FRI-UW-7718
May 1977

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

by

Steven L. Schroder

Completion Report
Anadromous Fish Project

Project No. AFC-67
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Submitted: May 23, 1977

Approved
Robert L Burgner
Director

PREFACE

The final report for project AFC-67 has been divided into three separate parts. Each part is independent of the others and has been supplied with its own literature cited section. Some redundancy was unavoidable but this organizational scheme allows the reader to quickly extract information of interest to him.

The first part describes the attempts to maximize chum salmon fry production in the Big Beef Creek spawning channel by allowing waves of spawners to use the same gravel areas. The second part examines several problems related to salmon enhancement programs which must rely on artificial propagation. The principle areas of discussion include: 1) An examination of the mate selection processes found in chum salmon; 2) the effects of parental characteristics on fry growth; and 3) the impacts of various types of substrates on the efficiency of yolk material utilization by chum salmon larvae incubated within Heath Tecna incubators. The third part examines the contribution that the Big Beef Creek spawning channel has apparently made to the commercial fishery and to the stream. Additionally the theses of Messrs. Steve Schroder and Kenneth Bruya (upon completion and approval) serve as supplements to this report.

CONTENTS

LIST OF TABLES

PART A

PART B

PART C

LIST OF FIGURES

PART A

PART B

ABSTRACT

The possibility of layering groups of chum salmon into the Big Beef Creek spawning channel to maximize fry production was examined. It was found that when previously deposited eggs had become immune to mechanical shock, it was possible to introduce another wave of fish into the same area without adversely affecting the production of fry from either group. Patterns of mate selections in chum salmon demes were also examined. The process appears to be governed by the "operating" sex ratio (number of gravid males; number of territorial and gravid females) that exists within a deme. When the operating sex ratio favored females (more males than females) mating tended to be assortative, while when it favored males, mating became essentially random. Experiments on the effects of parental age and size on larvae size and growth were also conducted. Egg size and possibly male age appear to influence the size and growth patterns of chum salmon fry. The importance of a resting substrate during yolk absorption was also demonstrated. Lastly, the contribution that the Big Beef Creek spawning channel has made to the commercial fishery and the stream is delineated.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the many people who were involved with various aspects of this project. First, special thanks must go to Mr. Bruce Snyder, who often managed the budget, procured needed materials and was deeply involved in some of the hatchery work. Mr. Ken Bruya helped design, and was responsible for studies concerned with examining the feasibility of improving spawning beds by the addition of gravel (these studies will be described in his thesis), while Mr. Al Didier developed several computer programs and also assisted in the field. Mr. Dennis Moore turned very little into two workable hatcheries and Ms. Diana Dickerson fed the experimental lots of chum salmon fry during 1975 and 1976.

The project is also indebted to Dr. Michael Gass who graciously allowed us to use his artesian water supply and barn as a hatchery location, and to Dr. Brian Allee and his associates at the Weyerhauser Company who provided us with several stacks of Heath Tecna incubator trays. Other individuals who assisted the project by helping in the field are Messrs. Al Collins, Paul Dorn, Gary Duker, Jim Franzel, Dave Goit, John Knowles, Gary Maxwell, Don Mortensen, Cavin Philbin, Chuck Rogers, Dave Smith, Cliff Whitmus, Ms. Jacque Baker and Ms. Debbie Pratt. Ms. Helen Bailey and her staff also very ably performed the necessary computer work.

Ms. Mary Lou Overturf and Ms. Ingrid Pearson typed the rough drafts of the report while Ms. Dorothy Beall and her staff prepared the final copy. Drs. E.O. Salo and R.L. Burgner reviewed the manuscript and made many helpful comments.

Mr. John Garrett and Ms. Fae Bishop of the National Marine Fisheries Service also deserve special thanks for their long standing support and patience.

PART A

THE EFFECTS OF REDD SUPERIMPOSITION ON THE SURVIVAL AND EMERGENCE TIMING OF CHUM SALMON FRY PRODUCED FROM A SPAWNING CHANNEL

INTRODUCTION

About 30 years ago, it was suggested that some of the freshwater mortality experienced by incubating salmon eggs in streams could be reduced by controlling their incubation environment (White 1942; Neave 1948; and Royce 1959). Early experiments by Widkett (1952) and Hourston and MacKinnon (1956) demonstrated that controlled flow areas such as spawning and incubation channels were capable of increasing egg-to-fry survival. However, even optimizing the physical environment within a spawning bed does not necessarily ensure maximum production of salmon fry. The number of salmon eggs deposited and their subsequent survival is also influenced by the density of adults utilizing a spawning area.

The number of fish using a spawning bed can be thought of in two ways, the numbers existing at any given instant (instantaneous density) and the total number present throughout the spawning season (overall density). High spawner densities of either type may adversely affect the number of fry produced from a spawning bed. Excessive use of a spawning area can increase the probability that previously buried eggs will be dislodged and destroyed by shock or predation. High instantaneous spawner densities may also cause a greater than average amount of egg retention to occur (Kuznetsov 1928; Semko 1954; Hanavan and Skud 1954; Mathisen 1962; Helle et al. 1964; McNeil 1964, 1967, and 1969; Helle 1970; and Schroder 1973).

It is likely that fry production in spawning channels is limited more by adult behavior (adult-carrying capacity) than by the potential of the spawning bed to successfully incubate eggs (egg-carrying capacity) (Thomas 1975). One way the egg-carrying capacity of a channel could be reached would be by temporally isolating groups of fish and allowing sufficient waves of spawners to utilize the same gravel areas. The number of layers or separate groups of adults which could utilize an area would depend upon several factors: 1) The availability of gravid adults; 2) their potential distribution over previously used spawning areas; 3) the sensitivity of formerly buried eggs to mechanical shock; 4) the gravel composition of the spawning bed which influences both the egg-carrying capacity of the spawning bed and how easily eggs from preceding layers may be dislodged; and 5) whether differences in fry quality result from multiple use of spawning areas.

Beginning in 1972 portions of the Big Beef Creek spawning channel were used to determine the practicality of this strategy in maximizing chum salmon fry production. Information was obtained on how both behavioral interactions and topological features of a spawning bed may influence redd locations. Data were also gathered on fry survival, developmental index (K_D; Bams 1970) and timing of emergence for populations of fry originating from superimposed and nonsuperimposed sections of the spawning channel.

METHODS AND MATERIALS

Species and Population of Salmon Utilized

Neave (1953) observed that chum salmon often arrive on a spawning ground over an extended period of time and that they usually are ready to spawn soon after entering freshwater. These characteristics make them an ideal species to test whether fry production can be increased by controlled superimposition. The chum salmon utilized during our experiments originated from Big Beef Creek (Kitsap County, Washington State). The salmon entered the stream from early September through mid-January, with peaks of abundance occurring in early October (early run), mid-November (middle run), and late December (late run).

As the fish migrated into the stream they were captured in one of two traps and processed as previously described by Schroder (1973) and Koski (1975). Each fish was examined for maturity, anesthetized in tricaine methanesulfonate (MS-222), weighed, measured, aged, and tagged with large (3 cm in diameter) Petersen disks. They were then transported 400 m or less to designated sections of a spawning channel located on a side branch of Big Beef Creek. Detailed descriptions of the channel can be found in Beall (1972), Schroder (1973), and Koski (1975).

Spawning Channel

Twelve 3.05 m x 15.24 m and five 1.52 m x 3.05 m sections of the spawning channel were used during 1972-75 to determine whether fry production could be increased by planned superimposition of spawners over the same gravel areas. Each section had a 0.25 percent gradient (.25 m/100 m) and was equipped with a 3 m high observation wall supplied with viewing ports. The larger sections ("C" sections) had a substrate of stream gravel (.8 cm to 6.25 cm in diameter) 75 cm in depth. Three of the smaller ("A") sections were also filled with a layer, 30 cm thick, of stream gravel ($\leq$ 3 mm to 6.25 cm in diameter) which was then covered by an upper crust (16 cm thick) of large rubble (5.6 cm to 16.25 cm in diameter). The other two small sections ("B" sections) did not have rubble crusts and were filled with a layer of similar gravel ($\leq$ 3 mm to 6.25 cm in diameter) 46 cm in thickness. A more precise breakdown of the gravel composition in the sections is shown in Table la. Methods previously described by McNeil and Ahnell (1964) and Koski (1966 and 1975) were used to determine the percentage of gravel in each size fraction.

All of the A and B sections were lined with 6 mil black plastic to prevent fry from escaping into other sections of the channel. Water velocity in the channel (A, B and C sections) was kept at 22.5 cm/sec and depth at 30 cm. Standpipes were also placed into each section so that dissolved oxygen readings could be made routinely during the incubation period.

Table 1a. The average percentage of various gravel fractions present in A, B, and C sections of the Big Beef Creek spawning channel

Type of	Diameter of the Gravel Fractions in mm										No. of
channel section	<.105	.105	.210	.420	.841	1.680	3.360	6.730	13.500	26.900	samples
A and B	.050	.004	.010	.040	.060	.060	.040	.160	.270	.290	4
C	.370	.010	.000	.000	.000	.000	.000	.040	.330	.240	24
	Diameter of the Gravel Fractions in cm (rubble crust)										
	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	
A	.003	.390	.450	.100	.030	.020	.010	.000	.002	.00	406[1]

[1] The frequency distribution of the rubble crust was obtained by measuring 406 randomly chosen rocks.

Timing of Entrance and Placement of Adults into the Spawning Channel

Two groups of adults with similar instantaneous densities were placed into each C section where superimposition occurred. The second group was introduced only after the eggs of the first layer had closed their blastopores. Eggs at this stage of development have been reported to be resistant to mechanical shock (Volodin as quoted by Soin 1954; and Smirnov 1955). A variety of densities were used (6.64 to 1.5 m^2/♀) and thus data were obtained on: 1) The propensity of adults to reuse previously excavated areas; 2) how territory size changes with instantaneous density; and 3) whether total production of fry was increased by controlled superimposition. Other C sections were used as controls with only a single layer of fish being permitted to spawn. The number of fish placed into each control section varied from 7.5 to 0.6 m^2/♀ and provided data on egg-to-fry survival obtained under various instantaneous densities.

The A and B sections were used to determine whether it would be possible to increase fry production by superimposing groups of adults without having to wait for previously deposited eggs to become resistant to shock. Single pairs were introduced into each section (4.65 m^2/♀) and allowed to spawn. In one A section the first pair was removed after they had finished spawning and a second pair was then immediately introduced into the section. In another A section the second pair was introduced after the eggs of the first pair had closed their blastopores. The last A section had only one pair of fish and was used as a control.

Three pairs of fish were allowed to spawn in succession in one of the B sections. The eggs deposited by the first two pairs were not permitted to become resistant to mechanical shock before superimposition occurred. The second B section had only one pair of fish, and like one of the A sections it was used as a control.

Fish Location and Changes in Gravel Contour

Three grid systems were used to help evaluate how chum salmon located themselves over previously used areas. Each system was composed of 30 cm squares and was placed over a C section where redd superimposition was planned. The grid was made from tightly stretched nylon cord 2 mm in diameter and placed 20 cm above the water surface. It was divided by colored lines into five sections of 100 squares (or 110 points each).

The gravel contour of a section was determined by measuring the vertical distance between each point of the grid and the surface of the gravel directly beneath it. Measurements were made before fish were introduced and after each group of adults had completed spawning. The data were then analyzed by a computer program, FRD 345 (Fisheries Research Institute) prepared by Mr. Al Didier.

The program initially sorts all the data points (i.e., those obtained by measuring a section before it was used and after each successive utilization) and determines at which point the gravel surface is the greatest distance from the grid system. The horizontal plane parallel to the grid system, which passes through this point, is established as the zero plane and the gravel depths are expressed as the distance from this plane to the gravel surface (Fig. 1a). Each square in the grid system then forms the boundary for a rectangular column of gravel whose base is the zero plane and whose top is the gravel surface. The volume of each column is calculated by determining the surface area of the up- and downstream side of the column and multiplying this value by the width (30.5 cm) of the column. The two cubic volumes obtained are then averaged and this value is used as the cubic volume of the column (Didier 1975).

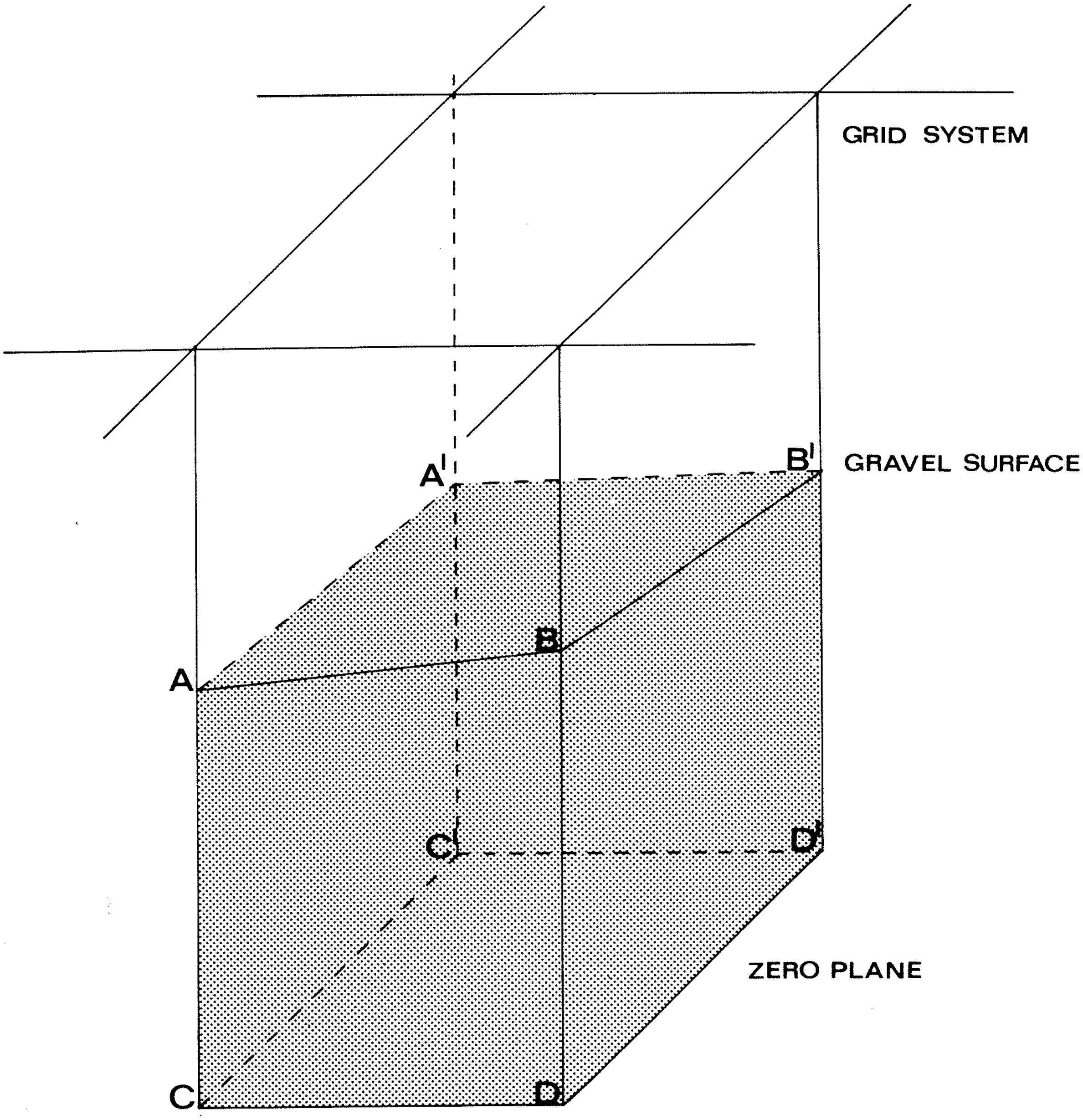
Shifts in the volume of gravel in the columns could then be estimated after each group of fish had finished spawning. Additionally, the volume of gravel present in the columns could be used to detect the presence of depressions or mounds in the spawning substrate. This information was used to produce relief maps representing each section. The maps were analyzed to examine the relationships between gravel contour and the placement of nest sites. The grid system and observation walls were also used to determine the size and location of territories in each section. This was done by making observations once every two hours from dawn until dusk of the locations of each female while she was involved with nest construction activities.

The Measurement of Fry Emerging from Each Section

Methods developed by Koski (1975) were used to enumerate and measure newly emerging fry. Just prior to emergence modified fyke nets with attached floating live boxes were placed at the ends of each channel section. These were checked daily, and fry were removed and taken to a field laboratory where they were gravimetrically counted.

Average length and weight were determined routinely on samples from each section. Every other day a sample of fry from each section was anesthetized in MS 222 and individual fish were measured (tip of snout to fork in tail) to the nearest mm. Because variation in size among fry migrating out of a section on a given day is usually small (Koski 1975), the sample size was often less than 50 fry.

The average wet weight of the fry was determined daily. Lots of 100 fry or smaller lots (i.e., 10, 25, or 50) were blotted dry on a damp sponge while in a fine mesh sieve. The blotted fry were poured into a tared beaker of water resting on a Mettler P 1200 balance and weighed to the nearest hundredth of a gram. The number of lots measured per section was proportional to the number of fry emerging on a given day (*see* Koski 1975). The remaining fry were not counted into lots but were weighed in a similar fashion. To determine the number of weighed but uncounted fry a simple algebraic relationship was used.



FORMULAS USED TO CALCULATE THE VOLUME OF GRAVEL IN A COLUMN

CD, DD', $D'C'$, AND CC' ALL = 0.305 M

AREA $ABCD = (.5)(AC + BD)(CD)$

VOLUME BASED ON $AB = (\text{AREA } ABCD)(CC')$

AREA $A'B'C'D' = (.5)(A'C' + B'D')(C'D')$

VOLUME BASED ON $A'B' = (\text{AREA } A'B'C'D')(DD')$

VOLUME OF GRAVEL COLUMN = VOL. AB + VOL. $A'B'/2$

Fig. 1a. A three-dimensional view of a single column of gravel and a list of the formulas used to calculate its cubic volume.

The average lengths and weights obtained were used to determine periodically the mean developmental index (K_D; Bams 1970) at emergence. Comparisons among these values were made to determine if fry emerged from the various sections at different developmental stages. In addition, the number of accumulated temperature units (C) needed to complete emergence were estimated by using a Honeywell-Brown type 602 Thermograph. This seven-day temperature recorder was equipped with two temperature probes, one for intragravel and the other for surface water temperature. The mean daily intragravel water temperature of the channel was used to estimate the number of temperature units which had been accumulated by each section.

Estimating Egg-to-Fry Survival

Since the size and number of females introduced into each channel section was known, it was possible to use previously described relationships between female fecundity and body weight (Schroder 1973; and Koski 1975) to estimate the potential egg deposition (PED) of each section. Egg-to-fry survival rates were then calculated by determining the percentage of fry produced from the PED of each section.

RESULTS AND DISCUSSION

Relationships Among Territorial Females

Behavioral and physiological adaptations may have evolved in chum salmon to protect their eggs from dislodgment and mechanical shock during spawning and incubation. It is important to determine if such adaptations occur and how effective they may be under a variety of spawner densities. For if natural systems of protection exist then they may suggest management options that can be used to achieve maximum production of salmon fry. With these considerations in mind, some observations were made on the interactions occurring within and between chum salmon demes utilizing the same gravel areas.

It has long been recognized that adult female chum salmon have territories or redds consisting of three to six discrete nests (Kusnetsov 1928). The juxtaposition of these territories with respect to one another can theoretically be random, repulsed, or contagious (McNeil 1967). Since recently deposited eggs are sensitive to shock, a female should be able to increase the probability of her eggs surviving by protecting them from neighboring fish that are preparing or burying nests. Thus, one would expect that territories belonging to different females would be distributed in a repulsed fashion for as long as the females were able to defend them. One way to examine the spacial relationships existing among territories being defended at the same time is to use the Poisson distribution (Sokal and Rohlf 1969).

Because of the equality of the mean and variance in the Poisson distribution, it is possible to employ a rapid test to determine whether an observed frequency distribution occurs in a random fashion. The test is performed by computing a coefficient of dispersion (C.D. = variance/mean). In distributions that are essentially random (Poisson), the C.D. value will equal 1.0, in contagious or clumped cases it will be greater than 1.0, and in repulsed or uniform distributions less than 1.0 (Sokal and Rohlf 1969).

Table 2a shows that the territories held by female chum salmon were distributed in the expected repulsed fashion at the instantaneous densities examined. However, the integrity of a territory did appear to decrease as competition among females for space to bury their eggs escalated. Territory size also appeared to be strongly influenced by the presence of conspecifics. This is illustrated in Table 3a which shows that as intrasexual competition for space intensifies, the area a female can successfully defend diminishes. This phenomenon does not appear to be unique to chum salmon for Groot (personal communication) observed that female sockeye salmon (*O. nerka*) while spawning under high instantaneous densities became "locked" into small territorial spaces. Such females were seen dislodging their own eggs in the process of creating new nests.

Possible Roles of Cover and Gravel Contour in Nest Site Selection

Where a female establishes her territory may be influenced by both social and physical factors existing within a spawning area (Neave 1966; and Bakkala 1970). A Goodness-of-Fit test ("G" test, which makes comparisons between observed and expected frequency distributions) described by Sokal and Rohlf (1969) was used to evaluate whether certain areas within channel sections were preferred as spawning sites. As previously mentioned, two separate groups of spawners were placed into three C sections (3.05 m x 15.24 m) where a grid system had been installed. The territory locations of all the females using these sections were analyzed with the "G" test. It was found that females in both groups did not distribute themselves randomly within a section. Instead they preferred to establish their territories 60 cm or closer to the longitudinal walls of the spawning channel (Table 4a). Even though the females in a second group preferred to spawn in the same areas as prior resident females, they distributed their territories randomly over the first group's redd sites (Table 5a).

To determine if differences in gravel contour may have caused the females to prefer to spawn along the longitudinal walls, statistical comparisons were made between the frequency of depressed and elevated areas next to the walls and the rest of a channel section. In four of the five cases which were analyzed, there was no detectable difference. The one case in which there was a difference occurred because the areas running parallel to the walls were slightly elevated above the rest of the section (Table 6a).

One possible advantage of establishing a territory next to a wall is that such a location may protect one-half of a female's flank from attacks by neighboring conspecifics. The possible importance of water

Table 2a. The spacial relationships among female territory locations as determined by the Poisson distribution for a variety of instantaneous spawner densities

Instantaneous spawner density m²/♀	No. of disturbances/grid quadrant by different ♀♀ 0	1	2	3	Coefficient of dispersion value	Type of distribution
6.64	330	170	0	0	.66	repulsed
6.64	334	166	0	0	.67	repulsed
2.58	205	248	47	0	.59	repulsed
2.58	241	227	30	2	.67	repulsed
2.32	86	347	59	8	.36	repulsed
1.66	46	396	56	8	.24	repulsed

Table 3a. The results of the Mann Whitney-U tests used to detect differences in territory sizes at various instantaneous densities

Instantaneous spawner density m^2/♀	$\bar{x}$ Territory size in m^2	Comparison	n[1]	Significantly different at the .05 level
6.64-a	2.88	6.64-a vs. 6.64-b	14	no
6.64-b	2.44	6.64-a vs. 2.58-a	25	yes
2.58-a	1.82	6.64-a vs. 2.58-b	25	yes
2.58-b	1.69	6.64-a vs. 2.32	27	yes
2.32	1.82	6.64-a vs. 1.66	35	yes
1.66	1.44	6.64-b vs. 2.58-a	25	yes
		6.64-b vs. 2.58-b	25	yes
		6.64-b vs. 2.32	27	yes
		6.64-b vs. 1.66	28	yes
		2.58-a vs. 2.58-b	36	no
		2.58-a vs. 2.32	38	no
		2.58-a vs. 1.66	46	yes
		2.58-b vs. 2.32	38	no
		2.58-b vs. 1.66	46	yes
		2.32 vs. 1.66	48	yes

[1] Total number of territories compared.

Table 4a. Results of the "G" tests used to determine if females preferred to locate their territories 60 cm or closer to the longitudinal walls of the spawning channel

Instantaneous spawner density m^2/♀	Results of the "G" tests	Preference shown for territory sites 60 cm or closer to channel wall:
6.64	$G = 49.30 > X^2$ .05 [3] = 7.815	yes
6.64	$G = 31.00 > X^2$ .05 [3] = 7.815	yes
2.58	$G = 74.52 > X^2$ .05 [3] = 7.815	yes
2.58	$G = 7.94 > X^2$ .05 [3] = 7.815	yes
2.32	$G = 30.49 > X^2$ .05 [3] = 7.815	yes
1.66	$G = 39.14 > X^2$ .05 [3] = 7.815	yes

Table 5a. Results of the "G" tests used to determine whether territories were located randomly over areas previously preferred by a prior group of females

Instantaneous spawner density $m^2/♀$	Results of the "G" tests	Distribution over previously used areas
6.64	$G = .66 < X^2 .05 [3] = 7.815$	random
2.58	$G = 1.36 < X^2 .05 [3] = 7.815$	random
2.32	$G = 4.12 < X^2 .05 [3] = 7.815$	random

Table 6a. The results of comparisons between the occurrence of raised and depressed areas next to the walls (60 cm or closer) and the rest of a channel section.

Instantaneous spawner density $m^2/♀$	Number of groups previously using the section	Results of the "G" tests	Differences in the occurrence of raised and depressed areas
2.58	0	$G = 1.44 < X^2 .05 [2] = 3.841$	none
1.66	0	$G = 47.46 > X^2 .05 [2] = 3.841$	areas next to wall higher
6.64	1	$G = 8.97 < X^2 .05 [4] = 9.488$	none
2.58	1	$G = 12.50 < X^2 .05 [8] = 15.507$	none
2.32	1	$G = 11.85 < X^2 .05 [8] = 15.507$	none

velocity and upwelling currents along the walls or elsewhere on the selection of territory sites was not determined. Nevertheless, analyses (Goodness-of-Fit tests) were performed to determine if females in second groups would randomly locate their territories with respect to the gravel contour of a section. In making these analyses only the locations of the first six or seven females to establish territories were used. This was done because the territory locations of these fish are usually not influenced by conspecific aggression. The results of the "G" tests suggest that females prefer to establish their territories in valleys or depressions in the gravel surface (Table 7a).

These areas may lower the amount of aggression a female experiences by reducing the visual contact she has with other conspecifics. Such sites may also have upwelling currents. Tautz and Groot (1975) suggested that an important criterion used by female chum salmon and steelhead trout (*Salmo gairdneri*) in establishing their territory locations was the presence of upwelling flows. Vronskiy (1972) observed that the same criterion may also be used by chinook salmon (*O. tschawytscha*) and similar observations have been made for other salmonid fishes (e.g., Webster and Eiriksdottir 1976; and Webster 1962).

Gravel Movement Caused by Spawning Fish

One result of this preference was that females would often initially establish their territories adjacent to mounds created by prior resident fish. In the process of excavating or burying their nests, females in a later arriving group would often disturb previously existing mounds. Fig. 2a illustrates the impact female digging had on the locations of raised and depressed areas within a channel section that was used by two groups of adults.

In general, the gravel disturbed by fish from each layer was moved downstream in a wave-like fashion. As Fig. 3a shows, each succeeding layer of fish moved the elevated and depressed areas within a section slightly downstream after spawning had been completed. The total amount of material which was physically displaced varied and was proportional to the number of fish allowed to spawn in a section (Table 8a). However, the average amount of material displaced by a female diminished as instantaneous density increased. This was probably caused by the reduction in territory size.

Fry Survival

These results suggest that the digging activities of spawners introduced into recently used areas could dislodge and destroy significant numbers of previously deposited eggs. However, it was hypothesized that if previously deposited eggs were protected by an immobile substrate (e.g., a rubble crust) or a stanza of development which was immune to shock, the egg-carrying capacity of a spawning bed could be reached with

Table 7a. The relationship between gravel contour and the location of the first six to seven territory sites in a previously used channel section

Instantaneous spawner density m²/♀	Results of the "G" tests	Interpretation
6.64	$G = 29.62 > X^2\ .05\ [4] = 9.488$	preference for depressed area
2.58	$G = 51.48 > X^2\ .05\ [5] = 11.070$	preference for depressed area
2.32	$G = 26.43 > X^2\ .05\ [6] = 12.592$	preference for depressed area

Table 8a. The amount of material disturbed by various instantaneous densities of females during the spawning process

Instantaneous density of spawners m²/♀	Number of ♀♀/section	Total m³ of gravel moved	Average quantity of material moved/♀ in m³
6.64	7	1.242	.177
2.58	18	1.319	.073
2.58	18	1.449	.081
2.32	20	1.194	.060
1.66	28	1.623	.058

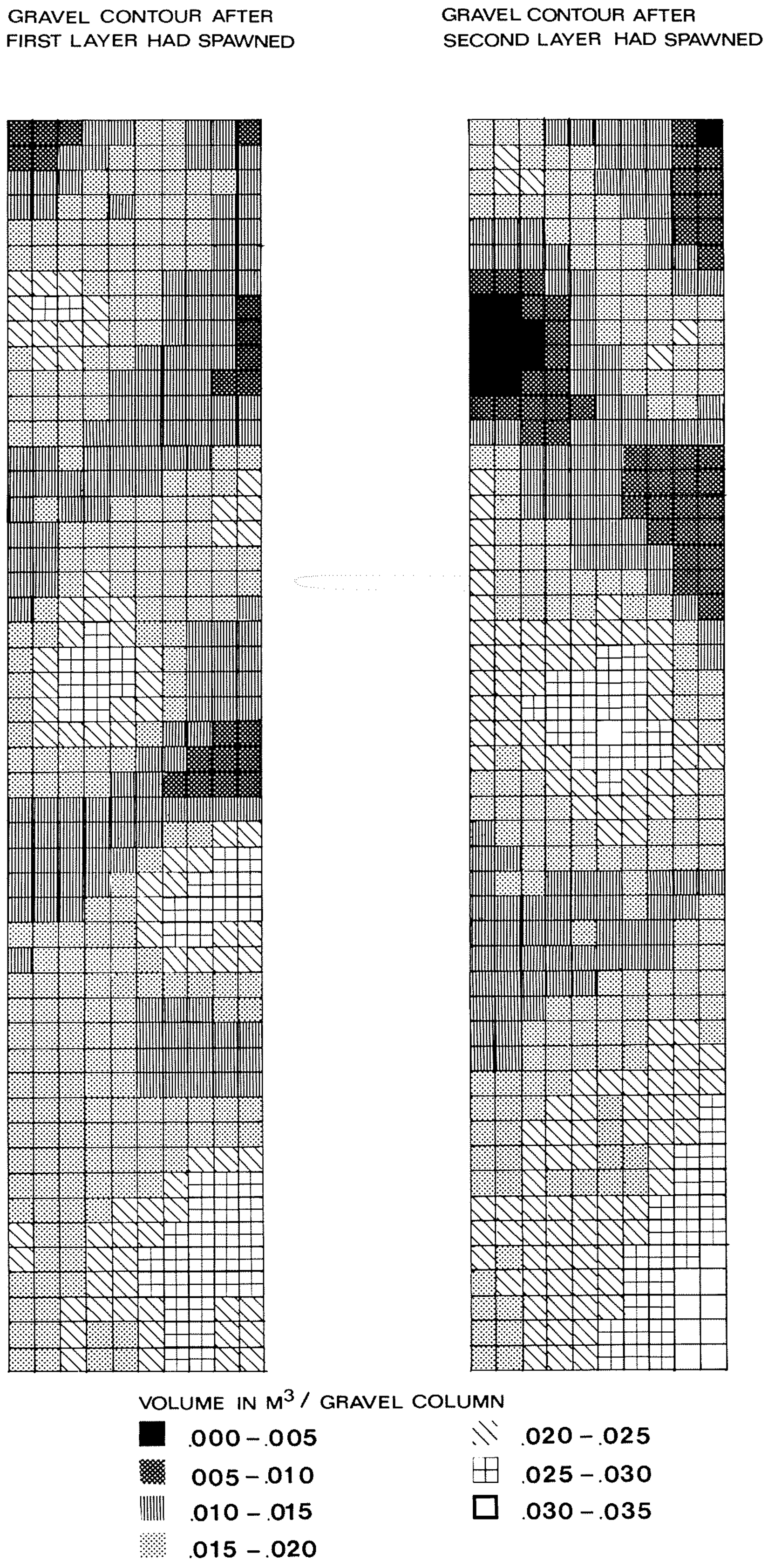


Fig. 2a. Relief maps showing how the digging activities of spawning chum salmon changed the locations of raised and depressed areas in a previously used channel section.

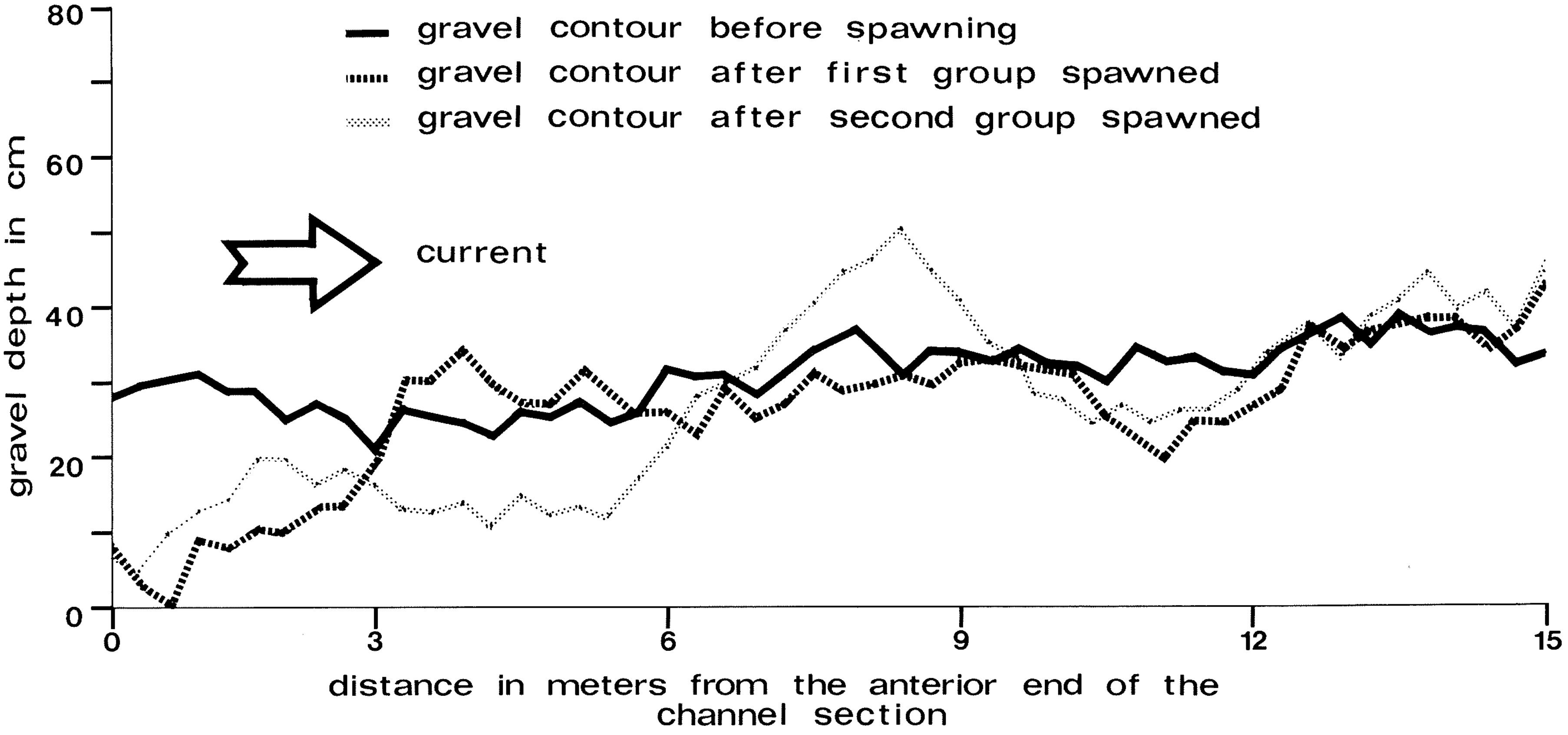


Fig. 3a. The gravel contour of a channel section taken along the same longitudinal plane before any fish were introduced and immediately after the first and second waves of chum salmon had spawned.

a minimum amount of egg mortality caused by mechanical agitation. These hypotheses were tested by: 1) Superimposing groups of spawners into C sections after a sufficient amount of time had elapsed to allow previously deposited eggs to become immune to shock; and 2) allowing superimposition to occur in an A section (section with a rubble crust) before the eggs deposited by the prior resident fish had closed their blastopores.

Before the usefulness of the above techniques could be evaluated, it was necessary to determine the survival rates of eggs in channel sections where superimposition had not occurred. The expected egg-to-fry survival rate for a variety of instantaneous spawner densities was estimated using data acquired from channel sections (C) which had been used as controls. Several environmental factors (heavy concentrations of sand or silt, low levels of dissolved oxygen, and cold water temperatures during early ontogenesis) were associated with poor survival in the spawning channel (Schroder et al. 1974; and Koski 1975) and consequently data on fry survival from sections which had experienced these impacts were not used.

Fig. 4a and Table 9a show the relationships between fry survival/female and the production of fry/m^2 in the control sections for a variety of instantaneous spawner densities. Table 10a illustrates the observed egg-to-fry survival rates in C sections where planned superimposition occurred. These data indicate that each wave of adults in a superimposed section produced approximately as many fry as a comparable control section where only a single layer of adults had spawned. Moreover, the total production of fry from superimposed sections was slightly greater than that expected if the same number of adults had been placed into a control section simultaneously. The largest gains occurred when the overall density of a superimposed section was below 1 m^2/female.

The survival rates of eggs deposited in the smaller A and B sections were also determined and are shown in Table 11a. Fry survival in the A sections (sections with a rubble crust) was similar to that which had been observed in the larger channel sections. Even in the section that was immediately superimposed upon, both groups had the expected egg-to-fry survival rates. This did not occur in the B section that was treated in the same manner. Instead the eggs deposited by the first female were dislodged while they were still sensitive to mechanical shock by the second pair. The third pair spawned in a slightly different area and did not disturb the second female's redd. Consequently, the eggs of the first female did not survive nearly as well as those of the last two pairs.

Females placed into the A sections did not retain an unusual percentage of their eggs (.002 percent, D.C. = .002, N=5) even though they were unable to construct typical nests. In lieu of nests, pairs were observed to wedge their bodies between several larger stones while spawning. The females did, however, appear to require a longer period of time to deposit their eggs than if they had spawned over smaller gravel. Neave

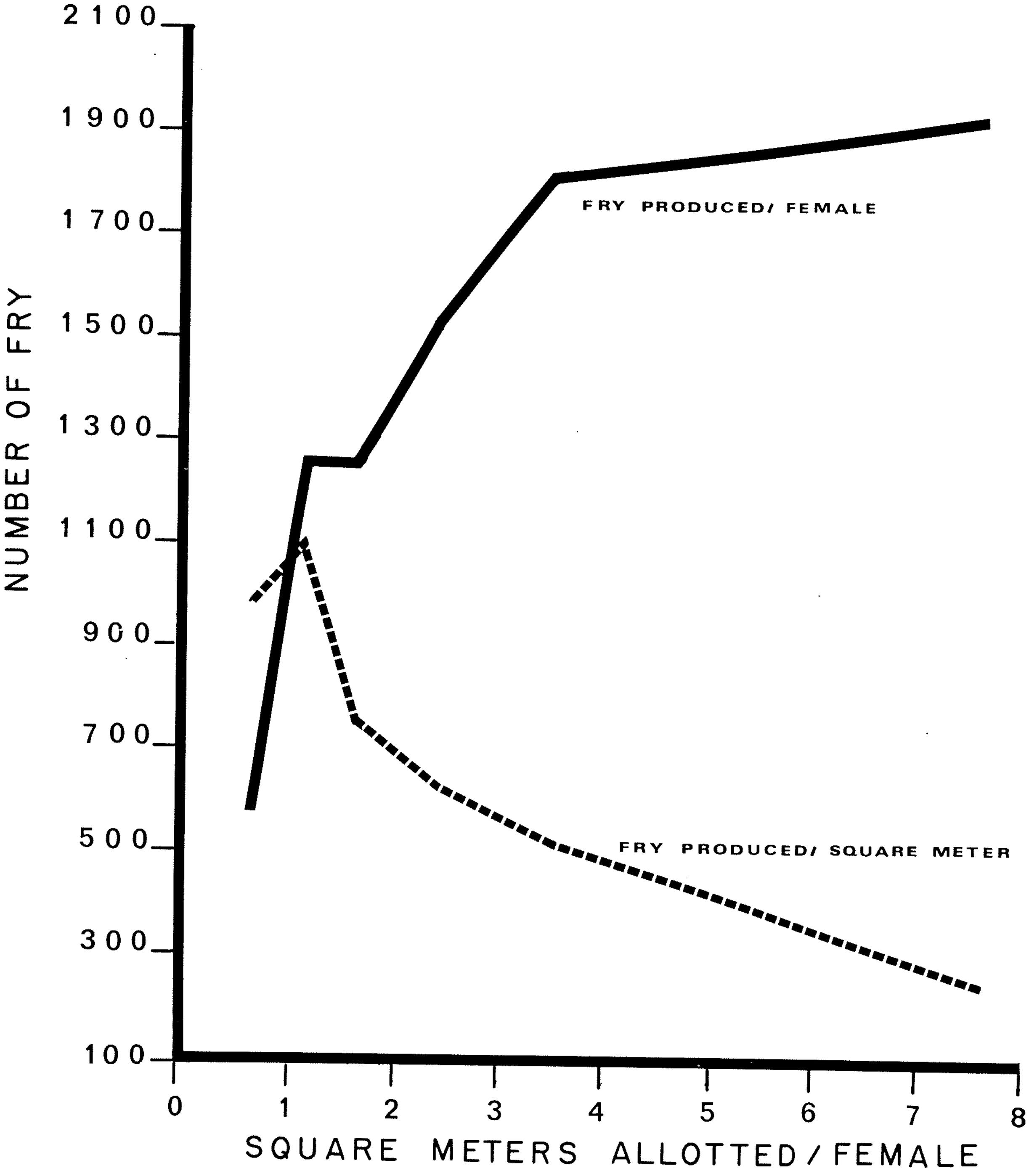


Fig. 4a. The average number of fry produced/m^2 and per female at various instantaneous spawner densities in control sections (3.05 m x 15.24 m) of the Big Beef Creek spawning channel.

Table 9a. Egg-to-fry survival, fry production/female and per m^2 for chum salmon populations[1] placed into control sections of the Big Beef Creek spawning channel for a variety of instantaneous spawner densities

Instantaneous spawner density m^2/♀		Fry produced/♀		Fry produced/m^2		Egg to fry survival		No. of populations
$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
7.53	1.56	1905.58	222.96	262.66	72.17	.566	.094	3
3.33	0.17	1766.92	488.73	526.91	126.07	.574	.162	5
2.28	0.11	1524.07	497.98	669.82	221.83	.508	.178	5
1.61	0.09	1279.99	430.21	790.46	234.56	.408	.146	3
1.10	0.02	1273.30	605.13	1164.24	533.87	.406	.196	2
0.56	-	583.02	-	1041.11	-	.195	-	1

[1] The adults placed into a section and their emerging fry are considered in this table to represent one population.

Table 10a. The egg-to-fry survival and production of chum salmon fry in channel sections where controlled superimposition of spawners occurred

Layer no.	Temperature units (c) between layers	Spawner density m^2/♀		Fry production		Egg-to-fry survival
		Instantaneous	Overall	1 ♀	1 m^2	
1	-	2.58	-	1,504.39	582.59	.444
2	315.14	2.58	-	1,767.83	684.62	.616
combined	-	-	1.29	1,636.11	1,267.21	.523
1	-	2.73	-	1,154.41	422.22	.420
2	175.00	2.21	-	1,119.38	505.74	.360
combined	-	-	1.22	1,135.05	927.96	.390
1	-	1.66	-	1.677.32	1,010.43	.529
2	223.95	2.32	-	996.55	428.81	.331
combined	-	-	0.97	1,393.67	1,439.24	.449

Table 11a. The egg-to-fry survival and production of chum salmon fry from A[1] and B[2] sections of the Big Beef Creek spawning channel

Layer no.	Temperature units (C) between layers	section type	No. of fry produced	Egg-to-fry survival
1		A	1475	.509
2	79		1627	.535
combined			3102	.522
1		A	1547	.515
2	454		1061	.326
combined			2608	.417
control		A	1763	.567
1		B	273	.078
2	143		2531	.699
3	109		1686	.544
combined			4490	.439
control		B	1971	.600

---

[1] The A sections were provided with an immobile layer of rubble which was layed on top of normal spawning gravel.

[2] The B sections had the same kind of gravel that the A sections had but were not provided with an upper, immobile, crust of rubble.

(1966) reported that a few populations of chum salmon had been observed to spawn over large rubble in their natal streams. But he did not mention the amount of egg retention, the mechanics of the spawning process, or whether these were preferred or marginal spawning areas.

These results indicate that a crust of large rubble over a normal spawning substrate might allow the quick successive utilization of spawning areas without adversely affecting total fry production. However, several disadvantages of rubble substrates have been suggested. First, Koski (1975) mentioned that areas with large gravel interstices can act as "sinks" for transported sand and fines. These materials have been shown to affect both fry survival and quality. Secondly, potential egg predation by sculpins (*Cottus* spp.) and other predators could be high in such a gravel matrix (McLarney 1964, as cited by McNeil et al. 1964). And lastly Dill (1969) observed that efficiency of yolk material utilization in chum salmon alevins was reduced when they were incubated in gravel with large interstices. Another factor related to survival is the chemical composition of the water surrounding the developing eggs. The amount of carbon dioxide, ammonia, and dissolved oxygen in the intragravel environment can be influenced by the concentration of live or decaying eggs. Various quantities of these chemicals have been shown to affect both the developmental rate and survival of salmon embryos (Smirnov 1947; Wickett 1954; McNeil et al. 1964; Brannon 1965; McNeil 1966; Bams 1969; and Dill 1969). Thus, it was important not only to examine the survival, but also to compare the physical characteristics and timing of fry emerging from the various sections.

Timing and Stage of Development at Emergence

Several criteria were used to compare fry produced from superimposed and control sections. They were the stage of development at emergence (K_D; Bams 1970) and the commencement and duration of the emergence period. In making the comparisons several restrictions were imposed. It had previously been shown by Koski (1975) that chum salmon fry produced from the early run required a greater number of temperature units before they would emerge. Moreover, they also had a consistently smaller K_D value at emergence than fry produced by adults spawning later during the fall (Koski 1975).

This meant that comparisons based upon these characteristics had to be made among fry produced from the same run of adults. Additionally, each incubation period is unique and appears to influence the number of temperature units required before emergence can commence. Thus, comparisons between various fry populations (fry produced from a section) were also restricted to those which had incubated during the same year.

Because fry size is related to egg size, single physical parameters such as weight or length could not be used to compare one fry population to another. Instead a two parameter index using the ratio between weight and length at emergence was used (Bams 1970, $K_D = 10\ \sqrt[3]{\text{wt mg}}/\text{length mm}$). A Mann-Whitney U test (Siegel 1956) was employed to make comparisons among the average K_D values of fry produced from control and superimposed sections.

An assumption about how K_D values would change over time was tested before the comparisons were made. It was assumed that there would be no directional change in these values during the middle 90 percent of the emergence period. Bams (1970) showed that this occurred in the pink and chum salmon populations he examined. The same appears to be true for fry emerging from the Big Beef Creek spawning channel (Table 12a).

Comparisons among the average K_D values obtained from fry emerging from the larger C sections were made. The results (Table 13a) indicated there were no differences among the stages of development at emergence between fry produced from control and superimposed sections.

Fry emerged from channel sections over varying amounts of time. Since the fry were enumerated every morning the patterns of emergence were divisible into daily segments. To ascertain whether these patterns were altered by superimposition, comparisons of time (beginning) and rate of emergence were made among control and superimposed sections.

When all the fry had emerged, the accumulative percentage, in daily increments, was calculated. These values were plotted against the daily accumulated temperature unit values and regression analyses were performed. The slope of the regression lines indicated what the rate of emergence was, while the "y" intercepts reflected when emergence had begun. Premature emergence or residency in a channel section could influence these values, so the first and last five percent of the fry to migrate from a section were excluded from the analyses.

Analysis of covariance was used to compare the regression lines with one another. Tables 14a and 15a show the results of the linear regression and analysis of covariance tests, respectively. No apparent differences existed in the rate of emergence regardless of whether a section was superimposed upon or not. Yet, in one case fry produced from the first group of adults to use a section did begin to emerge about two days sooner than its control section.

Similar analyses were done on the fry populations emerging from the A and B sections. In this case, fry K_D values, the rate of emergence, and when it began were not the same (Table 16a). The fry produced from A sections had lower K_D values and the emergence periods appeared to be more protracted than those in the B sections. The significance of these differences on fry survival is not known.

Table 12a. The temporal changes in the average K_D values determined every other day during the emergence period for chum salmon fry outmigrating from two typical C (3.05-m x 15.24-m) channel sections

Population[1] No.					
Population No. 1			Population No. 2		
Accumulative % of emergence	Daily $\bar{x}$ K_D value	Deviation[2] from the $\bar{x}$ K_D	Accumulative % of the emergence	Daily $\bar{x}$ K_D value	Deviation from the $\bar{x}$ K_D
.071	1.817	+ 0.002	.067	1.822	- 0.010
.144	1.795	- 0.020	.110	1.833	+ 0.001
.219	1.833	+ 0.018	.197	1.831	- 0.001
.545	1.816	+ 0.001	.443	1.845	+ 0.013
.638	1.810	- 0.005	.665	1.833	+ 0.001
.736	1.808	- 0.007	.778	1.834	+ 0.002
.863	1.800	- 0.015	.864	1.828	- 0.004
.933	1.826	+ 0.011	.939	1.828	- 0.004
.952	1.833	+ 0.018			

[1] The fry emerging from a channel section were considered a population in this table.

[2] The differences between the daily and overall average K_D values in a population of fry.

Table 13a. The results of the Mann Whitney-U tests used to compare the average daily K_D values of fry emerging from control and superimposed C channel sections

Populations which were compared		Values of N_1	N_2	U values	Critical value of U (.05 level)	Significantly different at .05 level
First layer in a superimposed section	vs. control	5	5	5	4	No
First layer in a superimposed section	vs. control	8	9	31.5	15	No
First layer in a superimposed section	vs. control	10	10	50	27	No

Table 14a. The results of linear regression analyses between the daily values of accumulative percent emergence and temperature unit accumulation during fry out-migration. These analyses were performed on fry populations originating from channel sections (C) which were superimposed or used as controls

Type of fry population	Slope	y intercept	r
Second layer in a superimposed section	.0126	-10.187	.981
Control	.0128	-10.420	.996
First layer in a superimposed section	.0111	-9.590	.991
Control	.0108	-9.440	.986
First layer in a superimposed section	.007	-6.94	.981
Control	.008	-7.97	.972

Table 15a. The F ratios obtained by comparing the emergence patterns of fry migrating out of equivalent control and superimposed channel sections with analysis of covariance

	Results of the analyses of covariance			
Fry populations compared	F ratio for slope	Significantly different at .05 level	F ratio for y intercept	Significantly different at .05 level
Second layer in a superimposed section vs. a control section	$.05 < F.05,1/15 = 4.54$	no	$.11 < F.05,1/16 = 4.49$	no
First layer in a superimposed section vs. a control section	$.14 < F.05,1/22 = 4.30$	no	$32.33 > F.05,1/23 = 4.28$	yes
First layer in a superimposed section vs. a control section	$2.76 < F.05,1/33 = 4.17$	no	$.83 < F.05,1/34 = 4.17$	no

Table 16a. Comparisons between the K_D values and emergence patterns of fry migrating from equivalent A and B sections of the spawning channel

Physical parameters compared	Test Statistic	Significantly different at the .05 level
K_D values during emergence	$U = 38.50 > 31$ $N_1 = 9$, $N_2 = 14$	yes
Rate of fry emergence	$9 > F.05, 1/26 = 4.23$	yes
Commencement of fry emergence	$1.25 < F.05, 1/27 = 4.21$	no

The Practicability of Using Controlled Superimposition as a Management Tool

Using controlled superimposition as a management tool in spawning channels is attractive for several reasons. Rather than just enhance a portion of a salmon run, several segments of it could be introduced and allowed to spawn in the same channel areas. Quite often there are temporal differences in the arrival times of different species of salmon onto their spawning grounds. If considerations were given to the spawning and incubation requirements of each species, then different species or mixtures of species could be layered over one another in the same channel areas. Additionally, gains in absolute production appear to be feasible. Some of the deleterious effects of high concentrations of spawning adults were eliminated by temporally isolating the spawning fish. Consequently, the carrying capacity of the spawning channel was determined more by its capability to incubate eggs rather than on the ability of the fish to successfully deposit them.

However, the above tests were conducted in a relatively predator-free environment and the impacts of predation on dislodged but viable eggs were not assessed, nor has the importance of the observed differences in fry quality on their ultimate survival been evaluated. What the egg-carrying capacity of our channel is, has also not bee fully determined. Until these factors are more fully examined, the true nature of any gains in production by this method will remain partly conjecture.

SUMMARY OF THE RESULTS

The production of chum salmon fry from spawning channels is influenced by the interactions of spawning fish and the capacity of the spawning bed to successfully incubate eggs. Since adult salmon are usually introduced into such facilities over a short period of time, the egg-carrying capacity of a spawning channel is often not reached. It was hypothesized that the egg-carrying capacity could be reached if separate layers of adults were temporally isolated and judiciously introduced into the same spawning areas.

The impact of such a management strategy was examined by comparing the survival and quality of fry produced from control and superimposed sections of the Big Beef Creek spawning channel. The general approach used was to examine or anticipate the impacts (observed and potential) of spawner activity on previously deposited eggs. These observations are summarized below:

1. Female chum salmon distributed their territories in a repulsed manner for as long as they were able to defend them. However, the integrity of a territory deteriorated as competition among females for space to bury their eggs escalated.

2. The area of a female's territory is influenced by the number of competing conspecifics around her during egg deposition. Consequently, the size of a female's territory diminishes as instantaneous spawner density increases.

3. Territory locations within channel sections were not randomly chosen. Females preferred to establish their territories 60 cm or closer to the longitudinal walls of the spawning channel. However, females introduced into previously used sections did randomly distribute themselves over previous redd sites. It was also shown that females preferred to construct their first nests in valleys or depressed areas in the gravel surface.

4. The total amount of material moved by the females spawning within a section of the channel was proportional to the number of fish utilizing the section. Yet, the average amount of material displaced by a female diminished as instantaneous density increased. This was attributed to the above-mentioned reduction in territory size. In general, the gravel disturbed by each group of spawning fish moved downstream in a wave-like fashion.

5. The studies on territory location and gravel movement suggest that unless previously buried eggs are protected by an immobile substrate, stage of development, or some other technique, mortality caused by redd superimposition could be high.

6. The expected egg-to-fry survival rates for various instantaneous spawner densities were estimated. It was found that fry production/female gradually decreased as instantaneous spawner density rose, whereas fry production/m^2 increased and reached a peak of approximately 1,100 fry/m^2 when 1.1 to 1.2 m^2 were alloted/female. If the instantaneous spawner density exceeded this level, then fry production/m^2 decreased.

7. Each wave of adults in a superimposed channel section (3.05 m x 15.24 m) produced approximately as many fry as a comparable control section where only a single wave of adults had spawned. Moreoever, the total production of fry from superimposed sections was slightly greater than that expected if the same number of adults had been placed into a control section simultaneously. The largest gains of this type occurred when the overall density of a superimposed section was below 1 m^2/female.

8. Fry survival in the smaller (1.52 m x 3.05 m) A section (sections with a rubble crust) was similar to that observed in the larger control sections. Even in the section that was immediately superimposed upon, both groups had the expected egg-to-fry survival rates. This did not occur in the B section (small sections without a rubble crust) that was treated in the same manner. Instead, the egg-to-fry survival rate of the eggs deposited by the first spawning pair was much lower than that achieved by the last two pairs to use the section. These results suggest that a crust of large rubble over a "normal" spawning substrate might allow the quick successive utilization of spawning areas without adversely influencing total fry production.

9. The average stage of development (K_D) at emergence for fry produced from superimposed and control sections (3.05 m x 15.24 m) of the channel were statistically similar. Moreover, the patterns of fry emergence (i.e., its rate and when it began) also were not significantly different from one another.

10. The use of controlled superimposition of adult salmon in spawning channels is attractive for several reasons. First, it may be possible to enhance more than just one segment of a population. Secondly, if considerations are given to the spawning and incubation requirements of various species of salmon, it should be feasible to layer different species or combinations of species over the same gravel areas. And lastly, by temporally isolating groups of fish, it appears that the egg-carrying capacity of a spawning channel can be reached without incurring some of the deleterious effects of high instantaneous spawner density. However, before this management strategy is implemented, it should be tested under production conditions. The use of rubble substrates, in particular, should be carefully examined in larger areas.

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PART B

CHUM SALMON OCEAN RANCHING STUDIES AT THE BIG BEEF CREEK FISH RESEARCH STATION

GENERAL INTRODUCTION

Objectives

This portion of the final report examines several problems related to chum salmon (*Oncorhynchus keta*) enhancement programs which must rely on artificial propagation. The principal areas of discussion include: 1) An examination of mate selection patterns in chum salmon--a basis for decisions related to the development of breeding programs for this species; 2) maternal and paternal influences on the development and growth of chum salmon larvae and fry; and 3) effects of various types of substrates on the efficiency of yolk material utilization in chum salmon larvae incubated within Heath Tecna incubators.

Observations related to these questions were made either at the University of Washington's Big Beef Creek Fish Research Station (Fig. 1b) or at a neaby artesian water source approximately 2 kilometers from the station.

Experimental Fish

The chum salmon used for the investigations originated from Big Beef Creek which flows into the east shore of Hood Canal (Kitsap County, Washington state). Mature chum salmon enter the stream from early September through mid-January, with peaks of abundance occurring in early October (early run), mid-November (middle run), and late December (late run).

As the fish migrate into Big Beef Creek, they are captured in one of two traps and processed as described by Schroder (1973) and Koski (1975). Each fish used in the present studies was examined for maturity, anesthetized in MS-222 (tricane methanesulfonate), weighed, measured, and aged.

Fish which were used as broodstock for the hatchery investigations were often spawned the same day of their capture. Immature fish were held in pens until ripe (usually less than 4 days) and spawned at that time.

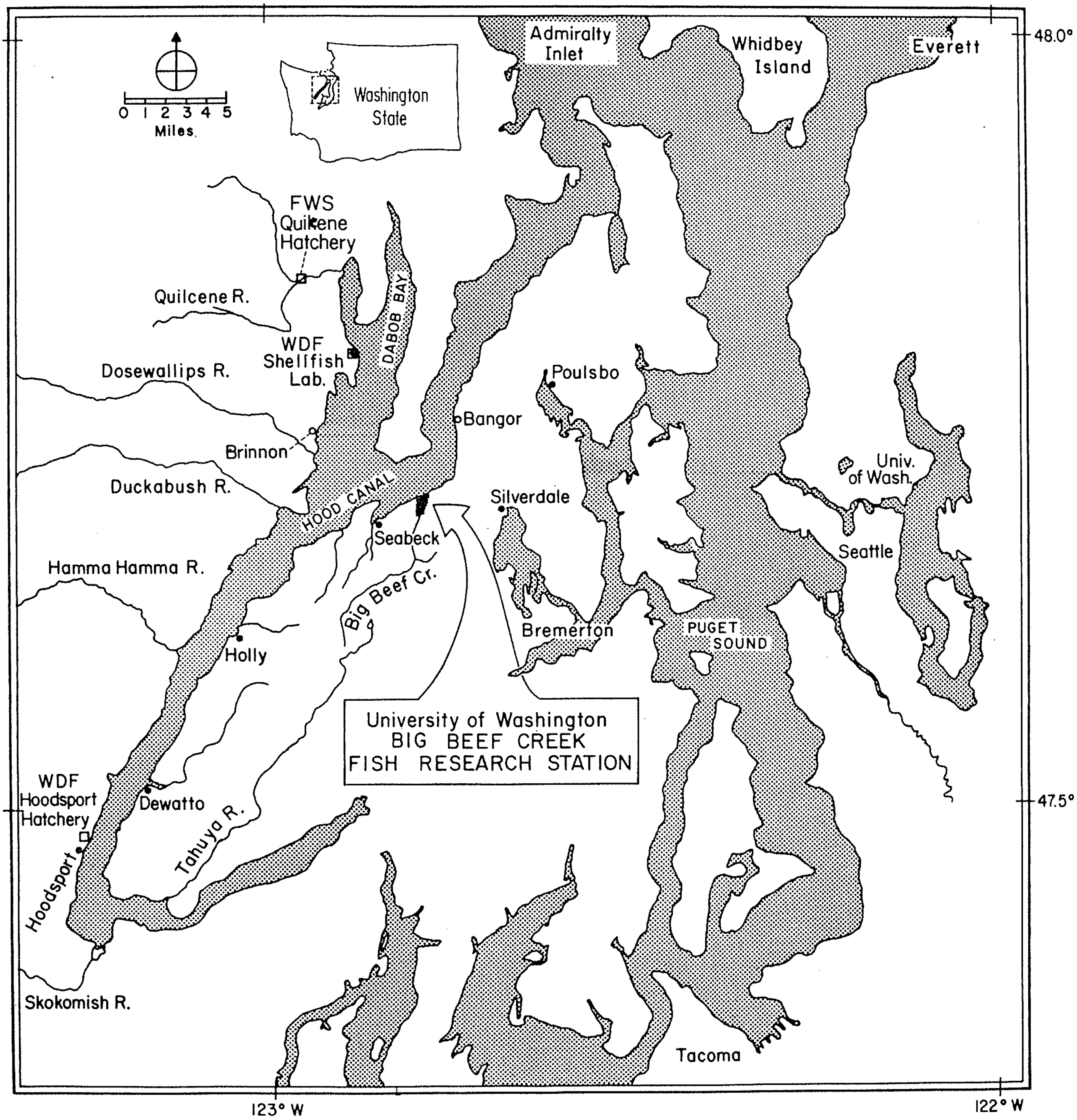


Fig. 1b. Location of the University of Washington's Big Beef Creek Fish Research Station.

I. AN EXAMINATION OF MATE SELECTION PATTERNS IN CHUM SALMON--A BASIS FOR DECISIONS RELATED TO THE DEVELOPMENT OF BREEDING SCHEMES FOR THIS SPECIES

Introduction

Two basically different systems of fish culture are possible; these are confined (intensive culture) and unconfined (extensive culture) systems (Helle, 1976). The genetic strategies needed for each system are different. Breeding programs similar to those developed in agriculture (e.g., development of inbred lines, heterosis, selective breeding, etc.) would be applicable if the fish were to be confined in ponds, raceways, etc., for their entire lifetimes (intensive culture). If, on the other hand, the animals are to be released into their natural habitat zones, then the above techniques, which tend to reduce genetic variability, may be more detrimental than beneficial to the enhanced stock (Helle 1976). For clearly, animals possessing a high degree of adaptive genetic variability will have a distinct advantage over those which do not, when both types are exposed to the fluctuating natural environment (Mayr 1970; and Helle 1976).

Consequently, the first thing of interest to a prospective or practicing fish culturist intending to use an unconfined system of aquaculture (such as an "ocean ranch") should be the comprehension of how and, more importantly, why genes are exchanged the way they are within demes of the species he is attempting to propagate. Yet, this concern is often ignored, and frequently at production facilities, assortative patterns of mate selection are employed that have no proven relationship with biological reality, but instead are based upon the intuitive knowledge and "art" of the fish culturist. One consequence of such poorly conceived breeding programs is a loss in genetic diversity in the cultured stock, and the subsequent creation of genetically uniform strains of fish. Such strains have been identified in hatcheries (Calaprice 1969; Simon 1972; and Helle 1976) and yet, little attention has been paid to the genetic implications of these findings (Helle 1976).

I felt that an understanding of how genes are exchanged in naturally reproducing populations of chum salmon would provide valuable information in the development of breeding schemes for ocean ranches utilizing this species. My attempts to examine this phenomenon were restricted to observations made on mature salmon that were placed into sections of the Big Beef Creek controlled-flow spawning channel (for a detailed account of these experiments, *see* Schroder, 1975).

Methods and Materials

Spawning Channel

Eight 3.05-m x 15.2-m sections of the spawning channel were used to examine mate selection patterns under various spawner densities and sex ratio regimes. Each section of the channel had a 0.25 percent gradient (.25 m/100 m), was filled with 75 cm of coarse (.8-cm to 6.25-cm) stream gravel, and was equipped with a 3-m high observation wall supplied with viewing ports. Water velocity was kept at 22.5 cm/sec and depth at 30 cm throughout the experiments. Further details concerning the construction, design, and additional experimental uses of the channel can be found in Beall (1972), Schroder (1973), and Koski (1975).

Observations of Fish in the Spawning Channel

Observations were made only during daylight hours and were primarily concerned with determining the reproductive status of both males and females in each experimental section of the channel. Since each fish had an identifying set of tags, it was possible to determine the size ratio and ages for each mating pair observed.

Results and Discussion

Basic Behavioral Patterns of Spawning Chum Salmon

In attempting to discover the patterns of mate selection that may exist in chum salmon, it was necessary to examine the social behavior of adults while they interacted on the spawning grounds. Fortunately, it appears that enough of the behavioral repertoire of this species is visually perceivable so that patterns can be recognized by simple observations.

We found that the basic behavioral patterns of each sex were distinctly different. Females are territorial and may utilize visual, tactile, and chemical clues in finding a suitable spawning site. Once a female has established a territory, she will construct a series of three to six discrete nests and remain in close proximity to them until she dies. In general, females are strongly substrate oriented, with the majority of their attention being directed to nest or mound (the collective burial of all the nests under one large mound of gravel) construction. Prolonged aggressive interactions among females are rare, with the preponderance of intrasex aggression occurring among females less than 2 m away (Schroder, 1973).

Males do not establish permanent territories but tend to be mobile, moving from one territorial female to another. Aggression among males is common, and prolonged ritualistic challenges and battles may occur among similarly sized rivals, usually directly over the contested female's nest site, often preventing other males from courting and spawning with her. After spawning, a male will remain by a female for approximately 20 minutes or less (often drifting away and returning at infrequent intervals) before he abandons her, possible locating another whose nest is nearer completion and hence, closer to spawning.

Both sexes tend to be opportunistic and promiscuous and thus, it is possible for a female's eggs to be fertilized by four or more males. If there are more males than females on the spawning grounds, or if the population of spawners is numerous enough to limit the numbers of females that can find and hold territories (producing a situation where males will outnumber females with territories), then more than one male quite often spawns with a female (Fig. 2b). Consequently, so-called satellite males can increase the number of sexual partners that may fertilize portions of a female's egg complement.

Dominant, or alpha, males can easily be distinguished from satellite males by their color patterns, courting movements, and close downstream proximity to a female. When observations were made to determine whether chum salmon paired in predictable patterns, only the size of the alpha male (often only one male was present) was used to calculate the size ratio that existed between a courting pair. Furthermore, it sometimes happens that a male may fertilize more than one clutch of eggs a female deposits. When such cases were observed, the size ratio of the pair was used as many times as it occurred.

The results of these observations are shown in Fig. 3b. Separate parts of the figure indicate what the expected (random) and observed frequencies of pairings were among fish of various size ratios (male body weight:female body weight). To test whether these frequencies were statistically different, a Goodness-of-Fit Test (G statistic, Sokal and Rohlf, 1969) was used. This test indicated that when the sex ratio was at parity or when there were more males than females, pairing did not occur randomly. Visual inspection of the figures suggests that chum salmon preferentially pair with individuals of approximately the same size. In most cases, if a male was smaller than a female, he was rarely able to exclusively court or spawn with her. Conversely, males that were larger than their prospective mates were often successful. By comparing the size ratios that existed between males and females originating from various brood years, to those which existed between the observed pairs, it was found that mate selection may also be assortative with respect to age as well as size.

Part C of Fig. 3b. illustrates that subtle changes may also occur in the size ratios of pairs that form when spawner density is moderate ($\leq 4m^2$/female) and there are twice as many males as females. Under these circumstances, competition among male rivals is intense and consequently, the relative size and strength of a male are given additional importance. However, when spawner density is low ($\geq 4m^2$/female) and the number of gravid females holding territories exceeds the number of males present, then mate selection tends to lose its assortative properties and mating becomes random (Part d, Fig. 3b).

The adaptive significance of mate selection patterns can only be speculated upon. Two major opposing selection pressures which deal with the degree of genetic diversity within populations appear to be in dynamic conflict. Briefly, these pressures can be identified as: 1) Those which cause a high degree of genetic diversity (giving succeeding

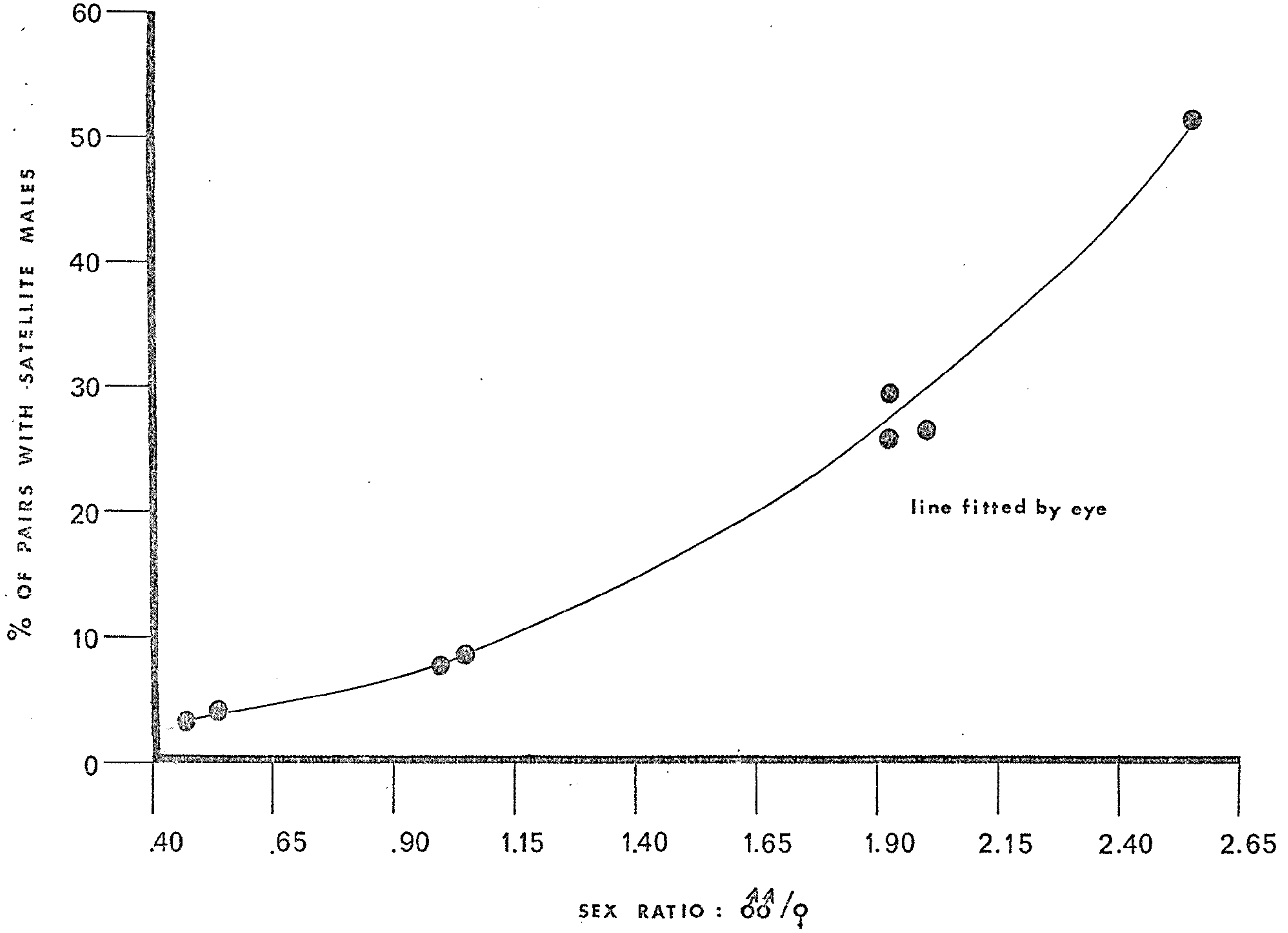


Fig. 2b. The occurrence of satellite males (socially subdominant males) behind courting pairs of chum salmon at various sex ratios,

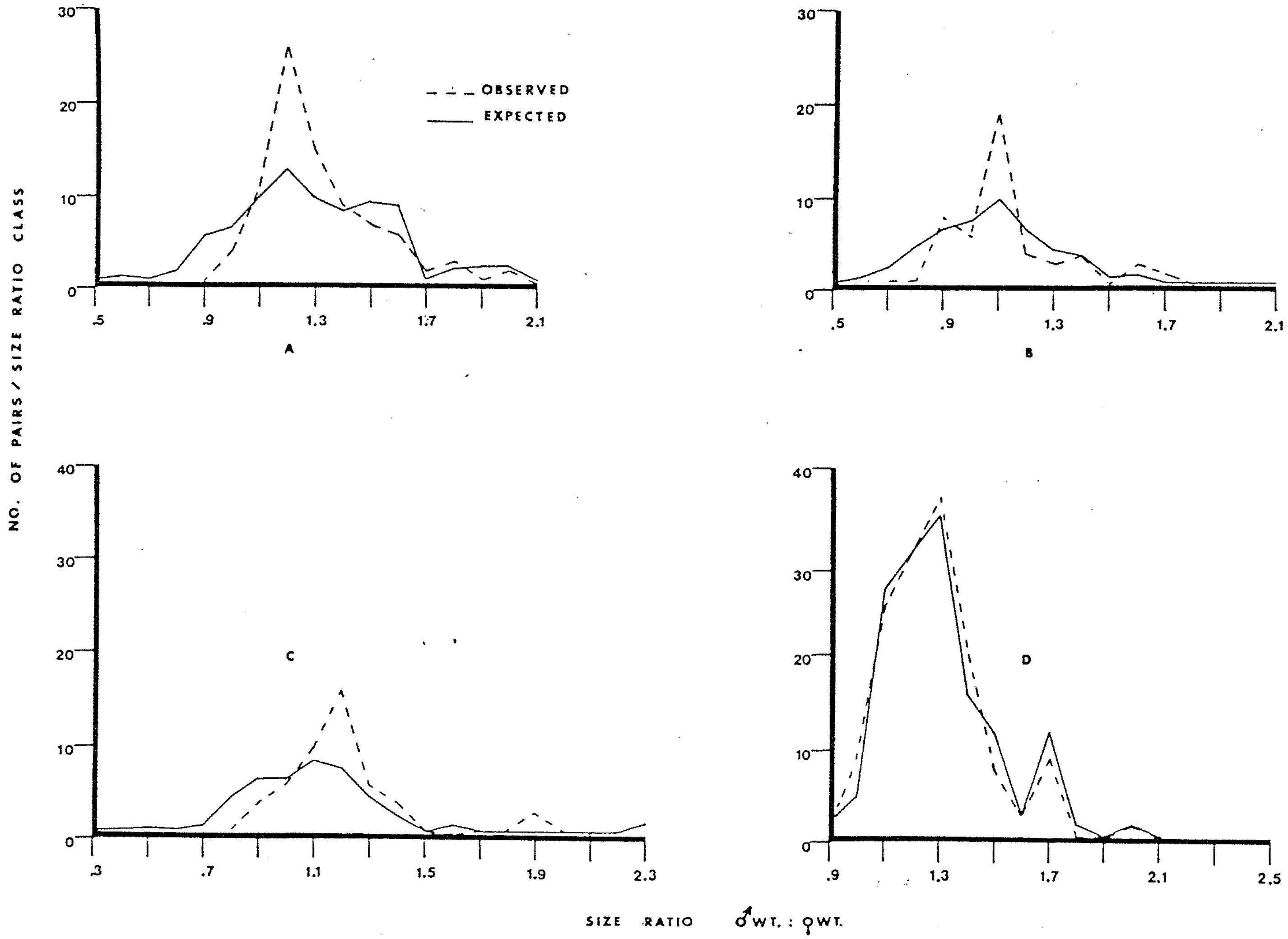


Fig. 3b. The expected (random) and observed frequencies of pairings between mating chum salmon of various size ratios (♂ body weight:♀ body weight) under a variety of sex ratios and spawner densities. The sex ratio in 3a and 3b was 1:1 with a spawner density of 1.55 m^2/♀. In 3c, the sex ratio was 2♂♂:1♀ and the spawner density equaled 3.58 m^2/♀, while in 3d the sex ratio was 1♂:2♀♀ and each female was allotted 1.5 m^2 of spawning substrate.

generations a greater genetic background to interact with a fluctuating environment); and 2) those which are designed to reduce the wasteful production of locally inferior genotypes. An equilibrium of these forces is maintained in populations because extreme genetic variability is just as detrimental as genetic uniformity (Mayr 1970).

Mating in chum salmon (although variable) rarely occurs in a random fashion. It seems reasonable to ask whether certain types of matings will provide a greater reproductive value to the spawners than other possible gene combinations that might have been selected. It may be possible that the behavioral activities I have observed are designed to perpetuate discrete life-history strategies within co-existing subpopulations of fish. My analyses of this possibility are incomplete so, until the evolutionary implications of the patterns I observed are understood, I recommend that the genetic variability of ocean ranch stocks be maintained by using gametes randomly chosen from individuals representing the entire stock (Helle 1976).

II. MATERNAL AND PATERNAL INFLUENCES ON THE DEVELOPMENT AND GROWTH OF CHUM SALMON LARVAE AND FRY

Introduction

In the previous section, I suggested that mate selection patterns may ultimately be caused by the differential survival of offspring produced by particular types of matings (gene exchanges). It would be of great practical value to determine whether maternal or paternal characteristics influence the fitness of progeny in a predictable and consequently exploitable fashion. The parental characteristics which I examined included egg sizes, and male and female age.

Egg Characteristics of 3- and 4-year-old chum salmon

Two hundred twenty-one females (47 3-year-olds and 174 4-year-olds) were used to examine the characteristics of eggs produced from 3- and 4-year-old fish originating from the middle run of Big Beef Creek. The entire egg complement of each female was removed and weighed to the nearest g on a Chatillon 6-k x 10-g balance. After the eggs were weighed, a sample of 60 to 200 eggs was withdrawn and weighed on a Mettler P 1200 balance to the nearest 0.01 g. These two weights were used in the following algebraic formula to estimate the fecundity of each female:

$$\text{fecundity} = \frac{(\text{no. of eggs/sample})\ (\text{total egg wt})}{\text{weight of the sample}}$$

The eggs from each sample were then allowed to water harden for 12 hours before subsamples were measured and weighed. Three subsamples of 20 eggs from each sample were measured to the nearest .5 mm on a board held by a stand at a 25-degree angle. The subsamples of measured eggs were blotted dry and weighed to the nearest .01 g on a Mettler P 120 balance, placed in a Precision Thelco Model 17 drying oven, and baked for 24 hours at 97°C. After drying, the eggs were placed in a vacuum dessicator with anhydrous calcium chloride and allowed to cool before they were reweighed on the Mettler P 120 balance.

Fish Culture

To examine the possible effects of parental age and size on the developmental rates and growth patterns in alevins and fry, two sets of controlled breeding experiments were performed. In both experiments, the female parents were anesthetized in MS-222, had their caudal peduncles severed, and were bled thoroughly before any eggs were removed. Milt from selected males was added to the eggs and the spawn was then transported approximately 2 km from the research station to an artesian water source. The eggs were fertilized at this location just prior to their placement into standard Heath incubator trays. After the eggs had reached the "eyed stage" of development, they were "shocked" and mortalities from each cross were removed. The remaining live eggs were returned to Heath trays which had been modified by the attachment of an Astroturf substrate to the bottom screen. A flow of 11 liters/min was maintained in each Heath tray and the water temperature ranged from 8.7 C to 8.9 C throughout the entire incubation period.

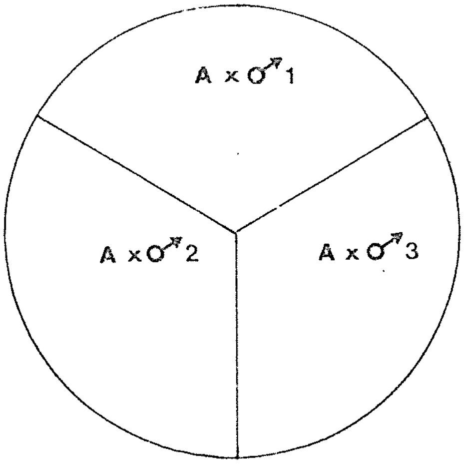
Nine male and nine female chum salmon were used to test the possible effects of male size and age on alevin and fry growth. The fish were spawned so that three sets of a 3 x 3 factorial cross were created. Female size and age were kept constant in each factorial cross, whereas male size and age varied. Three males and three females were spawned at the same time and the egg complement of every female was divided into thirds with each third being fertilized by a different male. In this manner, a total of 27 different crosses was created (Fig. 4b).

Each cross or population was kept separate by being incubated in its own Heath tray. Observations were made during the incubation period to determine the number of temperature units required to hatch eggs originating from the different crosses. The wet and dry weights of newly hatched alevins were also measured. Three groups of three alevins were removed from each cross, blotted dry, and weighed to the nearest .01 g on a Mettler P 120 balance. The groups were then placed in a drying oven and baked at 97° C for 24 hours. After being dried, the alevins were placed into a vacuum desiccator, allowed to cool, and reweighed on the Mettler P 120 balance.

A similar sample of nine fry/population was removed and weighed 102 days after fertilization. Also at this time, three groups of 100 fry from every cross were blotted dry on a damp sponge, placed in a tared beaker filled with water, and weighed to the nearest .01 g on a Mettler P 1200 balance. From these samples, 40 to 50 fork lengths (tip of snout to fork of tail) were obtained on fry representing each cross.

Immediately after sampling, the fry from each population were individually counted and transferred into rearing troughs. The troughs were 30.7 cm x 30.7 cm x 240 cm and divided by wooden-framed nylon-mesh (1/16-inch Delta) screens into three equal rearing areas 30.7 cm x 30.7 cm x 78.5 cm. During the 13-week rearing period, water depth was maintained at 16.5 cm, velocity at 11 liters/min (3 gal/min) and temperature varied between 8.7 C and 8.9 C. Dissolved oxygen concentrations in each trough were determined on a weekly basis by a Hach kit and were moderately low, ranging from 9.8 ppm to 5.4 ppm.

To test for possible location effects within the troughs, the three populations of fry produced from a male were placed into all three possible rearing areas (head, mid, and tail) in three different troughs, whereas the progeny originating from a single female were always reared in the same divided trough. Thus, each trough contained three populations of fry begot by the same female yet fertilized by different males (Fig. 5b).

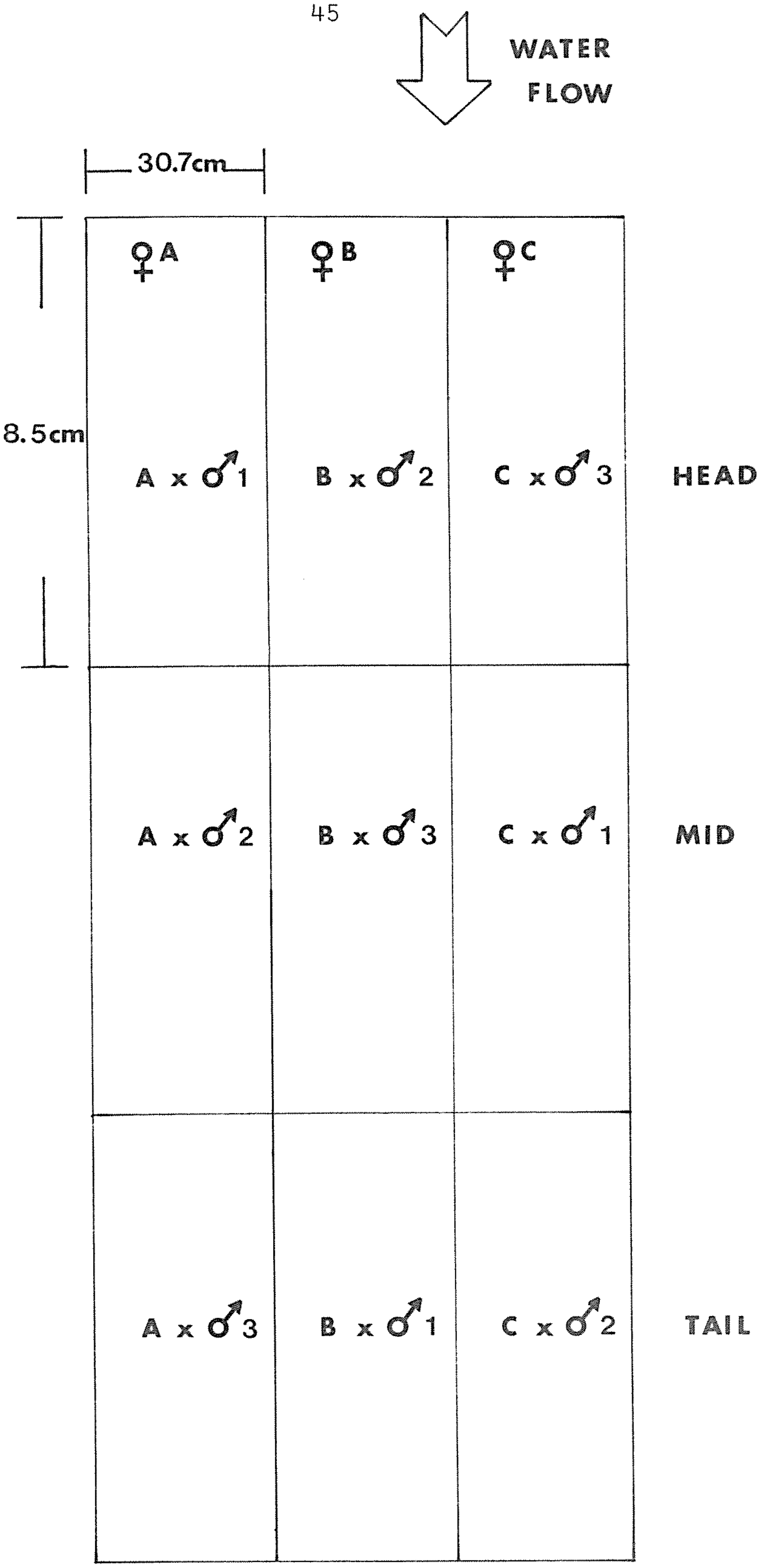


THE EGG COMPLEMENT OF ♀ A

♂♂ ♀♀	1 (3yrs)	2 (4yrs)	3 (4yrs)
A (4yrs)	A x 1 (4 x 3)	A x 2 (4 x 4)	A x 3 (4 x 4)
B (4yrs)	B x 1 (4 x 3)	B x 2 (4 x 4)	B x 3 (4 x 4)
C (4yrs)	C x 1 (4 x 3)	C x 2 (4 x 4)	C x 3 (4 x 4)

A REPRESENTATIVE 3X3 FACTORIAL CROSS

Fig. 4b. Three 3x3 factorial crosses were created by spawning three different groups of three males and females at the same time. In making the factorial crosses, the egg complements of every female were split into thirds, with each third being fertilized by a different male. In this fashion, 27 distinct crosses (15, 4-year-old females x 4-year-old males and 12, 4-year-old females x 3-year-old males) were produced.



REARING LOCATIONS WITHIN A TROUGH

Fig. 5. The rearing locations within a trough for fry begot from a single 3x3 factorial cross.

The fry were fed in excess 14 to 16 times/day on an Oregon Moist Pellet diet. During the period they were being reared, each population was sampled once a week. Twenty-five fry were randomly selected from each cross, killed with a heavy dosage of MS-222, and individual lengths (TSFT to the nearest .25 mm) and wet weights (to the nearest .001 g) were then taken. The sacrificed fry were next arbitrarily divided into five lots of five fry each and baked in a drying oven for 48 hours at 97 C. Upon removal from the oven, the fry were placed into a vacuum desiccator, allowed to cool, and weighed to the nearest .001 g on a Mettler P 120 balance.

Possible maternal effects on the developmental rate and size of fry at emergence were also examined. The eggs from three females (one 4-year-old and two 3-year-olds) were fertilized by two similarly sized 3-year-old males. A sample of eggs from each female was removed at the time of fertilization and allowed to water-harden for 24 hours. After water-hardening, the eggs were measured and weighed as previously described.

The remaining fertilized eggs from each female were placed in separate wire egg baskets and hung in rearing troughs. While incubating in the wire baskets, the eggs were kept in total darkness except during periods of routine sampling. Just before hatching, the eggs were removed from their baskets and transferred into Heath trays furnished with Astroturf substrate.

To determine if differences existed in the rate at which the eggs developed, three eggs from each lot were removed daily and preserved in 5% acetic acid. After the eggs hatched, alevins were removed once every 7 days and preserved in 5% formalin. The yolk and larval tissue material from each alevin were separated and both parts were weighed, dried, and reweighed.

Results and Discussion

The morphometric properties of both the females and eggs originating from the middle run are presented in Tables 1b and 2b. The tables are designed to allow comparisons between 3- and 4-year-old females which represent the dominant age classes returning to this stream. Not unexpectedly, 4-year-old females are larger and produce bigger eggs than 3-year-olds.

Linear regression analyses were used to test whether correlations existed between a female's age, weight, length, and condition factor and the diameter, weight, and condition factor of her eggs. These tests indicated that there was little linear correlation between the physical characteristics of 4-year-old females and their eggs. Yet, moderately strong correlations did exist between these characteristics (except female condition versus egg condition) in 3-year-old fish.

Table 1b. A comparison between the lengths, weights, condition factors[1], and egg parameters of 3- and 4-year-old females migrating into Big Beef Creek during November and December 1974

Age	Length		Weight		Condition factor		Egg diameter		Wet egg weight		Dry egg weight		Condition factor[2]	
	$\bar{x}$ value	SD	$\bar{x}$ value	SD	$\bar{x}$ value	SD	$\bar{x}$ value	SD	$\bar{x}$ value	SD	$\bar{x}$ value	SD	$\bar{x}$ value	SD
4	735 mm	29 mm	4.7 k	.6 k	1.17	.07	7.16 mm	.24 mm	.27 gr	.025 gr	.105 gr	.010 gr	.735	.046
3	664 mm	37 mm	3.4 k	.6 k	1.15	.12	6.72 mm	.22 mm	.23 gr	.021 gr	.088 gr	.088 gr	.742	.030

[1] Condition factor = (body weight/fork length^3) x 10^5.

[2] Egg condition factor = (wet egg weight/egg diameter^3 x 10^3.

SD = Standard deviation.

Table 2b. Conditional[1] linear regression analyses between the morphometric characteristics of 3- and 4-year-old chum salmon females and their eggs

Age	X variable	Y variable	r	r^2	B value	t test B = 0	Significance > .05
4	wet egg weight	Body weight	.387	.150	9574	5.104	Yes
3	wet egg weight	Body weight	.693	.481	20421	6.461	Yes
4	dry egg weight	Body weight	.432	.187	26815	5.828	Yes
3	dry egg weight	Body weight	.723	.522	51892	7.016	Yes
4	wet egg weight	Fork length	.308	.095	357	3.943	Yes
3	wet egg weight	Fork length	.622	.387	1114	5.335	Yes
4	dry egg weight	Fork length	.367	.134	1063	4.793	Yes
3	dry egg weight	Fork length	.657	.432	2868	5.858	Yes
4	egg diameter	Body weight	.335	.112	864	4.325	Yes
3	egg diameter	Body weight	.724	.524	2003	7.045	Yes
4	egg diameter	Fork length	.276	.076	33	3.487	Yes
3	egg diameter	Fork length	.638	.408	107	5.564	Yes
4	egg condition[2]	Condition factor	.054	.003	.079	.663	Non-linear relationship
3	egg condition	Condition factor	.091	.008	.376	-.613	Non-linear relationship

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[1] Linear regression analysis assumes that the independent variable X is fixed and measured without error. In the above analyses the independent variables were measured with error and hence the standard (Model I) tests for significance may not be applicable to this data unless we assume it is a typical Berkson case. The Berkson case assumes that the independent variables are measured with error but that the X values and the error terms associated with them are not correlated thus allowing one to use the so-called Model I regression methods for tests of significance (Sokal and Rohlf, 1969). Because these assumptions were made, the regression analyses have been labeled "conditional" to differentiate them from typical Model I or Model II regression analyses (McCaughran, personal communication).

[2] Egg Condition Factor = (Wet egg weight/egg diameter^3) X 10^3.

Because the eggs produced from variously sized females originating from one population are subjected to similar selection pressures, it should not be too surprising that there are moderate or low correlations between a female's physical parameters and the size of her eggs.

Eggs originating from 4-year-old females appear to have a greater nutritive value than those produced by younger fish. Koski (1975) demonstrated that fry produced from 4-year-old females weighed more upon their emergence than those produced from 3-year-old fish even though the diameter of the eggs was the same. This result may have been caused by a difference in the nutrients within the eggs or the presence of a different relationship between egg weight and diameter in 3- and 4-year-old fish. Since strong linearity was shown to exist between egg diameter and dry weight (Table 3b), it was possible to test with an analysis of covariance whether there were differences in the weights of eggs with similar diameters produced from differently aged females. This analysis indicated that the slopes but not the levels of the two regression lines were similar at the .05-level (Table 4b). This implies that eggs from 4-year-old females are lighter at a given diameter than those originating from 3-year-olds.

To determine if a relationship existed between egg and fry weight, a linear regression analysis was completed that compared the dry weights of eggs and fry produced from nine 4-year-old females. The results of this analysis (Table 5b) and data presented in Fig. 6b corroborate earlier findings by Koski (1975) that suggested a strong positive linear relationship between egg weight and fry size at emergence.

Parental influences on embryo growth rates and efficiency of yolk material utilization were also examined. It was found that egg weight did not influence the temperature unit requirements of eggs originating from 4-year-old females (analysis of variance $F = 2.88 < F_{.05}\ [5,6] = 4.39$). However, it was discovered that eggs produced by 4-year-old females hatched sooner when they were fertilized by 3-year-old males than if by 4-year-old fish (analysis of variance $F = 4.8405 > F_{.05}\ [1,25] = 4.24$). Withler and Morley (1970) examined the hatching times of interspecific hybrids made among sockeye (*O. nerka*), chum, and pink salmon (*O. gorbuscha*) and concluded that the female parent determined the embryo size at hatching, that the male parent controlled the rapidity at which the embryo reached this point, and therefore influenced the time at which the egg would hatch. It is speculated here that the inequalities observed in hatching times due to male age may reflect intrinsic differences in the metabolic characteristics of 4- and 3-year-old males.

Conversely, how efficient the embryo was in utilizing the energy resources of its egg was not influenced by the age of its male parent (analysis of variance $F = .01420528 < F_{.05}\ [1,16] = 4.49$) nor apparently by egg size.

Table 3b. Conditional linear regression analyses between the diameter and dry weights of eggs begot by both 3- and 4-year-old chum salmon originating from the middle run of Big Beef Creek

	Relationship					F ratio		t test B = 0	
						Value	Significance	Value	Significance
Age	X variable	Y variable	Regression formula	r	r^2		.001		.001
3	dry egg wt	egg diam	$\hat{y}=4.733+22.619(x)$	.871	.759	141.9	Yes	11.912	Yes
4	dry egg wt	egg diam	$\hat{y}=5.288+17.875(x)$	.743	.552	182.7	Yes	13,516	Yes

Table 4b. An analysis of covariance on the linear relationships observed between egg diameter and dry weight in 3- and 4-year-old chum salmon

Age group females	df	y^2	xy	x^2	df	Residuals	
						s.s.	m.s.
4 years	149	8.7986	.2719	.0152	148	3.939	
3 years	46	2.2156	.0744	.0033	45	.534	
				Totals	193	4.473	.02318
		Difference	for testing slopes		1	.061	.06054
	195	11.0142	.3463	.0185	194	4.534	.02337
		Difference	for testing levels		1	.225	.22516
	196	17.8392	.6121	.0286	195	4.758	

For differences in slope $F = 2.6120 < F_{.05}\ (1,193) = 3.92$ therefore fail to reject the null hypothesis at the .05 level

For differences in level $F = 9.6357 > F_{.05}\ (1,194) = 3.92$ therefore reject the null hypothesis at the .05 level.

Table 5b. A conditional linear regression analysis between the dry egg weights of nine 4-year old females and dry weights of their 102-day-old alevins

Relationship				F ratio		t test B = 0	
x variable	y variable	Regression formula	r	Value	Significance >.001	Value	Significance >.001
Dry egg wt	dry alevin wt	$\hat{y} = .0305 + .3938 (x)$	.724	27.47	Yes	5.241	Yes

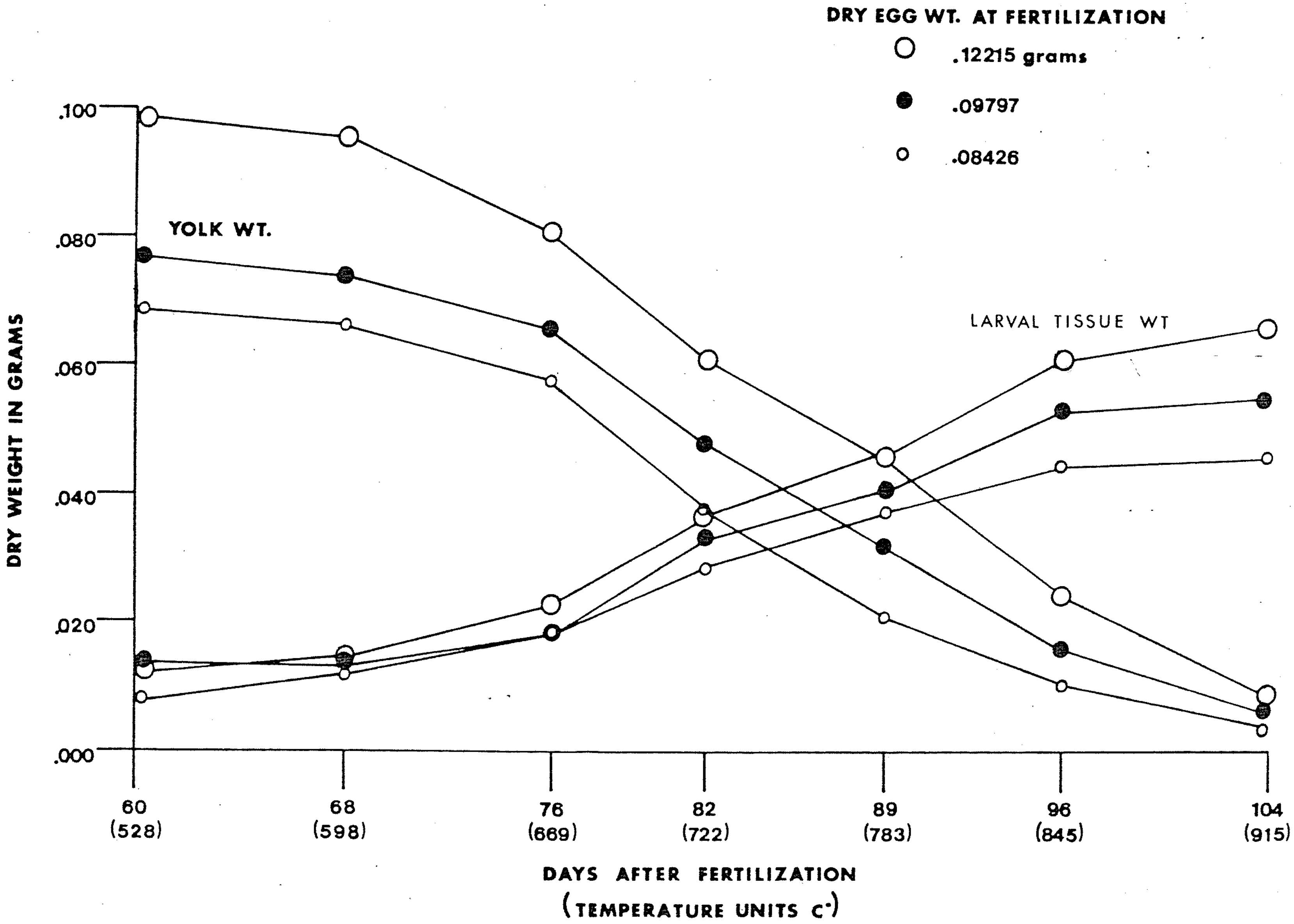

Fig. 6b. Temporal changes in the dry weights of both yolk and larval tissue materials in alevins produced from three batches of differently-sized eggs.

Fish Culture Results

Data gathered on the growth characteristics (weekly changes in dry weight) of reared fry produced from artificial crosses were analyzed by multiple regression analysis and analysis of covariance which incorporated dummy variables. First, the influence of seven variables (time reared, egg weight, age of male parent, rearing location within a trough, kg of fry/m^3, g of fry/liter per min, and absolute flow rate of water through a trough) on the dry weights of fry originating from each of the 27 experimental populations was determined by using multiple regression analysis. These variables accounted for 96% of the observed variance in the dry weight values of the examined fry.

To determine if any of the variables could be eliminated from further analysis, the explained sum of squares was divided into components attributable to each independent variable. This was done by using the standard regression method where each variable is treated as if it had been added to the regression equation in a separate step after all the other variables had been included (Nie et al. 1975). Results in Table 6b illustrate the calculated F ratios used to test the significance of the regression coefficients of each variable used in the equation. This analysis indicated that the absolute flow rates of water within the rearing troughs had little effect on dry weight values and consequently, they were excluded from further analysis.

Second, by using analysis of covariance with dummy variables, it is possible to determine whether a regression model with several lines will reduce the variability of Y to a greater extent than one with only a single line. This is determined by evaluating the F ratio obtained from such an analysis. This technique was used to test whether egg size, male age, and rearing position within a trough influenced dry weight values of sampled fry. We found that 3-year-old males significantly increased the growth rates of the fry they fathered, ($F = 4.4 > F_{.001}$ [5, 1828] = 4.10), and that larger eggs produced larger fry ($F = 15.2521 > F_{.001}$ [40, 1782] = 1.84), and that rearing position] also influenced fry growth ($F = 198.7619 > F_{.001}$ [10, 1818] = 2.96).

Whether these differences can be attributed to genetic factors related to age at maturity is impossible to determine. We have no data on the genetic background of the parental fish other than that they

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[1] During a portion of the rearing period water was recycled back into the rearing troughs. While this occurred fry which were reared in the anterior or head portion of a raceway (*see* Fig. 5b) experienced a greater mortality rate than those reared in a mid or tail portion. Excess food recycled back into the troughs apparently caused abrasions on the gills and other body surfaces which were lated infected with *Saprolegnia*. Consequently, the density of fry in a head portion of a raceway was reduced and this caused an apparent increase in the rate of growth on the surviving fish.

Table 6b. Results of a stepwise regression analysis on chum salmon fry rearing data

Multiple Regression
Dependent variable: Log 10 transformation of the dry weights of sampled fry

Step	Variable	Simple r	F to enter or remove	Significance
1	Time reared	.972	35163.82	.001
2	Dry egg weight	.099	397.22	.001
3	Fry wt/liter/min	.573	170.32	.001
4	Male age	-.023	38.49	.001
5	Fry wt/m^3	.804	9.82	.002
6	Rearing location	-.024	4.99	.026
7	Absolute flow rate	.457	.72	.396

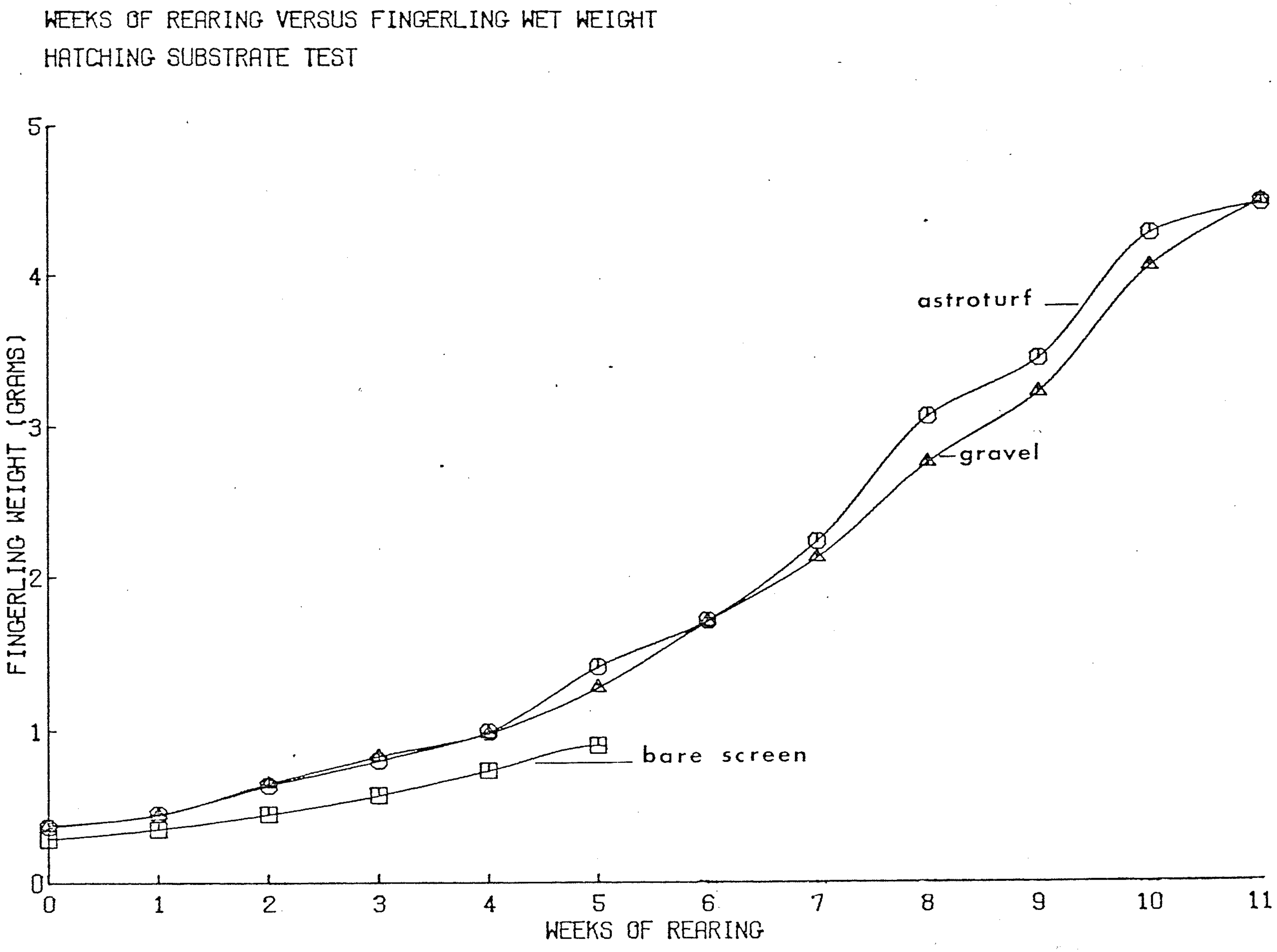

Fig. 7b. The growth rates of chum salmon fry incubated within Heath trays equipped with either a gravel, screen, or Astroturf substrate.

originated from Big Beef Creek. To fully assess the impact of parental age (particularly male age) on fry growth would require the capture and crossing of adults with known genetic background. Until we can do this, we can only be tantalized by a myriad of questions which deal with the heritability of life-history strategies.

No matter how, or why, we make our parental crosses, we are still confronted with providing the resulting eggs and alevins with an optimum incubation site. The next section, prepared jointly with Mr. Bruce Snyder, describes some experiments we carried out in Heath Tecna trays in an attempt to determine the effects of various incubation substrates on alevin survival and growth.

III. EFFECTS OF VARIOUS TYPES OF SUBSTRATES ON THE EFFICIENCY OF YOLK MATERIAL UTILIZATION IN CHUM SALMON LARVAE INCUBATED WITHIN HEATH TECNA INCUBATORS

Introduction

Artificial propagation of chum salmon in hatcheries has not generally enjoyed a great deal of success in North America. This has been attributed to the presence of incompatible incubation environments that often exist in such facilities (Brannon 1965; Bams 1967 and 1969; Bailey and Heard 1973; and McNeil 1973). Clearly, to optimize the potential of each cultivated egg, it is necessary to design and create incubation environments that allow the egg and alevin to develop naturally and consequently, to utilize its yolk materials in the most efficient way possible. This need has been recognized by quite a few investigators (Disler 1953; Brannon 1965; Bams 1967 and 1969; Poon 1970; Emadi 1972; McNeil 1973; and McNeil and Bailey 1975) and provided for in chum salmon hatcheries in Russia and Japan (McNeil 1973; and Mathews and Senn 1975).

Recently, Bob Dewey (personal communication) had the ingenious idea of utilizing plastic Astroturf as an artificial incubation substrate for incubating sockeye eggs and larvae. Bailey, Taylor, and Pella (1975) used the same incubation material and developed experiments that examined the effects of this substrate on pink salmon eggs. Their studies broached a very important question by examining the relationships existing among waterflow, fry density, incubation substrate, and fry size at emergence in artificial incubation structures. As a result of these studies, everyone involved in similar work is carrying a different form of plastic in his pocket. Yet, little work has been done in evaluating the efficiency of yolk material utilization on these substrates. We had the opportunity this past year to evaluate how efficient chum salmon alevins were in utilizing their yolk materials while incubating in Heath Tecna incubator trays equipped with either a gravel, Astroturf, or bare screen substrate.

Methods, Materials, and Results

Eyed eggs from ten 4-year-old females (Table 7b) were randomly mixed and placed into Heath Tecna incubator trays at a density of three alevins/cm^2 (20 alevins/square inch). The incubators were supplied with water from an artesian well that ranged in temperature from 8.7 C to 8.9 C throughout the entire incubation period. After 99 days (866 TU's C), the incubation period was completed and five samples of 100 fry from each treatment group were sampled gravimetrically to calculate the average wet weight of the fry. Additionally, to determine average lengths, 30 fry from each treatment were measured (TSFT) to the nearest mm. Significant weight and length differences of approximately .1 g and 3 mm occurred among the groups (Table 8b). Average dry weights of fry originating from each treatment were determined and used in conjunction

Table 7b. Average adult size and egg data parameters for the 10 chum salmon females used in the substrate experiments at Big Beef Creek, 1974

Date spawned	Age	$\bar{X}$ weight (g)	$\bar{X}$ length (mm)	$\bar{X}$ egg diameter (mm)	$\bar{X}$ egg weight	
					wet (g)	dry (g)
12/8/74	4	4765	746	6.934	.258	.102

Table 8b. The average wet weight (five groups of 100 fry from each treatment) and length (30 measurement/treatment group) of chum salmon fry incubated on different substrates in Heath Tecna trays

Physical parameters	Unaltered Heath screen tray	Treatment: Heath tray with Astroturf mat	Heath tray with gravel substrate
Average wet weight/ fry (g)	.2843	.3838	.3820
Average length (mm)	33.96	36.76	37.38

with dry weights to compute how efficient the alevins had been in converting yolk materials to larval tissue. Fry incubating on screen substrates proved to be 20% less efficient in utilizing their yolk materials than those incubating on either gravel or Astroturf (Table 9b).

A one-way analysis of variance, using the wet weights of fry incubated on the various substrates was performed (Table 10b) and showed that a highly significant ($P < .005$) difference existed among fry originating from the substrate treatments. A Tukey's w-procedure (honestly significant difference test) performed on the same data (Table 11b) indicated that fry incubated on bare screen were different (at the $P < .01$ level) from those which had been placed into trays with Astroturf or gravel.

To determine if this difference in size would persist over time, fry from each treatment were reared in freshwater under identical conditions. The growth rates of all the groups were similar, but because of their initially smaller size, fry originating from trays with bare screen were never able to catch up in weight or length to the other two groups (Fig. 7b).

Discussion

Astroturf appears to provide an excellent substrate for developing chum salmon larvae when they are incubated at low hatching densities (≤ 3 alevins/cm^2) with adequate water exchange (11 liters/min). Its use in incubation systems relying on groundwater sources which have periodic sediment loads has yet to be examined. Mortalities can be difficult to remove from this type of material and mats of fungus may develop which could significantly reduce egg-to-fry survival.

The yolk material utilization of chum salmon larvae originating from large eggs was slightly reduced when they were incubated on Astroturf with bent blades. Table 12b shows the results of a linear regression analysis between the dry egg weights of nine 4-year-old females and the efficiency of their embryos in utilizing yolk material. The observed relationship may be due to the inability of larger alevins to successfully penetrate into the plastic grass and, hence, they may spend more time swimming on the surface of the substrate than alevins produced from smaller eggs. Finally, Astroturf is difficult to attach to Heath trays and, as a result, may not be economical for large-scale use in production hatcheries.

These disadvantages have led us to test the suitability of different forms of Astroturf and other plastic devices as incubation substrates for developing chum salmon.

Table 9b. The average dry weight (5 groups of 3 fry each) and percentage of yolk material utilization of fry originating from each treatment group

Physical parameters	Unaltered Heath screen tray	Treatment: Heath tray with Astroturf mat	Heath tray with gravel substrate
Average dry weight/fry (g)	.0515	.0734	.0745
Average % of yolk material converted to larval tissue	50.72	72.36	73.43

Table 10b. Analysis of variance on the wet weights of chum salmon fry incubated on three different substrates in Heath incubator trays

Source of variation	SS	d.f.	Ms	F
Between locations	324.21	2	162.11	365.4
Within locations	3.44	12	0.286	
Total	327.65	14		

$F = 565.4 > F_{.005}\ (2, 12) = 8.51$ reject the $H{:}T_i = 0$

Table 11b. A comparison of all treatment (substrate types) mean wet weights by Tukey's w-procedure (honestly significant difference test)

Treatment	Heath tray with gravel substrate	Heath tray with Astroturf mat
Unaltered Heath screen tray	9.95[1]	9.77[1]
Heath tray with Astroturf mat	0.178	

[1] Values > W .01 level (1.206) indicate differences between the mean wet weights of fry produced from the various substrate types

Table 12b. A linear regression analysis on the relationship between dry egg weight and embryo efficiency in the utilization of yolk materials as exhibited by the progeny produced from nine 4-year-old female chum salmon

Relationship		Regression formula	r	F ratio		t test B = 0	
X variable	Y variable			Value	Significance >.001	Value	Significance >.001
dry egg weight	% of dry egg weight converted to dry alevin weight	$y = 98.25 - 282.04(x)$	-.595	13.928	Yes	3.732	Yes

1975-1976 Incubation Substrate Experiments

This year, one of us (Bruce Snyder) is examining the effects of four substrate types (bare screen, gravel, various types of Astroturf, and biofilters) on chum salmon alevins at different loading densities in hatcheries with and without sediment-free water. The densities being examined are 2, 2.5, 4.3, and 6 alevins/cm^2 (13, 15, 27, and 38 alevins/$inch^2$). A constant flow of 18 liters/min (5 gal/min) is being provided to each Heath incubator tray used in these experiments.

The most promising new substrate being tested this field season appears to be the Actifil biofilter (bio-ring) manufactured by the Norton Chemical Process Products Division, Akron, Ohio. Biofilters come in a variety of sizes and weights and we are testing only the 1-, 1.5-, and 2-inch floating and sinking types this year. The biofilters appear to stop unnecessary fry movement quite well at the loading densities we are examining.

GENERAL CONCLUSIONS

Ultimately, the strategies employed in operating a chum salmon ocean ranch are going to be based upon the kind of fish that is desired. Because fry survival and quality can, to a certain extent, be controlled during the incubation phase, our attention should be directed toward the development of genetic strains which have a high potential to survive in the marine environment. Any deliberate manipulation of genes within our enhanced populations will be controlled by what we want from our cultured stocks and by what they are capable of giving us.

In developing such a program, the first step is the delineation of the genetic variability existing within the population and the determination of whether we can effectively utilize some of it to produce fish with desirable characteristics. Unfortunately, our comprehension of the impact of environmental factors on various genotypes is almost nonexistent. Feedback of this type is essential in the development of rational breeding schemes and will most likely be accumulated through trial and error. Questions relating to chum salmon culture, such as whether to have extended rearing, with feeding and under what conditions, remain to be answered.

During its evolution, the species may have been confronted with life-history options that may have been analogous to some to which we may expose them. It seems logical to expect that the life-history pattern of a stock is the most efficient given the environmental circumstances under which it has developed. Consequently, we are faced with trying to evaluate the impact of our culture techniques on the traditional life-history pattern. We must ask ourselves what impact will the removal of certain selection pressures make upon the potential fitness of the populations.

At present, it would seem prudent to perturb the natural system in small increments and evaluate the impacts as they occur. We have the time to do so. The potentials of careful appraisal far outweigh the possible catastrophic consequences of disarranging a sophisticated and delicate natural system.

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PART C

PRODUCTION OF CHUM SALMON FROM THE BIG BEEF CREEK SPAWNING CHANNEL

INTRODUCTION

Although some of the experimental work conducted in the spawning channel located at Big Beef Creek has been described (Beall 1972; Schroder 1973; and Koski 1975), very little has been written about the contribution the channel has made to the commercial fishery. There are several reasons for this, the principal one being that the channel was never intended to serve as a production facility. Instead, it has been used as an experimental area where design criteria and operating techniques can be developed and tested. Nevertheless, the channel has produced chum salmon (*Oncorhynchus keta*) fry with varying success. The purpose of this portion of the report is to delineate the contribution these fish may have made to the fishery and the stream.

The chum salmon populations native to Big Beef Creek are roughly divisible into three runs[1] which migrate into the stream over a five-month period of time. The early run arrives in September and October and usually spawns in the lower mile of the stream. The middle run enters the stream in mid-November and December and most of the fish migrate several miles or more upstream before spawning. The last run consists of small and often silvery fish that spawn in the lower reaches and intertidal areas of the stream in late December and January. Fish from all of these runs have been placed into the spawning channel.

Prior to 1970, the chum salmon introduced into the spawning channel were captured by seining the stream or in a trap located at the downstream end of the channel (Koski 1975). During the summer of 1970, a weir was placed at the high tide interface of the stream. This location was chosen so that all the chum and coho salmon (*O. kisutch*) migrating into Big Beef Creek could be enumerated. However, a combination of factors, among them a stream improvement attempt (described by Cederholm 1972), soft and hardwood logging, housing developments, and the weir itself, have all acted to destabilize the watershed. As a result, the stream will often reach a flood stage after several days of heavy rainfall.

During such floods, which commonly occur in late fall and winter, the weir is often inoperative. Thus, exact counts, sex ratios, ages, and sizes of salmon migrating into the stream at high water flows are

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[1] A run of salmon is a group of stocks which migrate into their natal streams at similar times. A stock is an aggregation of fish that spawn in a particular stream (or area of it) at a specific time. Stocks usually do not interbreed with other stocks spawning in different areas or in the same area at different times (Ricker 1972).

often not possible to make. Another factor complicating the enumeration is the separation of salmon originating from the channel. No attempts have been made to mark or tag fry produced from the channel or the stream.

Even so, it is possible to monitor the impact of the channel on the abundance of the early run. This run usually finishes spawning before the first winter floods and fairly accurate counts of fish comprising the early run have been made. Moreover, on several occasions the early run spawned entirely in the channel or the stream so it was possible, for these brood years, to separate and enumerate the adults originating from each incubation environment.

In 1970, the entire early run was allowed to spawn in the stream. Conversely, in 1972, 1973, and 1974, almost all the fish were placed into the spawning channel. The progeny produced from these brood years obviously experienced different incubation and rearing environments. Consequently, unless certain assumptions are made, comparisons based upon survival to the adult stage cannot be made among any of them. The data do, however, provide an opportunity to examine the productivity of individual brood years which have experienced different kinds of environmental challenges.

METHODS AND MATERIALS

In evaluating the production of adult chum salmon from a given brood year, several pieces of information are necessary: 1) The potential egg deposition; 2) the numbers of emergent fry; 3) the fry-to-adult survival rate; and 4) the fishing mortality imposed upon the stock.

The potential egg deposition of each brood year of early-run fish was estimated from 1970 through 1976. This was done by calculating the fecundity of each female with a curvilinear relationship between female body weight and egg number (*see* Schroder 1973; and Koski 1975). The methods used to capture and enumerate fry produced from the spawning channel have been described by Koski (1975). Briefly, emergent fry were captured by modified fyke nets with attached live boxes. The live boxes were emptied daily and the fry were taken to a field laboratory where they were either counted individually or gravimetrically. After being counted, the fish were held in two 500-liter fiberglas tanks until darkness and then released into the stream. The methods used to estimate the egg-to-fry survival rate in the stream for the 1970 brood year have been described by Cederholm (1972).

The survival of fry to the adult stage has to be determined by estimating the fishing mortality and enumerating the fish arriving back to the stream. Unfortunately, little data are available that can be used to estimate the fishing pressure imposed on early-run chum salmon native to Hood Canal streams. It is likely that it varies between years. Nevertheless, an exploitation rate of .5 has been assumed in all the data analyses.

Chum salmon mature at various ages and thus, the fish originating from one brood year may arrive on the spawning grounds over a period of several years (Pritchard 1943; Henry 1954; and Semko 1954). To determine which brood year a fish originated from, ages were determined by examining scales that had been removed from the left side of each fish. Three or more scales were collected below the posterior edge of the dorsal fin, usually three scale rows dorsad of the lateral line. Efforts were made to collect scales from every chum salmon entering the stream throughout the entire migration period.

Once the scales had been collected, they were cleaned in soapy water and mounted ridge-side up on gummed cards. Each card could accommodate five rows of 10 scales each, with every scale representing one fish. Plastic impressions of the scales were made as described by Koo (1962). The gummed cards and plastic (cellulose acetate) sheets were placed into a heated hydraulic press and impressions of the scale ridges were obtained on one side of the plastic cards.

After the plastic cards had been made, they were placed on a Bausch and Lomb Tri-Simplex Microprojector. The scale image was projected 24 times life-size onto a white surface. The number of annuli were then counted and the fish were aged according to the Gilbert-Rich formula (Koo 1962).

RESULTS

The egg-to-fry survival rate and the number of fry produced from fish placed into the channel were calculated for each brood year and for the early run of 1970 that had spawned naturally in the stream (Table 1c). If the assumption is made that 1970 represents a typical incubation year, then it appears that the egg-to-fry survival rates in the channel are superior to those of the stream.

Table 2c shows the numbers of fish comprising the early run from 1970 to 1976. For the first four years, these values are relatively constant. However, during 1975 and 1976, an increase in the number of fish has occurred. The numbers of fish produced per brood year have also been determined and are presented in Table 3c. This table shows that there were some rather distinct differences in the capacity of the various brood years to produce returning adults. For example, the 1970 brood year produced an estimated 166 adults, while the 1972 brood year produced over 4,000 even though both brood years had approximately the same number of females. Whether these differences can be attributed to different incubation environments or oceanic conditions is not known. But it appears likely that marine conditions were highly favorable for the progeny of the 1972 brood year.

The potential egg deposition-to-adult and fry-to-adult survival rates for the 1970, 1971, and 1972 brood years are shown in Table 4c. Again, these values varied from year to year and most likely reflect differences in both the marine and freshwater environments.

Table 1c. The egg-to-fry survival and abundance of chum salmon fry originating from early-run fish placed into the Big Beef Creek spawning channel or the stream

Brood Year	No. of females		fry production	Egg-to-fry survival
	in channel	in stream	from channel	from PED[1]
1970	0	89	19,500[2]	.073[2]
1971	69	18	123,905	.558
1972	107	0	182,162	.569
1973	117	5	141,407	.355
1974	35	3	44,733	.441
1975	190	406	191,045	.366
1976	304	317	Fry emergence in progress	

[1] Potential egg deposition

[2] Taken from Cederholm's (1972) data

Table 2c. The total numbers of chum salmon returning to Big Beef Creek during the early run from 1970 to 1976

Brood year	Total No. of males	Total No. of females
1970	89	89
1971	72	87
1972	70	107
1973	116	128
1974	37	38
1975	556	596
1976	544	737

Table 3c. The number of adult salmon produced by the 1970 through 1974 brood years of early-run chum salmon native to Big Beef Creek

Brood year	No. of males produced	No. of females produced	No. of fish produced /spawner[1]
1970	35	48	.933
1971	44	49	1.170
1972	960[2]	1,199**	24.294[2]
1973	112[2]	119**	-[2]
1974	11[2]	0**	-[2]

[1] Assumes a .5 fishing mortality.

[2] More fish are expected to return from this brood year.

Table 4c. The potential egg deposition-to-adult and fry-to-adult survival rates for the 1970, 1971, and 1972 brood years of early-run chum salmon originating from Big Beef Creek

Brood Year	PED-to-adult survival to the fishery[1]	PED-to-adult survival to the stream	Fry-to-adult survival to the fishery[1]	Fry-to-adult survival to the stream
1970	.00061	.00031	.00852	.00426
1971	.00084	.00042	.00150	.00075
1972	.01348	.00674	.02370	.01185

[1] Assumes a .5 fishing mortality.

The age composition of the fish in the early runs also varies, with the adults being predominantly 3- or 4-years-old (Table 5c). In the two brood years where data are available, the progeny appeared to mature at the same age as their parents (Table 6c). Females exhibited this tendency more strongly than males, although the effects of a selective fishery on larger and older males have not been considered.

DISCUSSION

Clearly, comparisons within brood years concerning fry survival, emergence timing, and marine survival should be made to fully assess how fry produced from the channel compare with those originating from Big Beef Creek. At present, it appears that the channel has maintained and possibly enhanced the early run. The production of adults/spawner (with an estimated fishing mortality of .5) by the 1970 and 1971 brood years amounted to 0.93 and 1.17, respectively. These values are similar to those that have been reported for naturally reproducing populations of chum salmon in central and southeastern Alaska (Taguchi 1965) and British Columbia (Ricker and Manzer 1967). The 1972 brood year has so far produced over 24 adults/spawner. This rather extraordinary value is probably attributable to the high egg-to-fry survival rate observed in the channel and presumably to unusually good estuarine and marine conditions. Such a rate of return suggests that fry produced in the channel are ostensibly of similar quality to those originating from the stream.

The extensive scale sampling program has provided a record of the age composition of all the chum salmon runs (including the middle and late runs) native to Big Beef Creek. Further analyses of the scales already collected could provide some valuable insights into the heritability of age of return in chum salmon. Moreover, each additional year that scales are collected will also contribute information relating to this problem. For example, the 1975 brood year consisted almost entirely of 3-year-old fish. Does this mean that this brood year will produce progeny that predominantely mature at age 3? Or will the majority of them mature at age 4? suggesting that successive alternations in age at return may occur in chum salmon, as has been hypothesized by Bilton (1971) for sockeye salmon (*O. nerka*) native to the Skeena River (British Columbia). Age at maturity is undoubtedly controlled by both genetic and environmental mechanisms which at present are poorly understood. Perhaps these mechanisms will become clear if age at maturity can be correlated to the freshwater and marine conditions the animal experienced, as well as to their parentage. Unfortunately, extensive scale collections on single populations of Pacific salmon are rare. For this reason it is hoped that the Big Beef Creek records will be continued for as long as possible.

Table 5c. The age composition of chum salmon returning to Big Beef Creek during the early run from 1971 to 1976

Brood year	Age composition of males					Age composition of females				
	% 2	% 3	% 4	% 5	N[1]	% 2	% 3	% 4	% 5	N[1]
1971	.018	.500	.482	.000	56	.000	.610	.390	.000	70
1972	.000	.314	.685	.000	70	.000	.458	.551	.000	107
1973	.000	.234	.586	.180	111	.000	.299	.650	.051	117
1974	.030	.788	.182	.000	33	.000	.857	.143	.000	35
1975	.019	.951	.027	.002	474	.000	.974	.026	.000	547
1976	.020	.190	.790	.000	100	.000	.162	.838	.000	142

[1] Number of individuals aged.

Table 6c. Comparisons between the age composition of a brood year and the age of maturity for their offspring for early-run chum salmon originating from Big Beef Creek

Brood year	Age composition of the brood year						Age composition of the progeny					
	Females			Males			Females			Males		
	% 2	% 3	% 4	% 2	% 3	% 4	% 2	% 3	% 4	% 2	% 3	% 4
1971	.000	.610	.390	.018	.500	.482	.000	.673	.327	.000	.659	.341
1972	.000	.458	.551	.000	.314	.685	.000	.485	.515	.001	.551	.448

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