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ASSESSMENT OF PRODUCTION OF CHUM SALMON FRY
FROM THE BIG BEEF CREEK SPAWNING CHANNEL

by

Steven L. Schroder

ANNUAL REPORT
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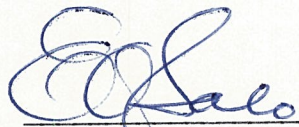
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PREFACE

This Annual Report provides preliminary results and background information on projects presently underway at Big Beef Creek.

The projects discussed include:

1. The effects of redd superimposition on the survival and quality of chum salmon fry produced from a spawning channel,
2. Effects of different gravel depths over sand substrates on the survival and quality of chum salmon fry, and
3. Renovation of portions of the existing spawning channel located at Big Beef Creek.

I. THE EFFECTS OF REDD SUPERIMPOSITION ON THE SURVIVAL AND QUALITY OF
CHUM SALMON FRY PRODUCED FROM A SPAWNING CHANNEL

Introduction

Because of changes in historic spawning grounds, overfishing, and unknown factors operating within the Pacific Ocean, stocks of chum salmon (Oncorhynchus keta) native to many North American streams have been declining in abundance (Fulton, 1970). The production of this species is governed to a large degree by the quality of its freshwater spawning grounds (McNeil, 1966). For this reason, and because of the economic importance of the species, various artificial propagation techniques have been developed to circumvent conditions that have proven to be detrimental to spawning chum salmon and the subsequent developing embryos.

Spawning channels are one of the successful techniques that are in use. They were developed to provide protected spawning and incubation environments to large numbers of salmon. Because these structures are often expensive, it is important that they be operated under a positive benefit-cost ratio. It is obvious that the biological requirements of the species utilizing such a structure should be understood. These requirements may be classified into two principal categories:

- 1) Interactions between the species and the physical environment (including adults, incubating eggs, and fry), and
- 2) interactions between individual conspecifics (including territoriality, aggression, and gene flow).

To delineate some of the biological and physical requirements of chum salmon, the effects of various gravel compositions and instantaneous

densities of spawning fish have been examined in the controlled-flow spawning channels located at Big Beef Creek (Koski, in press). Results of these investigations have led to additional questions regarding the maximum utilization of the gravel area found in our facility. During the fall of 1973, studies were begun to determine whether it is possible to allow various groups of spawning fish to use the same gravel area through time and not affect fry survival or quality.

The number of salmon eggs deposited and their subsequent survival may be influenced by the density of adults utilizing a spawning area. Such density-dependent survival appears to occur in at least two ways: (1) through behavioral interactions between conspecifics spawning in the same immediate area at the same time, and (2) through mechanical dislodging or shocking of previously-buried eggs. Generally, the productivity rate of a spawning bed declines when excessive numbers of adult salmon utilize it (Kuznetsov, 1928; Semko, 1939 and 1954; Hanavan and Skud, 1954; Gangmark and Bakkala, 1960; Mathisen, 1962; Helle et al, 1964; McNeil, 1964, 1967, and 1969; Lister and Walker, 1966; and Helle, 1970).

It may be possible to make optimum use of spawning channels if the carrying capacities of spawning beds can be defined in terms of adults and incubating fry. Schroder (1973) stated, after examining the effects of various instantaneous densities on chum salmon utilizing a spawning channel, that as the allotted area/spawning female decreased, there was a proportional increase in: (1) the average number of eggs retained/female;

(2) agonistic behavior between conspecifics; and (3) dislodgment of previously-buried eggs. Egg retention and excavation of previously-buried eggs were held to a minimum when 1.6 m² or more of spawning area were allotted/female.

Yet, within the Big Beef Creek spawning channel, it was found that maximum fry production but poorer fry survival/female occurred when each female was allotted 1.1 m² (Koski, in press). Obviously, it would be desirable to obtain maximum production of high quality fry without the detrimental side effects caused by the behavioral interactions of adult spawners. This may prove possible if groups of spawners can be temporally separated from one another without adversely affecting both the survival and quality of the fry produced from each group.

To develop a feasible means of increasing fry production by using a temporal isolation scheme, answers to the following questions are needed:

1. What kinds of criteria are utilized by spawning female chum salmon to determine the location and depth of their nests?
2. How many developing eggs can a spawning bed support without adversely affecting either fry survival or quality?
3. What is the sensitivity of developing chum salmon eggs at various embryonic stages to mechanical agitation and dislodgement? and
4. What is the survival and quality of fry that result from eggs that have been dislodged and resettled?

A survey of the literature reveals that most of these questions have been only partially answered. A summary of some of the available information relating to these questions is presented in the next three sections.

The Selection of Spawning Sites by Female Chum Salmon

In many streams, chum salmon will spawn in areas that have previously been used by earlier-arriving congeners. It is important to determine how these later-arriving fish locate themselves on the spawning grounds in regard to previously-used areas. McNeil (1967) suggests that redds can be distributed within a spawning area in three possible ways:

- 1) Randomly - redds are dug in random locations throughout a spawning area;
- 2) Uniformly - redds are dug in areas that have not previously been disturbed; and
- 3) Contagiously - redds are dug in previously-used locations.

McNeil (1967) found that pink salmon (O. gorbuscha) tended to distribute their redds in a contagious manner. Whether chum salmon locate their nests within spawning areas in a similar fashion has not yet been determined.

The characteristics of stream areas utilized by spawning chum salmon have been examined for both Asian and North American stocks (Bakkala, 1970). Sano (1966) found in Hokkaido streams that chum salmon generally selected areas with upwelling springs. Tautz and Groot (in press) demonstrated that the presence of upwelling waters played an important role in nest

site selection, and Helle (personal communication) has also found this to be true in his extensive examination of chum salmon spawning grounds throughout Alaska.

Upwelling waters may offer improved aeration and help the incubating embryos in metabolite removal. In addition, an attraction to such areas would make evolutionary sense if this species had evolved in polar regions where anchor ice would commonly occur, for eggs incubated in relatively warm, ice-free waters would have a much greater chance of survival than those deposited elsewhere (McNeil, 1966; and Sano, 1967).

Schroder (1973) and Groot (personal communication) have described specific behavioral movements used by gravid chum salmon females that apparently aid them in nest site selection. In general, it appears that this species is highly selective in choosing the locations of its nest sites.

Effects of High Concentrations of Developing Eggs on Fry Survival and Quality

Several investigators have suggested that the intragravel environment may become a limiting factor on fry survival and quality if egg concentrations exceed certain limits. Beall (1972) speculates that high concentrations of metabolites may influence fry size and ultimately early estuarine and marine survival. He found that fry that were incubated in sections of the Big Beef Creek spawning channel with high adult densities ($.56 \text{ m}^2/\text{female}$) were significantly smaller and had a poorer condition than those produced by similar-sized females that were allotted a greater area ($6.6 \text{ m}^2/\text{female}$) in which to spawn.

Soin (1954) reports that intensive spawning in an area disrupts the hydrochemical regime of the intragravel environment. Decreases in O_2 and accumulations of free CO_2 and decomposition products derived from organic substances reportedly occur in such areas and may lead to an increase in the mortality rate of developing eggs. In addition, toxic levels of ammonia may occur if egg and larvae concentrations are high and the circulation of intragravel water is poor (McNeil, 1966).

Egg Mortality Due to Shocking

The survival of both eggs and embryos of chum salmon can be affected by mechanical agitation or shocking. Smirnov (1955) found that developing eggs of this species were particularly sensitive to shock during water hardening, early embryo formation, and closure of the blastopore. Eggs may often be dislodged during floods or through superimposition of redds by later-arriving spawners. McNeil (1962) feels that egg losses due to superimposition may amount to 50% or more during the years of high spawning density.

The potential survival and quality of fry resulting from eggs that were resistant to shock at the time of their dislodgement has not been examined. Levanidov (1959), Reed (1967), and Bakkala (1970) suggest that dislodged eggs are usually eaten by an array of predators commonly found on the spawning grounds.

Redd Superimposition Experiments Conducted at Big Beef Creek

An attempt to increase fry production by carefully regulating the timing and numbers of spawners allowed into sections of the Big Beef Creek spawning channel was begun in the fall of 1973. In deciding what arrays of instantaneous densities should be used in these experiments, we re-examined previous production figures from our channels. Fig. 1 shows two curves; one represents fry survival/female and the other the production of fry/m² at various densities.

There appears to be a consistent mortality rate imposed upon deposited eggs at each instantaneous density of spawners so far examined. This mortality has been attributed to dislodgment of eggs and other environmental factors, e.g., siltation, cold water, etc. Based on previous experience, an experiment was designed allowing successive utilization of the same spawning areas by identical densities of spawners. The eggs deposited by a first group of spawners were allowed to reach the eyed stage of development before a second group was introduced. Because the groups of spawners were temporally isolated from one another, it was possible to separate the fry produced from each group. Further controlled superimposition at 1.1 and 2.2 m²/female is being planned for the 1974 spawning season.

To help determine how chum salmon locate themselves on previously-used spawning beds, a grid system composed of 30-cm squares was placed over several channel sections where redd superimposition was planned. The

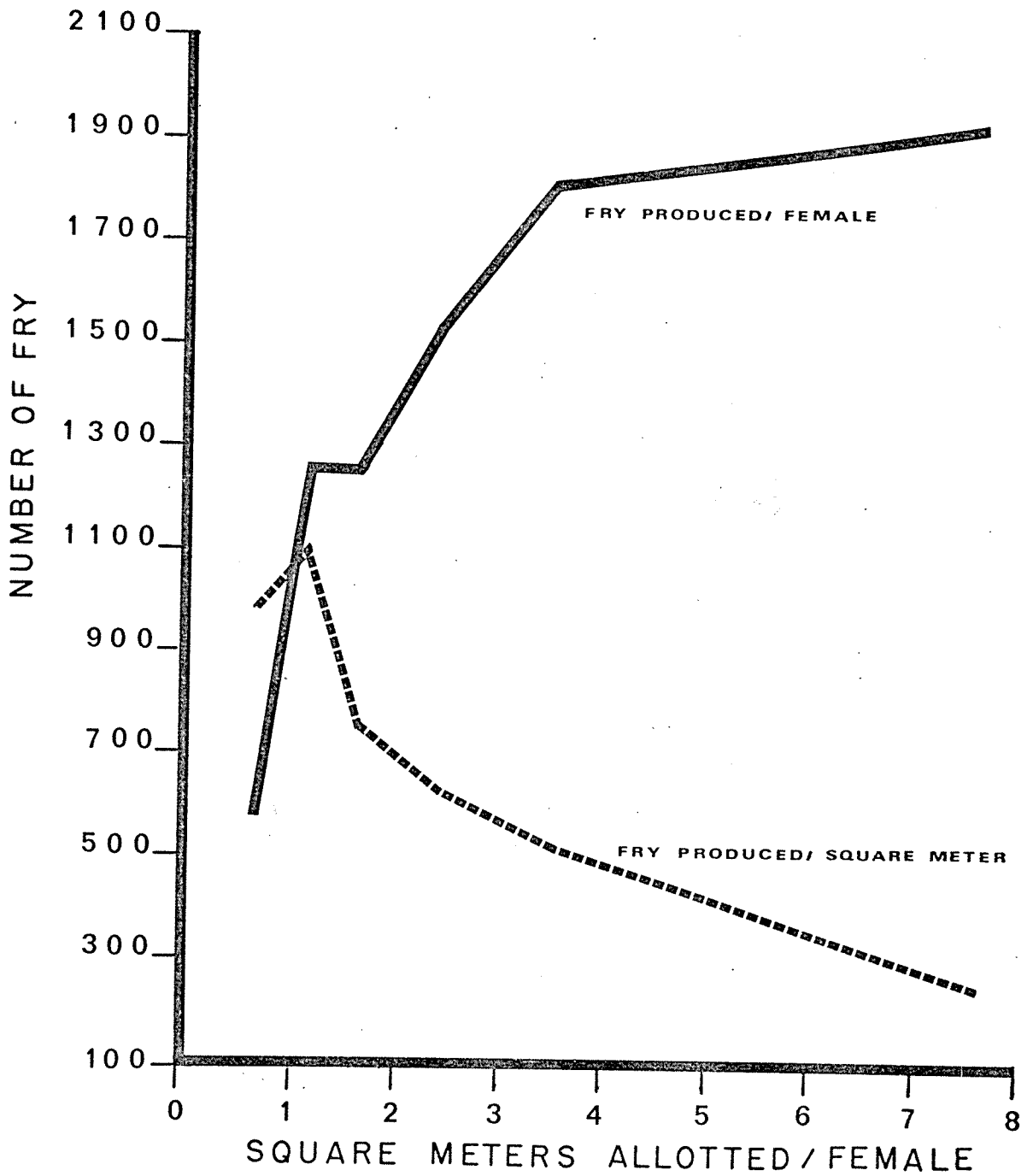


Fig. 1. The average egg-to-fry survival/female and production of fry/m² at various instantaneous densities from the experimental spawning channel located at Big Beef Creek, 1968 to 1973.

nest sites and locations of all the females using these sections were routinely taken during daylight hours, and detailed maps were made of the gravel surface before and after spawning. Additionally, nets were placed at the posterior ends of channel sections experiencing redd superimposition to capture the eggs that had been dislodged. Emerging fry were trapped in the same nets and lengths, weights, and photographs of the fry were taken to help evaluate their quality.

Distribution of Redd Sites in Previously-Used Spawning Channel Sections

It was hypothesized that chum salmon would locate their nests randomly in previously-used spawning areas. The Poisson distribution can be used to test randomness or independence of location, both spatially and temporally (Sokal and Rohlf, 1969). If females locate their nests in a random fashion, then the data obtained from mapping their locations should fit the Poisson distribution. In the Poisson distribution, there is a very simple relationship between the mean and variance: $\mu = \sigma^2$. Because of this equality, a rapid test can be used to determine whether an observed frequency distribution occurs in Poisson fashion. The test is performed by computing a coefficient of dispersion: $C. D. = S^2/\bar{Y}$. In distributions that are essentially Poisson, the C. D. value will be near 1.0; in contagious or clumped cases it will be greater than 1.0; and in uniform or repulsed distributions, less than 1.0 (Sokal and Rohlf, 1969).

Table 1 compares the observed distribution of two equal groups of female chum salmon that were allowed to spawn in a channel section to that of the expected random distribution. The calculated coefficient of dispersion

Table 1, Number of gravel disturbances caused by different female chum salmon/quadrat of spawning bed in a section of the Big Beef Creek spawning channel (overall density = $1.29 \text{ m}^2/\text{female}$)

No. of disturbances /quadrat k	Observed no. of quadrats with k disturbances	Expected under H; of random distribution	Deviation from expected
0	98	123.55	-25.55
1	159	172.72	-13.72
2	192	120.73	+71.27
3	48	56.26	- 8.26
4	3	19.66	-16.66
5	<u>0</u>	<u>5.49</u>	<u>- 5.49</u>
Totals	500	498.41	

$\bar{Y} = 1.398$, $S^2 = .8613$, and C. D. = .6161

was less than 1.0, indicating that females tended to disperse themselves uniformly throughout the spawning area. However, comparisons between the observed and expected values in Table 1 reveal that there may be two different kinds of distributions occurring when groups of spawning fish are temporally isolated from each other. Females present on the spawning grounds tend to repel competing conspecifics from areas in which they have buried or will potentially bury eggs. Because of this behavior pattern, one would expect a uniform dispersion of spawning animals throughout a given spawning area. This appears to be true for the instantaneous densities we have examined. However, once a female is no longer able to defend her territory, the area of the spawning bed she utilized is once again made available to other gravid females. The likelihood of this occurring when females are placed into channel sections at the same time is small, provided that each female is allotted enough space to bury her eggs (Schroder, 1973). Maps made of channel sections that have been superimposed show that there is a tendency for a later-arriving group of spawning females to prefer areas that have been previously used. Why this should occur may be related to the criteria that females use in selecting their nest sites. It would seem likely (all else being equal) that those areas which were preferred by one group of spawning fish would also be just as desirable to later-arriving conspecifics. If previously-deposited eggs are in an embryonic stage that is sensitive to mechanical agitation, such contagious dispersion may have detrimental effects on fry survival. Obviously, fry production could be increased if nest sites could be made less desirable to later-arriving fish, or possibly, if superimposition were to occur at embryonic

stages resistant to shocking.

Fry Survival and Production in Channel Sections Experiencing
Controlled Redd Superimposition

The pattern of fry emergence in a channel section where redd superimposition was allowed to occur is illustrated in Fig. 2. Table 2 shows that the eggs of the group which experienced superimposition had a lower egg-to-fry survival than those of the second group. Yet, both groups of adults produced approximately the expected number of fry for their instantaneous densities ($2.58 \text{ m}^2/\text{female}$). Moreover, the combined production of fry from the two groups was higher than the expected number of fry that would normally result if a similar density ($1.29 \text{ m}^2/\text{female}$) of adults had simultaneously been placed into a section of the spawning channel (see Fig. 1).

Although these results are encouraging, many questions remain to be answered before we can make any statements about the advisability of using superimposition as a means of increasing production in spawning channels. Further experiments concerned with these questions will be started next fall.

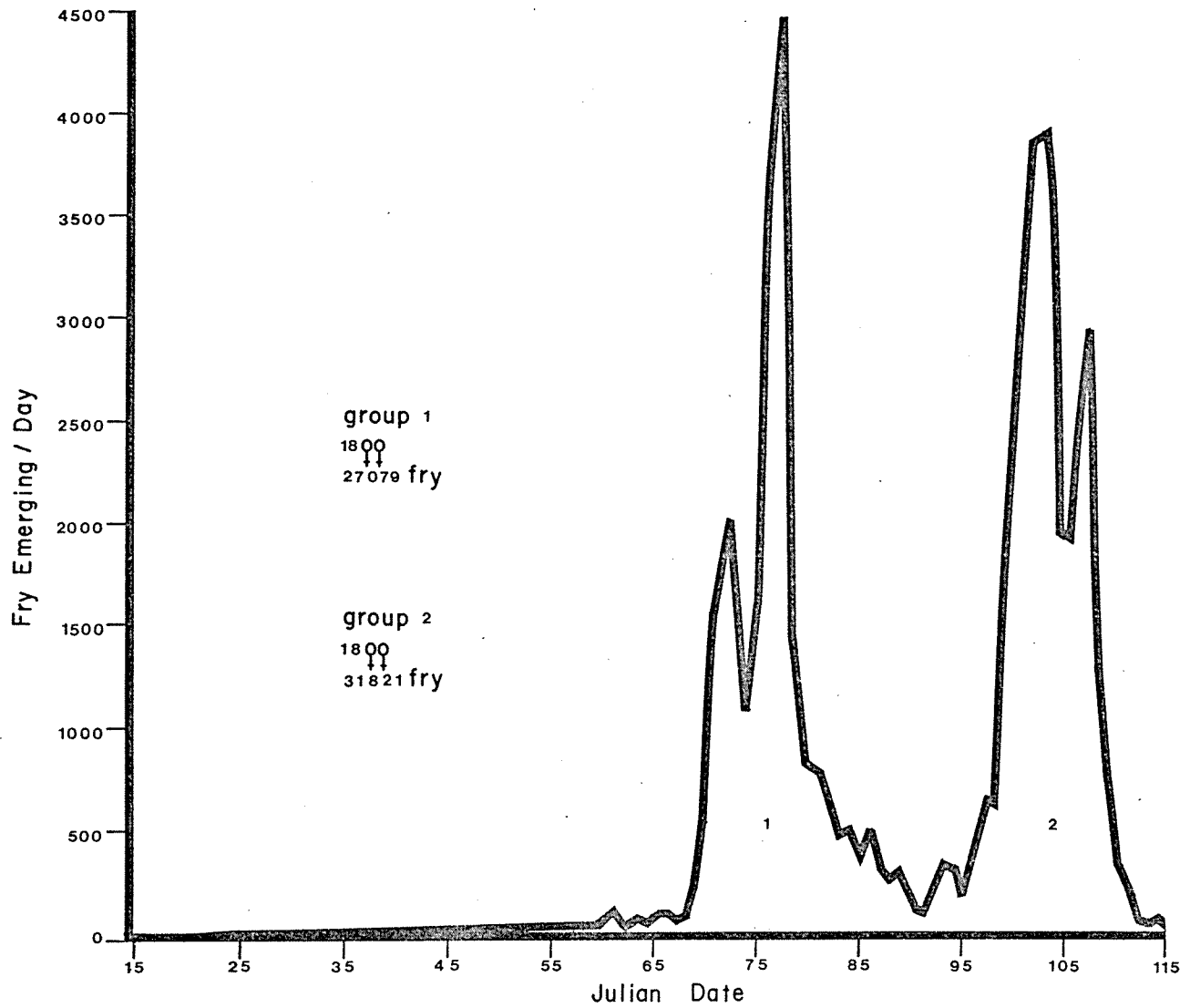


Fig. 2. The pattern of fry emergence in a section of the spawning channel ("C-5", 3-m x 15-m) where two identical but temporally isolated groups of chum salmon were permitted to spawn.

Table 2. The survival of chum salmon eggs deposited by two separate groups of spawners utilizing Section C-5 during fall, 1973

Group No.	No. of females	Julian date of egg deposition	Fry production	Fry produced /female	Fry produced /m ²	Percentage of survival	
						PED	AED
1	18	275	27,079	1,504	539	42.4	44.4
2	<u>18</u>	<u>317</u>	<u>31,821</u>	<u>1,768</u>	<u>657</u>	<u>54.7</u>	<u>61.6</u>
Totals	36	-	58,900	1,636	1,215	48.3	52.3

II. THE EFFECTS OF DIFFERENT GRAVEL DEPTHS OVER SAND SUBSTRATES ON THE SURVIVAL AND QUALITY OF CHUM SALMON FRY

Many streams in Western Washington that support runs of chum salmon have predominately sand or clay substrates. Such substrates have proven to be detrimental to the emergence and survival of chum salmon fry (Koski, in press; and Johnson, personal communication). In 1972, the Washington State Department of Fisheries began a program of improvement of several streams possessing poor spawning gravels. Eight to ten inches of 3/8-inch to 2-inch gravel were placed over the original streambed and chum salmon were allowed to spawn in the treated areas (Johnson and Gerke, personal communication). Results obtained by sampling for developing eggs before and after treatment suggest that egg-to-fry survival increases after the introduction of gravel (Johnson, personal communication).

How much gravel is necessary to ensure high egg-to-fry survival and how long such enhancement may last are presently being investigated in the controlled-flow spawning channel located at Big Beef Creek. Sections of the spawning channel have been subdivided, and varying depths of gravel (10, 20, 30, 40, and 50 cm) were placed over a pure sand substrate. Four additional channel sections (1.5 m x 15 m) are being divided into five equal subsections. The subsections will have either 10, 20, 30, 40, or 50 cm of selected gravel placed over a sand substrate. One pair of chum salmon will be permitted to spawn in each of the experimental subsections. Fry survival and quality, water velocities, gravel movement, and other physical parameters will be measured during the coming year.

The results of this study will be of immediate practical use to the Washington State Department of Fisheries, and possibly to other state or federal agencies concerned with maintaining or enhancing wild or quasi-wild stocks of chum salmon.

III. RENOVATION OF PORTIONS OF THE EXISTING SPAWNING CHANNEL LOCATED
AT BIG BEEF CREEK

Further experimentation on the production of salmon from spawning channels requires an environment that can be controlled and measured. Because of these requirements, portions of the existing spawning channel are presently undergoing extensive renovation. Two 3-m x 15-m sections of the channel will be replaced by concrete walls lined with a rubber membrane. One of the renovated sections will possess a viewing chamber. The chamber, a 1.8-m x 3.3-m room will have concrete walls, two viewing windows, and will be provided with both videotape and cinefilm equipment. The chamber will allow researchers to film and record ethological observations of the salmonid fishes native to Big Beef Creek.

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PROJECT PERSONNEL

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