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# Review of Literature on Herring in the Canadian Atlantic.

by

S. N. Tibbo and R. A. McKenzie

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# REVIEW OF LITERATURE ON HERRING IN THE CANADIAN ATLANTIC

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In planning for future investigations of herring and herring fisheries in the Northwest Atlantic it seems desirable to take stock of existing knowledge. The following review has been prepared with this in mind and is believed to contain references to all of the research work on herring that has been done either by Canadian Nationals or under the auspices of Canadian research organizations. All of the reports listed in the bibliography have been reviewed and the results summarized. Some of them, however, are not available for distribution and can be referred to only in the libraries of the Fisheries Research Board of Canada.

Leim (1956b) prepared a review of literature on Bay of Fundy herring which we used extensively in the preparation of the present review. Wherever it seemed appropriate we have quoted directly from Leim's (op. cit.) manuscript but to avoid excessive repetition have not so indicated in the text. The use of this manuscript has, however, made the present task far less arduous than it would otherwise have been.

This review has been organized under appropriate headings as far as possible although we have tried to keep individual author's contributions intact. This has resulted in some repetition and some misplacement of subject matter. For the most part contributions to the various aspects of herring research have been arranged in chronological order rather than on a geographic basis.

## History of the fishery

Fishing for herring in the Bay of Fundy goes back to the earliest settlement by Indians who caught herring by "torching". Weirs appear to have been introduced on the New Brunswick side of Bay about 1820. Fish were taken by gill-nets and by "torching" as well. The fishery was for larger herring than are common now. Spawning grounds at the southern end of Grand Manan were well known and were fished heavily. Perley (1852) refers to 120 vessels being congregated at Southern Head, Grand Manan, and engaged in gill-netting of spawning herring. These herring were either salted or smoked.

After their introduction about 1820, the number of herring weirs increased steadily. In 1849 there were 55 weirs at Grand Manan, Campobello and Deer Island. By 1880 there were 142 Canadian weirs in the Bay of Fundy and the increase continued until in 1933 there were 293 weirs. In recent years (1947-58) from 300 to 400 weirs (occasionally more) have been licensed annually. Records of weirs built and operated are incomplete but show an average number of about 350 each year.

The early history of herring fisheries in other parts of the Canadian area is not well documented but some of it can be inferred from the history of other fisheries that used herring for bait. The early colonists undoubtedly used some herring for food but probably used far greater quantities in the catching of cod for the salt cod export trade. United States vessels fished for herring in Canadian then 6th in importance both in quantity landed and marketed value in that area. The gear used was chiefly gill-nets, set at the surface except in the fall when some were sunk to bottom. A few trap nets were used (west of Halifax and in St. Margarets Bay) and made their best catches at night when the sea surface was rough. McKenzie (op. cit.) noted that a run of spawning herring arrived from Halifax eastward in May. Spawning runs also occurred in May and June around Sambro, St. Margarets Bay and from Halifax westward. There was also a run of autumn-spawning herring in the latter part of September. Unlike the spring spawners the autumn spawners spawned offshore in water of 6 to 15 fathoms deep and on hard bottom. The movement of autumn spawners seemed to be westward whereas spring spawners seemed to move eastward.

Tibbo (1951b) wrote "The herring fishery in Newfoundland has never attained a stable position. Many attempts have been made to establish the industry on a firmer foundation but with little success. The chief difficulties appear to be the inability to penetrate existing markets and the lack of success in developing new ones. This may be due to the fact that existing markets demand (a) "matje" herring for scotch cure, (b) immature fat herring for the fresh and frozen trade and for canned products and (c) large fat herring for kippering. Only small quantities of herring suitable for these demands are now caught in Newfoundland and the future of the fishery would be considerably brighter if these kinds of herring could be captured in quantity. The market for meal and oil is strong and further development in the spring fishery for poor quality herring to supply this demand is quite feasible. It is possible that the quality of herring would be improved by increasing the catch and thereby removing a large proportion of very old, slow-growing fish, the flesh of which is very coarse and tasteless even during the summer months. The removal or revision of restrictions on fishing dates and methods might be beneficial to the stock as a whole."

Huntsman (1953) described the movements and decline of large Quoddy herring. He noted that (beginning in 1876) the development of heavy fishing for "sardines", the yearling herring available in and near Passamaquoddy Bay between New Brunswick and Maine, was followed by decrease in numbers of older fish. The very local and very fat "Quoddy River" herring disappeared promptly. The immense accumulated stock of large spawning herring lasted ten years or more after recruitment was thus greatly reduced. This stock was being coincidently shifted from the Quoddy region, apparently owing to reduced rainfall.

The normal seasonal shifting of these fish was between the outer side of Grand Manan Island in summer and near the mainland (Charlotte and Saint John Counties) in winter. In mid-summer of 1877, their numbers at Grand Manan began to diminish and for four years remained very low. They were as abundant as ever in winter near the mainland, but farther from shore and more numerous eastward. They appeared inside the Reversing Falls of the Saint John River, whose outflow goes to Grand Manan, in all four years of their scarcity at Grand Manan. Large herring appeared in unexampled numbers at Quaco, east of Saint John, from 1878 to 1881 and then declined. A movement across the Bay to Nova Scotia became evident by a marked rise in Annapolis County in 1881, and, farther in, in Kings County in 1882, in each case lasting for four years and not going beyond the mouth of Minas Channel. These fish seemed to make the circuit of the Bay, affecting catches at its head and on to the New Brunswick side, with return to the Saint John outflow by 1884. Farther out, other lots reached the Nova Scotian coast from Digby to Cape Sable in 1881, remained high for four years and then declined. By 1891, catches everywhere were down to a very low level, indicating exhaustion of the stock.

Leim and Tibbo (1954) reported the geographic and monthly distribution of herring catches in the Canadian Atlantic from 1933 to 1945. They described the seasonal nature of the fishery in six areas and gave charts of average landings by months. The total Canadian landings from 1914 to 1950 are shown including the breakdown by sardines and large herring.

In 1943-44 Leim (1956c) conducted a survey of herring fishing methods in the Maritime Provinces, Quebec and Newfoundland. This was done mainly by interviewing fishermen, fishery officers and other interested persons. The report contains a great deal of "local" information about the herring fishery--seasons, gear, size and quality of fish, etc. No attempt at summarizing this information to provide a general picture of the herring fisheries was made.

Scattergood and Tibbo (1959) gave a general account of the history of the Northwest Atlantic fishery for herring (<u>Clupea harengus</u> L.) from aboriginal days to the present. They noted that the average catch during the last three decades had been 142,000 metric tons annually. About half of the catch is made on the Maine coast and in the Bay of Fundy. The Canadian Atlantic and the Gulf of St. Lawrence regions yield almost all of the remainder. They believed that the size of the catch seldom reflects the availability of the species in the fishing areas, and that expansion of the fishery was possible but would depend on an increased demand accompanied by a price that would make the fishery profitable. They also noted that offshore herring stocks, unfished as yet, could be harvested and that new and better types of gear should be developed to yield greater catches.

McKenzie and Tibbo (1959a, 1960) described the herring fishery in southern New Brunswick waters. They noted that most of the herring taken in the Passamaquoddy area of southern New Brunswick are caught in stationary weirs built close to shore. Analyses of weir catches show no significant relationships between average catches inside Passamaquoddy Bay and catches in outside areas for the same year. Weirs inside Passamaquoddy Bay are more efficient and catch about twice as many herring per weir as those outside the Bay.

Seasonal and annual variations both in individual weir catches and in total catches in the various statistical districts of Charlotte County are far greater now than any changes that can be forecast as resulting from the installation of the proposed Passamaquoddy tidal power dams.

<u>Spawning and larval distribution</u>

Prince (1907) described the eggs and early life-history of the herring and other clupeoids. He noted that in Canada there is a spring and fall migration of the herring, the earliest fish coming inshore as early as the month of March, or as soon as the ice disappears. The spring spawners deposit their ova in shallow water in May, while the fall spawners come in in the months of September and October, and besides containing large roes or milts are of much larger size than the earlier runs. Prince (op.cit.) first examined herring eggs in 1885 and made drawings of the ova and of the young fry when they hatched out. He described the destruction of herring spawn in Gloucester, Kent and Northumberland Counties, New Brunswick where, after severe gales, herring spawn was heaped up knee-high for many miles and then carried on to the fields for manure.

Prince (1907) described herring eggs as small translucent glossy spheres, possessing a strong hard shell-like thin transparent horn. They may cling together in spongy masses as bunches, or form a film of transparent pellets on stones, algae, shells, etc., and leave interspaces through which the water can flow freely, and thus aerate the eggs. Herring eggs are coated with a tenacious mucus, and as they fall through the water they are fertilized by the milt of the male, which beclouds the water, and on reaching the bottom, the external cement hardens so that they bunch together, or cling firmly to foreign objects. According to Prince (op. cit.) herring spawn in 10 to 20 fathoms of water on hard bottom, usually of a rough shingly or rocky nature. The number of eggs ranges from 10,000 to 30,000 or 40,000 or even 60,000 and at 53°F. they hatch out in six to eight days, while at 33° or 34°F they take thirty to forty days. He noted that the most distinctive feature of the larvae was the position of the anal opening about four-fifths of the distance along the under side of the body and very near, therefore, the basal portion of the tail. The length of newly-hatched herring larvae is 5 to 7 mm. It almost doubles its length in 10 days and by the fourth month is 29 mm long. He concluded that small herring 62 mm (2½ inches) long taken in September must have been hatched the previous autumn.

An investigation of herring spawning south of Grand Manan by Huntsman in 1917 (Huntsman, 1917a) late in September and early October showed Seal Cove to be the centre of production with only a few off Southern Head and none off Dark Harbour. Up to 61 larvae per tow were taken, ranging in length from 6 to 10 mm but some were up to 24 mm. Water temperatures were 8°C to 9°C when spawning took place. The larvae were repelled by light and did not school until about 50 mm long. However, they appeared to be contranatant by the time they were 18 mm long.

In October (Huntsman, 1917b) the young herring extended in an unbroken sheet from the south end of Grand Manan for at least 26 miles, and possibly farther, to the southwest. Strong tides in this area produce almost complete mixing of the water causing almost uniform temperatures from top to bottom even in considerable depths, thus providing suitable conditions over a wide range of time and depths.

Herring spawn found in groundfish caught in deep water together with small masses of herring eggs taken in tows in deep water, indicated spawning in deep water off southern Grand Manan. This spawning in deep water in the summer and fall was in contrast to the shallow-water, spring spawning in the Gulf of St. Lawrence. Because of the abundance of sardines in Saint John and Charlotte Counties and because of the fact that the herring numbers at the Magdalen Islands had been maintained without protection, Huntsman recommended against any closed areas off southern Grand Manan.

Huntsman (1917a) wrote "The numbers of herring larvae taken in tows (in the Bay of Fundy) which have been made at various times since 1917 have always been small in comparison with the quantities that are taken in similar tows in the Gulf of St. Lawrence. The number of larvae, 6 to 10 mm long per tow in the Bay of Fundy has rarely exceeded 100 and is usually much less than this. These larvae frequently carried some yolk. Water temperatures are 8 to 9°C when the herring spawn".

In the summer of 1917, Huntsman (op. cit.) found herring spawning to occur in the Gulf of St. Lawrence from May 6th to 26th at least and in temperatures of 8.9°C in Amherst Harbour. Water temperatures were 8.6°C in the same region on June 18th and hatching was finished. Tows on a line to Cheticamp, Cape Breton, showed the larvae to increase in number and length (5-9 mm) from Amherst Harbour to a peak just outside Entry Island (8-10 mm) then decline in numbers towards Cheticamp with large numbers still found up to 17 miles from Entry Island. The extensive shoal of larvae in the open area was 25 miles across. July collections with a metre net in this region took no larvae but a young fish trawl took specimens up to 21 mm long and chiefly at depths of 2 to 3 metres.

September collections around the Magdalens yielded but a few larvae and only outside of Entry Island. Temperatures ranged from 13.8°C to 14.8°C at the surface and 13.4°C (20 m) to 14.2°C (10 m) at depths. None were taken in Pleasant Bay and an increase in size occurred proceeding away from the Magdalens. Spawning thus occurred outside Pleasant Bay in appreciable depths, perhaps 20 m, and about the middle of August. Autumn spawning was thus quite limited in this region compared with spring spawning.

Off Cheticamp, Cape Breton, large numbers of recently-hatched herring larvae were found in the vicinity of the 30 m contour early in September. Spawning possibly occurred late in August.

Graham (1936) referring to his studies of the distribution and abundance of herring fry in the Bay of Fundy said: "at no time did we find any population of fry commensurate with the enormous numbers of sardines unless the body taken between Seal Island and Liverpool in April is considered to be sufficiently extensive. The observations, in fact, suggest that neither the Grand Manan spawning ground, nor all the spawning grounds in the Bay of Fundy considered together provide sufficient fry for the population of sardines". Graham (op. cit.) refers to small herring, 5 cm in length at Brier Island, Nova Scotia, on July 10 (1931?). Huntsman (undated ) reports that Fritz Johansen obtained herring of average length, 5.5 cm, near St. Andrews on June 11, 1917.

Fish and Johnson (1937) mapped the distribution of herring larvae in the Bay of Fundy in September, 1931, and in August, 1932. The distribution of larvae in these months indicated two distinct groups of the summer-autumn crop, one central in the Inner Bay, probably in New Brunswick waters and the other on the Nova Scotia coast near or outside the entrance. They caught large numbers of larvae (1,651 and 818) at stations off Digby and Digby Neck in mid-September, 1932. They did not get the same distribution picture in 1931 but 361 larvae were taken near Cape Spencer in September. Fish and Johnson's (op. cit.) results were also referred to by Graham (1936).

Leim (1958a) described the distribution of herring larvae in the lower Bay of Fundy and adjacent waters. The data included plankton tows over the years 1917-1955 and showed the presence of recently-hatched herring larvae in the months of September and October around southern Grand Manan and to the southwest of this towards the Maine coast and Machias Seal Island.

Tibbo et al (1958, 1959) surveyed a major portion of the Bay of Fundy and Gulf of Maine for occurrence and distribution of herring larvae. Offshore cruises with plankton nets and Hardy continuous plankton recorders were carried out from September through February in 1956-57 and 1957-58. During the two seasons 49,422 larvae were taken in plankton nets (1-metre) and 212 in recorders. In addition, 30 larvae from Prince station tows and 353 larvae from T.N. Gill cruises were available for study. The largest numbers of larvae were taken in September and October of each year. Catches decreased sharply in November and were very small in January and February. Larvae were abundant only in the Bay of Fundy and on Georges Bank. Small numbers were taken occasionally throughout most of the survey area. Newly-hatched larvae (4 to 9 mm) were found chiefly in September and October. In some seasons hatching may have extended well into November and possibly into December. Growth was slow and larvae, presumably from September and October hatchings, were found in February. About 73% of all larvae in plankton nets were taken at night. The difference between day and night catches was more pronounced for large (20 to 50 mm) larvae.

The largest spawning area in the Gulf of Maine is on the northern edge of Georges Bank. Large spawnings occur off the Nova Scotia coast from Trinity Ledges to Digby. Small spawnings occur in Penobscot Bay, on Stellwagen Bank, Nantucket shoals and south of Grand Manan. Late summer and autumn spawnings are undoubtedly the major contributors to the herring stocks in the Bay of Fundy and Gulf of Maine. Spring spawnings are of only minor importance. Larvae are found in the upper water layers and are probably carried from the spawning grounds by the non-tidal surface currents. Surface current patterns suggest that some larvae from Georges Bank spawnings are carried northward to Nova Scotia but the majority of them may be carried southward. Nova Scotia spawnings appear to be the major contributors to commercial stocks of herring in the inshore areas of Maine and New Brunswick.

Tibbo and Legaré (1960) reported on a continuation of the 1956-58 surveys for herring larvae in the Bay of Fundy and Gulf of Maine with cruises in May, October and November 1958 and in January and November 1959. Additional data were available from the waters of southwest Nova Scotia, the Passamaquoddy area and St. Mary Bay. Horizontal and vertical tows were made with 1-m and 12-in plankton nets. Hardy recorders, high speed plankton samplers and Isaacs-Kidd trawls were also used. In 3,169 tows, 1,651 herring larvae were collected. In addition, 7 larvae were taken by Hardy recorders towed over a distance of 7,078 miles. Almost 90% of the larvae were taken in October and November. They were autumn spawned and were found chiefly on the northern edge of Georges Bank and in the Bay of Fundy. Less than 1% of the larvae were taken in May and June. In June, 6 of the 7 larvae taken were almost certainly spring spawned. Larvae were more abundant on the Nova Scotia side than on the New Brunswick side of the Bay of Fundy. About 50% of the larvae collected were 6 to 10 mm in length. Less than 2% were greater than 49 mm long. The mean length of larvae increased during the period from September to February but showed a slight decrease during the spring months with the appearance of a small number of spring-spawned larvae. The mean catch of herring larvae per tow was greater at night than during the day. The night/day ratio was 4.95. Spawning sites were deduced from the location of newly-hatched larvae (6-10 mm in length). Heavy autumn spawnings occurred on the northern edge of Georges Bank and on the Lurcher Shoals.

Tibbo and Graham (1963) studied the changes in abundance of herring larvae at the western entrance to Northumberland Strait in the Gulf of St. Lawrence. Data collections were made annually during the period May to November from 1951 to 1961 inclusive. Almost all of the 157,422 larvae found in 2,945 tows were less than 20 mm in length and hence fairly recently hatched. No larvae were taken before June 15 or after September 30 in any year and very few were taken in July. From the variations in size and numbers of larvae throughout each year it was evident that in general larvae caught before July 15 were the result of spring spawnings while those caught after July 15 were the result of autumn spawnings. The greatest numbers of larvae were taken before July 15 in the years 1952, 1953 and 1955 in that order. After 1952 the numbers caught before July 15 declined irregularly to 0.2 larvae per tow in 1961. After 1956 there was some tendancy towards an increase in the numbers of larvae taken after July 15. Comparison of catches of larvae for the years 1951-53 and 1957-61 showed that the average catch of spring-hatched larvae decreased from 589.1 to 8.4 per tow whereas the average catch of autumn-hatched larvae increased from 0.03 to 4.6 per tow. While there appeared to be very little year-to-year relationship between commercial catches of spawning herring (the only available measure of abundance) and catches of larvae, it is perhaps significant that, over a fairly long period, changes in abundance of both follow the same trend.

On September 5-6, 1961, McKenzie (1963) located a small spawning ground 1.4 miles W x S Black Point near Cape St. Mary, southwest Nova Scotia in 6-7 fathoms of water by dredging with Ekman, Petersen and VanVeen dredges. Through sampling in various directions the extent and outline of the bed was determined and its total area of 725,000 square feet was calculated. These samples showed the eggs to be in a sheet of maximum thickness 1½ inches on a flat sand bottom. A few tiny flat, black stones occurred on this sandy bottom but no vegetation. Calculations based on counts of eggs in subsamples indicated that there were between 206 and 215 billion eggs on this ground. The average length of the spawners was found to be 30.7 cm. Using the formulae for the fecundity of north European herring (since no Canadian Atlantic data was available) McKenzie (op. cit.) calculated that the female spawners in this area in August and September 1961, should have had from 40 to 104 thousand eggs each. In the first case the spawning school should have consisted of about 10.5 million fish or 3,075 tons and in the second case about 4.0 million fish or 1,175 tons.

Another spawning ground was located, but not surveyed, about ¼ mile north of the Black Point ground. This ground was apparently covered with Desmarestia, for large masses of this seaweed completely permeated with herring eggs were brought up in commercial trawls.

Tibbo et. al. (1963), using free-diving (Scuba) techniques, surveyed a herring spawning ground off Blanchard Point, Chaleur Bay, N. B., in May 1962. This was a long, narrow bed running parallel with the shore in 1.3 to 6.0 m of water and occupying an area of about 375,200 sq. m. The sea bed was composed of small stones and gravel with large masses of red sandstone. In the deeper parts, the main vegetation was Phyllophora and Laminaria while in the shallower parts the vegetation was chiefly Chondrus, Fucus and Ascophyllum. The eggs were found only on this vegetation, none on the bare ground. The estimated total number of eggs was $35.46 \times 10^{11}$ and from this it was calculated that the spawning school involved consisted of 185 million fish or 24,812 metric tons. About one thousand metric tons of herring were caught in the vicinity of the survey area, representing a fishing mortality rate of 4.0%.

Hatching began about May 24 when large numbers of herring larvae 5-7 mm long were taken in plankton nets.

Population studies

The earliest natural history study of herring in the Canadian Atlantic appears to have been carried out by Johan Hjort in 1914 (Hjort, 1915). Hjort (op. cit.) believed that the most important problems were as follows: (1) do the herring that visit the Atlantic coast of Canada all belong to a single race or type or is it possible to distinguish several races in these waters, (2) does the rate of growth vary according to the conditions of the water along the coast and can types of different growths be distinguished and defined, (3) is the renewal of the stock of herring of a constant character or are there the same fluctuations in the stock as in European waters.

Hjort's material did not give any conclusive and final determinations of the racial characters of the herring types of the Atlantic coast of North America. However, it did indicate both a marked racial difference between northern and southern types and a difference between the racial characters of American and European herring. Hjort's study of age and growth resulted in distinguishing three groups or types of herring in North America waters (a) from the Atlantic coast of Nova Scotia containing oceanic herring spawning in the fall and characterized by their large size, (b) from the west coast of Newfoundland containing spring spawners and (c) from the Magdalen Islands in the Gulf of St. Lawrence also spring spawners.

Hjort's material regarding fluctuations in the abundance of year-classes of herring was inadequate for any definite conclusions although there were wide variations in the numbers of different age groups in the samples.

Lea (1919) examined material collected during the Canadian Fisheries Expedition in 1914-15 and prepared a report on the age and growth of herring in Canadian waters. He made extensive comparisons with material collected in European waters with special reference to the famous 1904 year-class which was abundant in some parts of the western Atlantic. He noted that scales offered the best means of age determination but that they should be taken from the middle part of the body. Newfoundland scale material from the Gulf of St. Lawrence presented no great difficulty in determination of ages but scales from other areas were difficult and errors in age determination occurred.

A preliminary survey of the Canadian Atlantic showed distinct marks on the scales from different localities as well as different dominant ages and hence a division of the material into four groups of samples was indicated. (a) Southwest Gulf of St. Lawrence excluding Magdalens, (b) Magdalens, (c) west coast of Newfoundland and (d) Atlantic coasts of Cape Breton, Nova Scotia, Bay of Fundy and Massachusetts.

Regarding age Lea (op. cit.) reported that in the southwest Gulf of St. Lawrence, the 1903 and 1907 year-clases were most numerous, the 1911 and 1913 were quite well represented, the 1908, 1909 and 1910 were intermediate and the 1912 was scarce. At Magdalens the 1903, 1910 and 1911 year-classes were relatively numerous but the 1907 one was scarcer than in the southwest Gulf. In the samples from Newfoundland there were many age groups from 4 to 20 but only the 1904 year-class was dominant and in this respect was totally different from the other three areas. Scale samples from the Atlantic coast were much more difficult to read than in the other three areas. The southern samples (Bay of Fundy and Massachusetts) were 2 and 3 summer zone fish. Samples from the east coast of Cape Breton were somewhat similar to those from Newfoundland. The 1903, 1904, 1908 and 1910 were fairly numerous in the Cape Breton samples whereas only the 1911 and to a lesser extent the 1910 and 19[illegible] year-classes were frequent in the southwest part of Nova Scotia. The results of studies of age- and year-class composition provided information for re-arrangement of population areas. (a) Newfoundland with one exception, (b) the Newfoundland exception plus St. George Bay and northeast Cape Breton, (c) Magdalens, Northumberland Strait and Gaspe, and (d) southwest Nova Scotia.

Lea's (1919) studies of growth showed on the whole that the samples were uniform and growth of the 1904 year-class was equal in samples from all areas. The growth of this year-class did not differ essentially from older or younger year-classes. The 9 samples from Newfoundland differed from those from the Magdalens, Northumberland Strait and the St. George Bay samples as well as the North Sydney sample which was similar to one from St. George Bay. The Newfoundland samples also differed from those of southwest Cape Breton and the outer coast of Nova Scotia, even when similar size and ages from the later area are considered. The Newfoundland fish grow slower than the others at first but catch up in later years. In comparing Magdalens with Northumberland Strait there was considerable resemblance in growth but with Atlantic coast fish there was considerable difference. Lea (op. cit.) further noted that summer growth in Canadian herring begins in the very late May or early June.

Material used for racial studies included abdominal vertebrae, number of keeled scales and number of rays on the dorsal and anal. fins. These characters were significantly different for material from (a) Newfoundland, (b) Magdalens and Northumberland Strait, and (c) Atlantic coast.

Lea's (1919) final conclusion based on studies of age, growth and meristic counts was that four distinct groups of herring could be identified and were located in (a) Newfoundland except St. George Bay, (b) the southern Gulf of St. Lawrence including Magdalens, (c) North Sydney, St. George Bay and Main-a-dieu, and (d) L'Ardoise, Port Hood and Lockeport.

The only published information on the rate of growth of Bay of Fundy herring in nature is that of Huntsman (1919). He reached tentative conclusions that spring-spawned fish reach a length of about 9 cm by the first winter and about 15 cm by the second winter. Fall-spawned schools reach a length of about 12½ cm by the second winter. Growth of about 5 cm occurs in the third season and another 4 cm is added in the fourth season. The growing period is from May to September. Huntsman's (op. cit.) conclusions were based on length-frequency observations as scales were found to be difficult to read.

MacFarland (1931a, b) in a study of Bay of Fundy herring counted vertebrae of herring from Whale Cove, Seal Cove and Navy Island. He found that the average vertebral count was lower in Navy Island herring but had only 40 specimens. Studies of fin-rays showed no evidence for racial divisions. He recognized 12 species of marine animals in the stomachs of 460 specimens. Length measurements on 6,000 fish indicated two distinct groups in June--16 cm fish at Grand Manan and 14 cm fish in Passamaquoddy Bay and he suggested that differences in the time of spawning might account for this difference in size. He also suggested (without much evidence) that there were separate and distinct groups of herring in Passamaquoddy Bay. MacFarland (op. cit.) also carried on some experimental studies. He attempted to hatch herring eggs at temperatures from 0°C to 30°C in multiples of 5°C. Development was normal when eggs were incubated for 74 hours at 10°C and 15°C. There was no development at 0°C and 5°C. At 20°C, 25°C and 30°C development began rapidly but the mortality was 100%.

MacFarland (1931a, b) indicated that the season of growth extended into the winter and that herring reach a length of 19 cm in two years. He noted, however, that the scales of Bay of Fundy herring lack well defined winter rings and are useless for age calculations. He suggested that "this condition is probably closely correlated with the abundant food supply".

Huntsman (1917a) gave some figures for the growth of herring larvae (6-8 mm long on September 19; 11-13 mm long on October 2; 17½ mm long on November 2).

McNairn (1932, 1933a,b) studied races of herring in the Bay of Fundy in 1932. He showed slight differences in the number of dorsal fin rays and keeled scales for spring herring in Kings County and in St. Mary Bay. He found fall herring in large numbers about the mouth of the Bay of Fundy or along the Nova Scotia side, while spring spawners were found in smaller quantity at the head of the Bay and at the head of St. Mary Bay. Various samples of both races (groups) were obtained and their scales compared with the object of discovering any distinguishing racial characteristics. The result was negative.

Graham (1936) carried out an investigation of the natural history of herring in the Passamaquoddy and adjacent regions of the Bay of Fundy. This investigation was part of a larger study of the effects that a proposed tidal power development might have on the fisheries of the Passamaquoddy region. Graham (op. cit.) noted that the young herring "sardine" fishery is partly dependent on extremely local conditions. The fish first appear in the catches when about 12 months old in August. They are generally segregated into shoals of similar length (within an age-group). Certain areas tend to have herring of particular sizes. The "sardine" region is poorly supplied with herring fry rather than well supplied. Turbidity of the water is the only physical factor found possibly rendering the region specially attractive to herring. Euphausiids at the surface are one of the striking features of the heart of the "sardine" region. The principal species of plankton animals (Thysanoessa, Calanus, Sagitta) behave in a manner best explained by diurnal quiescence and nocturnal activity. Large landings of "sardines" in the "sardine" region as compared with other places is partly to be explained as due to especial ease of capture in that region, but it is uncertain whether there is a larger population of fish. It is clear that the proposed dams across the mouths of Passamaquoddy and Cobscook Bays would make considerable havoc of the exceptionally rich fishery in their neighbourhood. The fishery inside the dams would almost certainly be reduced to negligible proportions, since it seems dependent on immigration. It cannot be foretold whether the total effect on capture immediately outside the dams would be deleterious or not. There appears little possibility of a wide-spread effect along the coast of Maine, or even seriously at Grand Manan.

Huntsman (1953) suggests that herring in the Passamaquoddy region probably live for 10 to 12 years.

What was perhaps the most extensive study of the natural history of herring in the Canadian Atlantic was carried out under the auspices of the Atlantic Herring Investigation Committee from 1944 to 1949. Preliminary reports on the results of these investigations are contained in the following manuscripts: Day and Tibbo (1947), Tibbo and Day (1948), Tibbo (1949a), Day (1954a,b), Day and Tibbo (1954a), Tibbo (1954e, f, g, h) and Tibbo and Day (1954). The published results are contained in the following papers: Tibbo (1949b), Tibbo (1950c), Day (1957a, b, c), Leim (1957a) and Tibbo (1957b, c, d).

Tibbo (1949b) obtained some 149 samples of herring from 16 localities in the Gulf of St. Lawrence and contiguous areas. These samples included 28,218 length measurements, 7,769 scales for age determination and 7,467 vertebral counts. He concluded that there were 6 more or less distinct groups of herring which could be identified on the basis of size, age, growth, year-class composition and mean vertebral counts. They were located in (a) the estuary of the St. Lawrence, (b) the Gaspe shore and Chaleur Bay, (c) the southern Gulf, (d) the west coast of Newfoundland, (e) the south coast of Newfoundland and (f) the southwest coast of Nova Scotia. Additional samples obtained in 1949 (Tibbo, 1950c) confirmed the results of earlier work.

Day (1957a) described the populations of herring in the northern Gulf of St. Lawrence. He compared growth and vertebral counts and concluded that two or more spring-spawning populations contributed to the commercial herring fisheries in the estuary and the northern part of the Gulf of St. Lawrence in 1946, 1947 and 1948. Herring samples from Seven Islands and Ile Verte could have been drawn from one homogeneous population, while those from Matane, Fox River and Havre St. Pierre differed from these and were indistinguishable among themselves. Mean vertebral counts varied inversely while rates of growth varied directly as the typical summer surface water temperature.

Accumulations of large, old spawning fish in the spring fisheries particularly, and lack of a fishery for fat, recovered, spent herring in the summer and fall months indicated that the herring fisheries have a potential for further development.

Tibbo (1957b) described the herring of the Chaleur Bay area. He stated that although catches of herring in Chaleur Bay approximate 20 million lb annually there is evidence that landings could be increased. The present fishery is chiefly for large and old fish. In Gloucester and Bonaventure Counties, where 74% of landings are made the average lengths are from 28.2 to 34.7 cm and average ages from 5.0 to 8.8 years. Growth is rapid and practically all herring in commercial catches are mature at the end of their fourth year when they are from 23 to 27 cm in length.

The herring taken in Bonaventure County have lower mean vertebral counts than herring in Gloucester and Gaspe Counties indicating that there are two populations of herring within the area.

In describing populations of herring in the southern Gulf of St. Lawrence, Day (1957b) wrote "comparisons of size, age, maturity and vertebral data collected in 1946, 1947 and 1948 suggest that two or more spring-spawning populations contribute to the commercial herring fisheries in the southern Gulf of St. Lawrence. Herring from Shediac and North Rustico and those from the Magdalen Islands and Cheticamp were drawn from different populations. Fall-spawning herring in the area differed from spring-spawning herring in all characteristics except vertebral numbers. Lack of any appreciable change in the size and age composition of the stocks of herring in the area since 1914 indicates that the commercial fishery had not reduced the level of abundance. Accumulations of large, old fish in the spring and fall suggest that the populations were being underfished. The greatest potential for development lay in the establishment of a summer fishery for the fat herring".

In a contribution to the biology of herring on the Atlantic coast of Nova Scotia, Tibbo (1957c) wrote "A general study is made of the length and age composition, rate of growth, sex, maturity and mean vertebral counts of herring on the Atlantic coast of Nova Scotia. Commercial catches consist chiefly of large, old herring. Average lengths are from 31.0 to 37.3 cm and average ages from 6.6 to 8.6 years. There are dominant year-classes in this area but not to the same extent as in the Gulf of St. Lawrence. The accumulations of very large and old herring indicate low mortalities. Spawning aggregations occur chiefly during the summer months and in the area west of Halifax. Mean vertebral counts are similar to those for summer spawning populations in the Gulf of St. Lawrence but the groups are distinct geographically. Vertebral count analysis suggests that there is a single, homogeneous population of herring in the area".

Day (1957c) showed that water temperatures are inversely related to vertebral number and directly related to first-year growth when compared for different areas, different year-classes and different ages of the same year-classes. These differences were considered and related to water temperature.

Tibbo (1957d) described herring populations on the south and west coasts of Newfoundland. He obtained samples of commercial catches of herring from Bay of Islands and Fortune Bay which showed that the fish in these areas are larger (34.4 to 36.1 cm) and older (10.9 to 13.0 yr) than herring from any other area on the east coast of Canada. There is little evidence of wide variations in year-class abundance although for Fortune Bay in the samples taken in 1948, the 1937 and 1944 year-classes were particularly well represented. Rates of growth are similar to the rates of growth for herring in the southern Gulf of St. Lawrence.

The herring fishery in Newfoundland is based on aggregations of prespawning fish that appear in inshore areas during the late fall and early winter. Sexual development is retarded during the winter months and spawning occurs in May and June. The fish disappear from inshore areas after spawning. Herring taken in Bay of Islands have lower mean vertebral counts (av. 55.521) than herring taken in Fortune Bay (av. 55.772), indicating that the populations in the two areas are separate and distinct.

In summarizing the results of the work of the Atlantic Herring Investigation Committee, Leim (1957a) noted that new information was secured on the distribution of the fish during the summer and fall months. Various methods of capture were tried and showed that successful purse seining was restricted to a few areas. Other methods offered wider promise. Notable progress was made in the study of populations and a good hydrographic background was established. A basis for future work was thus firmly established and was built on by subsequent investigations by the Fisheries Research Board of Canada.

Jean (1945) compared various features of herring from the estuary and the Gulf of St. Lawrence. He showed that spring spawners from the estuary of the St. Lawrence had smaller heads than spring spawners from Chaleur Bay. He related this difference to difference in water temperatures in the two areas.

Tibbo (1956b) described populations of herring in Newfoundland waters from data obtained in 1942, 1943 and 1944. The abstract of this paper is as follows "four separate and distinct populations of herring have been identified in Newfoundland waters. They are located during spawning seasons in Bay of Islands, Fortune Bay, Placentia Bay and Notre Dame Bay. They are distinguished by differences in growth, "Diameter" of the scales at the end of the first year, and average vertebral counts, also by the length, age, and year-class composition of the spawning aggregations. The herring that are caught off the Labrador coast may be an older and more migratory part of the population that spawns in Notre Dame Bay. The number of vertebrae tends to decrease from south to north in the Newfoundland area, which is the reverse of what is found elsewhere, but temperature at spawning may increase from south to north for these populations. The present fishery is chiefly for large (32.4 to 36.4 cm) and old (7.4 to 11.9 yr) herring and it is evident that catches could be increased considerably".

Jean (1956) made a study of spring and fall spawning herring at Grande-Rivière, Bay of Chaleur, Quebec. He noted that two spawning seasons of the herring occur at Grande-Rivière, one in the spring from May 1 to June 30, the other in the fall from August 15 to September 30. The temperature of water during spawning ranges from 0.5°C to 12.9°C (mean ca. 7.5°C) in the spring and from 16.6°C to 10°C (mean ca. 12.5°C) in the fall. Hatching takes from 32 to 35 days in early spring and from 10 to 15 days in early fall. It is believed that the differential rate of growth of larvae hatched in the spring, on the one hand, and in the fall, on the other, is reflected on the scales. Scales of herring hatched in the spring have a narrow 1st growth zone. Scales of herring hatched in the fall have a wide 1st growth zone. From the scales the season of origin of 7,817 adult herring from both spring and fall spawning populations was determined and was confirmed by vertebral counts. Herring with a narrow zone on their scales, believed to have been hatched in the spring, have a high mean vertebral count. Herring with a wide zone on their scales believed to have been hatched in the fall, generally have low mean vertebral counts. Both spring and fall spawning populations of herring from Grande-Riviere are composed of approximately 52% of herring hatched in the spring and at least 8% of herring hatched in the fall. The remaining 40% are said to be of mixed origin, since no season of hatching could be ascribed to them. The identical composition of the two spawning populations is further confirmed by the fact that they have similar mean vertebral counts: 56.68 in 683 spring spawners of the 1946-47 year-class and 56.67 in 353 fall spawners of the same year-class. It is concluded that herring from Grande Riviere do not necessarily spawn at the same season as the one in which they have been hatched.

Olsen (1959) studied mesh selection in herring gill-nets in order to determine the bias that must be considered and adjusted for in age and growth studies. He found that the selection curve was fairly sharply peaked and slightly skewed to the right. Simultaneous samples of catches taken by three different mesh sizes and adjusted accordingly for the effect of mesh selection did not, in general, differ significantly in length composition over the main range of length distribution.

In a study of the herring of the south and west coasts of Newfoundland in 1957 and 1958, Olsen (1961) showed that there were no great fluctuations in relative year-class strength which indicated a fairly high survival rate from the age of recruitment to the fishery. He found that the rate of growth was higher than that found by Tibbo (1956b) but that there was no significant difference in growth rate between the south coast and the region of Bay of Islands and Port au Port Bay. Olsen's (op. cit.) study indicated an unusual spread in spawning time with probable peaks in spring, autumn and winter as compared with the period prior to 1950 when Newfoundland herring were apparently all spring spawners. He suggested that this had caused changes in the traditional pattern of distribution, which had been unfavourable for the herring fishery and may also have resulted in an actual decrease in population size.

Graham (1962) established a relationship between growth, hatching and spawning season in Canadian Atlantic herring. In this investigation otoliths were used to determine the hatching season of fish, and the amount of 1st-year growth. It was concluded confirming Jean (1956) that the season in which these fish spawn was not necessarily the same as the season in which they were hatched, and that the spawning season was influenced or determined by the rate of growth in the first year. For the majority of herring, spring hatching leads to spring spawning and autumn hatching to autumn spawning. The remaining proportions are presumably made up of fast-growing, spring-hatched fish which become autumn spawners and slow-growing, autumn-hatched fish which become spring spawners.

Das and Tibbo (1962) studied the growth of young herring in captivity. They noted that herring preferred a diet of small pieces of herring and 5-6 hundred fish were fed 500 gm twice daily. Growth averaged 0.4 cm in 42 days and 3.0 cm in 89 days. This increase in the size of herring in captivity was compared with the increase in the average size of herring caught commercially throughout the period of the laboratory experiments. Results indicated that growth in captivity was only slightly less than growth in nature.

Food and feeding of herring

Johnson (1935) undertook an investigation to determine what factors make food available to herring and for this studied the behaviour of the food and the feeding habits of herring. He collected food at the surface only under different conditions of light and at four different depths simultaneously under different light conditions. Johnson (op. cit.) found that copepods were most abundant at the surface during moonlight (moon ¾ full) and least abundant in bright sunlight. The depth distribution of copepods was related both to light and to size--juveniles of a species being closer to the surface than adults at any particular time. Regarding the feeding of herring it seemed to Johnson that they undoubtedly used their eyesight and that the size of the food was a determining factor.

Battle (1935) specifically mentioned Calanus and Meganyctiphanes as food of herring and Battle et. al. (1936) listed, in addition Pseudocalanus elongatus, Acartia clausi, Eurytemora herdmani, and Tortanus discaudatus as food organisms indicating that all of them were taken by definite acts of capture.

Battle (1935) found the herring food scarcer in Passamaquoddy Bay than outside and this was associated with the poorer condition of the herring inside.

Fish and Johnson (1937) studied the distribution of plankton in the Bay of Fundy and Graham (1936) commented on the prevalence of euphausiids at the surface in this Bay. The fact that deep-water planktonic forms were found at the surface was mentioned by Huntsman (1938) as being one of the striking things about the Quoddy region and though some of the herring obtain enough food to become very fat in this area, neither the food or the herring are actually produced locally, both being carried passively into the area by the water currents.

Johnson (1940b) was the only investigator to compare the feeding of herring with water temperatures. He found that in temperatures of 8°C to 13°C they fed well but at 3.8°C and 4.5°C they ate little. In these tank experiments he found they took the feed from below, feeding where the light was best and ignoring the feed which settled to the bottom. In outdoor tanks they ate throughout the day whether clear or cloudy and on moonlight nights but not otherwise at night.

Studying the vertical migrations of marine copepods under natural conditions of light in the Passamaquoddy region and then the stomach contents of weir and gill-net caught herring Johnson, W. H. (1942) concluded that the occurrence of different kinds and amounts of copepods in herring stomachs can be explained by (a) time of capture of fish, (b) light conditions preceding this, (c) the vertical distribution of both herring and copepods under different light conditions and the rate of digestion in the herring.

Huntsman (1952b) showed that the turbulant waters of the Bay of Fundy, rich in nutrients, flows out counter-clockwise into the Gulf of Maine where great plant and animal growth occurs. The return currents carry this food into the Bay of Fundy. This supplies food for the herring which are transported to, and concentrated in this area.

Somerville (1956) studying the food of sardines found great fluctuations in the plankton volume due mainly to the abundance of the copepod Calanus which reached a peak in June and decreased in late July and August. Plankton abundance outside was about 8 times greater than inside Passamaquoddy Bay. Small herring were found to eat small copepods, crab larvae and eggs while larger herring ate Calanus, Euphausiids and Decapods. Feeding herring were most numerous at high tide and the first hour of ebb tide and close to the Passages in contrast with the Bay proper.

Further studies by Legaré and MacLellan (1959, 1960) confirmed the reduction in plankton inside, compared to outside, Passamaquoddy Bay, and also demonstrated a slight decrease in the amounts in the Passages. There was evidence that the herring were feeding in the upper water layers with low feeding activity from March to August and active feeding from September to November. The fat content of the herring was found to be directly related to active feeding but there seemed to be no relationship between degree of feeding activity and the amount of zooplankton nor any relationship between the zooplankton volumes and the herring catch during a 10-year period.

A number of investigators have reported on attempts to keep herring alive for periods in captivity but Das and Tibbo (1962) in reporting success in this respect found that the herring fed successfully only in the largest (6 ft X 4 ft--650 gal) tank of 3 sizes used. Maintaining a clean tank and artificially illuminating it on cloudy days seemed to encourage feeding and reduce the mortality rate. Of 4 diets used, (a) mussels and cat food, (b) poultry feed pellets, (c) squid and (d) herring, tiny bits of herring were preferred to all others contrary to a preference found for squid by other investigators. Water temperatures ranged from 9.0°C to 14.3°C from June to September. During this period the fish were fed twice daily. From mid August to mid September a significant rise in water temperature occurred and there was a decrease in the intake of feed.

Digestion and fatness

Battle (1934) established the relation between clearing time and temperature showing feedy fish become clear in 8 hours at 68°F., while it required 32 hours at 43°F. In some weirs at Deer Island herring obtain enough food while in the weir to remain feedy, but this situation is unusual.

The digestive enzymes of herring were investigated by Battle (1935) also and she found that the crustacean food became completely broken down by the time it reached the pyloric sac. She also believed the acidic condition of the gastric contents was probably instrumental in the reddening of the chitinous food in the intestinal tract.

In carrying out investigations re fatness, digestion and food of Passamaquoddy sardines, Battle et. al. (1936) found the fish to be fat in every part of this region. The fish did not eat in darkness but did so in light as weak as moonlight always moving towards the light in the act of capture.

Gastric digestion required 25½ hours at 6°C and 6-7 hours at 20°C for herring 14-16 cm long.

The fattest herring were found to contain the most food and this of the larger kinds. Correlation was imperfect between fatness and total quantity of food present locally as well as the local degree of concentration of the food.

Herring were mainly in the upper water layers in summer and near the surface when the light intensity was low and good correlation was found between fatness and the quantity of food present near the surface in a particular locality.

Where herring contain much food after moonlight nights, food organisms were found to be more abundant near the surface at night than in the sunlight. Greatest concentration of food was found in the passages and near shoals where thorough water mixing occurs. Deepwater forms from the Gulf of Maine were found at the surface in the passages at the mouth of Passamaquoddy Bay at all times of day and this was correlated with the presence of the fattest herring.

Leim (1943) confirmed the fatness of Campobello herring by fat determinations. Fat values for "sardines" over the area ranged from 6.1 to 20.3% of the wet weight. In general, large fish were fatter than the smaller ones within the same sample. While there was great variation from year-to-year, fall and winter fish were fatter than spring and early summer ones. Subsequent but unpublished determinations by Leim did not substantiate the claim that Perry Shore fish were always very poor.

Johnson, W.W. (1942) using a rapid method for fat determination (modified Gerber reagent) found a fat content of 10.5% by extraction and 10.55% by the digestion method.

Investigating the fat content of herring in the Gulf of St. Lawrence, the outer Nova Scotia coast and the south and west coasts of Newfoundland from 1944 to 1949, Leim (1954b, 1957b) found it to vary from 4.1 to 17.4% of the wet weight of the fish. This content was found to be lowest in April and May and highest in July and August. Spring spawning fish retained their fat later into the fall than the autumn spawning fish. No difference was found in the content of males and females.

Determining the fat content of Passamaquoddy region sardines by ether extraction during 1942 to 1952, Leim (1958b) found a variation of between 1.2% and 27.5% of the wet weight of the fish, lowest in April to June and highest from August to November as a rule. Significant variations occurred from year-to-year--the herring being extremely fat in the winter of 1942-43 and quite poor the following winter. Certain regions are noted for very high fatness values. Fatness increased with size until the sardines reach sexual maturity.

<u>Behaviour including migrations</u>

(a) <u>Temperature</u>. The mixing in Passamaquoddy Bay produces quite uniform water conditions from surface to bottom and the fish found in this area are those that inhabit cool water--cod and herring (Huntsman, 1931). Investigating water temperatures in this area Huntsman found that, coupled with dry summers, there was warmer water "(one to several degrees)" which reached a climax in 1930. At the same time there was a scarcity of groundfish, squid and sardines. Large schools of young pollock occurred along shore, fair catches of mackerel in a few places and dogfish were plentiful until early November. These changes in the fishery were correlated with the warmer water.

Though present in varying quantities all year few sardines are taken in winter in weirs in the general Passamaquoddy region. Huntsman (1933a) indicated that this was due to the fact that they were sluggish or "logy" at this time of year and showed by means of graphs that the catch was lowest in the 3 coldest months and highest in the 2 warmest months, concluding that the warmer the water the more active the fish and the greater the catch. Comparing water temperatures and catches in 1925 and 1926 Huntsman showed that in 1925 the water warmed up early and cooled off early compared with 1926; correspondingly the catch in 1925 began early and ended early compared to 1926. In 1927 the season was colder almost throughout than 1928 and the monthly catches were nearly all higher in 1928 than 1927. Comparing vernal warming in the various districts vs catches Huntsman (1933a) concluded that here again districts that warmed early had good spring fisheries whereas those that warmed slowly did not. The drop after May each year was attributed to the herring feeding actively and being out off the shore where food was more abundant--that is out, clear of the weirs.

Huntsman concluded in an unpublished report (undated a) that there was no sharp temperature limits for herring due to age and race variations but that below 6°C might be considered unfavourable, with 2°C decidedly so, and on the upper side 12°C as unfavourable with 16°C distinctly too warm. This corresponds with what is known of the behaviour of herring in Canadian waters, for in the shallow central part of Northumberland Strait a comparatively large fishery is limited to a period of about a month in the spring (April-May) when temperatures inshore become warm enough for spawning. Shortly after, the water from surface to bottom becomes too warm and the herring move out. By autumn they are too far away to be within reach when they congregate for autumn spawning and they do not return when the water cools suitably.

Northward and eastward in deeper, cooler more open waters, a fall fishery merges with that in the spring to bring about one continuous fishery lasting from about April to November with the heaviest fishing in the warmest months rather than spring and fall.

On the outer exposed coast of Nova Scotia, Huntsman, in the foregoing report, indicated that the season lengthens and on rounding Cape Sable it increases still more as far as Digby. However, from there to the head of the Bay of Fundy it shortens being finally restricted to the spring when fairly warm summer water develops from the surface to bottom at the head of the bay. Across from Digby in Charlotte County there is a fishery practically all year, for the water never becomes too warm or too cold for herring in the outer waters of this county. Inside Passamaquoddy Bay, however, the fishery is affected slightly by high temperature and distinctly so by low temperatures. Weirs situated well inland fish in the spring months as at the head of the Bay of Fundy and in Northumberland Strait while herring are absent generally from Passamaquoddy Bay in the coldest months.

Summarizing his information on herring and water movements Huntsman (1934) indicated that weir catches of herring were determined by temperature, feeding, light, enemies, and tidal currents but these were not believed to move herring any considerable distance. This investigator considers herring to be planktonic in behaviour with no purposeful migrations, being affected by differential movements of the water layers set up by fresh water inflow.

Preliminary studies in tanks suggest that herring on the Atlantic coast of Canada occupy almost the complete range of temperatures allowable within their range of resistance to both low and high temperature extremes (Brawn, 1959, 1960c). At the appropriate season herring have an upper lethal temperature of 19.9°C to 21.2°C according to size and can survive exposure to temperatures below -1°C, at least for a short period. Along the Canadian Atlantic coast herring have been taken in water ranging from 0°C to 18°C or practically the whole range of temperatures within which they can survive.

(b) Salinity. Experimenting on the resistance of herring to water of low salinity Brawn (1959, 1960d) found that 10 to 24 cm herring, when tested at temperatures mainly between 4°C and 8°C, could stand salinities down to 5% for 4 weeks with but low mortalities.

(c) Pressure. Brawn (1962) investigated the physical properties and hydrostatic function of the swimbladder of herring 11 to 20 cm long from Passamaquoddy Bay, N. B.

Herring assumed to have adjusted to the total pressure of 78.6 cmHg at the bottom of the holding tank had a mean sinking factor of 1003, density of 1.026 g/ml, percentage volume of swimbladder of 4.2 and relative sensitivity of the swimbladder of 0.8. Such fish had neutral buoyancy when the pressure was reduced 5.5% on the average from the pressure of adjustment. The mean excess pressure of the swimbladder gas was 1 cm Hg. Gas release through the posterior swimbladder duct occurred at a mean pressure decrease of 6% in rapidly swimming herring, at 32% in moderately swimming fish and brought the herring to within 19% of perfect adjustment to a new reduced pressure within half an hour. Herring could compensate for their increased buoyancy during pressure decrease until this was reduced by gas release. Decompression at rates up to 123 cm Hg/sec was not fatal after 16 hours at the greater pressure. No recovery of buoyancy after gas loss occurred in herring held 24 hours in running sea water even if fine air bubbles were present. Recovery occurred if these fish had access to the surface. Gas production by bacterial activity as a means of restoring buoyancy was not established. Herring responded to rapid pressure increases by swimming upwards. They could compensate for their increased density following pressure increase of 300% and survive increases of 430%. Herring from 10 to 25 feet depth at sea were positively buoyant at surface pressure when anaesthetized. Thus, in nature herring are adjusted to pressures greater than surface pressure. It is suggested that they take in air when feeding at the surface at night and slowly pass this to the swimbladder on returning to greater depths by day.

(d) Currents. Huntsman (1934) concluded that herring behaved as plankton and were shifted from place to place by superficial water movements set up by the wind. Spring freshets or heavy rains result in water of low density in the middle of Passamaquoddy Bay moving to localities of deep mixing carrying the herring to the so-called "spring weirs" irrespective of time of year. With reduction in fresh water outflow in the autumn or about 2 weeks after a heavy rain the process reverses and the herring are moved to the estuaries and big catches are usually made in the "fall weirs".

In discussing the probable effect of dams across the mouth of Passamaquoddy Bay on fisheries, Huntsman (1938) pointed out that it was incontrovertible that exceptionally great numbers of herring were in the Passamaquoddy region, that they obtained enough food to become very fat and that neither the herring or their food were produced locally but were carried in passively by the currents while the young produced south of Grand Manan were carried away. As a result it was concluded that the Bay of Fundy and the outer Quoddy region would not be any less favourable for the herring which were produced beyond the influence of local conditions. However, while the effect would not be a serious one from the dams out as far as Grand Manan or along the Maine coast it would reduce the fishery inside the dams to almost negligible proportions.

Again in 1952 Huntsman (1952b), writing on the production of life, in particular herring, in the Bay of Fundy pointed out that visual observation (herring live near the surface in summer) and various kinds of fishing showed herring to be exceptionally abundant in the Passamaquoddy region with the local point in their abundance at the entrance to this bay.

Because of their habit of keeping to the surface in summer the herring were drawn into the Bay of Fundy from the Gulf of Maine by the St. John River mixing. They were then believed to be carried from the stratified water of the outer Bay of Fundy to the mixing places just outside and in the entrances to Passamaquoddy Bay. The Coriolis force ensures slow circulation of the water into Passamaquoddy Bay through L'Etete Passage which is on the right going inward. Inside the Bay extensive mixing of the stratified water near the shore from the middle of the west or inner side to the head, takes such surface forms thitherwards and thus holds and concentrates them in Passamaquoddy Bay.

As the herring grow larger they go deeper and tend to be carried from the mixing places to the centre of the Bay and thence, in the outward movement, which from the action of the Coriolis force is through Head Harbour Passage on the right going out. The larger the herring grow, the farther out they are distributed on the whole, until as adults they are almost entirely outside Grand Manan during the summer.

Huntsman (undated b) in an unpublished report discussed rheotaxis in the capture of herring. He showed that "bar weirs" capture herring as they swim against the current. Collecting along the downstream side of a bar over which a strong flood tide current sets, they move into weirs on the upper side when a weaker current in the same direction develops in an ebb-tide eddy at the same point. This explains the location and concentration of weirs on the shores of the islands that form an archipelago across the mouth of Passamaquoddy Bay.

Brawn (1959, 1960a) observed the behaviour of herring in a cage at sea by underwater television. When lowered in the water in the cage at about 9 cm per second, the herring descended by sinking while swimming horizontally. At 39 m herring which had been lowered from the surface swam normally and responded to currents under artificial light. They rose towards the surface by swimming vertically. Herring responded to real and apparent currents greater than 3-9 cm/sec by swimming upstream at a rate in excess of the current speed until their maximum swimming speed had nearly been reached. Maximum swimming speed varied from 91 cm/sec for groups of mean length 15.2 cm to 143 cm/sec for fish 26.7 cm mean length (end of head to longer lobe of extended tail). This maximum swimming speed is the greatest speed that 50% of the fish group could maintain for 1 minute after swimming for 9 to 30 minutes at the rate shown by excited fish.

(e) <u>Light</u>. In studying the effects of light on herring movements Johnson (1940a) found the fishermen spoke of their weirs as "morning" or "evening" weirs, the light from the sun when it is low governing whether the fish enter or leave the weir, since they are attracted towards the light.

After determining the depth of the herring in the weir under different light conditions with a hydroscope by day and gill-nets set at different levels by night he summarized his results as follows: In the absence of appreciable light, i.e., moonlight, starlight, cloudy and foggy nights as well as the weak light of dawn and dusk all sizes were found within a foot of the surface. However, once the sun rises, then the higher the sun in the sky and the larger the fish the deeper they are found--e.g., at midday in June, 14-18 cm sizes were at 10 ft deep or deeper, 19-23 cm fish were deeper than 10 ft.

In experimental tanks (Johnson, 1940a) all sizes were found at the surface from time to time at night but when sunlight illuminated the entire surface they went to the bottom.

Brawn (1959, 1960b) studied the diurnal vertical movements of herring through examining echo-sounder records made from 1947 to 1958 on schools of immature herring in Passamaquoddy Bay. Because of boat depth, sound dome, etc., the records gave no information re presence of herring in the 4.3 metre surface layer and hence this zone was omitted from the calculations.

Herring schools showed diurnal vertical movements, being closer to the surface by night than day during every month of the year. From May to December the median depth varied from 9.1 m to 13.4 m by day and from 6.4 m to 7.9 m by night. From January to April the schools were deeper in the water by day with a median depth of 25.3 m to 38.4 m, though still rising towards the surface at night to a median depth of 11 m in February. No correlation was found between the mean solar radiation for the daylight hours and the median depth of herring by day in each month. Between 2°C and 4-7°C there was a significant inverse correlation between water temperature and the depth of the herring by day but as temperature increased above 7°C to 12°C there was no further decrease in median depth.

(f) Sound. Tibbo (1957a) described experiments and presented arguments to show that the use of echo sounders on boats does not affect the behaviour of herring.

Continuing the investigation of the effect of various noises on the behaviour of herring, Brawn (1959, 1960a) observed their reaction to boat noises, pumps, and engines of different types and horsepowers. Direct observations were made as well as through the use of echo sounders and underwater television. In all instances the response was obtained only when the engines started following a period of silence. Such responses were always of short duration--probably never exceeding 30 seconds after which the fish returned to their former pattern of behaviour, that is, heading into the current, feeding or just swimming slowly even though the noises continued at the same intensity. Sudden noises were thus more effective in startling herring than continuous noises or those gradually increasing in intensity as a boat approaching from a distance. There was nothing to suggest that normal behaviour patterns were disturbed by fishing activity.

(g) Migrations. Lea (1919) was able to show that herring on the Atlantic coast of Canada exhibited very striking differences from one locality with another and it was thus obvious that there were separate groups of herring which intermingled to a limited extent or not at all.

In a study of the distribution and movements of the herring of the Bay of Fundy MacFarland (1931a) wrote "The fish do not remain in one locality many days, e.g., 2-year olds come inshore early in summer and gradually move out to deeper water as the season progresses. Young fish continually appear all summer; hence fish of nearly all ages up to maturity are found in the Bay of Fundy practically all the year. Individual schools tend to separate--younger fish in shallower water and older fish in deeper water".

Tibbo (1952b) discussed the migrations of herring in the North Atlantic. Both vertical and horizontal movements were considered and he noted considerable differences between day and night drift-net catches in the Gulf of St. Lawrence and pointed out that these diurnal migrations, which often put the herring into water layers moving in different directions, may thus further their horizontal dispersion.

Of the 2,375 herring tagged internally in June 1948 at the Magdalen Islands, 1,860 were green celluloid tags and 515 were silver-plated steel. Nine of the former were recovered, 8 within a few days and 1 almost 2 years later, all locally. None of the others were recovered.

Continuing the discussion on migrations (Tibbo, 1952b) showed that there were 6 separate and distinct populations of herring on the Atlantic coast of Canada on the basis of morphological characters. Direct tagging of these was not carried out.

Most of the commercial fisheries around the Atlantic coast of Canada are based on spawning schools (except in the Bay of Fundy sardine fishery) which collect in various shore areas, spawn and disappear again. Practically all of the fishing is done within the surface layers but there is no particular relationship between the herring distribution and the surface water movements. However, there is some indication that the adult herring after spawning move for the most part in the direction of the current but later in the opposite direction, possibly in conformity with the evidence which shows a positive correlation between abundance of plankton and the quantities of herring captured.

During 1957 and 1958, 137,469 "sardine"herring ranging in mean total length from 9.9 to 20.0 cm and in age from 1 to 3 years were tagged in the southern Bay of Fundy and northwestern Gulf of Maine (McKenzie and Tibbo, 1958; McKenzie and Skud, 1958; McKenzie and Tibbo, 1959b, 1961).

Recovery of 3,582 (2.6%) of the tagging showed herring to move in and out of Passamaquoddy Bay irregularly throughout the summer and autumn with some tendency to concentrate at the head of this Bay. Outward movement reached a peak in July, considerable movement being eastward towards Point Lepreau. Herring moved into Passamaquoddy Bay from as far south as Grand Manan and as far east as Point Lepreau. Little interchange with Nova Scotia or Maine occurred. The greatest straight-line distance from points of release to recovery was 55 miles. More than half of the recaptures were within 2 miles of the tagging sites and 2/3 within 5 miles. About 28% of the recaptures were made within 1 week of tagging and 63% within 2 weeks. The average time from release to recapture was 12 days in 1957 and 17 days in 1958 while the longest time was 165 days. Drift bottles released with the tagged herring showed no apparent relationship between herring movements and surface drift.

Enemies of the herring including disease

Huntsman (1933b) referred to unusual conditions which for a year or two had allowed mackerel to invade the "sardine" area. He refers to the water movements carrying fry to and large herring away from Passamaquoddy Bay which he considers to be an important nursery area for herring. He states that the cold surface waters usually keep the mackerel away but during the previous two summers mackerel schools invaded the area. He considers that the mackerel reduced the supply of herring by eating the small ones and scattering the larger ones. However, he does not present any data for this phenomenon which is apparently speculation and fishermen's views.

Huntsman (1934) mentions silver hake, mackerel, dogfish and squid as herring enemies. Graham (1936) states that fishermen believe dogfish and silver hake keep the herring penned up in some areas.

The first detailed account of a disease of herring on the Canadian Atlantic coast was made by Cox (1916). This report covered the epidemic which occurred from mid June to mid July, 1914, in the west and north part of the Gulf of St. Lawrence (especially Chaleur Bay to Northumberland Strait) and during April in the waters surrounding Newfoundland.

A similar phenomenon occurred in 1913, but earlier in the year, and it was also learned from the fishermen "...that sixteen years before (1897-98) a similar run of diseased fish had visited the coast...".

Schools of herring crowded into very shallow water and the disease was most evident on the caudal third of the body. Cox (op. cit.) described both the macro and microscopic appearance of the diseased fish and attributed the disease to a member of the Myxosporidia which are propogated by means of spores.

In 1930-31 a serious outbreak of a disease occurred amongst herring in the Bay of Fundy. M'Gonigle (undated) examined a large female herring from Bear River and found that it was apparently affected with the disease. Alley (1930) described the progress of the disease in Passamaquoddy Bay throughout the summer of 1930 and discussed variations in the degree of infection amongst various groups of fish taken from the same and from different weirs. Alley (op. cit.) showed that the disease took a very erratic course with no tendency to increase or decrease towards the end of the summer and that large and small fish were affected to the same degree. Infection varied from 5% to 26% throughout the area and season.

Leim (1956a) reported an outbreak of disease with widespread mortality in the Gulf of St. Lawrence herring stocks in 1954 and concluded that the mortality was due to Ichthyosporidium hoferi, a parasitic fungus known to affect herring. Leim (op. cit.) examined the internal organs of herring and found that the internal organs contained white pustules on and within the muscle of the heart ventricle, and that the liver, spleen and gonads were also affected. Superficially no punctures of the skin were noted but underneath the skin whitish patches of the fungus were often found. Leim (op. cit.) further noted that the diseased herring behaved abnormally--the fish were lethargic and were swimming close to the surface in day-time. Their reaction to a dropped stone or a dipnet was slow and weak. Occasionally a fish would turn on its side; sometimes one would gulp at the surface and then slowly settle to bottom. When any of these fish were caught and the heart exposed immediately, the ventricular beat was either feeble or lacking. Mechanical stimulation elicited very little response. In some cases the auricle continued to beat.

Tibbo and Graham (1963) studied the changes that took place in the Gulf of St. Lawrence herring stocks following the disease epidemic of 1954-56. They showed that herring landings in the Chaleur Bay area of the Gulf declined from 25 million lb in 1947 to 12 million lb in 1959. This decline was attributed mainly to lower levels of abundance resulting from the disease. They compared Biological data taken in 1946-48 with similar data taken in 1960-61 and showed that although mean lengths of herring were unchanged--mean ages had decreased, growth rates had increased, fewer year-classes were represented in the commercial catches and relative abundance of autumn-hatched herring had increased. They further noted that sampling in 1961 showed some evidence of a partial return to pre-epidemic disease conditions.

Environmental studies

Huntsman (1952a) in writing of how Passamaquoddy Bay produces sardines pointed out that the rich waters of the Bay of Fundy produce abundant food in the Gulf of Maine. These waters, along with the tiny herring, are transported back into the Bay of Fundy and thence to Passamaquoddy Bay, where they are held and the fish grow to sardines. Large sardines congregate in the entrances to Passamaquoddy, feeding on deep water forms of plankton. Huntsman also indicated that the mechanism that brings the small herring to the Passamaquoddy region also keeps out the large herring, cod, pollock, mackerel, silver hake and squid.

Hachey (1957) discusses the oceanographic factors relative to the sardine fishery in the Bay of Fundy area. Considering wind effect this investigator shows that southerly winds cause a resultant movement of deeper waters out of Passamaquoddy Bay, while winds other than these cause a resultant movement of deeper waters into Passamaquoddy Bay. This feature no doubt has a bearing on fish feeding at random. In the St. Croix River wind direction is of considerable importance in distributing the surface waters around the Bay.

As the tidal amplitude in Passamaquoddy Bay increases from its low of 14 feet to the high of 28 feet, more and more water enters the Bay from outside and, if sardines are considered as plankton, more of them will be transferred into the Bay at such periods provided they are in the water layers above the threshold to the Bay. Similarly, fish within the Bay will have a greater tendency to be carried out when the amplitude is decreasing. The difference in water transported as between springs and neap tides amounts to about (28-14 X 100 X $5280^2$ = 39,029,760,000 cubic feet) 40 billion cubic feet. The tremendous upheaval in this water as it goes through the passages brings deep-living forms to the surface layers as food for the herring.

The time of tide is also important because of the vertical movements of the herring in relation to light, for example, it will determine whether or not the fish are at depths above or below the threshold to the Bay at the time of incoming tide. Similarly by governing the depth it controls their availability to the shore weirs.

Of temperature and salinity the former is probably the more important for it determines whether the fish are active or sluggish and this in turn will to some extent determine their depth. Except for the greater depths the lower temperatures of winter are possibly responsible for herring not remaining in the Bay during the winter months.

As part of the Passamaquoddy investigations, Tibbo and McKenzie (1959) carried out correlation studies to discover whether any relationships exist between seasonal or yearly yields of sardines in the Quoddy Region and various environmental factors. They were unable to establish any consistent correlation between catch and such factors as river discharge, wind speed and direction, air and sea temperatures, salinities at various depths, plankton, and cloud cover. Perhaps this was not surprising in view of the extremely variable market demand for herring in the Bay of Fundy area and the fact that weirs and bar or stop seines are only efficacious on the fringes of their distribution.

Explorations for herring

Cowie (1917) reported the results of herring fishing operations in 1916 using the steamer "Thirty-three". Drift-net fishing was carried out in George Bay in the southwest Gulf of St. Lawrence and on the open Atlantic coast from Cape Smoky to Halifax, and westward to Shelburne County. The period of operation was from early May to late August. From 9 to 55 herring nets 2½ inch stretched mesh were used and up to 8 mackerel nets. Catches up to 155 baskets of herring and 3,750 mackerel were made. Cowie's (op. cit.)

report is optimistic for the development of a drift-net fishery for both herring and mackerel. The report contains many details about size, quality and seasons for herring.

In 1920 Cowie also reported the results of drift-net fishing operations in 1918 using the steamer "Thirty-three". The results confirmed the work of 1916 in that a successful drift-net fishery could be carried on along the coast of Nova Scotia in spring and early summer. Catches of 40 to 60 bbl of herring per night were recorded. From July 6 to 20, 264 bbl were taken between Magdalen Islands and Cheticamp. In spite of this, however, Cowie (op. cit.) recommended that the use of the "Thirty-three" be discontinued as a successful fishery could only be assured by a fleet of several vessels working together--the one acting as a guide to the other in locating and keeping in touch with the moving fish.

Desbarats (1920) reported the results of drift-net fishing operations in 1919. Operations began at the end of May and ended in mid-September. They caught 17,530 lb of mackerel from May 27 to June 10 between Cape Sable and Cape Canso. From June 13 to 25, 25,795 lb of mackerel were caught between Inverness County, N. S., and Prince Edward Island. Fishing off Halifax from July 6-9 resulted in a total catch of 12 bbl of herring. In Chaleur Bay from August 8 to September 15, 184 bbl of herring and 1,500 lb of mackerel were taken.

Tibbo (1950a, b), Leim(1954a, c), Tibbo (1954a, b, c, d), Day andTibbo (1954b) and Leim et. al. (1957) described the work of the Atlantic Herring Investigation Committee in exploring for herring in the Canadian Atlantic from 1945 to 1950. This work was carried on with echo sounders and various types of fishing gear. The most massive echo-sounder recordings (Leim, 1954a) were made in the Newfoundland area in the autumn, winter and spring. Extensive recordings were also obtained in the Bay of Fundy in mid winter and in Chaleur Bay in the spring and autumn. Tibbo (1950b) described various attempts to catch herring with a mid-water trawl. No substantial landings were made although occasionally good catches were made but lost when the net burst. Leim (1954c) summarized the results of bottom-trawl fishing by the M.V. Harengus in 1948. No significant catches of herring were made. Tibbo (1950a) reported on explorations for herring in 1949 in the estuary of the St. Lawrence, the Magdalen Shallows and Sable Island Bank. Very few herring were taken in any of these areas. Only one catch of 5,000 lb or more was recorded from Sable Island Bank over a 3-month period.

Day and Tibbo (1954b) described gill-net experiments to determine: (a) the vertical distribution of herring, (b) the horizontal distribution of herring as related to water temperatures, and (c) gill-net selection. Results showed that except on two occasions all successful fishing was done within a surface layer of water which was well defined at all times and extended from 10 to 75 feet in depth. Catches were good when the surface temperature was less than 16°C. Above 16°C catches were insignificant. The experiments showed that a definite and direct relationship exists between the size of fish caught and the size mesh of gill-net used.

Tibbo (1951a) and Tibbo and Sollows (1953) described drift-net fishing experiments that were carried on from 1950 to 1952 inclusive. They found herring to be abundant in most of the southwestern portion of the Gulf of St. Lawrence throughout the period May to September. The average catch per net per night was 136 lb for nets 37½ yd long X 150 meshes deep and 300-400 lb for nets 37½ yd long X 360 meshes deep. The largest catches were associated with abundant plankton (chiefly Calanus). Best catches were made at night with relatively low temperatures. They found echo sounders to be an excellent but not infallible guide to good fishing. Fat contents of herring increased from 3.5 to 11.0% from mid May to mid June. They concluded that a drift-net fishery was economically feasible in the Gulf of St. Lawrence only if the landed value of the catch was 3 cents per lb or more. Tibbo (1956a) described drift-net experiments in the Newfoundland area in 1956. The results were insignificant.

Tibbo (1952a) described bottom-trawling experiments by the "Lil Abner" in the winter of 1952 to catch sardines in Charlotte County waters. The gear used was a ¾-35 yankee trawl with a small mesh codehd. Catches varied from 500 to 8,000 lb per tow and 50,000 lb were landed in 5 weeks.

Tibbo (1954a) described explorations for herring in the Scotian shelf area from 1950-52 using drift-nets and bottom trawls. The "Marion Crouse" made one trip (15 tows) to Emerald Bank and Sable Island Bank and caught 1,216 lb of herring and 5,200 lb of other species. The "Point Pleasant" made 9 trips (275 tows) to the Nova Scotia banks. The total catch amounted to 11,966 lb of herring and 104,225 lb of other species. Associated investigations included temperatures, food, light, weather and echo-sounder recordings.

Tibbo (1956a) and Tibbo (1959) recorded the results of drift-netting for herring along the south coast of Newfoundland. Commercial catches of herring on the south coast of Newfoundland had declined from 80 million lb in 1946 to negligible quantities in 1957. Drift-netting was carried on in 1956, 1957 and 1958 in an attempt to locate stocks of herring which supported these fisheries. During the summer months quantities of herring were taken in Fortune and Placentia Bays but were too small to be of commercial importance. However, in April, May and June good catches were made in Hermitage Bay. It was recommended that the drift-net method of fishing be extended to other areas along the south coast of Newfoundland during the late spring and early summer.

Tibbo and Brawn (1960) reported the results of explorations for herring in the Bay of Fundy and Gulf of Maine during the International Passamaquoddy Fisheries Board's investigations of 1956-59. These explorations were carried out chiefly in offshore areas of the Quoddy region but some work was done on Georges Bank and in the Kennebecasis and Long Reach sections of the Saint John River. Gear and equipment used included bottom and pelagic trawls, baited long-lines, gill-nets and echo sounders. The most significant results included the discovery of a large spawning population of herring on the northern edge of Georges Bank and the echo-sounder recordings of large schools of herring within the Quoddy region. The density of herring in a school (1 lb of herring per 5-6 cu ft of water) was calculated from purse-seine catches and frequently schools containing 50 million lb or more were recorded. The overall results suggested that the average annual catch of about 75 million lb was small as compared to the total population.

Economics

Gordon (1955) carried out a study of the economic factors in catch fluctuations for the principal commercial species of fish on the Atlantic and Pacific coasts. For Atlantic herring he concluded that approximately 68% of the variations in the annual catch was due to changes in the general level of effective demand in the economy.

Doucet (1959, 1960) reported the results of an economic survey of the herring fishery of Charlotte County, N. B., conducted in 1957 and 1958. This report contains (a) a detailed account of the capital investment and income position of the fishermen who were engaged in the herring fishery during the years 1956 and 1957; (b) some evaluation of the economic effects which the construction of hydro-electric power dams in Passamaquoddy Bay would have on the herring fishery of the area.

Except for a small complement of men employed on purse seiners, draggers and a few other modernized fishing craft, the fishing activity of Charlotte County fishermen is largely confined to in-shore operations. As a result, the primary fishing industry is not highly capitalized. Average net incomes are also low compared with those prevailing in other industries, even with those derived from a number of fisheries elsewhere in the Maritime Provinces. Incomes from the weir fishery are particularly uncertain, in view of the wide fluctuation in yearly catches and the high, rigid operating costs. In contrast with weir fishing, purse seining has proven to be an efficient method of fishing in the region, and holds considerable promise for the improvement of earnings in the herring fishery.

It is expected that the construction of the proposed power dams would add to the cost of maintaining and operating weirs in Passamaquoddy Bay, thereby reducing returns to owners and fishermen in this segment of the industry. In view of the low earnings now derived from weir fishing in certain sections of the area, it is likely that a number of weir owners would not continue to maintain their investments if the power dams were built.

General

Shanly (1919) carried out a study of the nature and sources of bacteria in the alimentary tract of herring and the variations in different species. She prepared cultures in the laboratory but made no attempt at identification. Williamson (1920) carried out a similar study in considerably greater detail and discovered six species of bacteria and a yeast in the intestines of feeding herring. She noted that the intestine was sterile when no food was present.

Almy (1926) studied the role of the proteolytic enzymes in the decomposition of herring. Much of the paper is devoted to the activity of pepsin and trypsin which were extracted from the digestive organs of the fish. The enzyme activity was studied at various temperatures up to 37°C and over a wide pH range. More pepsin and trypsin could be extracted from feedy than from non-feedy fish.

Almy (op. cit.) attributed the visible evidence of decomposition --the softening of the abdominal wall of the herring--almost solely to the action of trypsin which readily escapes from the delicate and highly congested tubules of the pyloric caecae. Bacteria play a small part in this early decomposition.

Tester (1946) compared Atlantic and Pacific herring and herring fisheries. He noted that 10-12 inch herring were common in the Atlantic as compared to 8-9½ inch herring in the Pacific. Immature fish in both areas were found to be approximately the same size. Mean vertebral counts for Atlantic herring were 55.5 (range 53-58) while those for Pacific herring were lower--51.8 (range 48-56). Pacific herring spawn chiefly within or just below the intertidal zone in the late winter and early spring whereas Atlantic herring probably spawn in deeper water in spring, summer and autumn although in certain places along the southern shore of the Gulf of St. Lawrence spawnings somewhat similar to those of the Pacific herring are known to occur. Pacific herring eggs (1.4-1.6 mm) are reportedly larger than Atlantic herring eggs (1.0-1.4 mm). The size of the catch 110,000 tons in the Atlantic in 1940 as compared with 70,000 tons in the Pacific suggests greater productivity in the Atlantic.

During the late 1920's there was a proposal to develop hydro-electric power from tidal forces by damming Passamaquoddy and Cobscook Bays. Huntsman (1928) believed that this would have a drastic effect on fisheries and recommended a full-scale investigation. Huntsman's (op. cit.) principal predicted effects included (a) sardine, clam, cod and haddock fisheries inside Passamaquoddy Bay would be wiped out, (b) sardine and pollock fisheries outside Passamaquoddy Bay would be wiped out also the sardine fishery along the whole coast, (c) the fishery for large fat herring would be greatly reduced but for spawning herring might be increased, (d) cod and haddock fisheries of the area generally would be reduced, (e) the mackerel fishery would be increased and dogfish would become more abundant, (f) lobsters would be more numerous but of smaller average size.

The investigation recommended by Huntsman (op. cit.) was carried out in the early 1930's and the results reported in the Proceedings of the North American Council on Fishery Investigations (1932a, b) and by Huntsman (1938). It was predicted that in the region outside the dams "the effect upon herring availability is likely to be considerable. Many changes in the set of tidal streams may be expected and probably every little change would have an effect on the fishery of nearby weirs. Some weirs would be made richer, some poorer. It cannot be foretold whether the total effect of disturbance of tidal streams on capture outside the dams would be deleterious or not. There appears to be little probability of the proposed dams affecting the sardine fishery along the coast of Maine or even seriously at Grand Manan." For the region inside the dams the prediction was that "the herring fishery would almost certainly be reduced to negligible proportions".

The Passamaquoddy Tidal Power Project was revived in the late 1950's and a second series of investigations was carried out. Parrish (1958) made an appraisal of the problem with respect to herring and suggested that the time was too short and the problem too formidable and fundamental for a precise assessment to be arrived at. He further suggested that all the oceanographers and biologists could attempt to do, was to put forward a comprehensive story of the most likely events in the light of known features of the biology of the herring in the area at present and the predicted changes in the environment. The investigations which were carried out from 1956 to 1959 were concerned with oceanography, biology and economics. Economic predictions were based on biological predictions which in turn were based on oceanographic predictions. The results of the various aspects of the investigations are reviewed under appropriate headings elsewhere in this manuscript. Hart and McKernan (1960) and Tibbo and Day (1960) summarized the results of the investigations including the predictions that (a) the general abundance of herring in the Bay of Fundy and the Gulf of Maine would remain unchanged, (b) although the rate at which herring accumulate inside Passamaquoddy and Cobscook Bays would be slower, there would be no reduction in overall abundance inside these Bays and (c) the predicted changes in the hydrography of the area would make it no less favourable for herring.

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