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CEDAR RIVER SOCKEYE SALMON PRODUCTION

1980

by

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## 1.0 ABSTRACT

The 1979 Cedar River escapement was estimated at 185,300 spawners which were the progeny of the 1975 brood year impacted by the maximum flood of record. The river discharge during the 1979 spawning season was regulated along the critical year flow curve due to extant drought conditions. A moderate flood in mid-December probably reduced natural egg survival. A total of  $14.9 \times 10^6$  fry were estimated to have entered Lake Washington. This included  $5.1 \times 10^6$  sockeye fry estimated to have survived from  $9.7 \times 10^6$  artificially produced fry from the WDF incubation facility. The egg-to-fry survival rate for the entire run was 4.0 percent.

Infectious hematopoietic necrosis (IHN) viral disease was isolated in all returning adults sampled. The first detection of virus in fry occurred simultaneously in the incubation boxes and fyke net catches. The infection rate declined to a low level after all fry had emigrated from the enhancement facilities.

Four brood years (1975, 1976, 1978 and 1979) were compared with associated environmental conditions. The 1976 and 1978 brood years are comparable, except the escapement in 1978 was doubled; however, the resulting fry productions were about equal with the unknown survivors from  $9.6 \times 10^6$  artificially produced fry. The egg-to-fry survival was 8.1, 4.5 and 4.0 for the 1976, 1978 and 1979 brood years, respectively. The number of pre-emergent fry has increased with enhancement production. Density-dependent mortality due to redd superimposition, disease and flood impacts are the most likely causes of the low egg-to-fry survival.

Keywords: instream flow\*, water diversion, sockeye salmon\*, fry production\*, flood effects\*, environmental effects, stream habitat, infectious hematopoietic necrosis\*, density-dependent mortality, fry marking, artificial enhancement.

## 2.0 ACKNOWLEDGEMENTS

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### 3.0 INTRODUCTION

The Cedar River is the major spawning ground for the Lake Washington sockeye salmon which were first introduced from Baker Lake, Washington, in 1935 (Woodey 1966). Adult returns were insignificant prior to 1964 (Kolb 1971). Since then the Cedar River escapements have exceeded 100,000 sockeye, with the record of 410,000 in 1977. The run now is of economic and biological importance to the State and the Seattle metropolitan area and is presently the largest run of this species in the contiguous 48 states.

The life cycle of the Lake Washington sockeye was described by Woodey (1966, 1972). The adults return from June to August and remain in the Lake for 1-4 months before spawning. Usually over 90 percent of the escapement spawns in the Cedar River from early September through late December. The fry emerge from the gravel from January through late May and immediately migrate down the river. Shortly after entering the lake, the fry move offshore into the limnetic zone and feed primarily on zooplankton. After 12-15 months rearing in the lake, the juveniles smolt and migrate to sea during the spring.

Instream flow requirements for sockeye salmon spawning, incubation and emergence have received considerable attention because the Cedar River watershed is managed as the primary source of municipal and industrial water supply for the Seattle metropolitan area. The effects of minimum discharge on the available spawning area were determined by Collings *et al.* (1972) and Stober and Graybill (1974). Miller (1976) investigated the relationships between discharge, fish production and water supply while Bryant (1976) modelled the biological production of Lake Washington sockeye salmon. The effects of a major flood, instream spawning flows and density dependent

mortality factors on sockeye production were determined by Stober et al. (1978a). Monitoring during the 1977 spawning season was also conducted to obtain data on the largest escapement in the Cedar River (Stober et al. 1978b); however, the fry production for that year class was not determined. Stober and Hamalainen (1979) reported the fry production in 1979 which resulted from the fourth largest escapement in 1978.

This report presents and interprets the data on (1) the environmental conditions during the 1979-80 season; (2) adult escapement; (3) fry mark-recapture studies; (4) incidence of infectious hematopoietic necrosis (IHN) viral disease; and (5) estimation of the artificial enhancement and natural sockeye fry production in 1980. Interpretation of the present data has been made by comparison with previous results in order to yield information useful in the future management of this run.

#### 4.0 DESCRIPTION OF STUDY AREA

The Cedar River drainage area covers 487 km<sup>2</sup>. The river originates on the west slope of the Cascade Mountains, flows across the lowlands of the Puget Sound area, and empties into Lake Washington at Renton (Fig. 1). Average annual rainfall ranges from 250 cm (primarily as snow) in the head waters 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 typical pattern of lowland streams. Runoff may occasionally increase during spring snowmelts.

The discharge of the Cedar River is regulated both by operation of the Cedar Falls hydroelectric station below Chester Morse Lake and by an annual diversion of about 4.8 m<sup>3</sup>/s at Landsburg by the Seattle Water Department. Only the lower 34.2 km of the river below the diversion dam are available to anadromous salmonids such as sockeye, chinook and coho salmon, and steelhead and cutthroat trout.

Fry sampling was conducted near the mouth of the river at the exact location of the 1976, 1977 and 1979 studies (Fig. 1). The site lies below all spawning areas in the river and was restricted to the general public. Electric power was obtained from Renton Municipal Airport. The channel at this site was straight with a coarse gravel bottom 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. The average depth varied from 0.4 m to 0.8 m. Increased flows were recorded in March and late April.

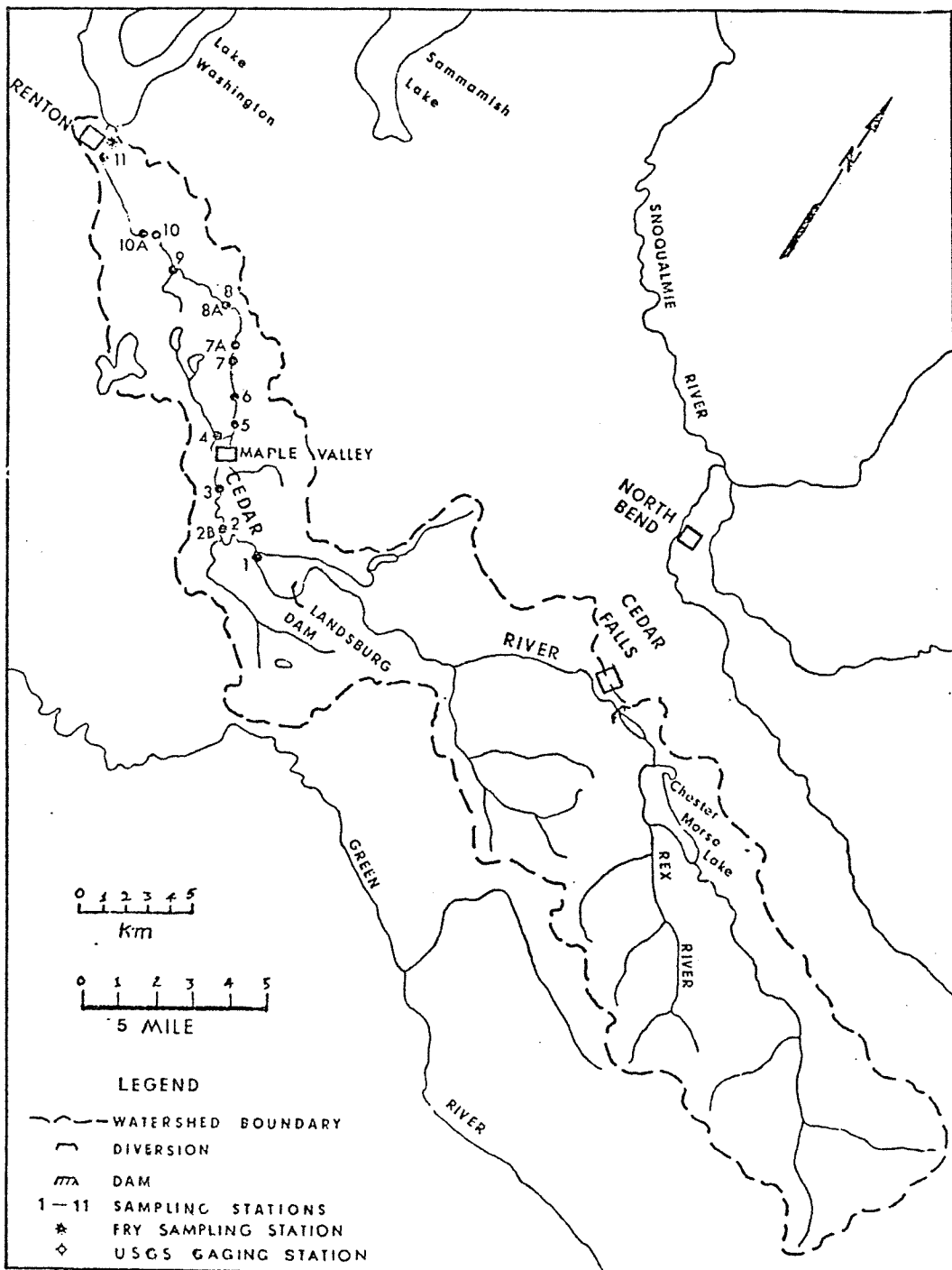


Fig. 1. Map of Cedar River watershed, showing location of study reaches, stream gauges, and fry sampling station.

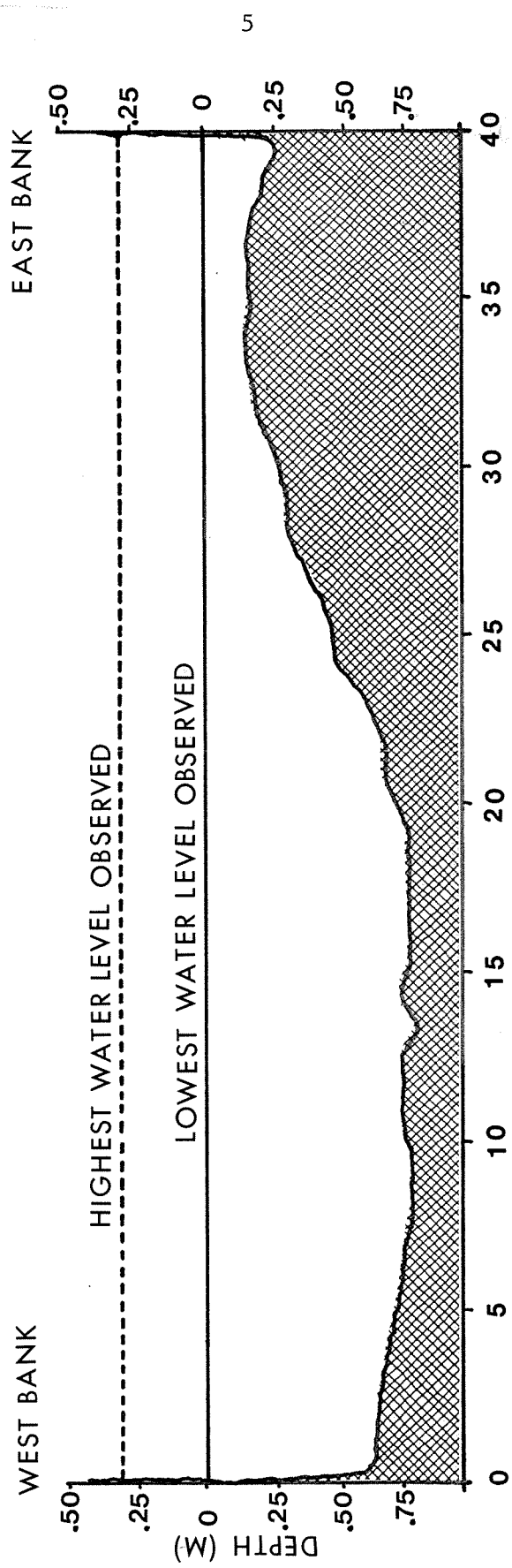


Fig. 2. Cross-section of the Cedar River at the fyke net sampling site.

## 5.0 MATERIALS AND METHODS

### 5.1 Potential Egg Deposition and Timing of Emergence

Estimates of the potential egg deposition were based on the following assumptions: (1) the female-to-male ratio was 58:42, and (2) the average egg deposition of each female was 3,500 eggs. Purse seine test fishing (Jewell et al. 1969) and the 1976 WDF sockeye enhancement program near the river mouth found a 58:42 female-to-male ratio. The average Cedar River sockeye fecundity was determined by Heiser (1962) and Bryant (1976) to be about 3,500 eggs.

The expected timing of emergence was calculated for 10-day spawning populations based on the 1979 escapement curve and previous incubation studies (Stober et al. 1978a). The number of temperature units calculated varied with the average incubation temperature. We assumed that fish deposited their eggs in an average of 10 days. Ames (WDF, personal communication) felt that 7 days used in previous studies was too short. This time period was probably longer than 10 days in the beginning, and shorter at the end of the spawning season. Since dissolved oxygen concentration in the intra-gravel water may have affected the rate of development, 56 temperature units (C) (TU, defined as 1°C above 0°C for a 24-hour period = 5.9 x TU F) were added to correct for potential oxygen deficits (Brannon, personal communication).

### 5.2 Emigrant Fry Sampling

The fyke net apparatus described in the 1976 and 1977 studies was used again to sample the emigrant sockeye fry (Stober et al. 1978a). This apparatus, powered by an electric winch, was easily operated by one person.

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 vinyl collar provided a reinforced surface for clamping to a live tank (Fig. 3). The net was made of 3-mm knotless nylon mesh. The seams were sewn with nylon tape and reinforced with polypropylene lines, which attached the net to the frame. A vinyl collar encircled the net mouth to provide a strong, abrasion-resistance 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. 3). 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 funnelled into a submersible live tank (Fig. 3). 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 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 in the ground (Figs. 4 and 5). Tension on the cable was adjusted by a large turnbuckle.

Movement of the net was facilitated by a polypropylene rope (positioning line) running through wooden blocks hung from the A-frame to a hand winch. A

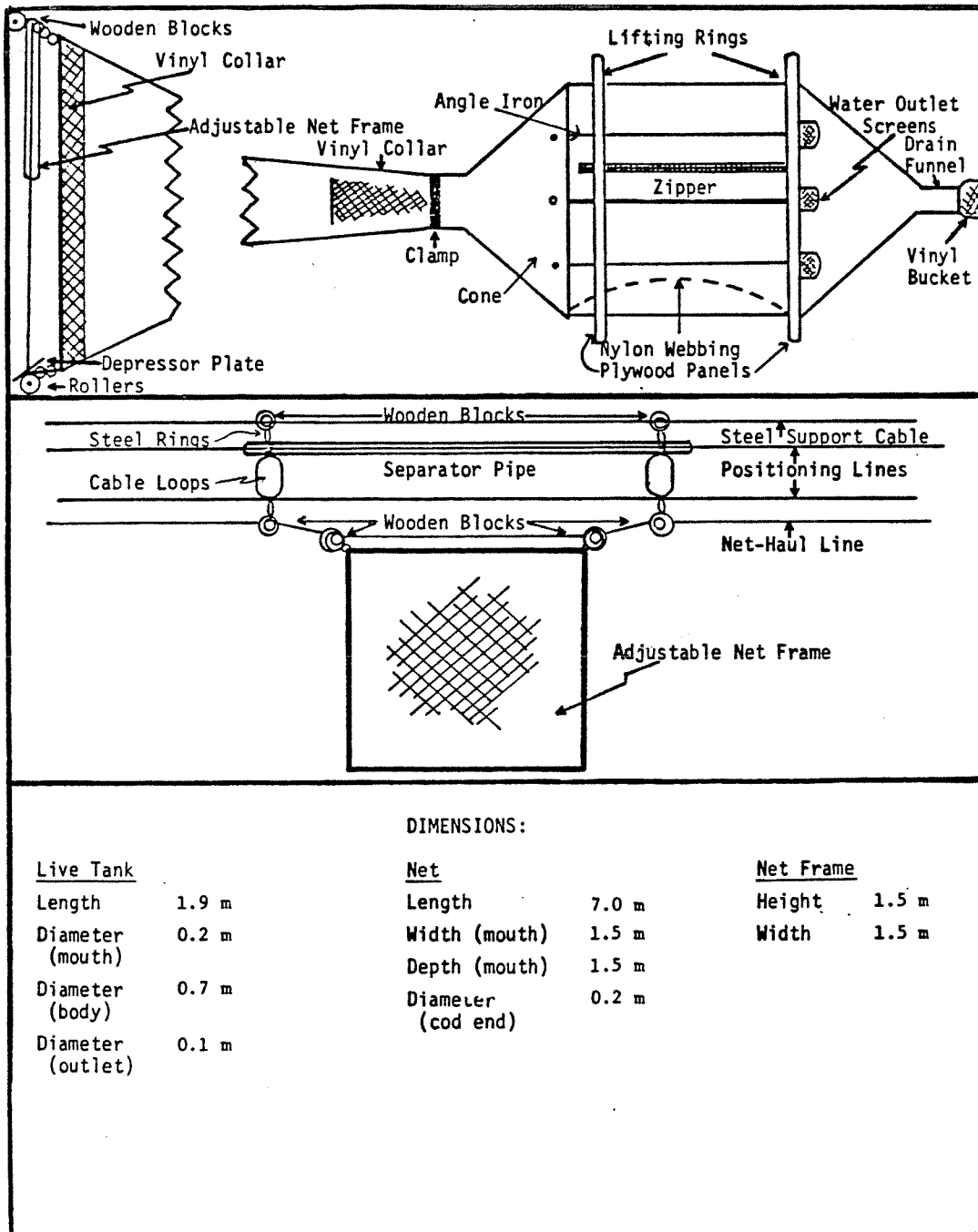


Fig. 3. Schematic diagram of the sockeye fry sampling nets, live tank, and positioning gear.

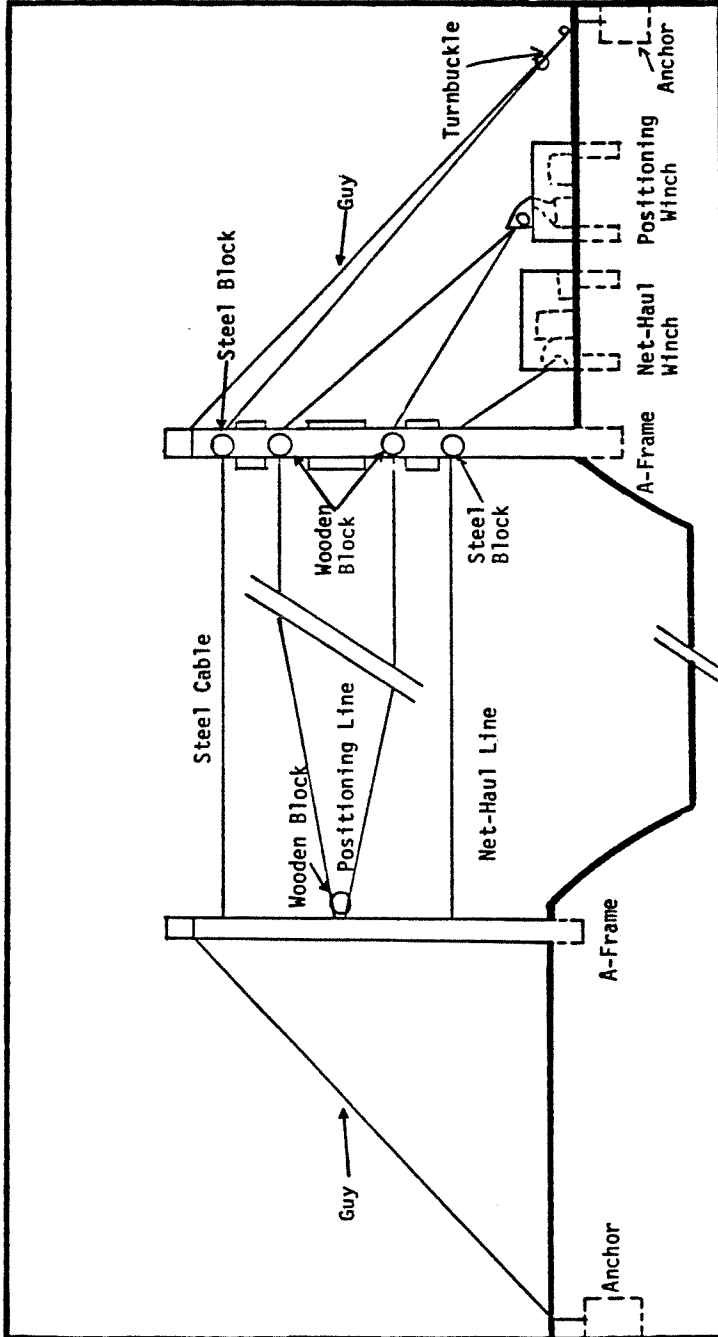


Fig. 4. Schematic diagram of the fyke net apparatus (side view).

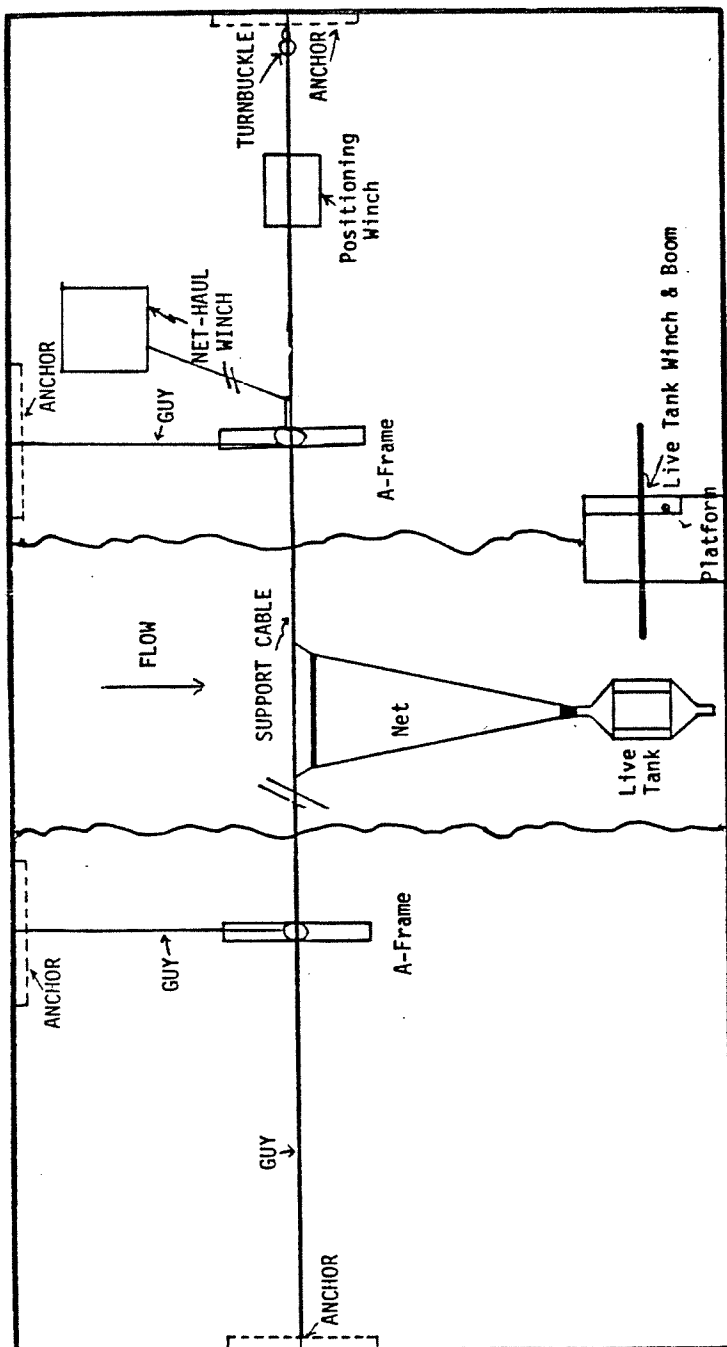


Fig. 5. Plan view of the sockeye fry sampling apparatus.

galvanized separator pipe with rings at each end was attached to the positioning line. Two wooden blocks, which travelled on the support cable, were secured to the pipe rings by cable loops. Hung below these rings were two blocks to which the lower corners of the net frame were secured by ropes. The 13-mm net haul line ran through these, and two similarly-sized blocks in 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.

The net was set by moving it with a hand winch 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 long boom, supported by a small A-frame mounted on a platform on the river bank. 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. Since no reduction in water

velocity inside the net mouth was observed and the velocities remained above 30.0 cm/s, 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 second (17.5 cm/s). 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/s. These studies supported our assumption of negligible net avoidance.

#### 5.2.1 Sampling Design

Diurnal sampling conducted in 1976, 1977 and 1979 showed insignificant emigration during daylight hours (Stober et al. 1978a, Stober and Hamalainen 1979). Therefore, nightly sampling was begun prior to sunset and ended after sunrise. The same four sampling locations as in 1976, 1977 and 1979 were chosen at distances of 4.6, 10.0, 16.5 and 22.0 m from the west bank. A random sampling scheme among these four sites was used to derive an estimate of the total fry emigration. Each net set 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. One-half hour was allowed between each set to process the catch and to clean and reset the net.

Pertinent fyke net sampling data were recorded on Fisheries Research Institute (FRI) coding form S.170.3 (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.

Samples were taken once or twice a week between January 24 and March 8, and May 17 and June 11. Sampling was conducted three times weekly (usually Monday, Tuesday and Thursday), except during the marking study when 4 consecutive nights were sampled following each release of marked fish.

#### 5.2.2 Fry Estimation

Fry estimation procedures followed those utilized during 1976, 1977 and 1979. 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 1980 were obtained by multiplying the hourly catches by these weighting factors.

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

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

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:

$$T_k = \frac{n_k \sum N_i}{m_k} , \quad (2)$$

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:

$$T_c = \sum T_k , \quad (3)$$

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,  $\text{Var}(\hat{T}_c)$  was estimated from:

$$\text{Var}(\hat{T}_c) = \sum \frac{n_k}{m_k} \sum \text{Var}(N_i) . \quad (4)$$

The interval estimate was then obtained from:

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

where

$$Z_\alpha = 95 \text{ percent normal probability, critical value} = 1.96.$$

### 5.2.3 Fry Quality

Length-weight data were collected from fry samples to provide information on 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 ( $\alpha = 0.05$ ) was used to establish significant within-season changes in length and in weight. Condition factors were computed using the formula:

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

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

#### 5.2.4 Fry Marking

In order to assess the fry contribution from the WDF enhancement program to Lake Washington, a large number of fry were marked at the Landsburg egg incubation boxes. The rate of emigration and the mortality for artificially propagated fry during the downstream emigration were determined from the fyke net catches.

A staining method detailed by Ward and Verhoeven (1963) was followed. The International Pacific Salmon Commission (IPSC) has used Bismarck Brown Y stain routinely with good results (Woodey, personal communication). This dye is a certified biological stain and contained 51 percent dye; therefore the conversion factor to obtain the true dye concentration was 1.96.

On March 10, 81,000 sockeye fry were placed in a deep hatchery trough (2.8 x 0.4 x 0.4 m) with 600 l of flowing water. Twenty g of dye (1:30,000 based on weight) was dissolved in a small amount of water and introduced into

the trough. Water flow was turned off immediately. Aeration was provided by a 1.8 hp aquarium compressor. At first the sockeye fry reacted with distress but returned to normal swimming patterns in about 10 minutes. After immersion in the staining solution for 1 hour, the dye was flushed out and the marked fry were held in flowing water until their release before sunset. Fyke netting at the river mouth was conducted during 4 consecutive nights with a 24-hour sampling on the third day.

To assess the mortality from the staining procedure, 500 fry each (treated and untreated) were placed in two small net cages. Dead fish were removed and counted at 2 to 3-day intervals. Stained and unstained fry were preserved throughout the holding period for color comparisons.

A second group of fry totalling 185,000 fry was stained on March 24 in two hatchery troughs. The methodology was exactly the same as on March 10. Water temperature on both days was 8.5°C.

Fry estimation on the marked fry was done using the same weighting factors as for the unmarked fry. We assumed that the marked fry were thoroughly mixed with other fry and had the same catchability. The fry contribution from the enhancement to Lake Washington was derived from the survival rate and the number of fry released. The natural production of sockeye salmon fry was then estimated by subtraction. We assumed that wild fry may have a slightly lower mortality rate than marked fry.

## 6.0 RESULTS AND DISCUSSION

### 6.1 Water Quantity and Quality

A provisional hydrograph of the river discharge recorded at the USGS gauging station at Renton is presented for the period from August 1979 through June 15, 1980 (Fig. 6). Normal and critical year minimum flows were established for the Cedar River by the Washington State Dept. of Ecology (DOE) in 1979. These curves are plotted for reference in Fig. 6. Drought conditions prevailed through the fall of 1979 and the river discharge was regulated by the City of Seattle Water Department along the critical year flow curve. Significant rainfall began in December and a small flood occurred during the last half of December 1979 with a maximum discharge of  $91.9 \text{ m}^3/\text{s}$ . Winter and spring of 1980 were characterized by a succession of random peaks in discharge of up to  $42 \text{ m}^3/\text{s}$ . Discharge in May and June declined to low levels.

The discharge (August–November) during the 1979 spawning season approximated the hydrograph developed by Stober and Graybill (1974) to meet the spawning requirements of sockeye salmon in the Cedar River. The flood in December probably decreased the survival of eggs spawned near mid-channel by earlier fish. The impact of the 1979 flood is considered moderate compared with the maximum discharge of  $249.3 \text{ m}^3/\text{sec}$  recorded in 1975 on this year class. Peak discharges of less than  $50 \text{ m}^3/\text{s}$  have been shown to have little effect on sockeye survival by comparison to the presmolt-to-spawner ratio (Stober et al. 1978). Sockeye spawning during late December and early January was probably restricted to the margins of the river channel where water depths and velocities were suitable for spawning.

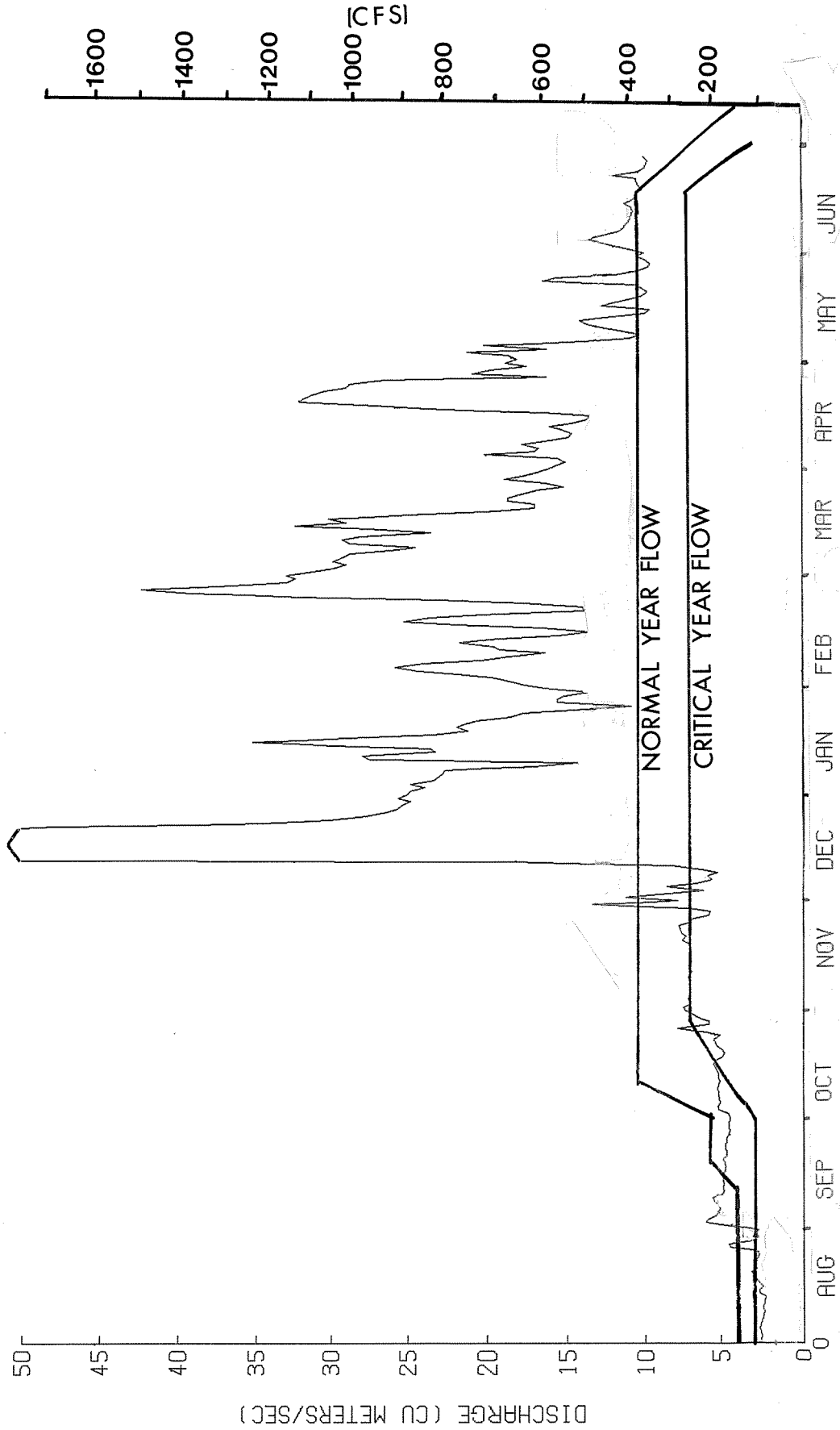


Fig. 6. Daily discharge at USGS Renton gauge from August 1979 through June 1980 (source: U.S. Geological Survey), with normal and critical year minimum flow curves (Wash. DOE).

Mean daily water temperature (based on hourly readings) for August 1979 through June 1980 measured at the Renton gauging station are presented in Fig. 7. The thermal ranges during the 1979 spawning season were warmer than in 1975 and 1978, but slightly lower than in 1976. The lowest water temperature recorded was 0.1°C.

The maximum daily turbidity at Landsburg for the period from August 1979 through June 1980 was closely related to the discharge pattern (Fig. 7). Turbidity increased during late fall and winter.

## 6.2 Escapement

The 1979 escapement to the Cedar River was estimated by the WDF at 185,300 of which about 13,000 salmon were taken for the enhancement program (Fig. 8). Ames (personal communication) felt that the tower counts were in error, so he based the estimate on six float trips and constructed an escapement curve (Fig. 9). The 1978 escapement curve and tower counts were plotted for comparison. Actual escapement in 1978, based on tower counts, was 278,000, which was within  $\pm 5.0$  percent of the escapement curve methodology. Normal procedure is to extend the escapement curve line to December 31; however, the peak abundance in the river was about 3 weeks later than normal, so the termination of the run was assumed to be late by a like time period. Tower counts in early December were higher than normal, supporting extension of the escapement curve. About 50 percent of the escapement had entered the river by October 21, which was the latest date since 1972 (Fig. 10). Reasons for this later timing are not known, but the prevailing low flows until early December may have played a part in delay of the escapement. This year class

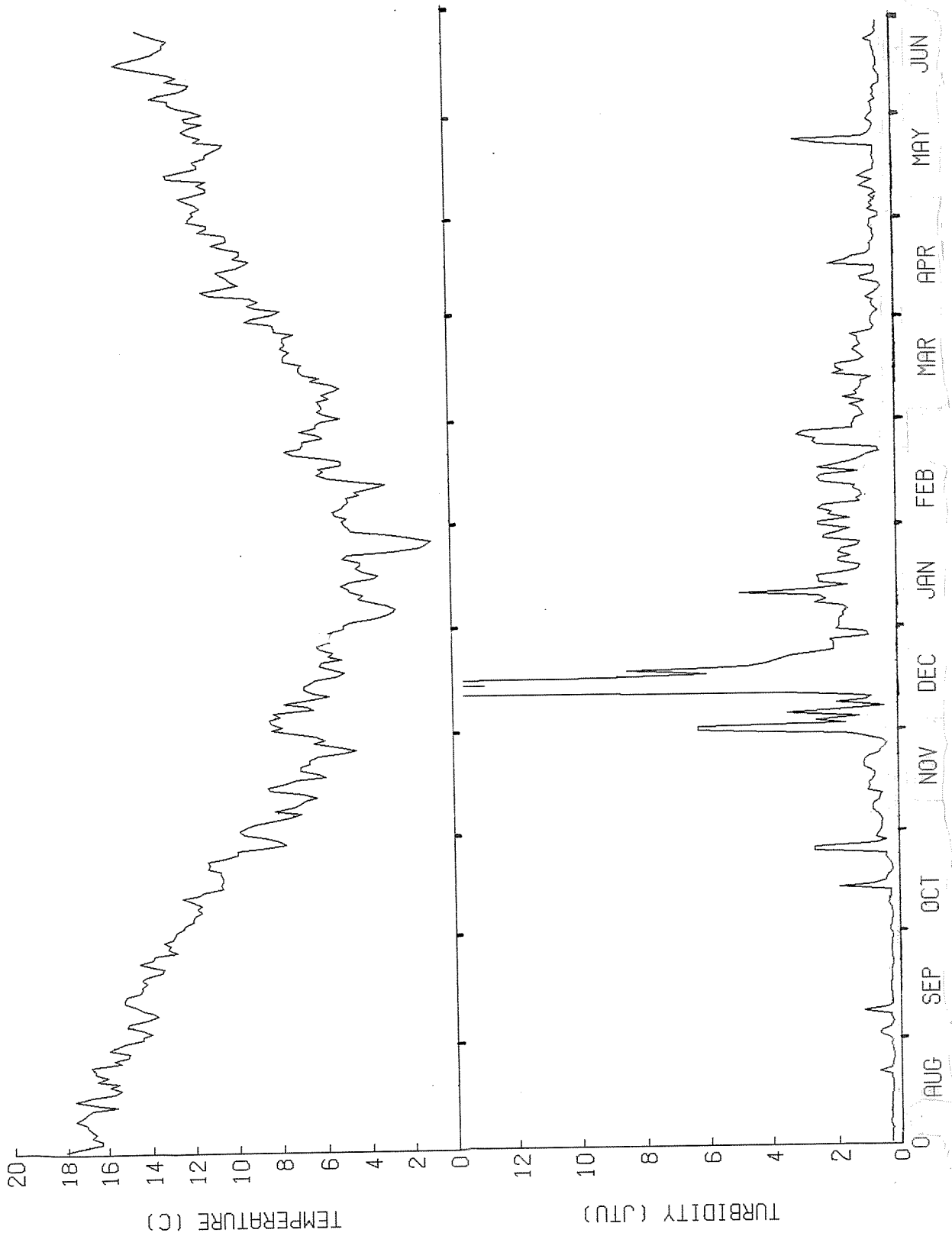


Fig. 7. Mean daily water temperatures at Renton and maximum daily turbidity at Landsburg from August 1979 through June 1980 (sources: U.S. Geological Survey and Seattle Water Department).

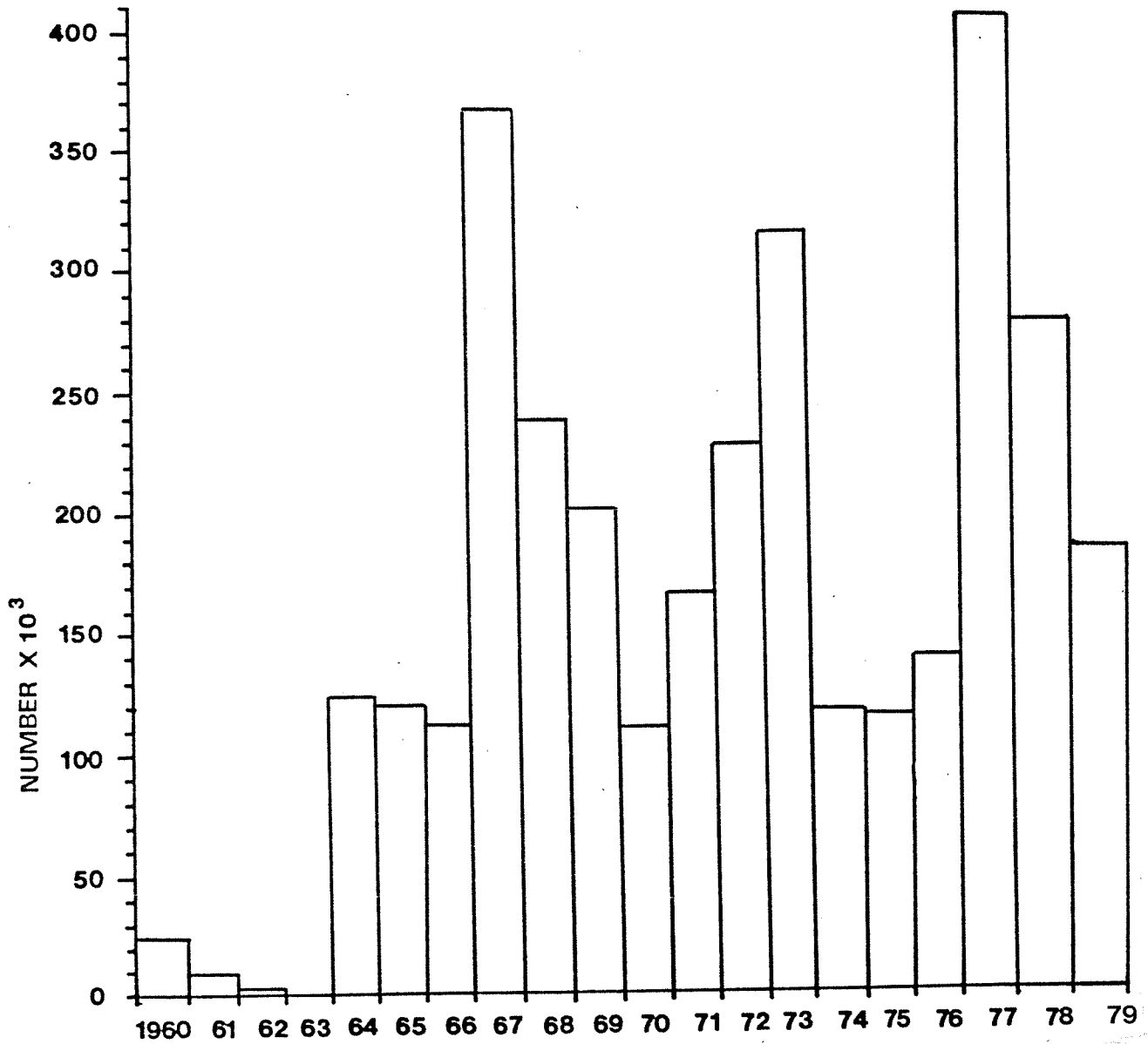


Fig. 8. Revised Cedar River sockeye salmon escapements 1960-1979 (WDF, unpublished).

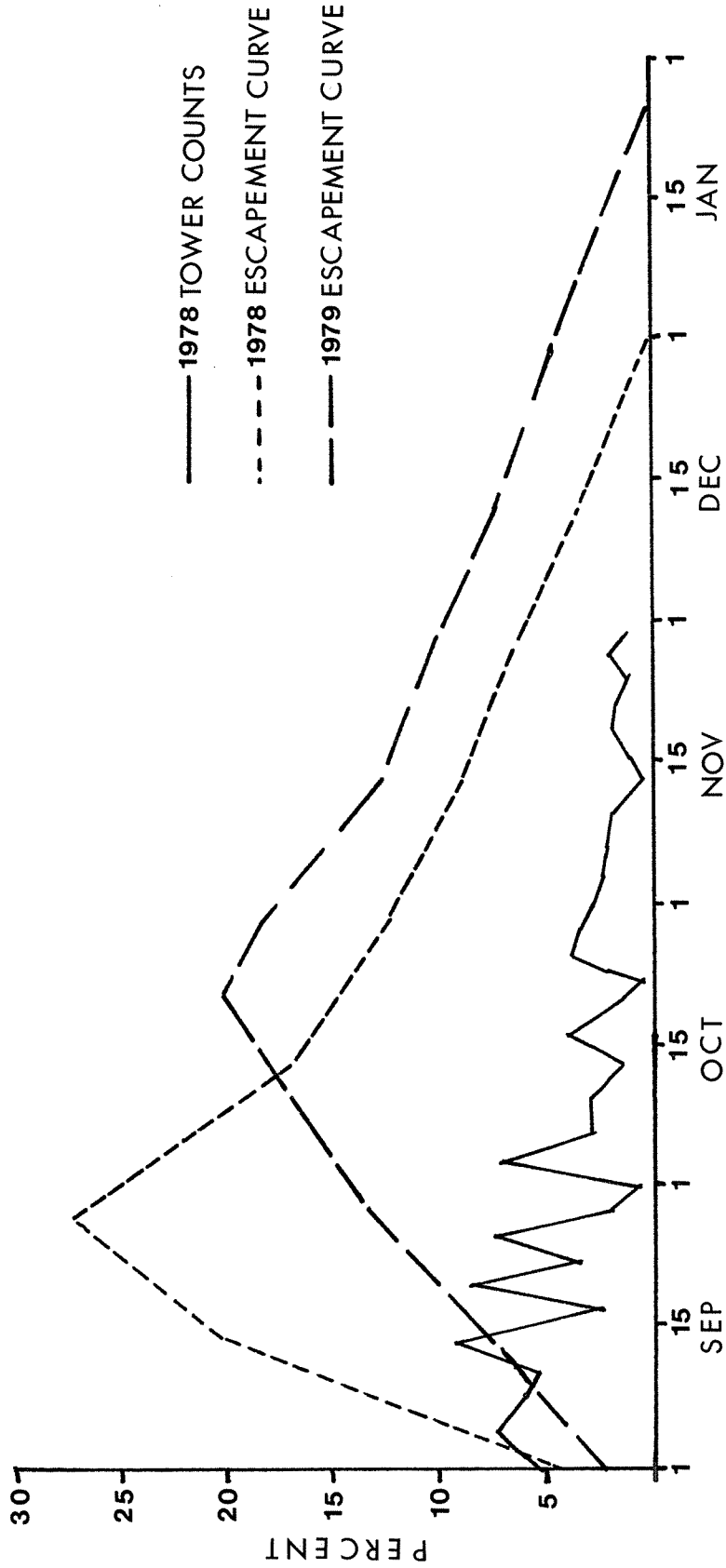


Fig. 9. 1978 tower counts and 1978 and 1979 escapement curves (source: WDF).

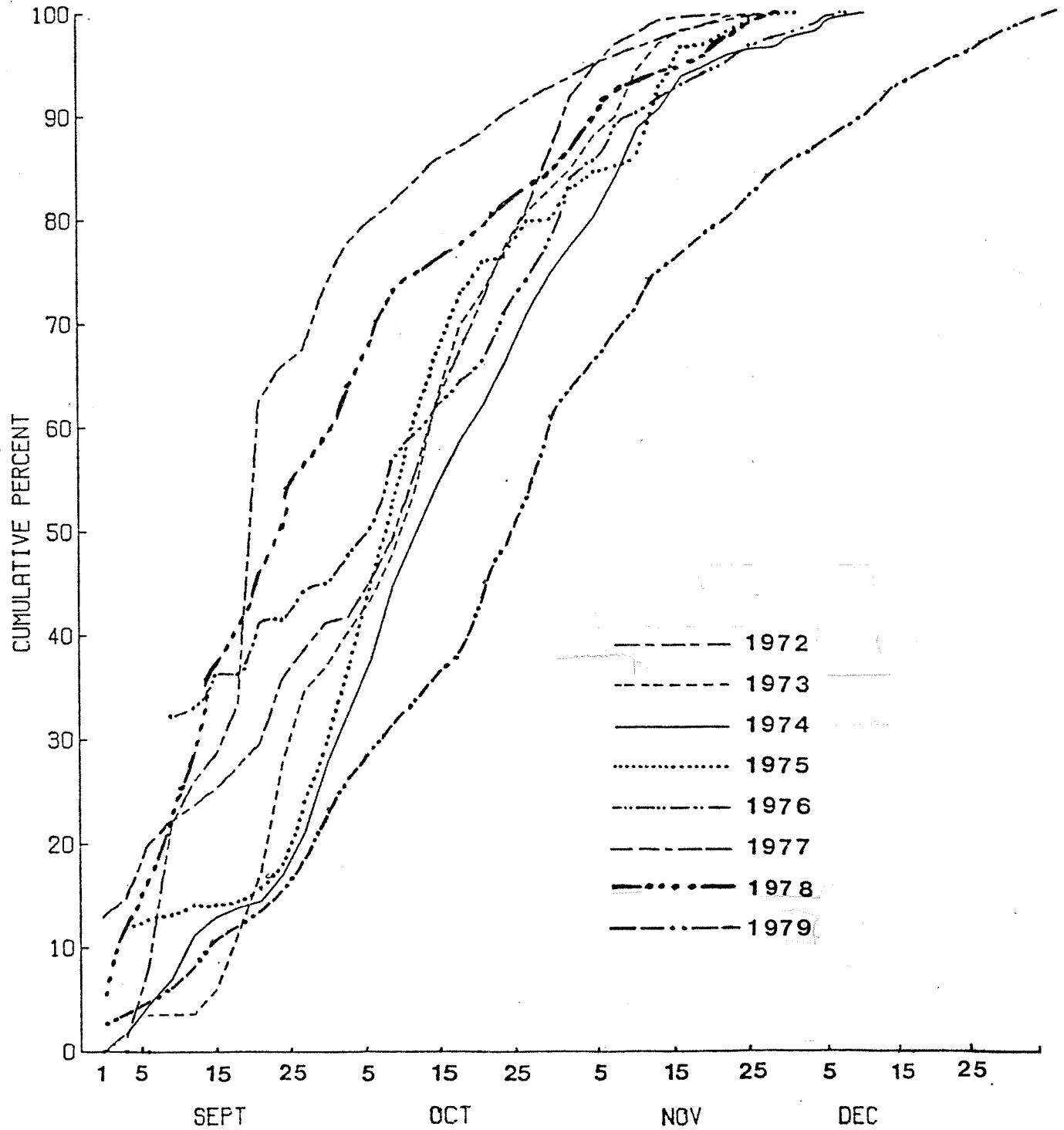


Fig. 10. Cumulative percentage of the tower counts by date for the Cedar River sockeye salmon escapement, 1972-1979 (source: WDF).

suffered a severe mortality due to the 1975 flood, which may have resulted in greater survival of the later-spawning fish. The timing of fry emigration was late in 1976, and only  $1.8 \times 10^6$  fry entered Lake Washington that year. The WDF forecast an escapement of less than 100,000 salmon but about twice as many returned. The 1976 year class seemed to experience exceptionally good lake and marine survival. A record number of jacks (10.7 percent) was estimated by the WDF (Ames, personal communication) in 1979. We suspect that the age composition may have included more than the usual number of 3 and 5-year-old fish.

### 6.3 Fry Behavior and Emigration

The downstream movement of sockeye salmon fry occurred during the dark and usually peaked from 2 to 5 hours after sunset (Fig. 11). Byrne (1971) observed a similar nightly behavior pattern under experimental conditions. Possible confounding due to site location across the channel was eliminated by restricting sampling to one site during nocturnal test sampling. The timing of peak emigration varied nightly, indicating differences in river and weather conditions, and very likely the distance of migration. The nightly migration period started later and became shorter as the daylight hours increased with the season. Twenty-four-hour sampling in March and May indicated that less than 1 percent emigrated during the daytime.

Our assumptions of the emigration rates (Stober and Hamalainen 1979) were confirmed by the marking studies. Fry released at Landsburg were first captured from 6 to 7 hours after sunset. The travel time of water from Landsburg to Renton has been estimated by the Seattle Water Department to be

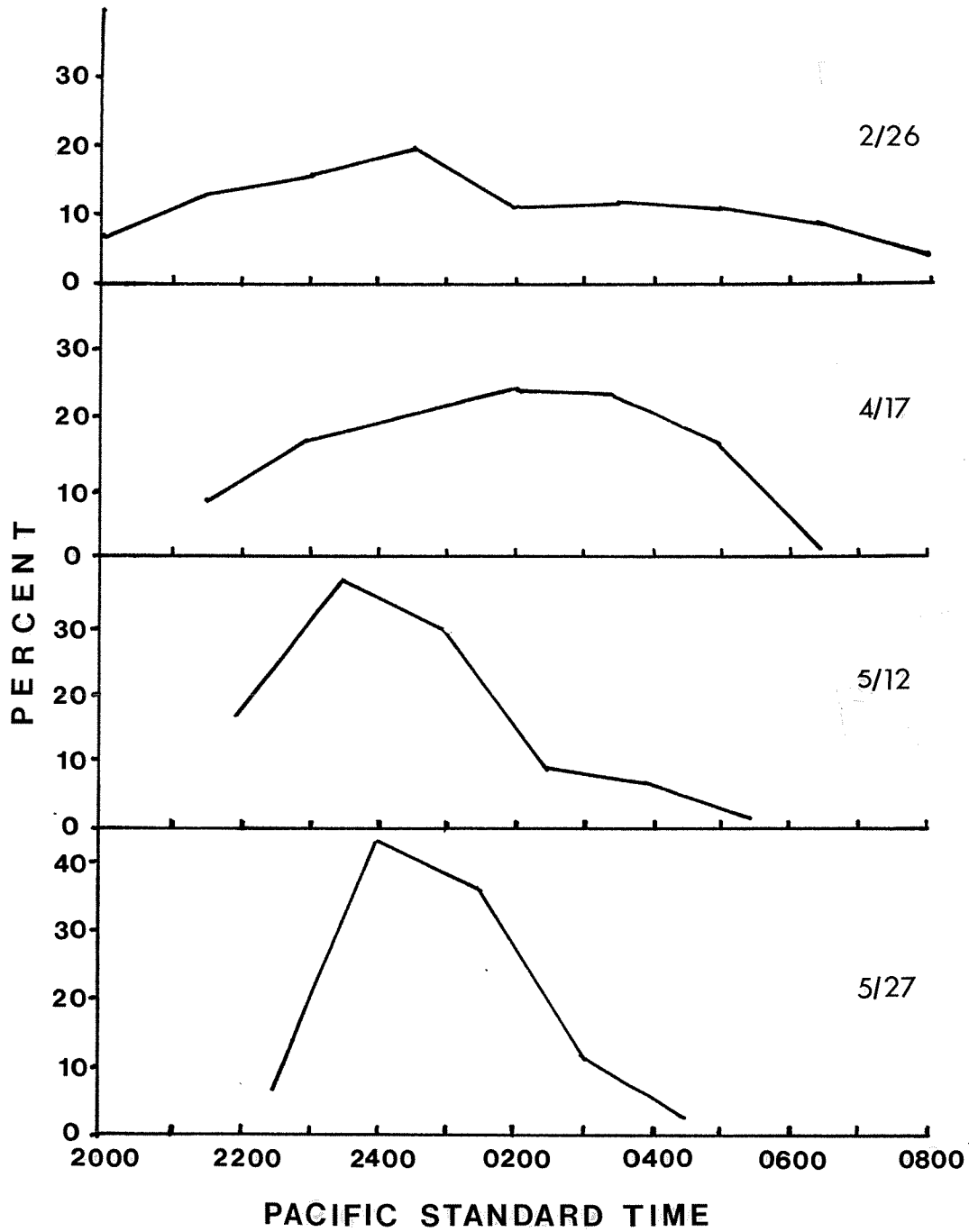


Fig. 11. Hourly distribution of nocturnal downstream movement of sockeye salmon fry for four representative periods in 1980.

from 6 to 8 hours depending on the flow. If fry emerged from the spawning gravel during early evening hours, they could reach the lake before sunrise. Active downstream movement by sockeye fry was observed by Hartman et al. (1962). Over 85 percent of the marked fry emigrated during the first night and more than 80 percent of that catch was taken in 1 hour. Small numbers of fry were captured the next 2 or 3 nights. The catch data indicated that all fry did not reach the lake during the night of emergence but delayed under vegetation and rocks during daylight hours.

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. Fry released during the daytime quickly disappeared under stones and vegetation.

The horizontal distribution of sockeye fry across the river channel was generally related to the velocity and water depth (Fig. 12). Fish sought the fastest current (Sites 2 and 3). Over the entire season, 71.2 percent of the fry were captured on these two sites. Site 1 had consistently the lowest catches, most likely due to the slowest water velocity.

The daily emigration pattern was characterized by a series of random peaks with the majority of fry emigrating in March and April (Fig. 13 and Appendix Table 1). Catches were unusually low in January and February. The number of fry generally increased until March 10 when the peak emigration occurred with an estimated 407,000 fry. The daily estimates varied widely between 83,000 and 375,000 for the next 9 weeks. The catches declined in mid-May and the sampling was terminated on June 11.

The timing of the fry migration from the incubation boxes is indicated

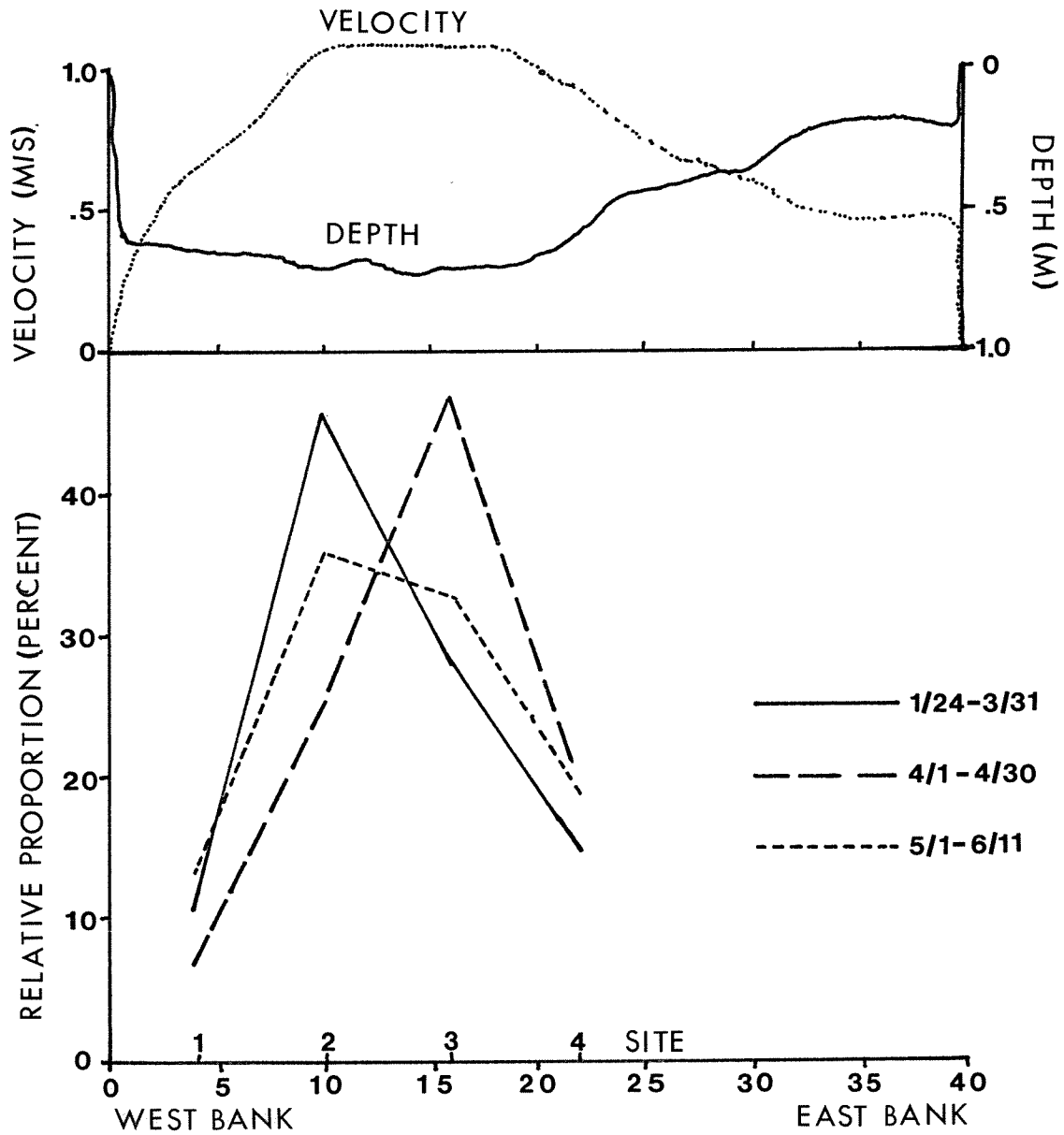


Fig. 12. Horizontal distribution of sockeye salmon fry by sample site during three periods of emigration with mean depth and velocity.

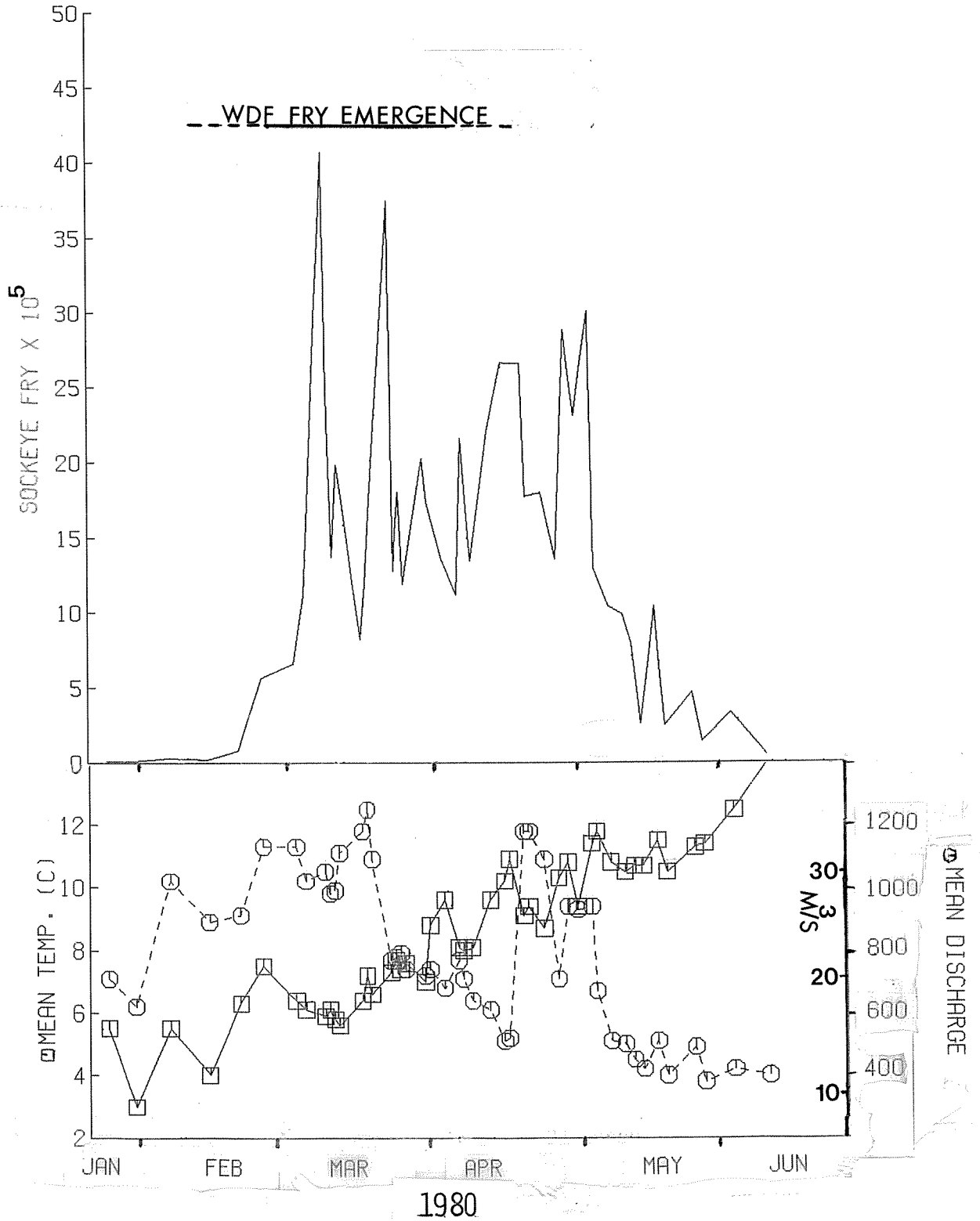


Fig. 13. Estimated daily emigration of sockeye fry from the 1979 brood year, with timing of the enhancement fry and with mean nocturnal discharge and temperature.

in Fig. 13. The WDF enumerated fry from only two boxes out of sixteen; therefore no daily contributions from the enhancement program could be evaluated. Emigration from these two index boxes occurred during the last 3 weeks in March, which represents less than half of the total emigration period from the incubation facilities.

Large day-to-day fluctuations in fry abundance at the sampling station were influenced by variations in discharge, water temperature, turbidity, light intensity, and the number of emerging fry. These parameters were often confounded, so it was difficult to single out any particular factor over a long period of time. Spearman correlation coefficients for nightly estimate, discharge, temperature, and turbidity are presented in Table 1. Discharge was a significant stimulus over the entire season and during the first and third time segments. Significant correlation was found between the estimate and the temperature in the beginning of the season while turbidity was a significant stimulus in May and June.

Daily estimates were used to derive weekly rates of emigration. These were increased by 1.0 percent to account for daytime movement. The weekly emigration pattern is presented in Fig. 14. Three major peaks in March and April were evident. The main emigration period occurred from early March through early May. The observed and expected migration pattern agreed quite well in timing with that calculated from the time of spawning and TU information; however, the overall survival was low.

Cumulative and monthly outputs of fry (percent) are presented in Fig. 15. Fifty percent of the emigration was completed by April 13. Comparative dates for 1976, 1977 and 1979 were April 21, March 21 and March 23, respectively.

Table 1. Relationship between the estimated number of sockeye fry and selected environmental factors (Spearman correlation coefficients) in 1980.

		1980		
	Estimate	Discharge	Temperature	Turbidity
		<u>Entire season</u> 1/24 - 6/11		
Estimate	1.0000			
Discharge	.3229*	1.0000	1.0000	
Temperature	.0612	-.6184**	-.4074*	
Turbidity	.0121	-.5651**		1.0000
		<u>First</u> 1/24 - 3/31		
Estimate	1.0000			
Discharge	.0948	1.0000	1.0000	
Temperature	.3839*	.0825	.2565	
Turbidity	-.1264	.7534**		1.0000
		<u>Second</u> 4/1 - 4/30		
Estimate	1.0000			
Discharge	-.1129	1.0000	1.0000	
Temperature	.5289	.3094	-.3670	
Turbidity	.2802	.2437		1.0000
		<u>Third</u> 5/1 - 6/11		
Estimate	1.0000			
Discharge	.9821**	1.0000	1.0000	
Temperature	.1903	-.1330	-.2130	
Turbidity	.5494*	.5317*		1.0000

\* Significant at the .05 level

\*\* Significant at the .001 level

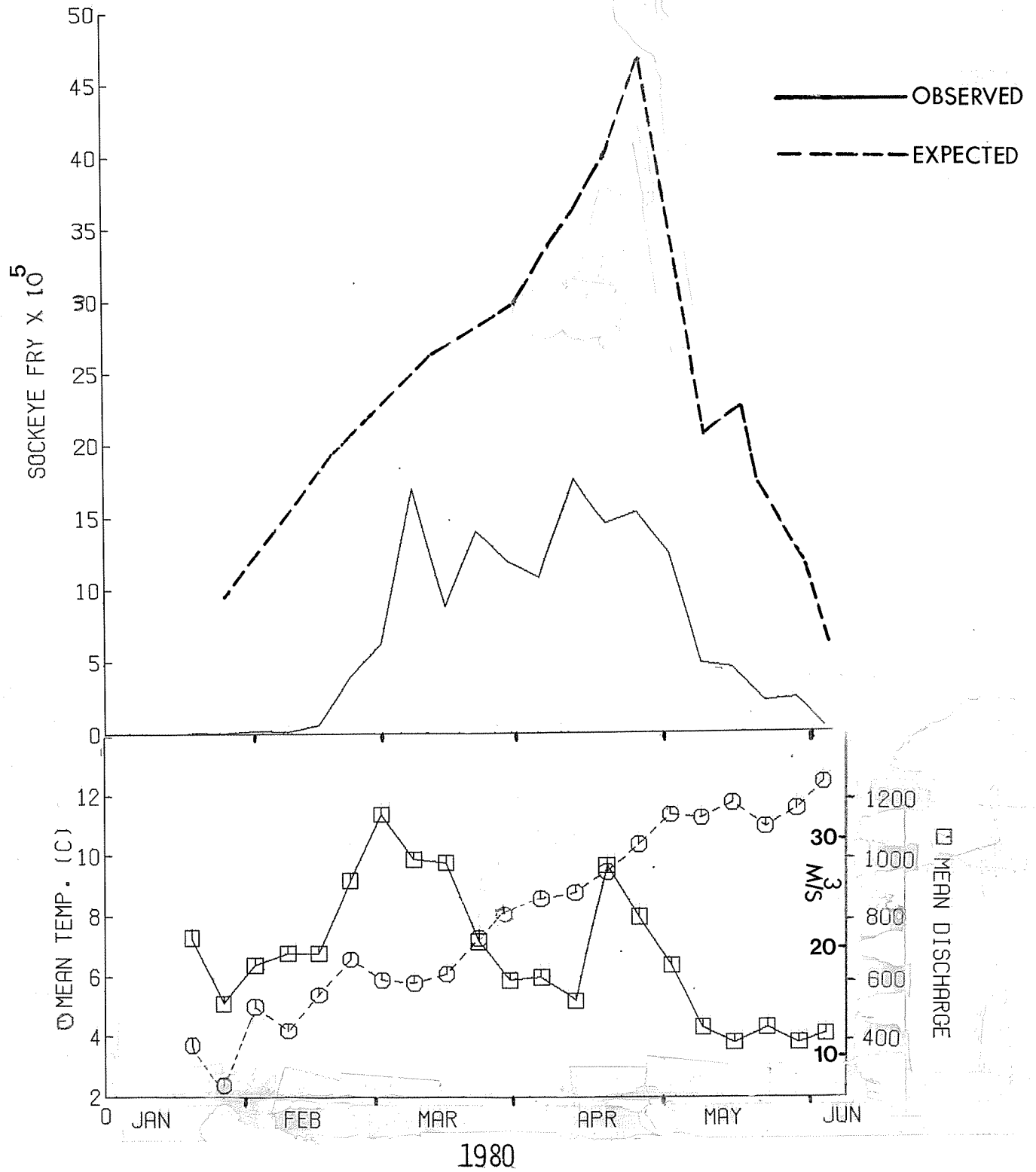


Fig. 14. Weekly observed and expected emigration of sockeye salmon fry from the 1979 brood year with mean temperature and discharge.

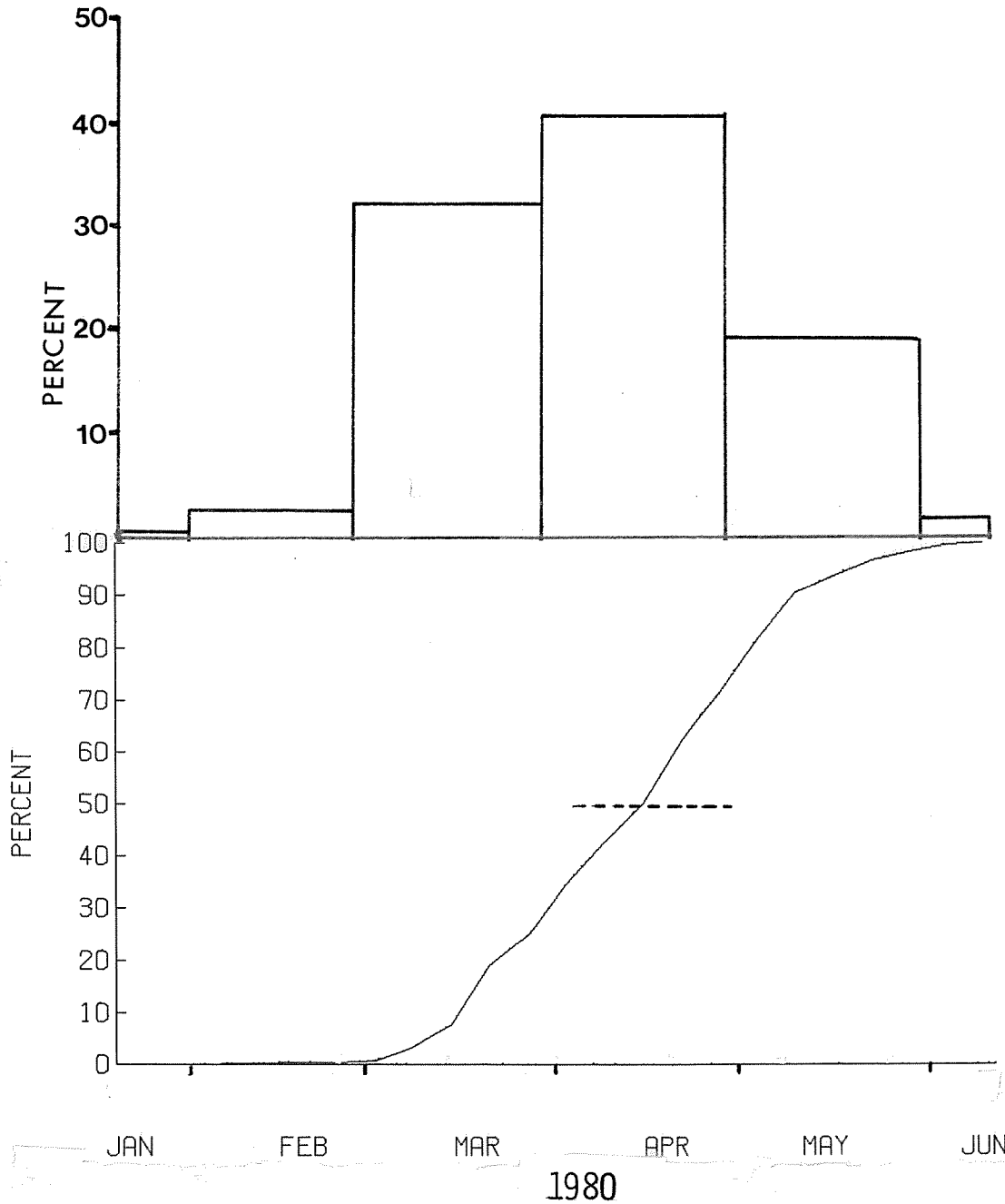


Fig. 15. Cumulative and monthly fry output from the 1979 brood year.

In 1980, 0.1 percent of the total downstream movement occurred in January, 3.3 percent in February, 33.4 percent in March, 42.2 percent in April, 19.2 percent in May and 1.8 percent in June. March and April accounted for 75.7 percent of the total emigration.

A total of 46 nights was sampled during the 4.5-month emigration period. The total estimate was  $14.9 \times 10^6$  ( $\pm 1.4 \times 10^6$ ) sockeye fry.

#### 6.4 Fry Survival

Based on the escapement estimates, sex ratio, and fecundity, the potential egg deposition for the 1979 brood year was calculated at  $3.76 \times 10^8$  eggs. Since the total estimate was  $14.9 \times 10^6$  fry, a 4.0 percent egg-to-fry survival resulted.

The success of the various segments of the escapement was determined. The season was divided into three time periods: early (August and September), middle (October), and late (November, December, and January) (Table 2). Only 12.7 percent was estimated to have spawned early, contributing 6.3 percent of the fry with the lowest survival of 2.0 percent. Approximately one third (36.2 percent) deposited their eggs in October. These eggs experienced a relatively good survival (6.0 percent) and produced over half of the fry (54.9 percent). The late portion of the escapement accounted for 51.1 percent of the run, contributing 38.8 percent of the fry produced. The survival was only 3.0 percent.

The egg-to-fry survival for the Cedar River was 0.8, 8.1, and 4.5 percent for the 1975, 1976, and 1978 brood years, respectively (Stober and Hamalainen 1979). Survival rates ranged from 0.8 to 19.3 percent (mean = 10.6 percent)

Table 2. Performance of the early, middle and late portions of the 1979 brood year.

Dates spawned	Escape- ment	%	Sex ratio	Fecun- dity	Potential egg depos.	Expected emergence	Days to emergence	Fry production	Survival %	Contribution
8/15- 9/30	23,600	12.7	42:58	3500	47,908,000	1/15-3/06	158	941,000	2.0	39.6
10/01- 10/31	67,000	36.2	42:58	3500	136,010,000	3/07-4/18	170	8,192,000	6.0	54.9
11/01- 1/15	94,700	51.1	42:58	3500	192,241,000	4/19-6/09	146	5,799,000	3.0	38.8
	185,300	100.0			376,159,000		158	14,932,000	4.0	100.0

in six river systems in British Columbia and the Soviet Union (Foerster 1968). Compared with previously published estimates, the fry survival in 1980 was low.

The pre-smolt to spawner (P/S) ratio for brood year 1979 was calculated for the Cedar River fry by equations of Bryant (1976) detailed by Stober et al. (1978a). This was necessary since acoustic smolt estimates in the lake have not yet been made for the 1979 brood year. The acoustic estimates also include smolts from sources other than the Cedar River as well as kokanee and it was necessary to calculate an independent estimate based only on the number of fry emigrating from the Cedar River. The equations were as follows:

$$S = J e^{-mt} , \quad (7)$$

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,

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

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:

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

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  $14.9 \times 10^6$  sockeye fry entered Lake Washington, of which  $9.7 \times 10^6$  fry were calculated to survive to July 1, 1980. A solution of equation (7) indicated that  $2.7 \times 10^6$  fry will survive to smolt, representing a 14.6 pre-smolt to spawner (P/S) ratio. This was similar to the 1968, 1972 and 1973 brood years with similar instantaneous peak flows (Miller 1976). He estimated the maximum P/S ratio to be 21.0. Flood flows, however, are only one of the several factors controlling survival.

### 6.5 Fry Quality

The 1980 length frequency distribution of sockeye salmon fry is presented in Fig. 16. Over 95 percent of the fry measured between 25 and 29 mm in length. The mean lengths ranged from 25.9 mm, at the mid-point of emigration (April), to 27.9 mm in February (Table 3). The fry sizes indicated that all fry until early May were newly emerged. The mean weights generally decreased with the season until early May when larger fry were observed (Table 3).

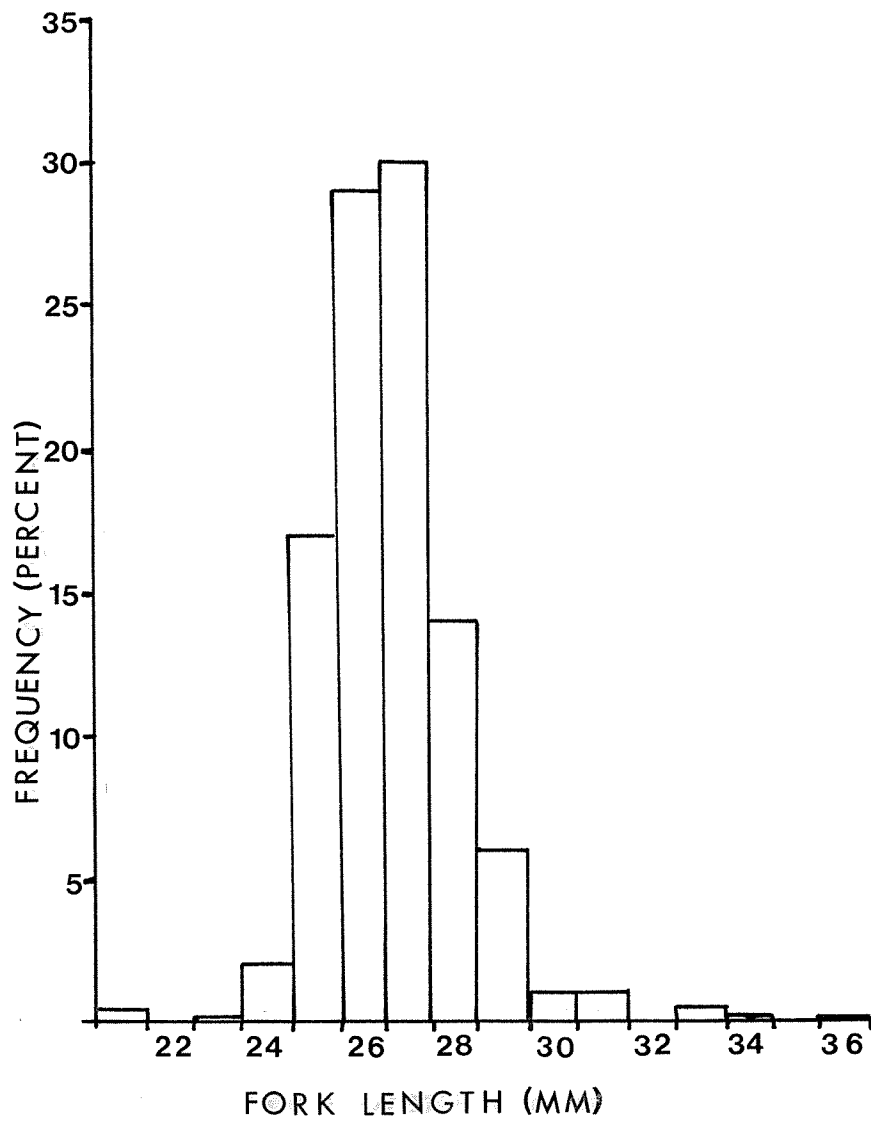


Fig. 16. Length frequency distribution of sockeye salmon fry in 1980.

Table 3. Mean length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for sockeye salmon fry sampled by fyke netting in 1980.

Week	N	Length (mm)	Weight (g)	Condition factor	Percent of complete fusion
1/19	16	27.4	.1438	.70	12.4
1/26	24	26.3	.1371	.75	41.7
2/02	50	26.9	.1494	.77	33.8
2/09	39	26.9	.1451	.75	23.1
2/16	50	27.8	.1694	.79	40.0
2/23	50	27.9	.1612	.74	61.0
3/01	50	27.5	.1610	.77	48.0
3/08	50	26.5	.1426	.77	93.0
3/15	50	26.4	.1476	.80	81.0
3/22	50	26.6	.1416	.75	87.0
3/29	50	26.1	.1402	.79	95.0
4/05	50	25.9	.1414	.81	84.0
4/12	50	26.0	.1394	.79	82.0
4/19	50	26.5	.1444	.78	85.0
4/26	50	26.4	.1370	.74	78.0
5/03	50	26.0	.1380	.79	73.0
5/10	50	27.7	.1356	.64	68.0
5/17	50	26.5	.1580	.85	77.0
5/24	50	26.4	.1452	.79	86.0
5/31	50	27.2	.1774	.88	97.0
6/07	50	27.1	.1752	.88	95.0
$\bar{X}$	46.6	26.6	.1491	.78	68.6

The weights ranged from .1356 to .1774 g. Condition factors fluctuated between .64 and .88, with no strong seasonal trend (Table 3). The high condition factors at the end of the season resulted from larger (> 30 mm) fry which had been rearing in the river.

The amount of yolk reserves in the fry were recorded to determine seasonal changes and relationship with environmental conditions. The percent of complete fusion of the mid-ventral wall ranged from a low 12.4 percent to 97.0 percent (Table 3). The degree of development generally advanced throughout the season, being high at about the mid-point and at the end of the downstream emigration period.

Size of the emerging fry is probably an important factor in their survival. Predator selectivity studies by Bams (1967), Beall (1972) and Ginetz (1972) showed a direct correlation between predation rate and fry length and stage of development. The proportion of "buttoned up" fry was unusually low during the first 7 weeks of sampling. These fish were emerging prematurely and likely experienced high mortality. High flows, which could have washed out fry from the spawning gravel, were not recorded during that time. This may have been a result of artificially produced fry with a large percentage of yolk reserves during the first half of the season.

#### 6.6 Fry Marking

After emerging from the gravel and during the migration to Lake Washington, the fry are vulnerable to consumption by predators, primarily other and larger fish species. Losses due to predation vary widely but are believed to be quite appreciable.

Data collected during the marking study are presented in Table 4. Almost 95 percent of the fry emigrated during the first night after marking (3/10) when the flow and turbidity were high, and the sky was overcast. The number of marked fry decreased rapidly during the following three nights. The effects of large fry releases from the two index gravel boxes are reflected in the total fry estimates on March 10, 13 and 24. An unknown number of fry could exit freely from the other boxes. The marked fry experienced a high survival rate of 74.8 percent from the March 10 release.

More than twice as many fry were stained on March 24. The rate of fry emigration during the first night was delayed (85.9 versus 94.6 percent). About equal numbers of fry were released by the WDF and estimated passing the fyke net station. Survival, however, was drastically reduced from 74.8 in the first release to 30.6 percent in the second release.

Bismarck Brown Y stain is an excellent method for marking small fish which cannot be handled individually in short-term studies. The anterior part of the body and all the fins were conspicuously stained golden brown. Fry were easily distinguishable for about 5 days. Bismarck Brown Y, which is readily soluble in water, fades after about 7 days. Control mortalities were 0 during the first week and varied from 1.2 to 5.2 percent during the following 7 days, coinciding with the observed losses from the IHN viral disease.

No studies were conducted to determine if stained and unstained fry were equally vulnerable to predation. Marked fry may have been better camouflaged at night.

There is a general lack of information on sockeye fry mortality during the downstream migration phase. Foerster (1968) cites three studies in British

Table 4. Estimated number of fry marked, recovered, fry survival, WDF fry releases from index boxes, and selected environmental factors during the marking study.

Date	Number of fry marked	Estimated number of marked fry	Percent of total marked fry	Percent survival	Total fry emigration	WDF fry releases	Discharge	Turbidity	Percent of cloud cover
3/10	81,000	57,300	94.6	70.7	407,000	237,000	1050	8	100
3/11		2,700	4.4	3.4	226,000		980	6	100
3/12		600	1.0	0.7	137,000		990	3	>90
3/13		0	0.0	0.0	198,000	175,000	1110	8	100
Total	81,000	60,000	100.0	74.8					
3/24	185,000	47,700	85.9	26.3	375,000	235,000	770	1	<10
3/25		6,700	11.8	3.6	128,000		780	0	>80
3/26		900	1.6	0.5	181,000		790	1	>90
3/27		400	0.7	0.2	120,000	40,000	740	2	<30
Total	185,000	56,700	100.0	30.6					

Columbia and the Soviet Union. Estimated mortalities due to predation ranged from about 10 percent to as high as 90 percent, mostly being between 50 and 75 percent.

Schouwenburg (personal communication) studied chinook salmon fry mortality during the downstream migration in British Columbia. He released marked fish 6.4 km above the counting weir and recorded a 60 percent loss. Spray-marked chum fry released 2.3 and 10.0 km above the enumeration weir at Big Beef Creek (Hood Canal, Washington) suffered 27 and 57 percent losses, respectively (Fresh, personal communication). Wetherall (1971) concluded that chinook salmon smolts experienced higher mortality during low flows and longer downstream migration.

Resident and anadromous trout (Salmo gairdneri, S. clarki), whitefish (Prosopium williamsoni), and sculpins (Cottus sp.) are potential predators of sockeye salmon fry in the Cedar River (Casne 1975). In addition, they were preyed upon by coho (Oncorhynchus kisutch) and chinook salmon (O. tshawytscha) and some birds.

Significant predation by coho salmon was reported by Hunter (1959), Roos (1960), Hartman et al. (1962), and Mead and Woodall (1968). Ward and Larkin (1964) concluded that predation by rainbow trout may be a significant factor in causing cyclic dominance in Adams River sockeye salmon. Ginetz (1972), and Ginetz and Larkin (1976) observed higher predation mortalities of sockeye fry by rainbow trout at an earlier development stage in moonlight by contrast to cloudy light intensities, at lesser turbidities and at lower water velocities.

Predation on salmon and trout fry by sculpins can be intense in certain situations (Hunter 1959; Sheridan and Meehan 1962; Patten 1962, 1971, 1972;

Clary 1972). Foerster (1968) reported the stomach content of sculpins contained on the average 4.63 to 5.41 sockeye fry in British Columbia. The effects of sculpin predation on sockeye fry in the Cedar River remain undefined, but it could be significant due to the great abundance of sculpins.

A wide range in fry survival was observed between the two marked fry releases. This was probably a result of the different environmental conditions during the critical first night. It was raining continuously on March 10 and 11, causing the river to be high, fast and turbid. Predators were less able to detect their prey, exposure time was shortened, and spatial distribution of fry expanded. Predators may have been confined along the river margins which were probably avoided by the downstream migrants. Compared to other studies, 74.8 percent survival over a 33.4 km downstream migration constitutes a very high survival rate.

The environmental conditions on March 24 and 25 were different from the first marking trial. The river was clear, low and slow, while the sky was completely clear. Fry seemed to delay their migration. Spatially and temporally prey and predators were more confined. Mortality was similar to the predation loss of 75 percent estimated by Foerster (1968) for British Columbia sockeye salmon.

#### 6.7 Artificial Enhancement

The WDF has been producing sockeye fry in gravel incubation boxes at Landsburg since 1975. Production has increased yearly to the total of  $9.7 \times 10^6$  fry in 1980 (personal communication, K. Bauersfeld). Fry emerged from the incubation boxes from late January through early April (Fig. 13),

during the first half of the emigration period. There were not enough data to determine daily emigration rates. About 50 percent of the egg take occurred in November (late portion of the spawning season) but all fry emerged during the early or middle portion of the emergence. This was due to the warmer water temperatures in the incubation boxes.

The fry quality for artificially produced and fyke net caught fry, which included both introduced and wild fry, during the same time period are presented in Table 5. All fry were measured by the junior author in the same laboratory. The WDF fry were always (except 3/22) shorter and less developed than the ones from the fyke net catches. Weights and condition factors were higher, a phenomenon often observed in premature fry. Survival in the natural river environment, however, is lower for fry with large yolk sacs (Bams 1967, Ginetz 1972).

Applying the mean survival of 52.7 percent obtained in the marking study to the total of  $9.7 \times 10^6$  fry artificially produced, the fry contribution to Lake Washington was estimated at  $5.1 \times 10^6$ . The natural fry production of  $9.8 \times 10^6$  fry in 1980 was obtained by subtraction.

#### 6.8 Infectious Hematopoetic Necrosis (IHN)

In 1978, the National Fisheries Research Center-Seattle (NFRC) diagnosed IHN virus in dying sockeye salmon fry produced in the WDF incubation boxes at Landsburg. A cooperative effort was begun in 1979 between the WDF and NFRC to characterize the disease. In addition, weekly samples of fry captured at the river mouth were taken to the NFRC laboratory.

Returning adults were tested for IHN virus which was found in 100 percent

Table 5. Mean length, weight, condition factor and percentage of complete fusion of the mid-ventral wall for sockeye salmon fry from the WDF incubation boxes and the fyke net catches in 1980.

Date	N		Length (mm)		Weight (g)		Condition factor		Percent of complete fusion	
	WDF	F.N.	WDF	F.N.	WDF	F.N.	WDF	F.N.	WDF	F.N.
2/23	50	50	26.7	27.9	.1736	.1612	.91	.74	45.0	61.0
3/01	50	50	25.3	27.5	.1646	.1610	1.02	.77	48.0	48.0
3/08	50	50	25.4	26.5	.1568	.1426	.96	.77	39.0	93.0
3/15	50	50	25.8	26.4	.1502	.1476	.87	.80	61.0	81.0
3/22	50	50	27.0	26.6	.1526	.1416	.78	.75	80.0	87.0
3/29	50	50	24.4	26.1	.1494	.1402	1.03	.79	96.0	95.0
$\bar{X}$ =	50	50	25.8	26.8	.1579	.1490	.93	.77	61.5	77.5

of the fish. High and low titer levels were more common than medium levels. Virus was also detected in water from the side channel used for egg taking. The high infection rate in returning salmon may be due to lifelong infection and horizontal spread through water-borne virus.

No virus was detected in water samples from the boxes, eggs or in pre-emergent fry (Fig. 17). The first mortalities and positive samples were observed simultaneously. All moribund fish suffered from IHN.

To determine if mortality continues after fry migrate out of the boxes, several hundred fry from four boxes were taken to the NFRC laboratory. Cumulative mortalities over a 7-week period were 98, 94, 8, and 0 percent. No mortality was recorded in the latter two boxes at Landsburg. Despite different water temperatures, mortality in box 13 and in fry at the laboratory coincided. Some of the tested fry had very high levels of virus. Most likely these fry died before emigration or probably suffered delayed mortality in the lake.

Fry captured at the river mouth were negative until the appearance of IHN virus in the artificially produced fry (Fig. 17). Unfortunately, 1 week's sample was partially ruined by equipment failure. It probably had a higher infection rate. Low incidence of virus was found in fry after mid-April when all fry were produced naturally. No positive fry were recorded in two samples in May of 1976, but this may have been due to limited sampling. IHN was detected through May 1980.

No virus was detected in the Cedar River chinook fry or in sockeye fry sampled from egg boxes in Thornton, Kelsey and Juanita Creeks. The sockeye eggs were transferred from the Cedar River. Undoubtedly this disease caused additional mortality of sockeye fry in the Cedar River in 1980. Williams and

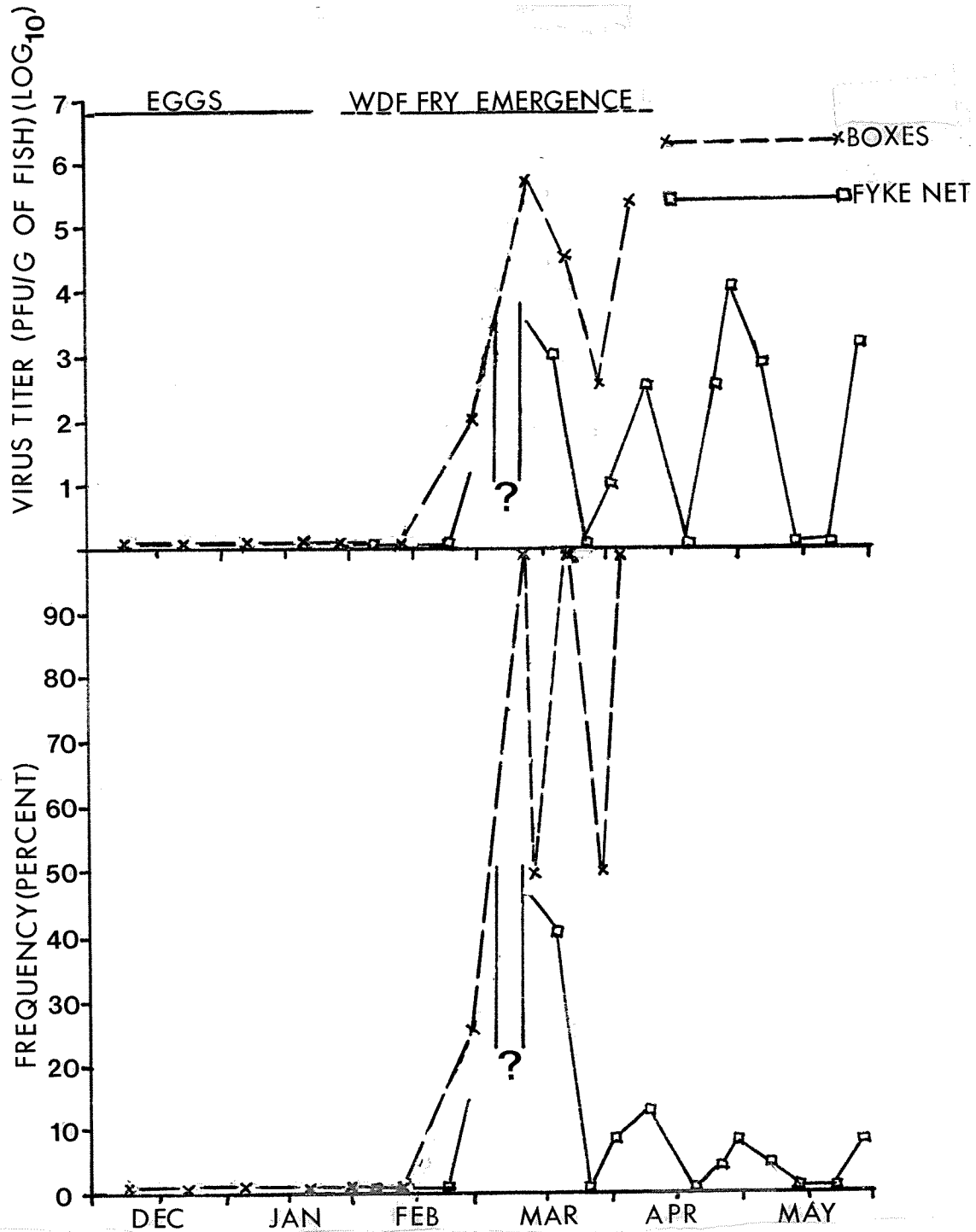


Fig. 17. Frequency and IHN virus titers in sockeye salmon fry sampled from WDF incubation boxes and fyke net catches in 1980.

Amend (1976) reported the first confirmed epizootic of IHN under natural conditions for sockeye salmon in Chilko Lake, British Columbia. The egg-to-fry survival of 3.8 percent was the lowest ever recorded at Chilko over a 25-year period.

#### 6.9 Sampling Mortality

Mortality caused by the fyke net and handling was determined on six occasions in 1980. Mortality ranged from 2.8 to 7.6 percent with a mean of 5.5 percent (Table 6). An estimated  $1.4 \times 10^4$  fry were killed of the total estimated  $14.9 \times 10^6$  fry. This represents a very small portion of the 1980 fry production.

#### 6.10 Incidental Species

Several other species of fish were captured incidental to sockeye fry sampling (Table 7). These were actual catches; no total estimates were done for these species. Chinook salmon fry were captured in large numbers. Frequent catches of cottids, longfin smelt (Spirinchus thaleichthys), juvenile coho salmon, and lampreys (Lampetra sp.) were made. For the first time in 4 years pink salmon fry (O. gorbuscha) were seen in the fyke net catches.

Table 6. Fry test mortality for the 1980 fyke net sampling season.

Date	Number of fry killed	Total	Percent
2/26	7	127	5.5
4/01	10	131	7.6
4/28	6	111	5.4
5/12	7	121	5.8
5/19	8	131	6.1
6/04	3	109	2.8
Mean			5.5

Table 7. Weekly catch of incidental species in 1980.

Date	Fry				Fingerling						
	Coho	Pink	Chinook	Steelhead	Coho	Chinook	Steelhead	Longfin smelt	Threespine Stickleback	Lamprey	Cottids
1/19					4						9
1/26			2		1					2	4
2/02			12		4					1	3
2/09			11		6						4
2/16			25		11						3
2/23											
3/01			76		7					1	5
3/08	4		243		3				1	4	11
3/15	6		150		8						4
3/22		31	267					13		8	6
3/29		43	194		2			46			5
4/05		18	397		4		1	57		5	7
4/12		7	89					7		1	
4/19	9	2	190		40	2	2	1		1	3
4/26			171	1	15		6	2		4	5
5/03	2		176	2	2		1			3	5
5/10			14	2						2	2
5/17			4	3		4				1	3
5/24			29	4					1		3
5/31				3		1					2
6/07				1							1
Total	21	101	2050	16	107	7	10	126	2	33	85

## 7.0 SUMMARY AND CONCLUSIONS

The 1979 escapement was estimated by the WDF at 185,300, which was more than twice the number of spawners predicted. The returning adults were from the brood year which suffered severe mortality due to the record 1975 flood and ascended the Cedar River later than any other escapement since 1972. A high abundance of jacks (10.7 percent) was estimated in 1979. The discharge pattern during the spawning season generally followed the critical year flow hydrograph adopted by DOE because of the drought conditions experienced through November. A moderate flood at the end of the spawning season probably reduced survival based on the comparison of discharge to the pre-smolt-to-spawner ratio. The most severe scouring may have occurred in the mid-channel, where the early spawners deposited their eggs. Adults spawning after mid-December were probably restricted to the margins of the river channel.

The fry emigration was monitored by fyke net sampling at the mouth of the Cedar River. Forty-six nights were sampled over a 4.5-month emigration period. A total of  $14.9 \times 10^6$  fry were estimated to have entered Lake Washington. This included  $5.1 \times 10^6$  sockeye fry estimated to have survived from  $9.7 \times 10^6$  artificially produced fry. Egg-to-fry survival was 4.0 percent for the entire escapement. Early (August-September), middle (October) and late (November, December, January) segments of the run had survival rates of 2.0, 6.0, and 3.0 percent, respectively.

The occurrence of IHN viral disease was studied by the NFRC laboratory. All returning adults tested were carriers but not all boxes and fry sampled were positive. There may be a threshold of viral infection before it can be detected. The virus was detected first in emerging fry at the incubation

boxes and in the fyke net catches. The infection rate declined to low levels after all fry had emigrated from the incubation facilities at Landsburg. Undoubtedly this disease caused additional mortality in sockeye fry. Infestation may increase when fry are incubated in boxes at high densities and dense natural spawning populations may spread the disease more readily.

Four brood years (1975, 1976, 1978 and 1979) with resulting fry production estimates, are compared in Table 8. The 1975 brood year was impacted by the most severe flood thus far recorded for the Cedar River. The egg-to-fry survival was only 0.8 percent. This flood was estimated to have reduced the total maximum instantaneous spawned area by 38 percent between 1975 and 1976 with roughly equal escapements (Stober et al. 1978b). This loss of spawning gravel appears to be even more extreme when compared with the 143,995 m<sup>2</sup> area spawned in 1973 by 313,000 spawners. The loss of spawning habitat was apparently sustained through 1977 since the total area spawned remained at about 61,000 m<sup>2</sup> with the record escapement of 410,000 adults. It is probable that the habitat loss has been sustained and will remain so until sufficient time has passed for natural recruitment of spawning gravel. Sufficient time has passed that the spawning area should be surveyed again to evaluate the process of recovery.

The environmental conditions for the 1976 and 1978 brood years were comparable; however, the escapement in 1978 was doubled. The resulting fry productions were about equal with the unknown survivors from  $9.6 \times 10^6$  artificially produced fry. For 1976 the egg-to-fry survival was 8.1 percent; for 1978 it declined to 4.5 percent. A further reduction to 4.0 was observed for the 1979 brood year. Coinciding with an increase in the enhancement program

Table 8. Comparison of various parameters during four years of fry enumeration.

	1975-76	1976-77	1978-79	1979-80
Escapement	114,100	138,949	277,801	185,300
Peak discharge (m <sup>3</sup> /s)	249.2	34.6	47.6	91.9
Time to 50% escapement	10/8	10/6	9/23	10/21
Total instantaneous spawned area (m <sup>2</sup> )	9.3x10 <sup>4</sup>	5.8x10 <sup>4</sup>	N.A.	N.A.
Fry estimate (total)	1.8x10 <sup>6</sup>	22.8x10 <sup>6</sup>	25.5x10 <sup>6</sup>	14.9x10 <sup>6</sup>
Artificial enhancement	0.04x10 <sup>6</sup>	0.8x10 <sup>6</sup>	9.6x10 <sup>6</sup>	9.7x10 <sup>6</sup>
Time of 50% of emigration	4/21	3/21	3/23	4/13
Egg-to-fry survival	0.8	8.1	4.5	4.0
P/S ratio	5.8	20.1	7.7	14.6
Fry quality (2/4-5/7)				
Length	27.0	27.3	26.8	26.7
Weight	.1412	.1623	.1557	.1470
Condition factor	.72	.80	.81	.77
Percent of complete fusion	83.8	90.1	55.8	68.6
Disease	unknown	unknown	IHN	IHN

the percent of complete fusion of emergent fry has decreased. IHN viral disease was isolated in emerging fry in 1979 and 1980.

The critical year flow pattern and the moderate flood observed during the spawning season probably resulted in density-dependent mortality. Spawning was confined to the mid-channel until early December, followed by high discharges which may have restricted spawners along the river margins. The stepwise increase in spawnable area may not have been achieved in 1979. Redd superimposition under a similar flow pattern through November was observed in 1976 with a smaller escapement (Stober et al. 1978a).

In the summer of 1980 an estimated 490,000 adult sockeye salmon returned to Lake Washington. This record run was produced by a small ( $\sim 140,000$ ) 1976 escapement which experienced good environmental conditions during the incubation period. This may indicate that only modest escapements are needed to achieve good returns in the absence of floods.

Based on the present information we believe that the low survival of the 1979 brood year was caused by a combination of factors. The December 1979 flood may have resulted in loss of eggs and alevins. IHN disease undoubtedly caused some mortality in the Cedar River sockeye fry. Further monitoring is needed to confirm the interaction of disease with fry density. Especially important is to assess the resulting fry production from the record run currently in the lake. Additional monitoring to determine the total instantaneous area spawned in the river would provide an assessment of the rate of recovery of the natural spawning habitat. Finally, a reduction in the escapement may be needed to achieve greater efficiency in the egg-to-fry survival rate.

## 8.0 LITERATURE CITED

- Andrews, F. J., and G. H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Int. Pac. Sal. Comm. Bull. 11. 259 pp.
- Bams, R. A. 1967. Differences in performance of naturally and artificially propagated sockeye salmon migrant fry, as measured with swimming and predation tests. J. Fish. Res. Board Can. 24(5):1117-1152.
- Beall, E. P. 1972. The use of predator-prey tests to assess the quality of chum salmon (Oncorhynchus keta) fry. M.S. Thesis, Univ. Washington, Seattle. 105 pp.
- Bryant, M. D. 1976. Lake Washington sockeye salmon: biological production and simulated harvest by three fisheries. Ph.D. Dissertation, Univ. Washington, Seattle. 159 pp.
- Byrne, J. E. 1971. Photoperiodic activity changes in juvenile sockeye salmon (Oncorhynchus nerka). Canad. J. Zool. 49(8):1155-1158.
- Casne, S. R. 1975. Production and food of salmonid populations in three sections of the Cedar River, Washington. M.S. Thesis, Univ. Washington, Seattle. 57 pp.
- Clary, J. R. 1972. Predation on the brown trout by the slimy sculpin. Prog. Fish - Cult. 34(2):91-95.
- Collings, M. R., R. W. Smith and G. T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species. U.S. Geol. Surv., Water Supply Paper 1968. 109 pp.
- Foerster, R. E. 1968. The sockeye salmon, Oncorhynchus nerka. Fish. Res. Board Can., Bull. 162. 422 pp.
- Ginetz, R. M. J. 1972. Some factors affecting rainbow trout (Salmo gairdneri) predation on migrant sockeye salmon (Oncorhynchus nerka) fry. Can. Dept. Environ. Fish. Serv. Technical Report 1972-8. 88 pp.
- Ginetz, R. M. J., and P. A. Larkin. 1976. Factors affecting rainbow trout (Salmo gairdneri) predation on migrant fry of sockeye salmon (Oncorhynchus nerka). J. Fish. Res. Board Can. 33(1):19-24.
- Greenland, D. E., and A. E. Thomas. 1972. Swimming speed of fall chinook salmon (Oncorhynchus tshawytscha) fry. Trans. Amer. Fish. Soc. 101(4): 696-700.

- Hartman, W. L., C. W. Strickland and D. T. Hoopes. 1962. Survival and behavior of sockeye salmon fry migrating into Brooks Lake, Alaska. *Trans. Amer. Fish. Soc.* 91(2):133-139.
- Heiser, D. W. 1969. Fecundity of Cedar River sockeye salmon (Oncorhynchus nerka) 1968, 1969. Unpubl. Ms., Washington State Dep. Fish. 7 pp.
- Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. *J. Fish. Res. Board Can.* 16:835-886.
- Jewell, E. D., G. I. Fiscus and D. L. Pratt. 1969. A review of the 1969 Lake Washington sockeye run. *Spec. Rep., Mgmt. Res. Div., Washington State Dep. Fish.* 13 pp.
- Kolb, R. 1971. A review of Lake Washington sockeye (Oncorhynchus nerka) age and racial characteristics as determined by scale analysis. *Suppl. Prog. Rep., Washington State Dep. Fish.* 9 pp.
- Mead, R. W., and W. L. Woodall. 1968. Comparison of sockeye salmon fry produced by hatcheries, artificial channels and natural spawning areas. *Int. Pac. Salm. Fish. Comm. Prog. Rept.* 20. 41 pp.
- Miller, J. W. 1976. The effects of minimum and peak Cedar River stream flows on fish production and water supply. M.S. Thesis, Univ. Washington, Seattle. 230 pp.
- Patten, B. G. 1962. Cottid predation upon salmon fry in a Washington stream. *Trans. Am. Fish. Soc.* 91:427-429.
- Patten, B. G. 1971. Increased predation by the torrent sculpin, Cottus rhotheus, on coho salmon fry, Oncorhynchus kisutch, during moonlight nights. *J. Fish. Res. Board Can.* 28(9):1352-1354.
- Patten, B. G. 1975. Comparative vulnerability of fry of Pacific salmon and steelhead trout to predation by torrent sculpins in stream aquaria. *U.S. Nat. Mar. Fish. Serv. Fish. Bull.* 73(4):931-934.
- Roos, J. F. 1960. Predation of young coho salmon on sockeye salmon fry at Chignik. *Trans. Am. Fish. Soc.* 89(4):377-379.
- Schroder, S. L. 1973. Effects of density on the spawning success of chum salmon (Oncorhynchus keta) in an artificial spawning channel. M.S. Thesis, Univ. Washington, Seattle. 78 pp.
- Sheridan, W. L., and W. R. Meehan. 1962. Rehabilitation of Big Kitoi outlet stream, Afognak Island, Alaska. Alaska Fish Game Dept. Information Leaflet 11. 13 pp.

- Stober, Q. J., and J. P. Graybill. 1974. Effects of discharge in the Cedar River on sockeye salmon spawning area. Univ. Washington, Fish. Res. Inst. Final Rep. FRI-UW-7407. 39 pp.
- Stober, Q. J., R. E. Narita and A. H. Hamalainen. 1978a. Instream flow and the reproductive efficiency of sockeye salmon. Completion Report. FRI-UW-7808. 124 pp.
- Stober, Q. J., S. C. Crumley and R. L. McComas. 1978b. Prespawning mortality and the reproductive efficiency of Cedar River sockeye salmon. Completion Report. FRI-UW-7809. 53 pp.
- Stober, Q. J., and A. H. Hamalainen. 1979. Cedar River sockeye salmon fry emigration. Final Report. FRI-UW-7917. 52 pp.
- U.S. Army Corps of Engineers. 1974. Average annual flood loss for Cedar River sockeye salmon harvest. Unpubl. memo, Seattle District, Seattle, Washington.
- Ward, F. J., and P. A. Larkin. 1964. Cyclic dominance in Adams River sockeye salmon. Int. Pac. Salm. Fish. Comm. Prog. Rept. 11.
- Ward, F. J., and L. A. Verhoeven. 1963. Two biological stains as markers for sockeye salmon fry. Trans. Am. Fish. Soc. 62:379-383.
- Wetherall, J. A. 1971. Estimation of survival rates for chinook salmon during their downstream migration in the Green River, Washington. Ph.D. Dissertation, Univ. Washington, Seattle. 170 pp.
- Williams, I. V., and D. F. Amend. 1976. A natural epizootic of infectious hematopoietic necrosis in fry of sockeye salmon (*Oncorhynchus nerka*) at Chilko Lake, British Columbia. J. Fish. Res. Board Can. 33:1564-1567.
- Woodey, J. C. 1966. Sockeye salmon spawning grounds and adult returns in the Lake Washington watershed, 1965. M.S. Thesis, Univ. Washington, Seattle. 101 pp.
- Woodey, F. C. 1972. Distribution, feeding, and growth of juvenile sockeye salmon in Lake Washington. Ph.D. Dissertation, Univ. Washington, Seattle. 207 pp.

Appendix Table 1. Daily sockeye fry estimate, mean temperature, mean discharge (Q), and turbidity in the Cedar River, 1980.

Date	Estimate Number	Temperature (°C)	Q (cfs)	Turbidity (JTU)
1/24	1,085	5.5	710	6
1/30	770	3.0	620	0
2/06	2,765	5.5	1020	19
2/14	1,890	4.0	890	6
2/21	8,154	6.3	910	3
2/26	56,471	7.5	1130	12
3/04	65,731	6.4	1130	11
3/06	111,400	6.1	1020	10
3/10	407,147	5.9	1050	8
3/11	226,319	6.1	980	6
3/12	137,412	5.8	990	3
3/13	198,447	5.6	1110	8
3/18	82,551	6.4	1180	8
3/19	119,682	7.2	1250	11
3/20	175,446	6.6	1090	6
3/24	374,697	7.3	770	1
3/25	127,705	7.7	780	0
3/26	180,588	7.4	790	1
3/27	119,536	7.6	740	2
3/31	202,350	7.0	720	2
4/01	173,784	8.8	740	1
4/04	135,976	9.6	680	3
4/07	111,926	8.1	770	4
4/08	216,271	8.0	710	7
4/10	134,771	8.1	640	4
4/14	220,608	9.6	610	2
4/17	266,609	10.2	510	7
4/18	266,293	10.9	520	2
4/21	265,977	9.1	1180	7
4/22	177,556	9.4	1180	4
4/25	179,811	8.7	1090	4
4/28	135,888	10.3	710	2
4/30	288,644	10.8	940	4
5/02	231,162	9.4	930	3
5/05	301,097	11.4	940	3
5/06	129,928	11.8	670	5
5/09	104,534	10.8	510	3
5/12	98,719	10.5	500	3
5/14	79,637	10.7	450	6
5/16	26,125	10.7	420	4
5/19	104,328	11.5	510	4
5/21	24,872	10.5	400	2
5/27	46,872	11.3	490	3
5/29	14,395	11.4	380	2
6/04	33,524	12.5	420	2
6/11	5,512	14.1	400	1