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GENERAL SUMMARY

This general summary is designed to present in advance a concise and coherent account of the more important methods, results and conclusions of this investigation into the causes of fluctuation in the abundance of herring in British Columbia. For the general reader, it should serve to bind together the many ramifications of the investigation and to show their essential bearing on the main problem of uncovering the part played by migration, year class variations and fishing activity, the three specific potential causes of fluctuation which are under consideration.

Methods

The extent of migration and the degree of intermingling of the runs are determined by an analysis of so-called "racial" characters. The general methods are well-known and consist essentially of comparing body measurements and counts of large numbers of herring from different localities. The extent of variation in the abundance of the different year classes comprising the runs is determined by a consideration of the length and age compositions of representative portions or samples. Because of the lack of reliable and detailed catch statistics previous to 1933-34, the study of fishing activity in relation to fluctuations is confined almost wholly to the detection of any trends in length and age

composition of the stock which might be related to the intensity of fishing.

These methods of approach necessitate the collection and examination of large numbers of herring from many localities over a period of several consecutive years. The adequacy of the sampling system in portraying the various attributes of the catch and of the population is discussed. As it has been impossible to sample all regions exhaustively, attention is focused on the two most important purse seine fisheries, that on the south-east coast of Vancouver island (Saltspring island fishery) and that on the west coast of Vancouver island (Barkley sound fishery). The most complete series of samples, covering a twenty-year period (1915-16 to 1934-35) are available from the former, although there are frequent gaps in the data. All of the material from these two regions collected previous to 1931-32, including measurements, counts and scale samples, was submitted by other investigators. From 1932-32 to 1934-35 samples are available from other purse seine fisheries on the west coast of Vancouver island and the north shore of British Columbia, from gill net fisheries in the strait of Georgia, and from localities which are not fished commercially. The sampling of these runs has been less regular and less complete than those supporting the major fisheries. The location of the areas from which samples are available may be seen by reference to Figure 1.

The various measurements, counts and determinations made on samples are defined and discussed in detail. These include the following,- weight, sex, standard length, total length, head length, length to the insertion of the dorsal fin, vertebral count, keeled scale count and pectoral fin-ray count.

As all samples from northern localities are preserved in salt, conversion factors to compensate for length shrinkage and loss in weight are calculated and applied to the data.

Ages of herring are estimated from their scales without reference to the size of the fish. The reliability of the scale theory of age determination is discussed and data are presented to show that the phenomena of scale growth in the Pacific herring are similar to those of the North Atlantic herring and that the scale theory of age estimation is equally applicable in the former. The clearness or "readability" of scales is found to vary between individuals, samples, localities and seasons. Fish from northern localities have clearer scales than those from southern localities and there appears to be a gradation in "readability" with latitude. On the whole, the interpretation of the scales in British Columbia appears to be more difficult than in other regions. On re-reading scales of herring taken on the south-east coast of Vancouver island during four seasons 7.5 per cent of the estimated ages are found to differ from the original determinations. While this inherent personal error is large it should not detract from the general reliability of conclusions based on age composition. In northern localities the age estimations are much more reliable.

Migration

Before presenting conclusions regarding the extent of migration and intermingling, the reliability of each racial character is discussed and the data are analyzed as completely as is feasible to uncover the sources of variation.

The vertebral count is considered to be one of the most useful and reliable of the racial characters. It is found that during the four seasons for which data are available there is a more or less regular increase in total mean vertebral count with latitude along the coast of British Columbia from Barkley sound in the south to Pearl harbour in the north. This conforms with the

general gradation along the west coast of North America reported by other workers. It suggests that within the waters of British Columbia migration in a north-westerly or south-easterly direction is limited and that intermingling between the herring of adjacent localities is slight.

Total mean vertebral counts, however, are found to vary considerably from year to year in any one locality. Further analysis of the data shows that significant differences may occur between the mean counts of the various year classes in one locality; that there is a slight but significant increase in the mean vertebral count of a year class with age; and that there is a significant increase in mean vertebral count with increase in standard length. These factors, particularly the first, detract from the reliability of comparisons of total vertebral count in the various localities. They can be overcome to some extent by restricting comparisons to one year class and by adopting the more stringent level of statistical significance.

Knowledge of the causes of variability in mean vertebral count is of great value in interpreting the biological significance of statistically significant differences. Year class variation in mean vertebral count is shown to be largely the result of variations in temperature conditions of the water during the period in which the eggs are spawned and the vertebral column developed. A significant negative correlation, similar to that found in Alaska by other workers is established between mean vertebral counts of year broods and mean spring air temperatures during the months of March, April, May and June in the herring of northern British Columbia. In southern localities significant correlations are not obtained. However, this might be expected for, in the latter region, air temperatures are not necessarily closely correlated with water temperatures and in addition there may be a considerable spread in the times and hence temperatures

at which individual spawnings take place on the same spawning ground in one season. The cause of the increase in vertebral count with age is doubtful, although it may possibly be related to differential growth or mortality. The increase in vertebral count with length in fish of one year class and age, may be indirectly caused by either the spread in spawning times and hence temperatures of early development in one season or it may be associated with varying individual rates of development from fertilization to the formation of the vertebral column.

Statistical proof is given of the heterogeniety of the vertebral material of one year class in all localities combined, and hence of the presence of more than one distinct population of herring in the waters of the province. On the other hand tests of heterogeniety of the vertebral material of one year class in individual localities gives negative results. As a working hypothesis, it is assumed that but one population is present in each locality, but the assumption in the case of the Saltspring island population and those localities from which but a few number of samples are available must be accepted with caution. The biological significance of the statistical results are discussed at length and it is pointed out that, because of the influence of temperature on vertebral count and because of the spread in times of spawning in one locality and season, vertebral material must be essentially heterogeneous although subsequent mixing within areas bounded by narrowly-defined physiographical and geographical barriers or broadly-defined barriers imposed by the degree of migration may take place. The author's concept of a local population is defined with reference to these barriers.

Comparisons of the mean vertebral counts of the same year class in the various localities are made and many significant differences are found. Some

of the localities which are compared and which show significant differences in the mean counts of one or more year classes are as follows: Point Grey and all other localities in the strait of Georgia; Saltspring island and Granite bay, Barkley sound, Quatsino sound, Bella Bella, Jap inlet; Barkley sound and Quatsino sound, Bella Bella and Jap inlet; Sydney inlet and Kyuquot sound; Bella Bella and Sydney inlet, Nootka sound, Kyuquot sound, Quatsino sound, Jap inlet, Pearl harbour. The conclusion is drawn that the runs to most localities tend to form distinct local populations.

A comparison of abdominal vertebral counts if dound to segregate the Saltspring island fish from those of Barkley sound, populations which do not show differences in the total vertebral count of every year class.

Consistent differences in sex ratio are found between the herring of Saltspring island and those of Barkley sound. Further analysis of the material shows that, particularly in the former locality, the percentage of males in relation to females undergoes a gradual decrease with increase in age, the rate of change being greater between the younger age groups. Possible causes of this phenomenon are discussed. The difference in sex ratio between the two localities if found to be real, however, and not caused by differences in age composition.

In agreement with the results of other investigators, the rate of growth of female fish, as indicated by the mean length at each age, is found to be more rapid than that of male fish. The rates of growth of both sexes are found to be higher in point Grey herring than in those from Pender harbour. In general, the mean length at each age is found to be larger in Barkley sound as compared with Saltspring island, although the difference is not consistent at all ages in all years. Calculations of the length of the fish at the time of formation of the first annulus also show a higher value in the former locality.

Growth in areas north of Vancouver island appears to be relatively slow. This is illustrated by a comparison of the length frequency curves of female fish in thei fourth year in Barkley sound and in Jap inlet.

Head lengths have been used as a racial character by other investigators without detailed analysis. It is shown that percentage head length varies both with standard length and with age. For this reason, comparisons must be made over all length groups and at one age; otherwise, differences in percentage head length between localities will reflect mostly differences in length and age composition. When the data are analyzed in this way, consistent differences are found between point Grey herring and those from other localities in the strait of Georgia. It is shown that these differences are not caused by differences in fatness or condition of the fish.

The percentage length to the insertion of the dorsal fin is found to vary uniformly with age but not with standard length. Comparisons of the mean percentage length to the dorsal insertion at each age in herring from the various localities reveals consistent and significant differences. This character segregates the population at point Grey from those in all other localities in the strait of Georgia. It also segregates the material of Granite bay from that of Saltspring island, Barkley sound from Saltspring island, and Quatsino sound from all other localities on the west coast of Vancouver island.

Considerable difficulty is experienced in making accurate keeled scale counts. This is overcome to some extent by further standardization of the count and by omitting doubtful cases from the calculations. The mean values show a marked tendency to decrease with increase in latitude, a gradation opposite to that shown by vertebral counts. Complete analysis of the data is not attempted because of the uncertainty regarding its absolute reliability.

The pectoral fin-ray count is found not to vary uniformly with latitude nor to vary to any great extent from locality to locality. It does not appear to give any evidence of the segregation of the populations.

From a consideration of the evidence summarized above and from additional evidence derived from age composition it is concluded that intermingling of the runs to the various localities is limited in extent. Herring of the strait of Georgia, the west coast of Vancouver island, and the north shore of British Columbia are quite distinct from each other. Within these general areas, local populations are found. In the strait of Georgia the runs to point Grey, Granite bay and Saltspring island differ in many respects from each other and are classed as local populations. However, the Saltspring island run has not been shown to be distinct from that of Departure bay and Nanoose bay. On the west coast of Vancouver island, although some slight degree of intermingling may take place between the runs to adjacent localities, the populations in Barkley sound, Sydney inlet and Quatsino sound appear to be distinct units. The data on hand have not segregated the populations in Nootka sound, Esperanza inlet and Kyuquot sound. In localities to the north of Vancouver island, the Bella Bella run is separate from that of Quatsino sound to the south and Jap inlet to the north. Likewise the herring of Skidegate inlet appear to form a local population. The status of the herring in other localities cannot be established without additional data, although there is some evidence which indicates that the Pearl habrour run is not part of that to Jap inlet and Butler cove.

Although intermingling between the herring of adjacent localities is slight and migration along the coast is limited, seasonal migration of mature fish from feeding to spawning grounds may take place. As the extent of this is not known, no attempt is made to define the boundaries of local populations.

Further, there is no guarantee that occasional mixing of the runs has not taken place in the past or will not take place in the future, nor that additional sampling would not reveal the presence of two or more separate units in any of the localities studied.

The results demonstrate that the migration of herring from one fishing area to another can play at best but a minor part as a cause of annual fluctuations in abundance.

Year Class Variation

An investigation is made of the extent of variation in the length and age composition of the catch in one locality and season. Whereas successive samples from the same catch are found to be essentially similar, those from successive catches in the same locality and season are found to show significant differences. It is concluded that, because of this variation, a reliable estimate of the length and age composition of a population can be obtained only by the examination of several samples, each from a different school. Estimates of the length and age composition of a population which are based on a single large sample must be accepted with due reservation. All data on hand indicate that there is no regular change in age composition throughout the fishing season such as that which takes place in certain other herring fisheries.

Length frequency curves are found to vary slightly in shape and position from locality to locality in the same season and from season to season in the same locality. The majority of the curves have but one mode. In some localities, however, bimodal curves are encountered and the progression of these modes may be followed for three seasons. Curves such as these suggest the presence of one or more richly-represented or dominant year classes in the catch.

The contributions made by successive year classes are found to vary to some extent and dominance of a type is encountered. It is found that the age compositions in the various localities in the same season may differ considerably from each other and that the same year class does not necessarily form a dominant group in all. This is similar to conditions in Alaska but in marked contrast to those in Norway. In general, in southern localities, the richer year classes rarely persist as dominant groups in the catches for more than two years (in their third and fourth years of age), and rarely predominate over preceding and following year classes for more than three or four years (beyond their fifth and sixth years of age). In northern British Columbia the richer year classes have been found to persist as dominant groups for somewhat longer periods. However, on the whole, the contributions made by successive year classes to be alternately richly and poorly represented is noted but the sequence is not maintained consistently. The difference in the degree of dominance and persistence of the better-represented year classes in the catch between the herring of British Columbia and those of Norway, the North sea and Alaska, is attributed to (a) a smaller spread in age distribution, which is in turn related to an earlier age of maturity and a higher rate of natural mortality, and (b) more equal spawning and survival conditions from year to year.

The role of year class variation as a cause of fluctuation in abundance is discussed. As successive year classes are more uniformly represented in British Columbia as compared with other regions, fluctuations in abundance should be correspondingly less extensive. Nevertheless, it is shown that in southern British Columbia the extent of variation is sufficient to influence the catch. A method is evolved whereby the relative strengths of successive year classes may be compared. In the Saltspring island fishery, the presence of a

relatively rich year class (1931) and one of average strength (1932) is related to an increase in the yield per unit of fishing effort in 1934-35. In 1918-19 an unusual abundance of herring is reported and this is related to the advent of the relatively rich year class of 1916 to the runs. In northern British Columbia fluctuations in abundance as a result of year class variation should be more extensive than in southern British Columbia but less extensive than in Alaska.

Fishing activity

It is pointed out that in other great fisheries, including the halibut fishery of British Columbia and the herring fishery of south-eastern Alaska, the intensity of fishing activity has caused serious downward trends in the abundance of the species under exploitation and that these have been accompanied by a decline in the length and age composition of the catch. The total annual yield from the herring fishery of British Columbia is discussed. The length and age compositions of the two major fisheries are investigated in detail to determine whether or not trends in length and age composition have taken place.

Over a twenty-year period, it is found that there has been a decrease in average length, a decrease in the spread of lengths about the mean, a decrease in the relative numbers of older fish in the catches, a decrease in the range of ages and an apparent decrease in the frequency of occurrence and persistence of dominant year classes in the catch. Related to these changes, is an increase in the percentage rate of mortality between fish of successive ages. The trend has been greater in the Barkley sound fishery than in that of Saltspring island. In the former locality about fifty per cent of the catch during each season from

1929-30 to 1934-35 are found to consist of fish in their third year which have not spawned. At Sydney inlet a marked decrease in the relative numbers of older fish is found to occur in the third year of intensive fishing and this decline is associated with a scarcity of fish.

Possible causes of these changes are discussed and it is concluded that they are strongly indicative of a more or less gradual downward trend in abundance caused by fishing activity.

Economic considerations

The results of this investigation from an economic aspect are discussed briefly. It is pointed out that the herring of British Columbia is essentially a non-migratory species and that the results of intensive fishing will become manifest more rapidly than in one which is migratory. Over-fishing will result in local depletions in the areas exploited. There has been as yet no serious depletion of herring in the major fisheries although in Barkley sound poor runs have been reported in certain seasons. Curtailment of catches by marked conditions in recent years may have temporarily checked any downward trends.

It is pointed out that the most efficient exploitation of a fishery is attained when the abundance of fish remains at an approximately steady level from year to year and, at the same time, the maximum quantity of fish are removed and utilized. This is dependent on the arrival at and maintenance of a balance between rate of growth in weight and rate of mortality. By further investigation it may be possible to determine the optimum intensity of fishing that is necessary to achieve this goal. The maintenance of this optimum will be complicated by variations in the abundance of successive year classes. The administration of the fishery will also be complicated by the localisation and

varying sizes of the runs to the different fishing areas. Until such investigations are made, it seems advisable to guard against an intensity of fishing similar to that in force between 1925 and 1929 in the major fisheries.