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PRESPAWNING MORTALITY AND THE REPRODUCTIVE EFFICIENCY OF CEDAR RIVER SOCKEYE SALMON

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 ABSTRACT

An escapement of 410,000 sockeye salmon was monitored during the fall of 1977 in the Cedar River. A large prespawning mortality apparently due to infestation of the fish with the parasitic copepod, *Salmincola*, was observed. This resulted in an estimated differential mortality of about 119,813 females and an effective survival of 117,987 females. The total maximum effective escapement was estimated at 290,187 sockeye.

The amount of area spawned in the 28.8 km of river below Landsburg remained approximately the same in 1976 and 1977 at 60,000 m^2, while the total escapement increased about three times. This strongly indicated a sustained reduction in the spawning habitat following a severe (249.3 m^3/sec) December 1975 flood. Reduction of the spawning habitat as a result of major floods may necessitate an adjustment in the escapement goal.

Extensive mass spawning and a large prespawning mortality prevented reliable estimates of the potential egg densities on the spawning reaches where hydraulic egg samples were collected. For these reasons the efficiency of egg deposition could not be adequately determined. Intragravel mortality occurred at similar times and levels as found during the 1976 spawning season. Flood losses of 49 and 86 percent of the egg-alevins were found on two reaches following a discharge of 116 m^3/s in December 1977.

Key words: prespawning mortality, sockeye salmon, flood effects, egg densities, hydraulic samples, spawning habitat, environmental effects, fish management, density-dependent mortality, instream flow.

2.0 ACKNOWLEDGMENTS

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3.0 INTRODUCTION

The freshwater production of Lake Washington sockeye salmon is largely controlled by the survival of eggs and alevins in the Cedar River. The effects of river discharge on spawning area utilization was determined by Stober and Graybill (1974) following the methods of Collings et al. (1972). Miller (1976) investigated the effects of flood discharges on sockeye presmolt production, while the biological production was modelled by both Miller (1976) and Bryant (1976). These studies have indicated a need to investigate an additional factor which is the control of sockeye fry production by density-dependent mortality (Stober et al. 1978) which can result from the superimposition of redds on the spawning beds. This most recent study was extended to the 1977 spawning season in an effort to obtain data on the largest escapement to occur in the Cedar River. Additional funding was anticipated to determine the production of fry resulting from this brood year; however, none was forthcoming.

This report presents and interprets the data collected on (1) the river discharge during the spawning season; (2) the spawner distribution, abundance, redd density and timing of the escapement; (3) prespawning mortality estimates and (4) egg-alevin densities and survival to the end of the spawning season. The techniques applied in this monitoring study were patterned after those which had been utilized during the previous two-year study (Stober et al. 1978). The size of the 1977 escapement, prespawning mortality and large degree of mass spawning complicated interpretation of results and served to point out difficulties which require consideration during future studies of similarly affected spawning runs.

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.

Twelve 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 1A to 11 were located at RKm 31.8, 31.6, 28.0, 25.3, 22.0, 21.6, 20.9, 20.1, 18.5, 10.8, 8.5, 2.4, respectively (Fig. 1). All reaches were identical to those of previous investigations by Stober, Narita and Hamalainen (1978), with the following exceptions. Stations 1A, located 0.2 km above Station 1 at RKm 31.8 and Station 9A, located 2.3 km above Station 10 at RKm 10.8 were added. Station 9, altered by the December 1975 flood received only limited use by spawning sockeye during 1976 and was discontinued as a study reach. The effects of instream flow and spawner density on egg-alevin density and survival were intensively studied at Stations 1A, 2B and 5.

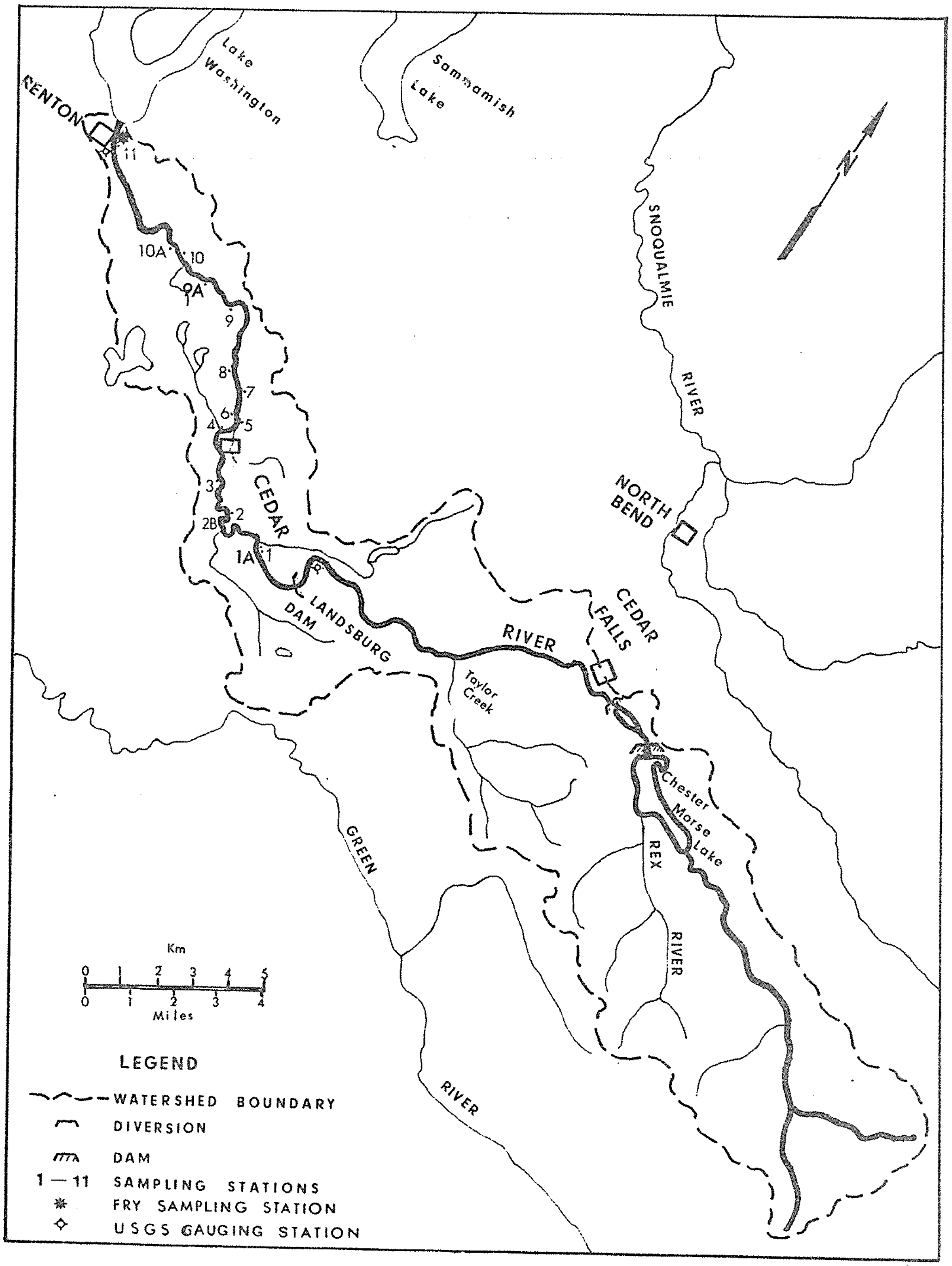

Fig. 1. Map of Cedar River watershed, showing location of study reaches, stream gauges and fry sampling station.

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 thirty 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 at a low discharge level early in the fall spawning season at each of the study reaches. Additional surveys were conducted later in the season at mid- and high-level discharges at the egg-alevin sampling Stations 1A, 2B and 5, and at Station 9A, which lacked previous hydraulic data.

5.2 Spawner Counts

The escapement of spawning sockeye to the Cedar River was estimated, as in the past, by the Washington Department of Fisheries (WDF) from tower counts made at RKm 8.5.

The distribution and abundance of spawning sockeye in the Cedar River were monitored in 1977 for comparison with previous years (Stober and Graybill 1974, Stober 1975, Stober et al. 1978). Active spawners within each of the twelve reaches were counted at 7-day intervals, which assumed a sockeye redd life of 7.0 days (Fraser 1970).

The number and location of redds which could be identified at weekly intervals on each reach were mapped using plane table methods. During 1977, mass spawning occurred on most of the reaches surveyed, in which case the periphery of the mass-spawned area and the wetted perimeter of the reach was mapped. The area of mass spawning and the total wetted area were determined by planimeter measurement of the plane table maps. Mass spawning resulted when large numbers of fish spawned in close proximity, superimposing redds and making individual redd identification difficult.

5.3 Prespawning Mortality

Extensive prespawning mortalities of sockeye salmon held in a fenced side channel at the site of the WDF weir on the lower river prompted the examination of carcasses at each of the twelve study reaches for similar prespawning losses. Fresh female sockeye carcasses were collected at weekly intervals from October 6 to November 11, 1977. The number of eggs retained in each fish was determined volumetrically. Fork length of each fish was measured and recorded.

5.4 Float Surveys

The area spawned in the 28.8 km (RKm 34.8 to 6.0) of river surveyed below Landsburg was outlined during weekly float trips on photocopies of aerial photographs of the river taken in August 1976. The lower 6.0 km of the river was sparsely spawned and therefore not included. The surveyed portion of the river included Stations 1A-10 and was divided into three approximately equal segments. The upper section extended from RKm 34.8 to 23.8 and included Stations 1A-3, the middle section extended from RKm 23.8 to 15.3 and included Stations 4-8A, and the lower section extended from RKm 15.3 to 6.0 and included Stations 9A-10. Landmarks (i.e., trees, logs, boulders, etc.) served as reference points in outlining actual spawning areas in the river channel. The area spawned each week was determined from the photocopy by using a "square" grid (each square = 10 mm^2) method.

5.5 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 1A, 2B and 5 from September to December 1977. The three reaches were chosen for study because they were well-utilized by sockeye spawners and because of contrasting physical and hydraulic characteristics. Stations 2B and 5 had previously been sampled during 1975 and 1976.

Egg-alevin sampling during each series was conducted along four transects at Stations 1A 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 the season. Samples were collected at 0.76-m intervals along each transect through the observed spawned area using a hydraulic sampler as described by McNeil (1964). Additional samples were taken in 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. Samples beyond the observed spawned area which contained no eggs-alevins were excluded in the calculation of sample densities. Similarly, samples producing no eggs-alevins and located in pockets of unspawned areas (i.e., no observed spawning within a 0.76-m radius) inside of a general spawned area were also excluded. Sampling efficiency was determined previously to be about 90 percent (Stober et al. 1978).

The frequency distributions of the number of eggs per sample were calculated for Stations 1A, 2B and 5 after the various sampling periods for each station had been combined. This analysis was conducted to determine if differences in frequency distribution would reflect the contrasting substrate and hydraulic characteristics of the three stations.

5.6 Potential Egg Densities

The expected potential egg densities in the gravel were calculated by estimating the number of contributing female spawners at each of the sampling stations from spawner counts. Mass spawning occurred at each station during the middle of the spawning season which prevented accurate enumeration of redds. We, therefore, relied on redd counts during the early and late spawning season at each station and estimated the number of spawning females during the middle of the season in two ways. The first estimate was made by applying the weekly variable sex ratios derived from estimates of the prespawning mortality to the weekly spawner counts. A variable sex ratio due to a differential prespawning mortality in the females was found. The second estimate was obtained by assuming equal prespawning mortality occurred in both sexes and therefore did not alter and assumed original sex ratio of 58 percent females-to-42 percent males. It was felt that neither method resulted in a reliable estimate of the potential egg densities on any reach, but it was the best which could be achieved in the absence of complete redd counts throughout the entire season or accurate weekly sex ratios of live and dead fish on the reaches. In addition, it is unknown if the redd life became less than seven days due to the high population density in 1977. If this were to occur, it would require observation on shorter time intervals.

Maps of redds and mass-spawned areas made at weekly intervals were utilized to determine the area spawned. A redd was assumed to be oval in shape and to include an area of 1.8 m^2 (Burner 1951). Similar redd area values were obtained by measuring a limited number of redds in the Cedar River. 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 totalled, except when mass spawning occurred. Overlapping areas were measured only once. Mass-spawned areas were outlined and the areas were determined with a planimeter. Areas not previously spawned were measured weekly and added to the cumulative total area spawned. During periods of mass spawning, the number of redds was calculated from the female spawner estimates, assuming one female corresponded to one redd. The value used for average potential egg deposition per female was 3,500 eggs (Heiser 1969, Bryant 1976, Allen and Cowan, personal communication). This value allowed for the normal amount of egg retention experienced during previous years.

5.7 Egg-Alevin Classification

Eggs and alevins from each hydraulic sample were 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 transparant 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. Broken shells or shell fragments could not be classified as dead with certainty, and therefore were not included in counts.

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.

5.8 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) and Stober et al. (1978) in the analysis of 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-alevins, live or dead, would not decrease.

b) The proportion of samples, including any live eggs-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-alevins at all; 2) no live eggs-alevins; and 3) no dead eggs-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-alevins have been removed from the gravel. During the September-December spawning period, this removal is assumed to represent mortality of eggs-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-alevins, and that a greater proportion of the samples collected on later dates did include dead eggs-alevins, indicating mortality had occurred.

Samples with only one egg-alevin were jointly classified with points which were totally devoid of eggs-alevins. The choice to categorize samples with single specimens was arbitrary. Preflood sampling sessions at Stations 1A and 2B were tested separately and in combination with postflood samples. Postflood samples could not be obtained at Station 5, due to extreme gravel deposition.

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 at each station. The pre- and postflood data were similarly analyzed for Stations 1A and 2B to detect significant mortality following the completion of egg deposition.

Periods during which mortality levels had changed were determined by setting 95 percent confidence limits to the number of samples containing zero or one dead eggs-alevins per .046 m^2. The following equation was utilized in setting 95 percent confidence limits to the number of samples with zero or one dead egg-alevins 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.

5.9 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-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.

The average dead-to-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 egg-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-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-to-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 ten 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 13 percent, the efficiency of equal weighting was about 95 percent. Therefore, McNeil assigned equal weight to all dead-to-total fractions of samples with ten or more total eggs-alevins.

The percentage of binomial variation for Stations 1A, 2B and 5 varied from 3 to 11 percent when this procedure was employed. These percentages corresponded to an efficiency at weighting of greater than 95 percent, which justified the calculation of the mortality ratio, M_r.

6.0 Results

6.1 Hydraulic Analysis

The hydraulic characteristics of Stations 1A, 2B, 5 and 9A (Fig. 2) 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 1A, 2B and 9A were characterized by a gradually sloping gravel bar which provided new spawnable area during the spawning season with increasing discharge. In contrast, the spawning area at Station 5 was relatively uniform in depth with a nearly constant area spawned throughout the season.

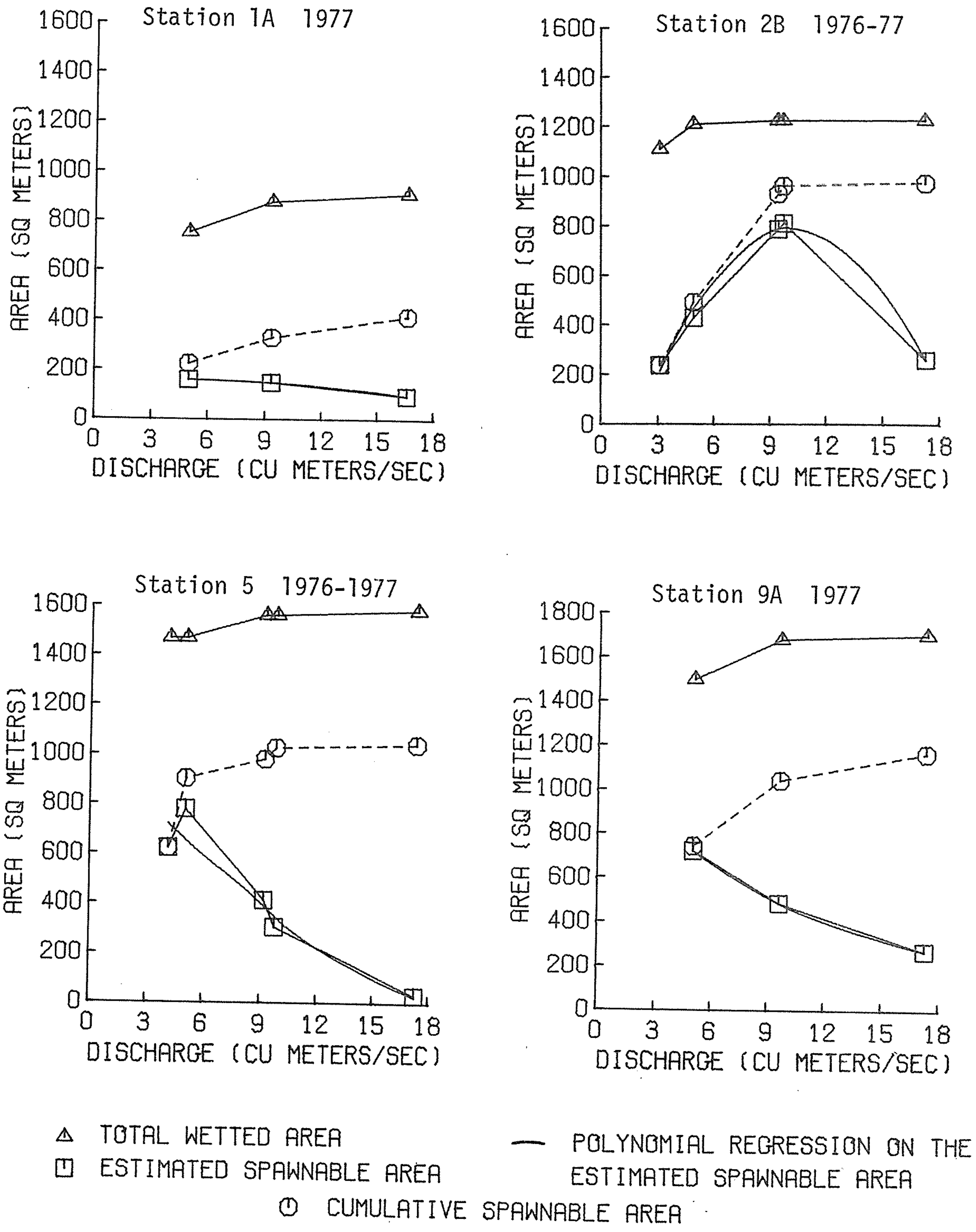

Fig. 2. Relationship between estimated spawnable area (80% depth and velocity ranges), polynomial regression on the estimated spawnable area, cumulative spawnable area, and total wetted area for Cedar River sockeye salmon at reaches 1A and 9A in 1977 and reaches 2B and 5 in 1976-1977.

6.2 Water Quantity and Quality

A hydrograph of the river discharge recorded at the USGS gauging station at Renton is shown for the period July through December 1977 (Fig. 3). Mean daily discharges showed a gradual increase during the fall spawning season ranging from 2.1 m^3/s in late August to 11 m^3/s on November 1. The discharge was held below the DOE operating curve due to an extended drought which preceded the spawning season. The drought began to subside in late August 1977 and some increase in upstream storage began. By late November, following an early snowfall and melt, the discharge increased substantially resulting in a flood (peak discharge 115.5 m^3/sec) which was sustained through mid-December. Severe scouring and redeposition of the substrate caused moderate physical alterations of the river channel.

The mean daily water temperatures recorded at the Renton gauge reached a high of 23.8°C in August, at a time of minimum river flow and maximum summer air temperature. Beginning in mid-August, temperatures declined steadily throughout the spawning season, with maximum and minimum values of 15.3 and 4.0°C, respectively.

6.3 Escapement

6.3.1 Tower Counts

The total escapement estimates presented in Fig. 4 are those of the WDF as revised by Ames through 1976 and Egan in 1977. The total escapement to the Cedar River in 1977 was estimated from tower counts at 410,000 sockeye salmon, the largest total thus far recorded. Daily counts of migrating adult sockeye by WDF from a tower located at RKm 8.5 are shown in Fig. 5. On August 31, 1977, prior to the initiation of tower monitoring, WDF conducted a float survey on the river from Landsburg to the tower site and recorded an early escapement of 51,164 sockeye salmon, the largest early escapement thus far recorded.

The tower counts from September through October were characterized by a series of random peaks, although a noticeable decrease in the escapement was observed in early October. Approximately 50 percent of the escapement had entered the river by October 11 (Fig. 6). Counts were discontinued by WDF on November 23, 1977, because of flooding.

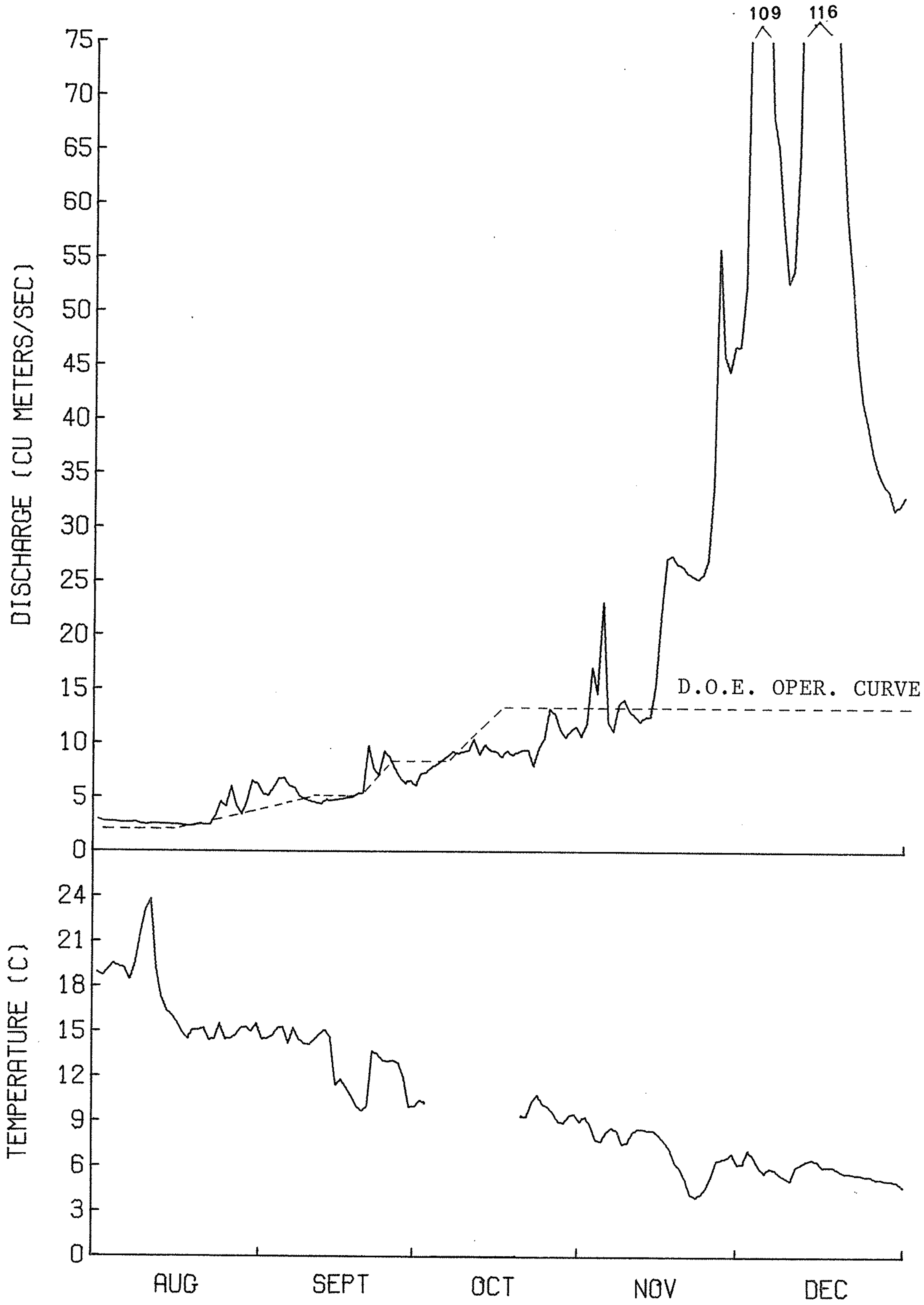

Fig. 3. Daily discharge, DOE operating curve and temperature at USGS Renton gauge from August through December 1977. (Source: U.S. Geological Survey).

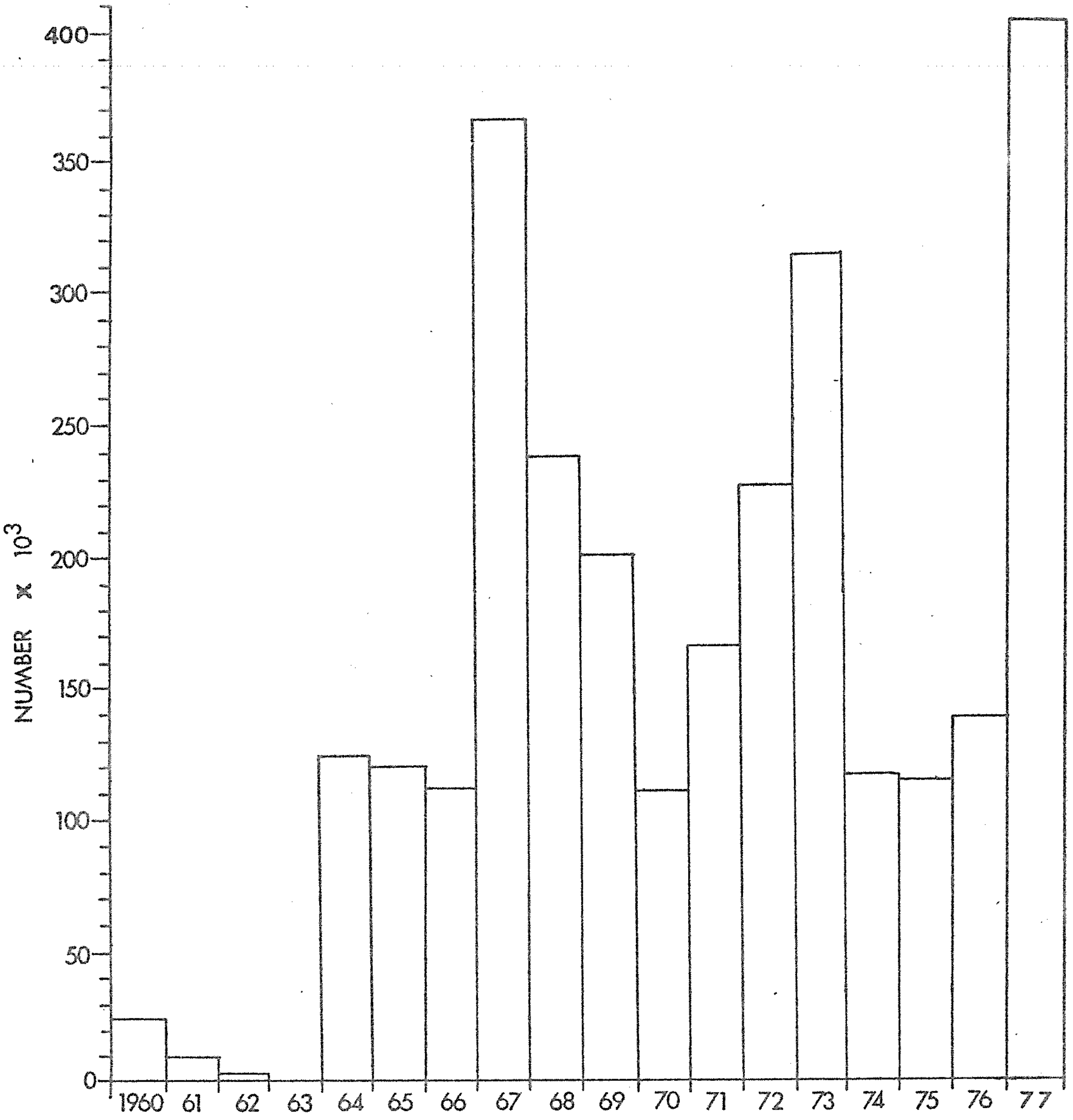

Fig. 4. Revised Cedar River sockeye salmon escapements 1960-1977, estimated by Ames (WDF, unpublished).

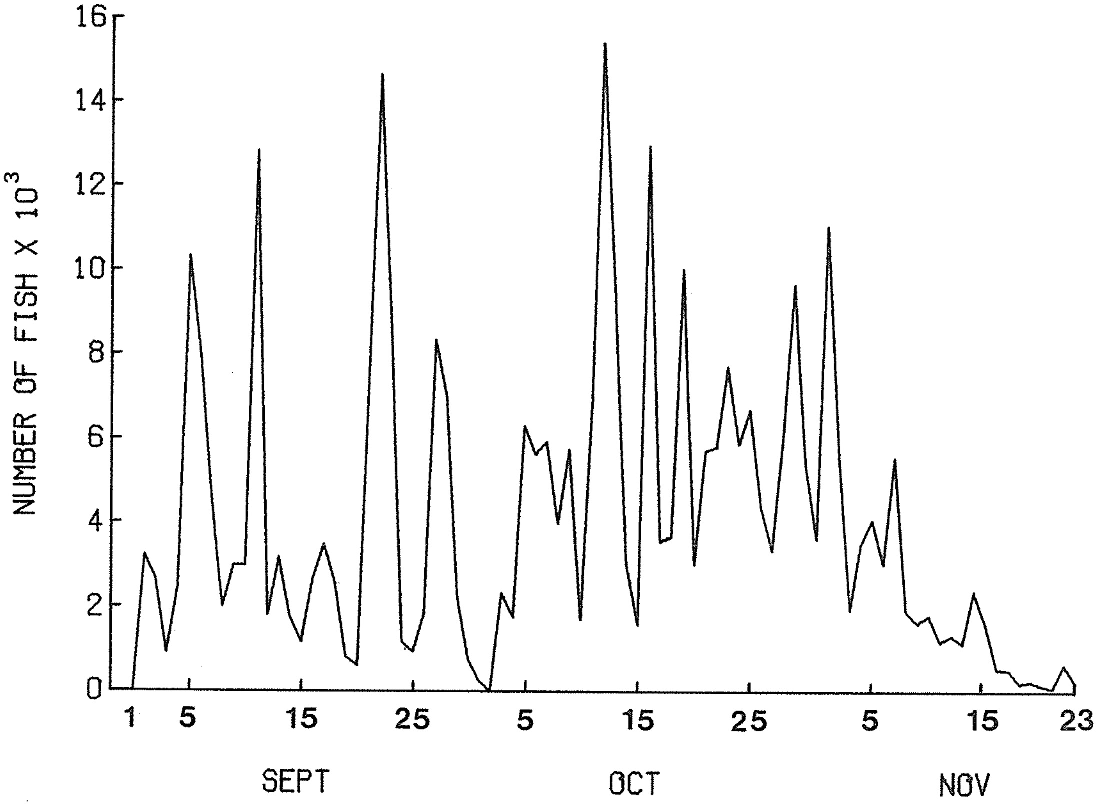

Fig. 5. Sockeye salmon tower counts, Cedar River, 1977. (Source: WDF).

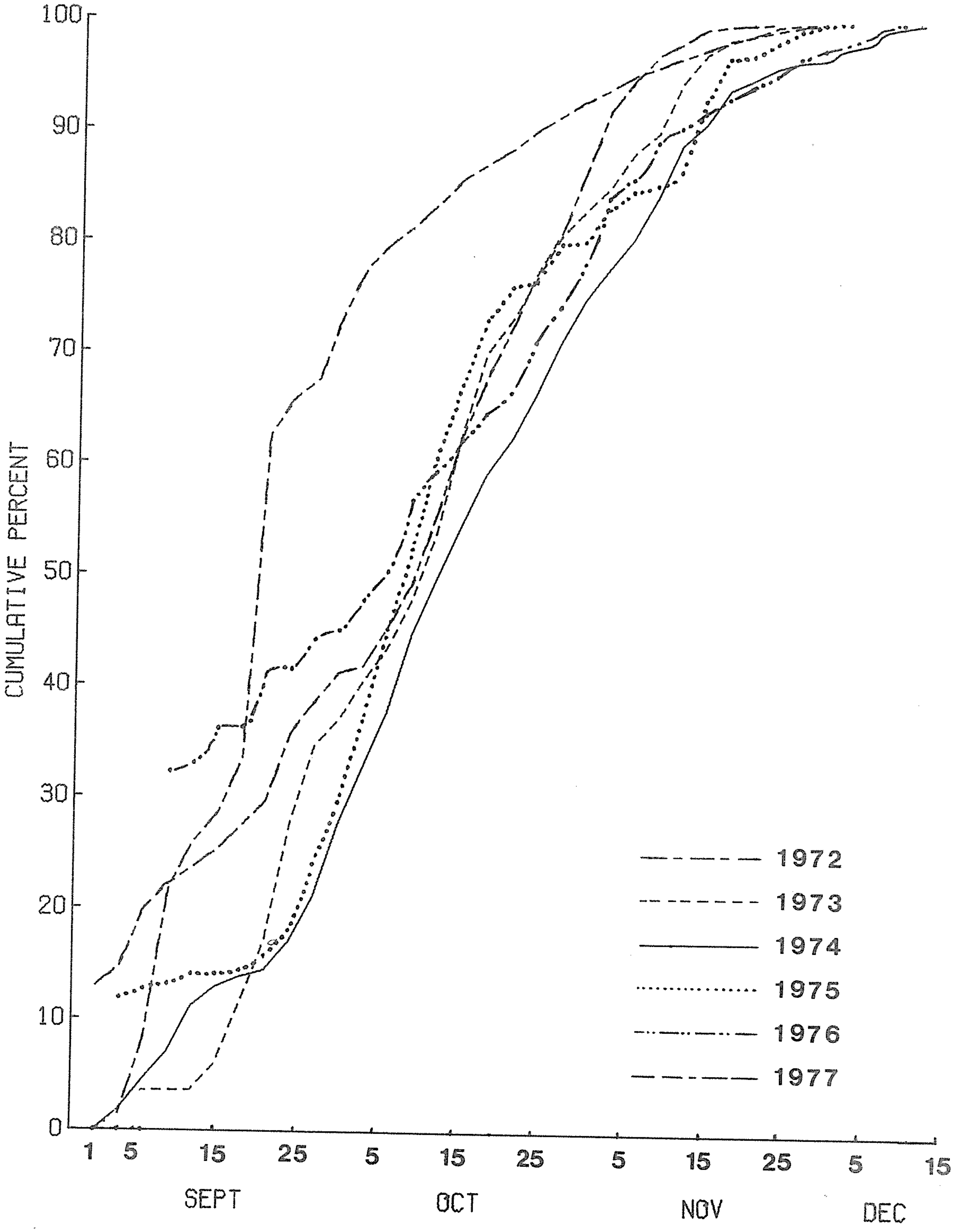

Fig. 6. Cumulative percentage of the tower counts by date for the Cedar River sockeye salmon escapement, 1972-1977. (Source: WDF).

6.3.2 Reach Counts

The total number of spawners observed on each study reach is presented in Fig. 7 and 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 moderate tendency for higher numbers of spawners in the upper river; however, Stations 1A and 9A had the highest individual totals. The number of sockeye spawning each week was combined by Station (1A-3, 4-8A, 9A-11) to represent the upper, middle and lower sections of the river below Landsburg (Fig. 8). Spawning activity was greatest in the upper third of the river followed by the middle and lower thirds, respectively. The upper river counts peaked in early October, the middle river in late October, and the lower river in early November. The total of weekly counts for all stations approached a maximum level in early October, which was sustained through four weeks, before declining in November.

6.3.3 Float Surveys

The area spawned each week in the 28.8 km (RKm 34.8 to 6.0) of river surveyed below Landsburg is presented in Fig. 9. The surveyed portion of the river included Stations 1A-10 (RKm 34.8 to 6.0) and was divided into three approximately equal segments, with Stations 1A-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 section (RKm 15.3 to 6.0). The maximum area spawned in the upper section occurred in late September at 31,005 m^2, while the middle section reached a maximum by late October, at about 29,612 m^2. The maximum area spawned in the lower section occurred around November 1, at 10,824 m^2. The total area spawned throughout the survey reached two maxima during the season. The first was 53,911 m^2 on October 11, followed by 61,372 m^2 (660,625 ft^2) on November 1.

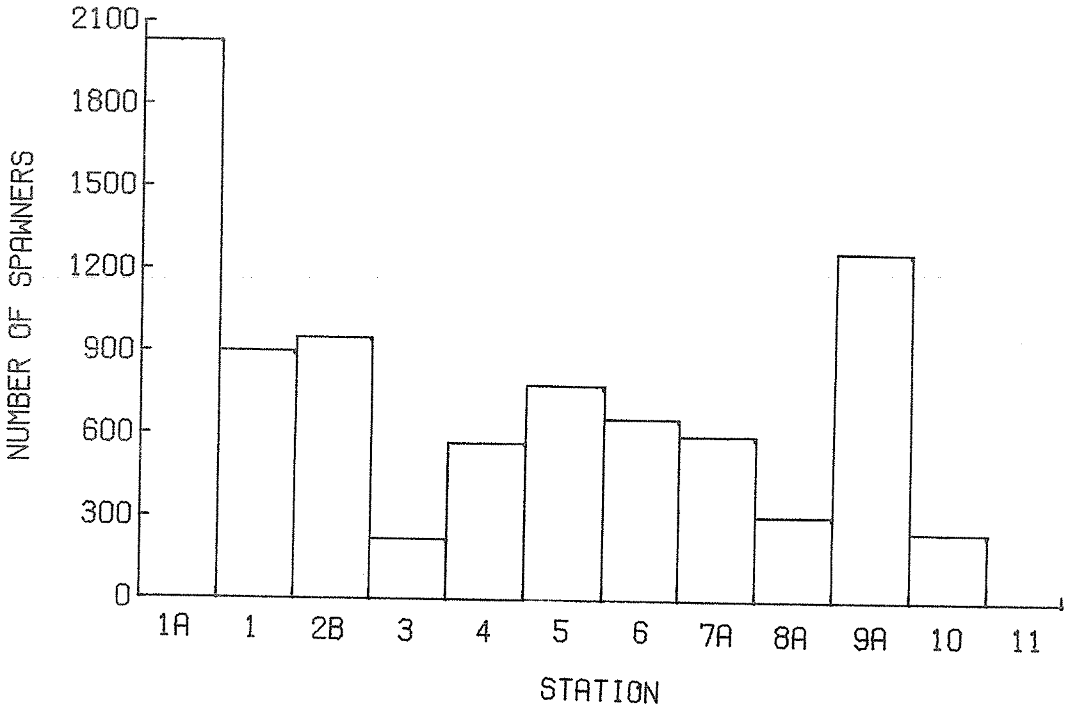

Fig. 7. Total number of spawning sockeye salmon per sample reach in 1977.

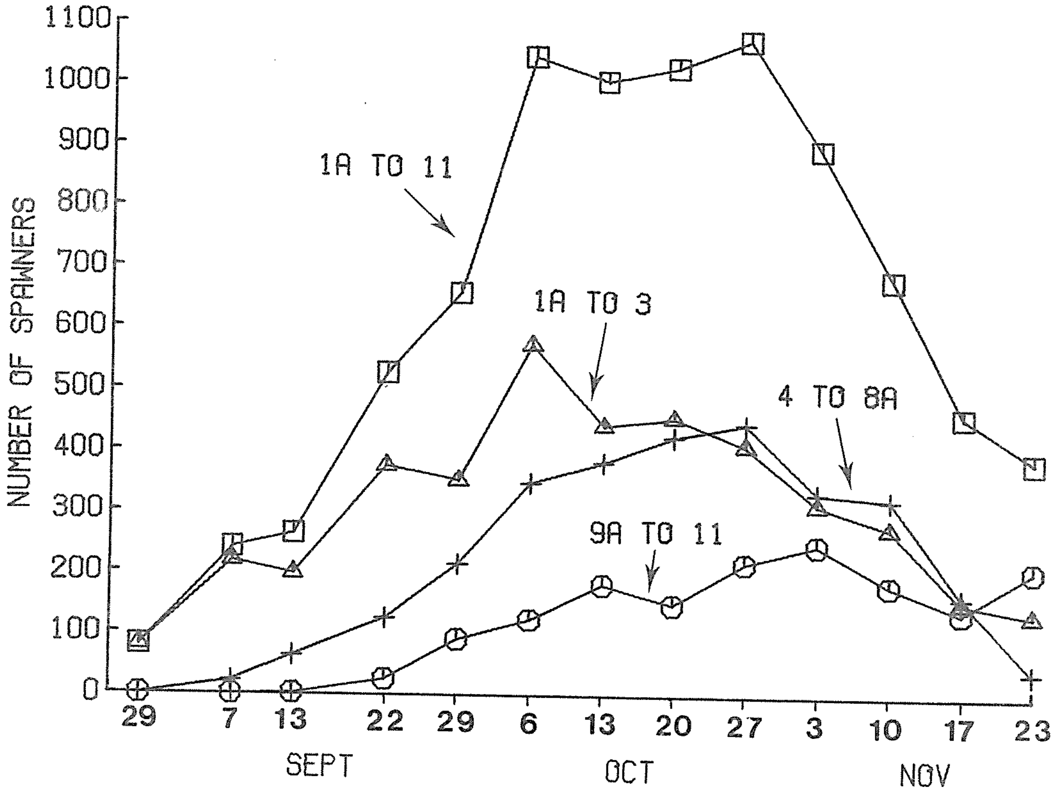

Fig. 8. Cedar River spawner counts by week in 1977. Data were grouped by Station to illustrate utilization in the lower (9A-11), middle (4-8A), and upper (1A-3) thirds of the river, and for all Stations (1A-11) surveyed below Landsburg.

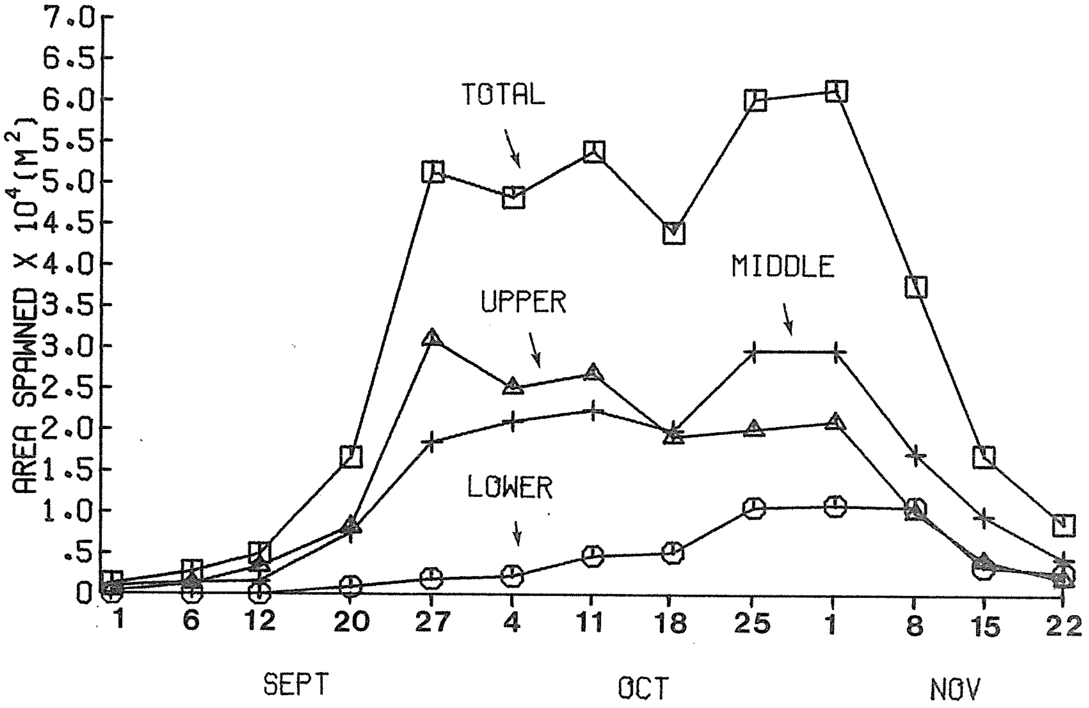

Fig. 9. Total area of the Cedar River spawned by sockeye salmon each week in 1977, as determined by float trip surveys. Data expressed for 28.8 km (total) and for approximately equal thirds of the river.

6.3.4 Prespawning Mortality

The large escapement in 1977 was complicated by a massive prespawning mortality which reduced the total potential egg deposition and the effective escapement to the Cedar River. Spawners were found to be heavily infested with the parasitic copepod, *Salmincola*, which primarily affected the gills. Secondary infections from bacteria and fungi probably also contributed to the reduced survival.

The term "prespawning mortality" when used in its strictest sense refers only to the females which died completely unspawned. However, for the purposes of this report, the definition was expanded to include the mortality of partially spawned females. Inclusion of both types of mortality allowed estimates of the reduction in the total potential egg deposition and the total effective escapement. Prespawning mortality was not evaluated in the males. Although it was possible to determine the number of males which died completely unspawned, few were observed. It was not possible to determine mortality in partially spawned males.

A weekly examination of fresh female sockeye carcasses showed that egg retention was highest early in the spawning season, at 65 percent on October 7 (Table 1), and declined to a relatively consistent 34 percent later in the season. The percentage of the eggs retained on each successive collection date was determined based on the assumption that the average deposition of each successful female was 3,500 eggs. This accounted for an average retention per female of 200 eggs, which was observed in previous years when prespawning mortality had not occurred.

The total escapement estimated by the WDF was assumed to have a sex ratio similar to that for runs in previous years with 58 percent females (237,800) and 42 percent males (172,200) prior to the prespawning mortality. This mortality was observed to primarily affect the females. The differential prespawning mortality to the female population was calculated in the following equation:

Table 1. Egg retention resulting from prespawning mortality in Cedar River sockeye salmon, 1977.

Collection Dates	Number of Females Sampled	Fork Length (cm) $\bar{x}$ ±S.D.	Number of eggs Retained $\bar{x}$ ±S.D.	Number of eggs Retained/3500[1]
10/ 7	56	57.1 ±2.5	2267 ±1566	.65
10/ 14	66	56.4 ±2.3	1956 ±1741	.56
10/ 21	43	57.2 ±1.9	2275 ±1817	.65
10/28	65	56.0 ±1.9	1132 ±1290	.33
11/3	25	57.0 ±1.6	1230 ±1332	.35
11/11	14	56.1 ±2.4	1187 ±1416	.34
12/31	-	-	-	(.34)[2]
Total	269			

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[1] Approximate potential egg deposition per female to account for normal egg retention.

[2] Estimated percentage of potential deposition retained.

$$\text{Effective female escapement} = \sum_{i=1}^{n} (1 - R_i)(E_i - E_{i-1})$$

where, R_i = percent of retained eggs estimated on date i (Table 1)

$1-R_i$ = percent of potential egg deposition on date i

E_i = cumulative escapement of females to the spawning grounds on date i

An estimate of the cumulative escapement to the spawning grounds (E_i) on the dates when female carcasses were collected took into consideration the variable delay between the cumulative tower count estimate made by the WDF and the cumulative area spawned in the river channel. A comparison between the cumulative percentage of the tower counts (escapement), the cumulative percentage of area spawned in the river and the spawner counts on the reaches throughout the spawning season is presented in Fig. 10. The delay between when spawners passed the tower and when spawning commenced was approximately 3 weeks early in the season. Fish held in pools in the river and in the waters below the Landsburg Dam before moving to a spawning area. The time-lag shortened to a week or less as the season progressed. The close agreement between the timing of the total area spawned and the spawner counts on the reaches is apparent in Fig. 10. The total area spawned in the river channel was utilized in the estimates of prespawning mortalities since it defined the timing of actual spawning in the entire river.

It was unlikely that prespawning mortality occurred immediately following passage of the counting tower, but rather at a later date as fish arrived on or near the spawning grounds. Therefore, estimates of escapement to the spawning grounds were obtained by assuming that on any given date, the percentage of cumulative area spawned for the entire river was spawned by an equivalent percentage of the cumulative escapement to the counting tower (Fig. 10). This equivalent percentage of cumulative escapement was used to subdivide

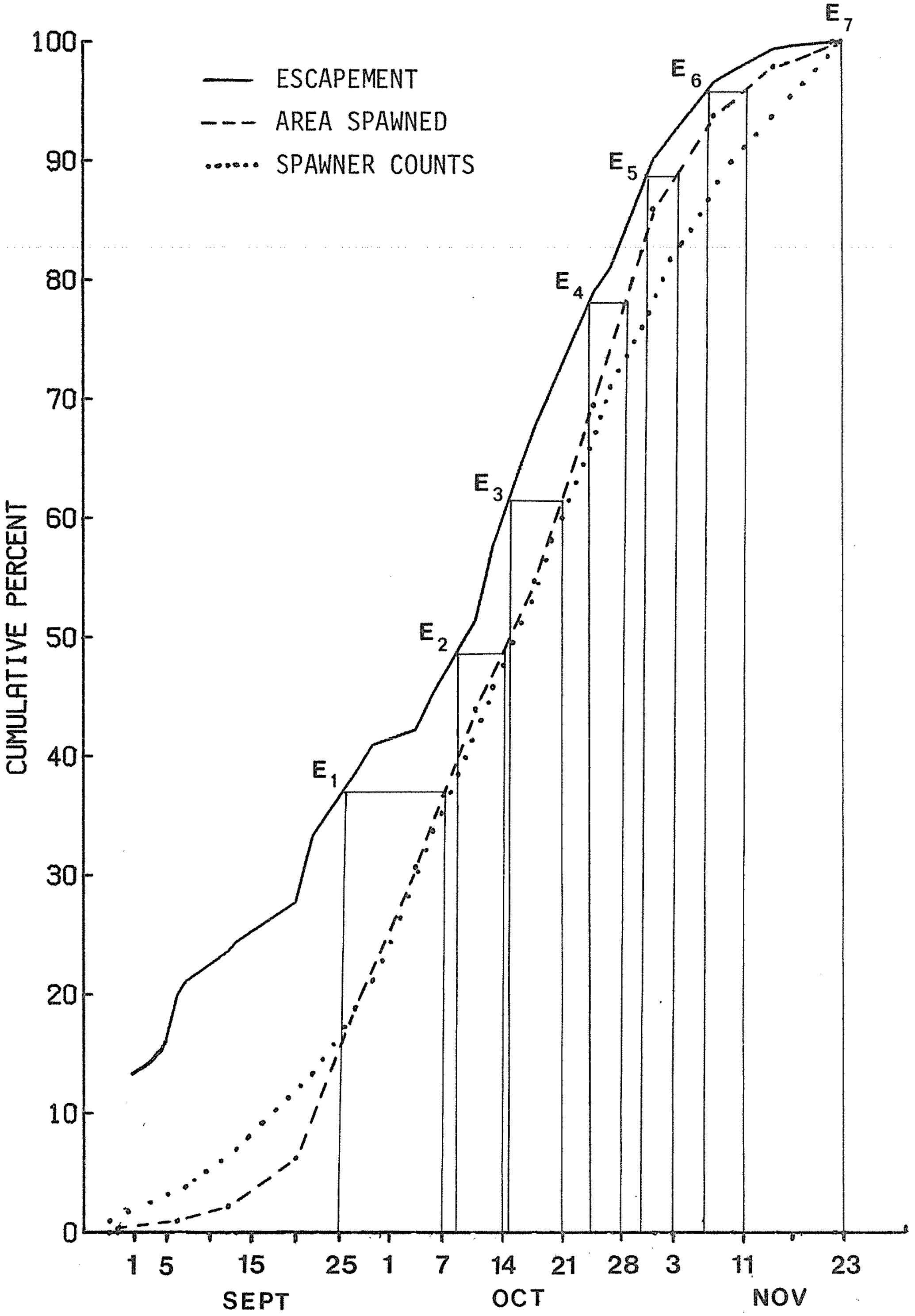

Fig. 10. Cumulative percentages of escapement past tower station, area spawned, and spawner counts by date for Cedar River sockeye salmon in 1977. Escapement to the spawning grounds on incremental dates is shown, E_1-E_7.

the tower escapement estimate in order to increase the accuracy of the estimate of the effective escapement over time. The prespawning mortality in the river amounted to a loss of about 119,813 female spawners, or 29 percent. This mortality resulted in an estimated effective escapement of 117,987 females (Table 2). A total maximum effective escapement of 290,187 spawners was estimated, which assumed no prespawning mortality occurred in the males.

6.4 Egg-Alevin Densities

6.4.1 Potential Egg Density

The expected potential egg densities at the hydraulic egg sampling stations were estimated from weekly spawner counts on each study reach. Although redd counts were shown by Stober et al. (1978) to yield a more conservative estimate, single redds could not be utilized because of the mass spawning which took place during 1977. Since the prespawning mortality reduced the number of spawning females, two estimates were calculated. The first utilized the variable sex ratio resulting from differential female mortality and assumed prespawning mortality occurred only in the females. The second applied the prespawning mortality equally to both sexes and utilized the original 58:42 sex ratio (female:male). The number of females in each weekly spawner count was determined from the calculated sex ratio for each week of the season. This was expanded by the average egg deposition (3,500 eggs/female) and divided by the area spawned to arrive at the potential deposition in number of eggs/m^2.

The distribution of the mass-spawned areas and individual isolated redds at each egg sampling station are shown in Figs. 11, 12 and 13 for three times during the spawning season. The mass-spawned areas tended to shift toward the lateral margins of the river during the season at Stations 1A and 2B with an increasing water discharge regime. The mass-spawned area at Station 5 did not shift laterally, but merely increased in size.

Table 2. Estimated total effective female sockeye salmon escapement in the Cedar River in 1977, based on weekly samples of egg retention resulting from prespawning mortality.

Date of Collection	Percentage of Eggs Retained (R_i)	Percentage of Potential Eggs Deposited ($1-R_i$)	Time Delay for Upstream Migration (days)	Date for Escapement E_i	Cumulative Escapement E_i (females)	Escapement between Collection Dates (E_i-E_i-1)	Effective Female Escapement for Each Period ($1-R_i$)(E_i-E_i-1)	Percentage Females with Males Surviving***
10/7	.65(R_1)	.35	12	9/25	82,612 (E_1)	82,612	28,914	32.6
10/14	.56(R_2)	.44	5	10/8	109,497 (E_2)	26,885	11,830	37.8
10/21	.65(R_3)	.35	6	10/14	134,134 (E_3)	24,637	8,623	32.6
10/28	.33(R_4)	.67	4	10/24	177,081 (E_4)	42,947	28,775	48.1
11/3	.35(R_5)	.65	3	10/31	200,122 (E_5)	23,041	14,977	47.3
11/11	.34(R_6)	.66	4	11/7	220,311 (E_6)	20,189	13,325	47.7
11/23	.34(R_7)*	.66	0	11/23	229,285 (E_7)	8,974	5,923	47.7
12/31	.34(R_8)*	.66	0	12/31	237,800** (E_8)	8,515	5,620	47.7

Total Effective Female Escapement 117,987

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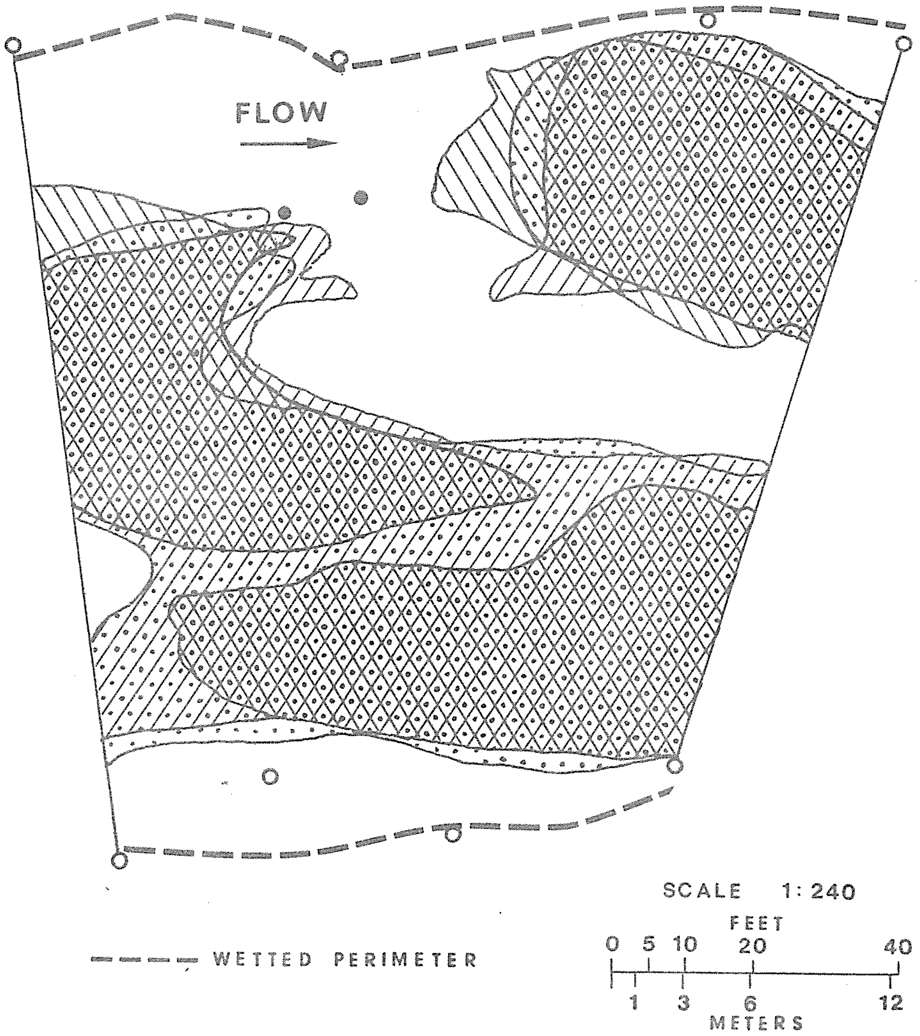
[*] Estimated number retained eggs.

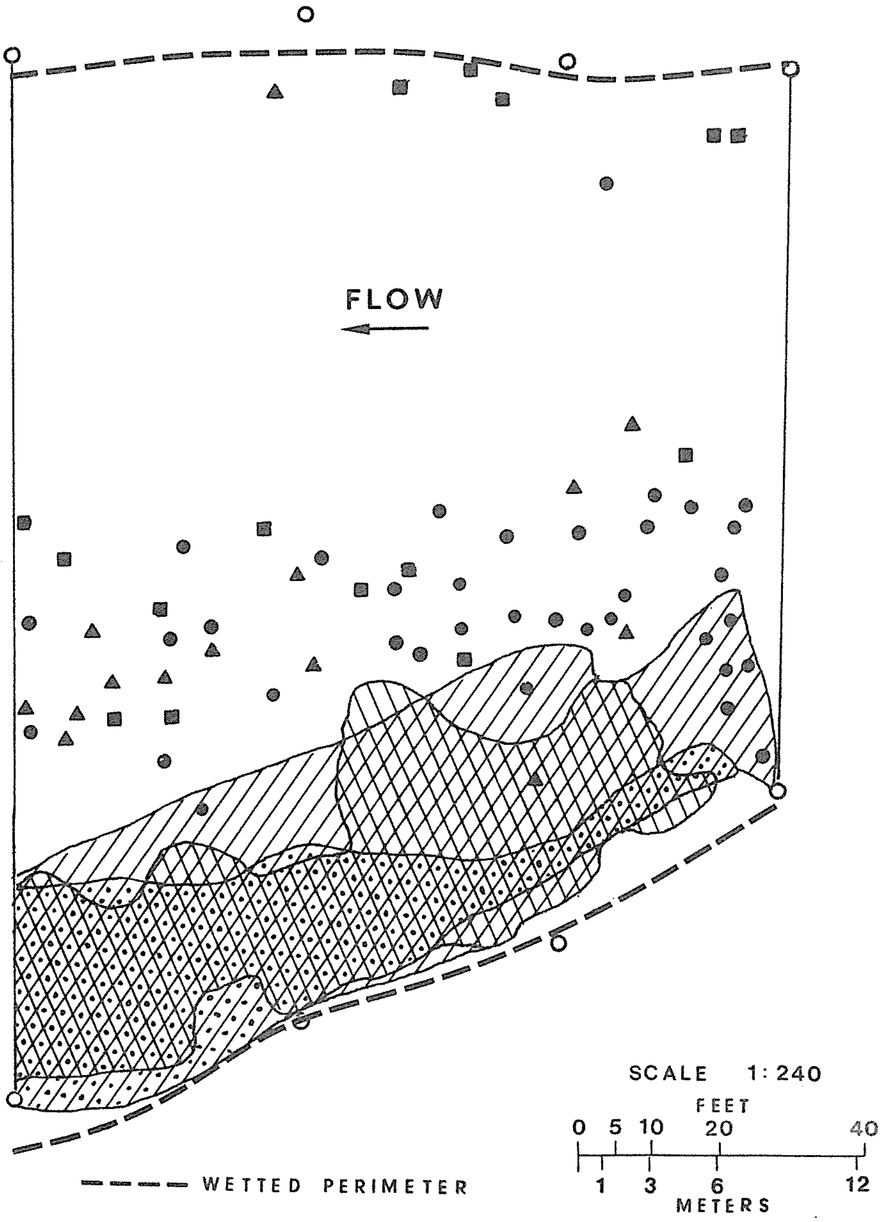
[**] Estimated beyond the date of the last tower count.

[***] Percentage of females following prespawning mortality, assuming all males survived to spawn.



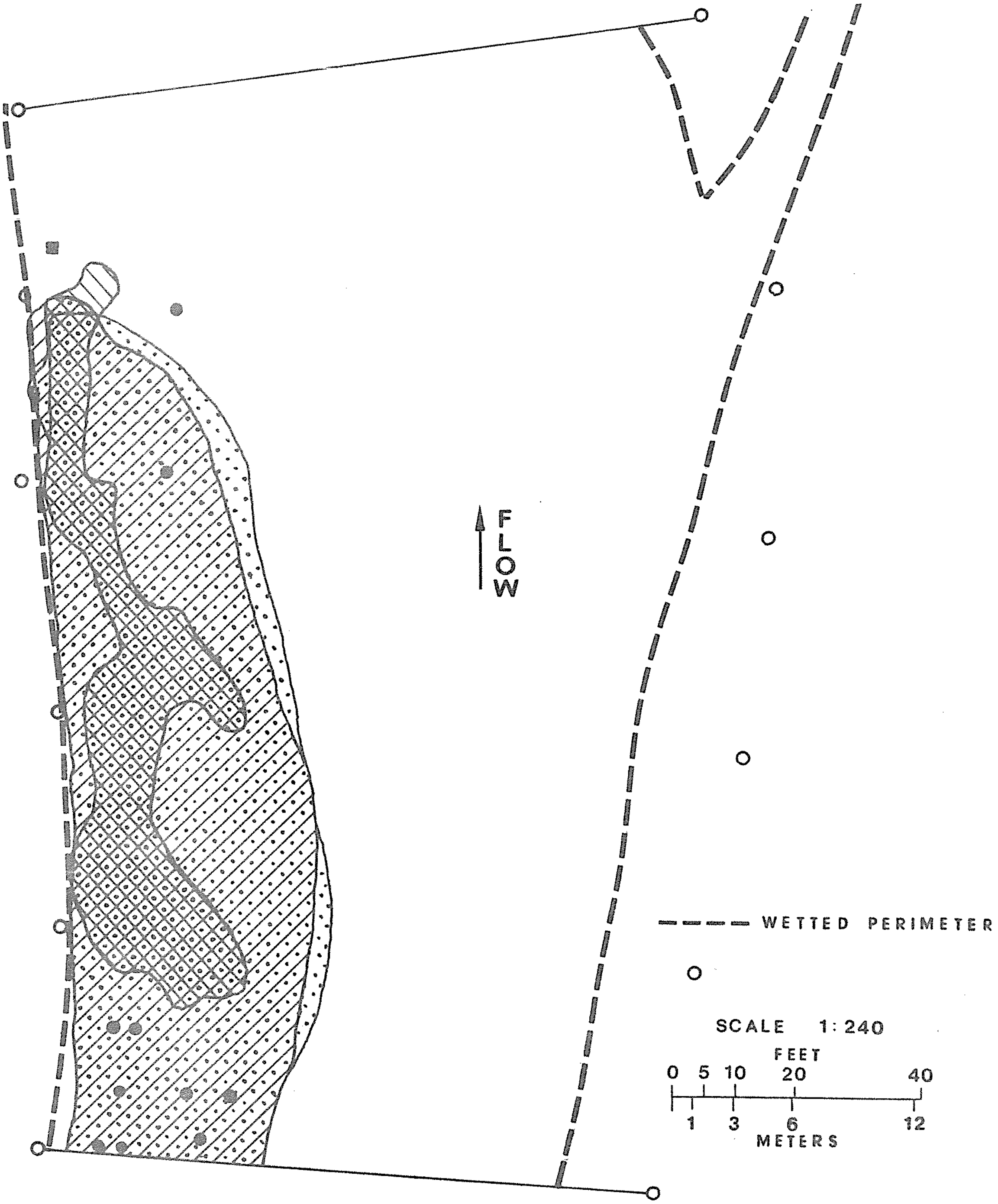
Dates	Discharge m^3/sec	Individual Redds	Mass Spawned Areas	Area Spawned m^2
8/29 - 9/29	4.39 - 9.77	●	\\\\\\	527
9/30 - 10/20	6.12 - 10.37	-	//////	541
10/20 - 11/23	7.93 - 27.39	-	:::::::::	547

Fig. 11. Location of redds and mass-spawned areas recorded at Station 1A by plane table survey during the early, middle, and late portions of the 1977 spawning season.



Dates	Discharge m^3/sec	Individual Redds	Mass Spawned Areas	Area Spawned m^2
8/29 - 9/29	4.39 - 9.77	●	\\\\\\	168
9/30 - 10/20	6.12 - 10.27	■	//////	326
10/20 - 11/23	7.93 - 27.93	▲	:::::::::	171

Fig. 12. Location of redds and mass-spawned areas recorded at Station 2B by plane table survey during the early, middle, and late portions of the 1977 spawning season.



Dates	Discharge m^3/sec	Individual Redds	Mass Spawned Areas	Area Spawned m^2
8/29 - 9/29	4.39 - 9.77	●	\\\\\\	126
9/30 - 10/20	6.12 - 10.37	■	/////	369
10/20 - 11/23	7.93 - 27.39	–	::::::::	419

Fig. 13. Location of redds and mass-spawned areas recorded at Station 5 by plane table survey during the early, middle, and late portions of the 1977 spawning season.

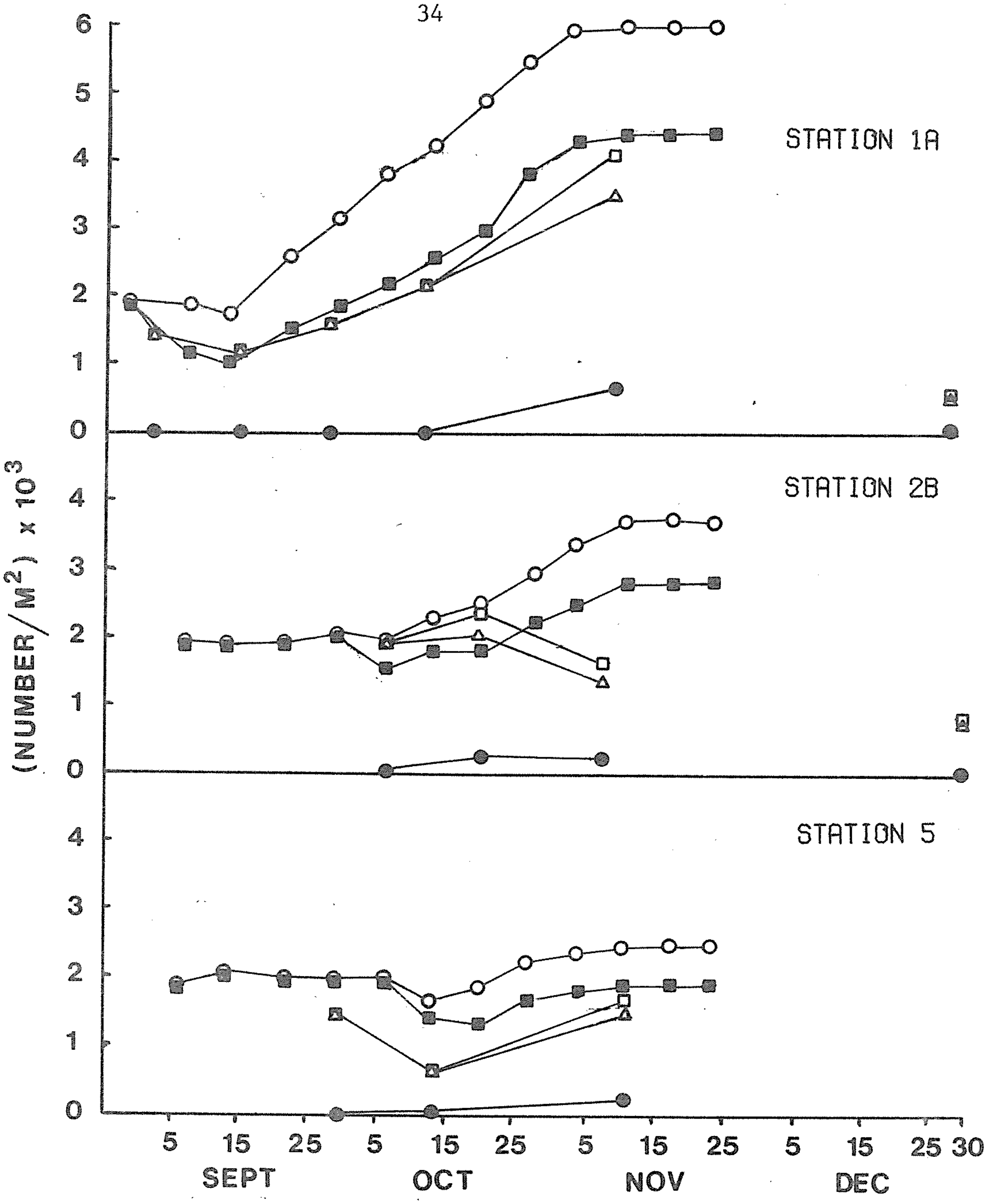
The apparent minor lateral shift in spawning area was probably due to the large numbers of spawners in the river during 1977. The high density resulted in extensive mass spawning which appeared to minimize the lateral shift of spawners with an increasing discharge regime.

The two potential egg densities at Station 1A, estimated from spawner counts are presented in Table 3 and Fig. 14. Due to mass spawning of this reach, it was not possible to enumerate individual redds. Neither of the two estimates of potential egg densities were considered reliable. In order to obtain accurate estimates of the potential egg densities deposited on a reach, an accurate sex ratio must be determined. This is a difficult task when prespawning mortality and mass spawning occur simultaneously. An additional source of error may have resulted due to a reduction of the redd life to less than seven days. This could have occurred as the result of extreme population pressure on the spawning reaches due to intraspecific intolerance of the spawners. In 1977, the mortality of a large number of partially spawned females suggested that the redd life had been reduced.

Similar problems were encountered at Stations 2B and 5, however, the estimates of potential egg densities on these reaches were considered to be somewhat more reliable because estimates were based on actual redd counts for a greater portion of the season than was possible at Station 1A (Tables 4 and 5 and Fig. 14).

6.4.2 Egg Densities Estimated from Hydraulic Sampling

The sample densities for Station 1A, 2B and 5 are graphed in Fig. 14 and given in Table 6 for September through December of 1977 to indicate the change in relative density during the spawning season. Sample densities calculated at Station 1A increased throughout the season from 1,459 to 4,158 egg-alevins/m^2. A final sample density was not obtained immediately prior to the December flood, however,



Potential densities calculated from actual and estimated number of redds
- ○ Assuming 58:42 - female:male sex ratio
- ■ Assuming a variable sex ratio

Sample densities
- □ Total live and dead eggs-alevins
- △ Live eggs-alevins
- ● Dead eggs-alevins

Fig. 14. Estimated potential egg-alevin densities based on redd counts and two sex ratios at Stations 1A, 2B and 5 during 1977. Observed densities were determined from hydraulic gravel samples.

Table 3. Estimated potential egg deposition at Station 1A, derived from actual and estimated numbers of redds resulting from spawning activity during 1977. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton[a] (m^3/s)	Spawners		Redds		Potential Egg Deposition		Area (m^2)			Weekly Cumulative Density
		Week	Total	Week	Total	Week	Total	Week	New	Total	(egg/m^2)
8/29	4.59	80	80	17[b]	17	59500	59500	30.6	30.6	30.6	1944
9/7	6.12	192	272	63[c]	80	220500	280000	234.6	206.2	236.8	1182
9/13	4.73	150	422	50[c]	130	175000	455000	394.5	192.9	429.7	1059
9/22	7.70	250	672	82[c]	212	287000	742000	406.1	50.1	479.8	1547
9/29	6.57	216	888	70[c]	282	245000	987000	491.9	47.2	527.0	1873
10/6	9.60	254	1142	83[c]	365	290500	1277500	529.9	47.2	574.2	2225
10/13	9.86	176	1318	67[c]	432	234500	1512000	450.4	20.7	594.9	2542
10/20	9.40	217	1535	71[c]	503	248500	1760500	467.7	12.7	607.6	2898
10/27	11.24	182	1717	88[c]	685	308000	2397500	532.2	7.5	615.1	3898
11/3	14.67	142	1859	67[c]	752	234500	2632000	126.6	0	615.1	4279
11/10	12.55	102	1961	13[b]	765	45500	2677500	23.4	0	615.1	4353
11/17	27.39	34	1995	3[b]	768	10500	2688000	5.4	1.8	616.9	4359
11/23	25.66	32	2027	6[b]	774	21000	2709000	10.8	3.6	620.5	4366
8/29	4.59	80	80	17[b]	17	59500	59500	30.6	30.6	30.6	1928
9/7	6.12	192	272	111[d]	128	388500	448000	234.6	206.2	236.8	1892
9/13	4.73	150	422	87[d]	215	304500	752500	294.5	192.9	429.7	1751
9/22	7.70	250	672	145[d]	360	507500	1260000	406.1	50.1	479.8	2626
9/29	6.57	216	888	125[d]	485	437500	1697500	491.9	47.2	527.0	3221
10/6	9.60	254	1142	147[d]	632	514500	2212000	529.9	47.2	574.2	3852
10/13	9.86	176	1318	102[d]	734	357000	2569000	450.4	20.7	594.9	4318
10/20	9.40	217	1535	126[d]	860	441000	3010000	467.7	12.7	607.6	4954
10/27	11.24	182	1717	106[d]	966	371000	3381000	532.2	7.5	615.1	4496
11/3	14.67	142	1859	82[d]	1048	287000	3668000	126.6	0	615.1	5963
11/10	12.55	102	1961	13[b]	1061	45500	3713500	23.4	0	615.1	6037
11/17	27.39	34	1995	3[b]	1064	10500	3724000	5.4	1.8	616.9	6037
11/23	25.66	32	2027	6[b]	1070	21000	3745000	10.8	3.6	620.5	6036

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[a] USGS gauge.

[b] Redd counts = number of contributing females.

[c] Estimated from spawner counts assuming a variable percentage of female spawners resulting from differential female prespawning mortalities and one female/redd.

[d] Estimated from spawner counts assuming 58 percent of spawners were females and one female/redd.

Table 4. Estimated potential egg deposition at Station 2B, derived from actual and estimated number of redds resulting from spawning activity during 1977. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton[a] (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	
9/7	6.12	8	8	4[b]	4	14000	14000	7.2	7.2	7.2	1944
9/13	4.73	14	22	8[b]	12	28000	42000	14.4	13.9	21.1	1991
9/22	7.70	67	89	27[b]	39	94500	136500	48.6	48.6	69.7	1958
9/29	6.57	126	215	61[b]	100	213500	350000	109.8	98.2	167.9	2085
10/6	9.60	138	353	45[c]	145	157500	507500	218.6	165.8	333.7	1521
10/13	9.86	124	477	47[c]	192	164500	672000	181.6	35.6	369.3	1820
10/20	9.40	116	593	38[c]	230	133000	805000	299.8	77.1	446.4	1803
10/27	11.24	112	705	54[c]	284	189000	994000	97.2	3.3	449.7	2210
11/3	14.67	86	791	41[c]	325	143500	1137500	33.3	0	449.7	2530
11/10	12.55	86	877	41[c]	366	143500	1281000	30.8	2.1	451.8	2835
11/17	27.39	48	925	8[b]	384	28000	1309000	14.4	7.6	459.4	2849
11/23	25.66	24	949	4[b]	388	14000	1323000	7.2	3.5	462.9	2858
9/7	6.12	8	8	4[b]	4	14000	14000	7.2	7.2	7.2	1944
9/13	4.73	14	22	8[b]	12	28000	42000	14.4	13.9	21.1	1991
9/22	7.70	67	89	27[b]	39	94500	136500	48.6	48.6	69.7	1958
9/29	6.57	126	215	61[b]	100	213500	350000	109.8	98.2	167.9	2085
10/6	9.60	138	353	80[d]	180	280000	630000	218.6	165.8	333.7	1888
10/13	9.86	124	477	72[d]	252	252000	882000	181.6	35.6	369.3	2388
10/20	9.40	116	593	67[d]	319	234500	1116500	299.8	77.1	446.4	2561
10/27	11.24	112	705	65[d]	384	227500	1344000	97.2	3.3	449.7	2988
11/3	14.67	86	791	50[d]	434	175000	1519000	33.3	0	449.7	3378
11/10	12.55	86	877	50[d]	484	175000	1694000	30.8	2.1	451.8	3750
11/17	27.39	48	925	8[b]	384	28000	1722000	14.4	7.6	459.4	3748
11/23	25.66	24	949	4[b]	388	14000	1736000	7.2	3.5	462.9	3758

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[a] USGS gauge.

[b] Redd counts = number of contributing females.

[c] Estimated from spawner counts assuming a variable percentage of female spawners resulting from differential female prespawning mortalities and one female/redd.

[d] Estimated from spawner counts assuming 58 percent of spawners were females and one female/redd.

Table 5. Estimated potential egg deposition at Station 5, derived from actual and estimated number of redds resulting from spawning activity during 1977. Total and weekly spawner counts are given in columns 3 and 4.

Date	Discharge at Renton[a] (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	
9/7	6.12	14	14	6[b]	6	21000	21000	10.8	10.8	10.8	1944
9/13	4.73	18	32	12[b]	18	42000	63000	21.6	19.5	30.3	2079
9/22	7.70	42	76	20[b]	38	70000	133000	36.0	35.5	65.8	2021
9/29	6.57	46	122	11[b]	49	38500	171500	19.8	19.3	85.1	2015
10/6	9.60	84	206	17[b]	66	59500	231000	30.6	28.1	113.2	2040
10/13	9.86	134	340	51[c]	117	178500	409500	256.3	178.3	291.5	1405
10/20	9.40	127	467	41[c]	158	143500	553000	369.5	112.3	403.8	1370
10/27	11.24	125	592	60[c]	218	210000	763000	375.7	35.1	438.9	1738
11/3	14.67	82	674	12[b]	230	42000	805000	21.6	0	438.9	1834
11/10	12.55	76	750	11[b]	241	38500	834500	19.8	0	438.9	1922
11/17	27.39	14	764	0[b]	241	0	843500	0	0	438.9	1922
11/23	25.66	11	775	0[b]	241	0	843500	0	0	438.9	1922
9/7	6.12	14	14	6[b]	6	21000	21000	10.8	10.8	10.8	1944
9/13	4.73	18	32	12[b]	18	42000	63000	21.6	19.5	30.3	2078
9/22	7.70	42	76	20[b]	38	70000	133000	36.0	35.5	65.8	2021
9/29	6.57	46	122	11[b]	49	38500	171500	19.8	19.3	85.1	2015
10/6	9.60	84	206	17[b]	66	59500	231000	30.6	28.1	113.2	2041
10/13	9.86	134	340	78[d]	144	273000	504000	256.3	178.3	291.5	1729
10/20	9.40	127	467	74[d]	218	259000	763000	369.5	112.3	403.8	1880
10/27	11.24	125	592	73[d]	291	255500	1018500	375.7	35.1	438.9	2321
11/3	14.67	82	674	12[b]	303	42000	1060500	21.6	0	438.9	2416
11/10	12.55	76	750	11[b]	314	38500	1099000	19.8	0	438.9	2504
11/17	27.39	14	764	0[b]	314	0	1099000	0	0	438.9	2504
11/23	25.66	11	775	0[b]	314	0	1099000	0	0	438.9	2504

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[a] USGS gauge.

[b] Redd counts = number of contributing females.

[c] Estimated from spawner counts assuming a variable percentage of female spawners resulting from differential female prespawning mortalities and one female/redd.

[d] Estimated from spawner counts assuming 58 percent of spawners were females and one female/redd.

Table 6. Estimated densities of eggs and alevins from hydraulic samples at Stations 1A, 2B and 5, resulting from spawning activity during 1977.

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
1A	9/2/77	24	1.10	1455	0	5	0	1454.31	5.03	1459.34
	9/14/77	52	2.39	2794	0	4	0	1168.90	1.67	1170.57
	9/28/77	94	4.32	6930	0	8	0	1604.22	1.80	1606.02
	10/12/77	96	4.42	9613	0	2	0	2174.92	.50	2175.42
	11/9/77	85	3.91	13362	328	2567	0	3501.28	656.44	4157.71
	12/28/77	102	4.69	2061	424	169	0	529.98	35.00	565.98
2B	10/5/77	63	2.90	5213	0	172	0	1798.94	59.43	1858.37
	10/19/77	76	3.50	7168	0	943	0	2048.05	269.51	2317.57
	11/7/77	74	3.40	4474	1	798	0	1316.10	234.69	1550.79
	12/30/77	63	2.90	1839	289	142	9	733.83	52.14	785.98
5	9/30/77	20	.92	1384	0	0	0	1504.83	0	1504.83
	10/14/77	51	2.35	1476	0	83	0	628.02	35.52	663.54
	11/11/77	64	2.94	4281	14	612	0	1460.98	208.33	1667.30

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*Assuming a sampler efficiency of 90 percent.

greater than 98 percent of the spawning had occurred by the time of the last sampling series. Significant numbers of dead eggs-alevins were not found until November 9. At Station 2B the sample densities increased initially, but subsequent to a brief period of high discharge (23.1 m^3/sec) in early November, the densities declined from a mid-October high of 2,318 eggs/m^2 to an early November value of 1,551 eggs/m^2. This latter density represented at least 92 percent of the observed spawning for the season. The sample density calculated at Station 5 for September 30 may have been biased by a few samples which contained unusually high numbers of eggs and the small number of total samples collected. This probably resulted in an overestimation of the mean for that date. The final sample density at Station 5 was 1,667 eggs/m^2 which represented 100 percent of the observed spawning for the season. Sample egg densities did not show increasing trends at Stations 2B and 5, suggesting that egg densities may have been held constant due to losses resulting from superimposition.

The frequency distributions of the number of eggs per sampling point indicate that at Station 1A there was a substantially higher percentage of sampling points with egg counts of 101 to 900 than at either Station 2B or 5 (Fig. 15). Conversely, a higher percentage of sampling points with egg counts of 0 to 5 were observed at Stations 2B and 5 than at Station 1A. These differences may be accounted for in part by the presence of larger substrate at Stations 2B and 5 which would allow for wider dispersal of eggs among the interstices following deposition. The substrate at Station 1A was smaller and more uniform which probably restricted the eggs to more discrete pockets. The gravel characteristics may influence the efficiency of egg deposition if the sockeye females have difficulty spawning in and around large cobble.

Postflood hydraulic egg sampling conducted at Stations 1A and 2B at the end of December produced markedly reduced densities of 566 and 786 eggs-alevins/m^2, respectively (Table 6).

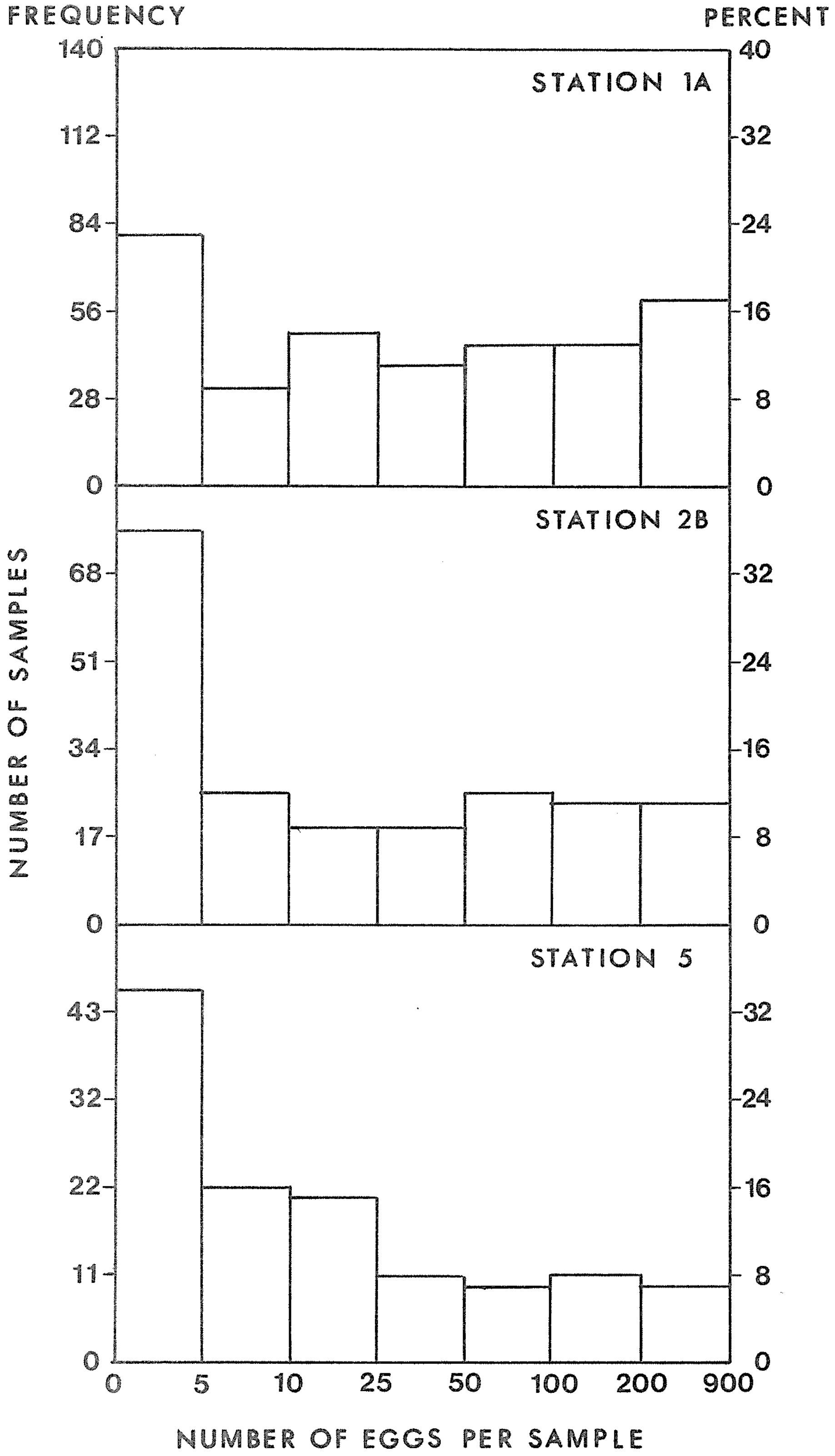

Fig. 15. Frequency distribution of the number of eggs per sampling point at Stations 1A, 2B and 5 for the 1977 spawning season.

Approximately 0.5 to 1.0 m of gravel had been deposited on the spawned areas of Station 5 during the flood which precluded sampling at that station. Following the December 1977 flood, the hydraulic sample densities declined 86 percent and 49 percent at Stations 1A and 2B, respectively. The effects of gravel deposition at Station 5 on egg and alevin survival are unknown.

6.4.3 Egg-Alevin Mortality

The tests of proportionate frequencies (Table 7) detected a significant decrease ($\chi^2 = 10.39$) in the proportion of sampling points containing a total of zero or one egg-alevins at Station 1A. No changes occurred at Stations 2B or 5. The proportions of sampling points with a total of zero or one live eggs-alevins did not change significantly at any of the stations.

A significant decrease in the proportion of points having a total of zero or one dead occurred at Station 1A ($\chi^2 = 215.17$), Station 2B ($\chi^2 = 8.14$), and Station 5 ($\chi^2 = 6.35$).

Inspection of the 95 percent confidence limits applied to the proportion of sampling points containing a total of zero or one dead egg-alevins (Table 8) revealed that significant increases in mortality occurred at Station 1A in early November; at Station 2B in mid-October; and at Station 5 in mid-October and early November.

Estimates of mortality, M_r, based on the percentage of dead eggs and alevins obtained during hydraulic sampling periods are presented with 95 percent confidence intervals in Table 9 and Fig. 16. Significant increases in mortality occurred in the first part of November at all stations. Furthermore, these increases corresponded to the periods of time when decreases in the proportion of sampling points containing zero or one dead total egg-alevins were observed.

Table 7. Chi-square test of independence on sample units with zero or one eggs-alevins per .046 m^2 sampled at Stations 1A, 2B and 5 during the 1977 season. Preflood samples at Stations 1A and 2B were tested separately and in combination with postflood samples.

Station	Date	Total No. of Sample Units	Zero or one total		Zero or one live		Zero or one dead	
			k_o	p_o	k_o	p_o	k_o	p_o
1A	9/2	24	3	.13	3	.13	23	.96
	9/14	52	13	.25	13	.25	51	.98
	9/28	94	5	.05	6	.06	94	1.00
	10/12	96	10	.10	10	.10	96	1.00
	11/9	85	4	.05	6	.07	20	.24
			35		38		284	
	preflood	χ^2(4 df) =	10.39*		7.52		215.17*	
	12/28	102	68	.67	69	.68	89	.87
			103		107		373	
pre- and postflood		χ^2(5 df) =	173.79*		169.13*		229.58*	
2B	10/5	63	6	.10	9	.14	52	.87
	10/19	76	8	.11	9	.12	52	.68
	11/7	74	7	.09	11	.15	43	.58
			21		29		150	
	preflood	χ^2(2 df) =	.11		.20		8.14*	
	12/30	63	36	.57	38	.60	51	.81
			57		67		201	
pre- and postflood		χ^2(3 df) =	60.69*		52.53*		8.96*	
5	9/30	20	5	.25	5	.25	20	1.00
	10/14	51	5	.10	7	.14	34	.67
	11/11	64	2	.03	5	.05	31	.48
			12		17		85	
		χ^2(3 df) =	2.58		-		6.35*	

*Significant at 95% level.

Table 8. 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 Stations 1A, 2B and 5, 1977.

Station	Date	Total Number of Sample Units	k_o	95% Confidence Limits	p_o	95% Confidence Limits
1A	9/2	24	23	±2.06	.96	±.09
	9/14	52	51	±1.98	.98	±.04
	9/28	94	94	-	1.00	-
	10/12	96	96	-	1.00	-
	11/9	85	20	±7.82	.24	±.09
	12/28	102	89	±6.74	.87	±.07
2B	10/5	63	55	±5.29	.87	±.08
	10/19	76	52	±8.11	.68	±.11
	11/7	74	43	±8.49	.58	±.06
	12/30	63	51	±6.23	.81	±.10
5	9/30	20	20	-	1.00	-
	10/14	51	34	±6.73	.67	±.13
	11/11	64	31	±8.00	.48	±.13

Table 9. The mortality ratios, M_r, with 95% confidence limits for Stations 1A, 2B and 5, 1977.

Station	Date	M_r	95% Confidence Limits
1A	9/2	.004	±.007
	9/14	.000	±.001
	9/28	.001	±.001
	10/12	.001	±.002
	11/9	.147	±.048
	12/28	.093	±.074
2B	10/5	.045	±.056
	10/19	.088	±.065
	11/7	.167	±.077
	12/30	.128	±.074
5	9/30	.000	±.000
	10/14	.095	±.074
	11/11	.168	±.064

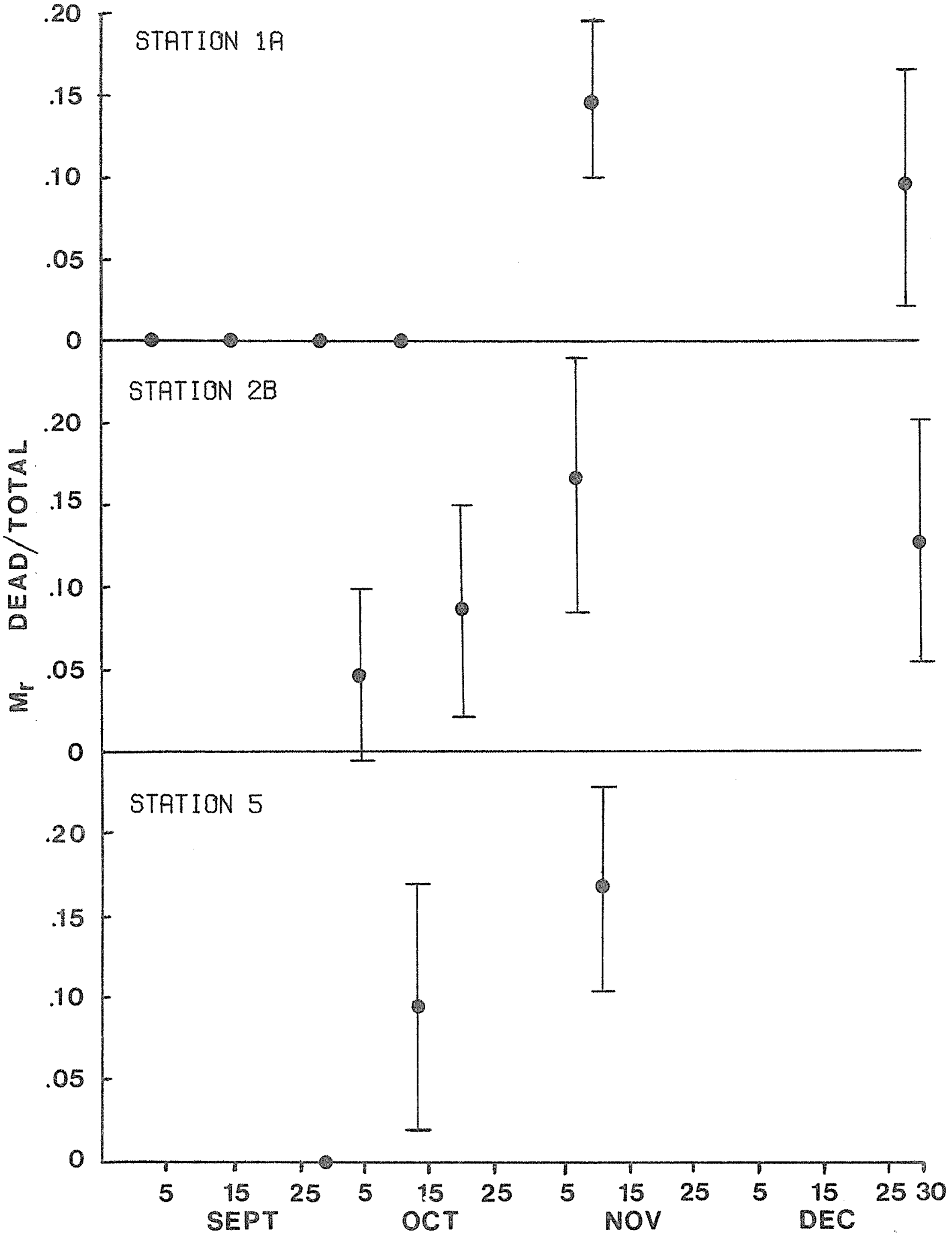

Fig. 16. Mortality estimates (M_r ratio = dead/total) of sockeye eggs-alevins in the gravel at Stations 1A, 2B, 5 during September-December 1977. The 95 percent confidence intervals are indicated by vertical bars around each point.

7.0 DISCUSSION

7.1 Water Quantity and Quality

The water temperatures reached extreme levels (23.8°C) in mid-August 1977 and greatly exceeded maximum summer temperatures recorded in 1975 and 1976. Water temperatures during the sockeye spawning season were similar to those recorded during previous years.

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 to follow a stepwise increase beginning in mid-August at 2.1 m^3/sec and reach 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 and the application of the USGS hydraulic survey methodology (Collings 1972). 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 was timed to maximize the available spawning area for the least amount of water by linearly increasing the discharge during the spawning season; thus presenting the maximum cumulative spawning area to the fish. Furthermore, the available spawning area is maximized by timing the peak spawning discharge with the maximum number of spawners in the river. After October 15, if additional water is available for fish, the discharge may be increased linearly to 14.2 m^3/sec by December 1 to gain the remaining 20 percent of the spawnable area near the margins of the river channel.

During the fall of 1977, the discharge pattern deviated from the DOE operating curve due to drought conditions which persisted throughout the preceding year and generally followed the suggested maximizing regime. The discharge ranged from 2.1 m^3/s in late August to 11 m^3/s by November 1. Some lateral shift in the spawned areas toward the riverbank was observed; however, this response was no doubt confounded by the large numbers of fish spawning throughout the season. The December flood, with a peak discharge at 115.5 m^3/s, physically altered the river channel through scouring and redeposition of the substrate. The most extensive shifting of the bed material occurred near midchannel where the early spawners had deposited eggs. A similar flood effect was demonstrated by Stober et al. (1978).

7.2 Escapement and Prespawning Mortality

The total escapement of 410,000 spawners to the Cedar River was the highest estimated by the WDF to date.

A large prespawning mortality was apparently due to heavy infestation with the parasitic copepod, *Salmincola*, as well as associated secondary infections from bacteria and fungi. Mortalities were largely restricted to the females. Weekly examination of the egg retention in dead females provided a means for estimating that a loss of about 119,813 females (29 percent) occurred, which resulted in an estimated effective escapement of 117,987 females. The total maximum effective escapement, including males, was estimated at 290,187 sockeye. This was the first year in which large prespawning mortalities occurred, which introduced several complications into this monitoring effort.

7.3 River Utilization

The largest number of spawners was concentrated in the upper river below the Landsburg dam, the upper limit to migration, during the early part of the spawning season. Densities in the middle and lower third of the river were highest during the latter half of the spawning season, similar to the utilization observed in previous years. Entry of about 50 percent of the escapement occurred by mid-October, similar to the timing observed in past years.

Hydraulic analysis of spawning reaches 1A, 2B and 5 based on sockeye salmon spawning depth and velocity criteria predicted cumulative spawnable areas of 415, 976 and 1,043 m^2, respectively, in 1977. The actual areas which were spawned during the 1977 season were 621, 463 and 439 m^2 at Stations 1A, 2B and 5, respectively. This indicated that 150, 47 and 42 percent of the predicted cumulative area was spawned at Stations 1A, 2B and 5, respectively. The percentage of the predicted cumulative area spawned in 1975 and 1976 ranged from 26 to 34 percent at Stations 1A, 2B and 5. Spawning at Station 1A exceeded the 80 preferred depth range and resulted in a larger spawned area than that predicted by SYMAP.

A large accumulation of spawners occurred at Landsburg. Only a very limited number of migrants could spawn effectively in the Landsburg reach due to a preponderance of large boulders and cobble in the riverbed. The spawners apparently fell back downstream in search of suitable spawning areas. Station 1A was one of the first available spawning reaches encountered by fish falling back downstream. The 1975 flood had reduced the area of suitable spawning substrate in a large portion of the upper river which resulted in concentrations of spawners in the few areas remaining.

Float surveys used to determine the total area spawned in 28.8 km of the river below Landsburg each week indicated trends similar to those of the spawner counts. Comparison of the escapement in 1973, 1975, 1976 and 1977 with the total instantaneous spawned area for each year indicated a sharp decline in spawned area in years following the December 1975 flood (Table 10). This suggested that the effects of extreme flooding on the habitat may persist beyond the year in which the flood occurs. The decline in the total instantaneous spawned area between 1975 and 1976, with roughly equal escapements, indicated the loss or reduction of the habitat (i.e., spawning gravel). The river channel following the 1975 flood

Table 10. Comparison of the total annual sockeye salmon escapement with the total instantaneous spawned area in 28.8 km of the Cedar River below Landsburg.

Year	1973	1975	1976	1977
Escapement	313,000	114,100	138,949	410,000
Total instantaneous spawned area in 28.8 km of river (m^2)	143,995	92,900	57,600	61,372

was extensively scoured down to hard pan. Much of the suitable spawning gravel was deposited either along the banks out of the river channel or transported into Lake Washington. The fact that the instantaneous spawned area did not approach the 1973 level in 1977, when the total effective escapements were about equal, strongly indicated that the loss of spawning gravel had been sustained across both the 1976 and 1977 spawning seasons. Maps of the spawned areas in the river before and after the 1975 flood generally indicated that where spawning occurred across the river channel in 1973 and 1975, it was restricted to narrow bands along the channel margins in the 1976 and 1977 surveys. Flood reduction of the spawning substrate in the Cedar River is an important factor to consider in the establishment of escapement goals for several years following extreme flooding. Recovery of the spawning habitat to preflood levels should be monitored to determine the full extent which flooding exerts on the Cedar River sockeye. Since downstream gravel transport in this river is inhibited by two dams, recovery may take longer than in rivers without dams.

7.4 Egg-Alevin Density and Mortality

Two estimates of potential egg densities were made on each reach where egg sampling was conducted, however, neither was considered reliable due to the complications introduced by mass spawning and prespawning mortality.

Hydraulic sample egg-alevin densities at Station 1A increased throughout the spawning season to the highest density (4,158 egg-alevins/m^2) during the last three years. A high degree of redd superimposition was observed at this station and all spawning gravel was mass-spawned throughout the season. The efficiency of egg deposition could not be determined from the available data.

Sample egg densities at Station 2B in 1977 declined in November from the mid-October level. It appeared that this station may have been particularly affected by the scouring action of the moderately high discharge which occurred early in November. In 1976, egg densities at this station increased throughout the season, and similar to Station 1A, it was not known whether or not the maximum egg density had been reached. Possible flood effects in 1977 precluded a comparison of final egg densities; however, mid-October densities for 1976 and 1977 reached comparable levels.

In 1975 and 1976 the maximum estimated sample egg and alevin densities were reached at Station 5. This level, which was attained midway through the spawning season, was less than half the potential egg deposition by the end of the season. Continued spawning activity during the latter half of the season without a corresponding increase in egg density suggested that, during spawning, as many eggs were removed from the gravel as were deposited. An egg density similar to the maximum observed in these two years was estimated at the end of the 1977 season. The data obtained at Station 5 over the past three years indicate that the maximum river escapement required to efficiently maximize gravel egg densities at that Station was less than the 120,000 fish counted in 1975.

Additional sampling periods were required to determine if the maximum egg densities had been reached at Stations 1A and 2B. It was not possible to predict a maximum escapement necessary to maximize gravel egg density at these stations. Additional factors due to hydraulic characteristics and gravel composition at each of the stations may have also influenced the egg densities found on these reaches.

A comparison of the markedly reduced egg densities estimated from hydraulic sampling following the December 1977 flood with the preflood densities indicated that flood-related losses were 86 and 49 percent at Stations 1A and 2B, respectively. The loss at Station 2B was based on the maximum egg density which occurred during mid-season. Whether or not the deposition of 0.5 to 1 m depth of gravel on the spawning bar at Station 5 resulted in egg or fry mortality is unknown. This large amount of gravel deposition during the December 1977 flood was localized due to bank erosion immediately upstream from Station 5. These data indicate that in order to maximize natural sockeye egg to fry survival in the river channel following a low flow regime during the spawning season, control of flood-related scouring is desirable.

Both proportionate frequency analysis and mortality ratios (M_r) indicated that mortality began to increase in the mid-October to early November period. Intragravel mortality at Stations 1A, 2B and 5 in 1977 occurred at the same time and at similar levels as mortalities during the 1976 spawning season. There did not appear to be a relationship between the level of mortality and intragravel egg and alevin densities. Environmental causes of intragravel mortality have been reviewed in Stober et al. (1978).

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