analyzing pink salmon egg sampling data from two collection periods, found that samples with 10 or more total eggs/alevins had a binomial variation percentage of not greater than 8 percent. Cochran showed that when this percentage was less than 10 percent, the efficiency of equal weighting was about 97 percent. Therefore, McNeil assigned equal weight to all dead-to-total fractions of samples with 10 or more total eggs/alevins.

The average binomial variance-to-total variance ratios were calculated for the samples with 10 or more total eggs/alevins for each to determine if weighting of the samples was necessary.

5.9 Incubation Studies

The development of Lake Washington sockeye salmon eggs was previously described in detail by Olsen (1968), but these were incubated under hatchery conditions at the University of Washington. The embryonic development of the Cedar River sockeye eggs taken from the early, middle, and late season spawners was studied in situ. Three or four females each were captured on September 17, October 15, and November 22, 1976, about 300 m below Station 2B (RKm 28.0). The eggs were stripped, fertilized with sperm from three males, and allowed to water-harden for about 30 min before transport to a site just below the diversion dam at Landsburg.

On each of the three dates, 50 eggs were placed in each of 24 perforated freezer containers with coarse gravel. These were set in two 65- x 54- x 13-cm perforated plywood boxes similar to those used by Gibbons (1977). Spaces between containers were filled with gravel to simulate the natural percolation of the spawning bed. The incubation boxes were submerged in the river, secured by cables to trees, and weighted with large rocks to prevent movement.

Starting on December 2, 1976, two containers were removed at 1- to 3-week intervals and brought to the laboratory. Eggs were preserved in Stockard's solution and alevins in 10 percent Formalin. The date on which yolk absorption (which closely coincided with emergence) occurred was determined and the cumulative temperature units (TU, defined as 1° C above 0° C for a 24-hour period = 5/9 x TU F) were calculated from the initial date eggs were planted. Temperature data were obtained from the thermographs maintained in the Renton gauge station and from the Seattle Water Department's gauging station at the Landsburg diversion dam. Mean temperatures for each month or a fraction thereof were determined. The number of TU's required to yolk absorption of sockeye salmon alevins at constant temperatures was determined by Brannon (personal communication). The temperature units required at 1°, 5°, 10°, and 15.6° C were 379, 907, 1,060, and 1,369 TU's (C). Brannon's data were used to estimate the percentage of development occurring each month or fraction thereof. These percentages were summed until eggs spawned on a given day had accumulated 100 percent. Calculated dates of yolk absorption agreed with the observed dates in the incubation boxes when Renton temperatures were multiplied by a factor of 0.8 or 0.9. This adjustment was justified by the fact that the spawning grounds experienced higher water temperatures than recorded at the Landsburg gauge.

The expected timing of emergence was calculated for weekly spawning populations based on calculated rates of development from the incubation study. We assumed that fish completed their spawning in an average of 7 days after passing the counting tower. This time period probably was longer than 7 days in the beginning, and shorter at the end of the spawning season. The sockeye which were in the river prior to tower counting were assumed to delay their spawning. These fish were proportioned over a 4-week period according to the spawner counts on the reaches. The proportions were calculated by determining the weekly percentages of the total number of spawners at the end of this 4-week period and were added to the weekly tower counts. Since dissolved oxygen concentration in the water immediately surrounding the eggs may have affected the rate of development, 56 TU's (C) (100 TU's F) were added to correct for potential oxygen deficits (Brannon, personal communication.)

5.10 Emigrant Fry Sampling

A fyke net apparatus similar to that used by Tyler and Wright (1974) was constructed to sample the emigrant sockeye fry. This apparatus, powered by two electric winches, was easily operated by one person and functioned reliably throughout both sampling seasons.

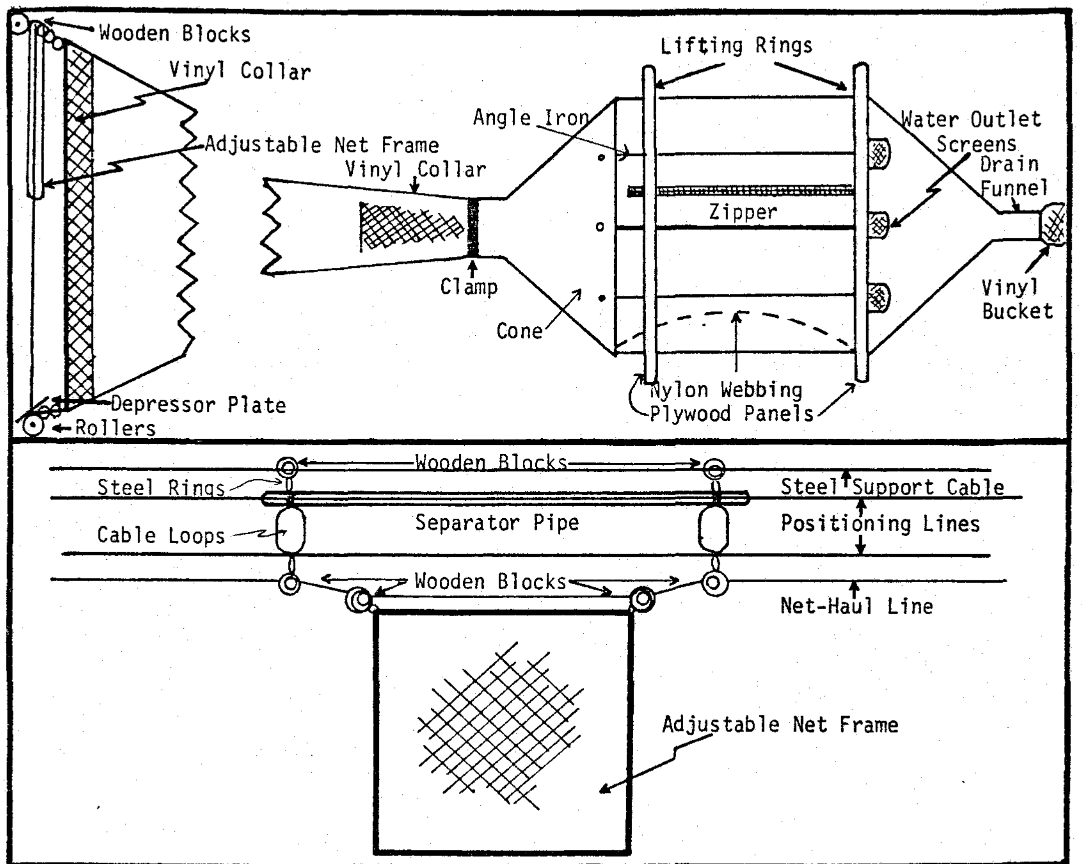
The net measured 1.5 x 1.5 m at the mouth, tapering uniformly within 7.0 m to a 0.2-m diameter opening, where a 0.5-m vinyl collar provided a reinforced surface for clamping to a live tank (Fig. 4). The net was made of 3-mm knotless nylon mesh. The seams were sewn with nylon tape and reinforced with 16-mm polypropylene lines, which attached the net to the frame. A 0.2-m-wide vinyl collar encircled the net mouth to provide a strong, abrasion-resistant surface. The cleaning of the cod end was facilitated by a zippered opening.

The net frame was constructed of 13-mm steel rod and galvanized pipe (Fig. 4). A variable-pitch depressor plate was bolted to the frame to stabilize the net, while two rubber rollers held it slightly off the bottom.

Fish were funneled into a submersible live tank (Fig. 4). The two end cones were made from 3-mm black iron sheet metal and connected with angle iron. The cylindrical tank measured 1.9 m in length and 0.7 m in diameter. Two steel rings were welded to the tank frame. Two floats and seven 0.3- x 0.8-m plywood panels were attached to the lifting rings to protect the net from bottom abrasion. A 3-mm knotless nylon webbing net was suspended inside the live tank frame. A full-length zipper facilitated removal of debris.

The fyke net was suspended from a 14-mm steel cable placed across the river and supported by two A-frames. These were constructed of 10- x 10-cm wood beams and anchored to two railroad ties buried 1.0 m in the ground (Figs. 5 and 6). Tension on the cable was adjusted by a 0.6-m turnbuckle. The A-frames were also guyed upstream with 5-mm cables.

Movement of the net was facilitated by a polypropylene rope (positioning line) running through 12.5-cm blocks hung from the A-frames to an electric winch with a capstan drum. A 3.3-m x 13-mm galvanized separator pipe with rings at each end was attached to the positioning line. Two 15-cm blocks, which traveled on the support cable, were secured to the pipe rings by 0.3-m loops. Hung below these rings were two 12.5-cm blocks to which the lower corners of the net frame were



DIMENSIONS:

Live Tank	
Length	1.9 m
Diameter (mouth)	0.2 m
Diameter (body)	0.7 m
Diameter (outlet)	0.1 m

Net	
Length	7.0 m
Width (mouth)	1.5 m
Depth (mouth)	1.5 m
Diameter (cod end)	0.2 m

Net Frame	
Height	1.5 m
Width	1.5 m

Fig. 4. Schematic diagram of the sockeye fry sampling nets, live tank, and positioning gear.

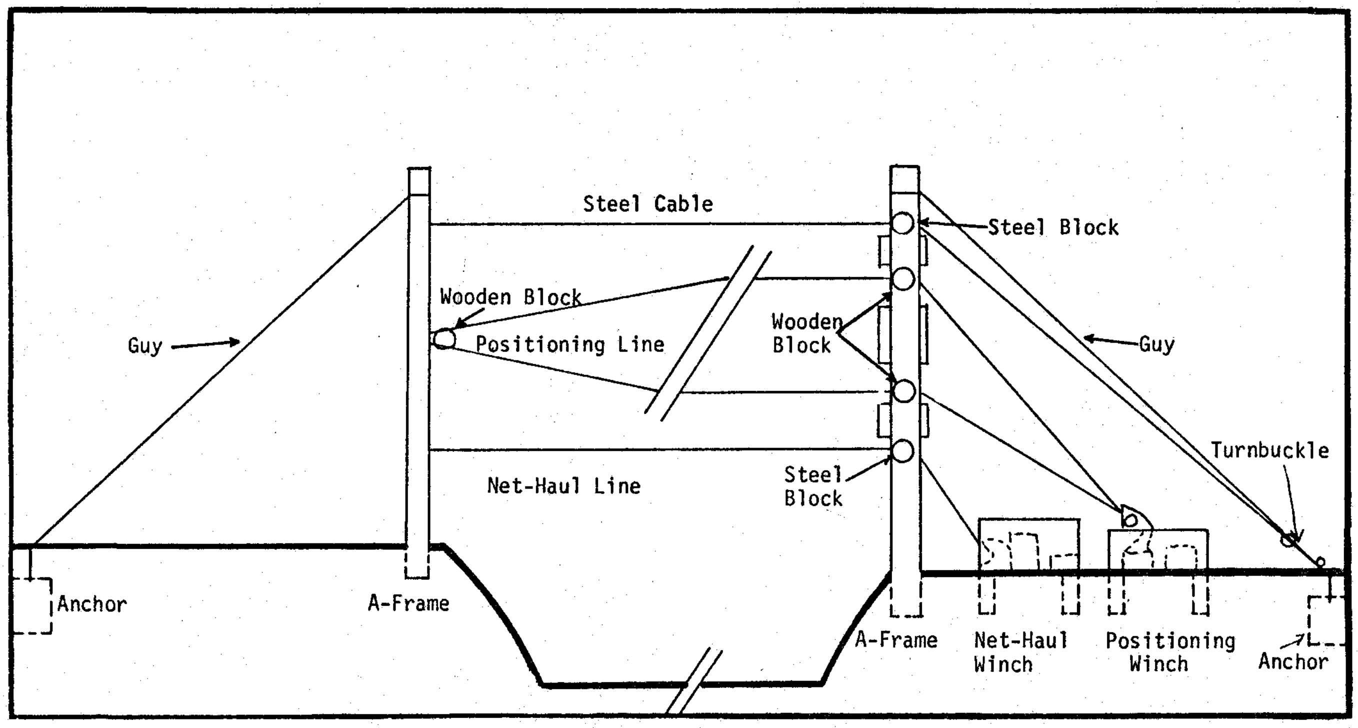


Fig. 5. Schematic diagram of the fyke net apparatus (side view).

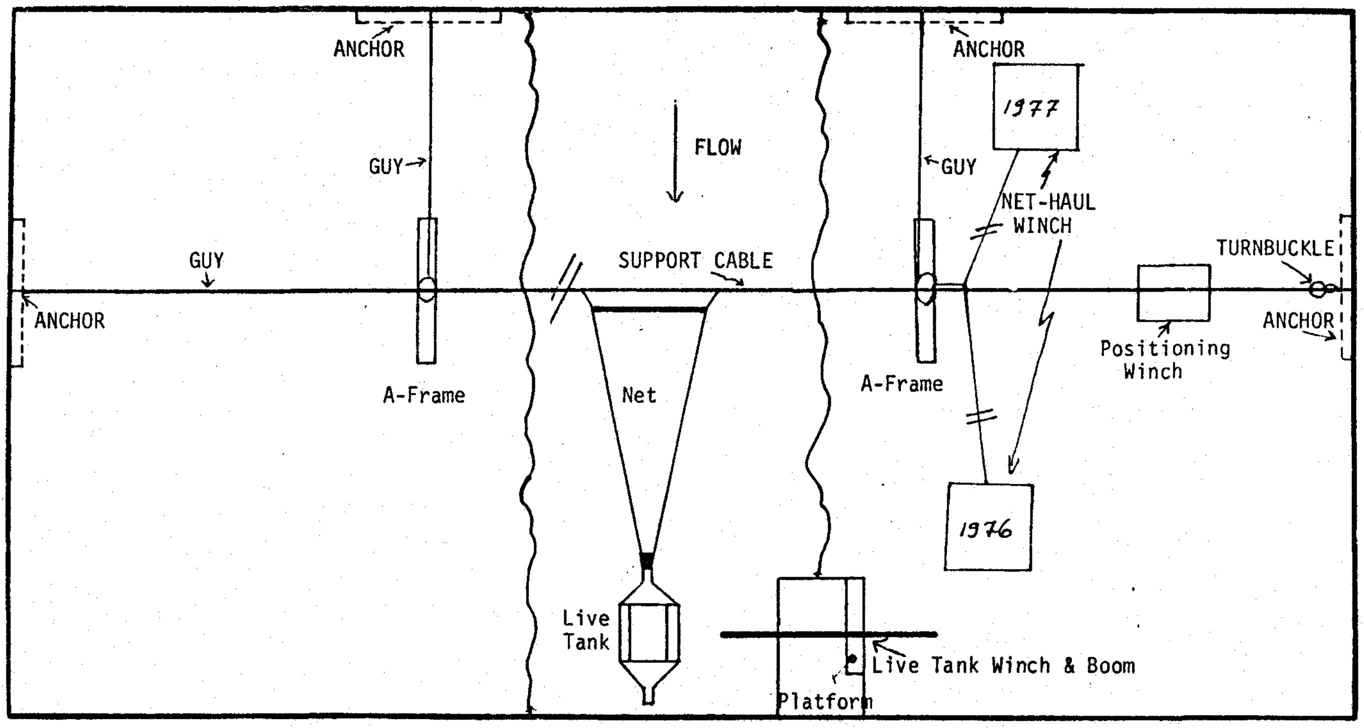


Fig. 6. Plan view of the sockeye fry sampling apparatus.

secured by 9.2-m ropes. The 13-mm net haul line ran through these and two similarly sized blocks on the top of the net frame and then through a steel snatch block secured to the A-frame. The net haul line was attached by a 45.8-m cable to a 3,632-kg capacity electric winch used to lift the net out of the water. In 1976 the net haul winch was placed downstream from the positioning winch while in 1977 it was located upstream.

Setting of the net was accompanied by wrapping the positioning line twice around the capstan drum and moving the net above the water to the desired location indicated by tape marks along the positioning line. The net haul line was then disengaged and the river current pulled the net into fishing position. This procedure was reversed for retrieval.

The live tank was lifted with a small hand winch from the river to remove the catch. The lifting apparatus consisted of a 4.8- x 0.1-m boom, supported by a small A-frame which was mounted on a 1.2- x 3.4-m platform on the riverbank. Fish and debris were released through the drain funnel into a plastic bucket, and fish were identified, counted, and returned to the river unharmed. Weekly subsamples were taken for length, weight, and condition determination.

Sampling mortality caused by netting and handling was determined on a small number of fry (usually 100-160) which were periodically placed in a large, darkened, plastic garbage can with aerated water. After 10-13 hours, the number of dead or fatally injured fry was recorded. No attempt was made to separate various causes of mortality.

The catch efficiency of a net may be considered to be 100 percent if it catches and holds all the fry it intercepts. None must detect, avoid the net, or swim back out. Due to difficulties in marking tiny sockeye fry and doubts about the validity of such results, the efficiency of the net was not tested. Since no reduction in water velocity inside the net mouth was observed and the velocities remained above 30.0 cm/sec, the catch efficiency was assumed to be 100 percent. Bams (1967) reported that the critical swimming speeds for sockeye fry were of the order of six to seven body lengths per sec (17.5 cm/sec). Andrews and Geen (1960) stated, ". . . in any river where sockeye fry are required to migrate upstream to their rearing lake, continuous marginal paths in which the velocity does not exceed 0.5 fps (15.2 cm/sec) for a distance of 1.5 ft (46 cm) should be available." Greenland and Thomas (1972) found that chinook fry, which were larger than sockeye fry, could not maintain their position in current with velocities above 17.5-20.0 cm/sec. These studies supported our assumption of negligible net avoidance.

5.10.1 Sampling Design

Diurnal sampling was conducted on February 5 and 10, and March 21, 1976, to determine the timing of emigration which usually began shortly after sunset and ended before sunrise. Five sampling locations across the river were chosen: one near each bank and three distributed in the main channel, at distances of 4.6, 10.0, 16.5, 22.0, and 32.9 m from the left bank. A random sampling scheme among these five sites was developed to derive an estimate of the total fry emigration. Each net haul was limited to 1 hour at each site to minimize both debris accumulation and the holding time of fish, and to allow a greater chance to sample all sites each night. Due to high discharge which dislodged large amounts of filamentous algae on May 15 and 17, 1976, the sampling time was reduced to 20 min/set. One-half hour was allowed between each set to process the catch and to clean and reset the net.

Fyke net sampling data were recorded on Fisheries Research Institute (FRI) coding form S170.3 (Cedar River Research Fyke Net Data Form). Air and water temperatures were measured hourly with a pocket thermometer during the sampling operation. The river height was determined from a staff gauge installed at the site. Information on cloud cover, light, and precipitation was also recorded. Daily turbidity determinations were made with a Hach kit. Periodic depth and velocity readings were made using a Marsh-McBirney electronic current meter.

In 1976, samples were taken every 3 to 5 days from February 5 through March 17. On March 19 the effort was increased to every other night. This scheme was carried out until May 13, with three exceptions. High discharge and large accumulations of algae in the net prevented sampling from May 10 to 14. On June 3 the effort was reduced to once or twice a week. Sampling was terminated on June 28, 1976.

The same sampling design with a few modifications was used during the 1977 season. The sampling along the right bank was eliminated due to low river discharges from December 1976 through February 1977. Elimination of this site had little effect on the sampling since only small numbers of sockeye fry had been caught in 1976 on the gravel bar. Two new sites were added in the main channel on January 3, 1977, but their use was discontinued on January 17, because the sampling procedure became unwieldy.

The first night of the 1977 sampling season was used to establish optimum duration of the sets. During low flows in December, fish could tolerate 2-hour sets. These had to be decreased to 1 hour on January 3, when the river discharge increased. The sampling was conducted once or twice a week between December 6 and January 15, and May 28 and June 20. Samples were taken three times weekly during the main emigration period (usually Monday, Tuesday, and Thursday).

5.10.2 Fry Estimation

Weighting factors based on the horizontal distribution of fry across the river channel were used to expand the hourly catches into estimates of the entire fry population passing the sampling station. The relative proportions of the mean hourly catches taken at each site during each of the three seasonal periods were computed. These points were graphed according to their location across the river channel and connected linearly with both banks. The percentage of the sampled area (1.5 m wide at each site) of the total area under the curve was computed and the reciprocal was utilized as the weighting factor for that site and seasonal time segment. Fry estimates in 1976 and 1977 were obtained by multiplying the hourly catches by these weighting factors.

Estimates of the daily emigration were derived by using the formula:

$$N_i = (\beta_i) \Sigma (k_{s,t} \times C_{j,s,t}), \qquad (1)$$

where,

N_i = estimated number of fish emigrating on day i,

$\beta_i = \frac{\text{hours from the beginning to the end of sampling}}{\text{actual hours fished}}$,

$C_{j,s,t}$ = number of fish caught during set j, site s, and period t,

$k_{s,t}$ = weighting factor for site s and period t.

Weekly emigration rates were computed by the expression:

$$T_k = \frac{n_k \Sigma N_i}{m_k}, \qquad (2)$$

where,

T_k = estimated weekly emigration rate,

n_k = number of days in week,

m_k = number of days sampled per week (1 to 3).

The point estimate for the season was calculated from:

$$T_c = \Sigma T_k, \qquad (3)$$

where,

T_c = total estimate for the season.

True variance for the net catches could not be determined because only one net was employed throughout the study. Variance for the entire season was approximated as follows: hourly estimates, excluding the first and last set of the night (these were always small due to partial daylight), were multiplied by the number of hours of daily emigration and treated as population estimates to compute daily variances. These were summed up over the entire season to construct the confidence interval for the estimate. The main components of the daily variance, however, were the large diel and site variations, resulting in larger than the true variance. Assuming that $C_{j,s,t}$ are independent random variables, Var $(\hat{T}_c)$ was estimated from:

$$\text{Var}\ (\hat{T}_c) = \Sigma\ \frac{n_k}{m_k}\ \Sigma\ \text{Var}\ (Ni). \tag{4}$$

The interval estimate was then obtained from:

$$T_c \pm Z_\alpha \sqrt{\text{Var}\ (\hat{T}_c)} \tag{5}$$

where,

Z_α = 95 percent normal probability, critical value = 1.96.

5.10.3 Fry Quality

Length weight data was collected from fry samples to provide indication of growth and to detect changes in size, condition, and stage of development. A weekly subsample of about 100 sockeye fry was preserved in 10 percent formalin and brought to the laboratory. At least 10 days were allowed for length and weight to stabilize (Rogers 1964). The fork lengths of 50 fry were measured to the nearest millimeter. Fry were blotted to remove excess moisture and weighed individually to the nearest hundredth of a gram on a balance. The lengths and weights were recorded on Form S130.2 (IBP Fish Length and Weight Data Form) and were analyzed using FRI computer program FRD294 (Length Frequency Analysis). Student Neuman-Keuls test (α = 0.05) was used to establish significant within season changes in length and in weight, while a t-test was performed to detect differences between years. Condition factors were computed using the formula:

$$\text{Condition factor} = \frac{(\text{mean weight in grams}) \times 100}{(\text{mean length in centimeters})^3} \tag{6}$$

The stage of development was classified: 1) complete fusion of the midventral wall; or 2) some yolk visible externally.

6.0 RESULTS

6.1 Hydraulic Analysis

The hydraulic characteristics of Stations 1, 2B and 5 (Fig. 7) were determined by SYMAP analysis of the 80 percent ranges of preferred sockeye spawning depths and velocities following the technique previously used by Stober and Graybill (1974). Stations 1 and 2B were generally characterized by a gradual sloping gravel bar which provided new spawnable area during the spawning season with increasing discharge. In contrast, Station 5 was relatively uniform in depth with a nearly constant area spawned throughout the season. Station 2B was substituted for Station 1 following the December 1975 flood because extreme scouring removed much of the spawning gravel of Station 1. Surveys before and after the 1975 flood indicated that Station 5 was not substantially altered by scouring or deposition during the study period. The increase in total wetted area and spawnable area from the 1972-1973 survey was due to the inclusion of an additional 715 m^2 in 1975 to the study area of Station 5.

6.2 Water Quantity and Quality

Hydrographs recorded at the USGS gauging station at Renton are shown for the periods July 1975 through June 1977 (Fig. 8). During the late summer and fall of 1975 a typical discharge pattern occurred during the spawning season with the following exceptions. The discharges during August 1975 which peaked at 11.3 to 22.6 m^3/sec were due to maintenance at Chester Morse Reservoir upstream and exceeded the normal low flow summer discharge. A flood during early December 1975, with a peak discharge of 249.2 m^3/sec, was one of the worst thus far recorded on the river. Severe scouring of the river channel and breach of the riprap occurred in several locations resulting in major physical alterations. Deposition of a large amount of bedload materials and gravel substrate occurred along the periphery of the channel and in a large delta near the river mouth in Lake Washington. Flood flows reoccurred in January 1976 causing further shifting of the unstable riverbed materials.

Following the January 1976 flood, the weather changed to an extended drought condition. The discharge was consistently low through May of

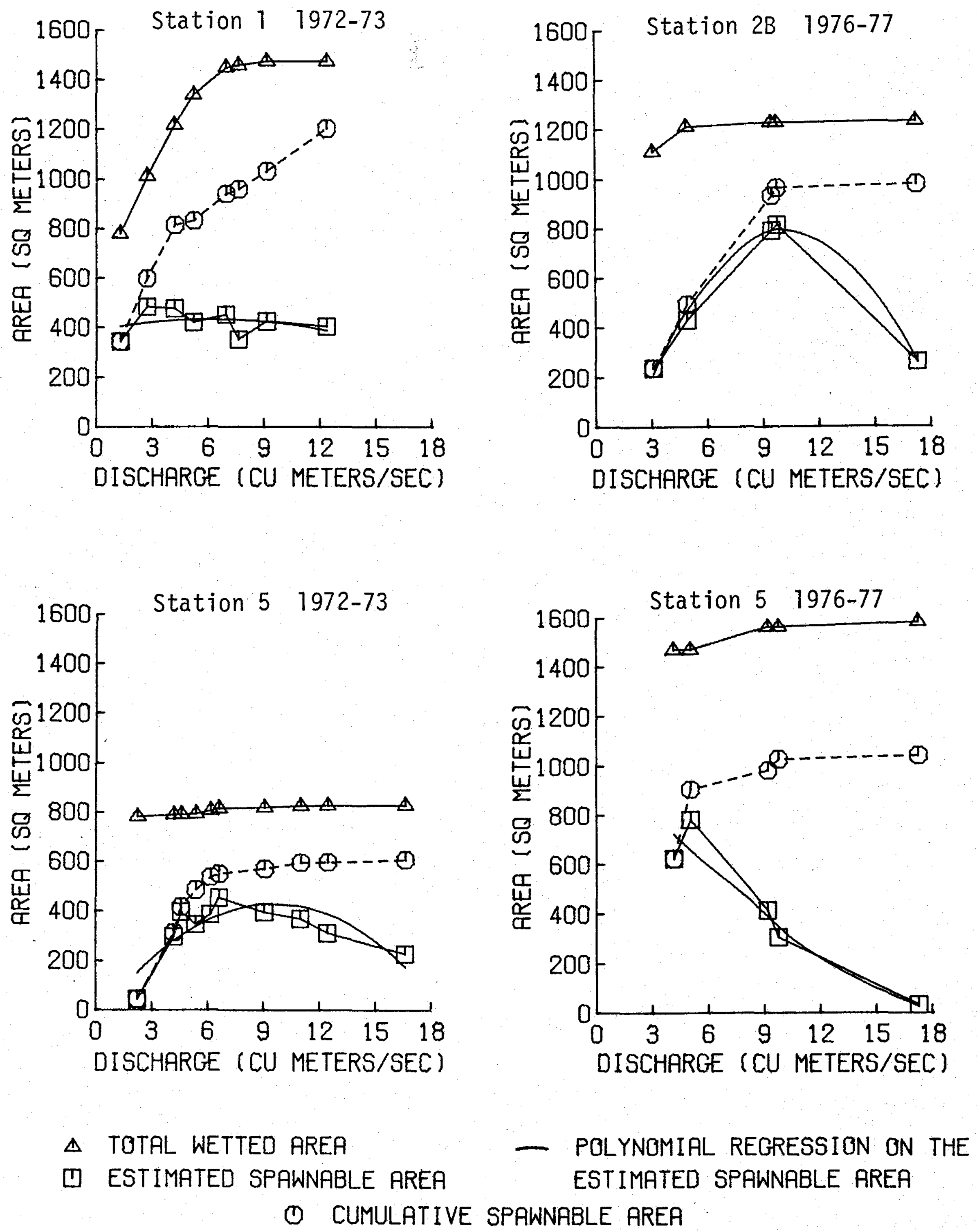


Fig. 7. Relationship between estimated spawnable area (80% depth and velocity ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at reaches 1 and 5 in 1972-1973 and reaches 2B and 5 in 1976-1977.

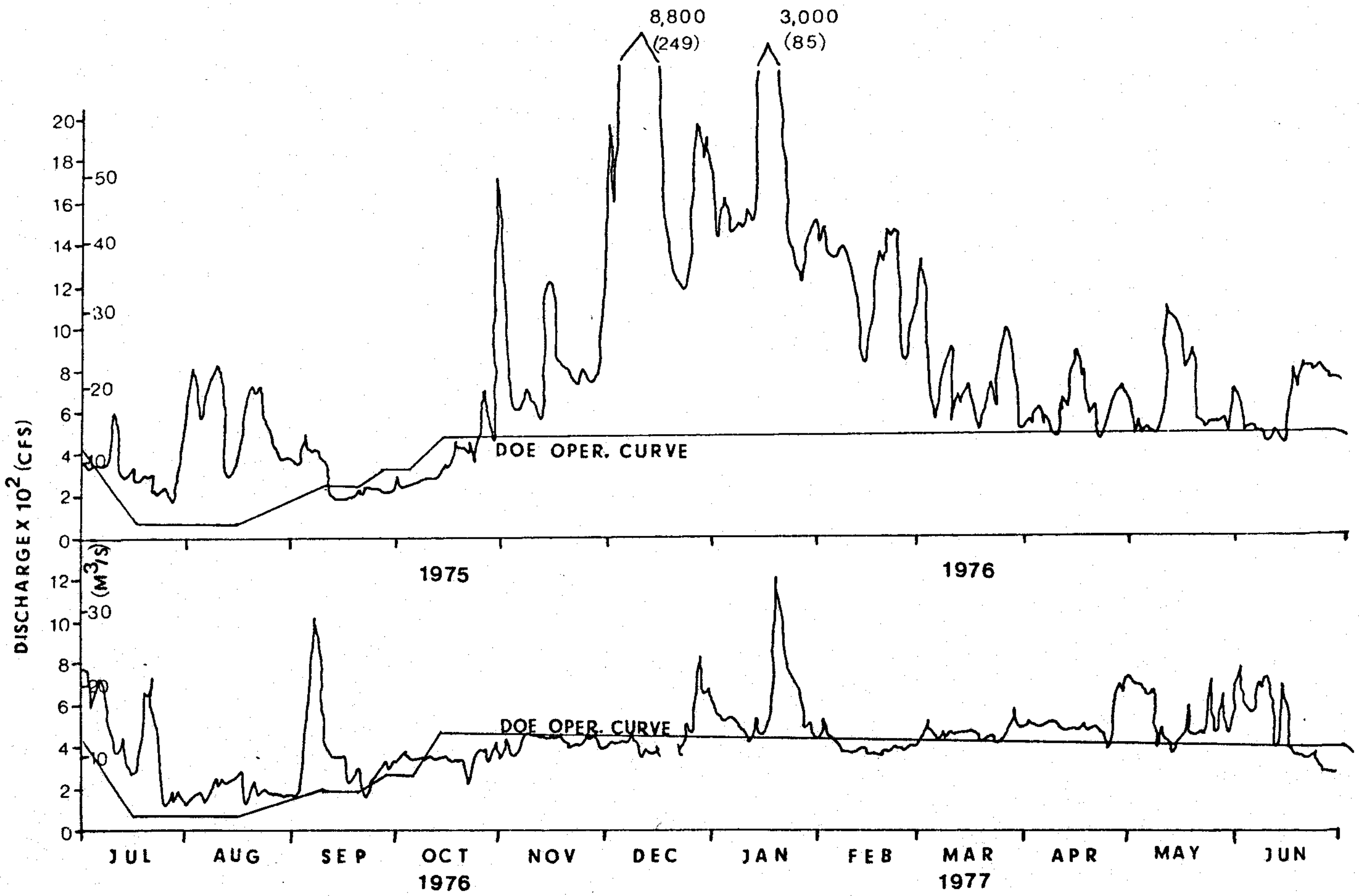


Fig. 8. Daily discharge at USGS Renton gauge from July 1975 through June 1977. (Source: U. S. Geological Survey).

1977 and exceeded 28.3 m^3/sec on only two occasions, once during early September 1976 (29.5 m^3/sec) due to dam maintenance upstream and again during January 1977 (34.6 m^3/sec) due to storm runoff. The period from August 1976 through May 1977 (Fig. 8) was significant due to the consistent low flows which occurred.

Mean daily water temperatures (based on hourly recordings at Renton) are presented for July 1975 through June 1977 (Fig. 9). The thermal range during the 1975 spawning season varied between 14° and 5° C and was similar to previous years. Temperatures during the 1976 spawning season were higher, ranging from 16° to 5° C. Following the spawning season during both years, temperatures were similar from January through June.

The maximum daily turbidity readings at Landsburg for 1975-1976 and 1976-1977 are presented in Fig. 10. Turbidity was directly related to discharge during late fall and winter.

6.3 Escapement

6.3.1 Tower Counts

The escapement estimates presented in Fig. 11 are those of the WDF as revised in 1976 by Ames. The escapement to the Cedar River in 1974, 1975, and 1976 was estimated to be 114,500, 114,100, and 138,949, respectively.

Daily counts of migrating adult sockeye, made by the WDF, from a tower located at RKm 7.9 in 1975 and RKm 8.5 in 1976 are presented in Fig. 12 for both years. Immediately prior to the initiation of tower monitoring each year usually during the first week of September, the WDF conducted a float survey on the river from Landsburg to the tower site to enumerate the number of sockeye which had already migrated. In previous years less than 5,000 fish were normally counted during the float trips. However, in 1975 and 1976, float surveys recorded 11,553 and 42,589 sockeye salmon, respectively. These fish had entered the river during the increased discharge in August 1975 and September 1976 which occurred due to dam maintenance upstream.

Sockeye tower counts during the 1975 spawning season occurred in two modes, the first peaking during early October and the later smaller

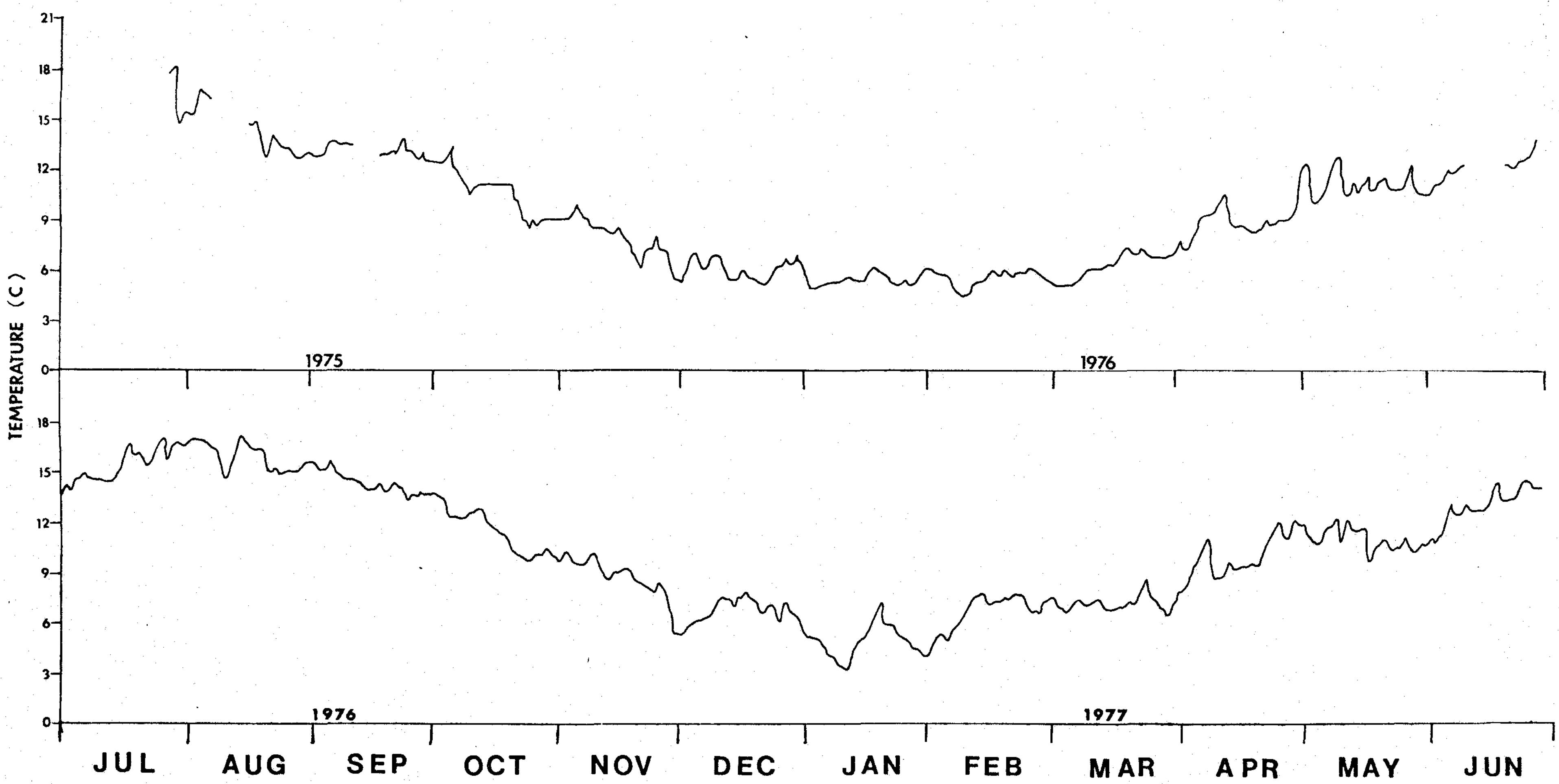


Fig. 9. Mean daily water temperatures at Renton, 1975-1977.

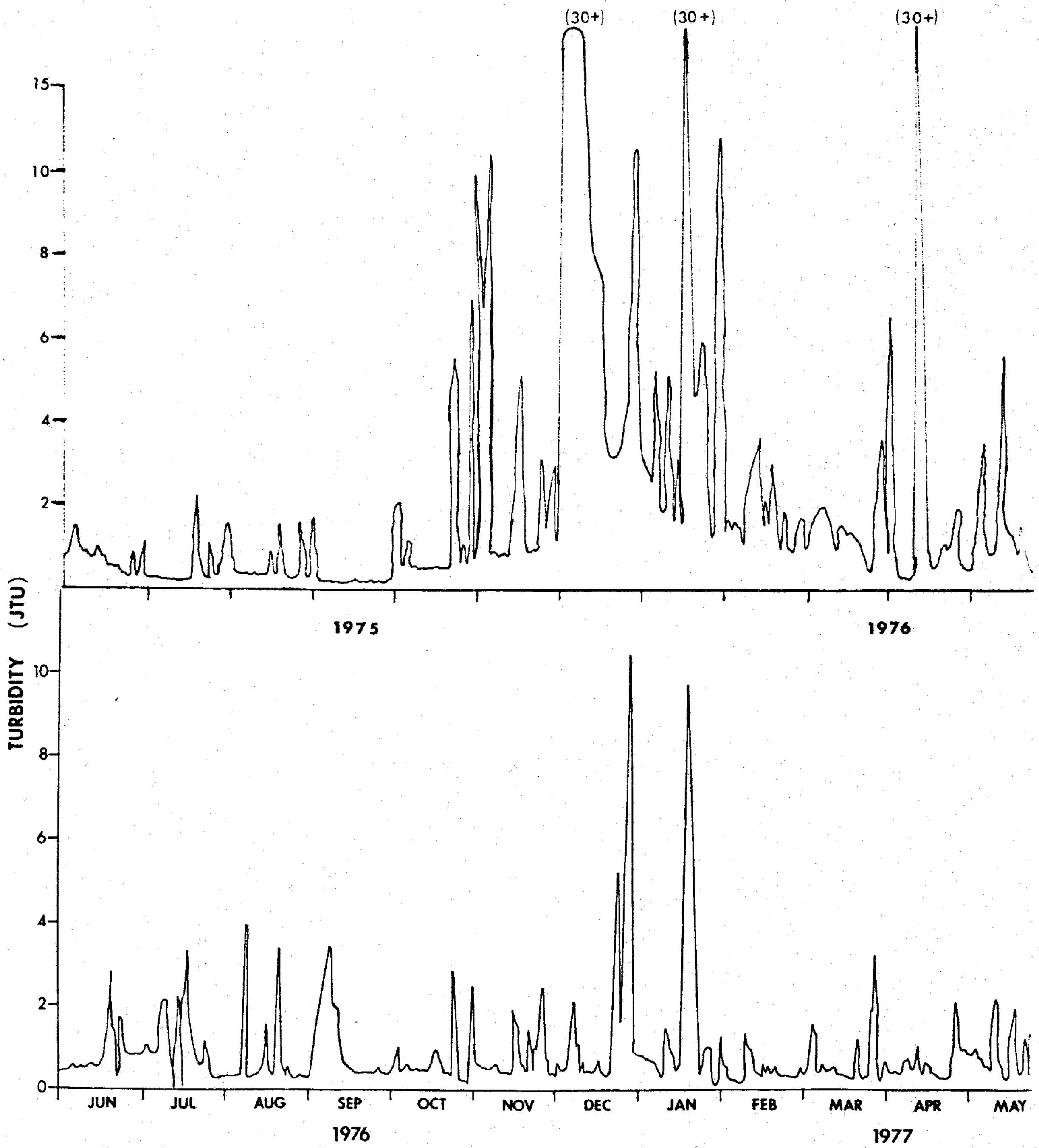


Fig. 10. Maximum daily turbidity at Landsburg from June 1975 through May 1977. (Source: Seattle Water Department).

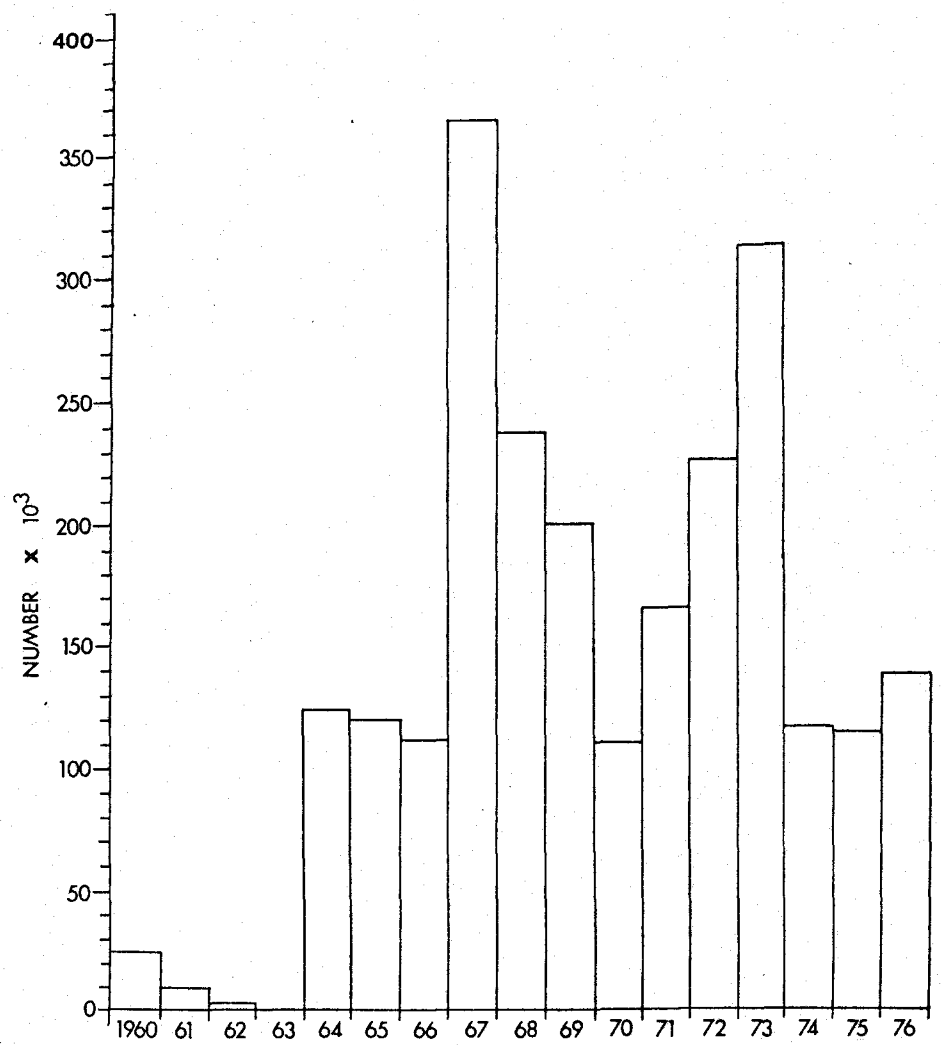


Fig. 11. Revised Cedar River sockeye salmon escapements, 1960-1976, estimated by Ames (WDF, unpublished).

mode during mid-November (Fig. 12). Counts decreased with increasing discharges in excess of 28.3 m^3/sec in late November when visibility became limiting. Tower counts were discontinued a few days prior to the December 1975 flood. The trend of the counts during the 1976 spawning season (Fig. 12) differed from the preceding year by exhibiting a random series of peaks over an unusually extended season. About 50 percent of the escapement had entered the river by September 22, October 12, October 17, October 8, and October 6, in 1972, 1973, 1974, 1975, and 1976, respectively (Fig. 13). Except for 1972, 50 percent of the escapement entered the river between October 6 and October 17.

6.3.2 Reach Counts

The total number of spawners observed on each study reach during the 1975 and 1976 seasons are presented in Figs. 14 and 15, respectively. The total number of spawners observed on each study reach is the sum of the weekly counts of active spawners. Active spawners were defined as those fish appearing over the spawned area. Transient fish holding in deeper or faster water off the spawning area were not included in the counts. There was a general tendency for higher numbers of spawners in the upper river during 1975 similar to the upstream distributions observed from 1972-1974. The midriver stations were most used in 1976. No spawners were observed at Stations 10 and 11 during 1975 or at Station 11 during 1976. The values for Stations 5 and 8A were not directly comparable to those of Stober and Graybill (1974) since the area of Station 5 was enlarged and Station 8A was located downstream in 1975. Following the 1975 flood, Stations 2B, 7A and 10A were selected to relocate stations which received extensive flood damage due to substrate scouring. In addition extensive scouring of the streambed occurred at Stations 1 and 9, which removed the spawning gravel and left large rubble and boulders. Station 1 was enlarged in area (413 m^2) to include a spawning riffle downstream.

The numbers of sockeye spawning each week were combined by station (1-3, 4-8, 9-11) to represent the upper, middle and lower sections of the river below Landsburg for 1975 and 1976 (Figs. 16A and B). A 1-week

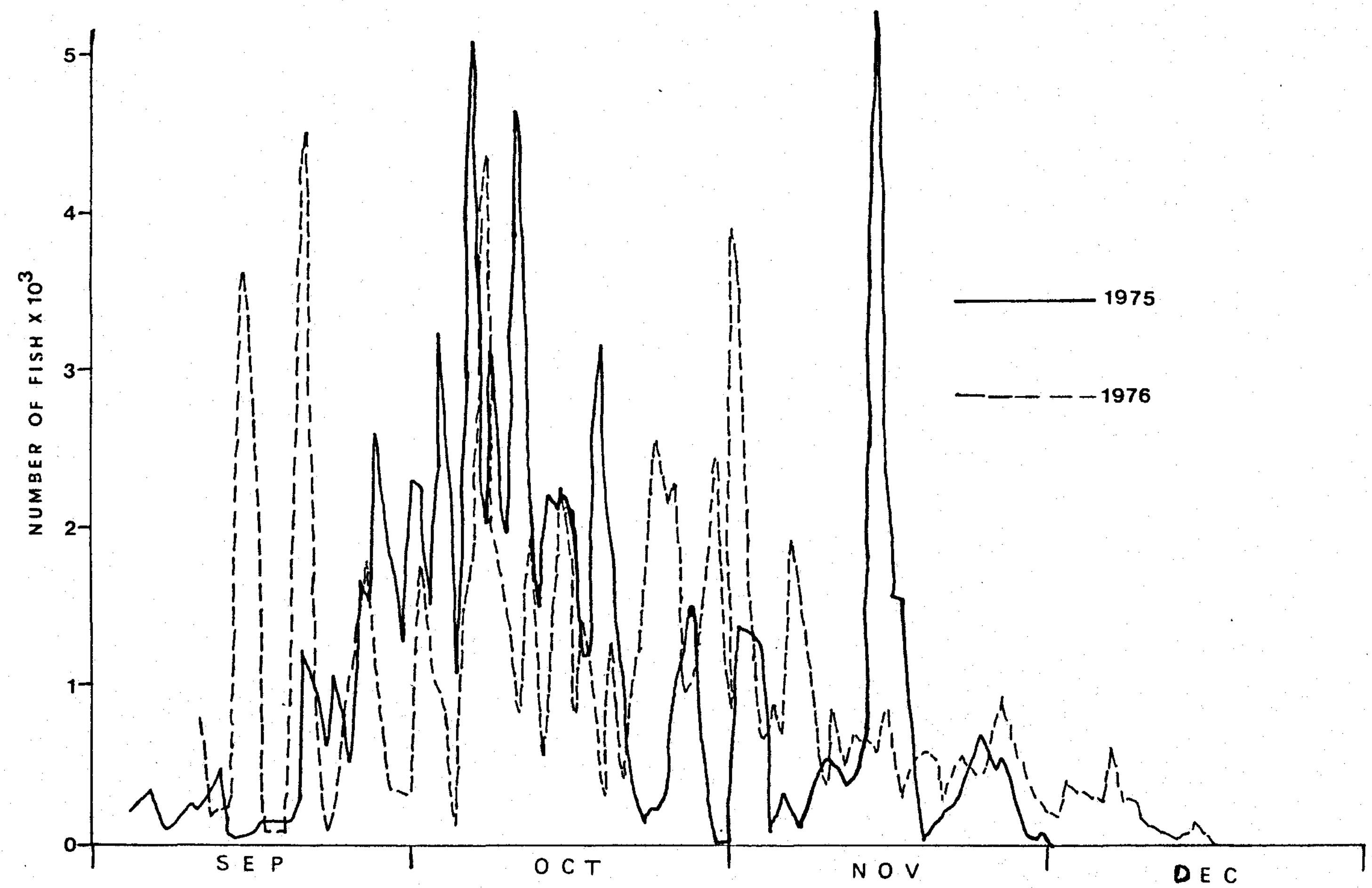


Fig. 12. Sockeye salmon tower counts, Cedar River, 1975 and 1976. (Source: WDF).

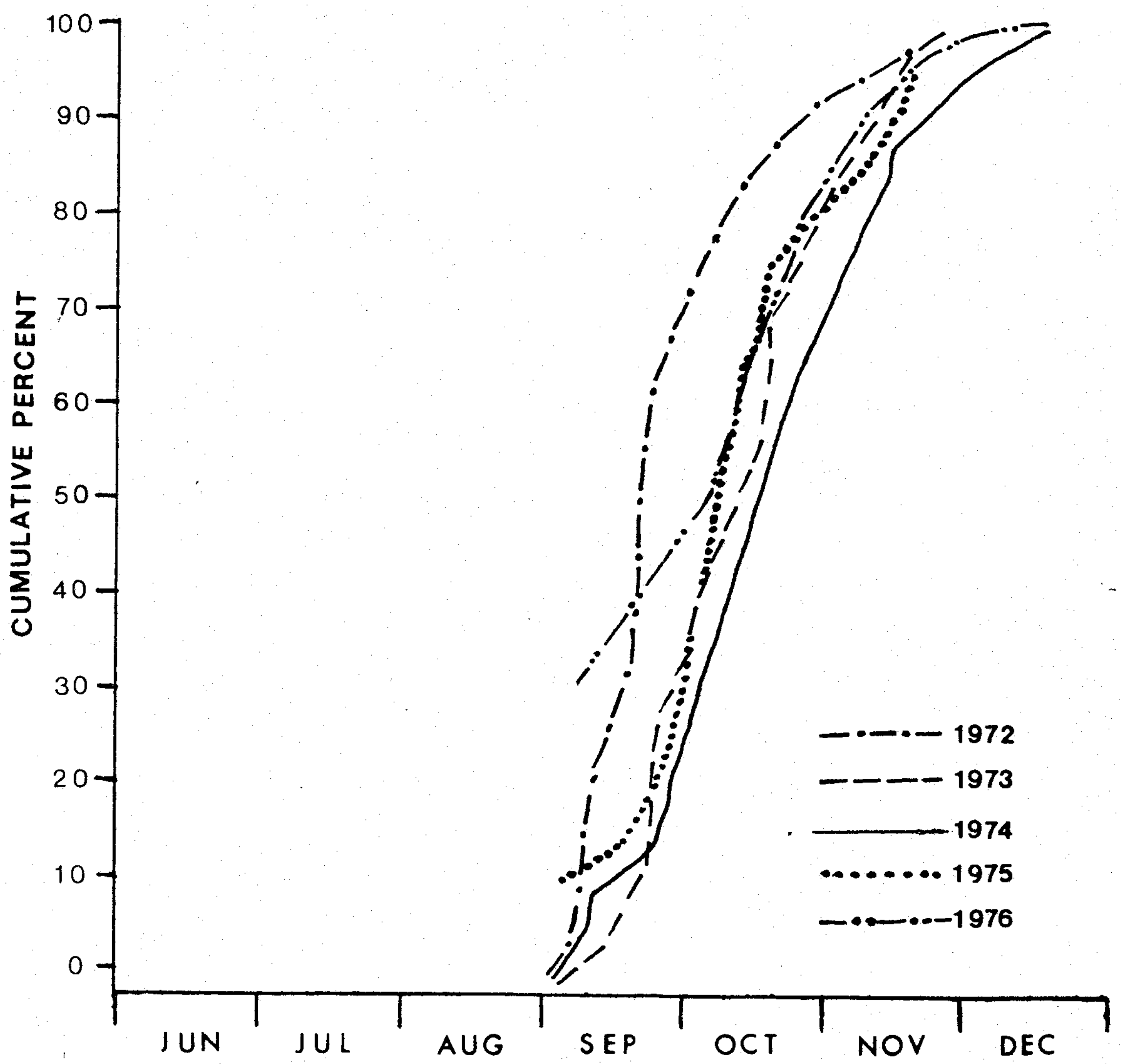


Fig. 13. Cumulative percentage of the tower counts by date for the Cedar River sockeye salmon escapement, 1972-1976. (WDF data).

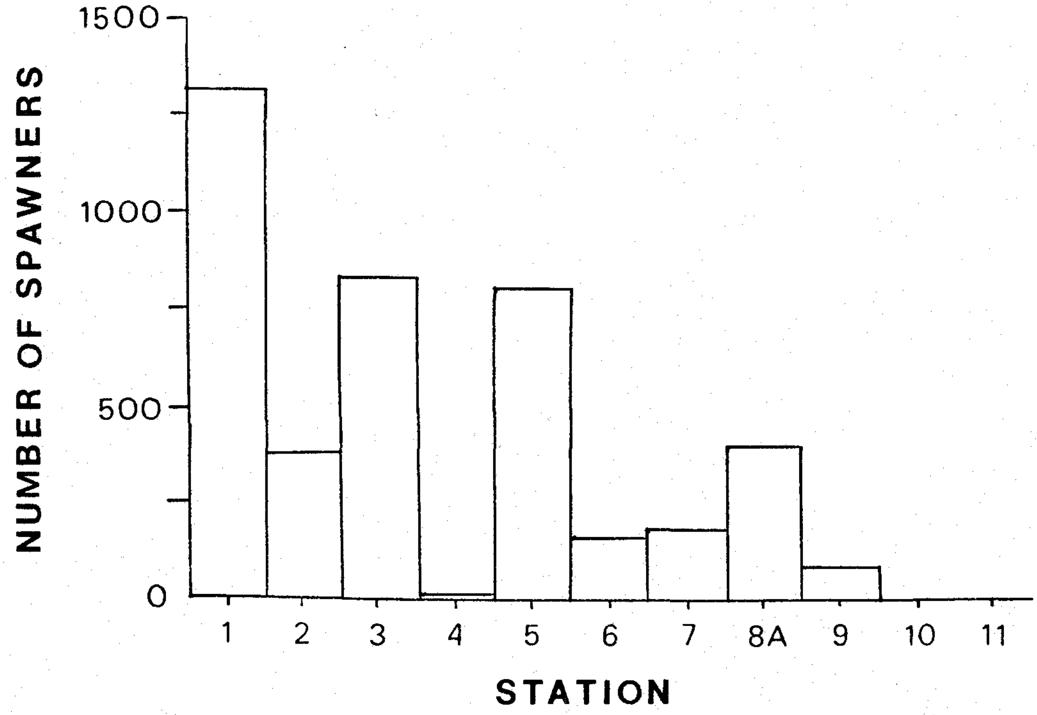


Fig. 14. Total number of spawning sockeye per sample reach in 1975.

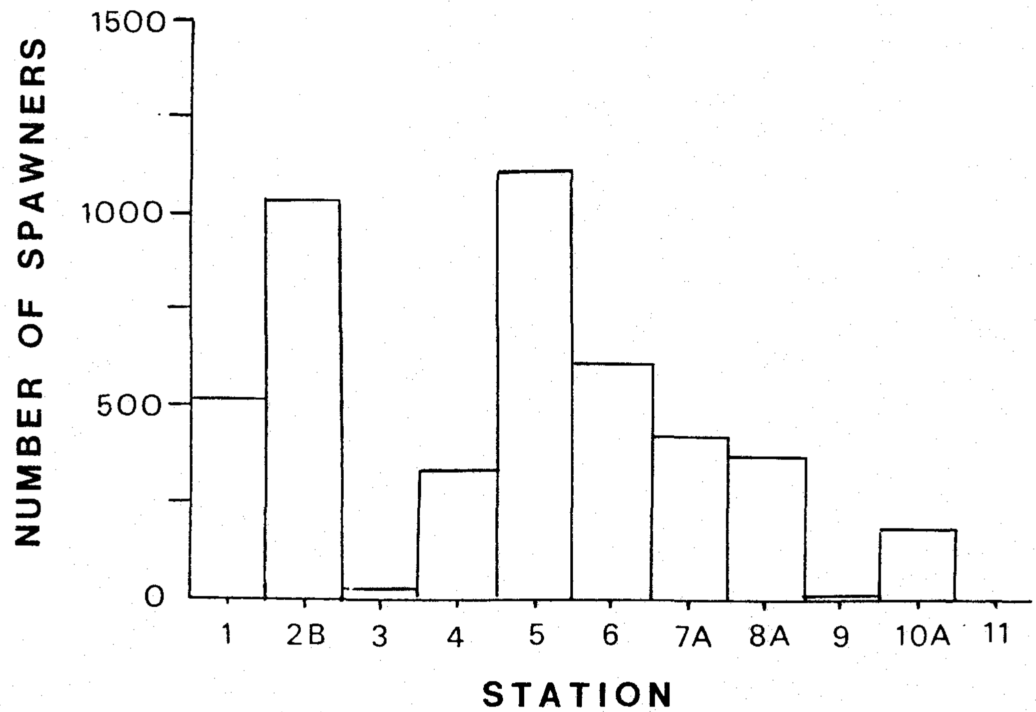


Fig. 15. Total number of spawning sockeye per sample reach in 1976.

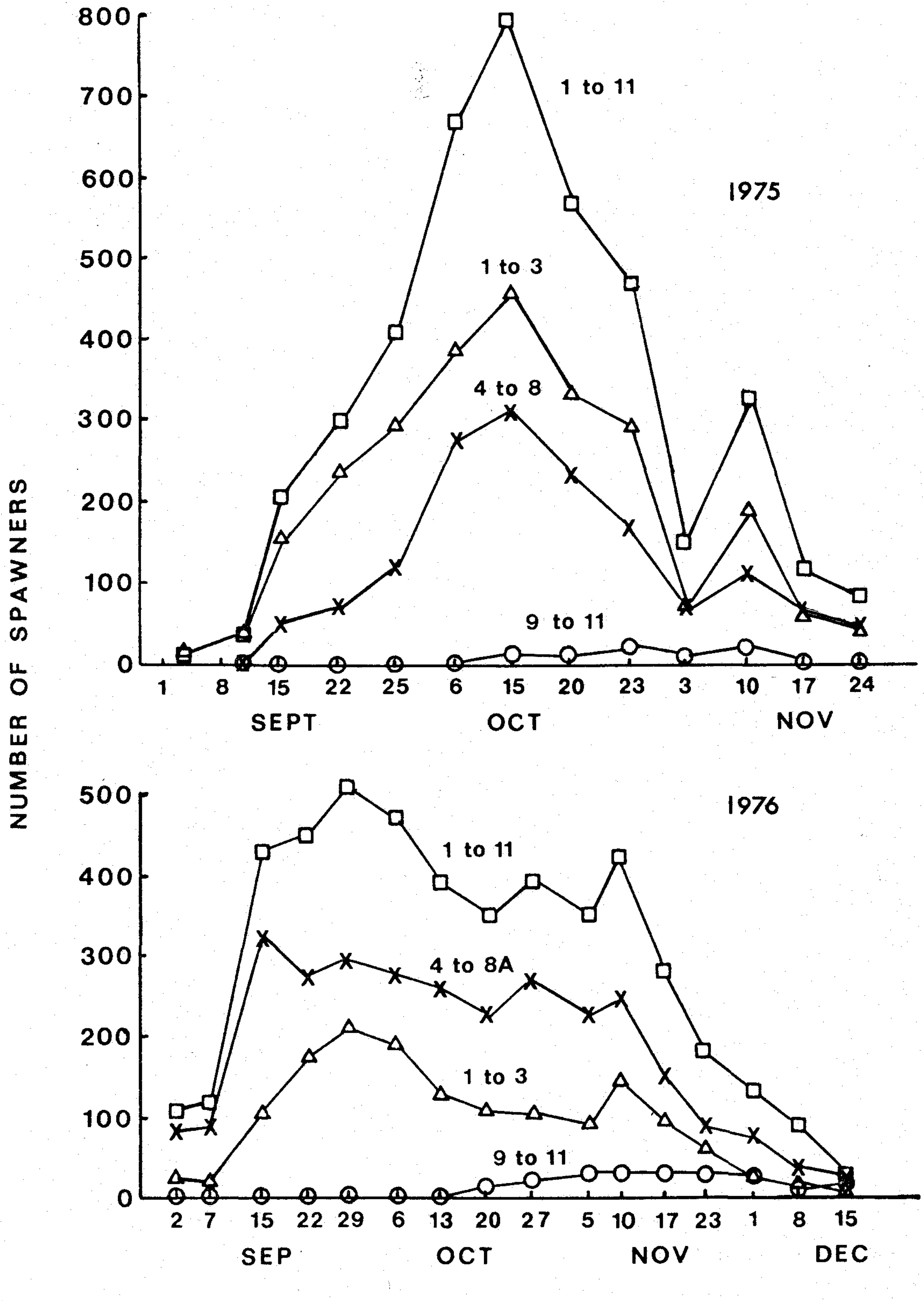


Fig. 16. Cedar River spawner counts by week in 1975 and 1976. Data were grouped by station to illustrate utilization in the lower (9-11), middle (4-8) and upper (1-3) thirds of the river, and for all stations (1-11) surveyed below Landsburg.

interval between counts was based on a redd life of 6.7 days (SD = 2.4 days) determined by Fraser (1970). The timing of the 1975 spawner counts on the reaches (Fig. 16A) generally followed the trend of the tower counts in a pattern similar to that observed by Stober and Graybill (1974). Spawning began at the upstream stations in early September. Spawners increased in number until mid-October, when spawner density was greatest. The late season utilization of the lower river noted in previous years (Stober and Graybill 1974) was observed again. The early portion of the run moved into the river earlier than usual. This was probably due to the increased flows in August, resulting from water released from Chester Morse Dam to accommodate construction and maintenance activities (Fig. 8). At Station 1, some redds made during the high flows in August were exposed in September and October when the low flow regime was resumed. Station 9 showed no spawner activity until October.

The decline in the weekly counts on November 3, 1975, may have been the result of the increase in discharge and turbidity which reduced visibility. During this period, daily mean discharge, which had averaged around 12.2 m^3/sec for the last half of October, increased to 50.0 m^3/sec on October 30 and continued at about 28.3 m^3/sec until November 4, 1975, at which time it decreased to 21.3 m^3/sec. Spawners were forced to the river margins and required vigorous swimming to maintain position at discharges over 25.5 m^3/sec.

In 1976, the timing and distribution of spawners on the reaches differed from previous years (Fig. 16B); by September 8, 42,589 spawners had moved into the river according to WDF estimates. Migrant sockeye were observed on the reaches of the upper and middle river on August 30. Instead of increasing to a well-defined peak by mid-October, as seen in past seasons, the total counts at all stations showed an early increase by mid-September, reaching a maximum on September 29. The combined counts for the middle river were greater than those of the upper river, in contrast to previous years when more spawners used the upper reaches. The combined spawner counts for the different segments of the river reached their maximum at different times. The middle river peaked in mid-September, upper river at the end of September and lower river during mid-November. As in 1975 and previous years, spawning in the upper river decreased more rapidly than in the middle reaches during the late season, while the lower river utilization increased.

6.3.3 Float Surveys

The area spawned in the 28.8 km (RKm 34.8 to 6.0) of river surveyed below Landsburg was outlined on aerial photographs of the channel during float trips each week. Figure 17 presents data for the 1975 and 1976 seasons. The lower 6.0 km of the river was sparsely spawned and therefore was not included in the weekly surveys. The surveyed portion of the river included Stations 1-10 and was divided into three approximately equal segments, with Stations 1-3 in the upper (RKm 34.8 to 23.8), Stations 4-8 in the middle (RKm 23.8 to 15.3), and Stations 9-10 in the lower sections (RKm 15.3 to 6.0).

In 1975 the greatest area spawned occurred in the upper and lower thirds of the river, while the middle third was used somewhat less (Fig. 17). These data present more comprehensive analysis of the total area of the river channel utilized by spawning sockeye than that indicated by the selected survey reaches. The trend in 1975 differed from that observed by Stober and Graybill in 1973, when escapement totaled about 200,000 more fish. The total spawned area at the peak of the season declined in 1975 to about 100,000 m^2 (1.076×10^6 ft^2) from about 143,995 m^2 (1.55×10^6 ft^2) spawned in 1973.

The float survey data obtained each week during the 1976 spawning season indicated that a maximum of about 57,600 m^2 (620,000 ft^2) was spawned at any time (Fig. 17). The middle third of the river received the maximum sustained utilization while the upper and lower thirds indicated reduced but about equal utilization until late October when the lower third was most utilized. Although the escapement increased by 24,849 spawners from 1975 to 1976 the maximum instantaneous area spawned decreased by 42,400 m^2 (456,224 ft^2). This decrease in area spawned may have been due to the removal of spawning gravel from the channel during the 1975 flood. It is evident from both the spawner counts on the reaches (Fig. 16) and the total area spawned in the river channel

(Fig. 17) that a consistent increase in spawning activity occurred until midseason followed by a consistent decline. This is in direct contrast to the sporadic movement of migrants indicated by the tower counts (Fig. 12) and indicates that migrants delay in pools prior to orderly movement to a spawning bed. The difference in the shape of the curve in 1976 was due to a large number of early migrants; however, the lack of a well-defined peak similar to those observed in 1973 and 1975 suggests that spawning area may have been severely limited for the number of fish escaping to the river.

6.4 Egg/Alevin Density

6.4.1 Hydraulic Sampler Efficiency

The efficiency of hydraulic sampling was tested by the recovery of preserved egg samples buried at a depth of at least 15 cm in the streambed near Stations 2B and 5. Several different water depths and velocities were represented by the locations of the planted eggs in the river. Under normal spawning season flows of approximately 8.5 m^3/sec efficiency averaged 95.9 percent while at flows around 28.3 m^3/sec, efficiency decreased to 73.8 percent (Table 1). The lower discharge was representative of flows experienced during the 1975 and 1976 spawning seasons and the 1977 preemergent fry period. The higher discharge represented conditions during late 1975 and the winter of 1976. The efficiency of the hydraulic sampler utilized while wading was actually tested in the field while the deepwater sampler was not; however, the area sampled was held constant in both. Reduction in the efficiency was related to river discharge.

6.4.2 Potential Egg Density

The expected potential egg densities at the hydraulic sampling stations through the 1975 and 1976 spawning seasons were determined using two methods. Potential egg densities were estimated from weekly spawner counts on each study reach as well as from weekly redd counts. Both methods were utilized because each produced a different result and because extreme escapement in future monitoring may preclude the use of

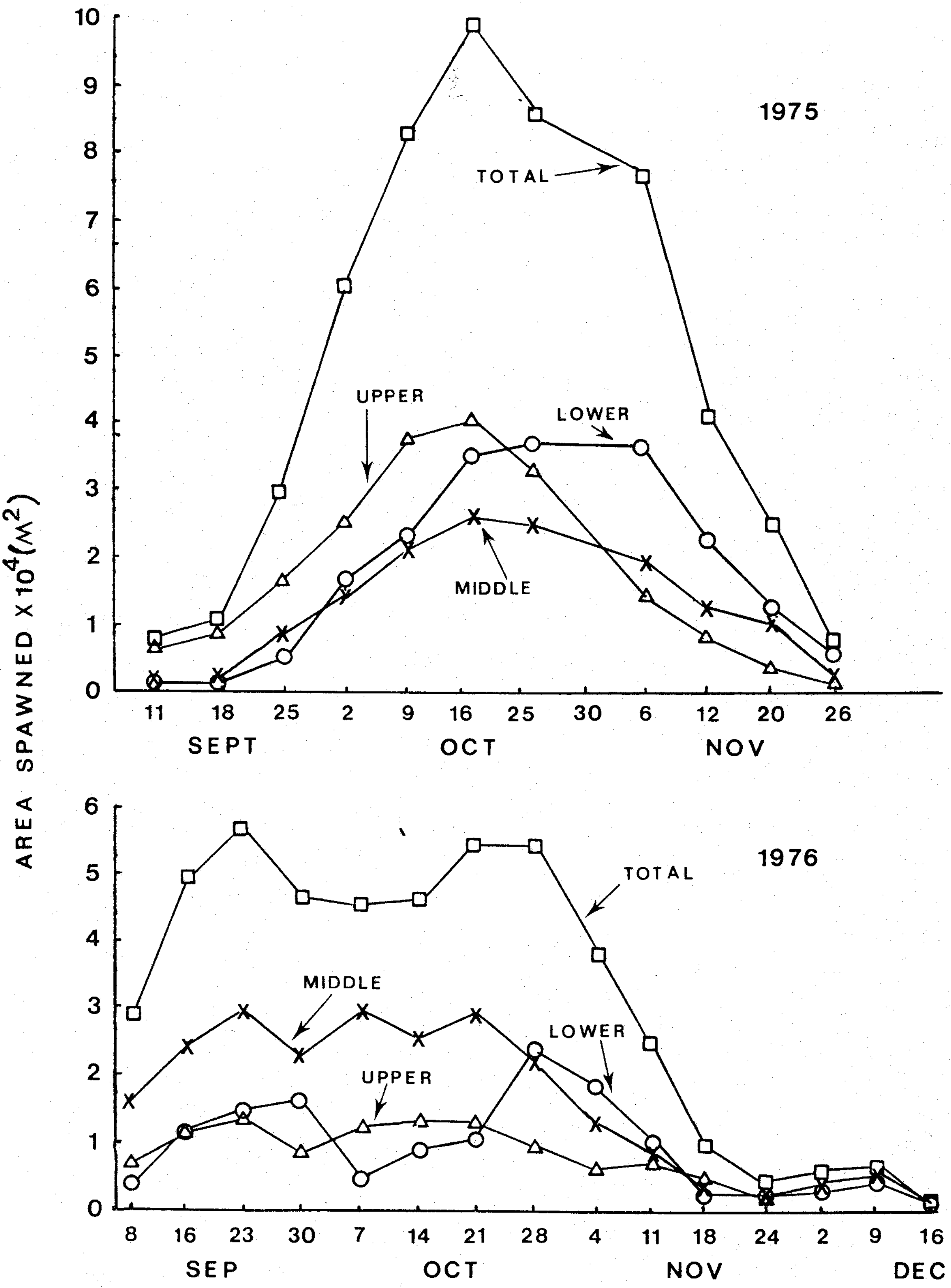


Fig. 17. Total area of the Cedar River spawned by sockeye salmon each week in 1975 and 1976 as determined by float surveys. Data expressed for 27.8 km (total) and for approximately equal thirds of the river.

Table 1. Number and percentage of buried eggs recovered by hydraulic sampling method.

Number of eggs buried	Number of eggs uncovered	Percent uncovered
	Low Discharge	
200	200	100.0
100	97	97.0
50	42	84.0
200	198	99.0
100	93	96.5
200	197	98.5
99	97	98.0
100	100	100.0
50	42	84.0
100	79	79.0
100	98	98.0
130	113	86.9
Mean =		93.1
S.D. =		7.6
	High Discharge	
200	192	96.0
200	182	91.0
200	147	73.5
200	162	81.0
200	138	69.0
200	176	88.0
200	39	19.5
200	63	31.5
200	196	98.0
200	161	80.5
Mean =		72.8
S.D. =		26.7

individual redd counts in mass spawned areas. Potential egg densities based on redd counts provided minimum estimates because all redds may not have been distinguished, spawner counts may have included some transients moving through a reach or the redd life may have been underestimated. The distribution of redds on reaches 1 and 5 during the 1975 spawning season is shown in Figs. 18 and 19, respectively. Similar data for reaches 2B and 5 during 1976 are presented in Figs. 20 and 21, respectively.

The potential egg densities at Station 1, as estimated from spawner counts, are graphed in Fig. 22. Station 1 in 1975 was an example of a river reach that exhibited a direct relationship between increasing discharge and spawnable area (Fig. 7), with spawners utilizing lateral parts of the streambed cross section as the discharge increased. The cumulative increase in spawned area resulted in the decrease in egg density around October 20, 1975, when daily mean discharge had increased to 11.9 m^3/sec. On that date, 67 percent of the recorded redds were located outside of what had been the wetted area of the previous weeks (Fig. 18). Most spawning was conducted in this new area through November 24. However, with declining spawner numbers, the overall cumulative density did not greatly increase in the latter part of the season. A maximum expected density of 9,858 eggs/m^2 was reached on October 6; however, the final density was calculated at 8,035 eggs/m^2.

The expected densities at Station 5 in 1975 contrasted with those of Station 1 in their constant increase throughout the season (Fig. 22). Only a small increase in cumulative spawned area occurred at this station with discharges exceeding 5.7 m^3/sec (200 cfs) (Fig. 7). The peak and final expected egg density calculated from spawner counts was 8,570 eggs/m^2.

Potential egg densities derived from spawner counts for Stations 2B and 5 in 1976 are presented in Fig. 23. Consistent and gradual increases throughout the extended spawning period were observed. During most of the autumn of 1976 the discharge level ranged between 8-12 m^3/sec (282 and 424 cfs). Similar to the previous year there was a cumulative increase in spawned area at Station 2B, but very little additional area was gained at Station 5. The maximum and final density levels were

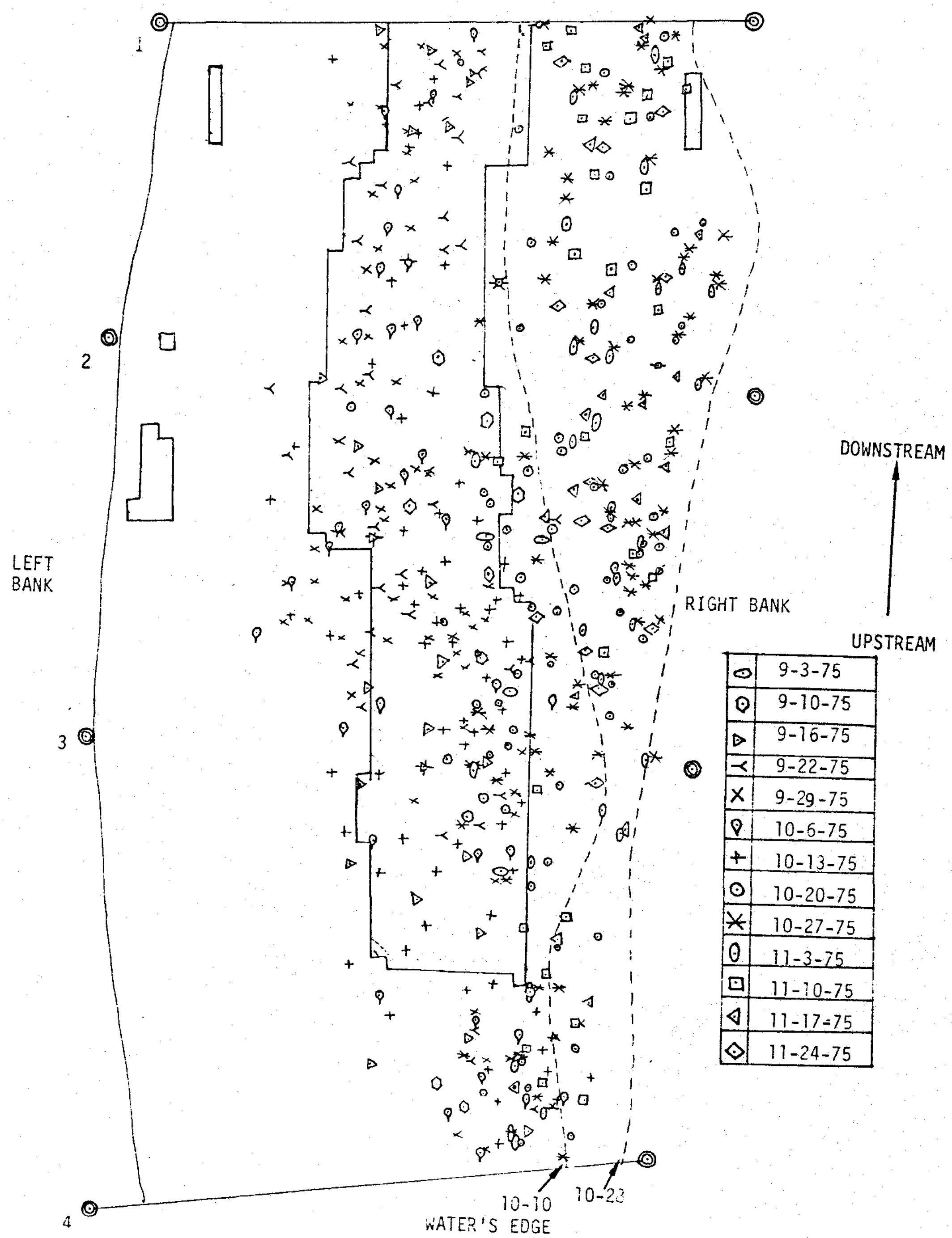


Fig. 18. Location of redds recorded each week at Station 1 by plane table survey. Spawnable area was calculated by SYMAP based on preferred depths and velocities at a discharge of 9.68 m^3/s on September 3, 1975.

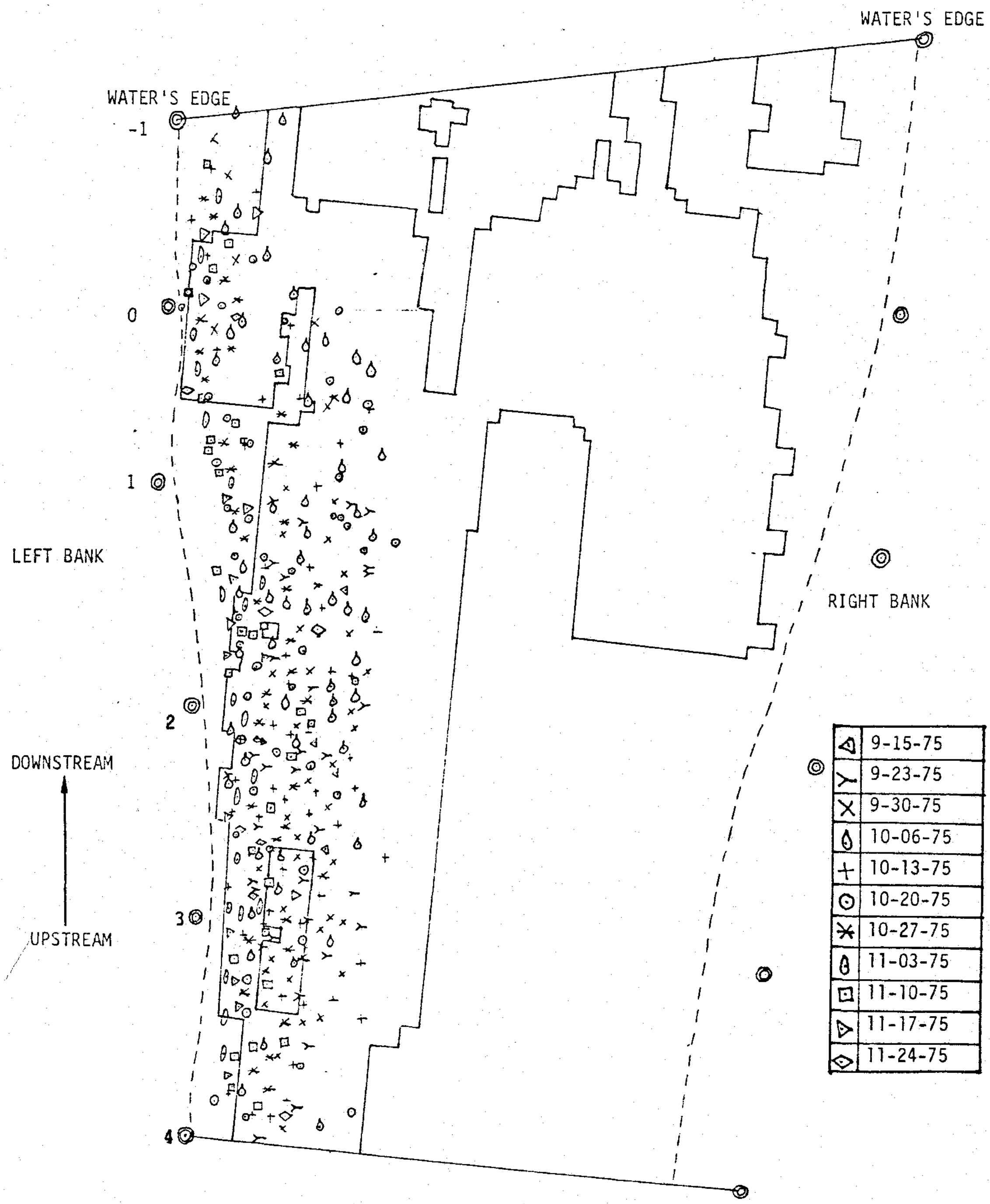


Fig. 19. Location of redds recorded each week at Station 5 by plane table survey. Spawnable area was calculated by SYMAP based on preferred depths and velocities at a discharge of 11.1 m^3/s on September 5, 1975.

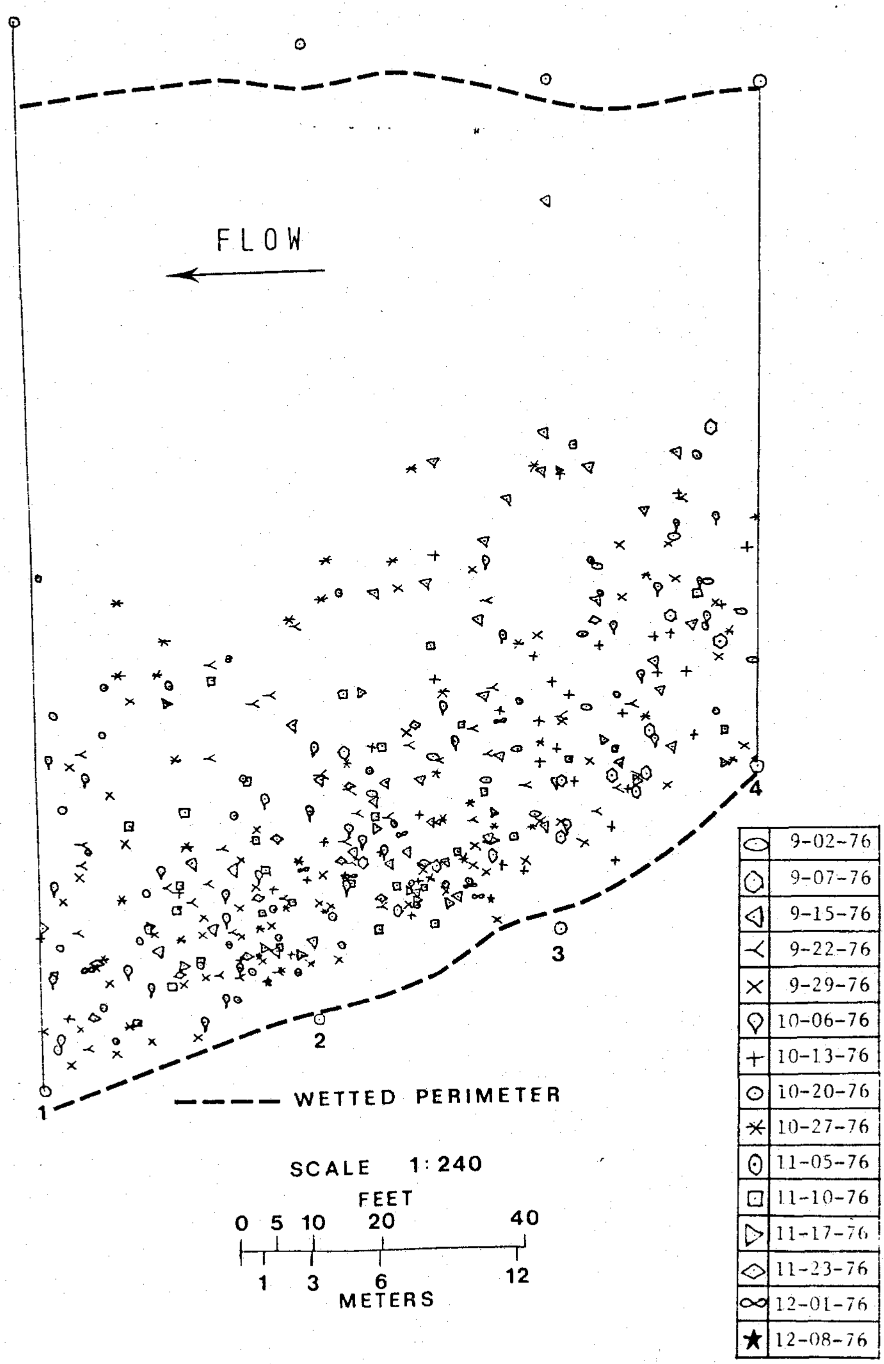


Fig. 20. Location of active redds recorded weekly at Station 2B during 1976.

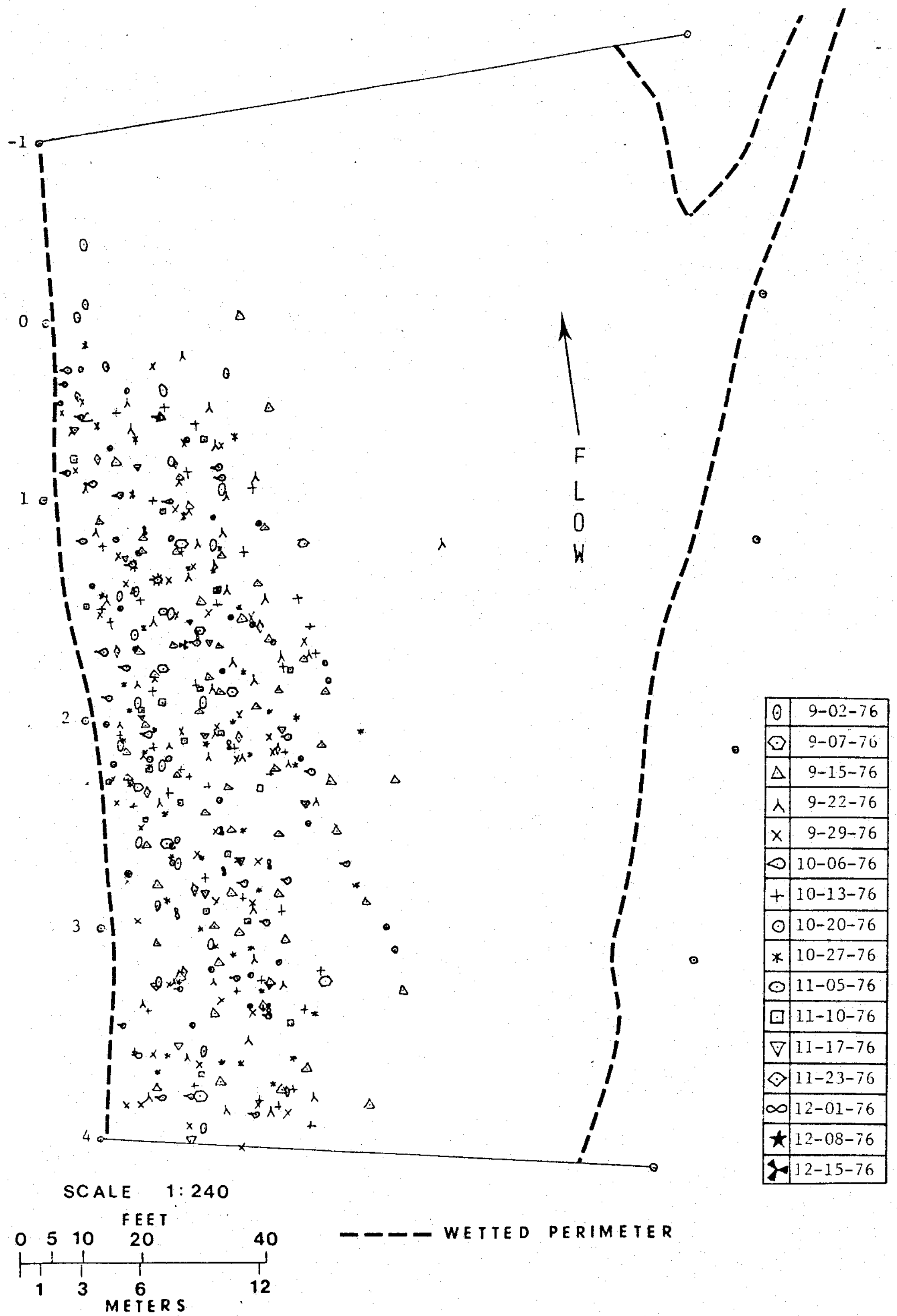


Fig. 21. Location of active redds recorded weekly at Station 5 during 1976.

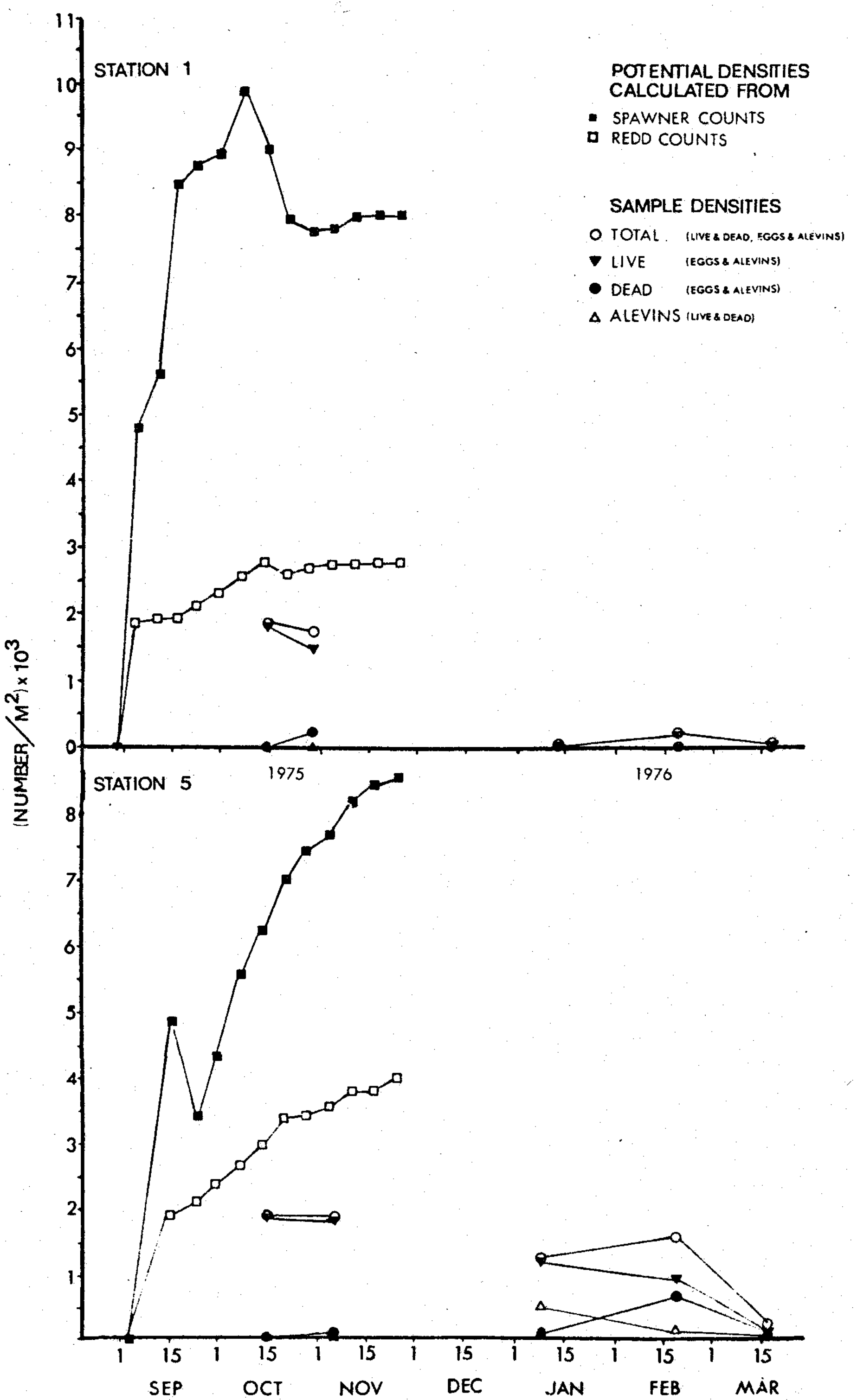


Fig. 22. Estimated potential egg/alevin densities based on spawner counts and redd counts at Stations 1 and 5 during 1975-1976. Observed densities were determined from hydraulic gravel samples.

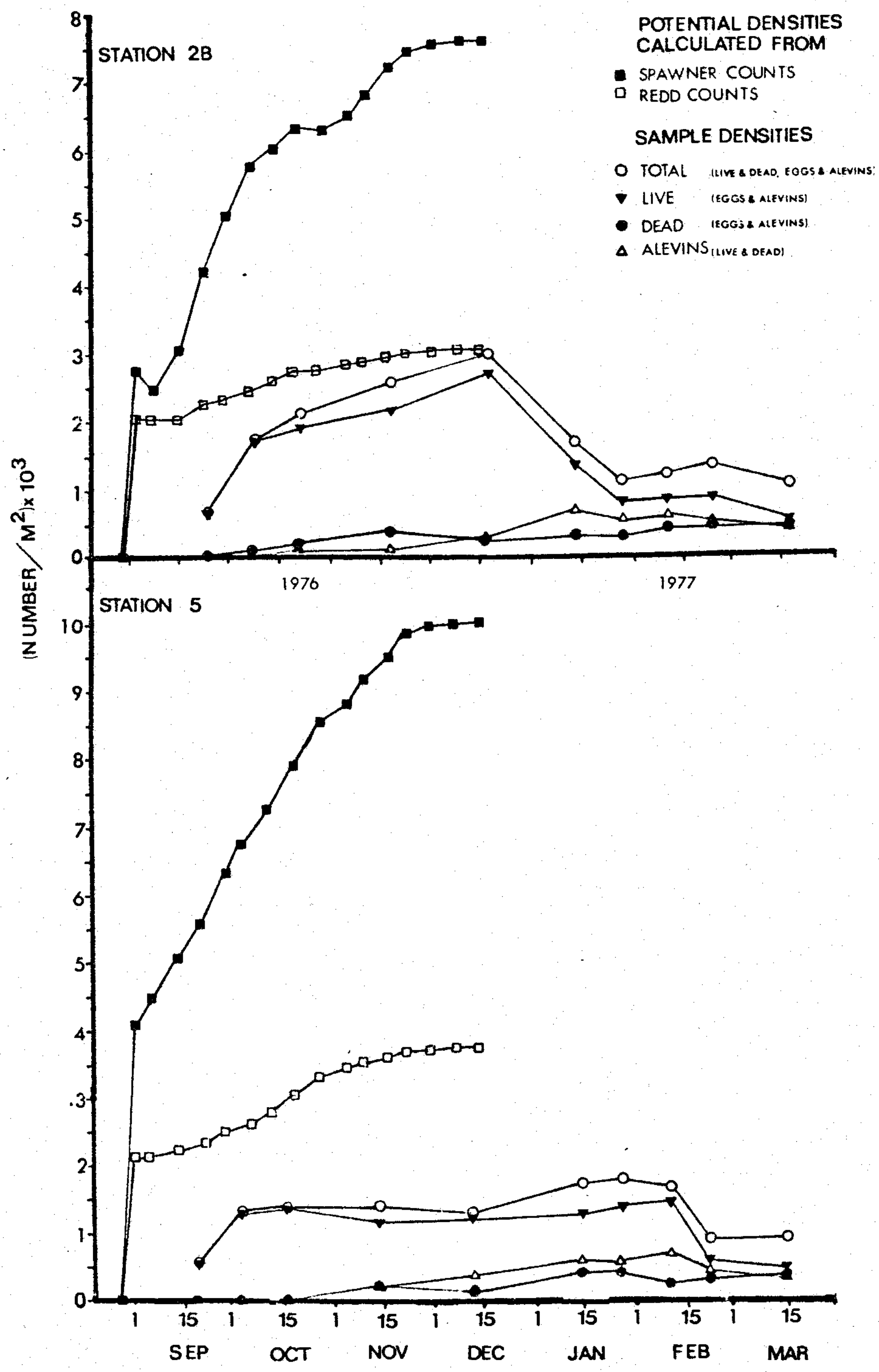


Fig. 23. Estimated potential egg/alevin densities based on spawner counts and redd counts at Stations 2B and 5 during 1976-1977. Observed densities were determined from hydraulic gravel samples.

7,653 and 10,087 eggs/m^2 at Stations 2B and 5, respectively, with slightly more area being used at Station 2B by 15 percent fewer spawners than at Station 5.

A comparison of the number of redds with the expected number of females calculated from the spawner counts, showed that the redd counts were consistently lower. Collective grouping of all 841 redds observed at Stations 1 and 5 in 1975 was lower than the 1,238 females estimated from the total spawner count of 2,134. Similarly in 1976, a total of 860 redds was counted at Stations 2B and 5, while 1,286 females were calculated to have used those reaches. Assuming one female per redd, the ratio of recorded redds to total spawners counted on the reaches should have equaled the expected ratio of 58 females/100 total spawners. However, the ratio of redds to total spawners for Stations 1 and 5 in 1975 was .394. In 1976 the ratio for Stations 2B and 5 was .386. Both years averaged .391 which differed from the expected 58 percent. The sex ratio of spawning sockeye deviated considerably from that observed prior to entrance into the river. This discrepancy suggests the need to express these results both on the basis of spawner counts and redd counts.

Potential egg densities based on the number of redds at Station 1 during 1975 increased more gradually and up to a lower final level than seen at Station 5 (Tables 2 and 3, Fig. 22). Initial values for the potential egg density of 1,944 eggs/m^2 were calculated by dividing the expected egg deposition of a single female (3,500 eggs) by the area of an average redd (1.8 m^2). The period of increasing density at both stations occurred during the late September-early October spawning period. Since the discharge did not increase substantially during this time, the same actual area was reused by successive waves of spawners. Therefore, an increase in egg density was expected as more eggs were deposited in the same approximate area. In mid-October 1975, the rate of density increase at Station 1 leveled off after reaching the calculated density of approximately 2,800 eggs/m^2, representing an increase of 44 percent of the initial density of 1,944 eggs/m^2. This period of constant average egg density resulted because the sockeye utilized previously unspawned areas made available by the increasing discharge

Table 2. Estimated potential egg deposition at Station 1, derived from redd counts, resulting from spawning activity during 1975. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton* (m^3/s)	Spawners		Redds		Potential Egg Deposition		Area (m^2)			Weekly Cumulative Density (egg/m^2)
		Week	Total	Week	Total	Week	Total	Week	New	Total	
9/3	11.47	10	10	4	4	14000	14000	7.20	7.20	7.20	1944.44
9/10	6.63	30	40	10	14	35000	49000	17.82	17.82	25.02	1958.43
9/16	4.53	120	160	23	37	80500	129500	40.68	40.68	65.70	1971.08
9/22	5.13	140	300	37	74	129500	259000	59.94	53.82	119.52	2167.00
9/29	5.64	177	477	52	126	182000	441000	77.94	66.60	186.12	2369.44
10/6	7.19	175	652	46	172	161000	602000	81.72	45.36	231.48	2600.66
10/13	6.17	160	812	81	253	28350	885500	138.06	82.80	314.28	2817.55
10/20	11.89	136	948	65	318	227500	1113000	115.02	101.52	415.80	2676.77
10/27	12.89	133	1081	60	378	210000	1323000	103.86	68.94	484.74	2729.30
11/3	25.88	72	1153	31	409	108500	1431500	54.36	30.42	515.16	2778.75
11/10	16.40	104	1257	28	437	98000	1524500	51.48	34.38	549.54	2783.24
11/17	24.98	49	1306	18	455	63000	1592500	32.40	14.94	564.48	2821.18
11/24	24.98	33	1339	15	470	52500	1645000	27.00	18.72	583.20	2820.64

*USGS gauge

Table 3. Estimated potential egg deposition at Station 5, derived from redd counts, resulting from spawning activity during 1975. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton* (m^3/s)	Spawners		Redds		Potential Egg Deposition		Area (m^2)			Weekly Cumulative Density (egg/m^2)
		Week	Total	Week	Total	Week	Total	Week	New	Total	
9/15	4.73	10	10	4	4	14000	14000	7.20	7.20	7.20	1944.44
9/23	5.64	54	64	36	40	126000	140000	66.24	57.42	64.62	2166.51
9/30	5.04	81	145	41	81	143500	283500	70.56	51.30	115.92	2445.65
10/6	7.19	142	287	59	140	206500	490000	91.80	63.18	179.10	2735.90
10/13	6.17	128	415	63	203	220500	710500	102.24	52.38	231.48	3069.38
10/20	11.89	118	533	49	262	171500	882000	84.78	33.12	264.60	3465.61
10/27	12.89	87	620	38	290	133000	1015000	64.44	25.74	290.34	3495.90
11/3	25.89	39	659	20	310	70000	1085000	34.02	9.00	299.34	3624.64
11/10	16.40	74	733	35	345	122500	1207500	59.94	13.50	312.84	3859.80
11/17	24.98	34	767	17	362	59500	1267000	29.34	5.04	317.88	3875.68
11/24	24.98	18	785	9	371	31500	1298500	16.02	2.70	320.58	4050.47

*USGS gauge

regime. The more heavily spawned Station 5, where higher discharge added very little new spawnable area, continued to demonstrate a constant increase even through the latter part of the season to the cumulative density of 3,775 eggs/m^2. This final density at Station 5 represented an increase equaling 76 percent of the initial density level. The rate of increase during the spawning season and the total cumulative density was lower than that based on spawner counts.

The egg density curves calculated from redd counts for 1976 at both Stations 2B and 5 (Tables 4 and 5, Fig. 23) showed a constant increase to maximum cumulative densities of 3,093 and 3,775 eggs/m^2, respectively. These final densities at Stations 2B and 5 represented 52 and 76 percent increases, respectively, over the initial densities. Through most of the spawning period of 1976, the discharge level ranged from 8 to 12 m^3/sec which resulted in an increase in spawnable area at Station 2B. The rate of increase during the spawning season and the total cumulative density was lower than that based on spawner counts for the same period of time.

6.4.3 <u>Egg Densities Estimated from Hydraulic Sampling</u>

The sample densities graphed in Figs. 22 and 23 and given in Tables 6 and 7 for the September through March periods of 1975-1976 and 1976-1977 have been presented for the purpose of indicating the occurrence of relative density increases and decreases during the spawning, incubation and the fry preemergent periods.

At Station 1, two sampling sessions during the spawning season were conducted on October 14 and 28, 1975. The calculated sample densities for these sessions were 1,886 and 1,776 eggs/alevins/m^2, respectively. Station 5 densities were 1,963 and 1,922 eggs/alevins/m^2 from samples collected on October 15 and November 5, 1975, respectively. The total sample densities at both stations were remarkable in their similarity, while the dead egg densities were greater at each of the stations on the second collection date. Unfortunately, a third sampling session indicating the final densities at the end of the spawning season was precluded by the December flood.

Table 4. Estimated potential egg deposition at Station 2B, derived from redd counts, resulting from spawning activity during 1976. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton* (m^3/s)	Spawners Week	Spawners Total	Redds Week	Redds Total	Potential Egg Deposition Week	Potential Egg Deposition Total	Area (m^2) Week	Area (m^2) New	Area (m^2) Total	Weekly Cumulative Density (egg/m^2)
9/2	4.84	15	15	11	11	38500	38500	18.90	18.90	18.90	2037.04
9/7	25.29	16	31	14	25	49000	87500	24.66	24.66	43.56	2008.72
9/15	8.01	69	100	40	65	140000	227500	72.72	68.76	112.32	2025.46
9/22	7.19	102	202	42	107	147000	374500	68.04	53.46	165.78	2259.02
9/29	9.12	137	339	52	159	182000	556500	89.46	67.32	233.10	2387.39
10/6	9.06	123	462	35	194	122500	679000	61.74	42.48	275.58	2463.89
10/13	9.18	84	546	41	235	143500	822500	68.58	37.80	313.38	2624.61
10/20	8.81	84	630	39	274	136500	959000	66.06	33.84	347.22	2761.94
10/27	8.81	72	702	35	309	122500	1081500	69.12	43.74	390.96	2766.27
11/5	10.70	68	770	29	338	101500	1183000	47.34	21.24	412.20	2869.97
11/10	12.21	107	877	33	371	115500	1298500	59.94	34.92	447.12	2904.14
11/17	12.52	69	946	16	387	56000	1354500	27.54	8.28	455.40	2974.31
11/23	11.33	40	986	13	400	45500	1400000	23.40	5.40	460.80	3038.19
12/1	10.87	19	1005	7	407	24500	1424500	12.24	3.78	464.58	3066.21
12/8	12.21	12	1017	4	411	14000	1438500	7.20	0.54	465.12	3092.75
12/15	11.33	0	1017	0	411	14000	1438500	0.00	0.00	465.12	3092.75

*USGS gauge

Table 5. Estimated potential egg deposition at Station 5, derived from redd counts, resulting from spawning activity during 1976. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton* (m^3/s)	Spawners		Redds		Potential Egg Deposition		Area (m^2)			Weekly Cumulative Density (egg/m^2)
		Week	Total	Week	Total	Week	Total	Week	New	Total	
9/2	4.84	46	46	24	24	84000	84000	39.06	39.06	39.06	2150.54
9/7	25.29	25	71	10	34	35000	119000	18.00	16.20	55.26	2153.46
9/15	8.01	142	213	60	94	210000	329000	105.84	90.54	145.80	2256.52
9/22	7.19	128	341	50	144	175000	504000	89.10	67.50	213.30	2362.87
9/29	9.12	138	479	46	190	161000	665000	77.22	51.66	264.96	2509.81
10/6	9.06	106	585	35	225	122500	787500	61.38	36.72	301.69	2610.39
10/13	9.18	107	692	44	269	154000	941500	77.04	31.86	333.54	2822.75
10/20	8.81	101	793	38	307	133000	1074500	55.44	15.84	349.38	3075.45
10/27	8.81	119	912	48	355	168000	1242500	72.72	21.78	371.16	3347.61
11/5	10.70	81	993	33	388	115500	1358000	62.46	21.78	392.94	3456.00
11/10	12.21	76	1069	22	410	77000	1435000	37.80	11.70	404.64	3546.36
11/17	12.52	48	1117	15	425	52500	1487500	27.00	4.68	409.32	3634.08
11/23	11.33	44	1161	12	437	42000	1529500	21.60	2.70	412.02	3712.20
12/1	10.87	26	1187	8	445	28000	1557500	14.40	3.96	415.98	3744.17
12/8	12.21	11	1198	3	448	10500	1568000	5.40	0.00	415.98	3769.41
12/15	11.33	2	1200	1	449	3500	1571500	1.80	0.36	416.34	3774.56

*USGS gauge

Table 6. Estimated densities of eggs and alevins from hydraulic samples at Stations 1 and 5, resulting from spawning activity during 1975.

Station	Date	No. of Sample Units	Area Sampled m^2	Actual Count Totals				Density (eggs-alevins/m^2)		
				Live		Dead				
				Eggs	Alevins	Eggs	Alevins	Live	Dead	Total
1	10/14/75	77	3.85	6372	4	159	0	1840.11	45.89	1886.00
	10/28/75	91	4.23	5822	0	940	0	1529.29	246.91	1776.20
	1/13/76*	36	1.67	28	0	63	0	23.96	53.89	77.84
	2/18/76*	32	1.49	0	206	27	0	197.51	25.89	223.40
	3/18/76	50	2.32	0	103	4	0	49.33	1.91	51.24
5	10/15/75	40	1.86	3211	0	72	0	1918.16	43.01	1961.17
	11/ 5/75	53	2.46	4058	2	195	0	1833.79	88.08	1921.86
	1/ 8/76*	17	0.79	256	388	30	0	1164.56	54.24	1218.80
	2/19/76*	19	0.88	748	124	385	0	1415.59	625.00	2040.59
	3/17/76	42	1.95	92	264	107	0	150.42	60.97	211.40

*Collected using deep-water sampling method (70% efficiency assumed). For all other dates, low-water sampler employed (90% efficiency assumed).

The first two of the three sampling sessions at both stations in 1976 following the flood utilized the deepwater sampling apparatus. Even after adjustment for a 70 percent sampling efficiency, the numbers were noticeably lower than preflood estimates and indicated severe scouring had occurred. The postflood sampling results are discussed further in the section on flood effects.

Five sampling sessions were conducted during the 1976 spawning season between September 21 and December 17 at both Stations 2B and 5 (Table 7 and Fig. 23). Total and live sample densities at Station 2B increased steadily through the season to the highest levels recorded for any station, 3,062 and 2,749 eggs/alevins/m^2, respectively. However, at Station 5, where expected potential densities exceeded those of Station 2B, total sample densities were, in fact, lower and showed no real change through the end of the spawning season after an initial increase in early October.

An increase in the density of dead eggs and alevins seemed to begin earlier in October at Station 2B than at Station 5, and continued to a higher level at both stations in mid-November. While the live count averages were higher in December, dead sample densities decreased in that month.

The hatching of eggs increased in December as indicated by the increased alevin counts in the samples. The natural development rate seemed to be closely correlated with the results of the in situ incubation studies (Section 6.6).

The egg/alevin densities of the five postspawning sampling sessions, conducted during incubation and fry emergence at Stations 2B and 5 between January 13 and March 14, 1977, are given in Table 7 and Fig. 23. A decrease in total and live egg/alevin sample density occurred at Station 2B between December 17, 1976, and January 13, 1977, bringing the sample densities at this station to a lower level than those at Station 5. Densities at Station 5 were constant, indicating no total or live density decrease had occurred there until mid-February.

The average sample densities at Station 2B indicated that removal of eggs and alevins from the gravel had occurred in late December or early January. Fry emergence had just begun, with only about 7 percent

Table 7. Estimated densities of eggs and alevins from hydraulic samples at Stations 2B and 5, resulting from spawning activity during 1976.

Station	Date	No. of Sample Units	Area Sampled m^2	Actual Count Totals: Live Eggs	Live Alevins	Dead Eggs	Dead Alevins	Density* ($eggs-alevins/m^2$): Live	Dead	Total
2B	9/24/76	48	2.23	1374	0	11	0	691.43	5.54	696.96
	10/ 8/76	74	3.40	5317	0	170	0	1735.55	55.49	1791.03
	10/22/76	75	3.45	5792	259	707	0	1948.79	227.70	2176.49
	11/18/76	73	3.36	6415	265	1270	0	2210.31	420.22	2630.53
	12/17/76	78	3.59	7656	1227	1012	0	2748.98	313.39	3062.37
	1/13/77	82	3.77	2113	2537	1078	2	1369.74	318.13	1687.88
	1/27/77	80	3.68	679	1989	1003	0	805.56	302.84	1108.39
	2/10/77	88	4.05	556	2436	1542	0	821.26	423.25	1244.51
	2/24/77	77	3.54	1152	1715	1326	69	899.36	437.60	1336.97
	3/18/77	59	2.71	214	1102	1208	2	538.77	495.37	1034.14
5	9/21/76	37	1.70	903	0	1	0	589.50	0.65	590.16
	10/ 4/76	59	2.71	3201	0	99	0	1310.49	40.53	1351.02
	10/18/76	58	2.67	3363	11	49	0	1405.13	20.41	1425.54
	11/15/76	64	2.94	2957	177	674	0	1182.82	254.38	1437.20
	12/13/76	54	2.48	1700	230	1031	0	1221.60	102.88	1324.48
	1/12/77	55	2.53	1425	1491	1060	0	1280.63	465.52	1746.16
	1/24/77	52	2.39	1718	1259	860	16	1382.28	406.91	1789.76
	2/ 8/77	62	2.85	1747	1879	620	0	1412.65	241.55	1654.20
	2/20/77	61	2.81	385	1120	730	0	595.95	289.06	885.01
	3/14/77	51	2.35	287	749	768	1	491.14	364.21	885.36

*Assuming 90% efficiency

of the fry emigration estimated from fry samples to have occurred during this period throughout the entire river. It is not known whether this loss from the gravel was due to emergence or due to a river discharge level of 23.6 m^3/sec (940 cfs) on December 27, 1976, which was second only to the highest peak during the incubation period of 34 m^3/sec (1,220 cfs) recorded on January 18, 1977. It is possible some scouring or movement of the streambed substrate occurred at Station 2B during this moderate flow.

The sample density at the time of completion of all spawning was compared with the final average potential density at each station for 1975 and 1976 (Fig. 24). The sample density was calculated from the samples taken from within the spawned perimeter and included unspawned areas between the redds. A final average potential density for each station at the end of each spawning season was calculated by: 1) measuring the total area within the perimeter of the final cumulative redd map; and 2) dividing this measured area into the potential egg deposition for the station estimated from the redd counts. This also included unspawned areas between the redds and provided a comparable density.

The final sample densities utilized in the calculation of the egg deposition efficiency for the 1975 spawning season were estimated from those calculated for Stations 1 and 5 on October 28 and November 5, respectively. Presuming that little further increase in the sample densities would have occurred following these dates preceding the December flood which terminated spawning, sample densities of total live and dead eggs/alevins for these dates were used to approximate the final egg densities at the end of the spawning season. Small decreases in densities found on the second sampling date at each station suggested no density increase had occurred during the latter half of October. The final sample densities utilized for the 1976 spawning season were the highest observed including the postspawning period.

While the average expected potential egg density at Station 5 was higher than those of the other stations in each year (3,714 eggs/m^2 in 1975 and 3,496 eggs/m^2 in 1976), the difference between the expected density and the corresponding final sample density (1,922 eggs/m^2 in

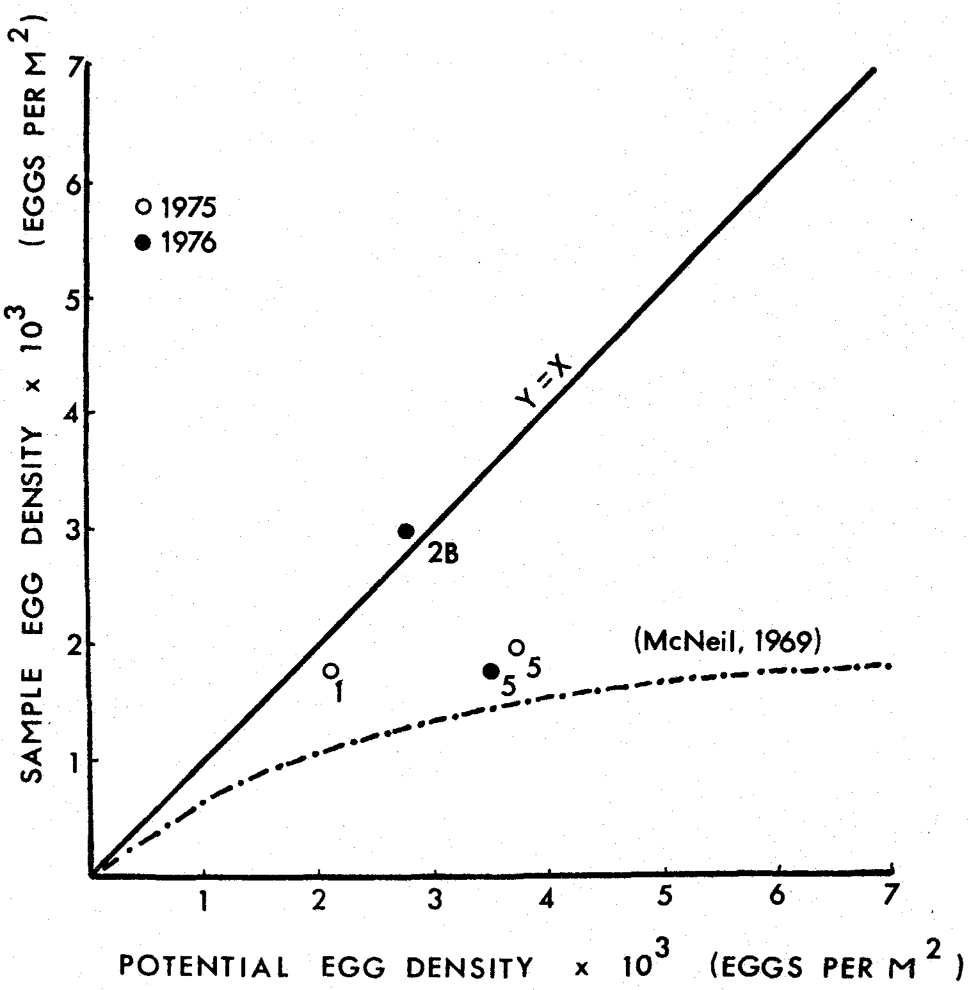


Fig. 24. Density of sockeye salmon eggs at the end of the spawning season, and potential egg densities calculated on the total area within the spawned perimeter at selected pairs of hydraulically contrasting reaches during 1975 and 1976. A curve derived by McNeil (1969) for pink and chum salmon is shown for comparison. The curve y = x represents 100 percent of potential egg deposition.

1975 and 1,789 eggs/m^2 in 1976) at this station was greater. The egg deposition efficiency was about 50 percent. Final potential densities for the other two study reaches, 2,135 eggs/m^2 for Station 1 and 2,802 eggs/m^2 for Station 2B, in 1975 and 1976, respectively, were lower than those of Station 5 and were more closely approached by their respective sample densities of 1,776 eggs/m^2 and 3,062 eggs/m^2. The egg deposition efficiency was about 80 and 100 percent at Stations 1 and 2B, respectively. At Stations 1 and 2B where spawner densities were lower than Station 5, sample densities approached the potential egg deposition level. Compared with the curve (Fig. 24) derived by McNeil (1969) who studied pink and chum salmon egg densities, the Cedar River sockeye egg densities were higher on reaches where the spawning area accumulated with discharge.

The distribution of clustered data such as found in this study has not yet been described mathematically. The negative binomial and Neyman's Type A distributions were tested and found to be unsatisfactory to describe the distribution of eggs collected on the spawning reaches. As a result, these data were not transformed to reduce any bias of the means, due to the clustered counts, preventing the conventional use of chi-square analysis of variance to compare mortality levels during the season. Therefore, alternative tests, which included proportionate frequencies and mortality ratios were employed to analyze the counts.

6.4.4 Intragravel Egg Mortality

In the tests of proportionate frequencies, the chi-square test of independence was employed to compare the changes in the proportions of samples devoid of eggs or alevins or with only a single specimen to determine when mortality had occurred within the gravel during the incubation period.

The data for the 1976-1977 sampling dates have been analyzed in Tables 8 and 9 for Stations 2B and 5, respectively. Due to the limited sampling effort and small sample size for the postflood sample dates of 1975-1976, analysis was not conducted on that date.

The calculated χ^2 values for Station 2B during the spawning season in 1976 showed neither a significant increase in the fraction of samples

Table 8. Chi-square test of independence on sample units with zero or one eggs/alevins per .046 m^2 sampled at Station 2B during the 1976-1977 season.

Date	Total No. of Sampled Points	Zero or one total k_o	Zero or one total p_o	Zero or one live k_o	Zero or one live p_o	Zero or one dead k_o	Zero or one dead p_o
			Spawning Season				
9/24/76	48	25	.52	26	.54	46	.96
10/8/76	74	25	.34	27	.36	54	.73
10/22/76	75	28	.37	30	.40	48	.64
11/18/76	73	16	.22	27	.37	33	.43
12/17/76	78	20	.26	21	.27	39	.50
	299	114		104		173	
χ^2 (4 d.f.) =		9.41		2.54		18.79*	
			Post-Spawning Season				
12/17/76	78	20	.26	21	.27	39	.50
1/13/77	82	26	.32	31	.38	32	.39
1/27/77	80	36	.45	40	.50	42	.53
2/10/77	88	23	.26	31	.35	31	.35
2/24/77	77	24	.31	37	.48	36	.47
3/18/77	59	20	.34	25	.42	32	.54
	464	149		185		212	
χ^2 (5 d.f.) =		8.14		10.62		4.06	

*significant at 95% level

Table 9. Chi-square test of independence on sample units with zero or one eggs/alevins per .046 m^2 sampled at Station 5 during the 1976-1977 season.

Date	Total No. of Sampled Points	Zero or one total k_o	Zero or one total p_o	Zero or one live k_o	Zero or one live p_o	Zero or one dead k_o	Zero or one dead p_o
			Spawning Season				
2/21/76	37	17	.46	17	.46	37	1.00
10/4/76	59	13	.22	14	.24	55	.93
10/18/76	58	18	.31	22	.38	45	.78
11/15/76	64	14	.22	24	.38	26	.41
12/31/76	54	12	.22	18	.33	24	.44
	272	74		95		187	
χ^2 (4 d.f.) =		3.97		2.50		55.16*	
			Post-Spawning Season				
12/31/76	54	12	.22	18	.33	24	.44
1/12/77	55	12	.22	18	.33	19	.35
1/24/77	52	12	.23	17	.33	23	.44
2/10/77	62	9	.15	11	.18	29	.47
2/20/77	61	13	.21	23	.38	23	.38
3/14/77	51	17	.33	21	.41	27	.53
	335	75		108		145	
χ^2 (5 d.f.) =		4.35		7.06		3.85	

*significant at 95% level

with zero or one total eggs or alevins (χ^2 = 9.40) nor any increase of significance in the fraction of the samples with zero or one live specimen (χ^2 = 2.54) which indicated that no significant removal of eggs or alevins from the streambed had occurred. The proportions of p_o in these two categories, in fact, generally decreased as eggs were being deposited in new areas during the season. However, the occurrence of intragravel mortality was indicated by the significant decrease in the number of samples with zero or one dead egg or alevin (χ^2 = 18.79).

Similarly, for Station 5, as for Station 2B, the chi-square tests of independence did not indicate a significant increase between the proportions of samples with zero or one egg or alevin in the total and live categories, but again actually a decrease (χ^2 = 3.97 and 2.50, respectively). As in the case of Station 2B, a significant decrease in the fraction of the dead egg and alevin classification was found (χ^2 = 55.16).

At both Stations 2B and 5, there were no differences of significance between the proportions of the postspawning dates.

Comparisons of the 95 percent confidence limits of the p_o values for the number of samples with zero or one dead egg at Station 2B and 5 are shown in Tables 10 and 11, respectively. Significant mortality occurred at Station 2B between the periods of September 24-October 8 and October 22-November 18 (Table 10). However, a 1-month period separated the latter two dates, which was about twice as long as the period of time between the first two dates.

Examination of the 95 percent confidence limits of p_o in Table 11 indicated that significant mortality had occurred during the periods between the first four sampling dates of the spawning season at Station 5. At both stations, postspawning season proportions of samples with zero or one dead egg or alevin (p_o) did not vary significantly.

6.4.5 Estimated Mortality Ratios from Dead-to-Total Eggs/Alevins

Prior to calculating the average ratios of dead-to-total eggs and alevins in samples for each sampling date, the percentages of binomial variation of samples with 10 or more eggs/alevins were calculated to determine if weighting of the individual samples was warranted. The

Table 10. Values of k_o and p_o with 95% confidence limits for sample units having zero or one dead eggs/alevins per .046 m^2 sampled at Station 2B, 1976-1977.

Date	Total Number of Sampled Points	k_o	95% Confidence Limits	p_o	95% Confidence Limits
9/24/76	48	46	±2.78	.96	±.06
10/8/76	74	54	±8.92	.73	±.12
10/22/76	75	48	±8.29	.64	±.11
11/18/76	73	33	±8.48	.45	±.12
12/17/76	78	39	±8.81	.50	±.11
1/13/77	82	32	±8.79	.39	±.11
1/27/77	80	42	±8.89	.53	±.11
2/10/77	88	31	±8.92	.35	±.10
2/24/77	77	36	±8.71	.47	±.11
3/18/77	59	32	±7.65	.54	±.13

Table 11. Values of k_o and p_o with 95% confidence limits for sample units having zero or one dead eggs/alevins per .046 m^2 sampled at Station 5, 1976-1977.

Date	Total Number of Sampled Points	k_o	95% Confidence Limits	p_o	95% Confidence Limits
9/21/76	37	37	-	1.00	-
10/4/76	59	55	± 3.86	.93	±.07
10/18/76	58	45	± 6.35	.78	±.11
11/15/76	64	26	± 7.86	.41	±.12
12/13/76	54	24	± 7.30	.44	±.13
1/12/77	55	19	± 7.09	.35	±.13
1/24/77	52	23	± 7.20	.44	±.14
2/10/77	62	29	±11.49	.47	±.19
2/20/77	61	23	±12.33	.38	±.20
3/14/77	51	27	± 9.85	.53	±.19

range of the percentages of binomial variation of samples with 10 or more sockeye eggs/alevins collected during hydraulic sampling at Stations 1, 2B, and 5 in 1975-1976 and 1976-1977 varied from 3 to 13 percent. Since, according to Cochran (1943), an efficiency of not less than 95 percent could be expected when binomial variation is 13 percent or less (op cit., page 289), fractions of samples with 10 or more total eggs and alevins were given equal weight in the determination of the average mortality ratio M_r.

The mortality estimates, M_r, for Stations 1 and 5 in Table 12 and for Stations 2B and 5 in Table 13, supplement the preceding results of the tests of proportionate frequencies by identifying when periods of significant ingravel mortality had occurred, as evidenced by changes in the dead-to-total eggs and alevins ratio in the samples.

The mortality estimates for 1975-1976 are presented (Fig. 25). The spawning season values were initially very low at both Stations 1 and 5 in mid-October, but showed a significant increase in the mortality levels on the next sampling dates. The M_r ratio at Station 1 was much greater than that seen at Station 5. Postspawning season sample sizes were very small due to the loss during the flood.

The mortality estimates of both Stations 2B and 5 followed similar trends over the entire sampling period between September 1976 and March 1977 (Fig. 26). The dead-to-total ratios generally increased linearly during the spawning season, remaining below 10 percent through mid-October, but significantly rising to greater than 20 percent by mid-November. A decline, which was significant at Station 2B, occurred at both stations between mid-November and December. The increasing mortality trend continued to a level of about 30 percent by mid-January, and thereafter generally increased at a lesser rate. The M_r values reached 40 percent at Station 2B and 48 percent at Station 5 by mid-March.

6.5 Flood Effects on Eggs/Alevins

The major flood of early December 1975 caused extensive damage to many of the study stations. Stations 1 and 9 suffered scouring and removal of most spawnable substrate, with only large boulders and rubble remaining after the flood. At Station 2 the river branched, carving a

Table 12. The mortality ratios, M_r, with 95% confidence limits for Stations 1 and 5, 1975-1976.

Date	M_r	95% Confidence Limits
	Station 1	
10/14/75	.003	±.002
10/28/75	.263	±.106
1/13/76	.509	±.472
2/18/76	.115	±.040
3/18/76	.286	±.457
	Station 5	
10/15/75	.002	±.003
11/5/75	.045	±.038
1/8/76	.108	±.121
2/19/76	.494	±.487
3/17/76	.245	±.298

Table 13. The mortality ratios, M_r, with 95% confidence limits for Stations 2B and 5, 1976-1977.

Date	M_r	95% Confidence Limits
	Station 1	
9/24/76	.011	±.019
10/8/76	.052	±.032
10/22/76	.070	±.038
11/18/76	.215	±.098
12/17/76	.104	±.040
1/31/77	.297	±.070
1/27/77	.305	±.088
2/10/77	.348	±.071
2/24/77	.368	±.101
3/18/77	.411	±.136
	Station 5	
9/21/76	.001	±.001
10/4/76	.065	±.091
10/18/76	.047	±.048
11/15/76	.203	±.096
12/13/76	.163	±.083
1/21/77	.306	±.100
1/24/77	.334	±.122
2/8/77	.187	±.067
2/20/77	.393	±.109
3/14/77	.479	±.175

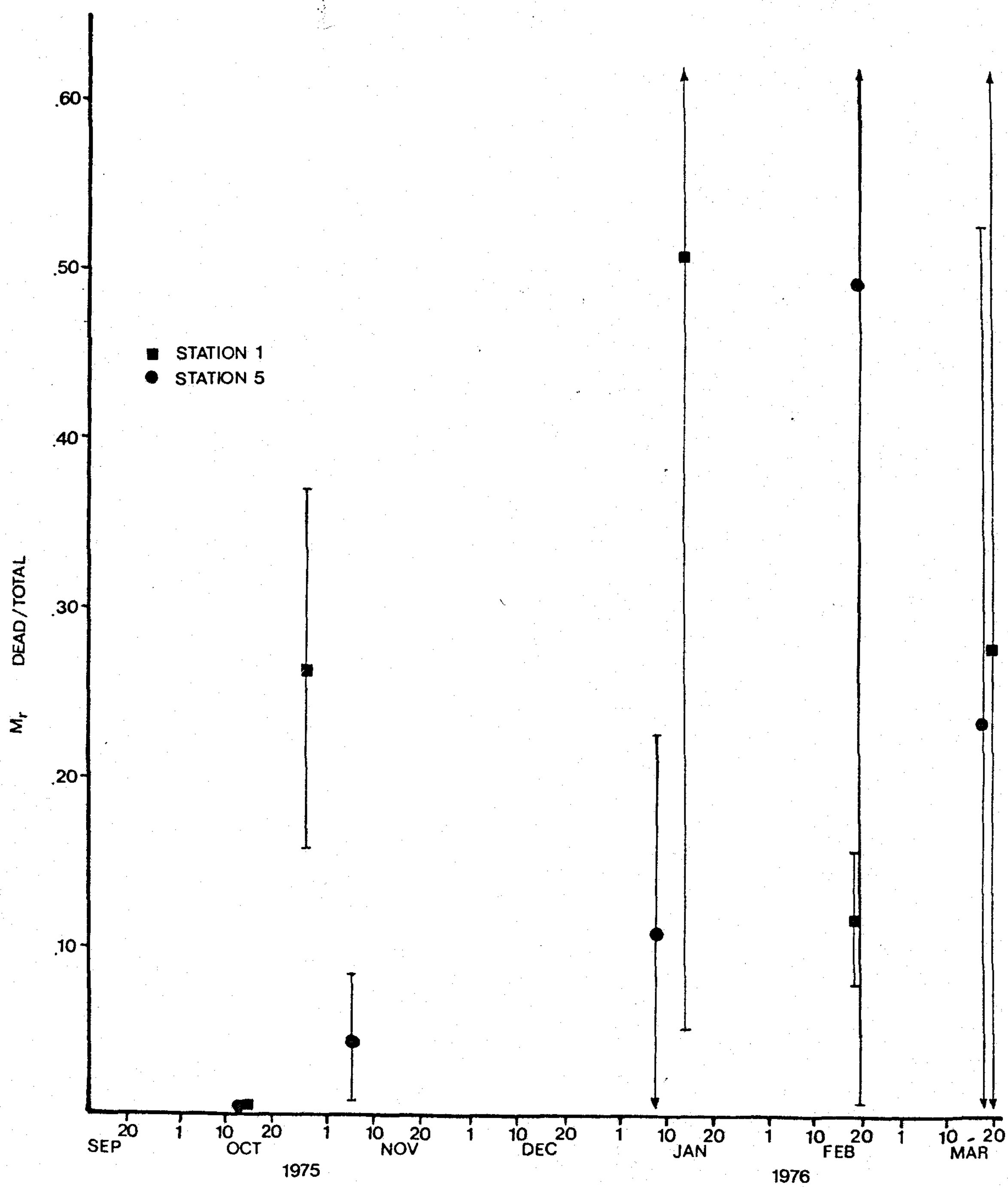


Fig. 25. Mortality estimates (M_r ratio = dead/total) of sockeye eggs and alevins in the gravel at Stations 1 and 5 during September-March 1975-1976. The 95 percent confidence intervals are indicated by vertical bars around each point.

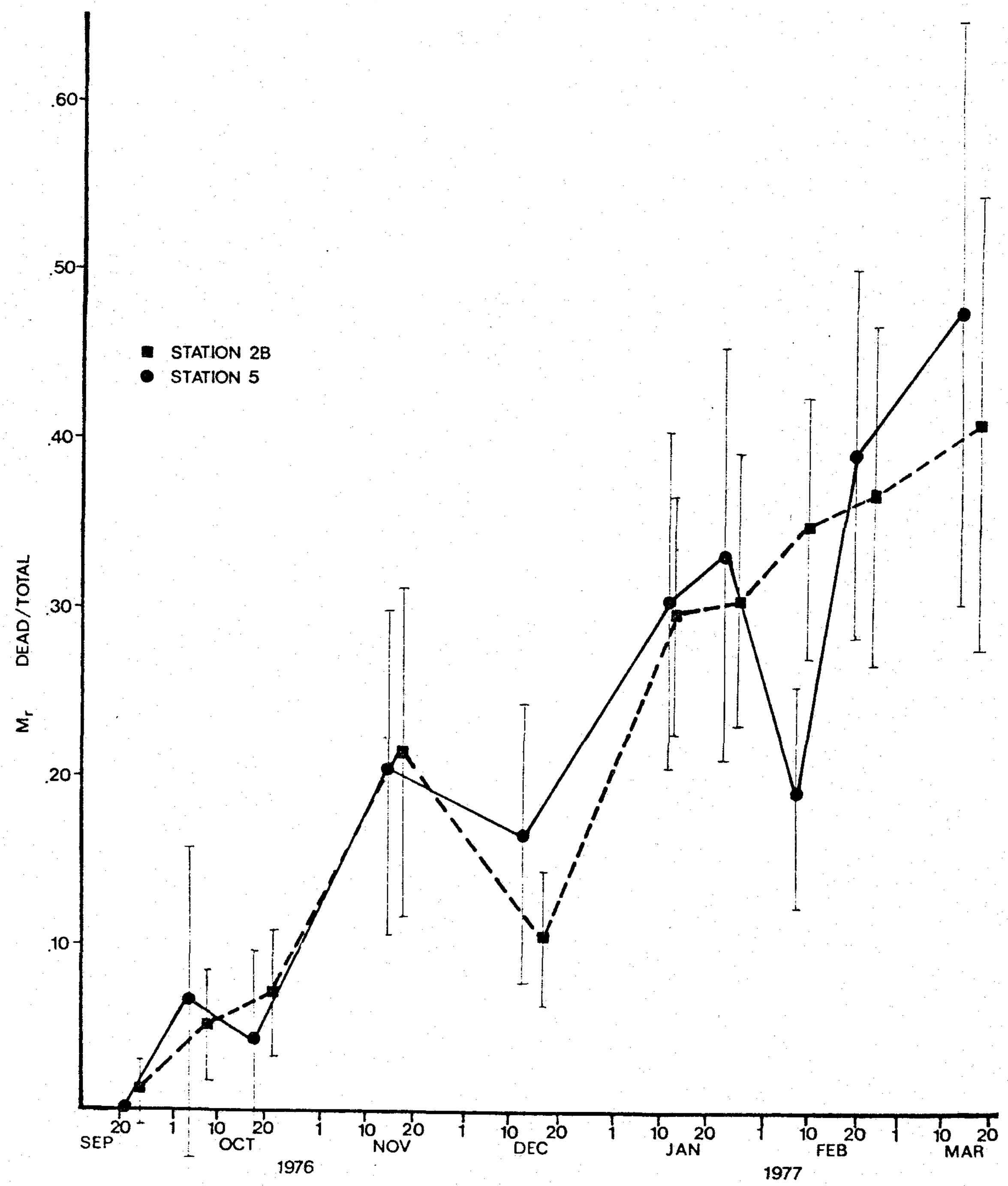


Fig. 26. Mortality estimates (M_r ratio = dead/total) of sockeye eggs and alevins in the gravel at Stations 2B and 5 during September-March 1976-1977. The 95 percent confidence intervals are indicated by vertical bars around each point.

new channel and washing away numerous large trees in the process. The flood deposited 0.9-1.8 m (3-6 ft) of gravel on spawned areas of Stations 6 and 7, while cutting the corners off the riverbends near each of these reaches and shifting the channel location. The riprap bordering Stations 4, 5, 6, 8, and 10 was eroded to some extent, and was completely washed away from one bank at Station 9.

The effects of the flood on Stations 1 and 5 were assessed from the data taken from two of the three postflood hydraulic sampling sessions conducted before the first emergence of fry in mid-February. A map of Station 1, showing the areas where egg/alevins were found prior to and following the flood, is presented in Fig. 27. The zones delineate segments of the spawning reach which suffered flood-imposed egg loss to different degrees. Zone I, nearest the center of the channel, exhibited nearly a complete loss of eggs/alevins due to flood effects. This 714.1 m^2 area represented 93.5 percent of the area within the spawned perimeter of the station. Within this area, 77 percent of the potential egg deposition calculated from redd counts (1,340,500 eggs) was spawned at an average potential density of 1,877 eggs/m^2. The postflood densities were calculated from the 51 hydraulic samples collected within Zone I on January 13 and February 18, 1976. The sampling efficiency of the deep-water sampling apparatus was assumed to be 70 percent based on the high discharge encountered at the time of sampling. The total sample density was 1.2 eggs/alevins/m^2, with a live density of only 0.6 eggs/m^2.

A restricted area of 49.6 m^2 nearest the right bank of Station 1, designated as Zone II, was the remaining portion of the spawning bar where limited numbers of eggs and alevins were recovered by hydraulic sampling. Since this part of the spawning bar became submerged only after flows increased on October 20, 1975, all eggs in Zone II were deposited following that date. According to potential egg deposition calculated from redd maps of the area within the spawned perimeter, Zone II represented 6.5 percent of the total spawned area with 23 percent of the deposition (304,500 eggs), having a potential average density of 6,133 eggs/m^2. On the basis of eight samples taken in this zone, the total density was 903 eggs/alevins/m^2, with 654 live eggs/alevins/m^2.

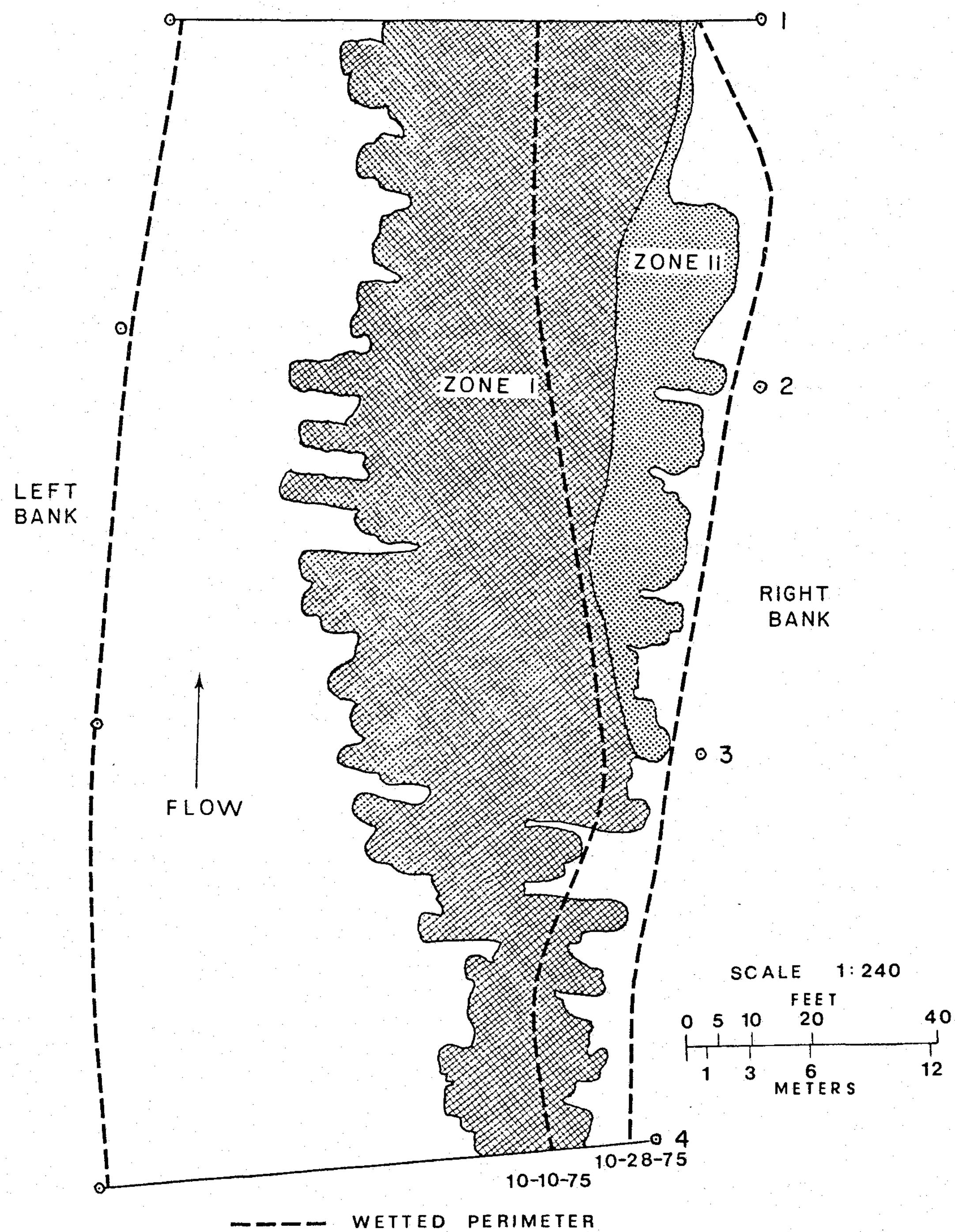


Fig. 27. The distribution of sockeye eggs/alevins in the gravel at Station 1, showing zones of survival following the flood of December 1975. Total densities of eggs/alevins remaining in Zones I and II were 1.2 and 903/m^2, respectively.

A comparison of pre- and postflood hydraulic sample densities indicated that 96.6 percent of the total eggs/alevins were lost due to the flood at Station 1.

The egg loss due to scouring at Station 5 was not uniform within the spawned area, as illustrated by the two zones in Fig. 28. Preflood estimates, derived from postspawning season redd maps, approximated that Zone I included 55.9 percent of the area (348.7 m^2) within the spawned perimeter, and 42.6 percent of the egg deposition (553,161 eggs) at an average density of 4,327 eggs/m^2. Based on 42 samples collected on January 8 and February 19, 1975, sample densities of 93 total eggs/alevins/m^2 and 0.73 live/m^2 indicated that a severe loss of eggs had occurred in Zone I, the area closest to the thalweg.

A 156.5-m^2 area of Zone II nearest the left bank was less affected. Although Zone II represented only 44.1 percent of the spawning reach, an estimated 57.4 percent of the egg deposition (745,339 eggs) occurred in this zone, with a final expected potential density of 4,761 eggs/alevins/m^2. Sample densities of 1,999 total and 1,528 live eggs/alevins/m^2, based on 42 samples, showed scouring effects were less severe in Zone II than in Zone I. A comparison of pre- and postflood hydraulic sample densities indicated that 50.6 percent of the total eggs/alevins were lost due to the flood at Station 5.

6.6 Incubation Studies

Development rates of eggs and alevins for the 1976 brood year were determined in egg incubation experiments at Landsburg. The time required to yolk absorption varied from 130 to 147 days (Fig. 29). The eggs spawned in mid-September developed most rapidly and required more TU's than eggs taken from middle and late spawners. The rate of embryonic development was retarded during cold water temperatures. The number of days to hatching increased and the period from hatching to yolk absorption decreased as the season progressed. Depending on the temperature regime, the cumulative TU's (C) to yolk absorption ranged between 878 and 1,000 units.

The expected fry emergence curves for the 1975 and 1976 brood years are given in Fig. 30. The 1976 emergence curve of the 1975 year class

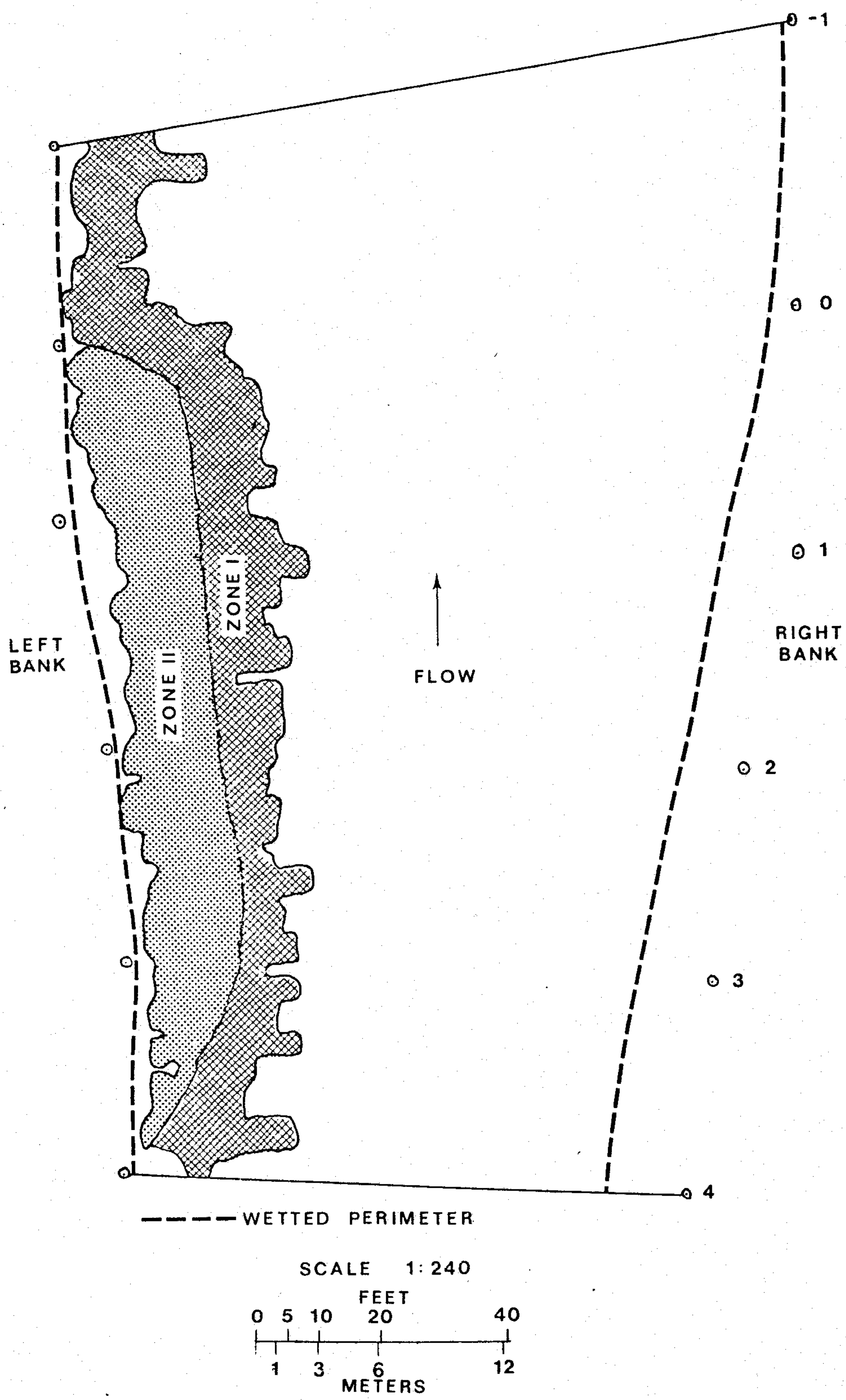


Fig. 28. The distribution of sockeye eggs/alevins in the gravel at Station 5, showing zones of survival following the flood of December 1975. Total densities of eggs/alevins remaining in Zones I and II were 93 and 1,999/m^2, respectively.

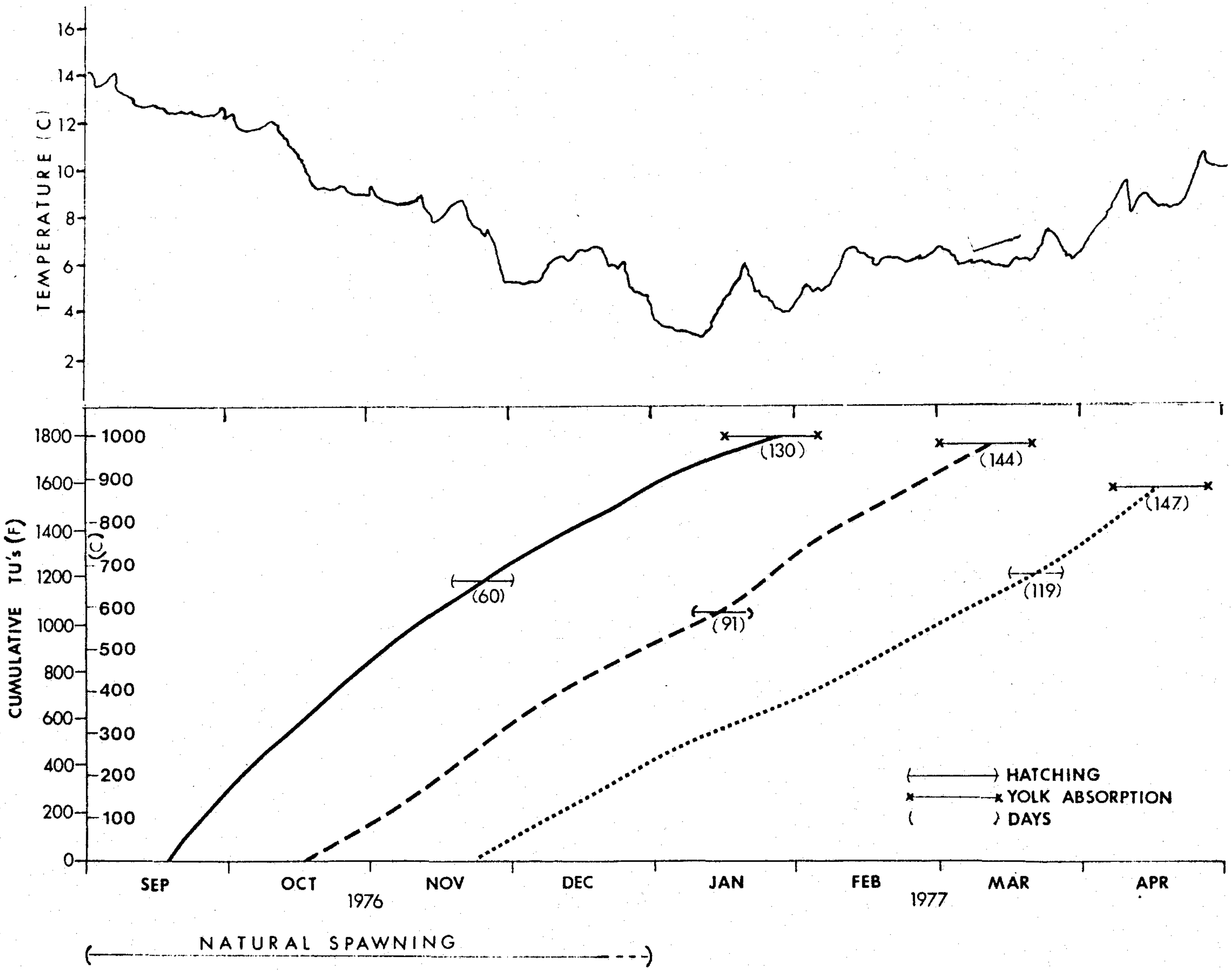


Fig. 29. Cumulative temperature units experienced by eggs planted in incubation boxes at Landsburg in 1976. The estimated days to hatching, yolk absorption, and water temperatures are shown.

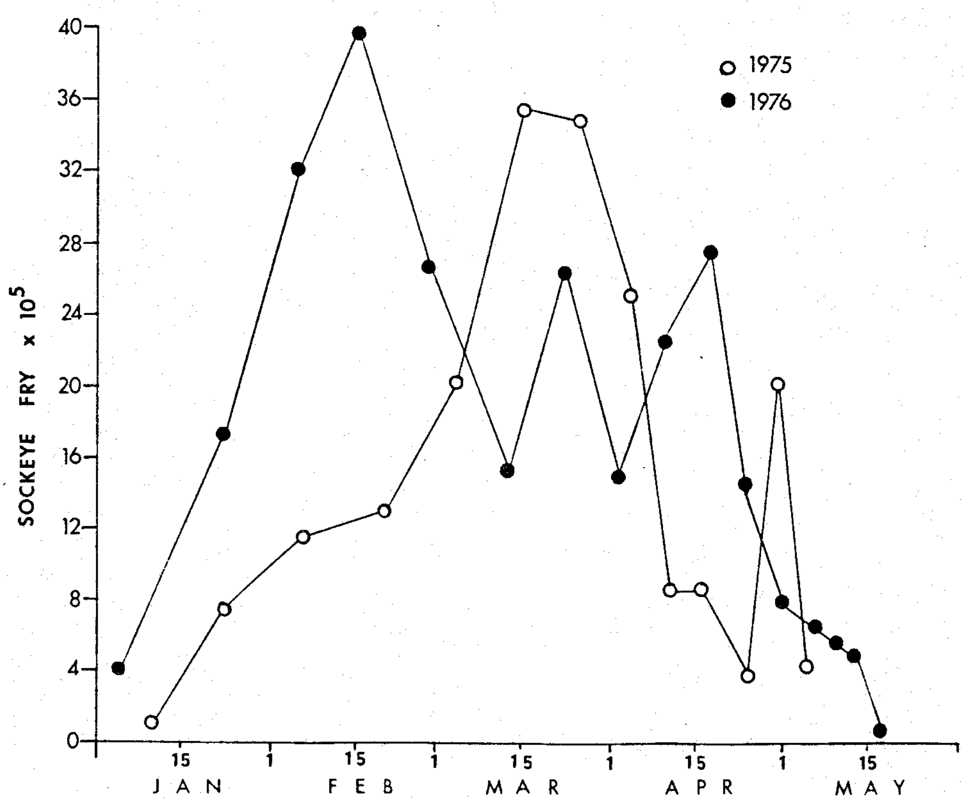


Fig. 30. Estimated emergence from the 1975 and 1976 brood years of Cedar River sockeye salmon, assuming 10.0% egg-to-fry survival.

assumed a dome-shaped emigration pattern. It indicated that the emigration started in mid-January and was completed by early May. The highest peak was in mid-March, followed by a smaller peak at the end of April. Three definite peaks were evident in the 1977 expected emergence curve. The highest peak occurred in mid-February, followed by smaller surges in late March and mid-April. The expected curve indicated that the emergence began in early January and lasted until late May.

6.7 Fry Emigration and Production

The downstream migration of sockeye salmon fry was confined to the darkest hours of the night (Table 14). A higher proportion of fry caught during the daytime in February 1976, was due to small numbers taken during high discharge and turbidity following the December 1975 flood. Generally, the downstream activity reached a peak from 2 to 5 hours after sunset (Fig. 31). Only one site was fished during these nights to eliminate any confounding effects which could occur due to the use of multiple sites. The timing of these peaks varied from night to night, indicating differences in stream and weather conditions, and probably the distance of migration. The nightly emigration period became shorter and was shifted to later hours as the photoperiod lengthened with the season.

If fry emerged from the spawning beds near Landsburg early in the evening and drifted passively with the current, it would be possible to complete their downstream emigration before dawn. However, active downstream movement of sockeye fry has been observed by Hartman et al. (1962). The travel time of water from Landsburg to Renton has been estimated by the Seattle Water Department to take from 6 to 8 hours. The catch data showed that all fry did not enter the lake during the night of emergence. Apparently, fry emerged at night, stopped their migration at dawn, hid under stones and vegetation, and then continued downstream movement the following evening.

The captured fry exhibited photonegative behavior when exposed to light. During enumeration, fry formed a tight ball on the bottom of the bucket and tried to hide under debris. When fry were released into the

Table 14. The proportion of sockeye salmon fry captured during daylight hours in 1976 and 1977.

Date	Daylight	Night	Total	Percent
		1976		
2/5	0	4	4	0.0
2/10	2	21	23	8.7
3/21	6	302	308	1.9
Mean				3.5
		1977		
1/3	6	192	198	3.0
2/3	12	2678	2690	0.4
3/10	39	13122	13161	0.3
4/4	30	35176	35206	0.1
Mean				1.23

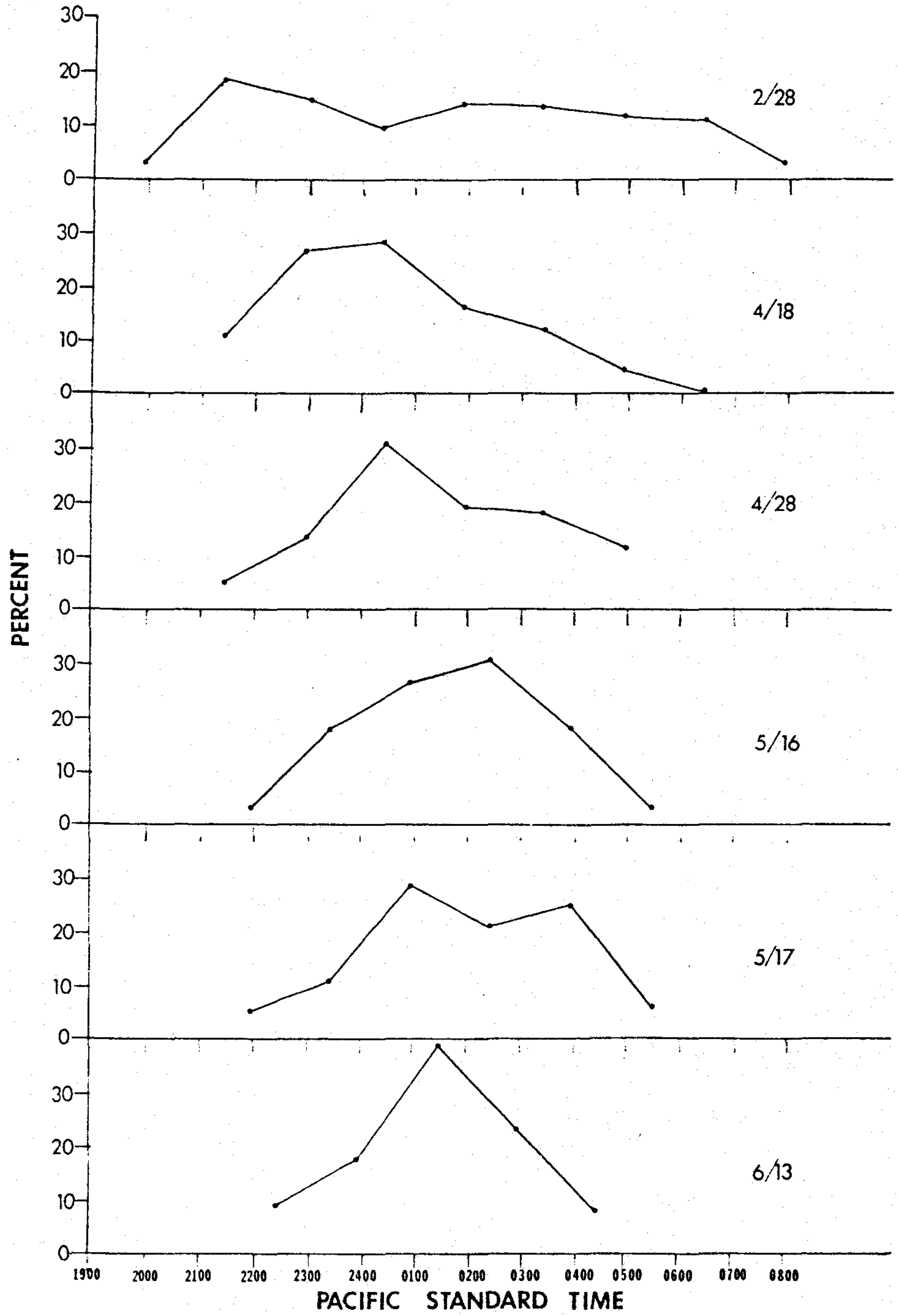


Fig. 31. Hourly distribution of nocturnal downstream movement of sockeye fry for six representative periods in 1977.

river during daylight, they quickly disappeared under stones and vegetation. Periodically, at dawn, small schools of fry were observed near the riverbank, but none could be seen by sunrise.

In 1976, a total of 51 sampling nights were distributed throughout the 5-month emigration period. The 1977 season involved 70 sampling nights distributed over a period of 6.5 months. The horizontal distribution of sockeye fry across the river channel was generally related to the velocity and depth of the water flowing past the sampling station (Fig. 32). The highest number of fry were consistently caught at Sites 2 and 3. Together, these two sites accounted for 75.5 and 73.0 percent of the total catch in 1976 and 1977, respectively. Water velocities became slower as the season progressed due to an increase in the lake level during early spring. It is unlikely that this reduced the efficiency of the fyke net since water velocities in the main channel remained above 0.3 m/sec.

In 1976, the first two sampling periods exhibited almost identical horizontal distributions (Fig. 32). The last sampling period after May 14 differed markedly from the earlier ones, when about two-thirds of the total number of fry were taken at Site 3. All three periods sampled in 1977 had almost identical horizontal distributions (Fig. 32). Even though the horizontal catch distribution was associated with maximum channel depth and velocity, the proportion of the catch could not be directly related to water velocity, discharge or cross-sectional area sampled. For example, in 1976 the proportion of the discharge fished varied between Sites 1 and 4 by 2 percent, while the mean catch varied by about 60 percent.

The daily downstream fry movement during 1976 was characterized by a succession of peaks (Fig. 33). When the sampling was initiated on February 5, the 24-hour catch was only four fry. The number of fry increased steadily with minor fluctuations until March 27, when 43,269 fry were estimated. Emigration then declined to a level of 10,000-20,000 migrants. High river discharge induced mass migration between May 10 and 14; however, a large amount of filamentous algae prevented sampling. Based on the river flows on May 10-14, and catch and discharge on May 17, the daily migration was estimated at 55,000 fish per day for the period.

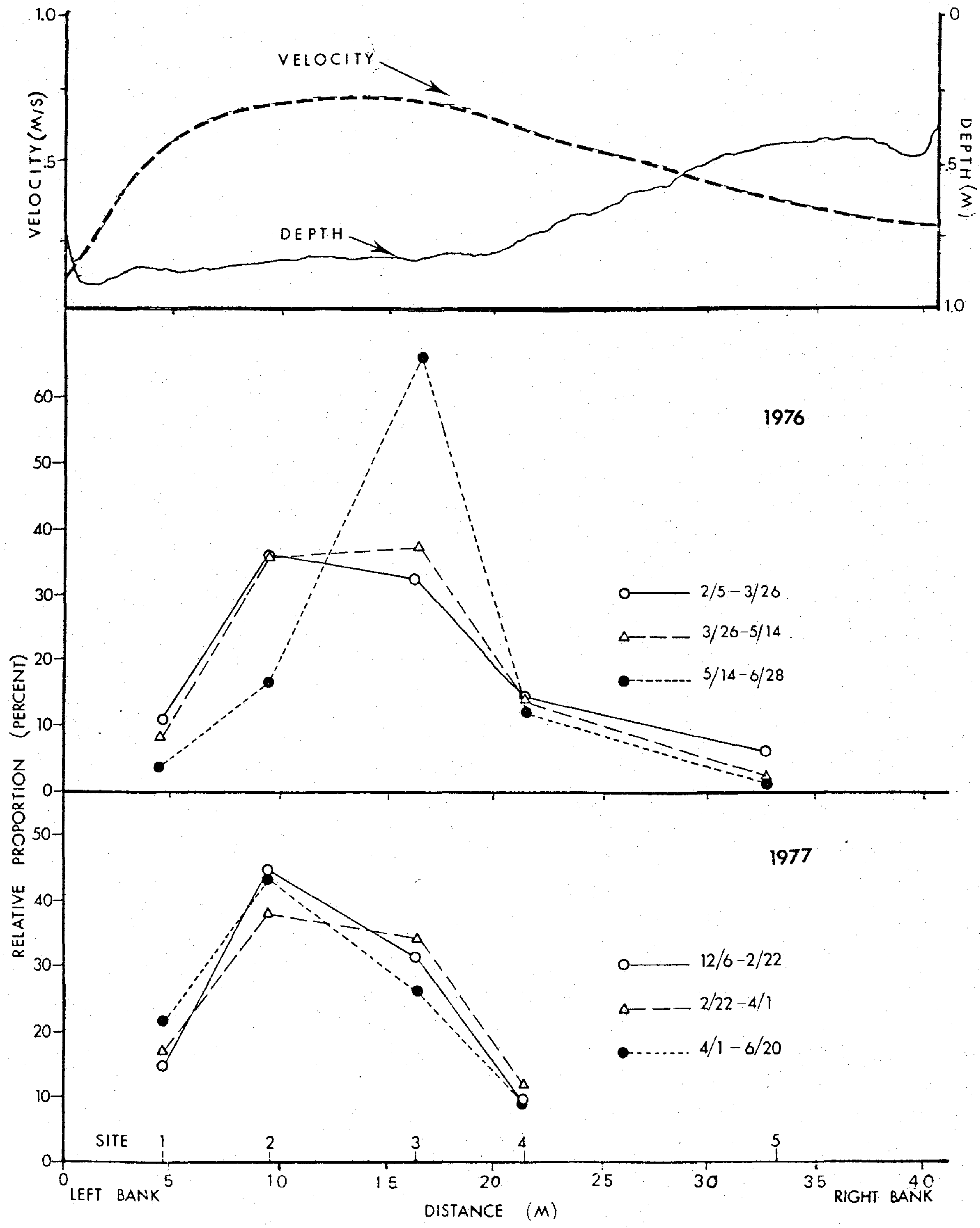


Fig. 32. Horizontal distribution of sockeye salmon fry by sample site during three periods of emigration with mean depth and velocity.

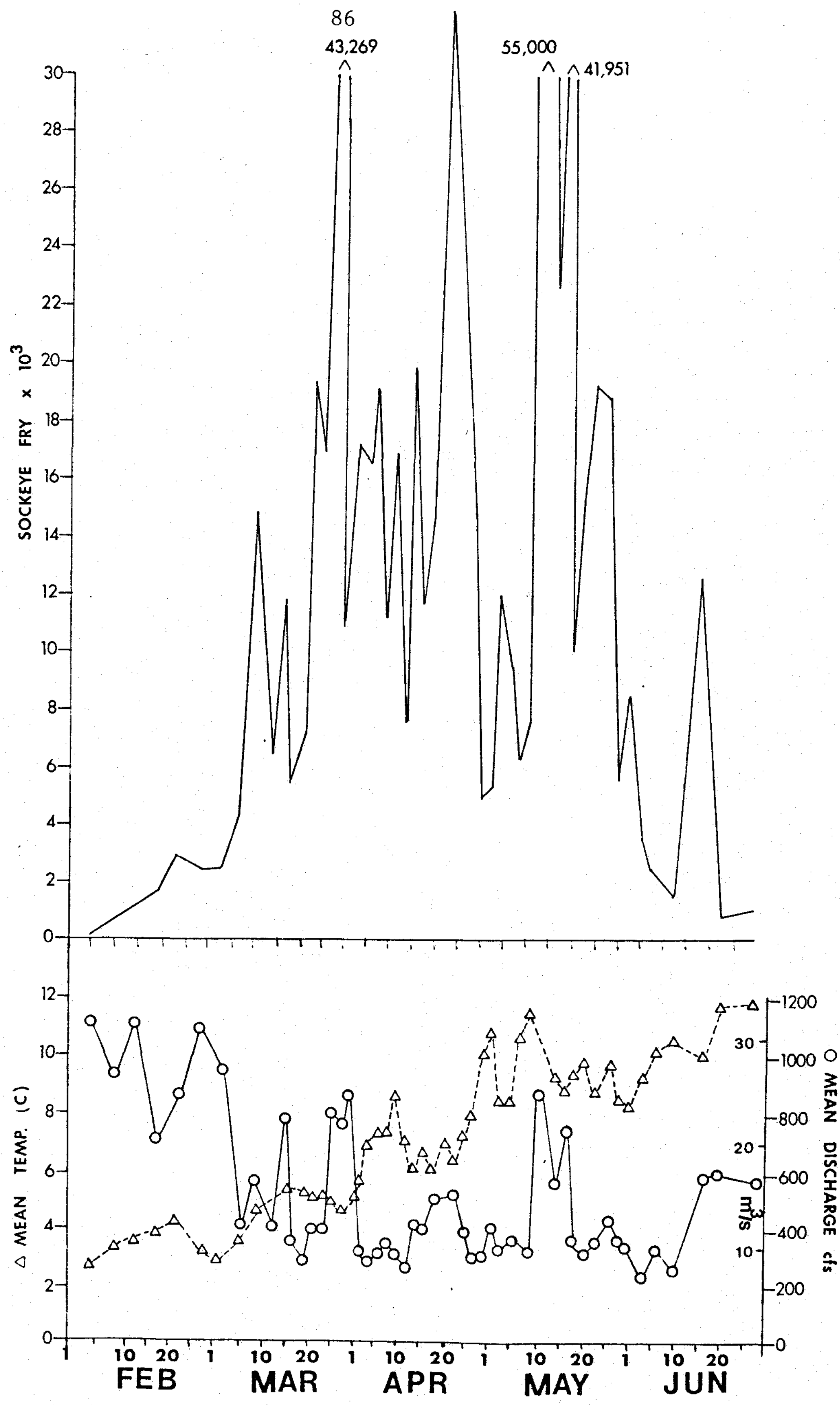


Fig. 33. Daily output of sockeye salmon fry from the 1975 brood year, with mean nocturnal discharge and temperature.

The estimate for the missing days seemed to be justified due to improved environmental conditions and a high emigration rate on May 17. The number of fry then declined. Another small peak occurred on June 16, when 12,702 fry were estimated. The late emigrating fry were reared in the river. Sampling was terminated on June 28.

The downstream migration was just beginning when sampling was initiated on December 6, 1976 (Fig. 34). Very low numbers of fry were captured until January 13, when 38,803 fry were estimated. On January 18, high flows and river temperatures increased sockeye emigration to 355,840 fry, followed by modest numbers until the end of February. The daily estimates fluctuated between 200,000 and 340,000 fry for the next 2 weeks and declined to a level of about 100,000 for a few days. Then, the majority of emigration occurred from March 22 to April 11, with the highest nightly estimate of 652,686 fry on April 4. After a brief decline, the estimates reached 300,000 fry and declined sharply during the first week in May. Very low numbers were observed until June 20, when the sampling was terminated.

Daily estimates were used to derive weekly rates of emigration. In 1976, these were increased by 5.0 percent to account for daytime movement due to high turbidity and discharge. The adjustment made was only 1.5 percent in 1977, due to lower turbidity discharge and relatively lower daytime catches. Analysis of the 1976 weekly emigration pattern from the 1975 brood showed three major peaks (Fig. 35). Greatest fry abundance occurred during May, late in the migratory period. It is apparent that a large number of fry expected, based on developmental rates, during February and March did not appear in the samples. The progeny of early spawning sockeye apparently suffered greater mortality due to the flood when compared to fry from later spawners.

The weekly emigration pattern for 1977 is shown in Fig. 36. The main emigration period occurred from mid-February through late April with three major peaks evident. The emigration period was earlier than the preceding year and catches declined rapidly during May and June. The observed and expected curves agreed closely in time; however, a large number of fry expected in late January and early February did not appear.

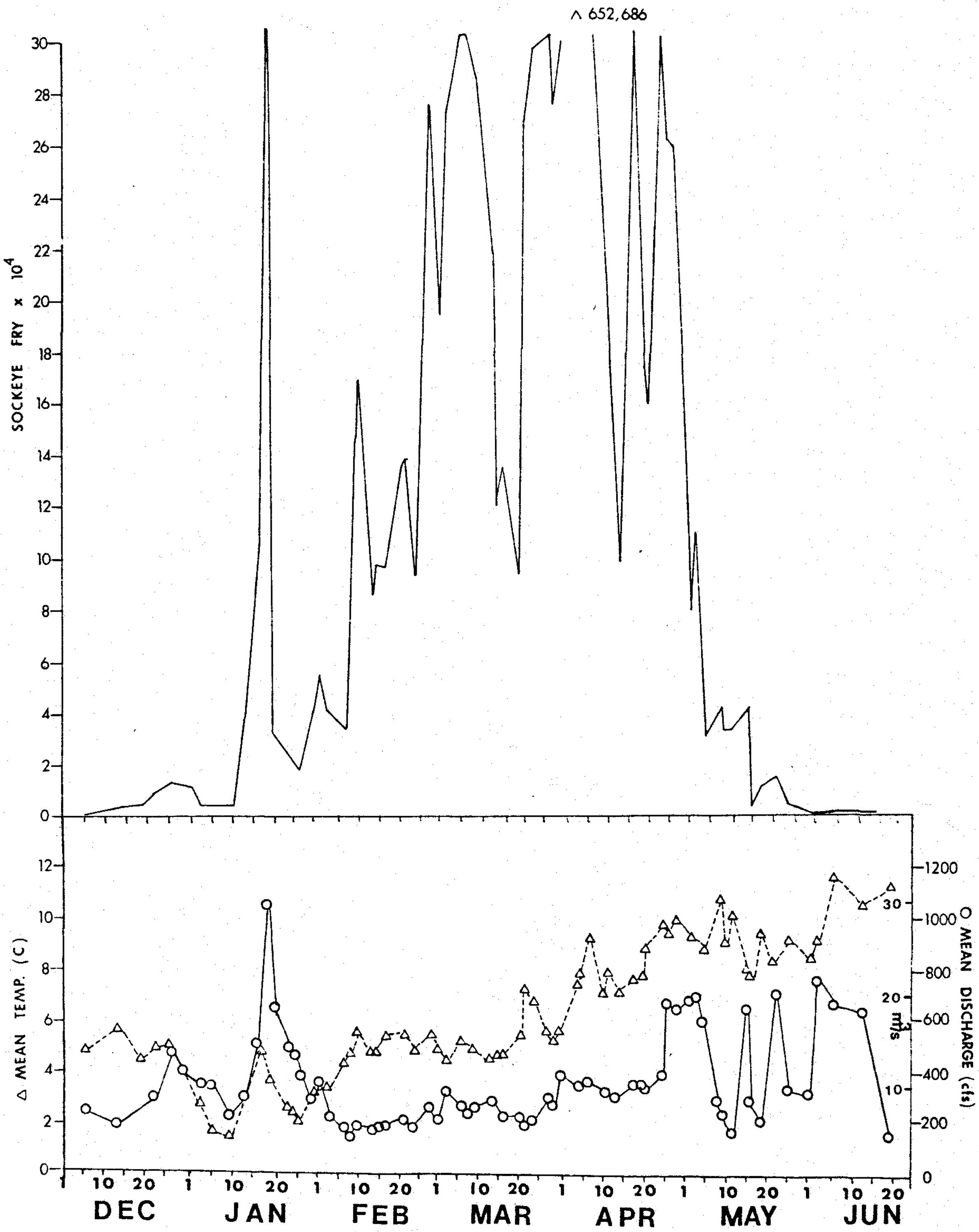


Fig. 34. Daily output of sockeye salmon fry from the 1976 brood year, with mean nocturnal discharge and temperature.

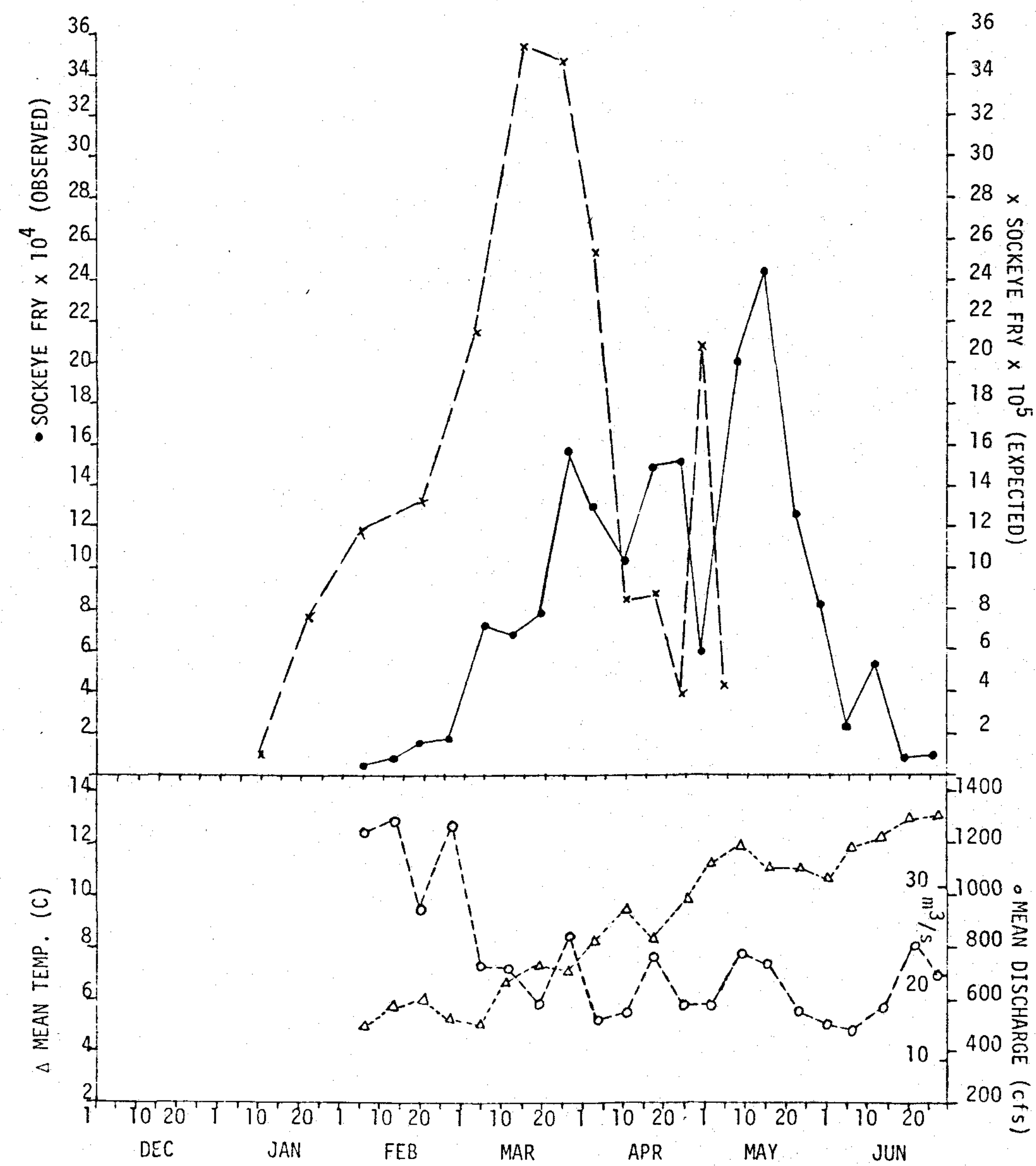


Fig. 35. Weekly observed and expected number of sockeye salmon fry from the 1975 brood year with mean temperature and discharge.

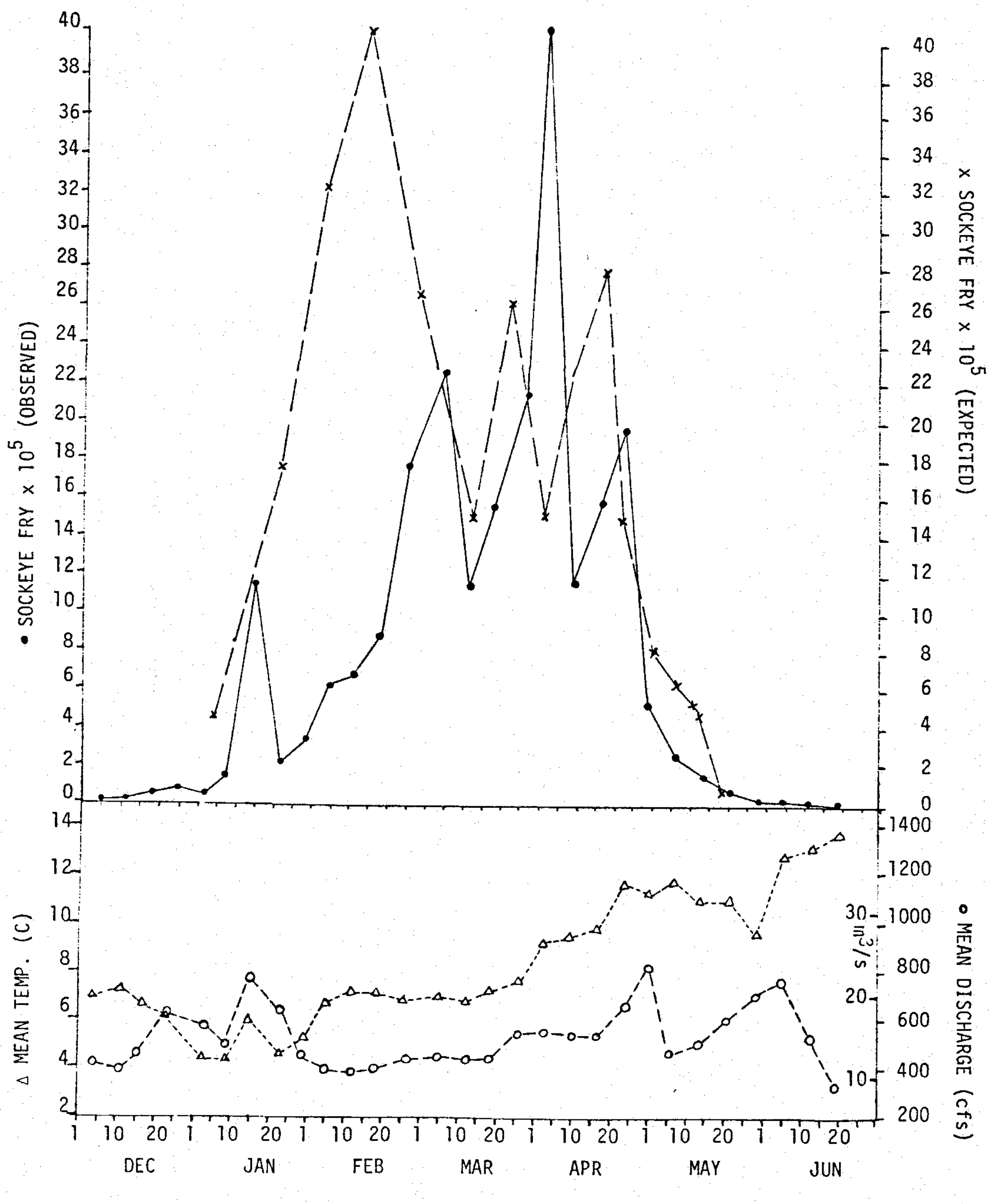


Fig. 36. Weekly observed and expected number of sockeye salmon fry from the 1976 brood year with mean temperature and discharge.

Cumulative and monthly fry outputs expressed as percent of total are plotted for 1976 and 1977 in Fig. 37. Fifty percent of the emigration was completed by April 21, 1976, and in 1977 by March 21. The patterns were quite similar but differed in timing. In 1976, 2.0 percent of the total downstream movement occurred in February, 20.6 percent in March, 29.7 percent in April, 36.5 percent in May, and 11.1 percent in June. About two-thirds were accumulated in April and May. In 1977, the monthly fry outputs were as follows: December (0.7 percent), January (7.0 percent), February (13.5 percent), March (34.2 percent), April (39.9 percent), May (4.1 percent), and June (0.1 percent). March and April together accounted for 74.1 percent of the total emigration.

The total estimated downstream fry emigration in 1976 and 1977 was 1.76×10^6 (± 464,818) and 22.8×10^6 (± 3,275,307), respectively.

6.8 Fry Survival

Based on the escapement estimates, sex ratio and fecundity, the potential egg deposition for the 1975 and 1976 brood years was 2.16×10^8 and 2.82×10^8 eggs, respectively. Since only 1.76×10^6 fry were estimated to have entered Lake Washington in 1976, a 0.81 percent egg to fry survival resulted. The fry survival in 1977 increased to 8.1 percent.

The success of the various segments of the spawning run was evaluated by dividing the spawning season into three parts: early (August and September), middle (October) and late (November and December) for both years (Tables 15 and 16). It was assumed that the sockeye deposited their eggs an average of 7 days after passing the tower monitoring site. No additional spawning was assumed to have occurred from about 8,000 late spawners after December 1, 1975. Although fry survival from the 1975 brood was extremely low throughout, it was lowest for the August-September period when 15.3 percent of the escapement contributed only 1.9 percent of the surviving fry. The middle and late segments of the run accounted for 54.7 and 30.0 percent of the escapement while contributing 33.5 and 64.6 percent of the fry produced (Table 15).

Escapement was about equal during the three periods in the 1976 brood year with 33.2, 35.2 and 31.6 percent, respectively (Table 16). The lowest fry survival (3.6 percent) occurred from August-September

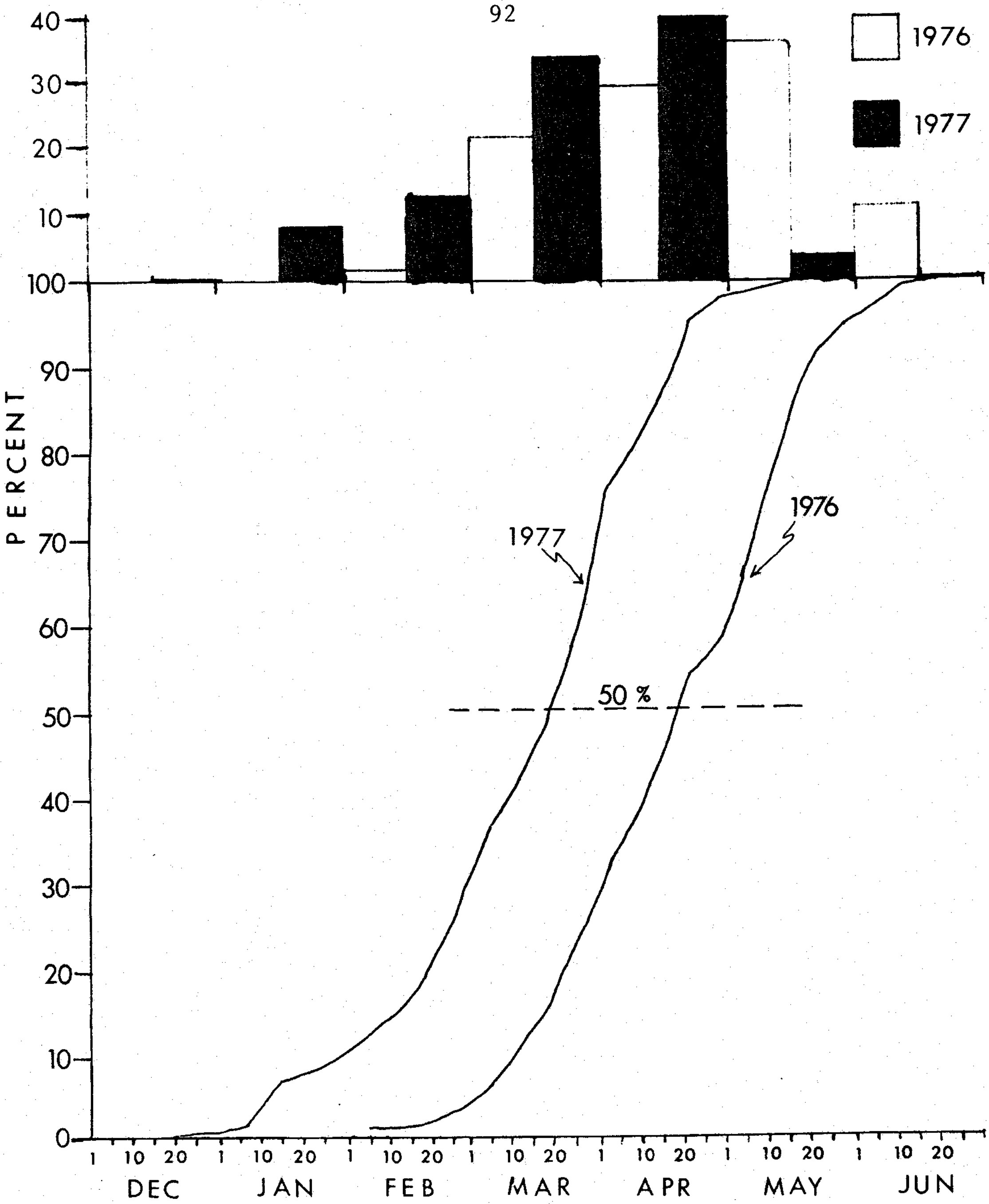


Fig. 37. Cumulative and monthly fry output from the 1976 and 1977 brood years.

Table 15. Performance of the early, middle and late portions of the 1975 brood year.

Dates Spawned	Escape-ment	%	Sex Ratio	Fecund-ity	Potential Egg Dep.	Expected Emergence	Days to Emergence	Fry Prod.	Survival %	Contribution
8/15-9/30	16368	15.3	42:58	3500	33227040	1/10 - 2/24	147	34003	0.1	1.9
10/1-10/31	58308	54.7	42:58	3500	118365240	2/25 - 4/7	159	589933	0.5	33.5
11/1-12/1	31954	30.0	42:58	3500	64866620	4/8 - 5/7	156	1138767	1.8	64.6
Total	106630	100.0			216458900		$\bar{x}$=154	1762703	$\bar{x}$=0.81	100.0

Table 16. Performance of the early, middle and late portions of the 1976 brood year.

Dates Spawned	Escape-ment	%	Sex Ratio	Fecund-ity	Potential Egg Dep.	Expected Emergence	Days to Emergence	Fry Prod.	Survival %	Contribution
8/15-9/30	46137	33.2	42:58	3500	93658110	1/5 - 2/18	141	3336666	3.6	14.6
10/1-10/31	48877	35.2	42:58	3500	99220310	2/19 - 4/5	156	12050011	12.1	52.8
11/1-12/22	43935	31.6	42:58	3500	89188050	4/6 - 5/17	155	7438016	8.3	32.6
Total	138949	100.0			282066470		$\bar{x}$=147	22824693	$\bar{x}$=8.1	100.0

which contributed only 14.6 percent of the total fry production. Fry survival (12.1 percent) was greatest from the October escapement which contributed the major proportion of fry (52.8 percent). November-December fry survival declined to 8.3 percent and contributed 32.6 percent of the fry. Throughout both brood years, fry survival and production from August-September spawners was lowest.

6.9 Flood Effects on Fry

Miller (1976) presented two curves (curves 2 and 3 in Fig. 38) describing the relationship between Cedar River sockeye presmolt-to-spawner ratio (P/S) and the instantaneous peak discharge (Q_f) at Renton during egg incubation. Curve 2 is defined by the equation $P/S = 26.55 - 0.0037\ Q_f + 1.16 \times 10^{-7}\ Q_f^2$ over the range 85.0 to 283.2 m^3/sec and is essentially linear. The form of this relationship was dictated to a great extent by two data points, 1971 and 1975 (Fig. 38). His rough estimate of 3.0×10^5 fry entering Lake Washington in 1976 (i.e., brood year 1975) was substantially lower than the estimate obtained in the present study based on sampling data.

Miller's attempt to calibrate a Cedar River sockeye fish production model using curve 2 indicated that it dropped off too drastically as flood flows increased. Since curve 3 had been used by the Corps of Engineers (1974) in an earlier study, it was tried in the model. This curve gave good results in the model calibration and was therefore used by Miller (1976) in his final fish production model. It gave a reasonable representation of the relationship between flood flows and sockeye production on the Cedar River since the initiation of the run in the late 1930's and early 1940's.

The P/S ratio for brood year 1975 was recalculated in this study with the updated estimate. Thorne and Dawson (1977) estimated the 1975 year class of smolts in the lake at 1.14×10^6 to 1.25×10^6. However, since this estimate included sockeye smolts from sources other than the Cedar River as well as an increasing number of kokanee, it was not used. In order to make the recalculation, it was necessary to estimate the

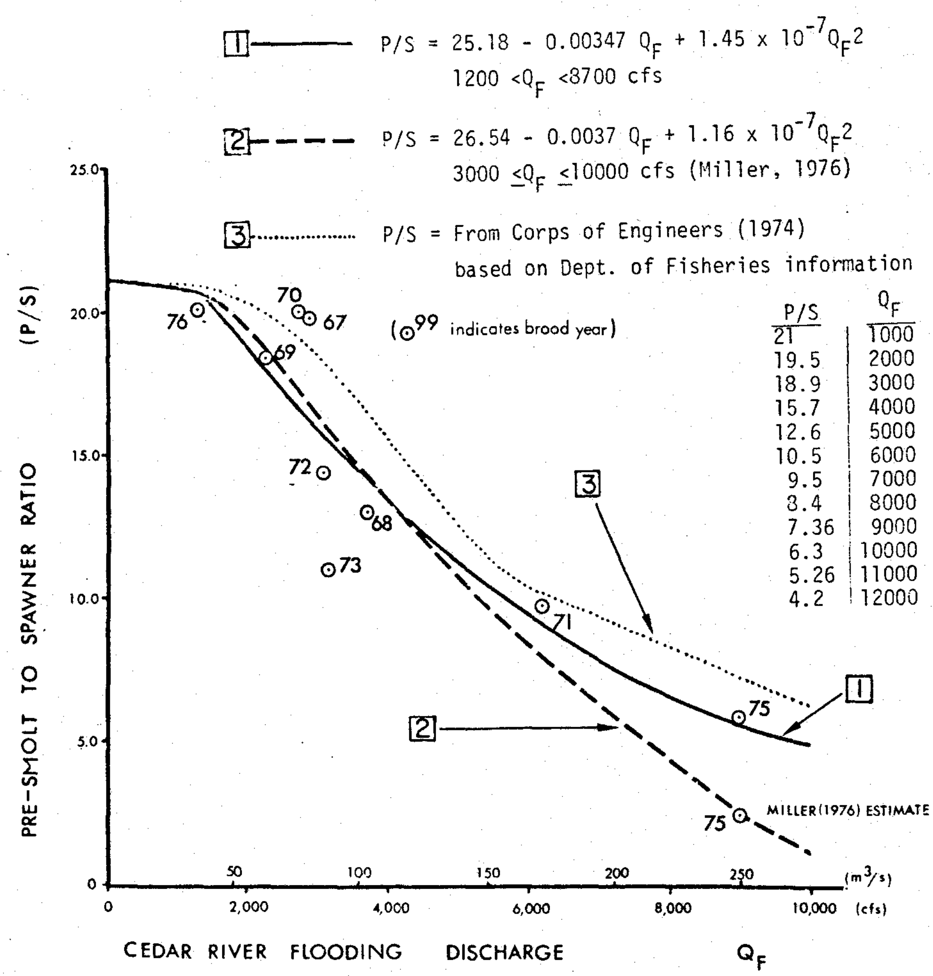


Fig. 38. Relationship between the instantaneous flood discharge at Renton (Q_f) during the sockeye egg incubation period and the presmolt to spawner ratio (P/S) for the years 1967-1976. A comparison with curves by Miller (1976) and Corps of Engineers (1974) is shown.

number of fish surviving to smolt. This was accomplished using the equations of Bryant (1976):

$$S = Je^{-mt}, \qquad (7)$$

where,

S = number of smolts,

J = number of juveniles in Lake Washington on July 1,

e = base of the natural logarithms,

m = the density-dependent monthly mortality rate calculated from equation (7),

t = number of months of lake residence,

$$m = (0.06245) + (0.00674)\ (J \times 10^{-6}). \qquad (8)$$

In order to calculate S, it was first necessary to estimate the number of fish surviving to July 1 (J). This was done using an equation similar to (7) which accounted for changing density resulting from monthly recruitment of emigrant fry. The number of fish surviving on month i + 1 was calculated by the following equation:

$$N_{(i+1)} = (E_i + n_i)\ e^{-mt}, \qquad (9)$$

where,

$N_{(i+1)}$ = number of fish surviving on month i + 1,

E_i = number of fish emigrating into Lake Washington on month i + 1,

n_i = number of fish surviving on month i which had previously emigrated,

m = mortality rate (*see* equation (8)),

t = number of months in lake prior to July 1.

An estimated 1.36×10^6 fry survived to July 1. A direct solution of equation (7) indicated that 6.66×10^5 smolts were produced from the 1975 brood year, representing a 5.8 P/S ratio.

In 1977, an estimated 22.8×10^6 fry entered Lake Washignton, with an estimated 10.8×10^6 juveniles surviving to July 1. An estimated 2.79×10^6 smolts will be produced, representing a 20.1 P/S ratio. This is similar to 3 other years with an instantaneous peak discharge less than 85.0 m^3/sec. Between 0 and about 28.3 m^3/sec a sharp increase in P/S ratio must occur, because at 0 discharge there cannot be any survival. Miller (1976) estimated the maximum P/S ratio to be 21.0.

The updated P/S ratios for 1975 and 1976 brood years are plotted in Fig. 38 as curve 1. Polynomial regression was used to estimate P/S = $f(Q_f)$. The relationship is almost linear over the range 40.0 to 225 m^3/sec. It is obvious, however, that once again the same two data points (1971 and 1975) played a significant role in determining the shape of the curve. Until the variation in P/S ratio for discharge above 200 m^3/sec is more accurately estimated, no definitive form can be ascribed to this relationship. It is interesting to note that this curve (1) approximates the general shape of curve 3 which Miller (1976) concluded best represents the sockeye production-flood flow relationship.

6.10 Fry Quality

The length frequency distribution of sockeye salmon fry sampled during the 1976 and 1977 fry emigration is given in Fig. 39. Over 80 percent of the fry ranged from 26 to 29 mm in length. In 1976, the mean lengths fluctuated between 26.6 and 27.8 mm until May 29, when larger fry were found in the samples (Table 17). The size increased rapidly and reached a mean length of 39.6 mm on June 28. The lengths after June 1 were significantly larger and differed from each other. A trend to smaller size was found at the end of April, and it continued throughout most of the remaining emigration period for fry less than 30 mm in length, which were considered as newly emerged. These accounted for approximately 95.3 percent of the total number of fry.

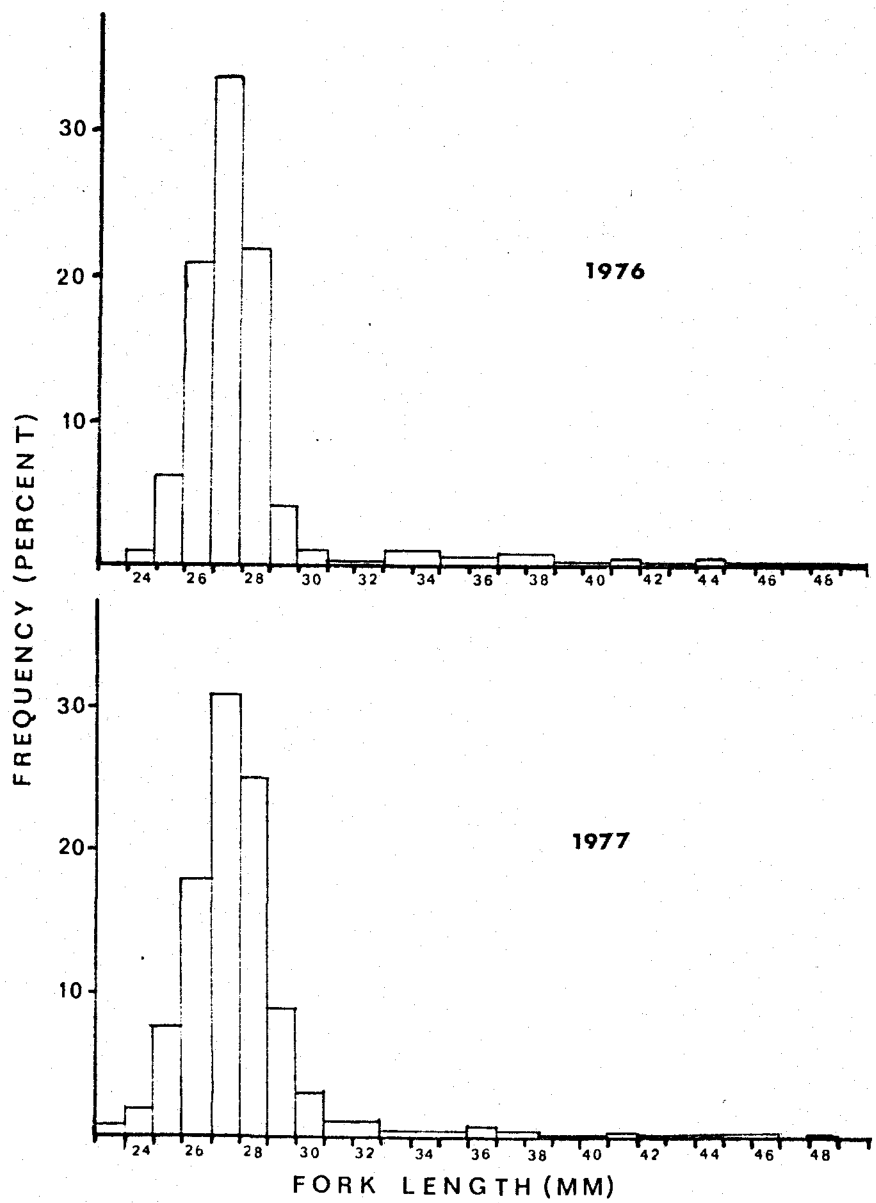


Fig. 39. Length frequency distribution of sockeye salmon fry in 1976 and 1977.

Table 17. Average length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for sockeye salmon fry sampled by fyke netting in 1976 and 1977.

	No.	Measured	Length (mm)		Weight (g)		Condition Factor		Percent of Complete Fusion	
Week	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977
12/4		6		24.7		.1417		.94		16.7
12/11		50		25.5		.1370		.81		32.0
12/18		50		27.3		.1748		.86		71.0
12/25		50		27.2		.1652		.82		94.0
1/1		50		27.0		.1556		.79		81.0
1/8		50		27.2		.1630		.81		73.0
1/15		50		27.8		.1614		.75		84.0
1/22		50		27.4		.1578		.77		70.0
1/29		50		27.6		.1746		.83		89.0
2/5	22	50	27.2	27.7	.1389	.1732	.69	.81	60.0	93.0
2/12	28	50	26.5	27.7	.1339	.1774	.72	.83	61.0	97.0
2/19	50	50	27.1	27.7	.1338	.1706	.67	.80	91.0	90.0
2/26		50		28.0		.1812		.83		95.0
3/5		50		27.8		.1710		.80		94.0
3/12	50	50	26.9	27.6	.1360	.1668	.70	.79	93.0	97.0
3/19	50	50	27.5	27.4	.1388	.1622	.67	.79	85.0	97.0
3/26	50	50	27.5	27.7	.1388	.1646	.67	.77	85.0	100.0
4/2	50	50	27.0	27.0	.1568	.1612	.80	.82	87.0	97.0
4/9	50	50	27.0	26.4	.1546	.1486	.79	.81	91.0	88.0
4/16	50	50	27.1	27.1	.1446	.1548	.73	.78	84.0	98.0
4/23	50	50	26.8	26.5	.1442	.1494	.74	.80	98.0	94.0
4/30	50	50	26.7	26.6	.1402	.1492	.74	.79	88.0	93.0
5/7	50	50	26.5	26.3	.1360	.1430	.73	.79	82.0	89.0
5/14		50		28.2		.1886		.84		94.0
5/21		50		28.0		.1682		.77		98.9
5/28	50	50	28.1	23.4	.1782	.1950	.80	.85	92.0	100.0
6/4	50	50	30.6	33.1	.3200	.4400	1.12	1.21	99.0	95.0
6/11	50	50	36.0	36.2	.5722	.5786	1.23	1.22	100.0	99.0
6/18		4		33.3		.4375		1.18		100.0
6/25	29		39.6		.7310		1.18		100.0	
	679	1310	28.57	27.86	.2118	.1969	0.81	0.85	87.3	86.9
t-test				.77*		.36*	.42*		.078*	

*Not significant at α = .05 level.

The mean weights of fry slowly increased, reached a peak on April 2, 1976, and then declined (Table 17). The weights at the end of the season indicated considerable growth had occurred in the river. Fry were significantly larger after June 1.

In 1977 the mean lengths of sockeye fry varied from 27.0 to 28.0 mm from December 18 to April 2 (Table 17). Fry in early December averaged shorter in length than during the main emigration period, but the differences were not significant. A trend of decreasing lengths for fry less than 30 mm was found after April 2. Significantly larger fry were again captured in June. They accounted for only 0.3 percent of the total number of fry.

In 1977 the weight generally increased from December through late February and declined through the middle of the emigration period followed by an increase near the end of the season (Table 17). Fry sampled in June were significantly heavier than those sampled earlier in the season. In 1977, except for 1 week the weights on comparable time periods were consistently, but not significantly, higher than in 1976.

The difference in robustness was also demonstrated by lower coefficients of condition in 1976. These ranged in 1976 between 0.67 and 0.80 for newly emergent fry, and from 1.12 to 1.23 for larger emigrants captured in June (Table 17). Prior to May 28, in 1977, condition coefficients varied from 0.75 to 0.94, and they were significantly higher than in 1976. For both years, fry in June had similar condition factors.

The degree of reabsorption of the yolk sac was recorded to determine seasonal changes and relationship with environmental factors. More fry contained visible yolk reserves in the beginning of both sampling seasons (Table 17). The degree of development advanced throughout the season. The proportion of "buttoned up" fry was not significantly different between 1976 and 1977.

The data from the egg incubation study at Landsburg are given in Table 18. These fry had emerged and were retained in the plastic freezer containers from which they were collected. No significant differences between these and naturally incubated fry were found.

Table 18. Fork length and blotted weight of the sockeye salmon fry collected from the gravel incubation boxes in 1977.

Date Spawned 1976	Date Collected 1977	Number Measured	Number Days	Fork Length	Blotted Weight	Condition Factor
9/17	1/23	57	128	27.6	0.1746	0.83
10/15	3/23	22	159	27.5	.1573	0.76
11/22	5/2	47	161	28.0	.1479	0.67

6.11 Sampling Mortality

In 1976, the mortality of fry resulting from netting and handling was measured on six occasions and varied from 3.4 to 10.5 percent with a mean of 7.0 percent (Table 19). A total of 23,287 fry were captured during the season, and an estimated 1,630 fry were killed during the sampling. This accounts for only about 0.001 percent of the total seasonal fry output.

Sampling mortality was determined 12 times in 1977 (Table 19). These varied widely from a low of 1.3 percent to 11.6 percent with a mean of 4.8 percent. This was considerably lower than in the previous year. An estimated 23,300 fry were killed from a total catch of 485,582 fry which represents a small proportion of the total estimated 23 million fry migration.

6.12 Artificial Production

The South Lake Washington Chapter of Northwest Steelheaders initiated a sockeye salmon enhancement program in 1975. That year most of the incubation facilities at Rock Creek (about RKm 26) were destroyed by the December flood. Starting on February 18, small numbers of fry were released into the Cedar River (Table 20). If a 50 percent mortality is assumed to occur during the downstream migration (Foerster 1968), these releases accounted for approximately 1.1 percent of the natural fry production in the Cedar River.

Egg incubation boxes were seeded with about 1 million eggs in 1976. A total of about 815,000 fry was released during the spring of 1977 (Table 20). Approximately 1.8 percent of the total fry output was produced artificially.

6.13 Incidental Species

Several other species of fish were captured incidental to sockeye fry sampling (Table 21). Longfin smelt (*Spirinchus thaleichthys*) were caught in large numbers during late February and early March 1976. This timing coincided with the peak spawning period of these fish (Moulton 1970). In 1977 longfin smelt were present in small numbers from December

Table 19. Number of fry killed during the fyke net sampling in 1976 and 1977.

Date	Number of Fry Killed	Total Sample	Percent
1976			
2/29	6	72	8.3
3/17	11	105	10.5
3/29	10	109	9.2
4/14	9	268	3.4
5/3	8	142	5.6
5/9	8	157	5.1
Mean			7.0
1977			
1/3	4	54	7.4
1/17	13	112	11.6
1/24	8	154	5.2
1/31	14	162	8.6
2/7	2	158	1.3
2/21	5	157	3.2
2/28	5	157	3.2
3/7	4	157	2.5
3/21	2	125	1.6
4/11	2	135	1.5
5/9	3	107	2.8
6/6	10	122	8.2
Mean			4.8

Table 20. Number of sockeye salmon fry released by Northwest Steelheaders. (Source, Northwest Steelheaders)

Date	1976 Daily	1976 Cumul.	1977 Daily	1977 Cumul.	Date	1977 Daily	1977 Cumul.
2/18	52	52			4/1	11686	575731
20	54	106			2	13189	588920
21					3	20368	609288
22	96	202			4	30049	639337
23	88	290			5	21869	661206
24	210	500			6	18197	679403
25	143	652	400	400	7	18030	706114
26	153	796	600	1000	8	8681	710010
27	190	986			9	3896	713773
28	153	1138			10	3763	718448
29	297	1436			11	4675	724625
3/1	444	1880			12	6177	733242
2	327	2207	1500	2500	13	8617	740254
3	477	2684	1823	4323	14	7012	744596
4	665	3349	600	4923	15	4342	750940
5	572	3921	1078	6001	16	6344	755448
6	816	4737			17	4508	760325
7	1629	6366	6141	12142	18	4877	764833
8	2516	8882	3200	15342	19	4508	770676
9	2920	11802	11718	27060	20	5843	778022
10	3117	14919	4294	31354	21	7346	784867
11	3230	18149	11294	42648	22	6845	799478
12	2243	20392	18200	60848	23	14611	805321
13	1690	22082	19000	29848	24	5843	809161
14	2213	24295	18988	98806	25	3840	810330
15	3855	26400	15675	114511	26	1169	811666
16	1464	29614	31123	145634	27	1336	812752
17	3005	32619	24617	170251	28	1086	813754
18	1967	34586	40888	211139	29	1002	814422
19	2288	36874	37647	248786	30	668	814839
20	1071	37945	43764	292550	5/1	417	815173
21	740	38685	30895	323445	2	334	815260
22	994	39679	33221	356666	3	87	815360
23	486	40165	60766	417432	4	100	815400
24	177	40342	28881	446313	5	40	815425
25	186	40528	23205	469518	6	25	
26	169	40697	16360	485878			
27	121	40818	25709	511587			
28	78	40996	13355	524942			
29			13689	538631			
30			8848	547479			
31			16566	564045			

Table 21. Weekly fyke net catch of incidental species in 1976 and 1977.

	Fry						Fingerling													
	Coho		Chinook		Steelhead		Steelhead		Coho		Chinook		Longfin Smelt		Threespine Stickleback		Lamprey		Cottids	
Date	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977	1976	1977
12/4				1						1				16						5
12/11				47						1				1						4
12/18				119										22		1		29		13
12/25				99										7						12
1/1				31				1		1				3		1				19
1/8				272						5				24		1		4		9
1/15				2043				1		6				95		2		13		34
1/22				296						3				155		3				14
1/29				499						1				83		1				10
2/5				526					1				448	611	2	1	2		16	7
2/12				535					1	1			9	202	1		1		4	1
2/19				569									9589	377	1	1			25	
2/26	1			796					2	3			14755	455	2	1		2	24	6
3/5	1			300									4488	687	1	1	1	2	20	5
3/12	2		7	79					2	2			1155	54			1	1	4	3
3/19			3	367									408	16	3		1		16	
3/26	6		21	339			1		3			1	112	11				1	32	
4/2				375						2		18	57	8	2	1		1	9	1
4/9				119								11	5	3	5		2		2	1
4/16			1	54						1		20	3	1	2	1			3	1
4/23				415		2		5		6		99	1	1		7		11	1	2
4/30		2		70		3		4				44	1		2			3	2	3
5/7				35		2		4	4	11		17		6	2	1				4
5/14	1	2		291		5		8	13	21		17			8		1	1	1	4
5/21		3		89			1	1	9	21		101			11		1	1	4	2
5/28	7			19					2	6		79			10					2
6/4	1			2		15		1		1		107			4	2	1	1	1	1
6/11	3				16	13			1	7	3	115			3		3	1	1	4
6/18					34		1			6					7		2		3	
6/25					7		1								1		1		1	
Total	22	7	32	8385	57	40	5	20	40	100	3	629	31031	2836	69	23	17	71	169	72

through late April. Chinook fry (*Oncorhynchus tshawytscha*) were the most abundant incidental species in 1977, but were practically absent the year before. Frequent catches of cottids (*Cottus* sp.), threespine stickleback (*Gasterosteus aculeatus*), and lampreys (*Lampetra* sp.) were also made. Juvenile coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Salmo gairdneri gairdneri*) were captured sporadically.

7.0 DISCUSSION

7.1 Water Quantity

The Washington State Department of Ecology (DOE) set a minimum streamflow operating curve for the Cedar River in 1971. According to this curve, the discharge is controlled to follow a stepwise increase beginning in mid-August at 2.1 m^3/sec and reaching a maximum level of 13.6 m^3/sec by mid-October. This level is maintained through June 30 and the discharge is again reduced to 2.1 m^3/sec by July 15. Stober and Graybill (1974) suggested a lower discharge regime based on actual measurements of spawning sockeye in the Cedar River. They proposed a gradual increase from 2.1 m^3/sec on August 20 to 7.1 m^3/sec (the peak spawning discharge for Cedar River sockeye salmon) by October 15. The peak spawning discharge is the minimum flow at which the maximum spawning area occurs. By linearly increasing the discharge during the spawning season, the maximum cumulative spawning area is made available to the fish. Furthermore, the available spawning area is maximized by timing the peak spawning discharge with the maximum number of spawners. After October 15, if additional water is available for fish, the discharge can be increased linearly to 14.2 m^3/sec to gain the remaining 20 percent of the spawnable area near the margins of the river channel.

Artificially high discharges occurred during August and early September of both 1975 and 1976 due to upstream maintenance requirements where it was necessary to reduce the level of Chester Morse reservoir. These discharges temporarily departed from the normal low flow for the period and stimulated an early migration of sockeye into the river. During the fall of 1975, the flow pattern generally followed the suggested maximizing regime from mid-September to late October and distributed spawners gradually from the midchannel to the peripheral areas of the river. However, the December 1975 flood (249.2 m^3/sec) and the recurring flood flows in January 1976 physically altered the river through scouring, transport, and deposition of the substrate. The most extensive shifting of the bed material occurred in the midchannel where the majority of the early spawners deposited eggs. After January 1976, the flow pattern declined because of drought conditions throughout the remainder of the 1976-1977 study period. The period from August 1976 through May 1977 was significant due to the consistent low flows which seemed to create ideal conditions for sockeye salmon production. The discharges maintained during the 1976 spawning season generally exceeded the suggested maximizing regime through low flow augmentation from upstream storage; however, a limited increase in discharge from mid-September to mid-December tended to spread some of the spawning fish laterally across the river channel. The river discharge during the spawning periods of both years was generally similar due to low flow augmentation; however, the contrast in flood discharge between the two incubation seasons served to present two extreme conditions during the course of this study.

7.2 Escapement and River Utilization

The escapements during the last 3 years (1974-1976) were similar to returns in 1964-1966 and 1970 when each was about 120,000 adults. Considerably higher escapements were observed in 1967-1969 and 1971-1973.

Large numbers of the early portion of the 1975 and 1976 runs entered the river earlier than usual due to the high artificial discharges during late August 1975 and early September 1976. The escapement patterns were similar in 1973, 1974, 1975 and during the latter part of 1976. A comparison of the cumulative percentage of the escapement with time for the years from 1972 to 1976 did not indicate any consistent shift in timing between years.

The spawning began in early September 1975 and 1976 on the upper river reaches. The late season utilization of the lower river noted in previous years (Stober and Graybill 1974) was observed again. However, the largest number of spawners utilized the upper reaches in 1975 and the middle reaches in 1976. The gradual increase in discharge and spawned area was accomplished in 1975 but discharge conditions were more uniform in 1976. In 1975, the area in the upper and lower thirds of the 27.8 km of river was more heavily spawned than the middle third, while the opposite was observed during the following year. Although the escapement increased by 22 percent from 1975 to 1976, the maximum instantaneous area utilized by spawners decreased by about 42 percent in

1976. This may have been due to the removal of desirable spawning gravel during the 1975 flood.

7.3 Egg/Alevin Density

The comparison of spawning reaches, selected because of opposing hydraulic characteristics, was made to determine if density-dependent mortality occurred due to superimposition of sockeye redds. The reaches either presented a static spawning area (Station 5) or an area which accumulated (Stations 1 and 2B) throughout the 12-week spawning season with associated increases in the discharge. Egg densities in the static area initially increased rapidly; however, the net gain decreased sharply by early October in 1976 and hydraulic sample densities remained constant. This indicated that late spawning sockeye females removed from the streambed as many eggs as were deposited (i.e. density-dependent mortality).

Spawning on the reaches where the area accumulated with increased discharge continued to add more eggs to the gravel throughout the season. Sample densities indicated that the actual average egg densities at these stations approached the expected potential densities. Spawners were able to distribute eggs over a larger spawning area at these stations. Compared with the curve derived by McNeil (1969) who studied pink and chum salmon spawning, the densities sampled for sockeye salmon were higher. Egg densities on the static area indicated that an asymptotic upper limit for this reach may have been attained during both years.

The egg densities observed on the two reach types studied indicated density-dependent mortality occurred on one due to redd superimposition while a desirable degree of egg deposition efficiency was achieved on the other. This occurred during 2 years of relatively moderate escapement. The high egg deposition efficiencies obtained where spawning area accumulated indicated that a management advantage can be achieved by increasing the discharge during the 3-month spawning season.

Although direct extrapolation of these results to all the spawning areas in the entire river is difficult, they do demonstrate the extremes occurring. Some degree of reduced efficiency must be tolerated on some part of the entire spawning area in the river in order to achieve maximum use and efficiency on the remaining areas. However, larger escapements than those observed in 1975 and 1976 could result in unacceptable density-dependent mortality on all reach types. An escapement goal should be established which attempts to achieve a reasonable degree of efficiency.

7.4 Ingravel Mortality

Changes in the proportions of dead/total ratios (M_r) gave clues to identify the possible causes of ingravel mortality and its timing. Survival of eggs and alevins remaining in the gravel is greatly influenced by the quality of the water. Environmental factors affecting mortality are discussed chronologically, according to the time of their possible effect during the incubation and preemergent periods.

Water temperature probably did not directly affect mortality during either year. Very little spawning was observed prior to decline of the temperature below 15.5° C. The low sample mortalities observed in the early spawning season provided evidence that the warmer temperatures were not detrimental to egg survival.

Both the proportionate frequencies and M_r ratios of sample egg/alevin data taken during the spawning season of 1976 agreed in that mortality began to increase in October, reaching the greatest dead egg density in mid-November. At this time, about 90 percent of all 1976 spawning had been completed. The most developed eggs had already reached the advanced prehatching stage. Some newly hatched alevins were collected in November. The timing of the prehatching stage with the significant increase in mortality may explain this change. Prior to hatching, the oxygen requirement of the sockeye embryo is known to increase due to the reduction of the density of the capillary network surrounding the yolk (Semko 1954).

The Cedar River experiences periods of high turbidity, especially during and after heavy rainfalls. Taylor Creek, a tributary of the Cedar River, is prone to mudslides which introduce sediments into the river below Chester Morse Reservoir. Erosion along the riverbanks was especially severe during the December 1975 flood, resulting in the deposition of new gravel bars in the middle and lower river. However, due to the large volume of the discharge, much of the deposition occurred out of the main channel which was severely scoured. Following the flood, sand and silt accumulation was heavy in the lateral parts of the streambed, where most remaining live eggs and alevins were collected, often under a thick layer of fines. Although the postflood M_r values calculated from the limited number of samples in 1976 ranged from 11 to 50 percent at both stations, it is probable that the latter value approached the total preemergent mortality rate which could have resulted due to entrapment of the emerging fry (Phillips 1965), lower oxygen supply due to reduced permeability of the gravel (Phillips and Campbell 1962) or the direct effects of fines on alevin respiration (Stuart 1953).

In addition to reduced survival, low oxygen concentration in the gravel has been shown to reduce fry size (Brannon 1965) and cause premature emergence (Phillips et al. 1975). Our data suggested that there was a higher percentage of complete fusion on comparable sample dates in 1977 than in 1976. Fyke netting in 1976 indicated fry were smaller than those during the subsequent low flow year when erosion and siltation were not as great. Siltation of redds in 1975-1976 could have caused the emergence of smaller fry.

The importance of predation on eggs and preemergent fry can be significant when bed materials are coarse enough to allow penetration of the substrate (Stuart 1953, Phillips and Claire 1966, and McNeil 1969). Although sculpins, stonefly larvae, leeches, and crayfish were prevalent in the hydraulic samples their importance in contributing to egg and alevin mortality was not determined in this investigation.

7.5 Flood Effects

Hydraulic sampling revealed the extent of the areas of Stations 1 and 5 affected by severe scouring during the flood of December 1975. Scouring began on the spawned area nearest the thalweg and moved laterally toward the river margins. A comparison of pre- and postflood hydraulic sample densities indicated that 96.6 and 50.6 percent of the total egg/alevins were lost due to the flood at Stations 1 and 5, respectively. Major mortality due to flood flows is not uncommon on salmon spawning grounds (McNeil 1966, Cederholm 1972). It is presumed that the eggs and alevins removed from the gravel by the high discharge did not survive.

Calculation of the presmolt to spawner ratio for brood years 1975 and 1976 and comparison to the Cedar River flood discharge each year indicated extreme differences in sockeye productivity. The 1975 flood resulted in the lowest P/S ratio (5.8) while the 1976 brood (P/S ratio = 20.2) was one of the most productive since 1967.

These data indicate the need for management alternatives to increase and maintain natural production at a more consistent level. A solution is to improve the upstream control of floods in order to reduce substrate scouring. Since the low flow maximizing regime during the spawning season places the early portion of the run near the middle of the channel, flood control would reduce the loss of these eggs and alevins. However, the alternate strategy of managing the water supply so as to distribute most spawners along the lateral margins of the river would: 1) minimize spawning area; 2) require an instream flow in excess of the natural seasonal low flow; and 3) increase density-dependent mortality on the early and middle portions of the run. To do this would suggest that the occurrence and magnitude of flooding is predictable every year in September.

7.6 Fry Development and Emigration

Observations on migratory behavior of sockeye salmon fry were important to ensure an efficient sampling design and method of estimation. The behavior during emergence and downstream migration was influenced by several factors (physiological readiness, light, temperature and river discharge) and can be summarized as follows: 1) fry are negatively phototactic and remained either in gravel or hidden in holding areas; and 2) with the onset of darkness those fry which were ready to emigrate emerged and actively swam with the current. Newly emerged fry rapidly left the spawning areas and entered the lake nursery. Quite often the emigration was probably completed in a single night, although the results indicated that this was not always the case. Increased diurnal emigration may have occurred during high turbidities as observed in February 1976. Coburn and McCart (1967) recorded increased sockeye fry output after the experimental addition of silt. Substantial daylight migration of pink and chum salmon fry in turbid streams was observed by Neave (1953). Generally, the peak of nightly downstream activity occurred from 2 to 5 hours after sunset. A similar nightly behavior pattern was observed by Byrne (1971) under experimental conditions.

Timing of emergence and the developmental stage at emigration has important consequences on survival. The embryos demonstrated a compensating mechanism in their rate of development in relation to water temperature. At warm water temperatures development was accelerated and more TU's were required. This adjusted the timing of the emergence to better coincide with optimum environmental conditions. The eggs spawned in September accumulated about 120 TU's more to yolk absorption than those in November. All fry captured at the mouth of the river were not "buttoned-up," demonstrating the flexibility of the emergence time. Heard (1964) reported that the emergence from single redds lasted from 37 to 48 days in Alaska. Such variability may provide greater run stability by assuring that some fry will encounter favorable survival conditions. Early emigrants in winter may encounter a reduced food supply and consequently experience higher mortality than later emerging fry in the Cedar River. Downstream fry migrations occurred on days with temperatures as low as 2.0° C and as high as 15.5° C.

Large day-to-day fluctuations in fry abundance at the sampling station were influenced by several environmental factors. Fry counts often increased with an increase in discharge or temperature followed by a decline in numbers even though the environmental factors remained high. Those fry which were ready to emigrate did so during the first favorable nights. No single environmental factor could be correlated with the daily emigration rate over the entire season since confounding occurred between parameters and the availability of fry. Water temperature was a significant trigger for emergence during the early emigration. Almost every peak in discharge and turbidity coincided with a peak in emigration, but the significance of single factors was masked. McCart (1967) found that the periodicity of sockeye fry emigration was most closely related to total river discharge.

7.7 Fry Quality and Survival

The size of the fry at emergence is an important factor in their overall ability to survive. Predator selectivity studies by Bams (1967) and Beall (1972) showed that fry vulnerability was directly correlated with length and stage of development. The fry in 1976 had poorer condition factors than fry in 1977. The small mean size of later emergent fry may have resulted because a larger proportion of the production came from late spawners in the lower river reaches where the amount of fines in the gravel seemed greater. A small number of fry attained growth in the river before emigrating in late May and June. Probably, the main source of these larger fry was a 2.7-ha pond at RKm 10.3, where diving by Jeff Neuner (personal communication) revealed large numbers of fry. Burgner (1962) and Burgner and Green (1963) reported holdover fry in the Wood River systems. In other systems their occurrence was rare (McCart 1967).

Foerster (1968) reported survival rates ranging from 1.8 to 19.3 percent (mean = 10.6 percent) for data collected from six river systems in British Columbia and the Soviet Union. The 1975 year class experienced excessive mortality due to flooding with a survival rate of only 0.81 percent.

Comparison of the expected and observed number of sockeye fry during both years indicated poor survival and production from the early portion of the run. Survival of the 1975 brood year was reduced by the flood which probably had a greater impact on the eggs and alevins from the early spawners. Emigration of the survivors may also have been delayed due to a reduction of dissolved oxygen concentration in the gravel. The eggs surviving the flood had been deposited near the riverbanks where low water velocity, silt and sandy bottom substrate could have resulted in poor intragravel flow. Brannon (1965) and Mead and Woodall (1968) found considerable delay in emergence dates due to the reduction in dissolved oxygen concentrations in the gravel.

A good agreement in timing between the expected and observed fry emigration was found in 1977. The size of the peaks differed, especially during the early emigration period, indicating a substantially reduced number of fry were observed than expected during the early portion of the season. This suggested that other factors in addition to flooding may be acting to reduce survival of the progeny from the early spawners.

McNeil (1966) found that during strong freshets, the egg losses often exceeded 50 percent, and on one occasion exceeded 90 percent. Big Qualicum Creek in British Columbia averaged 11.2 percent survival for chum fry during 4 years under natural stream conditions. After the discharge was controlled, the survival averaged 24.9 percent during subsequent years (Lister and Walker 1966). A similar increase in survival may be expected in the Cedar River; however, despite a lack of flooding during the incubation period of the 1976 brood year, the survival increased to only 8.1 percent. Such a low survival rate associated with ideal environmental conditions indicates that additional reasons for such a response need exploration. The decline of 42 percent in the total instantaneous area spawned in the river channel between 1975 and 1976 indicated that the 1975 flood had a sustained effect by reduction of the spawning habitat. In addition the 1976 escapement increased by 22 percent which resulted in a higher overall spawning ground density. This may have increased the superimposition of redds and resulted in a higher density-dependent mortality of the eggs deposited early in the 1976 spawning season. Similar observations on other populations have been made by Schroeder (1973) who observed that the loss of previously buried eggs increased proportionally with the overall density. Hunter (1959) and McNeil (1969) found an inverse relationship between numbers of pink and chum salmon eggs deposited and the percentage survival of eggs to emergent fry. Additional monitoring to determine the full extent of density-dependent mortality on the Cedar River sockeye salmon at higher population densities should be conducted in order to optimize the management needed to achieve the maximum annual production of fry.

8.0 SUMMARY AND CONCLUSIONS

The effect of instream flow level on the reproductive efficiency of sockeye salmon in the Cedar River was investigated during 2 years (1975-1977). The factors controlling reproduction and early development included the effects of augmented low flows, uncontrolled floods and density-dependent mortality. The river discharge during the spawning periods of both years generally increased during part of each season. A controlled increasing discharge regime based on the spawning depth and velocity criteria of sockeye salmon was attempted to maximize spawning area by laterally shifting the spawners in the river channel. The effectiveness of such an instream flow management strategy was tested during the extended spawning season in the Cedar River. The incubation period of the 1975 brood year was affected by the most extreme flood (249.2 m^3/sec) recorded on the river. This contrasted with the comparable period in 1976-1977 which was characterized by a prolonged drought. The contrast in flood discharge between the two egg incubation seasons presented extreme conditions during the course of this study.

Hydraulic and spawner surveys were conducted at several discharges throughout the spawning season on 11 reaches in the river. Weekly float surveys were conducted to estimate the total area spawned in the river. Hydraulic egg/alevin samples were taken to determine density and survival during the spawning and preemergent periods. Two types of spawning reaches were sampled to determine if density-dependent mortality occurred due to superimposition of sockeye redds. The reaches either presented a static spawning area or an area which accumulated with associated increases in the discharge throughout the 12-week spawning season. Sample egg/alevin densities were compared to potential densities based on redd counts. Production estimates of fry were made during both years from fyke net samples taken near the mouth of the river.

The maximum instantaneous area spawned was observed to decrease by about 42 percent from 1975 to 1976 while the escapement increased by about 22 percent from 114,100 in 1975 to 138,949 in 1976. The decline in the area spawned in 1976 probably reflects the sustained impact of the December 1975 flood which removed or redistributed most of the desirable spawning substrate in the river channel.

The egg densities observed on the two reach types studied indicated density-dependent mortality occurred on the static spawning area due to redd superimposition. Only about 50 percent of the potential eggs were deposited. A high egg deposition efficiency of about 80-100 percent was achieved on the reaches where the spawning area accumulated with an increase in discharge. This occurred during 2 years of relatively moderate escapement. The high egg deposition efficiencies obtained on the latter reaches indicated that a management advantage can be achieved by increasing the discharge during the 3-month spawning season. Although some degree of reduced efficiency must be tolerated on a portion of the total spawning area in the river, escapements larger than those observed during this study could result in unacceptable density-dependent mortality on all reach types.

Several environmental factors affecting ingravel mortality were reviewed to determine the possible effects during incubation and preemergent periods. Water temperature had no observed effect on egg or fry mortality. Both proportionate frequencies and dead-to-total ratios of sample egg/alevin data taken during the 1976 spawning season agreed in that mortality began to increase in October and reached the greatest dead egg density in mid-November. This increase in mortality occurred with the timing of the prehatching stage. Following the December 1975 flood, sand and silt accumulation was heavy in the lateral parts of the channel where most remaining live eggs and alevins were collected, often under a thick layer of fines. Transport and deposition of silt and sand during and following the flood is suspected of reducing survival.

Flood effects on eggs and alevins were obviously due to the extensive scouring of the spawning reaches which drastically reduced survival of the eggs/alevins by 50.6 and 96.6 percent. Scouring began on the spawned areas nearest the thalweg and moved laterally toward the river margins. Calculations of the presmolt-to-spawner ratio for brood years 1975 and 1976 indicated extreme differences in sockeye productivity. The P/S ratio in 1975 was 5.8, while that for 1976 was 20.2, which bracketed the extremes thus far observed since 1967. These data indicated the need for management alternatives to increase and maintain natural production at a more consistent level. The control of flooding would reduce the large losses observed. The condition factors of the fry in 1976 following the flood were lower than for fry produced in 1977 under ideal low flow conditions.

No single environmental factor could be correlated with the daily fry emigration rate over the entire season; however, increase in water temperature, discharge and turbidity appeared to stimulate emigration at certain times. The date when 50 percent of the emigration was complete varied by 1 month from April 21, in 1976, to March 21, in 1977.

In 1976 a total of 51 sampling nights was distributed throughout the 5-month emigration period. The 1977 season involved 70 sampling nights distributed over a period of 6.5 months. The total estimates of downstream migrants in 1976 and 1977 were 1.76×10^6 and 22.8×10^6 fry, respectively. Egg to fry survival was 0.81 and 8.1 percent in 1976 and 1977, respectively. Success of the early segment of the spawning run (August-September) during both years was lowest while mid (October) and late (November-December) season spawners produced the largest number of fry.

These studies indicate that the low flow maximizing regime previously suggested by Stober and Graybill (1974) for the Cedar River increases the total spawning area and thus reduces the density-dependent mortality due to redd superimposition. Density-dependent mortality was found to occur on a spawning area of static size at the moderate escapements observed. The survival rate of the 1976 brood year which occurred under the augmented low flow conditions during 1976-1977 was lower than expected compared to literature values from streams with controlled and uncontrolled discharges. This may have been due to the sustained loss of spawning substrate which occurred during the 1975 flood, coupled with the 22 percent increase in escapement in 1976. This probably increased the density-dependent mortality in 1976 due to redd superimposition especially on the early portion of the escapement. Consideration should be given to reductions in spawning habitat following major floods. An escapement goal for the Cedar River should be established which attempts to achieve a reasonable degree of egg deposition efficiency in the spawning habitat available. The results of this study should find application on other salmon streams affected by hydroelectric or diversion projects where instream flow can be managed to maximize spawning area and thus benefit fish production.

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