THE CORRELATION BETWEEN TEMPERATURE AND SALINITY

AND

THE CATCH OF COHO SALMON (<u>ONCORHYNCHUS KISUTCH</u>)

IN

THE KAINS ISLAND FISHING AREA

by

VINCENT REGINALD TAYLOR

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS

in the Department
of
ZOOLOGY

We accept this thesis as conforming to the
standard required from candidates for the
degree of MASTER OF ARTS

Members of the Department
of Zoology

UNIVERSITY OF BRITISH COLUMBIA

April, 1952

ABSTRACT

The relative abundance of coho salmon (*Oncorhynchus kisutch*) in the Kains island troll fishing area was computed, for the years 1943 to 1951 inclusive, on the basis of the average catch per boat per day each year. The resulting figures varied from a minimum of 75 pounds per boat per day in 1946 to a maximum of 231 pounds per boat per day in 1951.

These yield per unit effort figures were then statistically compared with the average surface salinity, or average surface temperature, for various periods in the life history of the coho taken by the fishery in these years.

It was found that a very high correlation ($r = 0.85$, $p = 0.01 - 0.001$) existed between the average "summer" salinity (June to September inclusive) and the poundage yield per unit effort during that same year.

It is suggested that this correlation is explainable in terms of varying growth rates in different years, and by variations in the numbers of fish taken in these years, both of these factors being governed by the availability of food, as evidenced by surface salinity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The relationship between animals living in the sea and their environment is a very intimate one, and small changes in environmental conditions are quickly brought to bear upon the forms living there. This is as true of the nektonic animals, especially fish, as it is of the numerous other types of life found in the sea. Workers in fisheries research have always appreciated that such a relationship existed, but it is only within relatively recent years that any concerted effort has been made to interpret variations in fish populations with the aid of oceanographic data.

The main drawback in using oceanographic data in fisheries research has been--and still is--a lack of fundamental knowledge about the marine areas concerned. In particular, there is a lack of longterm knowledge. Records over considerable numbers of years are necessary so that the "norms" of the various hydrographical components may be calculated. It is necessary that these "norms" be known if the changes in hydrographical conditions from year to year are to be properly assessed.

This present study is an attempt to interpret the yield of one commercially important species of fish in terms of some of the more obvious features of its marine habitat.

Statement of Problem

The study is an attempt to determine statistically, for a limited area, whether or not a correlation exists between the commercial catch of coho salmon (Oncorhynchus kisutch) in their marine habitat, and the environmental factors of salinity and temperature.

Limitations of the Study

There are two primary limitations affecting this study. These are:

(1) the number of species that are investigated, and (2) the limited area for which fishing records were obtained. It was considered that a small scale study such as this would lend itself better to an accurate assessment of the variables involved.

Species Limitations

The coho salmon has been the only species included in the investigation. It is one of the two species of Pacific salmon that is intensively fished in the marine habitat by ocean troll fishermen. The other species thus fished is the spring salmon (O. tshawytscha). The coho was chosen in preference to the spring, primarily because of the regularity of its life cycle, both in the river and in the sea, as compared with the irregularities of the life cycle of the spring.

Area Limitations

It would have been desirable, had the necessary information been available, to have considered the complete marine catch of coho salmon in British Columbia. The needed records were however, not available, and it was not possible to carry out such a comprehensive study. Instead it has been confined to only one of the major fishing areas of the coast of Vancouver island.

The area chosen from which to obtain the necessary records was the Kains island fishing area. This area is situated off the mouth of Quatsino sound, on the northwest coast of Vancouver island. The size of the area and its location are shown approximately in Figure 1. The area outlined within the quadrilateral indicates the area that is most consistently, and most intensively fished. The fishing fleet may, sporadically, range several miles in various directions from this area.

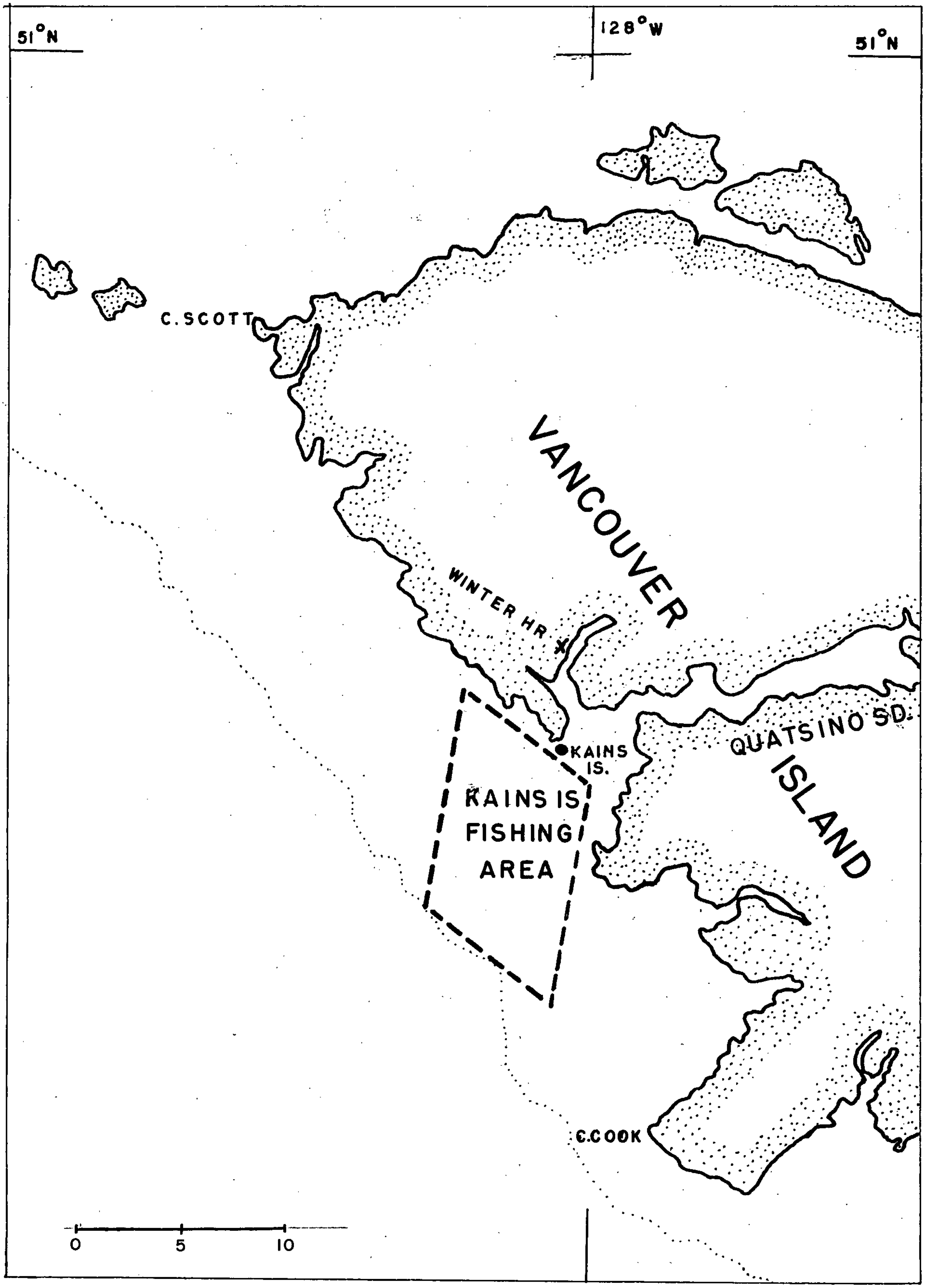

Figure 1. Map showing location of the Kains island fishing area. The dotted line off the coast represents the 100-fathom line.

As mentioned, there are several major fishing areas for coho on the British Columbia coast. Of these, the Kains island area is about the only one that has all of the following advantageous characteristics. These are:

(1) Kains island itself, which is situated on the edge of the actual fishing grounds, is a recording station for temperature and salinity data of the coastal waters.

(2) It is a well delimited area, and is intensively fished.

(3) All of the fish caught in the Kains island fishing area are landed at the same place, namely at Winter Harbour.

(4) It is a "day-fishing" area, which means that all fish caught are landed that same day.

(5) Little or no fish from other areas are landed at the Winter Harbour fishing camp. The exceptions will be noted later.

(6) Detailed records of the Kains island catch were available over a period of several years.

(7) The writer is personally familiar with the fishing area, and with the operations there.

All of the factors listed above contribute to the facility with which the fish population of the area may be interpreted in terms of the variables in their environment.

Life History of the Coho Salmon

The coho, like the other four species of Pacific salmons in British Columbia, is an anadromous fish. It is thus subjected to two completely different environments during its life history, one during the period that is spent in the sea, and the other during the time spent in the river.

In either of these two environments it exhibits a behaviour that is different from that in the other—each being a distinct part of its life cycle.

Fresh-water Phase

The maturing coho enter the British Columbia coastal streams between the months of September and November each year. The peak of the upstream migration usually occurs in October. They travel varying distances upstream, some spawning only a short distance from the sea, others going upriver for many miles until they reach the tributaries of the larger rivers. When a suitable location is found in the river bed the eggs and s aperm are deposited and covered with gravel. The adults, their life over, then drift downstream and shortly die.

The fry begin to emerge from the spawning beds during March and April of the following year and, in the smaller tributaries, immediately begin a migration downstream to the larger rivers. This migration continues throughout the spring of that year (43).

The majority of the young coho spend about one full year in the river system. A few migrate to the sea in their first and third years. According to the scale studies of Pritchard (48, 49) these first and third year coho make up less than two percent of the total migrants in any one year. The peak of the downstream migration occurs between April and June of the coho's second year. They are now between four and seven inches in length, the average being about five inches (20). Some few of them may spend a period in estuarial waters, vacillating between the river and the sea, but for the bulk of them the sea will be their home for almost two years.

Salt-water Phase

Little or nothing is known about the young coho during their first year in the sea. They seem to disappear, and are not seen again until they become available to the ocean troll fishery in the spring of the next year. At this time they may be up to five hundred miles from the streams that they left the previous year. They have also grown considerably and usually weigh between two and four pounds. The coho's second year in the sea is better known, and a large number of tagging experiments have been carried out on them during this period.

Pritchard and Tester (51) have studied their food habits in British Columbia waters during the second year. They found the main items of the coho diet during this time to be herring, sandlance, and other small fishes chiefly; but also including certain members of the zooplankton, especially euphausiids. The relative importance of the different species in the diet varied from year to year. It also varied in the different areas (22, 57).

The growth rate of the coho during their last year is a very rapid one. Their weight increases rapidly from about three or four pounds in May to six or eight pounds, or more, by the end of September (17, 18, 38, 67).

In general, when the coho appear in the open ocean troll fishery they seem to have reached the end of their seaward migration, and to have begun a movement toward the rivers. It is during this movement back to the streams that they are particularly available to the fishery.

The Ocean Troll Fishery for Coho

The fishery is mainly confined to the area over the continental shelf. It is an intensive fishery in British Columbia, and several hundred boats engage in it every year. Most of the catch is taken between the months of May and September, with July and August generally being the most productive.

A survey of the coho troll fishery of the Pacific states of the United States, where the fishery is similar to that in British Columbia, is given, by various authors, in bulletin number two of the Pacific Marine Fisheries Commission (19, 31, 67). A detailed description of the boats and gear used in the troll fishery may be found in Western Fisheries magazine (2, 69).

During the fishery, and usually in conjunction with it, many coho have been tagged or otherwise identified, and released into the sea. Much information about their movements in the sea during this last year, and other data as well, has been obtained in this manner.

Data from Tagging Experiments

The early tagging operations on coho, conducted in 1925 and 1926 in Canadian waters, seemed to indicate a general southeasterly movement of maturing fish from the feeding grounds to the coastal rivers. The results of more recent experiments tend to modify this conception somewhat.

Milne (39), summarizing the tagging operations up to 1950, showed that the coho tend to wander a good deal during this return period, and also that they radiate in many directions from their feeding areas. In British Columbia though the southeasterly movement is still predominant.

All of the evidence to date, both from tagging and from the fishery itself, indicates that while it is a spawning migration it is a more or less leisurely movement during which very active feeding occurs.

By the middle or late fall of each year, depending on the area, most of the coho have left the truly oceanic areas for the inlets and rivers. By the end of November the majority have entered the rivers where, when a suitable location is found, they will deposit their spawn. The adults die when spawning has been completed, but the cycle will be repeated by their progency which emerge from the gravel the following spring.

Coastal Oceanography

The biological productivity of an area is largely determined by the currents, both lateral and vertical, that are operative within it. These currents are responsible, not only for water temperatures within the area, but also for the amounts of basic nutrient materials that are available for the support of biological organisms.

The ocean currents off the coast of British Columbia may, for convenience, be divided into two categories. These are: the off-shore currents, whose primary influence is exerted some distance from the coast, and the in-shore currents which are operative between the coast and the inside edge of the off-shore water movements. The two systems are not independent, and the configuration of the inshore system is, to a large extent, determined by the vagaries of the off-shore currents.

The Off-shore Currents

The surface current of primary importance in the North Pacific ocean is that commonly known as the Japanese current, or the West Wind Drift. It is a mixture of the warm waters of the Kuroshio current that flows in a northeasterly direction along the coast of Japan, and of the cold waters of the Oyashio current flowing south along the northeast Japanese coast. The two meet and mix their waters at about 35° N latitude off the coast of Japan. The mixed water then flows in an easterly direction across the North Pacific. The flow becomes less well defined as it travels farther east, but is perpetuated and driven on by the prevailing westerly winds. This flow, usually called the Japanese current, is more correctly referred to as the Aleutian, or Subarctic current (59, pp. 712).

Before the Aleutian current reaches the west coast of North America it divides into two main branches, one of which flows south to become the California current, and one going north as the Alaskan current. According to "The Oceans" (59, pp. 724) this division takes place at about 35° N latitude. The drift bottle experiments of the International Fisheries Commission, however, indicate that the division may occur at least two degrees farther north than this. Thompson and Van Cleve (64, pp. 50-57) show this, and their results also show that there is probably considerable variation from year to year, as well as within the same year.

The main flows of the California and Alaskan currents, especially the California, do not usually extend to the immediate coastline. In the case of the Alaskan current it has been shown (64, pp. 59) that in its northerly flow it is deflected towards the coast and reaches into the passages of British Columbia and southeastern Alaska.

The configuration of these major currents determine to a large extent the configuration of the more local ones in any year.

The In-shore Currents

Over the area of the continental shelf, which has been called the "in-shore" area, there are both lateral and vertical currents, the vertical currents being mostly operative in the summer. These are intimately connected with the prevailing winds, and with the offshore systems.

Lateral In-shore System. In this more shallow water area, one hundred fathoms or less, which has been taken as the limits of the continental shelf, there are numerous eddies from the shore side of the main currents off-shore. These eddies are reinforced or dampened by the shape of the coastline and by local tidal influence, which is of great importance in the mixing of water immediate to the coast.

Besides these lateral water movements in the continental shelf area there is also a vertical movement of water upwards. The vertical movements are of first importance in terms of the life that the area supports.

Vertical In-shore System. In summer, the net effect of the prevailing winds along the British Columbia coastline is to produce a movement of the warmer and lighter surface water off-shore. To replace this, water comes up from the deeper layers. This coming to the surface of deeper water is known as "upwelling", a well established phenomenon. A detailed analysis of the upwelling process off California has been given by Sverdrup (58).

Some indication of the amount of water that is coming to the surface in an area may be gained by an examination of the surface temperature and salinity. However, McLeod (37) in 1951 showed that the surface salinities of certain areas in British Columbia also correlated well with the river runoff during the summer season. This, of itself, does not negate the existence of upwelling, since such a correlation would be expected due to the change in precipitation that is concomitant with a change from predominantly southeasterly winds during most of the year to predominantly northwesterly during the summer. Thus the same factor responsible for upwelling is also responsible for the amount of runoff. Because of this it would be expected that upwelling, as evidenced by surface salinity, would show some correlation with the amount of runoff.

The depth from which the rising waters originate is not entirely agreed upon. Sverdrup (59, pp. 725), says that it rises from moderate depths of probably not greater than two hundred meters off the California coast. Igelsrud (26), working on the distribution of phosphates off southern Vancouver island, found that it may come from as deep as five hundred meters, or more. Temperature and salinity data in the area gave the same results. It is probable that this also varies in different years, depending on the mean velocity of the summer winds.

The biological importance of these water movements lies in the fact that deep waters are rich in nutrient salts which are essential for phytoplankton growth. Because these plants, the phytoplankton, grow only in the euphotic zone, it is necessary that the salts, which they are using up, be constantly replenished to insure an abundant crop. The deep water coming to the surface accomplishes this replenishment. Because phytoplankton is at the base of the marine food chain, the fish production also in such an area, is indirectly related to the amount of upwelling that occurs.

In summary, it may be said that the area over the continental shelf of British Columbia is an area of diverse water movements, both lateral and vertical, and that due to this the waters are well mixed and the nutrients brought to the zone where they can be utilized by phytoplankton. To a large extent these things determine its biological potential. It is probable that within this area there exist local areas, the geographic and hydrographic features of which are such that they tend to be major centers of food production for the fish populations.

Local Features of the Kains Island Fishing Area

The limit of the continental shelf (the 100-fathom line) is close to the coast in this area, usually being between ten and fifteen miles offshore. The bottom configuration, as deduced from hydrographic charts, is fairly even and contains no major prominences or submarine canyons. The position of Brooks peninsula, jutting out into the sea about twelve miles to the south, probably contributes to eddy formation in the general area.

The fishermen operating in the area suggest--and this was also the writer's experience--that there is a general northwestward current proximate to the coast from the vicinity of the mouth of Quatsino Sound. This probably represents a net outflow of water from the Sound, which is deflected to the right parallel to the coast due to the influence of the earth's rotation.

There are numerous tiderips and eddies very close to the shore, and these contribute to mixing of the waters of the area.

MATERIALS

The records on which all of the calculations herein are based were obtained from two main sources. These were, the Fishermen's Cooperative Association, and the Pacific Oceanographic Group. The first named organization supplied the fishing records, while the published and unpublished records of the second were the source of salinity and temperature data (46).

Fishing Records

The records that have been used, those for the years 1943 to 1951, were compiled in the originals on a basis of the daily landings. For each fishing day during the coho seasons the poundage of coho salmon was given, and also the number of boats contributing to each day's landing, each of the boats being identified by the owner's name. Total catch records were available from the year 1936, but these were not used since these early years were a period of expansion for the company concerned in that area. Within the last decade the number of boats fishing the area has remained reasonably constant.

No adjustments were made to the records for the years 1943 to 1949. For the years 1950 and 1951 it was necessary to make some adjustments. This was due to the introduction of a new factor in the landings at the Winter Harbour camp, and stemmed from the opening of an ice-plant at that place in 1950.

Up until 1950 all, or practically all, of the fish landed at Winter Harbour had been fish taken in the Kains island fishing area. They were also fish that had been caught on the same day as landed. With the introduction of ice making operations at that place, it became an important landing place for the so-called "ice-boats". These "ice-boats" are larger salmon trollers, operated by a two man crew, which fish the more distant trolling grounds. These boats do not land their catch every day but about every five to ten days instead. It was necessary then because: (I) they were not landing fish caught in the Kains island area, and (II) they were confusing the daily record by landing several days' catch at once, to eliminate their influence from the daily record.

The records did not identify the ice-boats as such, but it was not difficult to remove the greater part of their influence from the catch. This was accomplished in two ways. The first was the writer's familiarity with the fishing fleet (the boats were identified by the owner's name in the record), which in many cases enabled him to exclude certain catches immediately. Secondly, and this was the important means, there is usually a very wide discrepancy between the poundage landed at any one time by a day-boat and that landed by an ice-boat. Day-boat landings usually run between one hundred pounds and twelve hundred pounds. It is rarely that they exceed the highest figure. The ice-boats, however, may land in one day (representing several days' fishing) between two thousand and five thousand pounds, or more. Except in a few instances then, it was easy to distinguish between the landings of the two types of boats.

Salinity and Temperature Records

These were available for the area concerned from the records of the Pacific Oceanographic Group. Only one minor adjustment was made to these records. It consisted of excluding from the mean salinity for the month of July, 1947, the reading given for the fourteenth day. It varied by about 5 ‰ (parts per thousand) from the readings of the days immediately preceding it and following it. It was concluded that the reading was influenced by some unknown factor since this was a greater variation than is usually found over the course of a year in this area.

METHODS

The time periods that have been used as a basis on which to compile the records are calendar periods. The monthly and yearly figures that are given are the average of the daily figures over these periods.

Treatment of Fishing Records

The troll fishing season for coho salmon in the Kains island area begins in May. This period constitutes the fishing season or, as it is sometimes called herein, a "fishing year".

From the original records the fishing data were arranged on a monthly basis in terms of: (1) the total poundage landed, and (2) the number of landings each month. Because the boats land their catch each day, the number of landings each month is equivalent to the number of "boat-days" fished each month. This lends itself readily to a criterion of effort based on the unit of a "boat-day". Thus, if twenty boats make a landing of coho in one day the total fishing effort expended that day is equal to twenty boat-days.

Criterion of Relative Abundance

Some index was necessary whereby the catch of coho from year to year might be compared. The yardstick of "yield per unit of effort" was selected to accomplish this. It is a measure that has been widely used in the past, and is probably the best such measure available. Ricker (53) gives a mathematical discussion of this index in terms of its relation to relative abundance and the rate of exploitation.

Various workers have used different units as their criterion of fishing effort; in every case the unit used is dependent on the type of fishery, and on the manner in which it is prosecuted (8, 9, 10, 61, 63).

The criterion of relative abundance used in this study has been the average catch per boat per day each year. Except for the daily time unit, this is strictly comparable to the method used by Clark (8) in his study of the California halibut (*Paralichthyes californicus*). This index has been used here without any adjustments. This means that two main assumptions have been made; they are: (1) that the total amount of gear used in the fishery has remained constant over the period of years considered, and (2) that the efficiency of the gear has remained unchanged.

Some idea of the total amount of gear used in the fishing area over these years may be gained from an examination of the number of boat-days fished each year. (The amount of gear fished by any one boat has been the same since several years earlier than the years studied.)

TABLE I

Year	Boat-days	Year	Boat-days
1943	2,515	1948	1,908
1944	2,778	1949	2,179
1945	2,181	1950	2,102
1946	2,066	1951	2,282
1947	1,544		

Table I shows that the amounts of gear used in each year, as measured by the number of boat-days fished, has been fairly constant. Such variations as do occur may probably be attributed to the influence of weather conditions, since this will limit or increase the number of days that the boats are able to fish; and, to the time of arrival in the different years of the main body of fish. The year 1947 may be an exception to this, the number of boat-days fished that year being considerably less than that for any other year, and it may be that fewer boats--that is, a lesser amount of gear--fished the area during that year. In any case, it is felt that the differences between the various years are not sufficient to invalidate the results obtained. It is worth noting that this same year, 1947, is the year that will later be shown to exhibit the greatest discrepancy in terms of correlation with yield of any of the years studied.

The second assumption made was that the efficiency of the gear remained unchanged. This is a valid assumption for the years considered. The actual fishing gear used by the troll fishermen has undergone no major changes within these years. There has, in recent years, been the introduction of such electronic aids as echo-sounders, direction finders, radio-telephone, etc. However, a majority of the day-boats (day-boats are the boats that land their catch every day, as opposed to ice-boats which may land only once a week or so) fishing the Kains island area still do not carry such aids; of those boats that may have one or more of these aids they benefit mostly by the extra safety factor that these bring, rather than by increased catches. In the case of the ice-boats these aids assume a greater importance but need not be considered here since their landings have been excluded from the records used.

The Boat-day, a Basic Unit of Effort

The boat-day, for the purposes of this study, is defined as "the amount of fishing effort expended by one boat fishing for one day or a part thereof." It has been necessary to include the idea of a part of a day because there was no distinction made in the records between those boats that fished a full day, and those that fished for only part of a day. We have assumed, in computing the relative abundance each year, that such errors as this may introduce balance each other out from year to year.

Average Catch per Boat per Day each Year

This is the index that has been used to compare the relative abundance of coho from year to year. It was calculated by adding up the total poundange of coho landed each fishing year, and dividing the figure obtained by the number of boat-days fished in the same period. Thus, if 200,000 pounds of coho were landed in year X, and it represented an expenditure of fishing effort equal to 2,000 boat days, then the average catch per boat per day for year X was 100 pounds.

Treatment of Salinity and Temperature Data

Average salinity and temperature figures were calculated for different periods in the marine life history of the coho salmon; the figures used in the calculations are the means of the monthly means within those periods.

Statistical Treatment

The statistical treatment of the data throughout has been of a simple nature. Four common statistics have been used to measure the correlation, or lack of correlation, between the variables of salinity (or temperature) and the yield to the commercial fishery of coho salmon.

The statistics used in the calculations are outlined below:

(I) The Coefficient of Correlation, r. This statistic is used to measure the degree of correlation between the variables; the formula used to compute the value of r is that of Johnson (29, pp. 54), where:

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{\left[\sum(X - \bar{X})^2\right]\left[\sum(Y - \bar{Y})^2\right]}}$$

In this equation X is the average salinity in parts per thousand (‰), and Y is the average yield per boat per day each year in pounds. $\bar{X}$ and $\bar{Y}$ are the means of X and Y.

(2) Test of Significance, t and p. This a test applied to r by calculating the value of t and using it in certain tables (the t tables). The formula used to compute t was:

$$t = r\sqrt{\frac{n - 2}{I - r^2}}$$

n, in this formula, is the number of pairs, while n - 2 is the number of degrees of freedom.

The value of p was found from the tables of the distribution of t (30, pp. 360). It may be interpreted as follows: let us suppose that for a certain value of r, the value of p is found to be 0.02. "... This is interpreted as meaning that if the population coefficient, P, is equal to zero, that is to say if there is no correlation between the variables sampled, we would expect to get an r value as large as that obtained only twice in a hundred times on the basis of random sampling ..." (29, pp. 63).

(3) <u>Regression Coefficient, b_{yx}</u>. This statistic was calculated to enable the path of the <u>Regression Line</u> between any two sets of variates to be plotted more precisely. The formula used was:

$$b_{yx} = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sum(X - \bar{X})^2}$$

The value for b_{yx} thus obtained was then substituted in the equation:

$$\hat{Y} = \bar{Y} + b_{yx}(\hat{X} - \bar{X})$$

In the above equation $\hat{X}$ and $\hat{Y}$ are the regression values of X and Y.

These statistics were taken in varying degrees from either Arkin and Colton (3), Johnson, L.P.V. (29), or Johnson, P. O. (30).

RESULTS

The relative abundance of coho salmon in the Kains island fishing area, for each of the years studied, was calculated on the basis of yield per unit of effort. This index, yield per unit of effort, is expressed for each year from 1943 to 1951 in terms of <u>the average catch per boat per day</u>. The figures are given in Table II, along with the total catch and the number of boat days fished in each year. These yield per unit effort figures are the figures that are used in all the calculations with which to compare the average salinity or temperature during the differe nt periods in the life history of the coho caught in any year.

TABLE II

The Fishing Record, Compiled on a Yearly Basis

Year	Total catch lbs.	No. of boat-days	lbs. per unit effort
1943	281,980	2,515	112
1944	404,700	2,778	182
1945	345,490	2,181	158
1946	155,830	2,066	75
1947	225,400	1,544	146
1948	170,700	1,908	89
1949	263,260	2,179	121
1950	216,130	2,102	103
1951	527,130	2,282	231

It has been shown by previous workers that the yield of certain marine fishes, insofar as hydrographic fluctuations are concerned, is determined by only a relatively small portion of their life history in the sea (28,68). Consequently, for this study, the marine history of the coho was divided into several periods. The average salinity, or temperature, of each of these periods was calculated for each population of third year coho, and the figures obtained compared statistically with the yield per unit of effort for these years.

On this basis, the life history of the coho in the sea was divided into the following periods:

A. During its first year in the sea:

(1) June to September; this is the period of upwelling during its

first year. If mortality in this year is dominant, due to hydrographic factors, it should be operative during this period.

B. During its second year in the sea;

(2) April to September; this covers the period during which the coho are available to the fishery.

(3) June to September; this is the period during which most upwelling occurs during the last year. It is also a period of very rapid growth for the coho.

C. During both years in the sea.

(4) This is the average of one and two above, and covers the period of upwelling during both years in the sea.

(5) April of the first year to September of the second year; this eighteen-month period covers, approximately, the entire time that the coho spends in the sea.

Average Salinity and Yield

The average salinities calculated for these periods are given in Table III. In this table the yield years, given in the left hand column, are the years that the coho were taken in the commercial fishery. The numbers at the top of the columns refer to the numbers given in the preceding classification.

TABLE III

Average Salinities for Periods in the Marine Life

of Coho Caught in any Year

Yield year	Period of Average Salinity				
	June to Sept. (1)	April to Sept. (2)	June to Sept. (3)	June to Sept. (4)	April to Sept. (5)
1943	‰ 32.05	‰ 31.43	‰ 32.01	‰ 32.03	‰ 30.95
1944	32.01	32.08	32.28	32.14	31.31
1945	32.28	31.58	32.05	32.16	31.08
1946	32.05	30.97	31.55	31.80	30.67
1947	31.55	31.25	31.63	31.59	30.70
1948	31.63	31.07	31.31	31.47	30.66
1949	31.31	31.04	31.67	31.49	30.67
1950	31.67	30.70	31.35	31.51	30.63
1951	31.35	31.99	32.37	31.86	30.65

From the data given in Tables II and III, the correlation between the average salinities of each period and the yield per unit effort over the years studied was determined. This correlation, or in many cases lack of correlation, has been expressed in terms of the correlation coefficient, r. That is to say, that the yield per unit of effort over the period of years from 1943 to 1951, has been separately compared with the average salinity during each of these periods of the coho's life in the sea.

Table IV gives the values of the correlation coefficients found to exist between the average salinities for the different periods, and the yield per unit effort. It also gives the values of the statistics t and p which are used to show the relative statistical significance of r. A value of unity for r indicates a perfect correlation between the variables examined. The value of p is the probability that such a value for r as shown would occur solely due to chance.

TABLE IV

The Correlation between Average Salinities and Yield

Salinity period	Value of r	Value of t	Value of p
(I) June - Sept. (first year)	-0.22	0.60	0.2 - 0.3
(2) April - Sept. (yield year)	+0.86	5.I8	0.0I - 0.00I
(3) June - Sept. (yield year)	+0.85	5.02	0.0I - 0.00I
(4) June - Sept. (both years)	+0.53	I.65	0.I0
(5) April - Sept. (I8 months)	+0.39	I.I2	0.30

Table IV shows, that for most of the periods in which average salinity was calculated, there was no significant correlation with yield. The periods that do show a significant correlation are those that were calculated for some period within the yield year itself, - namely, (I) April to September, and (II) June to September. These two correlations will be presented im some detail. The lack of correlation between the average salinity from June to September of the first year in the sea, and the yield of coho one year later, will also receive further consideration

<u>The Correlation between Yield and Average Salinity the Same Year.</u> The values of the correlation coefficient, r, obtained between yield and the average salinities of the periods from April to September, and June to September, were 0.86 and 0.85 respectively, the periods being calculated within the yield year. Statistically, these two correlations do not significantly differ one from the other.

It is known, from the oceanography of the coast, that intense upwelling is present each year during the months of June to September. It is probable that some upwelling occurs in May. The influence of this colder water during May may account in some degree for the similarity between the correlations of the two periods. It is likely that the influence of the upwelling from June to September is sufficient to influence the figures for the April to September period to the extent that the average of the two periods is very similar, thus showing a similar correlation with yield. Therefore only the correlation shown to exist between yield and average salinity from June to September will be presented in detail.

The correlation between the "summer" salinity ("summer" salinity is the June to September salinity) of the yield year, and the yield that year, are graphically shown in Figures 2 and 3.

In Figure 2, the data are plotted as percentage deviations from their respective means. It is obvious from this graph that the trends of the two variables parallel each other very closely. The greatest discrepancy is for the year 1947. It was earlier pointed out that in this year the fishing intensity--as measured by the number of boat-days--was much lower than that for any other year. The effect of this lowered

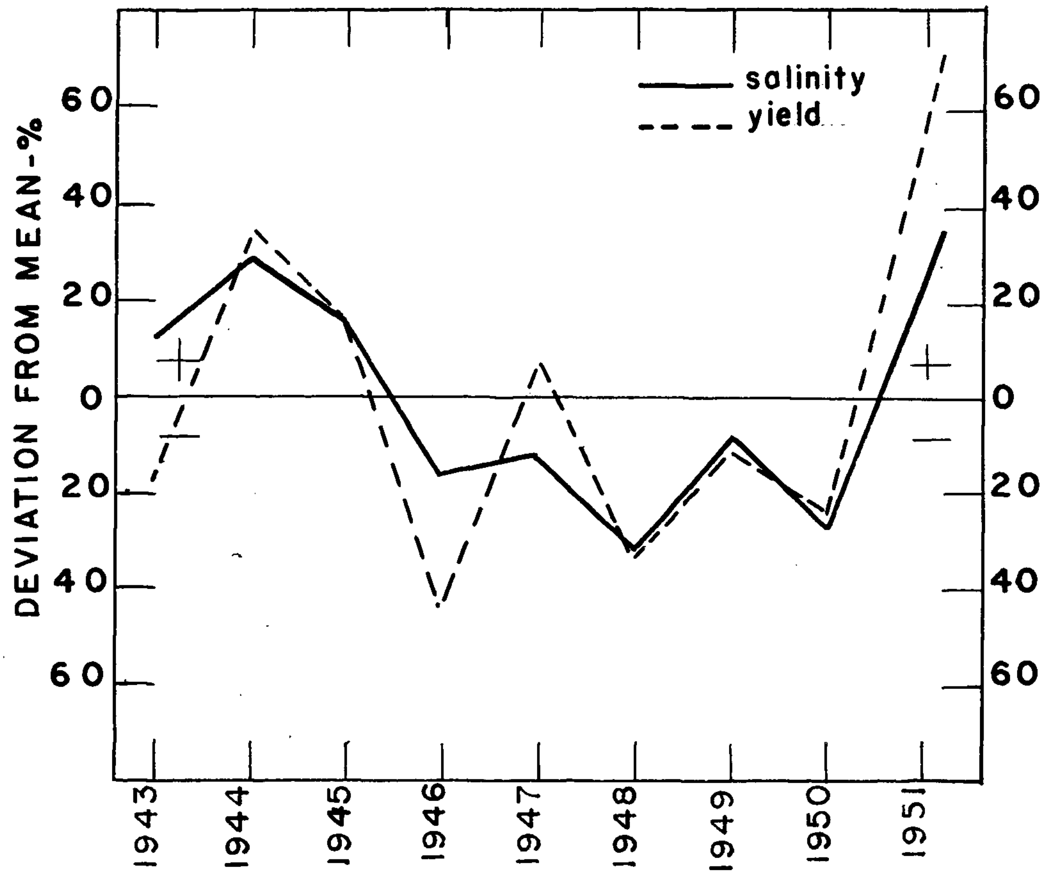

Figure 2. Average "summer" salinity and yield per unit-effort same year, plotted as percentage deviations from the mean (Salinity deviation x20)

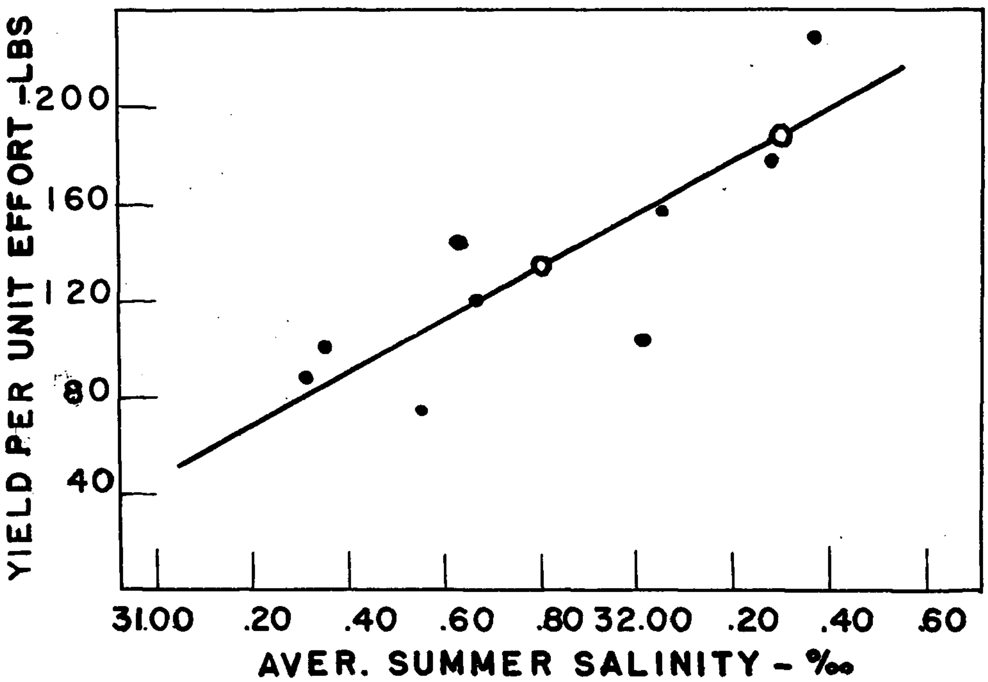

Figure 3. Scatter diagram of average "summer" salinity and yield per unit effort same year, 1943 to 1951, inclusive. The two hollow circles represent the two points $\bar{X}\bar{Y}$ and $\hat{X}\hat{Y}$.

fishing intensity on the criterion of yield per unit effort may be part of the cause of this discrepancy.

In Figure 3 the yield per unit effort data are plotted directly against the average "summer" salinities, this time in the form of a scatter diagram. The line running diagonally across the figure is the line of regression. The proximity of the plotted points to this line indicates the degree of correlation between the variables measured.

The value of the correlation coefficient between the average "summer" salinity and the yield per unit effort the same year ($r = 0.85$) is, statistically, a very significant correlation.

Average Salinity First Year in the Sea, and Yield Following Year. It was mentioned that earlier workers had found good correlations to exist between salinities during the brood years and yield several years later, for fish other than salmon. In 1946, Walford (66), found that almost a perfect correlation existed between the average summer salinity during the brood year of the California sardine (*Sardinops caerulea*) and the yield three years later. It was thought that something comparable might be operative in the coho population, and a similar comparison was made.

Although the coho salmon are not spawned in the sea, they are very small during their first year in the ocean. It might be expected that during this year they would be more sensitive to environmental changes than in the following year. In Figure 4, the average salinities during this first year in the sea are plotted against the yield the following year, as percentage deviations from the mean. The figure shows that there is no obvious correlation exhibited between the two variables. The value of the correlation coefficient, r, was calculated as being equal to -0.22. This value has no statistical significance.

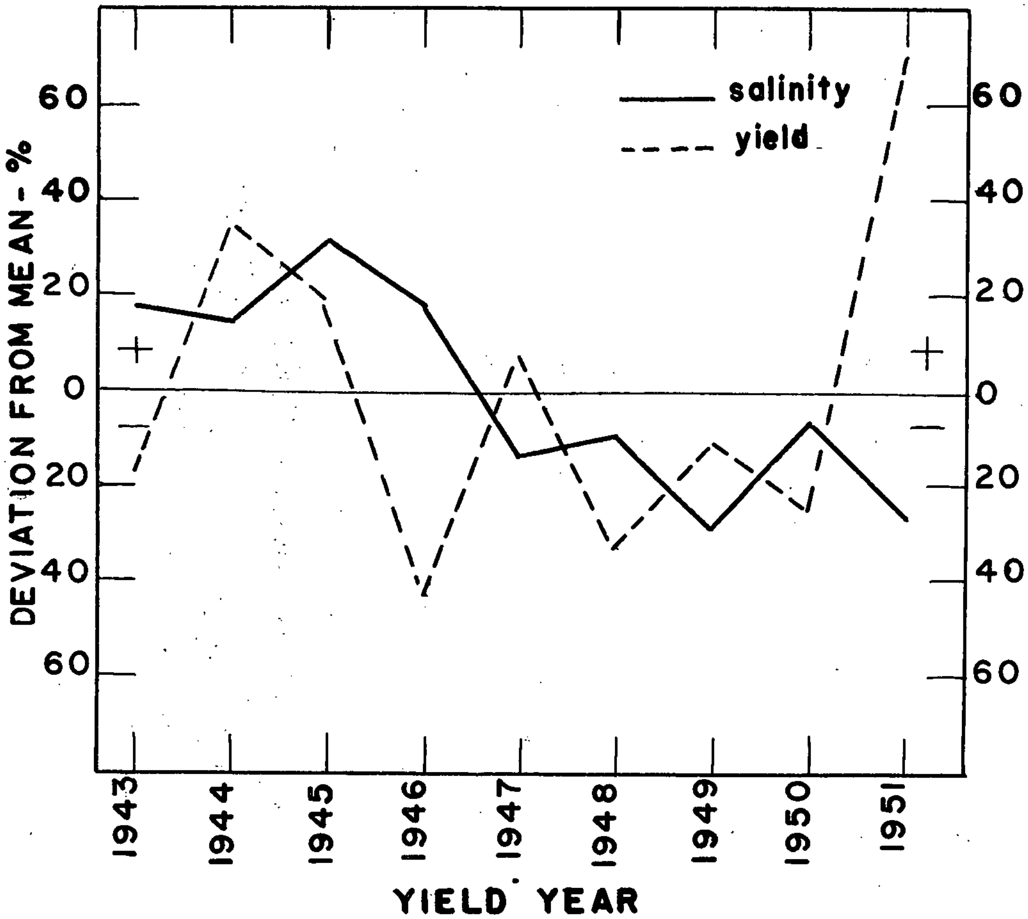

Figure 4. Yield per unit effort and "summer" salinity of preceding year, plotted as percentage deviations from the mean. (Years on scale are the yield years. Salinity deviation x20.)

The lack of correlation shown in Figure 4 may mean that during this period of the coho's sea life, of which almost nothing is known, it frequents an area that is not primarily dependent on upwelling for its supply of nutrient salts. Such an area might be the "inside waters" of Vancouver island. Another explanation, assuming that mortality during this year is not dependent on the amount of upwelling, may be that variations in the relatively slow growth rate during this period are of insufficient magnitude to be reflected in the poundage yield the following year.

Average Temperature and Yield

The same time periods have been used to compare average temperature with yield as were used to compare salinity with yield. They are:

(1) June to September of first year in the sea.

(2) April to September of second year in the sea.

(3) June to September of second year in the sea.

(4) June to September during both years in the sea.

(5) April of first year in sea to September of the second, a period of eighteen months.

The average temperatures for these periods in the life history of the coho caught in any year are given in Table V. The yield year is the year that the coho were caught. The number at the top of the columns refer to the numbers of the periods as given above.

TABLE V

Average Temperatures for Periods in the Marine Life of Coho caught in any Year.

Yield year	Period of Average Temperature				
	June to Sept. (1)	April to Sept. (2)	June to Sept. (3)	June to Sept. (4)	April to Sept. (5)
	F°	F°	F°	F°	F°
1943	55.4	52.8	54.7	55.0	51.2
1944	54.7	52.9	54.7	54.7	51.4
1945	54.7	51.3	52.7	53.7	51.3
1946	54.7	52.7	54.8	53.7	50.1
1947	54.8	53.2	55.2	55.0	50.5
1948	55.2	52.3	54.2	54.77	51.0
1949	54.2	52.3	54.3	54.2	50.1
1950	54.3	51.6	54.1	54.2	50.1
1951	54.1	52.1	53.7	53.9	50.4

From the average temperature figures of Table V, and the yield per unit effort figures given in Table II, the degree of correlation between the temperatures of the different periods and the yield per unit of effort was calculated. The values for the correlation coefficient, r, that were found are presented in Table VI.

TABLE VI

The Correlation between Average Temperatures and Yield

Temperature period	Value of r	Value of t	Value of p
(1) June to Sept. (first year)	+0.13	xx	xx
(2) April-Sept. (yield year)	-0.07	xx	xx
(3) June - Sept. (yield year)	-0.33	0.924	0.3 - 0.4
(4) June-Sept. (both years)	-0.09	xx	xx
(5) April to Sept. (18 months)	-0.13	xx	xx

xx Values not calculated.

The values of the statistics given in Table VI show that there is no obvious correlation existing between the temperature of the various periods and the yield in pounds over the years studied. The highest value found for the correlation coefficient, r, was equal to -0.33. This value has no statistical significance.

DISCUSSION

The marine life of the coho salmon includes the period from about May of its second year to the fall of the following year, a period of approximately eighteen months. During this time it is subject to the influence of prevailing environmental conditions, the state of which at any time is determined by the current systems, both lateral and vertical, that are operative within the area.

A major factor that influences coho during their sea life is the availability of food. In this regard, the population of any marine animal is ultimately dependent on the annual crop of phytoplankton; the phytoplankton in turn are dependent on several other factors, one of the most important ones being the amount of nutrient salts available. These salts the phytoplankters must have for growth and reproduction, so that in the long run the salmon, and other fish, are also dependent on the amounts of nutrient salts.

Between the two variables of nutrient salts and fish populations, there is a long series of relations and interrelations, all of which together constitute the "chain of life" in the sea. The component links of this chain are: nutrient salts, phytoplankton, zooplankton, and nekton (which includes all of the free swimming animals). The relationships existing between these have been determined, in their essentials, by numerous workers in many countries.

Nutrient Salts and Phytoplankton

The dependency of the phytoplankton population on the nutrient salts (phosphates, nitrates, etc.) available has been well established by many investigators (11, 16, 21, 52, 54, 55). Their relationship is such that in areas where the waters of the euphotic zone (the lighted zone) constantly have their supply of nutrient salts replenished, due to lateral or vertical turbulence, the phytoplankton crop is very dense. Conversely, where the salts removed by the phytoplankton are not being replenished, as in areas of converging currents, the phytoplankton population is sparse.

The relationship has also been shown experimentally. Raymont (52) showed that when nitrate and phosphate salts were added to the waters of certain Scottish sea lochs the density of the phytoplankton was greatly increased. The same experiment also showed that such fertilized areas were able to support a higher zooplankton population.

Other factors besides the concentrations of nutrient salts affect the phytoplankton, a particularly important one being the amount of light available for photosynthesis. Johnson in "The Oceans" has summed it up thus "... many factors are still unknown but it is clear that with sufficient sunlight the combination of nutrient cycles and the vertical circulation of the water are dominant causes..." (59, pp. 784).

Phytoplankton and Zooplankton

Phytoplankton constitutes the food supply of the members of the zooplankton, which feed on them by filtering them from the water. The relationship between the two is, however, less obvious than that shown to exist between phytoplankton and nutrient salts.

Riley and Bumpus (56) have shown that between the phytoplankton--zooplankton populations of George's Bank an inverse correlation exists. This is attributed to the grazing effect of the zooplankters on the phytoplankton, such that in an area where the zooplankters are dense they rapidly reduce the phytoplankton by their feeding activity.

Zooplankton and Nekton

Many marine animals feed directly on zooplankton. Prominent among these are the Baleen whales (Mystacoceti), and certain fishes of major commercial importance, including some members of the mackerel family (Scombridae), and the herring family (Clupeidae).

The distribution of Baleen whales has been correlated with the distribution of the zooplankton on which they exist (59, pp. 904-907), especially in certain parts of the antarctic. The abundance of mackerels has also been correlated with the abundance of zooplankters. Bullen (4) showed that the abundance of mackerel in the English fishery paralleled the greater or less abundance of zooplankton during the same period.

Fish Populations and Hydrographic Factors

Many workers have analysed the oceanographic environment, when studying fish populations, in terms of temperature and salinity (hydrographic factors), rather than in terms of the abundance of the forms themselves that constitute the food supply. Such factors as salinity and temperature are easier to measure, quantitatively, than is the abundance of phytoplankton or zooplankton.

In 1927, Johansen (28) showed that there was a significant correlation between the fluctuations in the quantities of plaice fry and the surface salinities for January and February of the same years. The correlation he calculated to be equal to 0.57, and the mean error (σr) to be 0.15. He concluded from this that the correlation exhibited "...must be regarded as an established fact..." He found a somewhat lower correlation ($r = 0.31$) between surface temperature and plaice fry, but said that "...it seems to be a reality..." He then interpreted these correlations in terms of the availability of plankton organisms to the young plaice, as governed by the water movements into and out of the area.

Carruthers and Hodgson (6) showed, in 1937, that the percentage of a certain year class of herring in the East Anglian autumn fishery closely paralleled the atmospheric pressure gradients controlling the winds of the area during the spawning years; the winds being a major controlling factor in the surface water movements. It has also been shown (32) that the decline in the Plymouth herring fishery was coincident with a similar decline in the phosphate content of the waters of the area concerned.

In 1946, Walford (68), showed that there was almost a perfect correlation ($r = 0.96$) between the average summer salinities during the brood years of the California sardine (Sardinops caerulea) and the yield of fourth year fish for the year classes of 1934 to 1941 inclusive. He concluded from his correlation that "... the salinity reflects the intensity of upwelling which brings up material nourishing the plankton; and it is suggested that the summer, when the aforesaid relationship is best demonstrable, is the most critical period in the life of the young sardine, when an abundant supply of food is most essential."

An unsuccessful attempt to correlate the deviations from the catch trend of coho salmon in the Siletz river in Oregon with the surface salinities at Cape St. James, British Columbia, was reported in 1950 by McKernan, et al (36). Perhaps the fact that the two areas are some six hundred miles apart may be an important factor in determining the lack of correlation that these workers found. Their assumption that changes in surface salinity in the Cape St. James area reflect similar changes off the coast of Oregon is of doubtful validity.

The correlations that have been shown by these workers to exist between adult fish or, in the case of Johansen the numbers of fry, and various hydrographic factors have, in each case been interpreted in terms of larval mortality. Thus, Johansen (28) relates the numbers of young plaice fry in any year to the salinity and temperature during January and February of the same year; Carruthers and Hodgson (6) relate abundance of herring to factors influencing surface water movements during their spawning years; and, Walford (68), correlates the abundance of sardines with the salinity during their brood years. In the final analysis they have all attributed the correlations shown to greater or less larval mortality in the brood years, due to the paucity or abundance of food, as finally evidenced by temperature and salinity.

Salinity Correlation

In the results presented it was shown for the Kains island fishing area that, (I) there was a very high correlation between the "summer" salinity and the yield in pounds the same year; and. (II) that no obvious correlation existed between the "summer" salinity during the coho's first year in the sea and the yield the following year; (III) no significant correlation was shown between the average surface temperatures of any period and yield.

The correlation shown to exist between average "summer" salinity and the yield the same year is of such magnitude that it must be accepted as being a reality, and not attributable to a chance ~~ar~~ or nonsense correlation. This correlation must be due to the variations in salinity being reflected in some manner on the coho population. Generally speaking, this influence of salinity on the population of fish may be either direct or indirect.

Direct Influence of Salinity

Directly, salinity may influence the salmon either through physical changes in the environment, or, by the physiological effects on the fish itself.

The physical changes in the environment that are concomitant with a change in salinity are primarily either a change in specific gravity, in osmotic pressure, or in viscosity. Because the salmon is a completely tolerant form, spending part of its life in fresh water, and part in salt water, it is difficult to imagine that--due to the comparatively narrow range of the salinities of the years studied--any of these factors are of more than minor importance in determining the size of the fish population, or of the size of the animals making up that population. Were the salmon spawned in the sea, and the correlation found to exist between the salinity of the brood years and the yield at some later date, the factor of specific gravity might assume considerable importance; however, at the beginning of their second year the coho are relatively large fish and not, as in the case of eggs or larvae, dependent to some degree on the relation between their specific gravity and that of their environment.

For the same reasons it is not probable that the physiological effects of the changes in average salinity observed are of sufficient magnitude to be of more than minor importance.

It is concluded, therefore, that the correlation shown is not explainable in terms of these direct influences.

Indirect Influence of Salinity

The average summer salinities that have been used are, as shown, a criterion of the amount of upwelling that has occurred in the area over the year considered, the upwelling in turn being an index of the amount of nutrient salts available for the production of plankton and, through the food chain, the amount of food available for salmon production. Thus, in a year when salinity is low there is less food available to the salmon.

Indirectly, the greater or less abundance of food may affect the coho during this period in one or both of two ways, namely through their mortality rate, or through the individual growth rates.

Mortality during Second Year in the Sea. Insofar as natural mortality in the sea is concerned, due to fluctuations in food supply, their first year in the sea must be the most critical one. During their second year, when they are larger, they should be less subject to such changes in their immediate environment as variations in food supply. They are also larger and stronger fish and consequently better able to range afield sufficiently to avoid outright starvation, except in very extreme cases. It is difficult, therefore, to postulate that natural mortality during the second year in the sea, due to fluctuating food supply, is sufficient to account for the correlation shown.

Growth Rate during Second Year in the Sea. The coho salmon has a very rapid growth rate during its second year in the sea. Fraser (17) says "... there is a greater variation in the growth of coho in the third year in proportion to the size of the fish at the beginning of the year than is the case in any other species in any year." (Third year coho are coho in their second year in the sea.)

Milne (38) has shown that during the period from May to September in 1950 the average weight of coho landed at Ucluelet, B. C., increased from three and one-half pounds in May to about eight pounds in September. He also shows that at Nanaimo, B. C., the increase was from about two and one-half pounds to almost six pounds during the same period. A similarly rapid increase in weight was shown by Van Hyning (67) for troll coho landed in Oregon. In this area there was an increase from about four and one-half pounds in May to about nine pounds in November.

The actual rate of growth during this second year varies in different year classes. Milne (38) shows that the average size of coho landed at Nanaimo in May 1950 was considerably less than that in the corresponding month in 1928, indicating that in 1950 the growth rate was slower. Van Hyning (67) shows that the growth rates of coho in their second year in the sea in Oregon was different in each of the years of 1946, 1947, 1948 and 1949. It is probable that the major factor controlling the rate of growth of these fish in any year is the availability of food, the rate being faster when there is an abundance of food and slower when it is scarce. It must be emphasized at this point that the index of relative abundance has been compiled in terms of the number of pounds of coho landed, since no figures were available on the numbers of fish landed in these years.

Of the factors considered to account for the correlation shown to exist between average summer salinity and the yield per unit effort the same year, only the last named, growth rate, is of sufficient importance to be dominant. The effect of the rate of growth, which it is suggested is more rapid in years when food is abundant (high salinity), and slower when there is a scarcity of food (low salinity), would be to cause the weights of the individual coho to be greater in years of high salinity and less in years of low salinity. The yield per unit of effort, in terms of pounds of coho landed, would also fluctuate in the same manner.

Variations in growth rate, however, are not sufficient to account completely for the wide range of yield per unit effort values between the lowest figure and the highest one. To illustrate this, let us assume that the figures in the two extreme years were the actual weights of coho caught. They were a minimum figure of 75 pounds in 1947, and a maximum of 230 pounds in 1951, and let us simplify them to 100 pounds in 1947 and 250 pounds in 1951. If growth rate alone will account for these variations, we assume that a total of twenty fish were caught in 1947, then the average weight of coho in that year was 5 pounds. If the variation between that year and 1951 is completely explainable in terms of growth rates then the average weight of the fish caught in 1951 must be 12.5 pounds. It has not been shown that such a wide variation in average weights from year to year exists in the area under study. It is known that there is a wide variation from year to year, but probably not as wide as the above figures would suggest. It is probable then that some other factor is operating concurrently with the speeded up growth rate in the years of high yield. The only factor that this could be is an increase in the numbers of fish landed in these years.

An examination of the troll fishing areas off the West coast of Vancouver island shows that the great majority of the coho landed come from a few relatively small areas. Kains island fishing area, where approximately ninety square miles are intensively fished, is one of these; another is the "Steamer Grounds", which is a larger area off the Scott island group. Between these two areas is a distance of about fifty sea miles where, except for one small area, Sea Otter Cover, little or no fishing for coho is carried out. These "fishing areas" are areas that consistently give good yields of salmon, while the remainder of the area over the continental shelf does not. There must be some difference between the localized fishing areas and the general area off the coast that cause the salmon to be available in greater numbers there. This factor is probably the greater availability of food in these areas.

Due to changes in oceanographic conditions the food supply in these areas varies from year to year. It is probable also that the amount of food available varies between different areas in the same year, due to local factors, and to variations in the offshore current systems as they affect the fishing areas.

It is suggested that two major factors determine the positive correlation shown to exist between average "summer" salinity and the poundage yield per unit effort the same year, they are:

(I) Changes in growth rate, due to a greater or less abundance of food. This causes the average weight of the coho to vary up or down in different years in the same manner as the average salinity, and this is reflected in the number of pounds of fish landed.

(II) Variations in the number of fish landed in the area in different years, due to the length of time that the fish remain in the area, and thus the period during which they are available to the fishery. It is suggested that when food is abundant the coho stay in the area for a longer time and thus are available to the fishery for a greater period.

It is postulated then, that in a year when there is a great abundance of food in an area, not only are the fish landed there of a greater average weight, but also more of them are landed; and, that the variations in these two factors in different years accounts for the correlation that has been shown to exist between yield and average salinity.

Temperature Non-correlation

No correlation of statistical significance was shown to exist between average temperature during any period in the coho's marine life and the yield of third year coho to the troll fishery. It is thought such influence as temperature might be expected to show would be primarily an indirect one, and functional only insofar as it is a criterion of the amount of upwelling that occurs.

Surface salinity is a good criterion of the intensity of upwelling in different years because it is not readily susceptible to change due to atmospheric conditions above the sea surface. Surface tempereture, however, readily changes with changes with changes in atmospheric temperature, consequently it is not a good measure of the amount of upwelling that occurs. It is suggested that it is because of this that surface temperature does not show as significant a negative correlation with yield as salinity does a positive one (negative because high temperature should indicate less upwelling, and vice versa).

SUMMARY

I. The relative abundance of coho salmon in the Kains island fishing area during the years I943 to I95I was calculated on the basis of the average catch per boat per day each year.

2. The resulting figures were compared with average surface salinity, or average surface temperature, for different periods during the life history of the coho taken in any year.

3. No correlation was shown to exist between average surface temperature and yield per unit effort. No correlation was shown between yield and the average salinity of the preceding year.

4. A very high correlation (r=0.85, p=0.00I - 0.0I) was shown to exist between the average "summer" salinity (average salinity from June to September) and the yield that same year, in pounds.

5. This correlation is explained as being due to the fact that surface salinity may be used as a measure of the abundance of food in the different years.

6. It was suggested that the abundance of food in the fishing area

influenced the coho during their last year in the sea by, (I) controlling the growth rate, and thus the average size of the fish caught, and (II), restricting or lengthening the period during which the coho in a fishing area are available to the fishery.

7. It was postulated that in a year such as 1951, which gave the highest catch on record for the Kains island area, that not only were the fish caught of a greater average weight, but also they were available to the fishery for a longer period of time, consequently more of them were also taken.

ACKNOWLEDGEMENT

The writer is greatly indebted to the Fishermen's Cooperative Association for the use of their fishing records, and in particular to Mr. G. T. Greenwell, General Manager, and Mr. A. E. Carr, Manager at Victoria. Their help has been invaluable, not only in locating the necessary records, but also in their subsequent advice and helpful information.

Numerous other individuals have given much assistance throughout the course of the work. The writer particularly wishes to thank Dr. William Cameron of the Institute of Oceanography, University of B. C., for his very valuable help and advice, and Dr. D. J. Milne of the Pacific Biological Station who provided certain necessary information. The writer's thanks are also due to Dr. W. S. Hoar, and Dr. W. A. Clemens of the Department of Zoology, University of B. C., for their ever ready help and advice throughout.

LITERATURE CITED

(1) Allen, E. J. 1909. Mackerel and sunshine. J. Mar. Biol. Assoc. U. K., 8: 394-406.

(2) Anon. 1952. Salmon trolling gear. Western Fisheries magazine 43 (4): 47-49.

(3) Arkin, H. and R. R. Colton. 1934 (4th ed.) An outline of statistical methods. Barnes and Noble, Inc., New York, 224 pp.

(4) Bullen, G. E. 1909. Plankton studies in relation to the Western mackerel fishery. J. Mar. Biol. Assoc. U. K., 8: 269-302.

(5) Carl, G. C. and W. A. Clemens. 1948. The fresh-water fishes of British Columbia. Handbook No. 5, B. C. Prov. Mus., Victoria, B. C.

(6) Carruthers, J. C. and W. C. Hodgson. 1937. Similar fluctuations in the herrings of the East Anglian autumn fishery and certain physical conditions. Rapp. Cons. Expl. Mer 105, 3 (4): 10-13.

(7) Chidester, F. E. 1922. Studies in fish migration II. The influence of salinity on the dispersal of fishes. Amer. Naturalist 56, 373-380.

(8) Clark, G. H. 1931. The California halibut (Paralichthys californicus) and an analysis of boat catches. Cal. Fish and Game 32 (16):315-322.

(9) Clark, F. N., 1939. Measures of abundance of the sardine, Sardinops caerulea, in California waters. Bull. Cal. Fish and Game, Bur. of Mar. Fish., No. 53.

(10) ———— and A. E. Daugherty. 1950. Average lunar month catches by California sardine fishermen. Bull. Cal. Fish and Game, Bur. Mar. Fish., No. 76.

(11) Clark, G. L. 1946 . Dynamics of production in a marine area. Ecol. Mono., 16: 321-337.

(12) Clemens, W. A. 1929. Pacific salmon migration: The tagging of the coho salmon on the east coast of Vancouver island in 1927 and 1928. Bull. Fish. Res. Bd. Can., No. 15.

(13) ———— and G. V. Wilby. 1949. Fishes of the Pacific coast of Canada. Bull. Fish. Res. Bd. Can., No. 68.

(14) Doe, L. A. E. 1950. Oceanographic discovery. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 84, 69-83.

(15) ———— 1951. Sea surface temperatures, 1950-51. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 88, 53-56.

(16) Edmondson, W. T. and Yvette H. Edmondson. 1947. Measurements of production in fertilized salt water. J. Mar. Res., 6 (3): 228-245.

(17) Fraser, C. McL. 1919. Growth rate in the pacific salmon. Trans. Roy. Soc. Can., series III, 13: 163-226.

(18) ——————— 1921. Further studies on the growth rate in the Pacific salmon. Contrib. Can. Biol., 1918-1920, 7-27.

(19) Fry, D. H. and E. P. Hughes. 1951. The California salmon troll fishery. Bull. Pac. Mar. Fish. Comm., No. 2, 7-42.

(20) Gharrett, J. T. and J. I. Hodges. 1951. Salmon fisheries of the coastal rivers of Oregon. Contr. Ore. Fish. Comm., No. 13, 1-31.

(21) Harvey, H. W. 1950. On the production of living matter in the sea off Plymouth. J. Mar. Biol. Assoc., U. K., 29 (I): 97-137.

(22) Heg, R. H. and J. V. Hyning. 1951. Food of the chinook and silver salmon of the Oregon coast. Res. Briefs, Fish Comm. Ore., 3 (2): 32-40.

(23) Hoar, W. S. 1951. The chum and pink salmon fisheries of British Columbia 1917-1947. Bull. Fish. Res. Bd. Can., No. 90.

(24) Hollister, H. J. 1951. Daily sea water observations along the west coast of Vancouver island. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 86, 6-11.

(25) Hubbs, C. L. 1948. Changes in the fish fauna of North America correlated with changes in ocean temperature. J. Mar. Res. 7 (3): 459-482.

(26) Igelsrud, I., R. J. Robinson and T. G. Thompson. 1936. The distribution of phosphates in the sea water of the North Pacific. Univ. Wash. Publ. Ocean., 3 (I): 1-34.

(27) Iselin, C. O'D. 1939a. The influence of vertical and lateral turbulence on the characteristics of the waters at medium depths. Woods Hole Ocean. Instit., Coll. Repr., No. 220.

(28) Johansen, A. C. 1927. On the fluctuations in the quantity of young fry among plaice and certain other species of fish, and causes of the same. Dan. Biol. Sta. Rept., 33: 1-16.

(29) Johnson, L. P. V. 1950. An introduction to applied biometrics. Burgess Publishing Co., Minneapolis 15, Minn. 165 pp.

(30) Johnson, P. O. 1950. Statistical methods in research. Prentice-Hall, Inc., New York. 377 pp.

(31) Kauffman, D. E. 1951. Research report on the Washington State offshore troll fishery. Bull. Pac. Mar. Fish. Comm., No. 2, 77-92.

(32) Kemp, S. 1938. Oceanography and the fluctuations in abundance of some marine animals. Rept. Brit. Assoc. Adv. Sci. 1938, 85-

(33) Marine Research Committee. 1950. Cal. Sardine Coop. Res. Program Rept. for 1950. Dept. of Nat. Resources, State of California, San Francisco.

(34) Marr, J. C. 1943. Age, length, and weight studies on three species of Columbia river salmon. Stanford Icthy. Bull., 2 (6): 157-197.

(35) McEwen, G. F., T. G. Thompson and R. Van Cleve. 1930. Hydrographic sections and calculated currents in the Gulf of Alaska 1927 and 1928. Rept. Inter. Fish. Comm., No. 4.

(36) McKernan, D. L., D. R. Johnson and J. I. Hodges. 1950. Some factors influencing the trends of salmon populations in Oregon. Trans. 15th N. A. Wildl. Conf., 1950, 427-449.

(37) McLeod, D. C. 1951. The seasonal variations of the temperature and salinity of the British Columbia coast. M. A. Thesis, Univ. of B. C.

(38) Milne, D. J. 1950. The difference in growth of coho salmon on the east and west coasts of Vancouver island. Fish. Res. Bd. Can. Prog. Rept. Pac., No. 85, 80-82.

(39) ———— 1951. Ocean migration of Pacific salmon with particular reference to spring and coho salmon. M.S., Fish. Res. Bd. Can. (A review presented before the committee on biological investigations, F. R. B. C., Ottawa, Jan 2, 1951.)

(40) Moulton, R. F. (ed.). 1939. The migration and conservation of salmon. Publ. Amer. Assoc. Adv. Sci., No. 8.

(41) Murphy, G. I. 1952. An analysis of silver salmon counts at the Benbow dam, south fork of Eel river, California. Cal. Fish and Game, 38 (I): 105-112.

(42) ———— and Leo Shapovalov. 1951. A preliminary analysis of northern California salmon and steelhead runs. Cal. Fish and Game 37 (4): 499-507.

(43) Neave, Ferris. 1949. Game fish populations of the Cowichan river. Bull. Fish. Res. Bd. Can., No. 84.

(44) ———— and A. L. Pritchard. 1942. What did the tagging of salmon at Skutz falls, Cowichan river, reveal? Fish. Res. Bd. Can. Prog. Rept. Pac., No. 51, 8-11.

(45) ———————— 1942. Recoveries of Cowichan river coho... emphasize the value of marking experiments. Fish. Res. Bd. Can. Prog. Rept. Pac., No. 51, 3-7.

(46) Pacific Oceanographic Group. Observation of seawater temperatures, salinity and density on the Pacific coast of Canada.

Volume	V	1942 and 1943
"	VI	1944 and 1945
"	VII	1946 and 1947
"	VIII	1948
"	IX	1949
"	X	1950

(47) Pritchard, A. L. 1934. Pacific salmon migration: the tagging of coho salmon in British Columbia in 1929 and 1930. Bull. Fish. Res. Bd. Can., No. 40.

(48) ——————— 1936. Facts concerning the coho salmon in the commercial catches of British Columbia as determined from their scales. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 29, 16-20.

(49) ——————— 1940. Studies on the age of coho salmon (Oncorrhynchus kisutch) and the spring salmon (O. tshawytscha) in British Columbia. Trans. Roy. Soc. Can., Sec. 5, 99-124.

(50) ——————— 1945. Observations on the upstream migration of coho salmon. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 62, 14-16.

(51) ——————— and A. L. Tester. 1943. Food of spring and coho salmon in British Columbia. Bull. Fish. Res. Bd. Can., No. 65.

(52) Raymont, J. E. G. 1947. A fish farming experiment in Scottish sea lochs. J. Mar. Res., 6 (3): 219-227.

(53) Ricker, W. E. 1940. Relation of "Catch per unit effort" to abundance and rate of exploitation. J. Fish. Res. Bd. Can., 5 (I): 43-70.

(54) Riley, G. A. 1942. The relationship of vertical turbulence and spring diatom flowerings. J. Mar. Res., 5 (I): 67-87.

(55) ——————— 1946. Factors controlling phytoplankton population on George's Bank. J. Mar. Res., 6 (I): 54-71.

(56) ——————— and D. F. Bumpus. 1946. Phytoplankton-Zooplankton relationships on George's Bank. J. Mar. Res., 6 (I): 33-47.

(57) Silliman, R. P. 1941. Fluctuations in the diet of the chinook (Oncorrhynchus tshawytscha) and the silver (O. kisutch) salmons of Washington, as related to the troll catch of salmon. Copeia, 2: 80-87.

(58) Sverdrup, H. U. 1938. On the process of upwelling. J. Mar. Res., I (20): 155-164.

(59) ———————, M. W. Johnson and R. H. Fleming. 1942. The oceans. Prentice-Hall, Inc., New York. 1060 pp.

(60) Thompson, T. G. and R. Van Cleve. 1930. Determination of the chlorinity of ocean waters. Rept. Inter. Fish. Comm., No. 2.

(61) Thompson, T. G., H. A. Dunlop and F. H. Bell. 1931. Biological statistics of the Pacific halibut fishery. (I) Changes in yield of a standardized unit of gear. Rept. Inter. Fish. Commm., No. 6.

(62) Thompson, T. G., G. F. McEwen and R. Van Cleve. 1936. Hydrographic sections and calculated currents in the Gulf of Alaska 1929. Rept. Inter. Fish. Comm., No. 10.

(63) Thompson, W. F. and F. H. Bell 1934. Biological statistics of the Pacific halibut fishery. (2) Effect of changes in intensity upon total yield and yield per unit of gear. Rept. Inter. Fish. Comm., No. 8.

(64) ______________ and R. Van Cleve. 1936. Life history of the Pacific halibut. (2) Distribution and early life-history. Rept. Inter. Fish. Comm., No. 9, 16, 50-61, 161-175.

(65) Tully, J. P. 1937. Why is the water along the west coast of Vancouver island so cold? Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 34, 13-15.

(66) ___________ 1950. Seasonal cycles in the sea. Fish. Res. Bd. Canada. Prog. Rept., Pacific, No. 85, 88-90.

(67) Van Hyning, J. 1951. The ocean salmon troll fishery of Oregon. Bull. Pac. Mar. Fish. Comm., No. 2, 43-76.

(68) Walford, L. A. 1946. Correlation between fluctuations in abundance of the Pacific sardine (Sardinops caerulea) and salinity of the sea water. J. Mar. Res., 6 (I): 48-53.

(69) Wigutoff, N. W. 1951. Commercial salmon trolling. Western Fisheries magazine, 42 (3): 12-15.

(70) Williamson, H. C. and W. A. Clemens. 1932. Pacific salmon migration: the tagging operations at Quatsino and Kyuquot in 1927, with additional returns from the operations of 1925 and 1926. Bull. Fish. Res. Bd. Can., No. 26.