FISHERIES RESEARCH BOARD OF CANADA

MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

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Review of Literature on Bay of Fundy Herring

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This review has been prepared as an attempt to take stock of existing knowledge on the herring fishery of the Bay of Fundy. It is hoped that it will assist in planning for further investigations which are required before the herring or the fishery can be properly understood.

It is divided into four parts: I -- a summary (pp. 1-7); II -- synopses of the papers in the literature (pp. 7-58); III -- a bibliography (pp. 59-64); IV -- an index (p.65).

I. Summary

The earliest papers which have been reviewed (Perley, 1852, and Moore, 1898) contained much historical information on the Bay of Fundy herring fishery. Since 1920 a number of papers have appeared which deal with the results of investigations into various phases of the herring fishery. Some of these resulted from the investigations that were carried out under the International Passamaquoddy Fisheries Commission in 1931-32.

1. 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". Some historical picture is given by Perley (1852) and Moore (1898). Weirs appear to have been introduced on the New Brunswick side of the 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 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. Perley reported 55 weirs at Grand Manan, Campobello and Deer Island in 1849. By 1880 there were 142 Canadian weirs and 66 in United States waters. This increase continued until in 1933 there were 293 weirs in the Bay of Fundy.

Huntsman (1953) has reviewed the changes which have occurred in the Charlotte County herring fishery. With the increased utilization of small immature fish from 1879 on, a change occurred. The catches of large herring in winter dropped off about 1890 and the medium sizes, after a preliminary increase, declined also. The connection between the taking of immature fish and the disappearance of the larger ones was emphasized by Huntsman (1953). He also attributed the loss of large herring in the Passamaquoddy region to water movements carrying the large fish to the Nova Scotian side of the Bay and then from there across to the Quaco-St. Martins region. Later there was a

return of this fishery to its original location but it soon disappeared and in the twentieth century no winter fishery for large herring has been prosecuted. He presumed that the fishery for large herring died out because of lack of recruitment due to the intensive capture of the fish while immature.

2. Spawning and distribution of herring larvae

The chief spawning grounds in the Bay of Fundy are amongst the Murr Ledges and at the southern end of Grand Manan generally (Perley, 1852). Formerly, herring spawned in spring on the Nova Scotian side of the Bay at Trinity Ledge but it is maintained that this no longer occurs (Bigelow and Welsh, 1925). As herring larvae in early stages were taken in the upper Bay in August, it seems that some summer spawning may occur there. Also, herring with mature gonads were present in that area.

The numbers of herring larvae taken in tows 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 (Huntsman, undated Ms.).

Fish and Johnson (1937) mapped the distribution of herring larvae in September, 1931, and in August, 1932. They reported much higher numbers in some tows, for example, 818 and 1,651 larvae at stations off Digby and Digby Neck in mid-September, 1932. They took 361 larvae in a tow near Cape Spencer in September. These results are also referred to by Graham (1936).

Graham (1936) referring to his studies of the distribution and abundance of herring fry 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 refers to small herring, 5 cm. in length, at Brier Island, N. S., on July 10 (1931?). Huntsman (undated Ms.) reports that Frits Johansen obtained herring of average length, 5.5 cm., near St. Andrews on June 11, 1917.

3. Rate of growth of herring

The only published information on the rate of growth of Bay of Fundy herring 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.

The above information results chiefly from length-frequency observations. Scales were found to be difficult to read.

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

Huntsman (1953) suggests that herring probably live for 10 to 12 years.

4. Food of herring

The food of the herring has been given some consideration by several authors but frequently the reference has been casual. Moore (1898) mentioned rich feeding grounds on the Ripplings to which herring which had spawned in spring resorted. He also commented, referring to Passamaquoddy Bay, that herring past the "brit" stage feed chiefly at night. "The remarkable abundance of herring in the vicinity of Passamaquoddy Bay is doubtless a direct relation to the rich supply of nutritious food." No evidence was presented to support this contention.

Battle (1935) stated that the food of the herring consisted of crustaceans and chaetognaths. She mentioned Calanus and Meganyctiphanes. In a later paper, Battle et al (1936) the following food organisms were listed: Meganyctiphanes norvegica, Calanus finmarchicus, Pseudocalanus elongatus, Acartia clausi, Eurytemora herdmani, and Tortanus discaudatus.

They believed that the herring took copepods, including Calanus, by definite acts of capture. This is contrary to Moore, who thought that the herring took copepods "en masse".

They found that 69% of herring in the Channel had food in the stomach while only 11% of those on the Perry Shore did. They found food to be scarcer in Passamaquoddy Bay than outside and this is associated with poorer herring.

Fish and Johnson (1938) studied the distribution of plankton in the Bay of Fundy.

Graham (1936) commented on the prevalence of euphausiids at the surface in the Bay of Fundy. Huntsman (1938) also regarded the occurrence of deep planktonic forms at the surface as one of the striking things about the Quoddy region where the herring are. Although some of the herring obtain enough food to become very fat, neither the herring nor the

food are produced locally but are brought to the area by passive transport with the water currents.

Johnson (1940b) found that herring fed well at temperatures of 8 and 13°C. but ate little at 3.8 and 4.5°C.

5. Fatness and condition

Battle et al (1936) determined the condition factor for sardines from various sources. They noted the fatness of herring from Harbour du Loutre, Campobello, and neighbourhood, and the poor condition of fish in the Perry Shore region of Maine in Passamaquoddy Bay. Plankton tows were rich at Harbour du Loutre and poor on the Perry Shore. It was concluded that the herring remain long enough in these localities for their condition to be affected by the food supply.

Leim (1943) confirmed this fatness of herring from Campobello 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 do not substantiate the claim that Perry Shore fish are always very poor.

6. Digestion

Battle (1934) established the relation between clearing time and temperature showing that feedy fish became clear in eight hours at 68°F., while it required 32 hours at 43°F. In some weirs at Deer Island the herring can get enough food while in the weirs to remain feedy but this condition is unusual.

7. Enemies of the herring

Moore (1898) lists as enemies of the herring the cod, haddock, pollock, hake, sculpin, sea raven, flounder, dogfish, silver hake, albacore, squid, porpoise, seal, whale, gull and sea fowl. He considered that the enemies are important in determining the distribution of the herring.

Huntsman (1933) referred to unusual conditions which for a year or two have allowed the mackerel to invade the "sardine area". He considers that the mackerel have reduced the supply of herring by eating the small ones and scattering the larger ones.

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.

8. Movements of herring

Huntsman (1934, 1952, 1953) has put forward the theory that herring behave like plankton and are passively carried by water currents. On this basis, he is able to explain certain movements of herring into estuaries and even into some weirs, the concentration of "sardines" near the entrances to Passamaquoddy Bay and the movements of large herring in the Bay of Fundy prior to their disappearance in the 1880's. He makes use of the phenomena which occur when freshwater run-off mixes with the salt water. The mixed water moves away from the mixing point and deep return currents bring a replacement of the sea water which is used up in the mixing. Since run-off is variable, the strength of these currents varies and light, temperature, and probably other factors influence the depth at which the herring are and, therefore, their passive movement horizontally. He sees the explanation of the peculiar movements of the large herring between 1870 and 1885 as due to a decline in rainfall and unusually small discharge from the Saint John River. He considers that it is not just coincidence that the "sardine" area is bounded in one direction by the up-current end of the Saint John River influence and in the other direction by the seaward end of this outflow.

Winds may move surface waters and in this way affect the catches of weirs (Huntsman, 1934).

Battle et al (1936) state that the herring move more at high temperatures than at low and that they are more stationary during the feeding and growing period, June to August, than at other times.

Graham (1936) points out that the concentrations of herring are west of large rivers, the Saint John and the Penobscot; this places them in the areas where the outflows of these rivers spread. He considers that turbidity of water is a characteristic of the "sardine" area. He observes that it is very evident that extremely local conditions influence the movements and catches of herring.

9. Disease

In 1930-1931 a serious outbreak of a disease occurred amongst herring in the Bay of Fundy. It was studied first by Fish (1934) who identified the causative organism as Ichthyosporidium hoferi, one of the lower fungi. This fungus, which is also known from winter flounders and alewives, attacks visceral organs such as the heart, liver and spleen and also the lateral line musculature. In advanced cases the cysts break through the epidermis and the characteristic "pepper-spot" appearance is produced. In 1930-1931 so many fish had open sores on the sides that their use for canning was seriously curtailed.

Fish believed that the organism is a normal parasite

of the herring and that it reaches epidemic proportions only when certain unknown factors are operative. The organism is not believed to be capable of infecting warm-blooded animals.

Forster (1941) found 7.5% of inshore and 1.5% of offshore fish in the Mount Desert region to be infected. He concluded that the fungus does not elaborate a toxin since fish whose heart and liver tissues have almost disappeared continue to live for long periods.

Scattergood (1948) reviewed the fungus disease incidence in 1947 and 1948 when a mild epidemic was in evidence during part of the year. He pointed out the high incidence rate in the winter and spring months, when the water is cold, followed by low incidence by summer.

The fungus disease and its effect on herring are reviewed by Sindermann and Scattergood (1954).

Sindermann and Rosenfield (1954) report two additional diseases among sardine herring: (1) an ulcer disease, caused by a myxosporidian, Chloromyxum clupeidae. It produces large surface ulcers which ooze a white or yellowish material, and (2) a pigment spot disease, caused by a trematode, Cryptocotyle lingua. The cercariae encyst in the skin and occasionally in the underlying muscle of the herring.

The trematode infection is reported on further by Sindermann and Rosenfield (1954) who demonstrated some mortality in herring which were experimentally exposed to massive attack by cercariae of the parasite.

10. Comments

While not a part of the review of literature, the following comments are offered, after looking at the general picture of what is known about Bay of Fundy herring:

1. Much of the previous investigation has been devoted to the movements of herring and the conditions that may bring these about. There has been little comment or information on the size of the herring population in the Bay of Fundy. The quantities that are caught are known but no opinion is expressed as to what the intensity of the fishery has been. When much of the work herein reviewed was done, the echo sounder was not thought of as a "fish finder" and it is not referred to in any of the papers. With this useful tool it should be possible to improve knowledge of the abundance of the herring. Are the immature ones in the Bay of Fundy limited to the estuaries and other localities where the weirs take them and where the seiners take them? Or, are there large schools farther from land which serve as replenishment depots?

2. There has been a difference of opinion as to the source or sources of the herring in the Bay of Fundy. Some investigators have believed that this body of water is self-sufficient and that while the larvae may journey, passively, into the Gulf of Maine, they return to keep up the population in the Bay of Fundy. Graham has cast doubt on the idea that spawning in the Bay is sufficient to maintain the supply and suggests that important contributions may come from the outer Nova Scotian coast where more extensive herring spawning occurs. No adequate attempts have been made to trace the movements of the larvae outside the Bay of Fundy.

II. Synopses of papers in the literature

Almy, L. H. 1926. The role of the proteolytic enzymes in the decomposition of herring. J. Amer. Chem. Soc. 48: 2136-2146.

This was a biochemical investigation on immature or "sardine" herring to determine the cause of the decomposition of feedy fish, which makes them unacceptable for food purposes within a few hours. The investigation was conducted at the Atlantic Biological Station, St. Andrews, N. B.

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 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.

Battle, Helen I. 1934. Temperature and clearing time in the sardine. Biol. Bd. Canada, Atl. Prog. Rep. No. 11, pp. 14-16.

Describes the effect of red feed on decomposition in sardines.

Reproduces the curve of clearing time at temperatures from 43 to 68°F. (32 to 8 hours) for herring from $5\frac{1}{2}$ to $6\frac{1}{2}$ inches long.

Battle, Helen I. 1935. Digestion and digestive enzymes in the herring (Clupea harengus L.). J. Biol. Bd. Canada, 1(3): 145-157.

These observations were made during an investigation

of the clearing rates of digestive tracts at various temperatures. Almy had shown that decomposition of feedy fish is due to hypersecretion of digestive enzymes.

Describes the anatomy of the digestive tract.

Digestion of food

The food of the herring consists largely of crustacea and chaetognaths. The chitin is indigestible and is discarded.

Contrary to belief some digestion occurs in the caecum. The pyloric caecae contain oil when the fish have food and are believed to serve as organs where fat is absorbed. Herring excreta contain considerable oil.

Digestive enzymes

Pepsin has been isolated from the cardiac sac; tryptic and diastatic enzymes from the pyloric caecae.

Describes the methods used for preparing the extracts.

Measured the digestion of Meganyctiphanes by weighing at intervals; Calanus was done similarly but was weighed after being dried to constant weight.

Found that pepsin from non-feedy fish was more active than from feedy; but the pyloric caecal extract from feedy fish was more active than that from non-feedy ones (on Calanus substrate). In both cases enzyme activity rises with temperature up to 38°C. at least.

There is some amylolytic activity from most parts of the digestive tract. There is a weak lipase in the stomach and a strong one in the intestine and pyloric caecae.

The gastric extract (and also weak HCl) will dissolve scales but trypsin would not. Considers the experiments with scales to be inconclusive.

The gastric juices cause the chitin to become pink or red and perhaps earn the name "red-feed".

Battle, Helen I., A. G. Huntsman, Anne M. Jeffers, G. W. Jeffers, W. H. Johnson and N. A. McNairn. 1936. Fatness, digestion and food of Passamaquoddy young herring. J. Biol. Bd. Canada, 2(4): 401-429.

Evidence that herring remain sufficiently long in a given locality to be definitely affected by peculiar conditions occurring there, i.e., the fat herring of Cobscook Bay and Harbour du Loutre. Fatness -- as estimated by four sardine handlers -- diminishes as one goes from this area in every direction.

Considers the condition to be in harmony with the view that herring are carried by the movements of the water and they are fat or lean depending on the food available to them in the place where they are carried.

It was decided to procure facts during the season of 1933 in order to test this matter of characteristic local fatness and also to discover, if possible, the reasons for it. Full elucidation would require more time. Finally concentrated on four localities in line from Campobello Island to Oak Bay and the material from two of these is unsatisfactorily small.

Method of determining fatness

Fish were measured and weighed. Degree of fatness was determined by calculating the commonly used condition factor which is $\frac{100 \times w}{L^3}$. No allowance made for contents of alimentary tract. The season was a poor one and samples could be obtained only rarely at the times and places desired.

Results

Condition factor was found to vary in wide limits. From 0.45 to 1.02 (from tank fed specimens in January, 1934, to Calder Beach, Campobello in July, 1933, for 16 cm. total length). A fish 25 cm. long from Calder Beach, July 7, 1953, had a condition factor of 1.17; did not succeed in getting very thin fish during summer as Oak Bay reported unusually fat herring. Dark Harbour, Grand Manan and Kitty's Cove had very thin fish after confinement for a few weeks. Poor fish will soon fatten (in a few weeks) as at Harbour du Loutre.

In July, August and September, 1933, 17 samples in all were measured and weighed. Nine of these were from localities and at times which made them suitable for testing reputed local differences in fatness. Three samples from Campobello, three from Navy Island, two from Perry Shore and one from Oak Bay. Values of condition factor are plotted by sizes and months. Condition factor rises with increasing size. None had reached sexual maturity. The material considered consisted of only two year-classes (1931 and 1932).

Defines "brit" as 8 to 10 cm.; "snippers" (11 to 13 cm.); "oils" (14 to 18 cm.) and "mustards" (19 to 23 cm.). In July, order of fatness was: 1. Campobello; 2. Navy Island; and 3. Oak Bay. In 18 years' experience "feedy" fish were rare in Oak Bay but in 1933 "feedy" fish were frequently observed there.

August samples again showed Campobello fish to be very fat in comparison with others. Not much difference between Navy Island and Perry Shore but Navy Island was fatter.

September samples show a similar but less definite gradation with Campobello fish still fattest but poorer than earlier. Perry Shore again lowest.

Presents the data in tabular form also, choosing range from 15 to 20½ cm. -- adding June, 1934, figures -- when Campobello had highest condition factor but Oak Bay and St. Andrews were almost identical.

Area of greatest abundance of herring (near Little L'Etete) is not quite same as area of highest condition factor. Checks of the condition factor in July, 1933, indicate that fish from the "channel" area near Little L'Etete definitely had a lower condition factor than those of Campobello.

Feeding

Feeding was studied experimentally to provide a background for understanding feeding in nature. Nine to 20 cm. fish could be transported to the laboratory and they took food on the third day. Tank water temperature 11.5 to 14.5°C. Non-living food like minced clam or mussel was readily eaten when moving only. Mysis, Gammarus and lobster (Homarus) larvae have been captured by 15 cm. herring but kept to sides and bottom of tank and were rarely seen. Hyperia galba (taken from Aurelia) floated near tank surface and were rapidly eaten.

Meganyctiphanes were not eaten so readily. It required considerable time before the herring seemed to see them and attempts to capture them were often unsuccessful. After eating a few, the herring returned to the hon-feeding parallel formation. Thinks that herring were too small for these shrimp. In the weirs only the herring above 20 cm. ate Meganyctiphanes. They took Calanus and other copepods by a definite act of capture, perhaps seeing them when the copepods were between the light source and their eyes. Experimented with different degrees of illumination. Herring were unable to feed in the dark. Fed more quickly when dim light was increased.

Moore (1898) had stated that the herring take euphausiids individually but take copepods "en masse". Bigelow and Europeans believe herring (unlike menhaden) select organisms individually.

Herring continued to feed on copepods (chiefly Calanus) in February when tank temperature was 0.75°C.

Digestion

Work designed to answer two questions: (1) better understanding of conversion of food into fat, (2) discovering the clearing time; pH determinations made possible a more exact determination of the time at which food passed from the tract and the secretion of digestive juices had ceased. Arbitrarily chose time when microscopic examination showed no chitinous debris in intestine as showing clearance of intestine.

In laboratory experiments used temperatures of 6 and 20°F.; with the latter the fish regurgitated sometimes. Has table of pH values in different parts of alimentary tract. Has curve showing relation between clearing time and temperature. Some suggestion that small fish clear less rapidly than larger at same temperature. Q_{10} of clearing time is between 2 and 3, which is within the physiological limits.

Food in the herring

Thirty-two samples examined -- they were in size groups (50 fish each, approx.). Four samples from Campobello showed food present in 67%. Meganyctiphanes norvegica, Calanus finmarchicus, Pseudocalanus elongatus and Acartia clausi formed practically the entire food. In "Channel" samples food present in 69%. Eurytemora replaced Acartia in these. Only one Perry Shore sample; only 11% contained food (Temora, Calanus and Acartia). Eight samples from Navy Island -- 53% contained food (Temora longicornis, Eurytemora herdmani, Tortanus discaudatus were chief things). Single Oak Bay sample had no food whatever.

Discussion

Oak Bay fish traditionally non-feedy; near Navy Island experience is that fish are oftenest feedy after a moonlight night. Around Fairhaven fish will not clear in 24 hours as they feed in the weirs. Similar situation near Doctor Cove (near Cummings Cove). "Shrimp" important food there. Food available near surface all day and herring take it. Fish exceptionally fat.

The herring in the water

Herring move more at high temperatures than at low; more before and after than during growing season (June to August). In Quoddy passages they may be seen or heard breaking surface any hour of day or night when conditions are suitable. All evidence points to their keeping in more superficial part of the water mass, at least during summer season. Moonlight and sunlight at sunrise and sunset may attract them. They tend to be somewhat down in water during day. They feed at or near surface in Quoddy Passages during day.

The food in the water

Standard tows and comprehensive tows; took tows from Oak Bay to Campobello. Amount taken in standard tows did not differ appreciably from Oak Bay to main Quoddy Passage. The St. Croix stations did have (1) over twice as great a concentration of small copepods, (2) half as many Sagittae, (3) about 1/100 the amount of Calanus. Least plankton off the Perry Shore.

Except for Perry Shore the tows fail to show differences that correspond to the fatness data. Campobello and Navy Island do not differ significantly in respect to quantity and concen-

trations of the food animals in the plankton. Thinks food nearer surface at Campobello and more available to herring. Meganyctiphanes, Sagitta and Calanus are regularly at surface at Campobello but not at Navy Island. Marked drop in plankton inside Little L'Etete as compared to outside.

There is clear evidence that food is generally available close to the surface in the passages, though varying greatly in amount and that the amount available is correlated with the local fatness of the herring, the fish being fatter and the near surface food more abundant at Campobello as compared with the "Channel". Also, going from the Channel into the Inner Bay, there is a very marked decrease in the availability of food at the surface, and a decrease in total quantity and concentration of the plankton just as previously shown going from the main Quoddy Passage to the Inner Bay; more plankton near surface in Navy Island area on moonlight nights than in daytime.

The facts indicate that in the neighbourhood of the shoals near Navy Island, herring could get food near the surface much more readily on moonlight nights than in sunlight, while in the unmixed water in the middle of the Inner Bay they would have difficulty in getting food even on moonlight nights.

General discussion

The herring are reported and found to be fattest in localities related to the main Quoddy passage. These are not the localities where herring are most regularly abundant, and they are, in part, localities where the herring are largest (Campobello) and in part where they are smallest (Cobscook Bay). They may be described as comparatively shallow inlets or bays on the convex side of the main passage. In this passage the principal food forms (Calanus and Meganyctiphanes) for the intermediate and larger sizes of herring are apparently to be found most regularly in greatest abundance, as well as at all depths. These forms (from Gulf of Maine) are carried in by flood tide and out with the ebb which hugs the Campobello side, thereby providing that side with good herring food. Waters around Deer Island are not so favourably situated for food and have more herring which are less fat.

A very important element in this region of the Quoddy Passages between the Inner and Outer Bays would be the occurrence of Meganyctiphanes and Calanus near the surface where the herring keep and are able to see and capture them throughout the long summer day as well as on moonlight nights. While the herring requires light of the intensity of moonlight or better to see its food, both Calanus and Meganyctiphanes are of deep water habit, for the most part avoiding so much light. They require, therefore, to be brought near the surface if they are to serve at all extensively as food for herring.

The comparative scarcity of food in the Inner Bay and St. Croix Estuary is associated with the poorer herring. The principal food available inside consists of the endemic small copepods suitable only for small herring.

It has been sufficiently demonstrated that to a fair extent the young herring in various localities of this region exhibit characteristic degrees of fatness and this in correlation with the local feeding conditions, which are neither the local production nor the local amount of food, but its availability to the herring. To show the effect of local conditions the herring must remain a fair length of time in the particular locality. By report, it takes a matter of weeks for herring to become lean or fat. Water temperature in important feeding season is 6 to 11°-- it takes 19 to 32 hours for full digestion at this temperature.

Bensley, B. Arthur. 1901. Report on the sardine industry in relation to Canadian herring fisheries. Contrib. Canadian Biol. (1901), pp. 59-62.

The investigation was undertaken at the request of Professor Prince to determine whether the decline of the herring fisheries of the Bay of Fundy is due to weirs. The disappearance of large herring is complained of.

Professor Prince, in 1895, had written "It is doubtful whether any fishery can withstand for long so serious a drain upon immature individuals." He questioned whether other clupeoids besides herring were included in "sardines".

While the problem seems to have been appreciated, not much was added by this investigation, which records the examination of five or six very small samples from weir catches in August (1900 ?). Quinn's weir (back of Navy Island, and still so named) caught a few large herring (11 to 14"). Ova in the females were almost mature. Other fish caught were from $4\frac{3}{4}$" up. An occasional alewife was caught as well as mackerel of 14".

Undoubtedly the bulk of the catch is Clupea harengus.

Earll, R. Edward. 1887. The herring fishery and the sardine industry. In The Fisheries Industries of the United States, Section V, Vol. 1, pp. 417-524. Section 2 -- The frozen herring industry (pp. 439-443).

Fishing grounds

Newfoundland: The principal localities for frozen herring ....are the Island of Newfoundland and the southern coast of New Brunswick. The fishery at Newfoundland is confined almost exclusively to the southern shore of the island, which is of peculiar formation, being exceedingly high and rocky and indented by numerous long and deep arms of the sea, which are frequented by large schools of herring during the winter and spring months.

The first trip of frozen herring taken to the United

States was obtained at Rose Blanche .... Cargoes have frequently been secured at other points along the shore. The principal fishing ground, however, is at Fortune Bay..... The northern shore of the Bay is peculiarly rough, rugged and barren, being composed of a series of steep, rocky peninsulas, intersected by deep, narrow bays, which are the favourite feeding and spawning grounds of the herring. Long Harbour has for several years been the principal fishing point of the region. The lower part does not freeze over and affords an opportunity for seining and netting the fish. Other harbours, including St. Jacques, Bay the North and Rencontre, were formerly important in connection with this fishery.

New Brunswick: When the frozen herring trade of New Brunswick began, the principal fishing was at Grand Manan. At certain times the principal fisheries of the region have been prosecuted from the harbours and coves along its eastern shore. Gradually, however, the fisheries of the main shore have become more important and the bulk of the catch is taken there, few, if any, of the vessels going to Grand Manan for their cargoes.

The fish arrive off the southern head of Grand Manan during July where they remain until the middle of September. Late in October other schools gradually approach the shore of the mainland in the vicinity of Campobello Island, just opposite Eastport. As the season advances the numbers increase until, in mid-winter, the waters between Eastport and Lepreau are literally filled with herring, great numbers of them entering and remaining in St. Andrews Bay until late in the spring.

The fishing begins in a small way as soon as the fish arrive, but it does not become extensive until the weather is sufficiently cool to freeze the catch. During the first of the season the bulk of the herring are usually taken in the vicinity of Deer Island and Campobello; later they are more abundant about Beaver Harbour and Point Lepreau, while in the spring the fishing is often extensive in St. Andrews Bay. This rule is not constant, however, as the fisheries of the different localities vary greatly from time to time.

Herring also occur in considerable numbers along other portions of the coast and trips have been taken at various points along the shores of Nova Scotia and Cape Breton but there is no extensive fishery in these places.

Fish, Charles J. and Martin W. Johnson. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. J. Biol. Bd. Canada, 3(3): 189-322. Herring section, pp. 258-271.

In Bay of Fundy work they secured three herring larvae in April and large numbers in August and September (Table 10); one Clupea harengus (24 mm.), Sta. 5, Nov. 11, presumably 1931; apparently about same place as "Prince" Sta. 5, and one at Sta. 6 (off Swallowtail), 21 mm., Nov. 12. Occasional specimens of Clupea in advanced stages were taken by "Nova IV" in Nova Scotian waters in December and January. Herring were taken again in August-September, 1931.

On page 265 there is a figure showing distribution of herring larvae in September, 1931, and August, 1932. Bottom of page 265 et seq. refers to spawning of C. harengus. Consider, and Graham agrees, that spring spawning adds little to the crop.

The distribution of larvae in August-September would indicate two distinct groups of the summer-autumn crop, one centred in the Inner Bay, probably in New Brunswick waters and the other on the Nova Scotia coast near or outside the entrance.

Took large numbers of herring larvae (1,651 and 818) at stations off Digby and Digby Neck in mid-September, 1932. In September, 1932, 1,651 herring (7.5 to 11 mm.) were taken off Digby. Did not get the same picture in 1931 but 361 larvae were taken near Cape Spencer in September.

Figure 30, page 270, gives distribution of herring larvae in September, 1932.

Fish, Frederic F. 1934. A fungus disease in fishes of the Gulf of Maine. Parasitology, 26: 1-16.

In 1931 an outbreak of disease was particularly noted among fishes of the Gulf of Maine. Since 1931 the disease has not re-appeared with sufficient intensity to warrant resumption of the investigation. The disease was found in herring and probably to a lesser degree in the alewife. P. americanus was found to be parasitized in localized areas where many dead sea herring were available as food. The causative organism was found to be a pathogenic fungus similar or identical with one reported from both marine and freshwater fishes of Europe and described as Ichthyosporidium (Ichthyophonus) hoferi.

He gives an historical account of fungus diseases of this type in fishes. The name Ichthyosporidium has priority over Ichthyophonus. It, or a similar organism, has been reported from trout, flounder and mackerel. He considers that the organism which Cox found in the Gulf of St. Lawrence is identical and that this was its first recorded appearance in North America.

In 1928 Miss Ellis (N.S. Inst. Sci., 17, p. 185) reported the organism from P. americanus from Passamaquoddy Bay.

Taxonomy

Ichthyosporidium was, at first, erroneously described as a protozoan but the forms referred to were unquestionably fungi. It is concluded that the parasite which we have found should be classified in the genus Ichthyosporidium as it does not differ sufficiently from the description of that genus as given by Caullery and Mesnil to warrant separate generic classification. Pending further work the species is provisionally accepted as hoferi. Its position among the fungi cannot be entirely settled at present.

Life cycle

This is not completely known. It is usually encountered in the tissues of the host in a resting stage. A spherical, heavy-walled cell, which is probably growing and preparing for division, is seen. The hyphae seldom branch extensively. The hyphae may attain a length of 20 to 25 times that of the spherical organisms. The mycelium has remarkable penetrating abilities and is not impeded by connective tissue. The hyphae eventually break up into a large number of daughter cells similar to the parent cells. In another type of division, the parent cells break up directly into the daughter cells.

Morphology

The resting stage varies from 5 to 164.5 microns in diameter. Nuclei are invisible in fresh preparations. The cells are multi-nucleate.

Macroscopic pathology

The herring is the only host of the three which are attacked by the parasite known to exhibit external evidence of the disease. The growth of the parasite in the subcutaneous and muscular tissues of the herring causes a necrosis of the tissue. A pus sac results under the skin from the accumulation of necrotic tissue. This sac may vary in size from microscopic to well over three inches in length. Within the pus sac parasites in all stages of development may be found. Eventually such a pus sac perforates the silvery layer of the intact epidermis, giving rise to the so-called black spots which are the most conspicuous external evidence of the disease. These black spots are not accumulations of pigment in the skin but merely holes which, because they reflect no light, stand out in sharp relief against the bright silvery appearance of the intact skin. When the spots are very small and very abundant the fish may be called a "pepper spot". The skin lesions are believed to be entirely secondary, arising from the spread of the infection from some centre in the internal organs.

The distribution of the internal visible lesions in the herring is almost general. Parasitic cysts are found throughout the internal organs including the heart, liver, spleen, kidneys, intestinal tract, and very rarely on the coverings of the brain and spinal cord. No parasites have been observed in the reproductive organs but few ovaries or testes have been examined.

In the flounder no parasites have been observed within the body musculature although the internal organs are infected as severely as are those of the herring. In the alewife the parasitic invasion has been confined to the heart. The macroscopic, internal lesions appear as white, spherical, usually firm masses or cysts. The viscera of the herring and the flounder may be completely riddled with these cysts, ranging

in size from microscopic to that of a small bean. In extreme infections the heart may be completely overgrown and the entire cardiac cavity completely filled with a dense, parasitic mass. The firmness of the cysts varies. They usually appear as discrete masses and at times manyof these more or less discrete cysts may be enclosed in a single capsule of host connective tissue. In advanced lesions there is a tendency for the firm cysts to disintegrate. This liquefaction of cysts is more pronounced in the herring than in the flounder.

Microscopic pathology

Microscopically the lesions are essentially similar in all organs and in all hosts. An infiltration of mononuclear cells apparently follows the ingress of a single parasite into the tissues. The tissue immediately surrounding the parasite is replaced by an epitheloid type of tissue, derived apparently from the wandering monocytes. The epitheloid cells are arranged in more or less concentric layers around the parasite and present an appearance not unlike the hard tubercle found in human tuberculosis. This tissue eventually gives way to partial or complete connective tissue replacement which is apparently the chief defence mechanism on the part of the host to prevent further spread of the parasite. Usually this mechanism fails to accomplish its purpose because the hyphal growth penetrates the connective tissue barrier. The organisms spread, much of the central tissue dies, and the parasites remain to multiply in a mass of necrotic debris. The area soon becomes large enough to be detected macroscopically as the white cysts which were described above.

Epidemiology

(a) In herring. A herring from an unknown part of the Gulf of Maine, preserved in 1926, contained the parasite. The disease was common by 1929 and reached epidemic proportions in 1930 and 1931. The average incidence of infection in all age groups of sea herring ran about 70% throughout the winter and spring of 1931. In the fall, with the arrival of larger fish from offshore, the incidence fell off to about 18%. He concludes that Ichthyosporidium hoferi is a natural parasite of the sea herring and reaches epidemic proportions only when certain unknown factors are operating. It is believed that such an epidemic, once initiated, increases in severity, reaches a peak, and subsides to a sub-patent level. The unusual scarcity of sea herring in the Gulf of Maine during the past summer indicates that a large number of fish, infected during the past few years, succumbed to the disease.

(b) In alewives. Little is known of the disease in alewives. One eighth of a lot from the Machias River were infected. There was a smaller proportion in the Pembroke River. All the lesions were confined.

(c) In flounders. Flounders may be accidental hosts. Infected flounders were only found in regions where large numbers of dead sea herring were available as food. Sixty per cent of the

flounders from Lords Cove, N. B., were infected. At Boothbay Harbour, where some diseased herring were dumped, about 10% of the flounders were infected.

Mechanics of infection

Infection of fresh sea herring hosts is probably accomplished by the ingestion of resting stages of the parasite liberated from the ruptured pus pockets of infected fish. The alewife is probably likewise infected during occasional contact with the herring in deep water. The flounder is probably infected by eating infected herring. These conclusions are not indisputable.

It was not possible to keep herring alive under laboratory conditions and demonstrate the transfer of the disease. But transfers from diseased herring to flounders were demonstrated to some extent.

The parasite has been reported alive from the faeces of gulls which were feeding on infected herring.

Experimental evidence is entirely lacking as to how the parasite penetrates the tissues of the fish. Possibly once penetration is effected, distribution is via the blood stream or the lymphatics. No parasites have been observed in a blood vessel.

He considers that the greater incidence of infection in herring is due to their being plankton feeders. Search was made for the organisms in brown trout, pollock, codfish, sculpin, smelt, hake, mackerel and squid, but without success.

The author was able to culture the parasite.

Summary and conclusions

1. A fungus disease of epidemic proportions was found in the common sea herring (Clupea harengus) throughout the Gulf of Maine.
2. The fungus was also found to infect the common winter flounder, (Pseudopleuronectes americanus) and the alewife (Pomolobus pseudoharengus).
3. The causative organism was found to be a species of fungus belonging to the genus Ichthyosporidium Caullery and Mesnil (1905). The specific name is tentatively accepted as hoferi Plehn and Muslow (1911).
4. The organism is believed to be a normal parasite to the herring and reaches epidemic proportions only when certain unknown factors are operative.
5. The causative organism was found in herring preserved in 1926, and it is believed that the epidemic has been increasing in severity since that time.
6. It is believed that such an epidemic, once initiated, increases in severity, reaches a peak, and subsides to a sub-patent level. The peak is believed to have been reached in 1931.

7. The life-history and effects of the organism in the herring and flounder are described.
8. The herring is believed to acquire the infection by the consumption of infected herring. (This seems improbable -- A. H. L.)
9. The alewife is believed to acquire the infection by ingestion of the parasite during its infrequent association with the herring.
10. The flounder is believed to acquire the infection by the consumption of infected herring.
11. Infection is believed to be established by way of the alimentary canal and, once established, to spread throughout the host by way of the blood stream or the lymphatics.
12. Direct cross-infection from the herring to the flounder establishes the theory that the parasites in these two hosts are one and the same organism.
13. Direct cross-infection experiments from the herring to the flounder eliminate the necessity of an intermediate host.
14. There is no reason to believe that this parasite is capable of infecting warm-blooded animals.

Forster, Roy P. 1941. The present status of the systemic fungus disease in herring of the Gulf of Maine. Bull. Mount Desert Island Biol. Laboratory, (1941), pp. 33-36.

Over 6,000 herring taken from the Mount Desert region were examined for disease. Average incidence of disease was 7.5% for inshore and 1.5% for offshore fish. In fish from a single weir the incidence differed from 50 to 30% for different schools of fish. Alewives were similarly infected. There was no correlation between the incidence of disease in the herring and age in fish from 3 to 12 inches long.

The most frequent stage of the parasite in the herring examined was a resting stage -- usually a round multinucleate cyst, having up to several hundred nuclei and from 5 to 150 micra in diameter. Found fungus in all tissues except the brain but the greatest manifestation was in the liver, heart and lateral muscle.

Usually could see yellowish spots on the viscera but in some cases microscopic examination was necessary. In more advanced cases pus sacs, several inches long, may occur under the skin and ulcers may break through producing "pepper spot" appearance.

The host tissue reacts to the parasite by depositing epitheloid tissue and then connective tissue around the fungus. The fungus, if active, will break through and the process may be repeated over and over until yellowish, macroscopic, visceral spots are produced. The fungus does not appear to elaborate any toxin. Badly diseased fish move feebly, tending to remain stationary several feet below the surface. Much of the muscle may be replaced by fungus cysts. The heart has been observed in some cases to consist of nine parts fungus and one part cardiac

tissue and the liver may be almost totally destroyed. Yet the fish may remain alive, the heart beating feebly, and the fish swimming slowly. This would probably not happen if a toxin was present. The white blood corpuscle count is greatly increased -- perhaps fifty-fold.

He cultivated the fungus in four media. Describes the growth pattern in culture media. Considers the fungus to be one of the Archimycetes, resembling the family Chytridiales, several of which are parasites on freshwater and marine algae. Refers to widespread occurrence in western Atlantic in 1898, 1914 and 1930 and suggests a 16-year cycle.

Graham, Michael. 1936. Investigations of the herring of Passamaquoddy and adjacent regions. J. Biol. Bd. Canada, 2 (2): 95-140.

Narrative

September, 1931, to November, 1932, was occupied with field observations. Vessel "Nova IV" made 323 hauls from December 11 to June 29. Used Petersen net obliquely at three levels; metre net also obliquely; another metre net which was only about 30" in diameter; half-metre nets were also used.

The sardine fishery

The fishery is concentrated in Charlotte and Washington Counties and other high points are Knox to Cumberland Counties in Maine. Both general areas are west of large rivers -- the Saint John and Penobscot. This appears to be relevant to an important problem raised and discussed by Huntsman and Hachey (J. Biol. Bd. Canada, 1 (2), 1934).

The herring fishery of Charlotte County is of two kinds: (a) spawning fishery, chiefly at Grand Manan; (b) fishery for immature fish.

Refers to confusion between "herring" and "sardines" in the statistics. Fishery is chiefly from May to October. In Charlotte County all the herring are taken in weirs. Poor and good weirs may be close together. Has plotted monthly average catches for a five-year period for ten weirs on Frye's Island. Concludes that the fishery is evidently influenced by factors of which we are profoundly ignorant. Despite the strong tides of the neighbourhood there is apparently stability of the "sardine" herring in relation to the islands. It is abundantly clear that extremely local conditions influence the catches of herring.

Measurements of length of sardine herring (p.103)

It was thought that light might be thrown on the question of whether the sardine herring of the Quoddy region are to be considered as local, as distinct from being a part of a widespread population, by tracing the distribution of

herring of characteristic lengths within the area. The same investigation was expected to throw light on the first appearance of young herring in the fishery. Measured over 44,000 fish in 347 samples. The length frequency distributions were treated by the method of determining approximate modes and sub-modes, here called "peaks".

First appearance of smallest sardine herring

Fish 10 cm. long first appeared in week ending September 3 at Saint John and Deer Island. They would be about 12 months' old. Similar sized fish appeared at Boothbay Harbor about the same time.

Differential size distribution

There is manifest a distinct tendency for larger sardine herring to be taken near Friar Roads and Harbour du Loutre than elsewhere. It is clear that sardines are mainly taken in schools of the same length.

Invasion of area from elsewhere

The frequent occurrence of shoals of the same length in different areas indicates a widely distributed population or "main body". Suggests that most of the sardines have an open-sea rather than a coast-wise habitat.

Special cannery statistics were collected to give more detail than the official statistics. The two sides of L'Etete Passage were the most productive of sardines in 1927, 1929 and 1932. There were seasonal differences in other areas. In each year some area would supply sardines for most of the season -- fishermen said this was due to enemies keeping them "penned up" (dogfish, silver hake).

Looking over the weekly records and charts an impression is gained that the first sardines to be taken in spring are from a not very large population which has remained during the winter in the region between Point Lepreau and Deer Island.

Herring fry investigations

In September, 1932, a fair body of herring was taken from the Bay of Fundy, chiefly on the Nova Scotian side. Thinks these are a product of local spawning near Grand Manan. Considers that spring spawning makes no significant contribution to the stock.

At no time did he find any population of fry commensurate with the enormous numbers of sardines unless the body taken in April between Seal Island and Liverpool 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. If this is true, then the

Quoddy-Maine sardine fishery must represent concentration in a small area of the products of very widely distributed spawning grounds.

First appearance of metamorphosed herring

Obtained 5 cm. herring where driven on beach in quantity at Brier Island, July 10. Similar fish taken at Atlantic Biological Station weir about same time. A point of some interest is whether the extensive body of fry he found in April from Seal Island to the offing of Liverpool, N. S., would tend to be carried into the sardine area. Drift bottle experiments suggest that they would. Gives details of some drift bottle releases which tend to show a drift to the Bay of Fundy.

It seems probable that some, at any rate, of the fry he found in April extending around Cape Sable would tend to be drifted into the Bay of Fundy, although they might well have passed the eye-ball stage before reaching the sardine area proper. If the herring chose to resist the drift, this tendency might be nullified.

Study of physical conditions

Mostly the concern of his colleagues but some special observations were made. It was found in July that the most turbid water (between Portland, Me., and Liverpool, N. S.) was in Passamaquoddy Bay and off the Saint John River. The whole coastal water between Cape Spencer and Seguin, which is approximately the sardine area, was more turbid than anywhere else except the inner part of St. Mary Bay and the Annapolis Basin. The corresponding surface temperature observations showed the coldest water off Cape Sable and the warmest in St. Mary Bay. The water between Cape Spencer and Seguin was intermediate in temperature, warmer west of Mount Desert.

High tides of Bay of Fundy are referred to; fog also.

Plankton -- herring food

Took tows for herring fry with Petersen net which took some other plankton. Figures distribution of ctenophores and Sagitta for a series of months. The ctenophores were consistently located principally between Cape St. Mary and Digby and the greatest concentration of Sagitta was off Digby. Thinks that this may mean a lack of circulation or special conditions for survival or may be the result of a more complicated situation -- unique conditions for survival, etc. Comments on the prevalence of euphausiids at the surface -- related to upwelling. A series of 20 plankton hauls off Liverpool, N. S., did not show any significant differences in day and night catches of herring fry but did show something of the liability of euphausiids and other forms to capture. These tows were the subject of a special report by A. C. Gardiner -- 10 daylight and 10 dark tows. (Note: Gardiner's report in Journ. Mar. Biol. Assoc. U. K., Vol. 19, shows that this series of plankton hauls

was taken off Liverpool, N. S., in May, 1932. They took up to 29 herring larvae per tow in the dark hours. No indication is given of their size.)

Hall, Ansley. 1898. The herring industry of the Passamaquoddy Region. U. S. Comm. Fish and Fisheries, Rept. of Commissioner for 1896, 22:443-487.

Gives information on the number of persons employed and the monetary value of the industry in 1893 and 1894. Refers to the introduction of brush weirs in Passamaquoddy Bay about 1820. On pp. 447-449 describes the construction of brush weirs. Cost varies from $40 to $1,000; average $200-$400, plus $40 to $100 for a seine. Describes seining operations in weirs (pp. 450-451); dip-nets, weir boats, collecting boats. Describes smoking and pickling methods. Describes sardine canneries and processing methods. One cannery in Passamaquoddy Region of Maine in 1875, 15 in 1880 and 36 in 1895. Gives sardine production costs. Herring were included at $3.14 per hogshead. Gives statistics of various kinds for the industry of 1892-95.

Huntsman, A. G. (no date). Herring investigations: Spawning and behaviour and growth of the young; summer of 1917. Manuscript Reports Biol. Stations, No. 352, pp. 1-23.

The first ten pages deal with the Gulf of St. Lawrence.

Fall spawning at Grand Manan, Bay of Fundy (p. 10)

Investigated the spawning area on September 19 and 20 and on October 2 and 3, 1917. Herring larvae were hatched and were being distributed from a centre near the mouth of Seal Cove Sound. It is evident that the mouth of Seal Cove was the centre of abundance of the larvae and also it was the point where he found the largest proportion of recently-hatched individuals, as shown by the presence of yolk. Spawning must have taken place at the beginning of September. On September 19-20 the greatest number of herring larvae taken in one tow was 61. There were only a few off Southern Head and none off Dark Harbour. On October 2 and 3 the following were taken in surface and deep tows:

Off Whitehead Island	0 larvae	
Mouth Seal Cove	1 "	
1½ miles off Southern Head	3 "	
4½ " " " "	47 "	
7½ " " " "	25	(very few with yolk)
11 " " " "	21	
15 " " " "	10	
20 " " " "	10	
25 " " " "	2	

Most of the October larvae were from 6 to 10 mm. long but some were up to 24 mm. Larvae were carried southwesterly with the current but perhaps become contranatant when 15 mm. long. On November 2 a young fish trawl caught 27 larvae (16-23 mm.) at the mouth of Seal Cove. The water temperature at Grand

Manan when the herring spawned was 8 to 9°C. The larvae were driven down by light. The larvae do not school but herring of 50 mm. length do. Believes that larvae 6 to 8 mm. long on September 19 were 11 to 13 mm. on October 2 and 17½ mm. long on November 2.

On June 11, 1917, Frits Johansen obtained young herring, of average length 55 mm., near St. Andrews.

Huntsman, A. G. 1918(?). Report on spawning area for herring at Grand Manan. Atl. Biol. Sta. Orig. Ms. No. 508, pp. 1-3.

The Board was asked in May, 1917, to report on the desirability of changing the limits of the area at the southern end of Grand Manan in which no fishing for herring is allowed from July 15 to October 15.

Obtained from 4 to 49 herring larvae in tows in the region around Seal Cove and off Southern Head. These were 7 mm. long and with some yolk. Taken on September 19 and 20.

The decline in numbers of spawning herring visiting the Grand Manan shore has been used as an argument for the proposed change in limits. That there has been a decline is well established. This has occurred in spite of the protection afforded, whereas at the Magdalen Islands the numbers of herring have been maintained without protection. Protection must be a negligible factor in maintaining the spawning schools. Considers that the abundance of sardines in Saint John and Charlotte Counties is proof that no serious reduction of spawning has occurred. As the sardines are from 1½ to 3½ years old, failure of spawning for even one year would be rapidly apparent. Argues that in Gulf of St. Lawrence the spawning herring are taken in shallow water in quantity in spring but that the summer and fall spawning is in deeper water, where temperatures are right but they are not caught. At Grand Manan the strong tides make the temperature of the water almost uniform from top to bottom even at considerable depths. The herring find suitable conditions over a wide range of time as well as of depth. The fishermen know that the herring spawn in deep water for they find the masses of eggs in fish stomachs. On October 2 small masses of herring eggs were taken in a deep tow about five miles from the shore southwest of Grand Manan. At the same time herring larvae were captured, some as long as 24 mm. The young herring at that time extended in an unbroken sheet from the south end of Grand Manan for a distance of at least 26 miles to the southwest and probably much farther. There can be little doubt that the decline of the fish is due to the herring spawning predominantly deeper than formerly.

Recommends against any closed areas.

Huntsman, A. G. 1919. Growth of the young herring (so-called sardines) of the Bay of Fundy. Canadian Fisheries Exped., 1914-15, pp. 165-171, Dept. of Naval Service, Canada.

Gives the length frequency figures for 35 samples of herring from Passamaquoddy Bay and points between Jonesport and Lepreau; presumably for 1916; very few winter samples. Fish ranged from 7 to 28 cm. with most between 12 and 22 cm.

Conclusions (tentative)

The data, though incomplete, indicate that:

1. There are both spring- and fall-spawned young herring (sardines) in the Bay of Fundy.

2. The spring-spawned schools reach a length of about 9 cm. by the first winter and of about 15 cm. by the second winter.

3. The fall-spawned schools reach a length of about 12.5 cm. by the second winter.

4. The growth during the third season is about 5 cm.

5. The growth during the fourth season is about 4 cm.

6. The period of growth is May to September.

Huntsman, A. G. 1928. The Passamaquoddy Bay power project and its effect on the fisheries. Saint John, N. B., pp. 1-45.

There are several pages of description of the Passamaquoddy power project and of other attempts to wrest power from the sea elsewhere. Contrasts Bay of Fundy and Gulf of St. Lawrence. Explains the mixing which occurs near Passamaquoddy Bay. Not only the temperature of the surface water but the temperature of the air during the summer months drops from all directions going to the mouth of Passamaquoddy Bay, showing that much more cold water is brought to the surface there than at any other point. The fate of the cold surface water is shown by Dr. Bigelow's findings that in August the coldest surface water extends out around Grand Manan Island, down the Maine coast and across to the coast of Nova Scotia to the vicinity of Brier Island, with warmer water farther up the Bay of Fundy and in the Gulf of Maine from the Yarmouth shore all across to southern Maine and the coast of Massachusetts. If the mixing machine is stopped these conditions will change. He holds that the entrances to Passamaquoddy Bay are much more effective mixing agencies than the ledges off Grand Manan and elsewhere. (I would question this -- A. H. L.)

The effect on the fisheries (p. 29, etc.)

The outstanding peculiarity of the fisheries of the Passamaquoddy region, in which we include the waters in all directions from the mouth of that Bay, consists in the extent of its pollock and herring fisheries. Develops the idea of the fertility of the water being maintained by upwelling. Such mixing occurs in the Passamaquoddy area. Argues that in the Gulf of St. Lawrence the herring leave the shores when the water becomes too warm. Charlotte County waters are in marked contrast and warmth-loving fish like mackerel and dogfish are conspicuously absent.

We reach the general result that in providing both food and suitable water climate for the important sea fishes, the Passamaquoddy mixing mechanism is of the greatest importance for the fisheries of the region.

In 1919 the total fish production of Charlotte County per 10-mile frontage was 235,000 cwt. This is more than double the production of any similar area on either side. A similar result holds when herring alone are considered, pollock also. Mackerel show an inverse relation -- none in Charlotte County and increasing amounts as one goes farther away.

If the Passamaquoddy mixing mechanism is stopped the sardine fishery in Charlotte and neighbouring Counties will be wiped out as will the pollock fishery. Mackerel, lobster and dogfish will increase.

Huntsman, A. G. 1931. Temperature and the Passamaquoddy fishery. Biol. Bd. Canada, Atl. Prog. Rep. No. 2, pp. 14-15.

In recent dry, warm years the water has been somewhat warmer and silver hake and dogfish have been plentiful. Mackerel were more common in the Passamaquoddy area. Herring were driven out of Passamaquoddy Bay by the higher temperatures.

Huntsman, A. G. 1933. Heat and cold make herring seasons in Passamaquoddy. Biol. Bd. Canada, Atl. Prog. Rep. No. 7, pp. 3-6.

There is a graph showing the correspondence between herring catches and water temperature in Passamaquoddy Bay. This indicates that warmer water makes the fish more active and increases the catches. In 1925 the water warmed up early and cooled off early as compared with 1926. The catch in 1925 began early and ended early. He attributes the drop after May each year to the herring being actively feeding and hence out where the food is -- clear of the weirs.

Huntsman, A. G. 1933. Mackerel invade the herring nursery. Biol. Bd. Canada, Atl. Prog. Rep. No. 8, pp. 4-6.

Believes that mackerel have seriously reduced the stock of young herring in the Passamaquoddy area. This Bay, although far from the spawning grounds, is an important nursery for brit. He refers to the water movements carrying fry to and large herring away from the area, and to the decline of large herring. Usually the cold surface waters keep the mackerel away but during the past two summers mackerel schools have invaded the area. Fishermen believe that these mackerel scatter the herring schools and eat small ones. Does not present any data on this; apparently speculation and fishermen's views.

Huntsman, A. G. 1934. Herring and water movements. James Johnstone Memorial volume, Liverpool, pp. 81-96.

Because of thoroughly mixed water the Bay of Fundy exhibits an apparent uniformity of the herring population. Spawning seems graded from head of Bay to mouth. Describes weirs. Not much change in 50 years in fishing method. Map of region with much of Passamaquoddy drainage area shown. Capture by weirs is evidence of the movements of the fish. Activity of fish (herring) related to temperature -- very sluggish in February-March. Season of feeding and growth is May to September. Lowered catches in June, July and August are due to schools being stationary while feeding. Light (depending on intensity) will attract or repel herring into weirs. Enemies (silver hake, mackerel, dogfish and squid) also drive them in or out of weirs. Little indication that herring swim into a current unless turbulent; carried to and fro by currents. Factors so far mentioned act over short distances.

It seems justifiable to put to one side the theory of active migration until the facts demand it and to enquire whether the major movements of the herring may not be the results of water movement. Some fishermen believe herring go to fresh water to get a drink. Gives a case at Doctor Cove where herring are carried to mouths of two brooks by an in-movement of sea water in deeper layers.

The smaller the herring the nearer to the surface they are, at least during daylight. Consequently, small herring most likely to be carried by surface movements. Hence, wind currents may be important as at Mascarene shore.

Elmer Shirley claims northwest winds bring herring to his weir from Digdeguash area; lack wind records. Surface water of inner Bay (Passamaquoddy) influenced by inflows from Magaguadavic and Digdeguash. Heavy river inflow causes surface flow away from these river mouths. When small herring become active in spring they will be carried to the mixing points -- particularly L'Etete and St. Andrews Point -- "spring" weirs.

When inflow is slight these movements cease and herring go to other favourable places as estuaries and mouth

of Bay. This tends to be characteristic of fall season.

Year 1929 with pronounced freshet in April and May and small discharge in summer and autumn gave large mixing point catches in spring and large estuary and mouth catches in fall when temperature was high and feeding ceased.

In 1927 spring freshet spread out and not pronounced and river discharge increased from July to October. The mixing point weirs had large catches in the fall and moderate ones in the summer. The estuary and Bay mouth weirs had small catches.

Water movements following extreme precipitation may carry the herring toward the estuaries. Has two cases of this -- August 27, 1924, and September 17, 1933; evidence that herring appeared near the estuaries about two weeks later in each case. There is evident need for detailed knowledge of the levels which herring of different sizes occupy under various light conditions, as well as of the actual movements of the water layers.

There is a summary:

1. The capture of herring in the stationary weirs of the Passamaquoddy region is determined by many factors, of which temperature, feeding, light, enemies and tidal currents do not seem to be directly effective in moving the fish any considerable distances.

2. Active, purposeful migration from locality to locality may be disregarded until facts are discovered to show that it needs to be considered. The herring in the meantime may be treated as a planktonic form.

3. Direct observation in a cove or small inlet shows the herring to be affected in distribution by differential movements of the water layers, set up by freshwater inflow.

4. Weir catches indicate very definitely that the herring are shifted from place to place in the superficial movement set up by the wind.

5. During freshets, water of low density in the middle of the Bay passes to localities of deep mixing, carrying the herring to the so-called "spring weirs" irrespective of the time of year.

6. During freshets the herring are carried away from the vicinity of estuaries; but with lessened outflow, particularly in the autumn, they are moved to the estuaries and the Bay mouth to give large catches in the so-called "fall weirs".

7. A very heavy downpour of rain over the drainage basin is effective in about a week's time in carrying the fish from the estuaries and giving good catches in the "spring weirs", but in a little over a fortnight it reverses the process, giving big catches in the "fall weirs".

Huntsman, A. G. 1938. International Passamaquoddy fishery investigations. Jour. du Conseil, Vol. 13 (3), pp. 357-369.

The question was raised of the probable effect of dams on fisheries, due to such a major change in water movements. In 1931 an International Commission was set up to study the matter -- the effect on areas outside the dams -- for a two-year period. The North American Council on Fishery Investigations pointed out in advance that a two-year study would probably be inadequate. The problem required the study of adjacent areas including the Gulf of Maine. In October, 1933, the Commission submitted its report to the following effect: It was not expected that the physical effects of the installation of the dams would extend far into or beyond the outer Quoddy region (outside the dams). It was not considered that the dams would have an appreciable effect upon the production of plant life outside the Quoddy region. The rich fishery was not due to abundance of zooplankton, and the supply of the latter forming the food of herring was considered to be brought into the region from outside areas beyond the influence of the dams. For a sure forecast of the effect on the fishery more investigation would be required, but no way was foreseen by which the outer Quoddy region or the Bay of Fundy would be made less favourable for the herring which were produced beyond the influence of the local conditions. The effect upon the availability of herring was likely to be considerable but was not a serious one out as far as Grand Manan and not likely to occur along the coast of Maine. Inside the dams the herring fishery would almost certainly be reduced to negligible proportions.

Canada did not consider the report to be sufficiently reassuring to give her support to the power project. A smaller scheme involving Cobscook Bay was dropped for lack of funds.

The four main publications represent a precise and intensive attempt to relate a fishery to the physical conditions.

Figure 2 shows the location of all weirs in the Quoddy region with the best ones specially marked.

Notes freshwater discharge and tidal mixing.

<u>The results</u>

The principal mixing of fresh and salt water occurs in the narrow passages between the inner and outer parts of Quoddy. The mixed water leaves the area chiefly between Grand Manan and the Wolves, which is also the channel providing deep salt water. Where fresh water is supplied directly to the mixing mechanism, there is merely a surface outflow and a bottom inflow, as in the region which receives the Saint John outflow. When mixing occurs along the margin of a body of stratified water, the mixed water moves away at an intermediate depth while surface and bottom waters flow toward the place of mixing, as

occurs on the Nova Scotian side of the Bay.

The phyto-plankton investigations show that light and nutrient salts limit the phyto-plankton production in the Gulf of Maine. Conditions are more complex in the Bay of Fundy. The productive layer is thin (10 metres), phosphates and nitrates continue high. Neritic diatoms continue throughout the season but develop late and are a poorer crop than in the Gulf of Maine; partly due to poorer light but chiefly because turbulence prevents the diatoms from remaining long in the surface layers. When the surface layer is most stable as in the centre of bays and in May and August the diatom growth is greatest.

The zooplankton investigations show that in the Gulf of Maine and Bay of Fundy a relatively few boreal endemic species (all crustacea, mostly copepods) dominate, forming 87 to 97% of the population from April to September. Calanus finmarchicus makes up 35.5% of the plankton for the whole year. Local swarms of individual species are also common: Sagitta elegans, Temora longicornis and Euthemisto compressa. Fluctuations in zooplankton are largely due to changes in the abundance of C. finmarchicus which does not reproduce successfully in the Bay of Fundy and adjacent Maine coast. The western part of the Gulf of Maine is the chief source. Pseudocalanus minutus also is abundant. The near shore waters of the Quoddy region and the Maine coast have low volumes of zooplankton. There is an increase towards the Nova Scotian side of the Bay and offshore in the Gulf of Maine.

Graham's herring report dealt chiefly with the character of the fishery for sardines and with the possible factors responsible for it. Turbidity of the water was the only physical factor found which possibly rendered the region specially attractive to herring. Refers to spawning and fry distribution from southwest Grand Manan to Nova Scotia. Metamorphosed herring first appear in catches in August when about 12 months' old. The herring are generally segregated into shoals of similar length and certain areas tend to have herring of particular sizes.

Discussion

Even though the proposed power dams have been dropped the problem of explaining the concentration of herring remains. Develops the idea that regardless of accuracy of statistics or efficiency of weirs, the Quoddy region is the heaviest producer of sardines. Gradation of sizes -- "brit" in Passamaquoddy and Cobscook Bays and spawners at Grand Manan; refers to great abundance of small ones to be seen in tide rips.

Formerly, small herring were only used for bait and fertilizer but between 1865 and 1880 an intensive fishery developed. In spite of the intensive fishery for the immature fish there was no place along the Atlantic coast from Cape Breton to Cape Cod where so many large spawning herring were to be found as on the outer side of Grand Manan. There was also a winter fishery for recovering spent fish from Saint John to Grand Manan. With continued intensive capture of sardines the

winter fishery dwindled and the catch of spawners was reduced. "Stringers" although still numerous were likewise reduced. He maintains also that at the time of writing the concentration on the spawning grounds off Grand Manan exceeds that anywhere else along the coast.

With such a concentration of young herring in the region it might be expected that some clearly favourable conditions for them would be revealed, but the reverse has been found. There is no good spawning ground nearer than Grand Manan and a residual current carries the young away; while nutrient salts are present the turbidity of the surface layer prevents much phyto-plankton growth; food from elsewhere supplies the needs of the herring.

A number of arresting facts are brought out: (1) the concentration of herring; (2) the appearance of deep planktonic forms at the surface (euphausiids). Another point concerns residual currents. From Watson's hydrographic measurements it is concluded that these currents go past the region. Yet drift bottles set free well outside it (150 miles in some cases) enter it. It is noteworthy that more bottles were taken in the "sardine" area (from Saint John to Grand Manan) than were taken on the Nova Scotian coast where prevailing winds of summer would be expected to carry them.

It seems incontrovertible that the young herring are in the centre of the region in exceptionally great numbers and obtain enough food to become very fat. As neither the herring nor food are produced locally they must go or be carried there. There are good reasons for believing that the zooplankton and the herring are distributed by passive transport by currents. The precise movements of herring and zooplankton are therefore important in determining where they will go -- depth for example. Indicates the complexity of the water movements in the Quoddy area. "Only a beginning has been made in this direction of attack on the problem. ... It is perhaps of significance that the "sardine" area is abruptly limited at its up-current end by the Saint John outflow, the most pronounced freshwater influence along the whole coast, and that the greatest concentration of herring, from the "brit" of the inner bays to the spawners outside Grand Manan, is across the abrupt seaward termination, as a distinct entity of this same outflow. It is the fresh water that, when associated with varied mixing in the sea, gives such complicated differential movements of the water layers. Effectiveness in mixing should probably be measured, not by the energy required to raise the salt water, but by the amount of salt water actually incorporated with the fresh."

Huntsman, A. G. 1952. The production of life in the Bay of Fundy. Trans. Royal Soc. Canada, (V), Ser. 3, 46: 15-38.

Page 17. Referring to the Passamaquoddy Commission results: "The ichthyologist could not see (Graham, 1936) that there were necessarily any more herring in the region than elsewhere in

the Bay of Fundy and neighbouring Gulf of Maine and considered that the very large quantities caught might merely represent favourable conditions for their capture. This last was an attempt to solve the problem of the greatness of the fishery: but only by casting doubt on the uniform conclusions drawn from visual observation (herring live near the surface in summer) and from the results of various kinds of fishing, that the fish are exceptionally abundant in the region and that the focal point in their abundance is in the entrances to Passamaquoddy Bay."

"It seems incontrovertible that very large quantities of herring are grown in the region and become in some places extremely fat in feeding on planktonic animals that must come from the Gulf of Maine. Transport of the food and even of the herring was seen as possible solution of part of the problem."

Gives a figure of 1941 fish productivity of the area off Charlotte County as 147 pounds per acre.

The herring had long been known to breed only outside the sardine region and to reach it as fry.

"The herring, which are responsible for the exceptionally great productivity of the Passamaquoddy sardine region, are present there throughout the year. When the adults were very numerous in the middle of the last century, before the sardine industry developed, they were taken in summer in great quantities on the outer side of Grand Manan Island where they spawned. The spent fish could be taken during winter in such great numbers inland, even toward the head of Passamaquoddy Bay, that a big fishery for them was developed. The young enter that Bay in the late larval or "eye-ball" stage and the next stage, the brit, which is too small for canning is concentrated there. The mechanism of this concentration is seen to be that, as a result of their habit of keeping to the surface, they are 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 that 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 the Bay."

As the herring get larger they go deeper in the water 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 get, the farther out they are distributed on the whole, until as adults they are almost entirely outside Grand Manan during the summer. Their food is brought to them -- so amply that those in Quoddy River are extremely fat.

The small herring, or brit, that are concentrated in Passamaquoddy Bay grow too rapidly to become very fat. He refers to the abundance of brit and their excreta in 1951. The small herring are not only concentrated with suitable food animals, but they are segregated from the larger herring which would compete with them for food. They are also kept from their enemies (mackerel and dogfish), few of which ever reach Passamaquoddy Bay.

The Saint John River mixing draws the animals in from the Gulf of Maine.

Huntsman, A. G. 1953. Movements and decline of large Quoddy herring. J. Fish. Res. Bd. Canada, 10 (1): 1-50.

"During the last half of the nineteenth century, there was a major transformation of the herring population of the Bay of Fundy, of which the tempo was too slow for it to be understood by those who brought it about." Defines the Quoddy region as including not only Passamaquoddy Bay, but the region from Saint John to the outer end of Grand Manan. It is characterized by heavy tides and a large drainage area. It is the background for what seems to be the most concentrated and intense fishery for fish grown locally that exists in the world. From 40 to over 100 millions of pounds of herring are taken from the Canadian section alone.

The decline of large herring

Quotes Perley. In 1850 the main fishery in Charlotte County was for large spawning herring which were salted and smaller ones which were smoked. The spawners were taken chiefly in gill nets at the southern end of Grand Manan from July 15 to September 15. Later this ground was closed to fishing.

The herring for smoking were taken in brush weirs. Gives tables for catches of small, medium and large herring and totals for Charlotte and Saint John Counties combined for 1870-1946. Also shows graphically the period 1870-1939.

With the development of an intensive fishery for the small herring from 1879 to 1905, the medium herring at first increased rather sharply in quantity and then dropped somewhat to a lower level, which was nevertheless higher than the original one. The quantity of large herring dropped sharply about 1890 and still lower after 1900. But the total poundage of herring taken has remained high. Great reduction of the stock of large herring has not affected the supply of young.

Present abundance of small herring

Quotes from descriptions of herring fishing in the 70's. Much fishing in St. Andrews Bay and towards Beaver Harbour during January and February. In 1940-43 the average catch per weir was 877 barrels. In 1910-13 it was 492 barrels.

The evidence is strong that heavy removal of sardine herring progressively increased their numbers. Decrease in large herring, which came slowly, permitted more medium herring to survive. A second marked increase of the sardines resulted, when, with the large herring for the most part eliminated, intensive fishing for the sardines reduced the numbers of medium herring generally and gave very full scope for food from the Gulf of Maine to pass the parts of the region populated by large and medium herring and reach far inland where the sardines are congregated.

Changes in abundance of large spawning herring

Development of the sardine industry in the Quoddy region has not affected the numbers of large herring outside the region, on the Nova Scotia side of the Bay of Fundy. Large numbers of large herring concentrated in summer on the outer limits of the region. They spawned at the southern end of Grand Manan. As spent fish they were in deep water inside the region. A market developed for them as frozen fish in the late 60's. In the winter of 1880-81 about 10 million pounds were sold. They were sold by count. The Canadian statistics are poor because of the method of sale -- direct from the boats to the buyers. This fishing rose to a peak in 1888 and collapsed about 1890.

Gives several reports of Fishery Inspectors who report the failure of the fishery after 1890. That Moore, who described the passing of the winter fishery for large herring, should not have recognized the cause is not surprising. He was not aware of the rate of growth and age of the fish. The large herring disappeared about 10 years after the intense fishing for sardines developed. As the fish probably live 10 to 12 years, this timing fits very well.

The take of sardines rose rapidly from 1879-1886. The course of the winter fishery starting in the late 1870's was as follows: The winter fishery was, at first, near shore and fishermen did not try farther out when they disappeared inshore. But in 1877 they did try offshore when they disappeared during December and fishermen learned that they could get the fish five or six miles off. They did not have to go offshore the next four winters but in 1882-83 they were principally offshore throughout the whole coast and they did not again appear, to stay, in shallow waters up to the time when they finally disappeared in the winter of 1889-90. There was some comeback in 1894-95 when good catches of large herring were made over a short period (Dec. 22 to Jan. 10). The summer catch of herring about Grand Manan also decreased (see Fig. 3, p. 13).

When spawning herring were abundant, spawning was chiefly outside Grand Manan but there was some in Oak Bay. Also, the fish which wintered in Passamaquoddy Bay apparently spawned in May -- perhaps because of slightly warmer water there.

Sudden disappearance of fat Quoddy River herring

Fat, young herring are found near the surface in

Harbour du Loutre and Cobscook Bay . In the early days, which Perley reports, large, fat herring, without spawn, were taken there in autumn. They suddenly disappeared in 1877 and were not caught again until 1892 and then only in limited numbers. (Note: 30 million pounds large herring at Grand Manan in 1954.)

Seasonal or very local movements

Moore's descriptions were good but coloured by the idea that the fish had a purpose in going where they did. In Doctor's Cove, Deer Island, herring are observed to go to the mouth of the brook. Considers that they are carried there by a bottom inflow of salt water. Also describes the previously-mentioned (Huntsman, 1934) freshet effect off the Digdequash River.

"While all sizes of herring are in deepish water during winter, when they come to the surface in spring with rising temperature they become distributed so that the smallest, brit, are as far inland as the head of Passamaquoddy Bay, while the largest, the spawners, are on the outer limits outside Grand Manan."

When large herring were very abundant in the Bay of Fundy by far the greatest concentration was found in summer outside Grand Manan. W. B. McLaughlin, Seal Cove, Grand Manan, realized that they moved inland in winter. Earll (1887) recorded similar observations. Moore (1898) investigated the fishery for large herring after it had failed for several years. These observers agreed in an arrival at Grand Manan, then on the outside of Campobello in October, going on into Passamaquoddy Bay or up to Beaver Harbour and Lepreau and even the mouth of the Saint John River. In 1878-1883 they were in Kennebecasis Bay. Thus, there was a striking difference between their winter and summer distribution. The mixtures of fresh and salt water flow towards the shoals off Grand Manan where the summer herring are. Repeats the effects of Digdequash run-off and its effect on the deeper waters outside. The movements of the herring from outside Grand Manan in fall and winter toward the river mouths may be safely ascribed to the somewhat deep return current of salt water that replaces that used up in surface mixing with river water. The movement in the reverse direction in spring is more rapid, being near the surface.

Large-scale movement toward Saint John

In the upper Bay of Fundy an outflow on the New Brunswick side and an inflow on the Nova Scotia side occur. Between these two streams, there is a slow interchange of water across the Bay, the movement being toward Nova Scotia near the surface and toward New Brunswick near bottom. Into this circulation went a large body of Quoddy herring in 1877. Net fishing at Grand Manan was good for six months of that year and then there was a falling off in quantity and quality. The poor quality may have meant shortage of food. There was a large increase in catch between L'Etete and Lepreau; they were moving

toward Saint John. The Grand Manan catch was markedly low for the next four years. The local Guardian explained this as a movement of herring to Europe. That the fish had not really gone very far was shown by fairly large catches in the winter fishing areas with some shifting towards Saint John.

He lists the catches from Grand Manan to Advocate by districts from 1876 to 1891. These are also shown graphically in part.

About 1884 large catches were made in summer in the Saint John outflow.

Movement out into the open part of the Bay of Fundy

The quantities of herring, taken near Saint John, did not account for all the losses at Grand Manan. That some herring went beyond the Saint John outflow into the general circulation of the upper Bay of Fundy is shown by fair catches at Quaco from 1880-83. The Overseer in eastern Saint John County reported a large increase of herring in the period 1878-1880, with vessels from Campobello, Deer Island and St. Andrews fishing up there. Reported herring spawning near Ten Mile Creek in July. By 1884 he began to report some decline in herring but the statistics may be wrong because the Overseer was enforcing restrictions and was in conflict with the fishermen. He was replaced and his successor reported larger catches for a year or two and then, in 1888, the fishery collapsed. "The herring from Grand Manan had come to Quaco and given relatively wonderful fishing and when they gave out, either through moving away or becoming exhausted through old age without recruitment, the drop back to the previous low condition of the fishery was such an anticlimax as to be depressing."

Thinks that these herring could have passed eastward from the Saint John outflow and have been carried by the anti-clockwise circulation toward the shallows of the Quaco region. (Gives a hydrographic explanation of why the herring were moved there, which I find difficult to comprehend.)

Movement to Nova Scotia and around the inner Bay of Fundy

The first evident rise in herring catches on the Annapolis shore occurred in 1879 but in 1880 they were low again. In 1881 the catch was very high and this persisted for four years and dropped abruptly. He considers that the movement across the Bay of Fundy was a slow one, perhaps associated with the varying depth at which the herring were. High catches were most pronounced near Digby Gut and a year later they were seen up to Morden and Black Rock.

In 1884 very large summer catches were made in the Saint John outflow. He considers that these fish were moved over from the King's County shore. They passed Quaco since catches were increased there; in 1888 the Quaco catches declined, two years after the herring disappeared in King's County.

"That the herring should pass from the Saint John-Grand Manan circulation and later return to it implies a change in its relation to the water of the Bay on its east side. It would seem that from 1877 to 1881 the return flow to the Reversing Falls at Saint John of salt water to replace that mixed with the fresh was from Grand Manan rather than from the open Bay to the east ..... This condition ceased in 1882 .... With this change, it can be presumed that, in correspondence with the usual contra-clockwise circulation of water around basins, in the northern hemisphere, due to the Coriolis force, the return flow of salt water to the Reversing Falls would come in large part from the open bay to the east." This would bring into the Saint John outflow herring arriving there from the head of the Bay. The number of herring in the outflow continued high for four years; there was not much reduction in 1888, the fifth year. Thereafter there was a rapid decline, coincident with the disappearance of the winter herring in the Quoddy region because of exhaustion of the stock through old age without significant recruitment.

Movement out of the Bay of Fundy and to western Nova Scotia

There are no records to show whether herring became more abundant on the Maine coast after the exodus from Grand Manan. Such evidence as there is suggests that there was no increase. In the counties at the western end of Nova Scotia the picture was: the Digby County catch rose abruptly in 1881, remained high for three years and dropped. Yarmouth and Shelburne Counties do not show much change.

The movement as a whole

The two-year delay in reaching the full effect at Quaco, and something of the same on the Annapolis shore, indicates a great slowness in the movement of the main mass well out of the Grand Manan-Saint John axis. This might be due to relatively dead water between that circulation and the circulation of the main part of the Bay of Fundy. Figure 11 summarizes the herring movements outlined above and Figure 12 depicts the distribution of herring in the Bay of Fundy in 1876, 1881, 1886 and 1891.

Circulation of the Fundy water

Quotes Dawson, Mavor, Craigie, Bigelow, etc., as demonstrating a contra-clockwise circulation in the Bay of Fundy. Reviews various drift-bottle results which support this view. The area around Cape Sable has dead water -- drift bottles put out from Brazil Rock continued to be picked up around Cape Sable for a couple of months, while bottles put off near Yarmouth soon reached Brier Island and points beyond. Drift material collects at the mouth of Minas Channel in the so-called "cedar swamp". Refers to mixing at the Reversing Falls.

In addition to the movement of light surface water from the east into the Quoddy district, deep water from the

mouth of the Bay passes to the entrances to Passamaquoddy Bay. The inflow of the Passamaquoddy rivers is a factor in drawing this water and its plankton fauna into Passamaquoddy Bay.

Discussion

Sums up on pages 42-44 what has been said above. Movements of herring will depend on their depth and we lack precise knowledge of their depth distribution.

Young herring are concentrated in the Quoddy region from quite an area in the Gulf of Maine-Bay of Fundy system so that reduction of the spawning population in the Quoddy area has not had a serious effect. It is conceivable that the present greatly reduced, but still large number of adults, near Grand Manan produces as many surviving young at the stage of concentration in the region as were produced by the much greater numbers before the sardine industry developed.

The conditions back of the shifting of the large Quoddy herring toward Saint John and out of the Bay of Fundy cannot be elucidated to any great extent. They are evidently due to peculiarities in river discharge but we have few discharge or rainfall records for the period concerned. All we have for 1870-1885 are precipitation records for Saint John and Fredericton. There was a decline in summer rainfall from 1872-1877 and not much recovery before 1881. The effect of a greatly reduced summer circulation would be to move more or less of the stock towards Saint John. The inadequate facts (much of the Saint John water comes from above Fredericton) support the idea that shifting of the large herring from Grand Manan was an effect of unusually low discharge of the Saint John River. The contra-clockwise circulation would be strengthened and the Quoddy herring would leak into this circulation.

Conclusions

"The large herring of the Quoddy region are shifted seasonally by the currents that vary with depth and that are related to fresh water discharged by the rivers. With rising temperatures in spring they rise from the bottom and are shifted outward past Grand Manan, where the outflow of light water thins out on spreading into the Gulf of Maine. With falling temperature in autumn they sink into deep water and are shifted toward the coast and the estuaries where the fresh water is mixed deeply with the sea water."

"In the late 1870's low rainfall resulted in shifting a large part of the herring toward Saint John Harbour for four years, some even going inside the harbour to Kennebecasis Bay. To a very considerable extent these herring entered the general circulation of the Bay of Fundy and were carried in the course of years to the New Brunswick coast eastward of Saint John and to the Nova Scotian coast from Cape Sable to Minas Channel. They did not enter Minas Channel, but were carried thence along the New Brunswick coast back to the Saint John outflow. They became exhausted through age and otherwise from 1888 to 1890."

"Development of the canning of small herring as sardines, starting in 1875" caused (1) disappearance in 1877 of large Quoddy herring, (2) an increase, followed by a decrease in medium herring, (3) a great decrease in the numbers of large herring by 1890, and (4) an increase in the numbers and extension of distribution of small herring.

Johnson, W. H. 1940a. Effects of light on movements of herring. J. Fish. Res. Bd. Canada, 4 (5): 349-354.

He refers to "morning" and "evening" weirs but seems to have made no personal observations on them. Fishermen attribute the entrance and departure of fish in these weirs to light from the sun when it is low. The fish are attracted towards the light source.

He observed herring in weirs by means of a hydroscope by day and by setting gill nets at different depths by night. Observations were made under various light conditions to discover the depth at which the herring were. He summarized his results as follows:

"In the absence of appreciable light (moonlight, starlight, cloudy and foggy nights), all sizes (up to 23 cm. long) of herring are found quite near the surface." "During the weak light of dusk and dawn all sizes may still be found no more than a foot from the surface." "Once the sun rises above the horizon the higher the sun and the larger the fish, the farther down the latter are to be found; at mid-day in June "oils" (14 to 18 cm. long) being at 10 feet or deeper, and "mustards" (19 to 23 cm. long) being deeper than 10 feet." In experimental tanks all sizes may be near the surface at night. They go to bottom when sunlight illuminates the entire surface.

Johnson, W. H. 1940b. Feeding of the herring. J. Fish. Res. Bd. Canada, 4 (5): 392-395.

This paper deals with experiments with the feeding of herring in tanks. Chopped Meganyctiphanes norvegica was used as food. It was offered to the fish in naturally and artificially illuminated tanks. The temperature of the water was varied from 13 to 3.8°C. Particular fish and the water were cooled over this range in less than eight hours. When food was offered the herring broke their close non-feeding formation to separately pursue individual food particles. They usually took food from below and ignored any that reached the tank bottom. With indoor illumination they fed where the food was best lighted. In an outdoor tank they fed throughout the daytime, whether the sky was clear or not. They fed under full moonlight but not at all on moonless nights, even when these were starlit.

When the water was rapidly cooled, the herring ate less at lower temperatures. They ate to full capacity at 13°C. but not at all at 3.8°. They remained inactive at the latter temperature. (Note: The water was cooled 10°C. in less than eight hours. These experiments would bear repeating with acclimated fish. I found "feedy" herring in the winter of 1942 when water temperatures were less than 3°C. -- A.H.L.)

Johnson, W. H. 1942. Effect of light on copepods as food for Passamaquoddy herring. J. Fish. Res. Bd. Canada, 5 (4): 365-376.

This paper deals chiefly with vertical migrations of marine copepods under natural conditions of varying light at a number of points in the Quoddy region. In addition, samples of herring were obtained in 1936 from weirs and gill nets and their stomach contents were determined (Table V, pp. 373-4). Their food consisted of Calanus, Pseudocalanus, Acartia, Tortanus, Eurytemora and Meganyctiphanes. Johnson concludes: "The occurrence of different amounts and kinds of copepods in herring stomachs under different light conditions can be explained by: (a) the time when the fish were captured, (b) the light conditions preceding the time of capture, (c) the actual vertical distribution of both the herring and the copepods under different conditions of light, and (d) the rate of digestion of the food."

Leim, A. H. 1943. Seasonal variations in the fatness of "sardine" herring. Fish. Res. Bd. Canada, Atl. Prog. Rep. No. 34, pp. 17-19.

Reports fat contents of sardines from March, 1942, to August, 1943. Average values are from 6.1 to 20.3% of the wet weight. Larger fish are fatter than the small ones in the same sample. Fish from Campobello tend to be fatter than those from other localities. Fall and winter sardines are fatter than the spring and early summer ones.

Moore, H. F. 1898. Observations on the herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. U. S. Comm. Fish and Fisheries, Report of Commissioner, 22 (1896): 387-442.

Herring range as far south as Cape Hatteras, being occasionally caught in the Chesapeake and off the outer shores of Virginia, Maryland and New Jersey. Newfoundland is the northernmost locality where they are persistently and extensively followed.

The herring fishery upon the shores of North America is entirely a shore fishery. The lack of an offshore fishery on our coasts is due not to the absence of fish, but to the fact that the shore fisheries are amply able to supply the somewhat limited demand.

The herring fisheries in the Passamaquoddy region are carried on by means of brush weirs, gill nets and torching. Torching is the oldest method. Weirs were introduced in 1820. Torching is said to be effective only after the weather has grown cool, about the time of new moon in September. Describes the torching method. Torching is prohibited in New Brunswick where the weir men allege that it breaks up and scatters the schools. Gill nets were introduced in Passamaquoddy Bay about 1829.

There is ample evidence that simple forms of weirs were

used by the aboriginal inhabitants of the United States prior to the coming of the white man but they seem to have been unknown, or at least unused, by settlers on the border between Maine and New Brunswick prior to about 1820.

Weirs were used in Nova Scotia before 1800 and seem to have been brought from there to Campobello about 1820. In 1835 weirs were built at Grand Manan.

In 1849 according to Perley, there were 27 weirs at Grand Manan, 21 at Campobello, and 7 on West Isles; total 55. In 1880 there were 142 Canadian weirs and 66 in the United States. In 1888 there were 327 licenses issued -- a number which has never been exceeded. In 1893 there were 285 weirs -- 239 in Canada and 46 in the United States. The distribution was:

St. Croix district	5	U.S. side Lubec Narrows	4
St. Andrews	35	West Quoddy Bay (U.S.)	7
Lepreau & Beaver Harbour	78	North Lubec	5
West Isles	74	Morrison Cove	1
Campobello	23	Eastport	3
Grand Manan	24	Eastport to Robbinston	9
		Pennamaquam River & East Bay	17

Distribution and movements

Apart from winter herring and spring- and fall-spawning runs, there is little evidence of any definite or extensive migrations of herring in Passamaquoddy Bay. The schools of sardine herring, and larger individuals which are more or less associated with them during summer and fall, are constantly moving back and forth without apparent system. It appears, however, that the fish found in the waters inside of Campobello usually enter by Head Harbour Passage at the east end of the Island. In many cases in 1893 and 1895, it was possible to trace the movements of these schools from the vicinity of L'Etang westward to Deer Island, Cobscook Bay and the vicinity of Lubec, or northward to the several parts of St. Andrews Bay and the vicinity of Robbinston. Sometimes the schools work out through Lubec Narrows and are caught in West Quoddy Bay.

The small herring and some of the larger ones, remain in the vicinity throughout the year, and the same statement will hold concerning sardine herring on other parts of the coast of Maine. During winter, they apparently keep in deeper water but occasional catches have been made in weirs in February. Schools of small fish are seen in the Bay of Fundy throughout the winter and bodies of larger ones sometimes occur in the vicinity of Grand Manan during the colder months but they do not usually approach the shores and very few are said to enter Dark Harbour after November.

In spring the herring, especially the smaller ones, begin to approach the shores, but they are not caught in abundance in the weirs until July. Some of the fishermen state that prior

to about 1883 considerable quantities were caught during March but that since then the advent of the schools has grown gradually later until, at the present time, they are not expected until July. The fish taken in the spring are usually quite small -- in such poor condition that they yield but little oil.

The record of catches in individual weirs in 1878 and 1879 show that comparatively few herring were taken before July or August, precisely as is now the case. The probability is that the herring arrive about the same time they always did and that the weirs are not fished until July merely because of lack of demand.

"I am informed that there was at one time and may still be a distinct migration of herring from the Bay of Fundy shore of Nova Scotia across to Grand Manan. The schools, after spawning in the spring, ran over to the Ripplings early in July in order to avail themselves of the rich food supply of that locality. It is by no means certain that the schools in the two localities were identical."

The appearance of the "Quoddy River herring" in Quoddy Roads appears to have been the result of a distinct though limited migration but whence they came and whither they went cannot be stated.

Effects of physical phenomena

1. Tides: The movements of herring on and offshore are largely influenced by tides, this being true at least of such as come toward land for other purposes than for spawning -- run into coves on flood tide and drop off on ebb tide. The shoreward movement may be either to procure food for themselves or to avoid becoming food for their enemies, the reverse movement on the ebbing tide being induced by the instinct of the herring to avoid stranding at low water. Thinks they resort to places where the current is strong because of the food that is there. Thinks they attempt to keep with their food supply.

2. Winds: May affect distribution of the food of the herring. Surf and heavy seas will drive them from the coast and from the surface into deeper waters.

3. Light: During hours of bright sunlight, the herring, with the exception of the "brit" keep in the deeper waters and rarely come close to shore or to the surface. Unless enemies drive the herring, the best weir fishing is on dark nights.

4. Sound: While nearby sounds frighten the fish momentarily there is no apparent effect from fog horns and steamers.

5. Fresh and brackish water: Doubts the belief that herring go towards fresh water.

6. Impure water: Effect probably exaggerated.

7. Temperature: No data except on requirements of eggs.

8. Rain, snow and ice: Probably becomes a light and temperature effect.

9. Food: After "brit" stage, 2 to 4 inches, is passed, herring appear to feed chiefly at night. The remarkable abundance of herring in the vicinity of Passamaquoddy Bay is doubtless a direct relation to its rich supply of nutritious food.

Enemies

Cod, haddock, pollock, hake, sculpins, sea ravens, flounders, dogfish, silver hake, albacore, squid, porpoises, seals, whales, gulls and sea fowl are listed as enemies. The enemies of the herring are important factors governing its local distribution. Flight is its only protection. Its ancient lineage shows that it is well able to maintain itself despite all perils.

Spawning, growth, etc.

Recognizes two spawning periods on both sides of the Atlantic. The summer and fall schools in the western Atlantic spawn when the temperature of the water is between 47 and 57°F. Gives some data on size and rate of growth, copied from European sources and other opinions; not very convincing.

Decline

A very valuable weir at Treat Island failed about 1870 and did not take fish again. In 1895 at L'Etang some herring sold for as little as 26 cents per hogshead. Believes that more herring were taken in the Passamaquoddy area in 1894 and 1895 than ever before. There was a failure of West Quoddy fish in 1868.

Did not find much evidence to support claims that offal from factories affected the catches of nearby weirs.

Other fishermen place stress on the injury effected by the capture of spawning fish in gill nets. As has been argued elsewhere, there is no greater damage done by catching the fish during the spawning season than by taking them at any other time -- for instance just before spawning. It seems that these accusations are but a manifestation of the universal warfare between the users of fixed and portable nets.

"When all the factors in the case are reviewed, I think that it has been shown that not only has there been no decrease in the sardine herring in the region under discussion, but that there are at present no practices connected with the fishery which are liable to seriously affect their future abundance."

Winter herring

From the early part of the present century herring were known to frequent portions of the coast between Quoddy Head and Lepreau during winter months. They came in large numbers and although certain localities appear to have been for a time deserted by them, there is no tradition among the fishermen that there was ever a period until recently when the winter school of herring did not occur. Perley mentions their sudden appearance in 1850 but the evidence indicates that he was in error and old fishermen can remember them back to 1829 and tradition dates them back beyond that. Large quantities ran into L'Etang. It was not until about 1860 that these winter herring were fished very much.

At first the winter herring were torched. Gill netting for them began about 1845. About 1865 it became known that winter herring could be caught in the Bay of Fundy and Gloucester boats came there instead of going to Newfoundland. The presence of the fish was detected by setting trial nets. Prosecuting these fisheries in the earlier years, each man set two gill nets (30 fm. by 150 meshes, 2¼" mesh). Later three nets per man were set. Until 1880 they were set near shore in 10 to 20 fathoms of water. They were set overnight. Later the nets were set up to 6 miles offshore. The winter fishery for herring was most important and profitable, especially on the "North Shore", between Beaver Harbour and Lepreau. Frozen herring were sold by count -- price ranged from $0.15 to $1.00 per hundred. Average was about $0.25 per hundred.

The winter herring were found from Saint John to Cutler, Maine, although not throughout this area every winter. Sometimes they were very abundant in St. Andrews Bay. Usually arrived at Herring Cove, Campobello, in October. Usually reached Beaver Harbour in November and Point Lepreau early in December. Whales and gulls usually followed the herring. From 1880-1889 the herring tended to stay offshore and in 1889-90 they disappeared altogether. In the last years of the fishery they were later and later in arriving.

Cold northerly winds were said to favour the fishery for winter herring. The herring of the winter school were usually lean although occasionally a few fat ones were seen. Their stomachs contained shrimp and "red seed" (copepods).

In December the genital glands were small, in March some were well advanced in development. Thinks that the shoreward movement of these herring was induced by a search for food.

There are grounds for belief that the schools, or at least a goodly portion of them, which frequented the coast in winter, spawned in the vicinity of St. Andrews Bay. It is admitted by all that the herring some years ago ceased to spawn in those waters except in limited numbers and as nearly as the date could be fixed from rather vague information, corresponds approximately to the time of disappearance of the winter herring.

There is no explanation of the disappearance of the winter herring -- it was not from overfishing. Refers to the periodicity of herring in Sweden. "They are called periodical because, as far as known, they have only lasted from 20 to 80 years, with intervals of 60 to 100." When disappearing in the Swedish waters, they arrived later and later each year and stayed farther offshore.

Quoddy River herring

The justly celebrated herring, which were known in the markets of the country under this name, appear to have occurred practically no where but in "Quoddy River", the waters lying between Campobello on one side and Deer Island and the shores of Maine on the other. The fishery began in 1829, although the fishermen appear to have been aware of the occurrence of these large fish prior to that. In the year mentioned, Mr. Parker, a fisherman, brought a gaspereau net from Saint John and determined to catch these herring for market. This was the first net used in the herring fishery in the Passamaquoddy district and it met with immediate success. The large herring were found to be more abundant than had been supposed and the pecuniary results were such that in the following year, fishermen came from Saint John to get their share of the fish which found such a ready market. The local fishermen, not to lose such an opportunity, soon provided themselves with nets and the fishery developed within a few years to such an extent that 40 to 50 boats were engaged almost nightly, the herring being caught by "drifting". The fish arrived in August and continued through September and October in each year until 1877 when they rather suddenly disappeared. It was not until 1892 that they were again caught, but in that fall they again appeared in limited numbers and have since come every year, without any increase in numbers.

These fish were very large and fat. They were usually pickled. In 1894, 89 selected ones filled a half barrel -- took a prize and sold for $5.00. The nets used were 3" mesh, 30 fathoms long, 150 meshes deep (ca. 2½ fm. when hung). These large herring never contained spawn but sometimes spawning fish were mixed with them.

Cannot relate this always small school to any others.

Perley, M. H. 1852. Reports on the sea and river fisheries of New Brunswick. Queen's Printer, Fredericton, 294 pp.

The herring (pp. 2-6)

Describes the Dutch method of curing large herring -- in which bleeding is regarded as important. Apart from references to curing, this section deals only with the Gulf of St. Lawrence.

Report upon the fisheries of the Bay of Fundy (pp. 92-178)

At Flagg's Cove, Grand Manan, he observed the torching or driving of herring (p. 94). Perley visited Southern Head on August 29 and found 48 fishing vessels at anchor -- the herring had not struck yet. Herring spawn on a sandbank at Wilcox Cove -- 2 miles east of Southern Head. The mesh of the nets used for herring is from 2¼ to 3". Nets are set from Wilcox Cove to Bradford's Cove, close to shore in 10 fathoms of water. The nets are 20-30 fathoms long and about 160 meshes deep. Some are set at the surface and some 5 fathoms down.

The natives complained of overfishing and impending ruin.

In September, 1849, 120 fishing vessels were at Southern Head.

The herring nets described above cost about £3. A weir at Money Cove is described on page 103.

At Campobello the herring season is from May to December. They fish 21 weirs. A Mr. Flagg believes that herring mature in three years. Mentions "fine Quoddy herring" at Deer Island. A Mr. James Chaffey of Indian Island blamed fishing at Grand Manan for the absence of brit -- not a single specimen having been seen for 10 years. In dead of winter herring frequently enter L'Etang Harbour in large quantities; they are then taken in 2" set nets (30 fm. x 150 meshes). "Herrings will still drive in this locality, probably from the schulls not being broken up, as elsewhere, by the numerous brush weirs."

In 1849 herring were unusually abundant at Great Salmon River (between Quaco and Martin Head). He saw 60 barrels of cured herring at Quaco in 1850. The fish were from 10 to 12" long.

Annapolis Basin (p. 160). The principal fishery is for small herring to be cured by smoking. They are taken in low brush weirs. There were 47 such weirs in 1850. The fish are caught in May, June and July, as far up as the Clements shore. The herring are from 4" up, many being 8 to 9" long.

Brier Island (p. 164). Herring appear about April 10th; they are large and full of roe. Offshore fishing for herring commences at the end of May when they are caught ½ to 6 miles offshore.

On pages 173-175 he deals with complaints regarding the destruction of herring on spawning grounds. The greatest spawning ground in the Bay of Fundy is at Southern Head, Grand Manan. Considers that protection is necessary or the fishery will cease. Refers to Scottish experience. "The herring fishery of the Bay of Fundy will not continue many years longer unless an immediate stop is put to the fishery during the spawning season at the Southern Head of Grand Manan."

On pages 175-176 he reviews the differences of opinion regarding the effect of weirs on the fisheries. This refers chiefly to shad.

Scattergood, Leslie W. 1948. A report on the appearance of the fungus Ichthyosporidium hoferi in the herring of the northwestern Atlantic. U. S. Fish and Wildlife Serv., Spec. Scient. Rep. No. 58, pp. 1-33.

The fungus attacking the herring is identical with or similar to Ichthyosporidium hoferi. In Europe it is found in flounders, mackerel, haddock, and several species of trout. In the northwestern Atlantic it has been found in winter flounder, herring and alewife. Thinks that the herring is probably the chief host of the disease and that other fish may become infected by consuming a fungus-contaminated herring. Fish (1934) was able to infect flounders by feeding them diseased herring. Observations on the alewife and flounder show that the infection is localized in the internal organs. In the herring the infection is general, so that both internal and external indications of the attack can often be seen. The musculature of the body as well as the heart, liver, spleen, kidneys, intestinal tract and brain may contain the fungus. In the internal organs the fungi characteristically appear as small, tough, white nodules. In extreme cases the heart may be enlarged several times by the formation of these nodules. The herring may be infected internally with fungi and show no external symptoms. Also, there may be small nodules imbedded in the musculature under the skin and their presence is often difficult to detect without removing the skin. The nodules or cysts are a result of the fishes' reaction to the infection, for the herring forms connective tissue around the fungi to try to keep them from spreading to other parts of the body. The connective tissue does not always prove sufficient to contain the organisms and the fungi may break out of the nodule and begin spreading to other parts of the fish. Often the attacks of the fungi cause pus sacs which are visible under the skin, or the outer layer of the skin may be broken and a pepper spot or lesion formed. A fish with pus sacs, pepper spots or lesions can be easily recognized as infected.

Spores, or resting stages of the fungus, leave the fish from the ruptured pus sacs and the open lesions of the herring. A plausible explanation of the means by which the fungus from one herring is transmitted to the other is that these fish may pick up the spores while feeding. Or, the spores may be eaten by smaller animals on which the herring feed. In Great Britain, M. W. Jepps ("On the sporozoan parasites of Calanus finmarchicus in the Clyde Sea area", Quart. Rev. Microsc. Sci. Vol. 79, 589-658, 1937) has found a fungus which may be Ichthyosporidium in Calanus finmarchicus. Nora G. Sproston ("Ichthyosporidium hoferi (Plehn & Mulsow, 1911), an internal parasite of the mackerel", Mar. Biol. Assoc. U. K., Vol. 26, 72-98, 1944) states that the fungus is rare in copepods. Apparently little work has been done on the parasites of marine copepods in New England and Canada.

One noticeable feature of the infection is that some herring seem able to tolerate severe attacks of the organism. Fish with extensive areas of open sores and pus sacs can be seen swimming normally in the school. Whether or not the infected fish can recover is not known. Meagre experiments indicate that the fungi grow slowly. None of the investigators have been able to present any definite conclusion concerning the reason for the occurrence of increased fungus incidence in some years or the possibility of predicting future outbreaks.

The possibility of cyclic appearance of high rates of infections was mentioned by Fish. His report stated that the fungus was common in 1929 and reached epidemic proportions in 1930 and 1931. Cox (1916) had described an epidemic in the Gulf of St. Lawrence in 1916 and mentioned that the fishermen of that region saw a similar epidemic among herring in 1898. Thus 18 years elapsed between the first two outbreaks on the North Shore of New Brunswick, 14 or 15 years elapsed between 1916 and 1930-31 and the heavy infection of 1946-47 occurred 16 or 17 years later. But as far as we can determine from enquiries and our examination of fish from that region, there has been no infection in fish from the Gulf of St. Lawrence for a number of years. Furthermore, one cannot be entirely certain that the outbreak described by Cox was due to Ichthyosporidium although it seems highly probable that it was. Because of these two facts, it seems logical to eliminate the Gulf of St. Lawrence herring from consideration in the determination of a cycle. We are left with 1930-31 and 1946-47--hardly enough to establish a cycle.

The above is not meant to represent a criticism of the cycle concept, but, instead, to point out that a cycle of infection has not yet been clearly indicated. It seems to be unanimously agreed among those who are interested in the condition of the herring that the years 1930-31 and 1946-47 represented high points in the incidence of the infection.

Sorting infected fish

(1) Mechanical picking was not practical. (2) Clear and infected fish could not be separated by specific gravity methods. (3) Experiments in 1947 showed that culling of raw fish either before or after brining could be done satisfactorily when the incidence of infection was 15 to 20%. Sorting after steaming or drying was not economical.

Literature

Suggests reading Sproston (above) for a complete list of references to the occurrence of the fungus in commercial marine fish. In general, those who study epidemics believe that there are two important and interdependent factors which govern the occurrence of the sudden and widespread attacks of disease which characterize an epidemic. One of the factors is the resistance of the host to a particular disease. Such resistance may depend upon the general health of the host. If a population is in poor

condition due to improper diet or unfavourable environmental conditions, such as extreme heat or cold, then it may be more susceptible to a disease. Also, once the disease has been contracted, a member of such a population may become a great deal more ill than if he were in good physical condition. Another form of resistance may occur after a disease when the host sometimes develops substances in his body to protect him for varying periods of time against future, severe attacks of the particular malady.

A second factor which may cause epidemics is the development of new strains of disease organisms. Bacteria and fungi, like all living matter, are in a constant state of change. Each individual organism is a little different from any other individual organism, no matter how closely related. Occasionally an individual may vary considerably in some respects from his predecessors. The newly-acquired difference may, if the organism is a disease producer, increase greatly the virulence of the individual. This individual may reproduce offspring of increased virulence. The resistances of hosts may no longer be sufficient to overcome the effects of the organisms and an epidemic may result.

Objectives of investigation

He decided to analyze the incidence of the infection from a geographical and temporal standpoint. An interesting theory pertaining to the reason for outbreaks concerns the possible relation between the size of the population and the occurrence of epidemics. It has been generally recognized that, among certain wildlife populations such as the jack-rabbit of the western plains of the United States, disease epidemics usually occur when the animals are most abundant. Just why this should happen is not known. One explanation is that the increasing population results in an increased competition for food with a consequent reduction in available food supply, and, because of resultant malnutrition, a general lowering of body resistance to the disease. Also, with an increased population, it is easier for the disease to be transmitted from one host to another. After reducing the number of animals to a low level, the incidence of the disease also descends markedly. The rabbit population then begins to increase and, after a few years, again reaches its peak, at which time the disease strikes once more. Perhaps the fungus infection and the size of the herring populations vary in a similar manner; however, we do not have enough information on the past history of either disease or population densities of herring to do more than merely mention this theory.

Many years of close study of the disease and the herring would be necessary to demonstrate whether or not this theory has any validity when applied to fish populations. It is quite obvious that, if the fungus infection becomes widespread when the population of herring is large, then it might conceivably be possible to keep the numbers of herring below

the level conducive to epidemic outbreaks.

During 1947 the infection was widespread throughout the New Brunswick and Maine fishing areas. In those regions our sampling failed to reveal any schools of fungus-free herring. In other parts of the Gulf of Maine, the prevalence of this disease was also demonstrated. In three samples from Provincetown, Mass., taken during May, 1947, 18.7, 20.2 and 22.6% of the fish were infected. A May, 1947, sample from Digby, N. S., had a 10% infection, while an August lot from that region had a 6.7% rate. Two 1947 samples from St. Mary Bay, N. S., had infection rates of 37.3% in June and 6.3% in August. April and May, 1947, lots of "Shediac" herring contained no infected fish and the inspectors did not find any in 1948. It appeared that disease decreased in eastern Maine sooner than in central and western Maine.

It is quite important that none of the Gulf of Maine herring samples were free of infection, regardless of the place and date of capture. It is quite possible that the disease is always present in varying degrees in the herring. Forster, examining herring in 1939 and 1940, had no difficulty in finding diseased specimens and neither did Fish nor Daniel in 1931. Fish's opinion that the organism is a normal parasite of the herring appears to be true.

Seasonal variation in incidence

It is quite apparent that the incidence of the infection had a marked seasonal variation. The magnitude of the seasonal change such as experienced in 1947 was obvious to all engaged in the Gulf of Maine herring fishery. In general, herring samples in April and May from all areas showed high incidence rates. The high rate continued in western Maine during June and part of July, but in other areas it decreased rapidly after May.

By the middle of November the fishery had ended in central Maine and by the first of December the western Maine season was finished. In both these areas there was no marked increase in infection during the fall. In New Brunswick and eastern Maine the rate of infection began to show an increase in November and December. Eastern Maine herring fishing ceased in the middle of December when the Maine sardine canning season officially ended; however, in New Brunswick, fishing continued during January and February -- by purse seine. Maine canning opened officially in March. During the first three months of 1948 it was possible to obtain a few samples and these did not show any marked increase over the late fall figures.

In 1948 in the Gulf of Maine there was an extreme scarcity of available herring between the middle of March and the first of June. A few samples obtained in May and June from New Brunswick indicated that the fish then present in the bays had a somewhat higher infection rate than the fish taken during the winter but were still in better condition than those in 1947 from the same general area. When the fishermen began to

catch herring in Maine in May the disease incidence was low.

Gives tables on incidence as follows:

Table 1.	New Brunswick	4/26/47 -- 6/18/48
2.	Eastern Maine	5/ 5/47 -- 6/18/48
3.	Central Maine	5/29/47 -- 6/24/48
4.	Western Maine	6/10/47 -- 6/23/48
5.	Recapitulation	

The season of 1947 was evidently somewhat similar to that of 1931 about which Fish stated "apparently the high incidence of infection found during the winter and spring of 1931 was the result of samples taken from a more or less static population living in shallow water, a region where the transmission of the parasite is most favoured. As the inshore fish were joined by the migrating offshore group the general level fell, indicating that this offshore group was less heavily infected, and that the dilution of the affected fish remaining inshore by the migrating offshore group was the primary reason for the decline in the general infection level and that it was not caused by seasonal variation of the disease." He has stated that the incidence of the disease in 1947 had an evident seasonal variation. That such a variation is due to the immigration of offshore fish to inshore areas during the summer would explain the seasonal change in the incidence rate.

It has been quite apparent to all those concerned with the herring industry that, in general, highly infected fish are those which are caught in small quantities during the winter and spring months. The general opinion has been that the fish are more subject to fungus attacks when the water is cold, the animals are sluggish and food is not readily available.

The catch of herring and the temperature of the surface water have the same trend. In general, the catch increased as the water temperature did and as the water temperature declined the catch decreased. Considering the evident fluctuations in availability of the herring during the season, it is remarkable that the catch and the temperature of the water are so closely correlated. In western Maine the correlation is not so good. Believes that further investigation of the factors influencing the catching of herring is warranted.

The graphs indicate in a general way that the incidence of the disease decreased when the temperature and catch increased, and in New Brunswick and eastern Maine where the fishery continued on a large scale in November and December there was an increase in the percentage of infected fish as temperature and catch descended.

His observations have indicated that the high rates of fungus infection are found during the winter and spring months of the year when the water is cold and the herring, available to the fishermen, are found largely in the bays and estuaries.

With careful use of inspection belts such fish can probably be handled safely by the canners, but this procedure would not always be feasible financially. If the canners do not wish to handle the highly-infected winter and spring fish, then they must wait the appearance of the large summer schools. There are not nearly enough yearly observations to demonstrate the relationship, if any, between the infection rates of the fish available in winter and spring and those of summer fish. It may be possible that the degree of disease incidence during the cold season may indicate the condition of the schools appearing in the summer. "Such can be determined only after continued observations are conducted; with the small amount of information which we possess concerning the herring and with our knowledge of the great variability in biological problems, we would hesitate to say that a high disease incidence in winter and spring means a greater than usual incidence in summer and fall fish. It may be that the winter and spring fish present along the coast, living under possibly unfavourable conditions of cold water and diminished food supplies, have such a decreased physical resistance to the disease that the infection makes severe inroads on the individuals. On the other hand the fish living in deeper water may find living conditions more suitable there and not be afflicted so severely. Unfortunately we have no knowledge of the conditions under which great bodies of the herring spend their lives when they are not present near the surface in coastal regions."

Scattergood, Leslie W. 1949. The production and fishing methods of the Maine herring industry with notes on the 1947 season. U. S. Fish and Wildlife Serv., Spec. Scient. Rep. No. 67, pp. 1-26, plus 7 figures.

A non-technical account.

The greatest yield of herring in the United States is in Maine. During the period 1924-44 the average Maine catch was approximately 58 million pounds, 6 million pounds in Massachusetts, 1 million pounds in New Yersey, and other areas less. Gives a table of the catches in certain years between 1924 and 1943. The maximum Maine catch has been about 93 million pounds. Economic conditions greatly influence the catch. The California sardine is a competitor.

Gear employed

The herring fisheries of Europe and of the North Pacific are using more efficient gear. "Torching" was one of the earliest methods. The Indians used brush weirs very early; colonists built them about 1820. In 1947, 132 weirs took one third of the Maine catch. In 1947 there were 327 weirs in Charlotte County, 18 in Saint John County and 2 in Westmorland and Albert Counties. Gill nets were used in Maine at one time to catch herring but their use has virtually disappeared. The stop or haul seine is the dominant gear in Maine, taking 60% of the herring in 1947. Prior to 1947 the catches of stop and purse seines were combined. Stop seines are used chiefly at night.

Purse seining came in during World War I. In 1917-19 the principal purse seine grounds were around Monhegan Island. There was difficulty with feedy fish. Purse seining was resumed in 1941-47. The seines used were small in comparison with those of Europe and the Pacific.

Herring are located by "firing", by echo sounder and by feeling wire. Stop seines are more efficient than weirs since they can be moved. Otter trawls are a possibility -- some success is reported with them in British Columbia.

Statistics

The statistics as now collected may err seasonally and geographically. He recommends future collection on the basis of 17 areas, 4 of which are in Canada. He gives the 1947 weekly catches by gear, for the Maine areas (V-XVII); and defines the limits of each area (with charts). The number of weirs in each area is given. No worthwhile fishery exists west of Cape Elizabeth.

Scattergood, Leslie W. 1952. The maturity of the Maine herring (Clupea harengus). Maine, Dept. Sea and Shore Fish., Research Bull. No. 7, pp. 1-11.

Uses the average size at maturity. Ages were not determined.

Studied 4,768 herring in 1949, 1951 and 1952 and concluded that 50% maturity was attained at 22.9 cm. (9.0") standard length. This equals 9.5" fork length or 10.6" greatest total length. Refers to Moore's (1898) paper in which he said that ripe fish under 9" standard length were very rare. This may indicate that the average size at maturity has declined. The male and female herring appear to mature at the same size. A table of length frequencies, with percentage maturity indicated, is given on pp. 6-7. He also recorded the condition of the reproductive organs. During August the mature herring are not fully ripe; some spawning may occur in the latter part of September and certainly during October. By November spawning has been completed. Table 3 records stages of maturity for a number of Maine samples.

Scattergood, Leslie W. 1952. Conversions of the standard, fork and total lengths of the Maine herring. Maine, Dept. Sea and Shore Fish., Techn. Bull. No. 2, pp. 1-16.

Agrees with Ricker and Merriman that convenience is the most important criterion in choosing a length. Indicates four measurements -- standard length, fork length, total length (natural), and total length (folded tip) (equals our G.T.L. -- A.H.L.).

Scattergood picks the standard length as most convenient because of damaged tails in some of his material.

Between 1949 and 1951 he measured six samples of fish in the various ways and compared them (588 fish). They were from 100 to 300 mm. standard length. The various lengths are plotted in Figure 2. As the tails grow more slowly than the rest of the body, the relation is not a constant one. Tables 7-9 provide a rapid method of converting lengths (in inches) from a standard length of 4" to 11.50".

Scattergood, Leslie W. 1952. United States imports and exports of herring and sardines in recent years. Maine, Dept. Sea and Shore Fish., Research Bull. No. 6, pp. 1-51.

Imports

Frozen herring: up to 3½ million pounds, mostly from Canada and chiefly used for bait (Graph in Fig. 2).

Fresh sea herring: "sardines" in the Eastport-Lubec area; an average of 43½ million pounds annually (Fig. 3).

Smoked or kippered herring: 2 1/3 million pounds a year from Canada (Fig. 4).

Pickled or salted herring: Canada leads but various other countries supply much. Canada has sent as much as 35 million pounds in one year (Figs. 6 & 7).

Canned herring and sardines not in oil: Norway is the chief supplier (Figs. 8 & 9).

Canned sardines in oil: disregarding the war years, Norway has supplied 17 million pounds of sardines annually; maximum was 30 million pounds. Portugal supplies some (Figs. 10 & 11).

Exports

The United States has exported salted, pickled, smoked, dry cured herring and sardines; total about 11 million pounds per year (Figs. 12 & 13).

The United States exports up to 2 billion pounds of sardines annually -- much of this from California. Cannot separate the Maine product from this. Exports are chiefly to the United Kingdom and the Phillipines. Since 1943 the exports to the U.K. have been smaller (Figs. 16 & 17).

Scattergood, Leslie W. and Parker S. Trefethen. 1952. A statistical summary of the Maine herring fishery. Maine, Dept. Sea and Shore Fish., Research Bull. No. 5, pp. 1-62.

Carefully collected statistics of the herring catches may provide a measure of the availability of the herring populations, which in turn may be related to the actual abundance of fish. There may be a relation between the size of the herring population and the incidence of fungus disease.

Data are given by weeks, area and gear for the herring caught. The unit is a bushel or 70 pounds of fish. Figure 1 shows the Maine statistical areas. In 1949 the inspectors were provided with Keysort cards.

The data are not complete as lobster bait sales are not included. Estimates have been made of how much lobster bait is used. It is believed to be as much as 25 to 30 million pounds per year. Maine totals otherwise for 1948: 1,929,734 bushels; 1949: 1,982,336 bushels.

There is a section dealing with the catches in Charlotte and Saint John Counties. Tabulates the catches by months for 1948 and 1949 (Table 3). Figure 2 is a graph showing the U.S. imports from Canada and the Canadian production (Charlotte and Saint John only).

The Maine areas are defined and the positions of weirs are shown. Other gear used is mentioned for each area; not many weirs west of Rockland. The number of weirs increased from 135 to 217 in period 1947 to 1949.

Have not completed enough years of study to attempt to correlate the catchability of the fish with any environmental factors.

Figures 19-21 are graphs of weekly catches by areas and gear for 1947-1949.

Sindermann, Carl and Aaron Rosenfield. 1954. Diseases of fishes of the western North Atlantic. I. Diseases of the sea herring (Clupea harengus). Maine, Dept. Sea and Shore Fish., Research Bull. No. 18, pp. 1-23.

1. Fungus disease (Ichthyosporidian infection)

This is perhaps the most serious disease of the herring. The causative organism is Ichthyosporidium hoferi. Refers to the sandpaper effect on the skin and ulcers with indefinite margins. The disease reached epidemic proportions in the Gulf of Maine in 1931 and 1947. In non-epidemic years the disease occurs in a small, variable percentage of every catch sampled. Believes the infection to occur in the digestive tract. Spores have been demonstrated in the blood. The heart, liver, kidney, spleen and lateral musculature may be largely replaced by fungus.

2. Ulcer disease (Myxosporidian infection)

Herring older than one year are sometimes found with discrete, usually circular ulcers up to one centimetre in diameter. These may ooze a white to yellowish material. There is no sandpaper effect and no infection except in the musculature. It is due to a myxosporidian protozoan (Chloromyxum clupeidae). (Note: A letter from Sindermann, December 12, 1955, says that the name is altered to Kudoa clupeidae.) Ulcers are most often

observed in summer in the larger fish. Herring 3 to 5" long, though lacking ulcers, may have opaque, white, spindle-shaped masses in the muscle. These are up to 5 mm. long. Microscopic examination reveals spores with four polar capsules.

3. Pigment spot disease (Trematode infection)

Herring may be peppered with black spots, often on fins also. Due to cercariae of a trematode, Cryptocotyle lingua, which enters through the skin and encysts. Alternate hosts are the gull or tern and Littorina littorea. The latter releases the cercariae into the water. Invasion is usually light but may sometimes cause mortality. Infection is in the inshore areas where the snails are. Unlike the raised papules of the fungus infection, the trematode produces a shallow pit. In advanced stages the metacercariae may show as raised centres in these pits. Sometimes the cercariae are deep in the muscle. Pigment forms around the cysts.

On page 15 there is a table comparing the three diseases.

4. Bacterial tail rot

Such diseases are common in fresh water but reports on marine fish diseases caused by bacteria are rare. Tail rot has been seen chiefly in herring kept in tanks at Boothbay Harbor. It is occasionally encountered in wild fish. The tails and the epidermis on the posterior part of the body slough off and the fish die within three days. A gram-negative, non-spore-forming, pleomorphic rod bacterium has been isolated.

5. Other diseases

"Pop-eye" and other conditions appear to be diseases of herring in captivity.

Sindermann, Carl J. and Leslie W. Scattergood. 1954. Diseases of fishes of the western North Atlantic. II. Ichthyosporidium disease of the sea herring (Clupea harengus). Maine, Dept. of Sea and Shore Fish., Research Bull. No. 19, pp. 1-40.

Conclusions

1. Gross external and internal manifestations of the infection of the herring by Ichthyosporidium hoferi are constant and can be differentiated from other types of infection by careful examination. Externally, the "sandpaper" effect of multiple tiny papules, followed by the sloughing of skin is characteristic. Internally, white nodules on and in the heart, liver and lateral body musculature distinguish the disease.

2. Transmission of the disease appears to be direct, from fish to fish, and infection is effected by invasion of the digestive tract. Experimental infections have been obtained consistently in the present work by repeated feeding of fungus material removed from infected herring.

3. The disease is systemic in nature. Hyphal activity is responsible for localized dissemination within the herring, while spore stages may be demonstrated in the circulating blood and can account for the generalized nature of the infection -- involving all areas and organs of the fish. Spores lodge in the smaller vessels and germinate, setting up foci of infection. Proliferation of the fungus occurs principally by formation and germination of hyphal bodies.

4. Heart, liver and lateral musculature of the herring are most heavily invaded. In advanced infections, much of the tissue of these organs is replaced by fungus. Involvement of the nervous system of the herring, though not severe, is also characteristic of the disease.

5. The disease does not usually exist in a dormant condition. Once the invasion is effected, systemic involvement proceeds rapidly. Gross symptoms of infection have been obtained in as little as 30 days following feeding of infected material. No "pool" of lightly infected fish, which do not exhibit gross symptoms of infection, exists in the herring population.

6. From gross and histological examination of 0-age group herring (brit) it appears that infection occurs in inshore waters. Such fish are uninfected at the time of their first inshore movement and during the first summer of life. The first evidence of infection in the present work was found in early September when the herring were about one year old. Herring of all sizes may be infected and the present work has disclosed no significant difference in infection rate among fish of different ages. Infection during the period 1951-54 was consistently low -- less than 1% in all samples -- and was lower in 1953 than in 1951 or 1952.

7. Examination of the disease organism in artificial culture discloses a definite sequence of development involving radial germination of "resting" spores, hyphal development, and the formation of hyphal bodies or resting spores. Growth forms in culture are quite similar to parasitic forms in the herring, except for greater hyphal length in the artificial media.

8. Because of insufficient knowledge of the size of the herring stocks and their fluctuations, it is difficult to determine with any precision the exact reasons for periodic increase in infection to epidemic proportions. Environmental factors such as sea-water temperature and salinity may play some role in disease fluctuation, but information on population density must be included before proper evaluation of such factors can be made.

Sindermann, Carl J. and Aaron Rosenfield. 1954. Diseases of fishes of the western North Atlantic. III. Mortalities of sea herring (Clupea harengus) caused by larval trematode invasion. Maine, Dept. of Sea and Shore Fish., Research Bull. No. 21, pp. 1-16.

Pigment spots of herring are caused by a larval stage

of Cryptocotyle lingua. The periwinkle and the gull complete the life cycle of this trematode.

The work reported was experimental and was carried out in tanks at the Boothbay Harbor Fisheries Research Station. They used an antibiotic (Terramycin) to reduce bacterial infection in the herring. Snails with cercariae were placed in the tanks. Brit succumbed to massive infection sooner than yearlings did. "Pop-eye" may develop in some fish; they demonstrated larval worms in the eye tissues. A single snail can release 15,000 cercariae in 24 hours. Most cercariae emerge in summer. Gross appearance and sections of infected herring are shown; numerous metacercariae under the skin.

Conclusions

1. Pigment spot disease of herring is caused by the cercariae of Cryptocotyle lingua emitted by the snail Littorina littorea.

2. Mortalities may be produced experimentally in the herring by massive continuous exposure to cercariae of C. lingua in sea-water. Deaths may also result from massive exposure of short duration but this is less marked than the effects of continuous exposure. Continuous experimental exposure to few cercariae appears to have little effect on survival of the herring.

3. Brit (age group 0), when almost one year old, are more severely affected by exposure to cercariae than are age group 1 herring (fish almost two years old). In the present work, brit mortalities ensued in one half the time of those in one year olds exposed to the same degree of larval trematode invasion.

4. Massive continuous exposure of herring to cercariae of C. lingua may produce "pop-eye" -- a conspicuous bulging of the cornea, and opacity of the lens of the eye, often bilateral. This effect concurrent with the development of pigment spot of the skin and fins, becomes apparent after about 10 days' exposure to cercariae.

5. The numbers of cercariae emerging from infested Littorina littorea are variable from snail to snail, but averaged 3,000 per day per snail during July and August, 1954. Under natural conditions such a rate of emergence would provide an extensive zone of potential invasion of herring in bays and coves where infested snails are abundant.

6. Numbers of cercariae emitted from infested snails vary with season as well. Emergence is sharply reduced in autumn -- in many cases to zero. The incidence of cercarial invasion of the herring and the impact of this disease on the herring population should vary correspondingly since (1) fewer cercariae are present, and (2) immature herring tend to leave coves and estuaries in late autumn.

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IV. Subject Index