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RESPONSES OF YOUNG CHUM SALMON, ONCORHYNCHUS KETA (WALBAUM) TO CHANGES IN SEA WATER CONTENT OF THE ENVIRONMENT

by

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ABSTRACT

A method is described for measuring the preferential responses of fish to alterations in the chemical and physical nature of their environment. Changes in the responses of young chum salmon at various stages of growth to alterations in the environmental sea water content have been studied. The effects of small alterations in temperature (2 to 3 C^{o}) and in rates of flow of environmental liquids on the fishes' responses to salinity change, were also studied. Preliminary experiments on the responses of coho salmon fry to sea water are described. The results indicate that changes in the environmental sea water content, such as those encountered in the estuaries of salmon streams may exert a directive influence on the seaward movement of chum salmon fry.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
MATERIALS AND METHODS	
Materials	11
Methods	18
RESULTS	
Changes in the responses of young chum salmon with relation to growth.	30
Responses of young chum fry to dilute sea water.	36
Effect of temperature differences on the responses of chum fry to sea water.	39
Responses of coho fry to sea water.	41
DISCUSSION AND CONCLUSIONS	42
SUMMARY	47
ACKNOWLEDGEMENTS	48
LITERATURE CITED	49
APPENDIX	i-xxx

INTRODUCTION

The young of the anadromous salmons, migrating from their fresh water hatching sites to the sea, encounter far reaching changes in the nature of their environment. Changes in food conditions, the nature of predators and competitors, changes in the physical and chemical properties of the water such as temperature, light conditions, salinity, gaseous content, acid-base balances, water current conditions, are but a few of the identities affecting the fish. It stands to reason that these differences in the environment bring about significant changes in the animals' activity. The rapid growth exhibited by the sockeye salmon (Oncorhynchus nerka) during their stay in the sea as contrasted with the relatively slow growth of the land-locked members of the species (kokanee) serves to emphasize the effects of the change.

In order to understand the pattern of interacting factors that influence the fish during migration, a knowledge must be gained of how single isolated factors affect the fish. Field observations provide an overall picture of the activity pattern, but laboratory experiments must define the component units and offer the final explanation of that pattern.

The most evident change encountered by the migrating fish is the change in the chemistry of the water. The purpose of the present study has been to describe the responses of the young of two species of Pacific salmon to a stimulus consisting of a stream of sea water directed into the fresh water environment of the fish. No attempt will be made to

attribute any response of the fish to specific properties of the sea water, but rather the sea water will be considered as the stable unit that the fish must meet and compensate for as a whole.

The environment influences the activity of the organism by acting on its metabolism, or by stimulating some sensory mechanism which brings about an appropriate response. Fry (1947) offers a good approach to the study of animal activity by considering the various environmental identities in terms of how they affect the metabolism and hence the activity of the animal. A review of the various ways that changes in the water medium affect the activity of fish offers some picture of how anadromous fish are limited and controlled by the chemical nature, especially the salt content, of their environment.

That all fish can tolerate only certain ranges of salinity is well known. It has been repeatedly observed that sea water with concentrations below a threshold value will kill certain marine fishes (Crozier, 1919; Chaisson, 1932, 1933). Likewise salinities above a certain level cause death in many fresh water forms (Bert, quoted by Chidester, 1924). It is therefore obvious that anadromous fish, moving from fresh to sea water must be osmotically prepared for the sudden change in salinity or be subject to lethal consequences, i.e. the physical development of some osmo-regulatory mechanism must be complete before entry into the sea.

Some anadromous salmonoids seem to be able to tolerate

sudden changes in the salinity of their environment far in advance of their seaward migration, while others do not seem to develop the necessary tolerance until just before migration. Sumner (1905) mentions that spring salmon (Oncorhynchus tshawytscha) fry could be transferred directly to dilute sea water and suggests that stronger salinities would have hurt them. Other investigators (V.S.Black and W.P.Wickett, unpub. data) report that fry of the coho salmon (O. kisutch) can be transferred directly into sea water with a chlorinity of 7‰ and acclimated to full sea water (about 16 ‰ Cl.) by increasing the time of exposure to full sea water each day for a few days. Wickett also reports that alevins of chum salmon (O. keta) in good condition, have been found buried in the gravel of the saline intertidal zone at the mouth of Nile creek, B.C. E.H. Moore (unpub. data) has raised chum salmon eggs in approximately 4‰ Cl. and although an increased mortality was observed in the eggs, the hatched alevins showed no ill effects.

In a preliminary experiment performed by the author, it was found that 10 chum alevins placed in an aerated sea water solution containing 14.77‰ Cl. suffered no mortality at the end of two days. On the other hand, Huntsman and Hoar (1939) showed that parr of the Atlantic salmon (Salmo salar) died upon being placed in sea water of chlorinity as low as 11.06‰ Cl. These investigators feel that the ability of such fish to tolerate high salinity develops rather suddenly at the time when they metamorphose from parr to smolt. In connection with

this they observed dead parr in the sea water off the mouth of the parent stream, prior to the time of metamorphosis, but could find no evidence of mortality occuring during the normal movement of the smolts to the sea. Jones (1947) however, showed that even smolts could not stand an abrupt transfer from fresh to sea water (contrary to the suggestion of Huntsman and Hoar), but that if the concentration of the sea water was increased slowly for a time (10 hrs.), complete survival resulted. Huntsman and Hoar observed that smolts "are quite inactive for a time when entering the sea water abruptly, and may be seen scattered near the bottom where there is little movement of sea water." Both Huntsman (1948) and White (1940) note that speckled trout (Salvelinus fontinalis) migrating from the rivers are largely absent from "high salinity areas". It would seem from the above observations that sea-going brook trout and smolts of the Atlantic salmon spend a short time in the dilute waters off the mouth of the parent stream. This suggests that these fish may be acclimating in areas of low salinity before moving into the more concentrated waters offshore.

In general, there is a good indication that the time of the seaward migration of anadromous salmonoids closely follows the full development of an osmo-regulatory mechanism. Chum salmon, migrating as fry, emerge from the gravel with a wide tolerance for sea water while cohos, normally migrating in the yearling stage, do not develop this tolerance until the early fry stage has passed. In the Atlantic salmon, which

migrate after spending one or two years in fresh water a wide tolerance to salinity does not seem to be evident in the parr stage.

Upon leaving the parent stream, the seaward migrants are confronted with a gradient in sea water content, extending from the mouth of the stream to the open sea. Whether or not this gradient has a directive effect on the migrating fish by influencing their movement through the estuary to the sea, is not known. Evidence has been presented indicating that certain euryhaline forms may react to changes in the salinity of their environment. Chidester (1922) worked on the killifish (Fundulus heteroclitus), a form which moves from sea water to brackish or fresh water areas to spawn. He exposed the fish to two currents simultaneously, one fresh and the other sea water. He found that the fish were more "reactive" to the sea water than to the fresh stream. However, these experiments must be considered to be of a very preliminary nature, for without describing experiments involving factors other than sea water, the author states that factors such as temperature and current have a more profound effect on the activity of these fish than the difference in salinity. Such conclusions do not seem to follow from the limited data presented. Rogers (1939) observed the responses of sticklebacks (Gasterosteus aculeatus) when they were simultaneously exposed to two currents; one fresh, the other salt. The fish normally living in an estuary of low salinity were sometimes carried from the estuary by the outgoing tide. The fresh flow from the river and the saline tidal flow exerted their influence

on the fish at the same time and Rogers noted that the fish always moved into the fresh water of the stream. In corroborative experiments where he established two parallel flows in a trough, one fresh and one salt, he found that there were always twice as many fish present in the fresh water stream. He repeated this experiment with Fundulus and Menidia, (both estuarial forms) and achieved the same results. In this short report the author did not describe temperature and flow conditions, etc., and expresses the thought that the fishes' response to current was more important to their return to the estuary than the presence or absence of salinity. Both authors have stressed the influence of other factors on the fishes' response to salinity differences and an experiment by Doudoroff (1938) seems to indicate that when these other conditions are closely controlled, the response to salinity differences is radically modified. He established a salinity gradient in a specially constructed tank. The salinity at one end was 26‰ decreasing throughout the length of the trough to 5‰ at the other end. It was his intention to consider only salinity. To establish the desired control, the oxygen tension and temperature were made uniform throughout the trough and the water movements minimized. Using Fundulus as the experimental animal (as well as Girella), he states that he could obtain no stable orientation of the fish with respect to salinity. However, when he established a temperature gradient along with the salinity gradient, he found that the fish responded to the temperature in the same way that

they would have if the salinity gradient were not present.

In the salmonoids, reports of responses to salinity or sea water gradients are few. Huntsman (1948) can find no evidence that gradients in the sea water off the mouths of streams affect the seaward movement of Atlantic salmon smolts. However he makes the following statement based on observations of the streamward movements of the adults: "Salinity gradients seem to be the principal factor for overall movement of the salmon riverward." He observed adult salmon moving towards the spawning stream at which time the fish would be confronted by a whole pattern of changing factors, such as current and temperature. Differences in identities such as these, distinguish a marine environment from a fresh water environment and to single out one factor as the influence directing the movement of the fish, does not seem to be a valid analysis of the situation.

The conflicting evidence cited above does not present a clear-cut picture of how migrating fishes respond to changes in sea water content of the environment. Before gaining an understanding of the possible relationship between sea water gradients and migration, two basic principles must be defined. First it must be established whether or not migrating fish possess the ability to discriminate between different concentrations of sea water, and if so, the receptor mechanism involved in the perception should be described. Secondly, it should be established whether or not the fish respond to the stimulus in a definite purposive manner.

The first problem, the perception of salinity change, has been investigated by several workers. Bull (1938), worked with 17 different species of marine fishes and found that by associating a slight reduction in the salinity of the environmental sea water with feeding, he could develop a conditioned response to the salinity change alone. He found that all experimental species could discriminate differences of as little as 0.45 ‰ Cl. and some could distinguish a change of only 0.06‰ Cl. The sensory mechansim that permits fish to discern the presence of salt in their environment is an obscure one; olfactory and gustatory sense organs may be involved. Hoagland (1932) reports that he was able to stimulate the sensory nerves of the barbels of catfish (Ameiurus nebulosus) with a 10% NaCl solution. Craigie (1926) showed that removal of the olfactory nerve did not seriously affect the streamward migration of adult sockeye salmon (O. nerka): Half of a sample of 519 fish tagged on Johnstone strait, B.C. had their olfactory nerves removed. As computed from tagging returns, it was "evident that fish were able to make their way to the Fraser river without use of the olfactory sense orgen". Allowance was made for the harmful effects of the operative procedure.

Although Parker (1902, 1905) failed to show that changes in the salinity stimulate the nerves of the lateral line organs in certain teleosts, Smith (1930, 1933) observes that there is a circulation of environmental fluids through the lateral line canals of the gold fish (Carassius auratus),

and feels that this mechanism may operate to sense physical and chemical changes in the environment.

The second basic problem requiring clarification is the nature of a response mechanism that might control the movements of the fish during migration. The well coordinated and purposive pattern of migration suggests that this mechanism is nervous in nature. However, the influence of hormones cannot be overlooked, for migration occurs during phases of the life history, typefied by changes in growth and reproductive patterns. The nature of the response mechanism cannot be adequately discussed without an extensive consideration of the nervous system and endocrine activity. However, the following example indicates that changes in sea water content do bring about nervous responses. The extensive activities observed with osmo-regulation are partially accomplished by nervous control (e.g. when anadromous eels (Anguilla vulgaris or A. rostrata) are transferred from fresh water to sea water, they actively swallow water to counteract the loss of fluid to the hypertonic environment (Krogh, 1939)).

In summary, it may be said that the chemical nature of sea water influences anadromous salmonoids in three general ways. First, in some species, an osmo-regulatory system does not seem to develop until shortly before the actual seaward movement begins. Secondly, in Atlantic salmon and speckled trout, a period of acclimation to sea water may take place in dilute waters before the fish move into a more concentrated environment. Third, it has been shown that certain marine

forms can discriminate between small differences in the salinity of their environment and that some euryhaline forms, notably Fundulus, may respond to alterations in sea water content. Although some property or properties of the estuarial waters may exert a directive "pressure" on the fish by influencing their movement from the stream mouth to the sea, there is no direct evidence indicating that the presence of a gradient in sea water content is the chief directive factor.

It is the main purpose of this thesis to investigate the role of sea water in its capacity as a directive influence on the activity of chum salmon fry, and to suggest how this influence may be modified by other factors such as water currents and temperature changes.

MATERIALS AND METHODS

Materials

Alevins (the larval stage), fry (the initial free swimming stage) of the chum salmon (Oncorhynchus keta Walbaum), and fry of the coho salmon (O. kisutch Walbaum), were used in the experiments.

Both these species belong to the genus Oncorhynchus (the Pacific salmons) and have the following systematic position:

Class	-	PISCES
Subclass	-	NEOPTERYGII
Order	-	ISOSPONDYLI
Suborder	-	SALMONOIDEA
Family	-	SALMONIDAE
Genus	-	Oncorhynchus

The Pacific salmons are anadromous fish, living in fresh water during the initial phases of their life history and later migrating to the sea where maturity is reached and the major period of growth and feeding is spent. The adults return to fresh water, spawn, and usually die soon after.

Spawning takes place in the late Summer or Fall, the eggs being deposited in the loose gravel of the coastal salmon streams and rivers. The hatching alevins appear approximately a month and a half later. They remain for a time buried beneath about a foot of gravel, deriving nourishment from the prominent yolk sac. As development continues, the fish gradually "work their way up" through the gravel to emerge a month and a half after hatching as free swimming fry. The chum migrate to sea immediately, while the majority of the coho remain in fresh water for a year or more before moving seaward.

The chum salmon spawn in most of the West coast salmon streams, generally not far from the sea. The spawning areas of the coho are extensive, fish being found in the upper tributaries of the larger rivers as well as in the lower reaches of the rivers and streams.

The fry of the two experimental species are readily distinguished by a comparison of the body shape, structure of the anal fin, distribution of parr marks and fin markings. Elongated rays in the anal fin are evident in the coho but absent from the chum. The body of the chum is slender and shallow, while that of the coho is deep, and broad in the head region. The chum parr marks are slender and usually extend no lower than the lateral line while the coho have broad, heavy marks extending well below the lateral line. A light orange or reddish tinge in the pectoral, pelvic and anal fins is noticeable in the coho, but absent from the chum. The dorsal surface of the chum is blue-green to green in colour, while the coho has a brownish-green colouration.

Four separate groups of chums were used in the experiments: Fish reared in the laboratory at the University of British Columbia, fish captured at Nile creek, B.C., and transported to the University, fish captured and used experimentally at Nile creek, and fish captured in the Cowichan river and used experimentally at Lake Cowichan, B.C.

The cohos used in experiments at Lake Cowichan were captured in the Cowichan river.

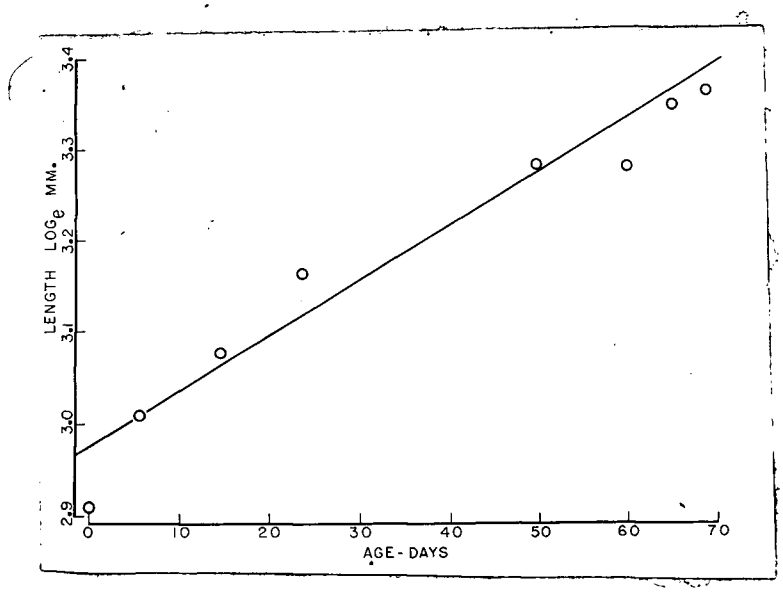

FIGURE 1 - Linear growth of chum salmon alevins reared from eggs at the University of British Columbia.

1) Fish reared in the laboratory.

Eggs were obtained from several spawning females captured in Nelson creek, West Vancouver, B.C., on Nov. 12th, 1947. These were artificially fertilized by the 'dry method' and transported to the laboratory at the University of British Columbia. They were immediately placed in large stacking dishes and provided with a continual flow of tap water (avg. pH 6.60, oxygen near saturation) to insure adequate ventilation. The temperature of the water rose gradually from an average of 3.1°C. in December and January to about 6.1°C. in late February and early March, reaching a height of 7.2°C. in early April. Little change was noted up to the end of May when laboratory experiments were discontinued.

The first alevin appeared on Jan. 29th, 1948. Hatching continued until the latter part of March and reached its peak in the middle of this month. Infertile and diseased eggs were removed throughout the hatching period. Sincere thanks are due to Mr. I. W. Barrett and Mr. S. B. Smith who were responsible for obtaining eggs and maintaining them until the author began experiments in mid-March.

Linear growth of these specimens is illustrated in fig. 1. The instantaneous growth rate for length was found to be 0.894. The measurements for fish sampled in February were obtained from specimens preserved by Dr. W. S. Hoar, while all other measurements were made from fish used experimentally. Although no attempt was made to separate the

fish with respect to the day of hatching, it is felt that a random sampling of all the fish present on a given day presents a fair estimate of the average rate of growth. While the ability of the more active individuals to elude capture might provide a selective factor, sampling was considered to be sufficiently random due to the large number of fish present in each stacking dish (200 to 300).

2) Fish transported from Nile creek.

Chum salmon fry were captured at a counting fence situated near the mouth of Nile creek (47 miles north of Nanaimo, B.C.).

The portion of the creek normally utilized for spawning extends from about 150 yds. above the mouth to about half a mile upstream from here. The stream bottom is mainly small gravel and small boulders interspersed with sand. The width varies between 30 and 100 ft. while the depth averaged about 3 ft. at the time of observation (Apr. 25th to May 13th).

Approximately 80 fish were captured and placed in a hatchery fry can (cap. 10 gals.) and transported to Vancouver. The temperature was maintained close to 7°C. by the addition of ice to the water. On arrival, the fish were placed in a battery jar provided with a supply of running tap water (temp. 7°C.). No evident mortality resulted from the transporting, although about 10 fish died the following day and several more the day after. No cause other than unnatural confinement was thought to be responsible for this. The average size of these fish was 35.80 mm., considerably larger

than that of the laboratory reared specimens used two weeks previously.

3) Fish used experimentally at Nile creek.

From May 4th to May 13th, a series of experiments was performed on chum fry captured at the Nile creek counting fence. Because no cooling apparatus was available, the temperature of the experimental solutions could not be lowered below 9 or 10°C. As the temperature of the creek water was between 6 and 7°C., it was felt necessary to acclimate the fish to the experimental temperature. To do this, fish captured the day before an experiment were maintained overnight in hatchery buckets coated with black asphaltum. The temperature in the bucket rose to room temperature (never above 12.0°C.). Thus for the greater part of the acclimation period, the fish were in water near the experimental temperature. If Brett's (1944) findings on acclimation times for various species of Cyprinidae and Ameiuridae are roughly applicable here, this period probably did not allow for complete acclimation. He felt that a change of 1 C° per day was a safe margin to insure complete acclimation of any of these species. However, the few fish migrating at the time of experimentation made the lengthening of the acclimation period impractical.

The average length of these specimens was 34.02 mm., not significantly different from the length of the fish captured and transported to Vancouver two weeks previously.

4) Fish captured in the Cowichan river and transported to Lake Cowichan, B.C.

A series of experiments was carried out at a hatchery operated by the Pacific Biological Station at Lake Cowichan, B. C. Using a hand seine, chum and coho fry were captured in a back eddy of the Cowichan river. This point, 5 miles above the mouth of the river, is well above the influence of the ocean tide, and is about 150 ft. wide with a depth averaging 5 ft. The bottom consists chiefly of large gravel and small boulders.

The fish were transported in 10 gallon fry cans to the Lake Cowichan hatchery (about 20 miles from the point of capture) and retained in standard hatchery troughs ($17\frac{1}{2}'$ x $10\frac{1}{2}''$ x $7\frac{1}{2}''$). These were provided with a continuous flow of fresh water piped from a nearby spring-fed creek. The temperature of the trough water varied between 7.0°C. and 11.0°C. during the period of experimentation. Diurnal fluctuation occured, the peak temperature being reached in mid-afternoon, with the minimum in the early morning. This variation was rarely more than 2 C° per day. The oxygen content of the water averaged 29.0 1 cc./l. while the pH (determined colourimetrically) did not vary significantly from 7.0.

Experimental sea water solutions.

Sea water used in experiments performed at the University of British Columbia was obtained from English Bay, Vancouver, B.C., and transported to the University in 50 liter glass carboys. The chlorinity of three solutions obtained in March

and early April was fairly constant at about 15‰ Cl., but a solution obtained on April 26th was only 9.88‰ Cl. The pH of the stronger solutions was determined by a Beckman pH meter and averaged 7.8.

At Nile creek, sea water was obtained from Qualicum bay (about 1½ miles from the experimental site) was transported in paraffin coated barrels. As a noticeable amount of organic material was present in the water, all solutions were filtered through coarse cotton cloth before use. To eliminate the danger of pollution due to the disintegration of organic material, fresh quantities of water were brought in at least once a day. All experimental dilutions were made by mixing creek water with the stock sea water solutions. The chlorinity was fairly constant between 12 and 13‰ Cl.

Sea water used in experiments at Lake Cowichan, was transported in 10 gallon fry cans and paraffin coated barrels from Maple bay (20 miles from the hatchery). Three 150 gallon quantities were obtained between May 20th and June 10th. Again, to reduce the danger of pollution, all solutions were filtered through coarse cotton cloth. Finer filtration was felt to be impractical considering the large quantity of liquid involved. All retaining troughs and fry cans were thoroughly washed with soap and water and rinsed with large quantities of fresh water. Despite these precautions, in the last two shipments an oily slick appeared on the surface of the solutions in the retaining troughs. When used in experiments, these solutions were found to be toxic to the fish,

a sample of ten fish placed in the solution dying within 48 hours. The toxicity of the water became evident about five days after the transport from the sea had been made. In the last shipment, water carried in the barrels was segregated from that transported in the fry cans, but both solutions proved to be equally toxic. Experiments performed with these solutions were discarded.

The average chlorinity of the solutions used in experiments was 14.96 ‰ Cl., while the pH was near 8.0.

Methods.

The primary purpose of the experiments was to study the responses of the young of chum and coho salmon to a stimulus consisting of a flow of sea water directed into their fresh water environment. Changes in their response to sea water accompanying growth, changes in concentration of the sea water, alterations in current conditions, and temperature changes, were also studied.

The basic method of study involved the presentation of two alternatives to the fish; either moving into an environment of their native fresh water, or moving into a sea water medium. The nature of the sea water was modified to study the effects of other factors on the basic response.

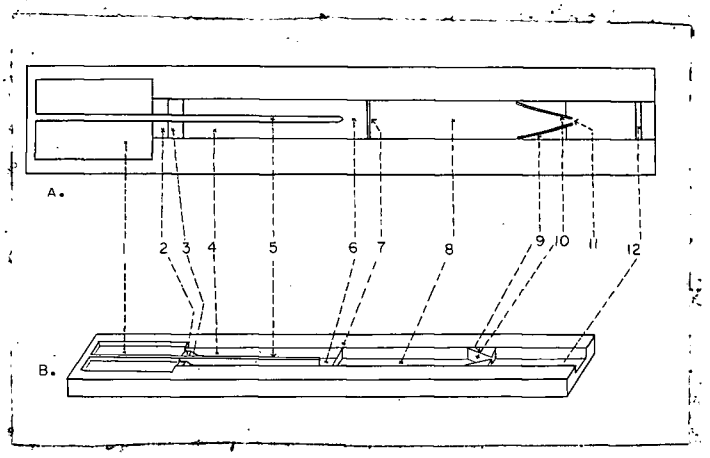

FIGURE 2 - A: Top view of apparatus. Scale: 1" = 10"

B: Plan view of apparatus. Scale: 1" = 1',2"

1 - Reservoir.
2 - Partition separating reservoir from trough arm.
3 - Curving ramp leading into trough arm.
4 - Trough arm.
5 - Partition separating trough arms.
6 - Undivided portion of trough
7 - Screening partition.
8 - Non-experimental part of undivided portion.
9 - Triangular paraffin blocks forming sides of Outlet.
10 - Adjustable glass slides for changing width of outlet.
11 - Outlet.
12 - Drain.

Apparatus.

The purpose of the apparatus was to provide two parallel flows of experimental solutions so that fish would have freedom to move into either flow.

The experimental chamber (illustrated in fig. 2) consisted of a wooden trough divided at one end into two 'arms'. A reservoir situated at the end of each of the arms, was separated from each arm by a partition. Experimental solutions introduced into the reservoirs flowed over these partitions and down the trough arms. At the other end of the divided portion, the two arms led into a common chamber. A short distance down this undivided portion, a screen was placed. An outlet system at the far end of the trough consisted of a partial partition constructed so that the width of the trough tapered to a narrow opening. The width of the opening could be adjusted by manipulating two microscope slides, fitted in grooves in the floor of the trough.

Experimental solutions usually were placed in two 50 liter glass carboys, or paraffin coated barrels (in field experiments). From here the solutions were siphoned through rubber tubing, provided with screw stopcocks to regulate flow, into two 2 qt. Mason jars. These jars were placed about 1½ ft. above the experimental trough. The solutions were then siphoned through pressure tubing, (equiped with burette type stopcocks) into the two reservoirs. When these stopcocks were adjusted to deliver the desired flow through the experimental chamber, the flows from the carboys or barrels were

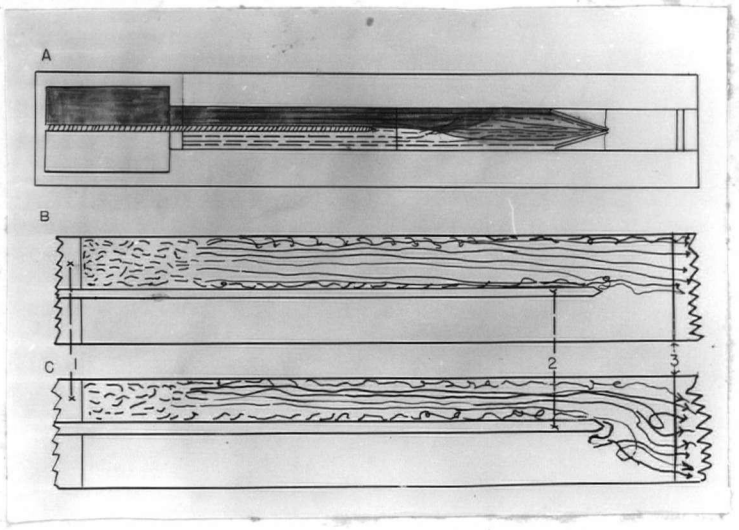

FIGURE 3 - A: Diagram of the mixing of two test solutions. Black portion and solid lines represent presence of one test solution. White portion and broken lines indicate presence of other test solution. Scale: 1" = 10".

B: Diagram of lines of flow of one of two test solutions flowing through experimental portion of trough. Rate of flow in both trough arms 2 cm./sec. Scale: 1" = 5".

C: Diagram of lines of flow of one of two test solutions flowing through experimental portion of trough. Rate of flow in arm drawn uppermost - 2 cm./sec; in lower arm 0.7 cm./sec. Scale: 1" = 5".

1 - Ramp leading into trough arm.
2 - Partition separating trough arms.
3 - Screening partition.

adjusted so that the Mason jars were kept full to the top. This insured a constant head of water and provided a constant flow throughout the experiment.

Flow conditions were studied by adding small quantities of methylene blue dye to the experimental solutions and observing their passage through the trough. As is illustrated in fig. 3, solutions flowing down the two arms met in the undivided portion and gradually mixed toward the outlet end of the trough. The small velocities of flow present in the experiments (1 to 2 cm./sex.) are seen to produce laminar current conditions (where the solution particles tend to move in a definite linear pattern) as opposed to turbulent conditions (where the movement of particles is irregular.).

Fig. 3b represents the flow lines when the velocities of the two solutions are equal. It is seen that the flows begin mixing about one inch from the emergence of the flows from the two arms. With unequal rates of flow (fig. 3c), mixing occured nearer the inlet end of the trough. Eddy currents, not evident in conditions of equal flow, were observed in the undivided portion of the trough on the side of the slower moving current.

With slow moving currents, there was a tendency for the salt solution to diffuse along the floor of the trough and along the inside walls of the partition separating the arms (due to frictional forces) and also along the surface of the solutions (due to surface tension.). However, with flow velocities of the order of those used in the experiments, these

factors were felt to be negligible.

The outlet was arranged so that the velocity of flow was as equal as possible between the solution surface and the floor of the trough. Of course surface tension and frictional forces cause some slowing of the current at the top and bottom, but this influence was felt to be negligible for the purposes of the experiment.

Frictional forces were partially overcome by coating the trough with paraffin wax, thus producing a surface smoother than that of the rough wood. This covering also served to protect the fish from abrasions and prevented the salt solutions from soaking into the wood.

Design of Experiments.

All experiments were conducted along the same lines. The following general procedure was employed:

1) the experimental solutions were prepared in the carboys or barrels.

2) The desired rates of flow through the trough were established. In experiments dealing with the response of the fish to sea water, a sea water solution was directed down one arm of the trough while fresh water flowed down the other.

3) A sample of approximately ten or more fish was selected at random and placed in the undivided portion of the trough so that about half of the fish were on either side of the mid-line of the trough.

4) The room was darkened.

5) Ten minutes later, and at intervals of 10 minutes

for 80 minutes after this, the positions of the fish in the trough were observed. A dimmed flashlight or a 7½ watt bulb was used to make the observations and was extinguished immediately after. In field experiments, to insure more accurate counts, a piece of zinc or plastic screening was inserted to separate the two arms from the undivided portion of the trough (see Apparatus). This was inserted immediately before the observation light was turned on, and was removed upon completion of the count.

6) The following records were made:

a) the temperature of both test solutions.

b) The chlorinity of both solutions.

c) The rates of flow of both solutions.

d) The positions of the fish:
1. The number of fish in each of the trough arms.
2. The number of fish in the undivided portion of the trough.

7) Determination of the oxygen content of the test solutions was made twice at Nile creek, and for all solutions at Lake Cowichan.

Analysis of data.

To provide a quantitative estimate rather than a qualitative description of the fishes' responses to the various experimental solutions, the following treatment was applied to the data:

If the fish when placed in the experimental trough showed no 'preference' for either of the solutions flowing down the two arms, then it is reasonable to expect that they would assume a random distribution in the trough, so that there would be about the same number of fish in each of the identically constructed arms of the trough. If on the other hand, a 'preference' existed, then the expected 1:1 distribution would not be likely to result. If the assumption is made that the greater the deviation from the 1:1 ration, the greater the response of the fish to one of the test solutions, then some measure of this deviation offers an expression of the degree of response. χ^2 is an index of deviation (Snedecor, 1946); if the observed results were the same as those that might be expected when the fish were not responding, then a χ^2 value of 0.00 is obtained and the more the observed results vary from the expected distribution, the greater the χ^2 value becomes.

However, χ^2 values vary with the total number of variates (here the total number of fish in the two arms of the trough) making direct comparison of experiments involving different numbers of fish difficult. To 'compensate' for this variation some factor of which takes the number of variates into consideration should be used. Pearson's coefficient of contingency (Goulden, 1939) is a modified expression of χ^2,

'compensating' for the above mentioned variation, and has been used in this thesis as an expression of the degree of the fishes' responses to the various test solutions. If the fish are equally distributed between the two arms, a coefficient of .000 is obtained, while if all the fish move into one arm only, a maximum value of .707 is obtained.

Sample calculation

Data: In experiment 10 (see appendix), sea water was directed through the right arm of the trough while fresh water flowed through the left. The distribution of the fish in the arms was recorded as follows:

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)
10	5	2
20	5	1
30	3	1
40	4	2
50	6	1
60	3	4
70	4	3
80	5	2
90	6	3

Calculations: The purpose of the calculations is to indicate the degree of response of the fish to the sea water flow. The following procedure (Goulden, loc. cit.) was used:

If the fish show no preference for either solution, then the theoretical ratio between the numbers of fish in each trough arm is 1:1. Thus when total number of fish in both arms is 7 (as

in the 10 minute reading of the sample experiment) we would expect $3\frac{1}{2}$ fish to be present in each arm, if no preference were shown. However, the actual numbers of fish observed were 5 in the sea water arm and 2 in the fresh water arm. The degree of deviation of these observations from the theoretical values is expressed by χ^2:

$$\chi^2 = \sum \frac{(a-t)^2}{t}$$

where a = the number of fish in one of the arms.
t = the number of fish in one of the arms, if a 1:1 ratio existed.

The coefficient of contingency is then calculated:

$$C = \sqrt{\frac{\chi^2}{N+\chi^2}}$$

where N = the total number of fish in both arms.

With respect to the sea water solution, the fish were responding positively (i.e. more fish were observed in the arm containing the sea water), and therefore the contingency coefficient was arbitrarily assigned a positive value. However, if more fish had been present in the fresh water, the degree of

response would have been expressed by a negative value of the contingency coefficient. Thus it may be said that at the time of observation, the degree of response of the fish to the sea water flow was +.394 as compared with zero if there was no response, and +.707 if the response had been a maximum one.

For presentation, the analysed data were treated in three ways.

1) The 'average response'.

The mean of the contingency coefficients for all readings made during a given experimental series was calculated. This figure will be referred to as the average response.

2) Changes of the response occuring with length of exposure to experimental conditions.

In a given series of experiments, for the first 15 minutes and for each 20 minute period after this, an average value of the contingency coefficient was calculated. Represented graphically, these values plotted against time give a picture of any changes in the degree of response occuring with the length of exposure of the fish to the experimental conditions.

3) Changes in the relative 'activity' of the fish.

The fish present in the arms of the trough were for the most part actively swimming against the current, while those in the undivided portion were generally passive, swimming from side to side or merely holding their positions in

the flow. Thus by comparing the number of fish in the arms with the number observed in the undivided portion of the trough, some measure of the relative 'activity' of the fish to current is obtained. By calculating contingency coefficients for the numbers of fish observed in these two portions of the trough, a mathematical expression of the degree of 'activity' is obtained. A contingency coefficient of zero indicates that an equal number of fish were present in each portion, while a positive value for the coefficient indicates that more fish were actively swimming in the arms. A negative value indicates that more fish were present in the undivided part.

4) The adjustment of certain contingency coefficient values.

The contingency coefficient calculated for a distribution of any number of fish in one arm and no fish in the other, was always .707. It was felt that this value was not truly representative of the responses of the fish (e.g. a distribution of 1 to 0 would be represented by the same value as 16 to 0). Thus in calculations, the minimum number of fish in one arm of the trough was established as 1. Values calculated in this manner were felt to offer a more representative expression of the degree of response than if the number were zero.

Chemical methods.

The chlorinities of all solutions used at the University of British Columbia and at Nile creek, were determined by the use of hydrometers. Density values obtained were transposed to corresponding chlorinity values by the use of a standard set of hydrographical tables (Knudsen, 1901). The standard silver nitrate test for chlorides was used at Lake Cowichan. The unmodified Winkler test was employed for the determination of the amount of dissolved oxygen present in the various test solutions. Measurements of pH made at the University were obtained by using a Beckman pH meter, and in the field experiments, by colourimetric comparison. All determinations were made according to procedures outlined by Ellis, et. al. (1946).

Discussion of methods.

Preliminary experiments were performed involving different numbers of fish. When the sample exceeded 15 fish, it was found that the fish did not achieve the 1:1 distribution that was expected when two fresh water flows were initiated in each of the arms with identical conditions of flow, temperature, etc. In this case the fish tended to aggregate so that the majority grouped in one arm or the other. The position of these groups was not consistent even under identical experimental conditions. This tendency was not evident to the same degree when the sample size was cut to about 10 fish.

For 10 to 15 minutes after the fish had been placed in the trough, they were extremely active, their movements being

irregular and apparently undirected by the experimental conditions. However, they soon 'quieted down' and began to respond to the experimental flows by facing into the current. Throughout the remainder of the experiment the fish exhibited exploratory behaviour, first moving into one arm and then the other or holding their positions in the flow in the undivided portion of the trough. In experiments where the fish showed an apparent 'preference' for one test solution, they would spend more time in the 'preferred' flow, making fewer runs into the less favoured solution. The fish ranged freely throughout all parts of the experimental chamber and exhibited this 'preference' by moving into one arm of the trough more often than into the other, rather than remaining in the favoured arm throughout the experimental period.

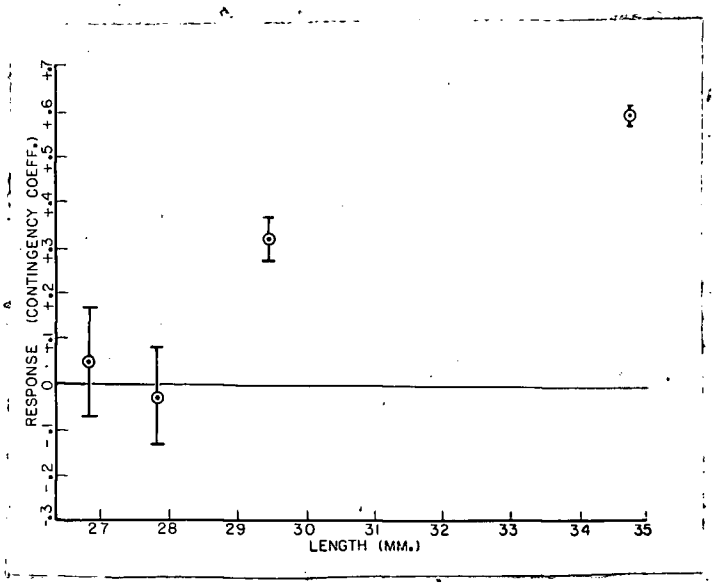

FIGURE 4 - Changes in the average response of chum salmon alevins and fry occuring with linear growth.

Circled dots - Average response.
Vertical lines - Standard error of the average response.

RESULTS

Changes in the responses of young chum salmon with relation to growth.

A series of experiments was performed on three groups of fish representing three phases of the early life history of the chum salmon. Newly hatched alevins, alevins completing the absorbtion of the yolk sac, and migrating fry, were studied with respect to their responses to a sea water stimulus.

Average Response.

1) Newly hatched alevins.

Two sets of three experiments involving recently hatched alevins were conducted. In both series full sea water (here between 15.36 and 15.94‰Cl.) flowed down one arm of the trough while fresh water of equal temperature and rate of flow was directed down the other. The fish of the first group experimented on, averaged 26.8 mm. in length while the mean length of the second sample, used experimentally 10 days later, was 28.8 mm. The mean responses of these fish to the sea water stimulus (fig. 4), was not distinctively different from the response that might have been expected had they been reacting to the two test solutions in the same degree, (i.e. the response value was near zero).

The standard errors (Snedecor, loc. cit.) calculated for the two series indicated that variation occuring between individual experiments was larger than that observed between experiments on the older alevins and those on the fry. This seems to indicate that the response of these fish was less uniform

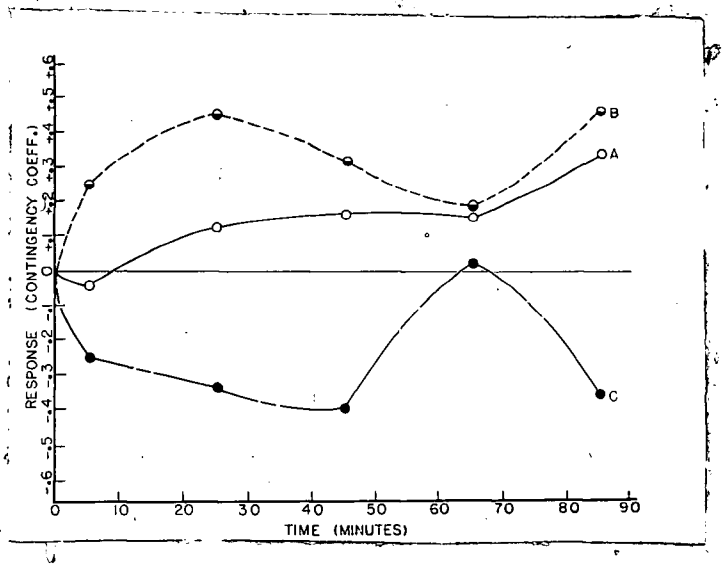

FIGURE 5 - The responses of chum salmon alevins averaging 24.9 mm. in length, to the faster moving of two solutions flowing at different velocities. (one approx. 2 cm./sec., the other approx. 0.7 cm./sec.)

Line A - When both test solutions were fresh water.

Line B - When the stronger current consisted of full sea water.

Line C - When the weaker current consisted of full sea water.

in nature than the response of the later fish, and in turn suggests that they failed to attain a stable orientation to either of the currents. The two standard errors are seen to overlap considerably in their ranges, and so it can be assumed that the two samples did not differ significantly in the nature of their response. In general it may be said that the young alevins do not exhibit a marked 'preference' for either a sea water or fresh water flow.

2) Alevins completing the absorption of the yolk sac.

The next group tested was comprised of alevins which normally would be about to emerge from the gravel beds as fry. To positively associate the observed responses with the difference in sea water content of the test solutions rather than with some incidental difference in experimental conditions, the design of the test was changed: The rates of flow of the two solutions were varied so that in two 90 minute experiments the sea water was flowing about three times as fast as the fresh (approx. 2 cm./sec. to 0.7 cm./sec.), while in two other tests the fresh water flow was three times that of the salt. Three control runs were made with fresh water in both arms but with the flow in one arm three times that in the other. The responses considered with respect to the duration of the fishes' exposure to the experimental conditions are illustrated in fig. 5. It is evident that the fish show a moderate positive response to the faster moving current when given an opportunity of moving into two fresh water flows, one of which is faster than the other. When this

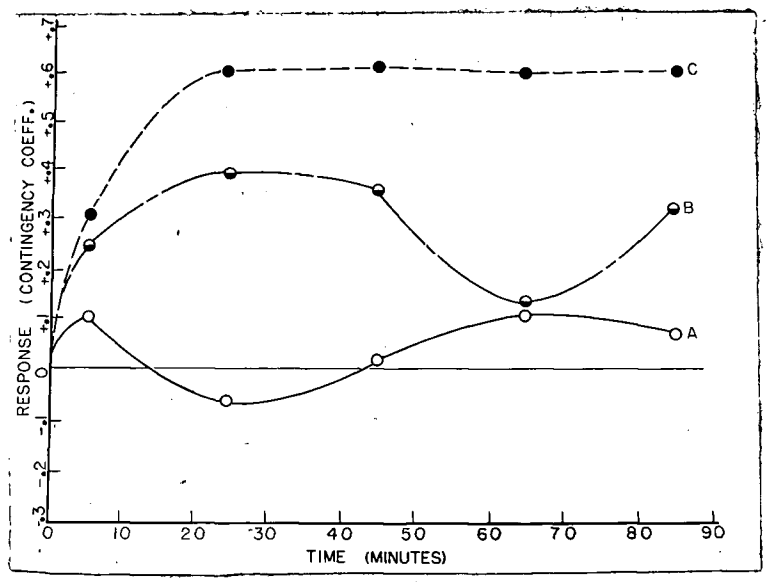

FIGURE 6 - The responses of three groups of chum salmon to full sea water, occuring during experimental periods lasting 90 minutes.

Line A - Recently hatched alevins averaging 27.4 mm. in length.

Line B - Alevins completing the absorbtion of the yolk sac, averaging 29.4 mm. in length.

Line C - Migrating fry, averaging 34.0 mm. in length.

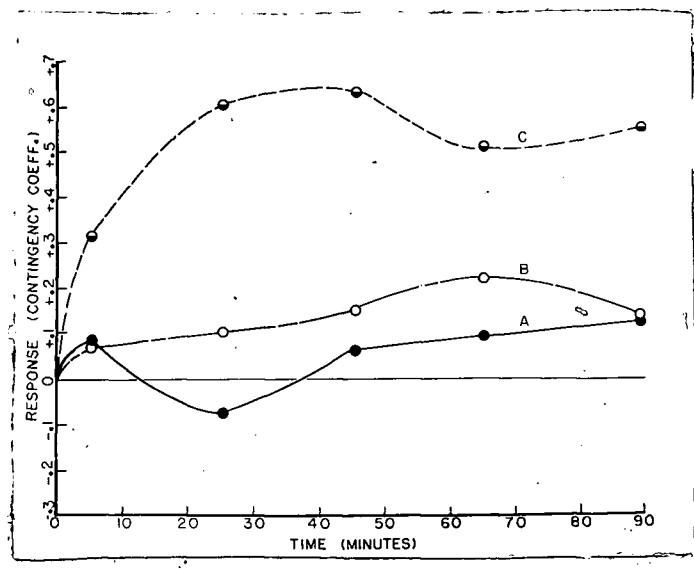

FIGURE 7 - Changes in the relative 'activity' of two groups of chum salmon in experiments where both test solutions were flowing with the same velocity (approx. 1 - 1.5 cm./sec.).

Line A - Alevins averaging 26.8 mm. in length. Fresh water in both trough arms.

Line B - Newly hatched alevins averaging 29.4 mm. in length. Full sea water in one trough arm.

Line C - Migrating fry averaging 34.0 mm. in length. Full sea water in one trough arm.

faster moving flow consisted of full sea water, the fish showed an even more positive response to the flow. However, when the slower moving current was composed of sea water, the majority response of the fish was away from the faster moving fresh water and into the saline flow. Thus the fish were responding to the sea water regardless of the flow conditions imposed.

The average length of the chums in this case was 29.4 mm. and their average response (fig. 4) was a marked positive reaction to the sea water. The standard error calculated for the four experiments performed with sea water in one arm was distinctly smaller and obviously beyond the range of those calculated for the experiments on the younger alevins. This indicates that the responses of the older fish were of a more uniform nature.

3) Fry.

The last group tested consisted of fry, captured just before their entry into the sea, and averaging 34.0 mm. In order to limit error, flow conditions were again varied so that the fresh water current in two experiments was flowing three times as fast as the salt, while in another two, the sea water flow was three times that of the fresh. Another set of two experiments was performed with identical flow conditions in both arms. In these experiments a more dilute sea water was used (9.88‰Cl.). In all experiments the responses of the fish to the sea water were similar regardless of the flow conditions imposed. This is evident from the small standard

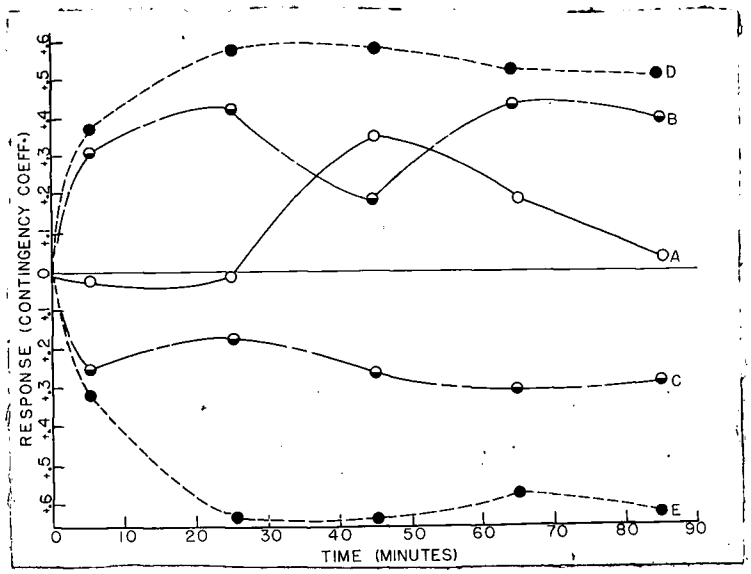

FIGURE 8 - Changes in the relative 'activity' of two groups of chum salmon in experiments where one test solution was flowing faster than the other (approx. 2 cm./sec. to approx. 0.7 cm./sec.).

Line A - Alevins averaging 29.4 mm. in length. Fresh water in both trough arms.

Line B - Alevins averaging 29.4 mm. in length. Full sea water faster moving current.

Line C - Alevins averaging 29.4 mm. in length. Full sea water slower moving current.

Line D - Migrating fry averaging 34.0 mm. in length. Sea water of 9.88 Cl. faster moving current.

Line E - Migrating fry averaging 34.0 mm. in length. Sea water of 9.88 Cl. slower moving current.

error (fig. 4), which indicates that there was very little variation between the individual experiments. The average response of these fish was a more marked movement toward the sea water than that observed in either of the earlier groups of fish.

Changes in Response with Relation to Length of Exposure.

Changes in the responses of the three groups of fish to sea water throughout the 90 minute experimental period, are shown in fig. 6. The younger alevins showed no marked response at any point in the 90 minute period, while the fry showed a strong and consistent 'preference' for the sea water. The older alevins exhibited a response of intermediate intensity which seemed to decrease towards the end of the run.

'Activity' of the Fish as Affected by a Sea Water Stimulus.

As has been pointed out, a comparison of the numbers of fish present in the undivided portion and the arms of the trough, offers a measure of the 'activity' of the fish as affected by a sea water stimulus. Fig. 7 represents the changes in 'activity' occuring in the experiments involving fresh and salt flows of equal velocity. In experiments on the early alevins, when fresh water flowed down both arms of the trough, there were about as many fish in the undivided portion as in the arms. When sea water replaced one of the fresh water flows, there was little noticeable response, except perhaps a very slight movement of the fish into the arms. With the fry however, a marked change was noted, the majority of the fish actively swimming in the arms.

Fig. 8 represents the changes in activity occuring in experiments where unequal rates of flow were involved. In both the older alevins and the fry, when either flow consisted of sea water, a marked movement towards the arms was observed. Again the response of the fry was consistently stronger than that of the alevins.

Summary

The above observations must be qualified by a consideration of the variation occuring in experimental conditions. As has been pointed out, the design of the experiments was changed so that the rates of flow were varied in the last two series, but not in the first. This makes a direct comparison between the experiments on the newly hatched alevins and those on the older alevins of questionable value. However, it has been demonstrated that the differences in the rates of flow used in the experiments did not significantly alter the fishes' response to the sea water, making this variation relatively unimportant.

The chlorinity of the sea water used in the experiments on the fry, was much lower than that used in the other two series. It will be demonstrated in the next series of experiments that changes in the concentration of the sea water do alter the nature of the fishes' responses. Thus a comparison of these results with the earlier ones, must be made with this fact in mind.

Temperature conditions were made as uniform as possible throughout the entire group of experiments, all tests being

carried out with temperatures of 10.0°C. ± 0.9C°. In any one experiment the difference between the two test solutions never exceeded 0.5 C°.

Several general trends are evident from a consideration of the experimental results. During the transition from the larval alevin stage to the free swimming fry stage, the fish seemed to respond to a sea water stimulus with increasing intensity. Recently hatched alevins showed a response to a sea water current not markedly different from their response to fresh water current. However, alevins used experimentally just before the absorbtion of the yolk sac, seemed to show a moderate 'preference' for sea water when given freedom to move into either a fresh water or a sea water flow. This response seemed to diminish as their exposure to the experimental conditions lengthened. Actively migrating fry showed a very marked and consistent tendency to move into a sea water stream of a lower concentration than was present in the experiments on the younger fish.

It has also been demonstrated that the older alevins will swim more actively in a current when a stimulus of sea water is present, than in a fresh water current alone. This phenomenum could not be demonstrated in the newly hatched fish. The response to a sea water current observed above, was more intense in the migrating fry than in the younger fish.

It is of note that these responses were consistent even when the velocity of the sea water and fresh water flows were adjusted so that one solution was flowing at about 2 cm./sec. while the other flowed at about 0.7 cm./sec.

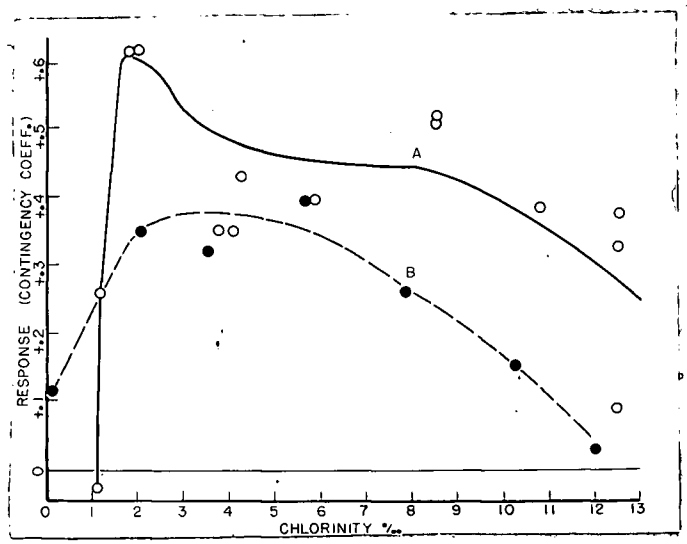

FIGURE 9 - Changes in the average response of chum salmon fry to sea water of different concentrations.

Line A - Experiments performed at Nile creek, B.C.

Line B - Experiments performed at Lake Cowichan, B.C.

Responses of chum fry to dilute sea water.

When the concentration of the sea water used in the experiments was lowered a significant change in the responses of the chum fry was noted. Twenty-two experiments were performed on fry at Nile creek and at Lake Cowichan, involving sea water with chlorinities varying from 1.07 to 16.22 .

Average Response

The average degree of response for each 90 minute experiment is illustrated in fig. 9. When the responses are considered with relation to the concentration of the sea water used, a general pattern was observed in both groups of fish. The maximum average response was noted with stimuli of dilute sea water while concentrated solutions elicited less intense responses. It was also noted that below a certain concentration, no response could be obtained. This threshold value was observed to be between 1.07 ‰ Cl. and 1.79 ‰ Cl., no response being obtained with a concentration of 1.07 ‰ Cl., a slightly positive one at 1.15 ‰ Cl., while the maximum response was observed at 1.79 ‰ Cl. This would suggest that while the fish seem to be attracted to sea water, some degree of acclimation is needed before they move into the stronger concentrations. Thus the fish moved readily into the lower solutions but demonstrated only a moderate positive response to the stronger solutions.

Changes in Response with Relation to Length of Exposure.

This presumption (i.e. that acclimation to experimental conditions takes place), is borne out when the responses are

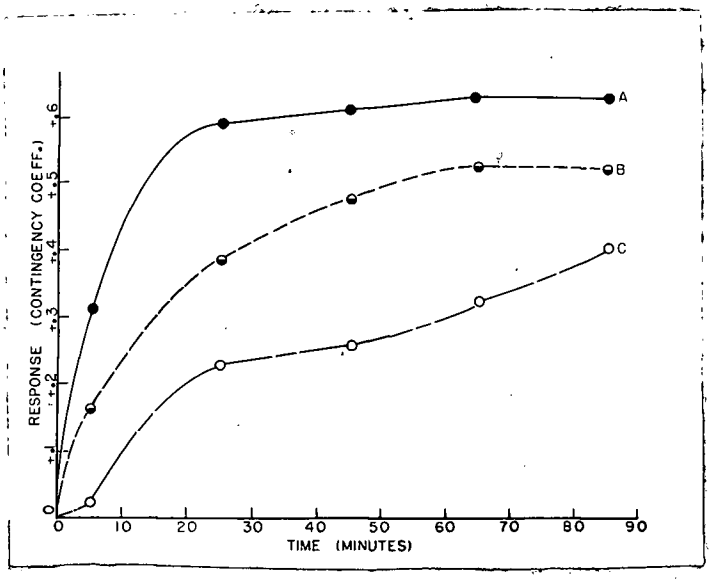

FIGURE 10 - Changes in the responses of chum salmon fry to different concentrations of sea water, occuring during experimental periods lasting 90 minutes. (Nile creek fish).

Line A - Mean of responses to concentrations between 1.15 ‰ Cl. and 1.98 ‰ Cl.

Line B - Mean of responses to concentrations between 1.98 ‰ Cl. and 8.48 ‰ Cl.

Line C - Mean of responses to concentrations between 8.48 ‰ Cl. and 12.70 ‰ Cl.

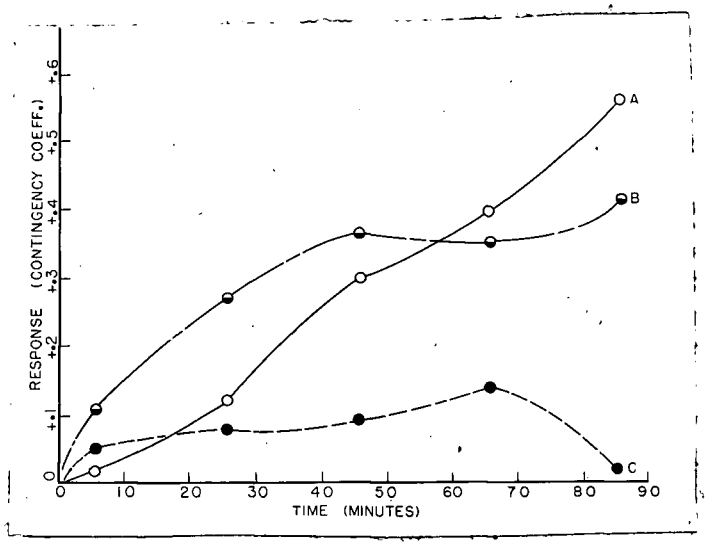

FIGURE 11 - Changes in the responses of chum fry to different concentrations of sea water, occuring during experimental periods lasting 90 minutes. (Lake Cowichan fish).

Line A - Mean of responses to concentrations between 1.83 ‰Cl. and 6.52 ‰Cl.

Line B - Mean of responses to concentrations between 6.52 ‰ Cl. and 12.52 ‰Cl.

Line C - Mean of responses to concentrations between 12.52 ‰ Cl. and 14.62 ‰Cl.

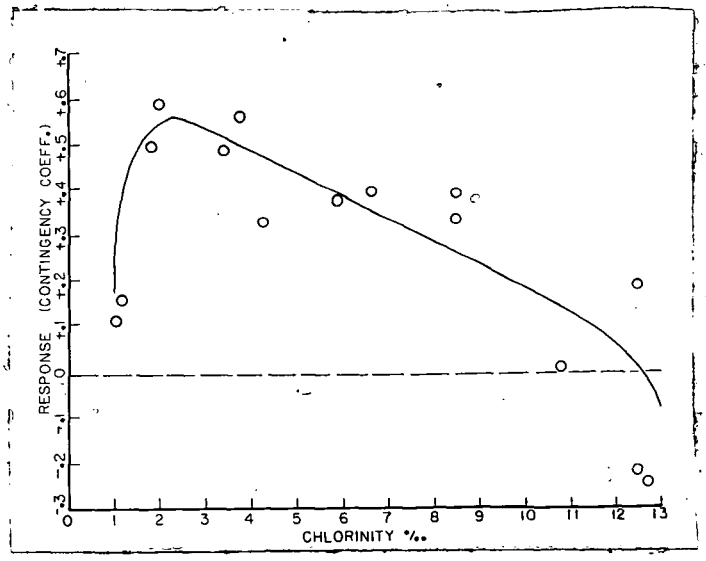

FIGURE 12 - Changes in the relative 'activity' of chum salmon fry occuring with changes in sea water concentration.

considered with respect to the duration of the fishes' exposure to the experimental conditions (figs. 10 and 11). The weak solutions of sea water were seen to elicit a speedy and strong response, while strong concentrations produced a slower response of less intensity. The range of concentrations between the two extremes was seen to result in responses of an intermediate speed and intensity. Thus it seems that acclimation of the fish to the difference in sea water content takes place, and that the rate of acclimation increases with the dilution of the sea water.

'Activity' of the Fish as Affected by a Sea Water Stimulus.

When the data were analysed to compare the numbers of fish actively swimming with those remaining relatively inactive, a significant difference in response was noted when the concentration of the sea water was varied. Weaker concentrations brought about more marked responses than strong ones (fig. 12). Nearly all the fish were actively swimming in the arms of the trough when the chlorinity of the sea water was between 1.79 and 3.72 ‰, while progressively fewer fish were observed in the arms as the concentration increased until at about 12.5 ‰ Cl., more fish were found in the undivided portion than in the arms. Between 1.07 and 1.79 ‰ Cl. (the apparent threshold of sea water discrimination), the fish were relatively inactive.

Summary

Experiments indicate that while migrating chum fry respond positively to full sea water, a period of acclimation takes place before a maximum response is elicited. The rate of acclimation seems to vary with the concentration of the sea water used as stimulus, being faster in dilute waters than in concentrated solutions.

It is evident that the response varied in three groups of experiments performed with fry from three different locations, and using test solutions obtained from these locations. In experiments performed at the University, Nile creek and Lake Cowichan, considerable variation existed in the average responses of the chum fry to a sea water solution of approximately 10 ‰Cl. The experiments carried out at the University indicated that the fry responded maximally to the stimulus, while the Nile creek results demonstrated a response of only moderate intensity. At Lake Cowichan, the fish exhibited a response of even less intensity.

Several facts seem to indicate that these discrepancies were due to the nature of the test solutions used. The fish used at the University were obtained from Nile creek and did not significantly differ in size from those experimented on at Nile creek two weeks later. Therefore these two groups of fish would not be expected to differ markedly in their response. The fresh water solutions used at the University consisted of chlorinated tap water, distinctly mor acidic than the Lake Cowichan fresh water obtained from a spring fed creek. It has

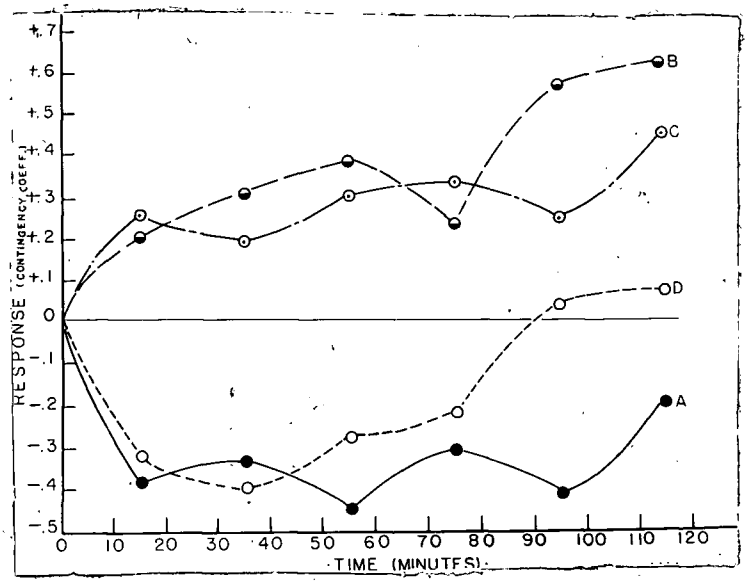

FIGURE 13 - Changes in the responses of chum salmon fry to sea water of about 7 ·Cl., as affected by a temperature difference of 2.5 C^{O}.

Line A - Responses of the fish to the warmer of two fresh water flows one of which was 2 C^{O} above the other.

Line B - Fresh flow 2.5 C^{O} above sea water flow.

Line C - Fresh and sea water flows of equal temperature.

Line D - Sea water flow 2.5 C^{O} above fresh.

also been pointed out that the sea water used at Lake Cowichan became toxic after a time due to the distance it had to be transported, and the length of time it was retained.

These chemical variations are felt to be the most likely cause of the differences in the degrees of response observed. However, the variation in responses noted above, was one of magnitude and not of basic pattern, the same general trends being observed in all experimental series performed.

Effect of temperature differences on the responses of chum fry to sea water.

To investigate the effects of a temperature difference on the responses of chum fry to sea water, the temperature of the test solution in one arm was raised approximately 2.5 C^{o} above that in the other arm, which was near the acclimation temperature of the fish (fig. 13).

When both arms of the trough contained fresh water and the temperature in one arm was raised 2.5 C^{o} above that in the other, the chum showed a marked 'preference' for the colder water. With equal temperatures in both arms, but with sea water of about 7‰ Cl. in one of the arms, the fish showed a marked 'preference' for the saline solution. When the temperature of the salt solution was raised 2.5 C^{o} above that of the fresh water, it was noted that the fish moved into the colder fresh water regardless of the presence of the sea water stimulus. However, acclimation to the higher temperature seemed to occur, and after 90 minutes, the fish were beginning

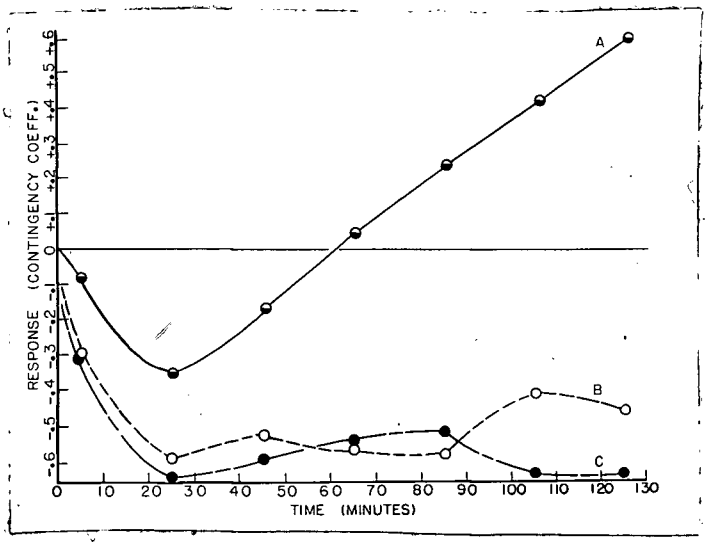

FIGURE 14 - Changes in the response of chum salmon fry to a toxic sea water solution as affected by a temperature difference of 3.0 C^{o}.

Line A - Fresh water flow 3.0 C^{o} above toxic sea water.

Line B - Fresh and toxic sea water flows of equal temperatures.

Line C - Toxic sea water flow 3.0 C^{o} above fresh water.

to respond positively to the sea water solution, regardless of the apparently unfavourable difference in temperature. This was probably due to the presence of the sea water stimulus as when both solutions consisted of fresh water and the temperature of one was raised, no evident acclimation to the warmer solution occured. When the fresh water solution was 2.5 C^{o} warmer than the sea water, the fish responded positively to the saline flow.

The profound effect of such temperature differences was seen in an experiment where the sea water used proved to be toxic. When one arm of the trough contained this solution and the other contained fresh water of the same temperature, the fish exhibited a negative response to the sea water (fig. 14). However, if the temperature of the fresh water solution was raised to 3 C^{o} above that of the toxic flow, the fish though initially repelled, became increasingly attracted to the harmful sea water until at about 120 minutes, nearly all the fish had moved into the sea water arm. When the temperature of the sea water was raised 3 C^{o} above the fresh water, a strong and sustained negative reaction resulted.

Summary.

When chum fry were exposed to two fresh water flows with different temperatures, they responded positively to the colder one. The temperature of this solution was the same as that of the water in the hatchery troughs. When sea water replaced the warmer fresh water flow, the expected 'preference' for sea water was modified, the fish responding primarily to

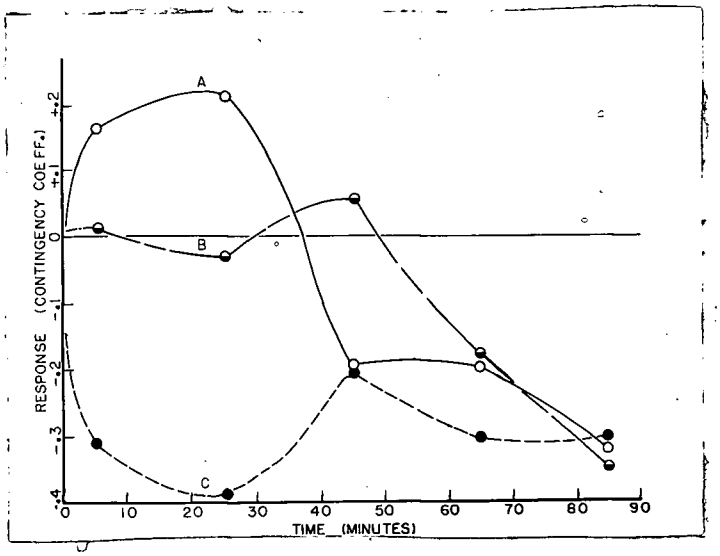

FIGURE 15 - Changes in the responses of coho salmon fry to different concentrations of sea water, occuring during experimental periods lasting 90 minutes.

Line A - Mean of responses to concentrations between 1.55 ‰ Cl. and 6.10 ‰ Cl.

Line B - Mean of responses to concentrations between 6.10 ‰ Cl. and 11.50 ‰ Cl.

Line C - Mean of responses to concentrations between 11.50 ‰ Cl. and 15.30 ‰ Cl.

the temperature difference. However, in this case acclimation to the warmer temperature occured, and after 120 minutes of exposure, the fish began responding positively to the sea water flow. Thus the apparent acclimation to the temperature difference was speeded when a sea water stimulus, tending to 'attract' the fish into the warmer flow, was applied.

When the presence of a toxic sea water solution was associated with a temperature difference such as that described above, it was found that the fish responded positively to the colder flow even though this entailed moving into the harmful solution.

Responses of coho fry to sea water.

When the responses of coho fry to various concentrations of sea water were tested, a typically negative reaction was observed. Weaker solutions brought about an initial response close to zero (fig. 15), but as the experiment progressed, the fish avoided the sea water to an increasing degree. More concentrated solutions brought about a consistently strong negative response. It is of note that at the end of the 90 minute period, all concentrations had caused a negative response of about the same degree. Thus it seems that coho fry avoided sea water flows of all concentrations, the stronger solutions eliciting the most marked negative responses.

DISCUSSION AND CONCLUSIONS

When chum salmon fry first reach the influence of the sea, they are presented with an opportunity of either returning to fresh water or moving into a saline environment. The sea water first confronting the fish would in most cases, be diluted by the fresh water of the parent stream. In experiments on fry captured just prior to entry into the sea, a 'preference' for dilute sea water was exhibited when the fish were given an opportunity of moving either into a fresh or saline flow. If an analogy between experimental and natural conditions is valid, then it seems likely that fry reaching the river mouth would be attracted rather than repelled by the dilute sea water lying immediately off the mouth of the stream. Fry moving from the stream to the open sea encounter increasing concentrations of sea water. In larger rivers where the influence of the fresh water extends far out into the sea, this gradient in sea water content is gradual, while in smaller streams, the gradient is steep due to the relatively small outflow.

It has been demonstrated that chum fry responded to dilute sea water with an almost immediate response of strong intensity, but as the concentration increased, a longer period of exposure to the sea water took place before a marked positive response was elicited. The rate at which the intensity of the response increased seemed to bear an inverse relationship to the concentration of the sea water. This indicates that before the fish move into more concentrated sea water, they undergo a period of acclimation. This acclimation is

probably closely associated with the regulatory activities occuring with salinity changes, for these processes take some time to restore the normal osmotic conditions of the fish after salinity alterations. These processes are fully discussed in Krogh's (loc. cit.) study of osmotic regulation, and in Copeland's (1948) complete study of chloride secreting cells in Fundulus. V. S. Black (unpub. data) studied the relation of tissue chloride content to sea water concentration in chum salmon fry. This author reports that when chum fry are placed in sea water (here between 15 and 17 ‰ Cl.), their tissue chloride content rises steadily for about 12 hours and then begins to drop, reaching approximately normal content within 24 hours. With more dilute solutions (near 7 ‰ Cl.), the same general pattern occured although the extent of the chloride change was considerably less. Thus chum fry seem to require about 24 hours to adjust to full sea water.

In general, the presence of a gradient in sea water off the mouth of a salmon stream, seems to exert a directive influence on the seaward movement of chum salmon fry. The rate at which the fish seem to respond to a gradient is controlled in part at least, by the rate at which the fish can physiologically adjust to the changing environment. Thus the steep gradient present at the mouth of a small stream might present a temporary barrier to the seaward movement of the fry, necessitating a slow passage through the estuary to permit acclimation to sea water. In larger streams with gradual gradients, this effect would not likely be as evident.

Growth of chum salmon from alevin to fry stage seems to be attended by an increasing ability to respond to a sea water stimulus. Although newly hatched alevins did not avoid sea water in experiments, they showed no preference for it. Fry however, showed a marked positive response toward a saline flow. The development of this response mechanism seemed to take place gradually throughout the fresh water phase of the young chums' life history, reaching its peak at about the time of the seaward movement.

As has been pointed out previously, the changes in sea water content are not the only alterations in the fish's environment, occuring with seaward migration. Two other factor differences were considered in the experiments; small differences in flow velocity, and small differences in temperature conditions. It has been noted that chum fry responded to the faster moving of two fresh water currents, when an alternative of moving into either of two currents flowing at different rates was presented. It was also demonstrated that this response did not occur if the slower moving current consisted of sea water, the fish responding primarily to the sea water stimulus. The velocities of flow used in the experiments (0.7 to 2 cm./sec.), were far below those normally found with tidal or river flows (e.g. flow at the mouth of Nile creek on May 13th, 1948, was approx. 1 meter/sec.). Thus any comparison between experimental flow conditions and those encountered by the migrating fry, would be open to question. However, it can be stated that slight varitions in current, do not

significantly alter the directive influence of sea water gradients on the fish.

It is evident that if the stream temperature were below that of the sea, the migrating fish would be faced with a temperature gradient as well as a sea water gradient. Thus the seaward movement of the fish would entail adjustments to both environmental changes. Experiments indicate that within the experimental period (here 2 hours), the fish avoided the higher temperature when they were presented with an alternative of moving into two flows, one of which was heated 2.5 C^{o} above the acclimation temperature of the fish. When sea water comprised the warmer flow, the fish slowly overcame their aversion to the higher temperature and responded positively to the saline solution. Again applying the analogy between experimental and natural conditions, it is suggested that if the stream temperature were below that of the ocean (e.g. from May 4th to May 13th, 1948, at Nile creek, the temperature of the stream water was between 6 and 7° C., while that of the ocean was between 9 and 10° C at the surface), the sea water would still exert its directive influence on the fish although the period needed for adjustment to the new environment would probably be longer than if no temperature difference were present.

In experiments, coho fry unlike the chums, respond negatively to sea water. In the chums, the most marked response to sea water did not seem to appear until just before the fish entered the sea. If a similar response pattern is

involved in the seaward movement of coho yearlings, its final development does not seem to occur during the early fresh water phases of their life history.

In summary, the evidence presented indicates that migrating chum salmon fry possess a mechanism permitting them to respond to changes in the sea water content of their environment. It is thought that this mechanism plays an important role in effecting the movement of the fish from the stream mouth to the sea.

SUMMARY

Experiments were performed on the young of chum and coho salmon wherein the fish were presented with the alternative of moving either into a fresh or sea water flow. Examination of the results indicates the following:

1) During the transition from the larval alevin stage to the free swimming fry stage, chum salmon fry show an increasingly marked preference for sea water rather than for fresh water.
2) Although chum fry will respond to a slight difference in the velocity of two fresh water currents by 'choosing' the faster flow, their response to sea water is not altered by such small differences in flow conditions.
3) Chum fry do not respond immediately to a sea water difference, the rate at which they reach a maximum response bearing a roughly inverse relationship to the concentration of the sea water.
4) Although chum fry will respond to a slight difference in the temperatures of two fresh water currents by 'choosing' the temperature closest to the one they have been acclimated to, they will respond to sea water despite such differences, though the period occuring before a marked response is elicited, is longer than if the temperature difference were not present.
5) Coho fry show a marked aversion to sea water even in dilute concentrations.

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APPENDIX

Key:

Experiments 1 to 20	-	Changes in the responses of young chum salmon with relation to growth (performed at the University of British Columbia).
Experiments 21 to 36	-	Responses of chum salmon fry to dilute sea water (performed at Nile creek, B. C.).
Experiments 37 to 43	-	Responses of chum salmon fry to dilute sea water (performed at Lake Cowichan, B.C.).
Experiments 44 to 51	-	Responses of coho salmon fry to sea water (performed at Lake Cowichan, B.C.).
Experiments 52 to 58	-	Effect of temperature differences on the responses of chum salmon fry (performed at Lake Cowichan, B.C.).
Samples A to D	-	Measurements of preserved fish.
Samples 1 to 38	-	Measurements of fish used in experiments.

Experiment no. ---1
Date ----------March 22nd, 1948.
Time ----------8:30 P.M.
Sample no. -------1

	Right Arm	Left Arm
Temp. °C:	7.5	7.5
Chlorinity ‰ :	0.00	0.00
Rate of Flow: cm./sec.	1.21	1.21

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	3	.447	6
20	1	3	.447	5
30	1	2	.268	6
40	1	2	.268	6
50	1	4	.500	4
60	3	3	.000	4
70	-	-	-	-
80	-	-	-	-
90	4	2	.316	4

Experiment no. ---2
Date ----------March 23rd, 1948.
Time ----------7:25 P.M.
Sample no. -------2

	Right Arm	Left Arm
Temp.°C:	7.5	7.5
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	1.19	1.19

Distribution of Fish

Time (min.)	Right Arm (No.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	3	.219	2
20	5	1	.555	4
30	5	1	.555	4
40	5	2	.394	3
50	5	3.	.219	2
60	4	3	.141	3
70	2	3	.195	5
80	6	3	.315	1
90	4	3	.141	3

Experiment no. ---3
Date ----------March 23rd, 1948.
Time ----------10:00 P.M.
Sample no. -------3

	Right Arm	Left Arm
Temp. °C:	7.5	7.5
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	1.19	1.19

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	3	.195	4
20	3	1	.447	5
30	2	1	.268	6
40	1	1	.000	6
50	1	2	.268	4
60	1	2	.268	5
70	1	4	.500	4
80	-	-	-	-
90	-	-	-	-

Experiment no. ---4
Date ----------March 24th, 1948.
Time ----------7:00 P.M.
Sample no. -------1

	Right Arm	Left Arm
Temp. °C:	9.0	9.2
Chlorinity ‰:	15.36	0.00
Rate of Flow: cm./sec.	1.16	1.16

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	4	.000	1
20	4	3	.141	2
30	1	1	.000	7
40	3	2	.195	4
50	1	2	.268	6
60	2	2	.000	4
70	4	1	.500	3
80	3	1	.447	5
90	3	2	.195	4

Experiment no. ---5
Date ----------March 24th, 1948.
Time ----------9:00 P.M.
Sample no. -------2

	Right Arm	Left Arm
Temp. °C:	9.1	9.2
Chlorinity ‰ :	15.36	0.00
Rate of Flow: cm./sec.	1.00	1.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	1	.447	4
20	2	2	.000	4
30	2	2	.000	4
40	2	1	.268	5
50	2	2	.000	4
60	2	4	.316	2
70	2	2	.000	5
80	1	2	.268	5
90	2	4	.316	2

Experiment no. ---6
Date ----------March 25th, 1948.
Time ----------11:30 A.M.
Sample no. -------3

	Right Arm	Left Arm
Temp. °C:	9.5	9.7
Chlorinity ‰ :	15.36	0.00
Rate of Flow: cm./sec.	1.01	1.01

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	3	.000	3
20	6	1	.581	1
30	3	3	.000	3
40	3	1	.447	5
50	-	-	-	-
60	2	2	.000	4
70	3	2	.195	3
80	3	2	.195	3
90	3	2	.195	3

Experiment no. ---7
Date ----------April 1st, 1948.
Time ----------7:45 P.M.
Sample no. -------4

	Right Arm	Left Arm
Temp. °C:	9.7	10.0
Chlorinity ‰:	15.94	0.00
Rate of Flow: cm./sec.	.98	.98

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	4	.500	4
20	-	-	-	-
30	1	4	.500	3
40	1	4	.500	3
50	3	2	.195	4
60	2	3	.195	4
70	4	3	.141	1
80	1	2	.268	6
90	3	4	.141	2

Experiment no. ---8
Date ----------April 6th, 1948.
Time ----------9:55 P.M.
Sample no. -------5

	Right Arm	Left Arm
Temp. °C:	9.3	9.5
Chlorinity ‰:	0.00	15.94
Rate of Flow: cm./sec.	1.35	1.38

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	-	-	-	-
20	2	3	.195	4
30	3	2	.195	5
40	3	5	.219	2
50	3	3	.000	4
60	6	2	.333	2
70	1	5	.555	4
80	1	6	.581	3
90	1	4	.500	4

Experiment no. ---9
Date ----------April 6th, 1948.
Time ----------11:50 P.M.
Sample no. -------6

	Right Arm	Left Arm
Temp. °C:	10.2	10.5
Chlorinity ‰ :	0.00	15.94
Rate of Flow: cm./sec.	1.40	1.33

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	2	.268	6
20	2	1	.268	6
30	4	3	.141	2
40	5	2	.394	2
50	1	2	.269	5
60	1	4	.500	3
70	-	-	-	-
80	2	2	.000	4
90	3	2	.195	3

Experiment no. ---10
Date ----------April 10th, 1948.
Time ----------1:00 P.M.
Sample no. -------7

	Right Arm	Left Arm
Temp. °C:	10.0	10.0
Chlorinity ‰ :	16.00	0.00
Rate of Flow: cm./sec.	0.67	1.33

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	2	.394	3
20	5	1	.555	3
30	3	1	.447	4
40	4	2	.316	3
50	6	1	.581	3
60	3	4	.141	2
70	4	3	.141	3
80	5	2	.394	3
90	6	3	.315	1

Experiment no. ---11
Date ----------April 10th, 1948.
Time ----------3:00 P.M.
Sample no. -------8

	Right Arm	Left Arm
Temp.°C:	9.2	9.5
Chlorinity ‰:	16.00	0.00
Rate of Flow: cm./sec.	1.33	0.67

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	1	.614	0
20	6	2	.333	1
30	7	2	.479	1
40	6	2	.333	2
50	4	2	.316	4
60	5	2	.394	2
70	7	1	.600	1
80	5	1	.555	3
90	5	2	.394	2

Experiment no. ---12
Date ----------April 10th, 1948.
Time ----------5:00 P.M.
Sample no. -------9

	Right Arm	Left Arm
Temp.°C:	10.0	9.6
Chlorinity :	0.00	16.00
Rate of Flow: cm./sec.	0.67	1.33

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	5	.394	2
20	1	3	.447	4
30	1	6	.581	2
40	1	3	.447	5
50	2	3	.195	5
60	3	2	.195	3
70	3	3	.000	3

Experiment no. ---13
Date ----------April 13th, 1948.
Time ----------9:00 P.M.
Sample no. -------10

	Right Arm	Left Arm
Temp.°C:	10.2	10.2
Chlorinity ‰:	16.00	0.00
Rate of Flow: cm./sec.	0.62	2.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	7	0	.600	2
20	6	2	.333	2
30	3	3	.000	4
40	4	1	.500	4
50	3	2	.195	3
60	2	4	.316	4
70	3	2	.195	4
80	4	1	.500	5
90	2	3	.195	5

Experiment no. ---14
Date ----------April 11th, 1948.
Time ----------9:00 P.M.
Sample no. -------8

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	0.80	1.21

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	2	.195	4
20	1	1	.000	6
30	0	5	.555	4
40	4	2	.316	3
50	1	1	.000	6
60	2	2	.000	5
70	2	5	.394	4
80	1	3	.447	4
90	2	5	.394	2

Experiment no.---15
Date ----------April 12th, 1948.
Time ----------8:00 P.M.
Sample no. ------10

	Right Arm	Left Arm
Temp.°C:	9.4	9.4
Chlorinity ‰ :	0.00	0.00
Rate of Flow: cm./sec.	0.67	1.82

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	1	.268	7
20	3	3	.000	3
30	2	2	.000	5
40	3	5	.219	2
50	3	6	.315	1
60	2	3	.195	3
70	2	3	.195	4
80	1	4	.500	3
90	2	5	.394	1

Experiment no. ---16
Date ----------April 12th, 1948.
Time ----------11:00 P.M.
Sample no. -------11

	Right Arm	Left Arm
Temp.°C:	10.8	10.5
Chlorinity ‰ :	0.00	0.00
Rate of Flow: cm./sec.	1.86	0.67

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	3	.195	3
20	1	3	.447	5
30	3	2	.195	4
40	1	6	.581	1
50	0	5	.555	3
60	3	3	.000	4
70	3	4	.141	3
80	3	2	.195	5
90	1	5	.555	4

Experiment no. ---17
Date ----------April 27th, 1948.
Time ----------9:00 P.M.
Sample no. -------12

	Right Arm	Left Arm
Temp. °C:	9.0	9.2
Chlorinity ‰ :	0.00	9.88
Rate of Flow: cm./sec.	1.83	0.63

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	7	.600	1
20	1	9	.626	0
30	2	7	.479	1
40	0	8	.614	1
50	0	8	.614	1
60	0	9	.626	0
70	1	7	.600	2
80	1	7	.600	0
90	0	7	.600	1

Experiment no. ---18
Date ----------April 27th, 1948.
Time ----------11:30 P.M.
Sample no. -------13

	Right Arm	Left Arm
Temp. °C:	10.0	9.7
Chlorinity ‰:	0.00	9.88
Rate of Flow: cm./sec.	0.66	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	0	10	.633	0
20	1	8	.614	1
30	1	7	.600	1
40	1	10	.633	0
50	2	6	.581	1
60	0	9	.626	2
70	0	8	.614	2
80	0	8	.614	2
90	2	7	.479	1

Experiment no. ---19
Date ----------April 28th, 1948.
Time ----------11:00 A.M.
Sample no. -------14

	Right Arm	Left Arm
Temp. °C:	10.2	9.8
Chlorinity ‰ :	0.00	9.88
Rate of Flow: cm./sec.	1.31	1.31

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	0	11	.640	1
20	1	9	.626	1
30	0	10	.633	2
40	1	10	.633	1
50	-	-	-	-
60	1	9	.626	2
70	0	8	.614	2
80	0	10	.633	0
90	0	10	.633	0

Experiment no. ---20
Date ----------April 28th, 1948.
Time ----------10:45 P.M.
Sample no. -------15

	Right Arm	Left Arm
Temp. °C:	10.8	10.8
Chlorinity ‰ :	9.88	0.00
Rate of Flow: cm./sec.	1.19	1.26

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	1	.614	1
20	10	1	.633	0
30	8	1	.614	2
40	8	0	.614	1
50	7	1	.600	1
60	7	1	.600	2
70	7	0	.600	2
80	8	0	.614	1
90	5	1	.555	3

Experiment no. ---21
Date ----------May 9th, 1948.
Time ----------5:00 P.M.

	Right Arm	Left Arm
Temp.°C:	10.3	10.2
Chlorinity ‰ :	0.00	1.07
Rate of Flow: cm./sec.	1.22	1.22

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (No.fish)
10	4	4	.000	2
20	3	3	.000	5
30	3	5	.219	3
40	4	3	.141	3
50	6	3	.315	3
60	6	4	.197	2
70	5	3	.219	4
80	5	4	.110	3
90	2	5	.394	4

Experiment no. ---22
Date ----------May 12th, 1948.
Time ----------9:00 A.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰ :	0.00	1.15
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	7	.479	3
20	2	6	.333	4
30	4	4	.000	4
40	3	6	.316	3
50	3	5	.219	4
60	3	4	.141	3
70	2	5	.394	3
80	2	3	.195	5
90	-	-	-	-

Experiment no. ---23
Date ----------May 10th, 1948.
Time ----------5:00 P.M.

	Right Arm	Left Arm
Temp.°C:	10.1	10.2
Chlorinity ‰:	1.79	0.00
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	9	0	.625	2
20	8	0	.614	2
30	7	1	.600	3
40	6	0	.581	4
50	9	1	.625	1
60	10	0	.633	1
70	9	0	.625	2
80	9	1	.625	1
90	7	0	.600	4

Experiment no. ---24
Date ----------May 10th, 1948
Time ----------9:20 A.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	1.98	0.00
Rate of Flow: cm./sec.	1.25	1.31

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	1	.614	3
20	9	1	.626	2
30	8	2	.515	1
40	9	1	.626	2
50	9	0	.626	2
60	11	0	.640	1
70	11	1	.640	0
80	11	0	.640	1
90	11	0	.640	1

Experiment no. ---25
Date ----------May 10th, 1948
Time ----------10:10 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰ :	3.34	0.00
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	10	0	.633	1
20	7	2	.479	2
30	10	0	.633	1
40	5	0	.555	6
50	9	0	.625	2
60	8	0	.614	3
70	8	0	.614	3
80	8	1	.614	1
90	9	0	.625	2

Experiment no. ---26
Date ----------May 12th, 1948.
Time ----------2:15 P.M.

	Right Arm	Left Arm
Temp.°C:	10.1	10.2
Chlorinity ‰:	0.00	3.72
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	6	.197	2
20	4	4	.000	4
30	4	6	.197	2
40	3	8	.414	1
50	4	8	.316	0
60	3	7	.371	1
70	0	10	.633	2
80	2	9	.537	1
90	2	10	.554	0

Experiment no. ---27
Date ----------May 8th, 1948.
Time ----------9:20 P.M.

	Right Arm	Left Arm
Temp.°C:	9.7	9.7
Chlorinity ‰ :	4.04	0.00
Rate of Flow: cm./sec.	1.28	1.22

Distribution of Fish

Time (sec.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	3	.219	2
20	5	1	.555	3
30	6	3	.315	1
40	7	0	.600	4
50	5	1	.555	4
60	4	3	.141	2
70	3	3	.000	4
80	5	3	.219	2
90	5	1	.555	4

Experiment no. ---28
Date ----------May 9th, 1948.
Time ----------1:00 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity: ‰	4.20	0.00
Rate of Flow: cm./sec.	1.22	1.22

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	2	.595	4
20	5	2	.394	3
30	6	2	.333	2
40	6	1	.581	4
50	5	3	.219	2
60	4	1	.500	6
70	6	0	.581	5
80	10	1	.633	0
90	9	2	.472	0

Experiment no. ---29
Date ----------May 10th, 1948.
Time ----------2:45 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰ :	5.84	0.00
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (min.)	Right Arm (No.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	7	1	.600	2
20	6	1	.581	5
30	7	1	.600	3
40	6	2	.333	2
50	5	3	.219	3
60	5	4	.110	3
70	7	3	.372	1
80	7	3	.372	2
90	-	-	-	-

EXperiment no. ---30
Date ----------May 9th, 1948.
Time ----------8:15 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	0.00	8.48
Rate of Flow: cm./sec.	1.22	1.25

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	8	.614	1
20	2	5	.394	1
30	0	6	.581	5
40	2	6	.333	2
50	2	7	.479	1
60	0	7	.600	4
70	0	7	.600	4
80	1	4	.500	5
90	1	6	.581	3

Experiment no. ---31
Date ----------May 12th, 1948.
Time ----------9:40 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	0.00	8.48
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	5	.110	3
20	0	4	.500	6
30	2	6	.448	4
40	2	7	.481	2
50	1	6	.581	4
60	1	7	.579	3
70	0	6	.614	2
80	1	9	.626	0
90	0	11	.640	0

Experiment no. ---32
Date ----------May 12th, 1948.
Time ----------12:10 P.M.

	Right Arm	Left Arm
Temp. °C:	10.0	10.0
Chlorinity: ‰	0.00	10.73
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	1	2	.315	8
20	2	5	.394	4
30	3	4	.141	4
40	2	5	.394	4
50	1	4	.530	6
60	2	3	.195	8
70	2	9	.537	2
80	2	7	.485	3
90	2	7	.485	4

Experiment no. ---33
Date ----------May 10th, 1948.
Time ----------7:15 P.M.

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	12.47	0.00
Rate of Flow: cm./sec.	1.25	1.25

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	3	.141	4
20	2	2	.000	6
30	2	2	.000	7
40	4	3	.141	5
50	2	2	.000	7
60	4	3	.141	4
70	-	-	-	-
80	4	3	.141	4
90	4	3	.141	4

Experiment no. ---34
Date ----------May 8th, 1948.
Time ----------7:30 P.M.

	Right Arm	Left Arm
Temp. °C:	9.5	9.5
Chlorinity ‰:	0.00	12.50
Rate of Flow: cm./sec.	1.22	1.22

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	2	.000	5
20	2	4	.316	4
30	3	4	.141	3
40	3	4	.141	3
50	2	6	.333	2
60	2	5	.394	2
70	2	5	.394	3
80	1	6	.581	3
90	1	6	.581	3

Experiment no. ---35
Date ----------May 7th, 1948.
Time ----------11:00 A.M.

	Right Arm	Left Arm
Temp.°C:	9.7	9.7
Chlorinity ‰ :	0.00	12.70
Rate of Flow: cm./sec.	1.19	1.25

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	2	.000	6
20	0	4	.500	6
30	1	4	.500	4
40	1	5	.555	3
50	0	2	.268	7
60	1	0	.000	8
70	1	5	.555	3
80	0	2	.268	7
90	0	5	.558	4

Experiment no. ---36
Date ----------May 9th, 1948.
Time ----------10:00 A.M.

	Right Arm	Left Arm
Temp.°C:	8.9	9.2
Chlorinity ‰:	0.00	16.22
Rate of Flow: cm./sec.	1.19	1.16

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	2	.195	6
20	3	2	.195	6
30	3	2	.195	6
40	6	2	.333	2
50	4	3	.141	3
60	2	3	.195	4
70	4	1	.500	4
80	4	2	.316	3
90	3	2	.195	4

Experiment no. ---37
Date ----------May 20th, 1948.
Time ----------10:30 A.M.
Sample no. -------18

	Right Arm	Left Arm
Temp.°C:	9.5	9.7
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	1.43	1.43

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	undiv. Port. (no.fish)
10	2	1	.268	8
20	5	1	.555	5
30	4	2	.316	5
40	2	5	.394	5
50	2	4	.316	5
60	3	2	.195	4
70	4	4	.000	4
80	5	4	.110	4
90	4	2	.316	6

Experiment no. ---38
Date ----------May 21st, 1948.
Time ----------4:15 P.M.
Sample no. -------19

	Right Arm	Left Arm
Temp.°C:	11.3	11.3
Chlorinity ‰:	0.00	1.83
Rate of Flow: cm./sec.	1.62	1.62

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	5	.000	0
20	6	5	.095	3
30	2	7	.479	2
40	2	8	.515	1
50	2	7	.479	1
60	5	7	.164	1
70	3	7	.371	3
80	0	9	.626	3
90	0	6	.581	4

Experiment no. ---39
Date ----------May 21st, 19 48.
Time ----------1:00 P.M.
Sample no. -------20

	Right Arm	Left Arm
Temp.°C:	10.2	10.3
Chlorinity ‰:	0.00	3.73
Rate of Flow: cm./sec.	1.52	1.52

Distribution of Fish

Time (min.)	RightArm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port.) (no.fish)
10	6	7	.078	1
20	6	6	.000	2
30	7	6	.078	1
40	6	5	.095	3
50	4	8	.316	2
60	2	8	.515	3
70	2	10	.555	2
80	4	5	.515	3
90	2	8	.515	3
100	2	10	.555	1
110	3	8	.414	2
120	3	7	.371	3
130	1	9	.626	3

Experiment no. ---40
Date ----------May 21st, 1948.
Time ----------9:45 A.M.
Sample no. -------21

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	6.52	0.00
Rate of Flow: cm./sec.	1.52	1.52

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	7	5	.164	2
20	8	3	.414	1
30	7	3	.371	3
40	9	2	.537	1
50	7	2	.479	3
60	6	3	.316	3
70	7	2	.479	3
80	6	1	.581	5
90	5	3	.219	3

Experiment no. ---41
Date ----------May 22nd, 1948.
Time ----------10:00 A.M.
Sample no. -------22

	Right Arm	Left Arm
Temp.°C:	11.2	11.3
Chlorinity ‰:	0.00	9.58
Rate of Flow: cm./sec.	1.43	1.43

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	7	.263	1
20	4	6	.197	2
30	4	5	.110	3
40	4	7	.263	1
50	4	4	.000	3
60	4	7	.263	1
70	3	7	.371	2
80	2	8	.515	1
90	3	7	.371	2

Experiment no. ---42
Date ----------May 20th, 1948.
Time ----------5:00 P.M.
Sample no. -------23

	Right Arm	Left Arm
Temp.°C:	11.7	11.7
Chlorinity ‰:	0.00	12.52
Rate of Flow: cm./sec.	1.43	1.43

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	6	.316	4
20	4	4	.000	5
30	2	5	.394	6
40	5	5	.000	3
50	3	4	.141	6
60	4	5	.110	3
70	7	4	.263	1
80	4	6	.197	2
90	5	5	.000	2

Experiment no. ---43
Date ----------May 20th, 1948.
Time ----------2:10 P.M.
Sample no. -------24

	Right Arm	Left Arm
Temp.°C:	10.6	10.4
Chlorinity ‰:	14.62	0.00
Rate of Flow: cm./sec.	1.62	1.57

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	6	.095	3
20	5	5	.000	5
30	5	6	.095	2
40	3	3	.000	8
50	5	3	.219	6
60	4	4	.000	6
70	4	6	.197	4
80	3	5	.219	4
90	5	4	.110	3

Experiment no. ---44
Date ----------May 25th, 1948.
Time ----------10:00 A.M.
Sample no. -------25

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	2.80	2.36

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	5	.210	0
20	5	6	.095	2
30	7	3	.371	2
40	5	8	.210	0
50	4	4	.000	4
60	6	3	.316	4
70	5	7	.164	1
80	4	5	.110	4
90	5	6	.095	2

Experiment no. ---45
Date ----------May 25th, 1948.
Time ----------12:15 A.M.
Sample no. -------26

	Right Arm	Left Arm
Temp.°C:	10.2	10.2
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	1.28	2.36

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	9	.447	2
20	6	6	.000	2
30	2	10	.555	2
40	3	8	.414	2
50	5	7	.164	0
60	4	5	.110	3
70	4	4	.000	4
80	3	8	.414	1
90	4	4	.000	4

Experiment no. ---46
Date ----------May 26th, 1948.
Time ----------2:30 P.M.
Sample no. -------27

	Right Arm	Left Arm
Temp.°C:	11.7	11.7
Chlorinity ‰:	0.00	1.55
Rate of Flow: cm./sec.	2.15	2.07

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	8	.226	1
20	4	6	.195	4
30	4	5	.110	5
40	8	3	.414	3
50	6	4	.195	4
60	6	2	.448	5
70	4	5	.118	4
80	6	4	.195	4
90	8	2	.515	3

Experiment no. ---47
Date ----------May 26th, 1948.
Time ----------10:00 A.M.
Sample no. -------28

	Right Arm	Left Arm
Temp.°C:	11.0	11.0
Chlorinity ‰ :	3.00	0.00
Rate of Flow: cm./sec.	2.00	2.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	3	.414	1
20	8	5	.226	0
30	7	5	.167	1
40	6	5	.095	3
50	4	7	.267	1
60	4	7	.267	2
70	4	6	.195	2
80	4	5	.110	3
90	2	7	.481	2

Experiment no. ---48
Date ----------May 26th, 1948.
Time ----------12:15 A.M.
Sample no. -------29

	Right Arm	Left Arm
Temp.°C:	11.7	11.5
Chlorinity ‰:	0.00	6.10
Rate of Flow: cm./sec.	2.00	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	8	.515	1
20	0	7	.600	5
30	0	5	.555	7
40	2	6	.448	4
50	0	5	.555	5
60	2	5	.394	5
70	6	2	.448	3
80	4	3	.142	5
90	6	3	.317	3

Experiment no. ---49
Date ----------May 27th, 1948.
Time ----------10:30 A.M.
Sample no. -------30

	Right Arm	Left Arm
Temp.°C:	9.7	9.7
Chlorinity ‰:	0.00	9.40
Rate of Flow: cm./sec.	2.07	2.07

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	9	2	.472	2
20	9	1	.672	3
30	7	0	.600	7
40	8	2	.515	3
50	7	4	.263	2
60	5	3	.243	5
70	8	3	.414	2
80	8	2	.515	3
90	8	3	.414	2

Experiment no. ---50
Date ----------May 28th, 1948.
Time ----------10:30 A.M.
Sample no. -------31

	Right Arm	Left Arm
Temp.°C:	10.0	10.0
Chlorinity ‰:	0.00	11.50
Rate of Flow: cm./sec.	1.92	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	6	0	.614	6
20	6	3	.317	3
30	4	3	.141	5
40	2	2	.000	7
50	3	6	.317	3
60	4	4	.000	4
70	5	4	.110	3
80	6	4	.195	2
90	4	3	.141	5

Experiment no. ---51
Date ----------May 28th, 1948.
Time ----------2:00 P.M.
Sample no. -------32

	Right Arm	Left Arm
Temp. °C:	9.7	9.7
Chlorinity ‰:	0.00	15.30
Rate of Flow: cm./sec.	2.07	2.07

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	10	1	.632	2
20	7	2	.485	3
30	10	0	.633	2
40	6	1	.581	4
50	5	1	.555	4
60	6	1	.581	3
70	4	1	.521	4
80	5	1	.555	3
90	4	2	.318	2

Experiment no. ---52
Date ----------May 28th, 1948.
Time ----------9:25 P.M.
Sample no. -------33

	Right Arm	Left Arm
Temp. °C:	14.5	12.0
Chlorinity ‰:	0.00	0.00
Rate of Flow: cm./sec.	2.00	2.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	3	6	.317	4
20	3	9	.447	1
30	5	9	.272	0
40	4	10	.393	0
50	3	9	.447	2
60	3	10	.458	0
70	4	10	.393	0
80	5	8	.226	1
90	3	7	.371	2
100	-	-	-	-
110	5	9	.272	0
120	6	8	.134	0

Experiment no. ---53
Date ----------June 1st, 1948.
Time ----------9:50 A.M.
Sample no. -------33

	Right Arm	Left Arm
Temp. °C:	11.5	11.5
Chlorinity ‰ :	7.50	0.00
Rate of Flow: cm./sec.	2.00	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	9	5	.272	0
20	10	6	.243	0
30	-	-	-	-
40	9	6	.195	1
50	10	6	.243	0
60	11	5	.351	0
70	11	5	.351	0
80	10	5	.317	1
90	10	6	.243	0
100	10	6	.243	0
110	12	4	.448	0

Experiment no. ---54
Date ----------May 28th, 1948.
Time ----------5:05 P.M.
Sample no. -------34

	Right Arm	Left Arm
Temp. °C:	14.5	12.0
Chlorinity ‰ :	7.35	0.00
Rate of Flow: cm./sec.	2.00	2.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	4	8	.316	2
20	4	8	.316	2
30	4	9	.358	1
40	3	11	.423	0
50	4	10	.393	0
60	5	7	.164	2
70	4	9	.359	1
80	6	7	.078	1
90	6	6	.000	2
100	7	6	.078	1
110	8	6	.141	0
120	7	7	.000	0

Experiment no. ---55
Date ----------June 1st, 1948.
Time ----------2:05 P.M.
Sample no. -------35

	Right Arm	Left Arm
Temp. °C:	11.5	14.5
Chlorinity ‰ :	7.45	0.00
Rate of Flow: cm./sec.	2.07	2.00

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	8	6	.141	3
20	9	5	.274	1
30	8	5	.224	2
40	10	4	.393	0
50	11	3	.496	0
60	7	4	.263	4
70	8	6	.141	1
80	8	4	.316	3
90	11	2	.569	1
100	10	2	.555	2
110	13	1	.561	0
120	12	2	.581	0

Experiment no. ---56
Date ----------June 2nd, 1948.
Time ----------10:25 A.M.
Sample no. -------36

	Right Arm	Left Arm
Temp. °C:	11.0	14.0
Chlorinity ‰ :	11.22	0.00
Rate of Flow: cm./sec.	2.07	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	5	7	.164	4
20	3	7	.371	5
30	3	6	.316	5
40	-	-	-	-
50	5	7	.164	2
60	5	5	.000	4
70	6	5	.095	3
80	8	5	.224	1
90	7	4	.263	3
100	10	2	.555	2
110	8	4	.316	2
120	11	2	.569	1
130	12	1	.646	1

Experiment no. ---57
Date ----------June 2nd, 1948.
Time ----------1:35 P.M.
Sample no. -------37

	Right Arm	Left Arm
Temp.°C:	11.0	14.7
Chlorinity: ‰	11.70	0.00
Rate of Flow: cm./sec.	1.92	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	13	.592	1
20	1	14	.683	1
30	3	11	.496	2
40	1	14	.683	1
50	4	9	.358	3
60	3	11	.496	2
70	2	12	.581	2
80	1	13	.651	2
90	2	8	.515	6
100	3	9	.447	4
110	4	9	.358	3
120	3	9	.447	4
130	3	10	.458	3

Experiment no. ---58
Date ----------June 2nd, 1948.
Time ----------5:00 P.M.
Sample no. -------38

	Right Arm	Left Arm
Temp.°C:	12.0	12.0
Chlorinity ‰:	11.63	0.00
Rate of Flow: cm./sec.	1.92	1.92

Distribution of Fish

Time (min.)	Right Arm (no.fish)	Left Arm (no.fish)	Cont. Coeff.	Undiv. Port. (no.fish)
10	2	14	.600	0
20	1	14	.683	1
30	0	8	.614	6
40	0	9	.626	4
50	2	10	.555	1
60	2	9	.537	2
70	1	6	.581	6
80	2	8	.515	3
90	2	8	.515	3
100	0	10	.632	3
110	1	12	.646	0
120	0	10	.632	3
125	1	12	.646	0

Mean Lengths of Experimental Fish

Sample no.	Date	Number of Fish in sample	Mean Length mm.
A	Feb. 2	6	18.2
B	Feb. 7	8	20.3
C	Feb. 16	10	21.9
D	Feb. 25	40	23.7
1	Mar. 22	11	26.3
2	Mar. 23	10	28.0
3	Mar. 23	9	26.1
4	Apr. 1	10	26.8
5	Apr. 6	10	29.1
6	Apr. 6	9	28.4
7	Apr. 10	10	29.4
8	Apr. 10	10	29.3
9	Apr. 10	-	-
10	Apr1.12	8	31.2
11	Apr. 12	10	31.0
12	Apr. 27	8	34.9
13	Apr. 27	10	34.7
14	Apr. 28	10	34.3
15	Apr. 28	9	35.4
16	May 12	20	34.3
17	May 12	26	34.8
18	May 20	9	37.3
19	May 21	8	36.2
20	May 21	13	35.7
21	May 21	12	36.3
22	May 22	13	36.2
23	May 20	11	36.6
24	May 20	12	35.9
25	May 25	12	34.0
26	May 25	13	34.1
27	May 26	14	31.9
28	May 26	12	34.5
29	May 26	12	34.4
30	May 27	12	33.9
31	May 28	12	33.8
32	May 28	10	32.3
33	May 28	12	35.6
34	May 28	16	35.7
35	Jun. 1	13	35.6
36	Jun. 1	13	36.5
37	Jun. 2	14	37.2
38	Jun. 2	15	37.2