

**FISHERIES RESEARCH BOARD
OF CANADA**

MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No.

625

Title

Oceanographic Factors relative to the
Sardine Fishery of the Bay of Fundy Area

Author

H. B. Hachey

JOINT COMMITTEE ON OCEANOGRAPHY

OCEANOGRAPHIC FACTORS RELATIVE TO THE SARDINE
FISHERY OF THE BAY OF PUNDY AREA

by

H. B. Hachey

Oceanographic Factors Relative to the Sardine
Fishery of the Bay of Fundy Area

by

H. B. Hachey

Introduction

The only justification for recording the notes that follow is to present same as a basis for thought and investigation. Presently, the whole question of the Passamaquoddy Tidal Power Development will be under investigation, and once again its probable effect on the sardine fishery of the area will be given attention.

In making its final report, the International Passamaquoddy Fishery Commission reported, relative to the local concentration of herring catches in the Passamaquoddy area, that "It is quite clear that we have here a problem that current fundamental knowledge, current theories, and current investigational technique have been powerless to solve."

At this date, some twenty years later, it is questionable that we possess much more fundamental knowledge, and whether we have at our disposal much improved investigational techniques. It is probably true that the theoretical aspects have made some disgressions based on the facts presented by the earlier investigations.

It is true that high speed nets and mid-water trawls have been designed for sampling, and that echo sounders have been provided for fish detection. The essence of the problem seems to involve quantitative sampling and it is of prime

importance to know the efficiency of the sampling methods, and the ability of an observer to interpret the records of an echo sounder.

It is true that physical oceanographers have improved equipment at their disposal. In the investigation of the Bay of Fundy waters, the greatest difficulty is encountered with the ever changing conditions brought about by the extreme tides of the area. To further present knowledge, some new approaches and techniques are desirable, and some of the fundamental processes of water replacements might probably be given attention.

Observations on the Herring

Needler's chart of the herring landings for 1919 has been found valid for in the other years examined (Graham, 1936). Graham points out that the areas of concentration of landing are each of them west of a great river, namely the Saint John and the Penobscot, and that this appears to be relevant to an important problem raised and discussed by Huntsman (1928, 1932, 1933, 1934) and Hachey (1934).

In a study of concentration and catches within a small area, Graham points out in connection with the fishery of Frye's Island weirs:

(a) that "this fishery is evidently influenced by factors of which we are profoundly ignorant", and

(b) that "it is abundantly clear that extremely local conditions influence the catch of the herring".

Further statements extracted from Graham's report are as

follows:

(a) "At no time did we 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 sufficiently extensive."

(b) "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 be true, then the Quoddy-Maine sardine fishery must represent concentration in a small area of the products of very widely distributed spawning grounds."

(c) "The sardine area was poorly supplied with herring fry at this (passively drifting) stage." (see Figure 8, Graham, 1936).

(d) "It was found that in July the most turbid water (between Portland, Maine, and Liverpool, Nova Scotia) was in Passamaquoddy Bay. The central part of the Bay of Fundy, the mouth of St. Mary Bay, and the water near Cape Sable was relatively clear."

(e) "There seems to be little doubt that the availability of herring for such a long season in the Gulf of Maine and the Bay of Fundy generally has to do with comparatively equable temperature of the water."

(f) "The coast itself may act as a natural trap for herring, and the trap will naturally act more efficiently where there is more interchange of water. Also, more obviously, weir men need sheltered water, provided by the irregular coast line; and the weirs will be more efficient the greater the tides."

(g) "There may be little circulation in the Bay of Fundy at this season" - March, April and May.

(h) "The question of whether there are actually more sardine herring in the sea on the strip of coast between Cape Spencer and Cape Elizabeth than in other parts of the Gulf of Maine, the Bay of Fundy or Nova Scotian water, is open to argument."

The marine biologist at this date may be able to offer more efficient means of sampling of the herring fry, and be prepared to question the reliability of such data at Mr. Graham's disposal. The question as to the source of the fishery is still paramount; and the result of previous experience indicates that the sampling techniques must be critically examined.

The physical and chemical oceanographer will be attracted to suggestions:

(a) that differential water movements require study to elucidate their importance in concentrating herring to the west of the Saint John and Penobscot river mouths, and that these differential movements in restricted areas are factors determining the relative efficiency of individual weirs.

(b) that there are characteristic local differences in the turbidity of the water. It is true that great tidal action is responsible for the turbidity. This tidal action is also responsible for assuring a continued supply of nutrient material in the surface waters, making these surface waters a potential source for the production of fish food. The qualifying "potential" is stressed as "turbidity" infers a diminution of

the depth of light penetration, with light becoming a limiting factor in plant production. In the Bay of Fundy area, turbulence brings colder waters to the surface during the growing season, and these lower temperatures also slow up the process of plant production. Graham also suggests that turbid water may be attractive to herring enabling them to obtain cover from their natural enemies.

(c) that it is important to consider seasonal differences to appreciate the ever changing processes.

Observations on the Plankton

Gran and Braarud (1935) point out that with the strong turbulence, the result of tidal action, the nitrate and phosphate content of the waters of the Bay of Fundy was nearly always found to be high, even at the surface. The production of phytoplankton, therefore, can hardly be limited by the lack of nutrients. They point out that a relatively high turbidity of the waters and much cloudy weather make the productive zone shallow. Further the high degree of turbulence may even diminish the productivity of the waters by carrying the diatomic cells down below the illuminated zone for a greater part of their life. In summing up the phytoplankton production, these authors state: "A pronounced phytoplankton minimum in June probably is mainly a result of this turbulence." "During the winter the phytoplankton of the Bay of Fundy was quantitatively poor. In April-May the phytoplankton in the whole area had its annual quantitative maximum. Only along

the New Brunswick coast this rich spring growth of diatoms was never observed. In the Bay of Fundy the phytoplankton in June was very poor except in Passamaquoddy Bay. In September the same societies were found (as in June). At this season visitors from the Atlantic, particularly ocean coccolithophorides, were found in relatively great numbers, and more abundantly in 1931 than in 1932."

The following statements relative to the production and distribution of zooplankton in the Bay of Fundy and Gulf of Maine are extracted from Fish and Johnson (1937):

(a) "The turbulent New Brunswick eastern Maine coastal zone as far west as Mount Desert is relatively unproductive, and characterized by small zooplankton volume."

(b) "Productivity was found to be closely correlated with temperature and stability of the water mass, and dispersal with the nontidal circulation in the region."

(c) "The vernal crop of boreal plankton species appears to be derived largely from adults maturing in the western or outer Gulf."

(d) "Analysis in the Gulf of Maine and Bay of Fundy show the zooplankton population to be dominated by a relatively few species of boreal endemic crustaceans. *Calanus finmarchicus*, the most abundant form, average 39.9% by number in the total region during the period, April to September in 1932, and 35.5% for the year in the Bay of Fundy."

Fish (1936a) in reporting on the biology of *Pseudocalanus*, states: "There is no evidence of successful propagation in the

Bay of Fundy, and the western area declines in importance after the first brood. Subsequent propagation of all breeding stocks appears to be centered in the outer Gulf."

In reporting on the biology of *Calanus finmarchicus*, Fish (1936b) states:

(a) "*Calanus finmarchicus* is the most abundant pelagic animal in the Gulf of Maine, averaging 39.9 percent of the total zooplankton population during the period April to September, 1932, with a peak of 60.4 percent in May."

(b) "The adult stock varies markedly in abundance in different areas, the smallest numbers occurring in the Bay of Fundy and westward along the coast of Maine to Penobscot Bay. The population is everywhere at a minimum in late February and early March."

(c) "The western Gulf forms the principal source of supply of *Calanus* for the entire region. Propagation east of Mount Desert in the inner Gulf is largely, if not entirely, unsuccessful."

On the basis of the above findings two conclusions would seem to be warranted, viz:

(a) The Bay of Fundy waters, while potentially rich are not highly productive of copepods; the limiting factor, seemingly light. Consequently, if the herring move into the Bay of Fundy from outside areas, these movements can hardly be attributed to search for food.

(b) Considering *Calanus finmarchicus* and *Pseudocalanus* as "indicator organisms" or "drift bottles" an extensive interchange

of waters between the Gulf of Maine and the Bay of Fundy has been demonstrated.

No review would be complete without reference to the various papers listed and reviewed by Leim (1956). Among these are the various papers by Battle; Bigelow, Huntsman, Johnson and Scattergood, all of which are, for completeness, listed in the bibliography to this manuscript. The studies on the effects of light on the movements and feeding of herring, the studies of the reactions of copepods to various factors, and the various contributions of Huntsman to the herring problems are of basic interest to any student of the problem today.

Oceanographic Factors and Herring in the Bay of Fundy

The general oceanography of the Bay of Fundy has been described by Hachey (1952)(which was a revision by Hachey and Bailey of a manuscript written in 1931). This earlier manuscript reviews the many investigations of Bay of Fundy waters, and the various references cited are incorporated in this present manuscript. The only major work in the Bay of Fundy between 1930 and 1946 was that carried forward by the International Passamaquoddy Fisheries Commission (Watson, 1936). Since 1946, various aspects of Bay of Fundy waters have been dealt with as indicated in the bibliography attached.

Given that there is a source of sardine herring outside of the Bay of Fundy, these fish might move into the bay under the following circumstances:

- (a) they might swim in search of food or suitable water conditions.

- (b) they might be driven by squid, hake, etc., or
- (c) they might be carried in as plankton when feeding at random.

It is under the last mentioned circumstances that physical factors come into play, requiring for an understanding of the process, a knowledge of the circulation pattern of the Bay of Fundy.

On the subject of circulation, the general anticlockwise circulation of the Bay of Fundy has been demonstrated, by drift bottle experiments (Mavor, 1922, 1923; Hachey, 1952). The most prominent water movements are those associated with an inward movement on the Nova Scotia side of the Bay and an outward movement from the Saint John river area. According to Watson, 1932 "the Saint John estuarial water flows out to sea as a strongly stratified layer, about 10 metres thick, retaining its lower boundary as far as Grand Manan Island, a distance of 74 Km. Persistence is due to the high density gradient combined with the low velocity gradient through the layer as it flows out over the deep homogeneous water." Another prominent tendency, at times at least, as shown by the drift bottle experiments, is a movement in the surface layers towards the various passages leading into Passamaquoddy Bay. The direction of the dominant flow through Grand Manan Channel is probably variable, and in any event small.

From all observations, which have been generally limited to the spring and summer seasons, the general circulation is as indicated above. Studies on the replacement of Bay of Fundy

waters were initiated some time ago (Hachey, 1934) and it became evident that the main factors involved in the replacement of these waters were land drainage, wind, and tide. These replacement processes have been given further attention in recent years, and have been summarized by Hachey, 1955. In attempting to apply these processes to the problem of the herring fisheries, it is important to appreciate the significance of the water movements to the distribution of plankton, larval forms, or free-swimming forms feeding at random.

On the basis of the above, it is quite easy to appreciate that the circulatory system of the Bay of Fundy can, under the "open circulation" system (Hachey, 1955), transport planktonic forms into, around, and out of the Bay. Under the "closed circulation" system, these forms can be retained within the Bay. The effect on any particular planktonic form will depend upon its distribution with depth, which in turn may be related to the time of day or time of year. The circulation pattern as determined by drift bottles, indicates that the surface waters and the included planktonic forms have a tendency towards the passages leading into Passamaquoddy Bay. This tendency might only prevail at certain times of the year, and with favourable southwest winds. In any event it should be quite clear from the zooplankton distributions, as shown by Fish, that planktonic forms are carried into the Bay of Fundy and Passamaquoddy Bay and are distributed throughout these areas.

It is not so easy to appreciate the differential water movements that prevail in the Bay of Fundy. Superimposed upon

the tidal flow is the rotational effect of the earth, which tends to produce a resultant inward movement of waters on the Nova Scotia side of the Bay, and a resultant outward movement of waters on the New Brunswick side. As the lighter mixed waters tend to move out of the Bay in the surface layers, the indraft of replacement waters tends to take place at the greater depths. If drifting organisms are in the surface layers, they may be very quickly carried out of the Bay, particularly under favourable winds. They may be carried shoreward with onshore winds, or they may be retained within the Bay and carried about within an anti-clockwise circulatory system. On the other hand if the floating organs are in the deeper layers, they will be carried inward, the rate of inward movement dependent upon the rate of replacement at any given time.

Oceanographic Factors and Herring in Passamaquoddy Bay

Given that there are sardine herring present in the waters circulating about the Bay of Fundy, what factors determine their movement into Passamaquoddy Bay? For sake of argument herein, it is categorically stated that sardine herring move into Passamaquoddy Bay as fish feeding at random and therefore acting as plankton. This process is furthered at times, when the fish are driven by their natural enemies such as squid and hake.

Some Fundamentals

Ignoring the changing details of the tide, as to time of day, amplitude, low tide, mean tide and high tide levels, a

large body of water (100 x 20 x 5280²cu.ft.) moves on the average in and out of Passamaquoddy Bay.

The first question that arises is how much of this water flows through each of the various passages. There is little information on this, and the actual areas of the cross sections involved are not sufficient data on which to base conclusions. A more pertinent question is concerned when one attempts to estimate the differences relative to flood and ebb. While there is much less information on this question, the effect of the earth's rotation would seem to point to the following possibilities.

- (a) more water moves in through Letete Passage on the flood then moves out on the ebb.
- (b) less water moves in through Western Passage on the flood than moves out on the ebb.

Another point is concerned with the mixture of drainage waters flowing into Passamaquoddy Bay with those of the tide. None of the drainage water passes out of the bay as fresh water. It mixes with the tidal water, and because of the relatively low salinity and density of this mixed water, it tends to hold the surface. The rotational effect of the earth comes into play here, and the waters of Passamaquoddy Bay tend to circulate in an anticlockwise direction. As a result, it would be expected that this lighter, less saline, mixed surface water would tend to flow out of the bay chiefly through Western Passage.

As a consequence of the mixing of drainage waters with

the tidal waters, the mixed water will, on the whole, move away from the mixing area. Consequently, there must be a continued renewal of the tidal water which enters into the mixing process. It is probable that this renewal is directly proportional to the amount of drainage, but confining our attention to a limited area this is not necessarily so, as the efficiency of the mixing must be considered. If the mixing mechanism were of 100% efficiency, the mixed water would be of a constant salinity. It is readily observed that increased drainage generally results in the lowered salinity of the mixed water.

Given that there is mixing of drainage and tidal water at a point, or within a confined area, the resultant flow will be away from the point or area in the surface layer, and towards the point or area in the subsurface layer. Add to these tendencies, the effect of the earth's rotation, and these relative water movements, on a grand scale, are not necessarily superimposed on one another. For an area such as Passamaquoddy Bay, for example, the inward resultant flow probably holds to the eastern side, while the resultant outward flow tends to hold to the western.

In the St. Croix river area, if we apply the foregoing principles, the tidal flow has imposed on it a resultant outflow confined to the American shore and an inflow confined to the Canadian shore.

All of the above does not take into consideration a number of important factors, which we will now consider of themselves.

Wind:

On the whole, wind action is very effective in moving waters of the surface layer. In general, it may be considered that winds other than southerlies would tend to enhance the outflow of surface waters from Passamaquoddy Bay, while southwesterly winds would tend to confine surface waters to the Bay. This means that with other than southerly winds, there is a resultant movement of deeper waters into the Bay, while with southerlies there is a resultant movement of deeper waters out of the Bay. This feature is of particular importance when consideration is given to any fish that may be feeding at random.

In the St. Croix river, the specific direction of the wind will be of considerable importance in shifting the surface layer from the American to the Canadian shore and vice versa. So, too, will specific wind directions determine the distribution of surface waters in the open Bay.

Tidal Amplitude:

The tidal amplitude in Passamaquoddy Bay varies approximately between 14 and 28 feet. As the tidal amplitude is being increased as between neaps and springs, more and more water is entering the Bay from the outside. The reverse is true if the tidal amplitude is on the decrease. It should be quite obvious that if a body of herring is present outside of the Bay, and can be treated as "plankton", some of these fish will be transferred into the Bay during those periods of increasing tidal amplitude, provided they are in the water layers

above the threshold of the bay. Similarly, if there is a body of fish within the bay during periods of decreasing amplitude, some will be carried out of the bay. The amount of water involved as between springs and neaps should be appreciated, amounting to $(28-14) \times 100 \times 5280^2$ cubic feet.

Another factor of importance relative to the tidal amplitude, is the stirring and upheaval in the passage, which seems to have some bearing on the vertical movements of various forms of fish food, e.g. the euphausiids.

Time of Tide:

The time of tide is particularly important because of the vertical movements of herring with relation to light. The time of the incoming tide may, for example, determine whether the fish are at depths above the threshold of the bay or not. Similarly, within the bay, the time of tide will determine the efficiency of fishing of the various weirs. If the fish are too deep, they will not be available to the shore weirs.

Temperature and Salinity:

Of these two water characteristics relative to herring fishing in Passamaquoddy Bay, temperature is probably the most important one. The temperature will determine whether the fish are sluggish or active, and to some extent will determine the depth. It is considered that the lower temperatures of the winter months are unfavourable to herring remaining in the bay, except possibly at the greater depths.

Discussion

As noted in the introduction, the only justification for putting forward these ideas at the present time is to present same as a basis for thought and investigation. It would seem to the writer that the biggest factors concerned with the transportation of herring as "plankton" into Passamaquoddy Bay are the changing tidal amplitudes and the vertical movements of the fish. Once in the bay, the general circulation coupled with the vertical movement determine when and where the fish become available to the weirs. Superimposed upon the general circulation is the effect of the wind.

Addendum

No attempt is made to draw conclusions from the foregoing, which is put forward only for critical examination. Certain pertinent facts have been demonstrated by the earlier workers relating to:

- (a) the low productivity in the Bay of Fundy,
- (b) the concentrations of sardine herring west of the Saint John and Penobscot Rivers,
- (c) the general circulatory pattern, and
- (d) the interchange between the Gulf of Maine and Bay of Fundy waters.

Three main questions, of fundamental interest, require answers:

- (a) where is the main source of supply of sardine herring?

- (b) what physical, chemical and biological factors control the sardine fishery in Passamaquoddy Bay, and
- (c) does the prevailing physical system concentrate the herring in the Passamaquoddy area?

References

- Bailey, W. B. 1953. Seasonal variations in the hydrographic conditions of the Bay of Fundy. Fish. Res. Bd. Canada, MSS 551, 17 pp.
- Bailey, W. B., D. G. MacGregor and H. B. Hachey, 1953. Annual variations of temperature and salinity in the Bay of Fundy. J. Fish. Res. Bd. Can., 11(1): 32-47.
- Battle, Helen I. 1934. Temperature and "clearing" time for the sardine. Biol. Bd. Canada, Prog. Rep(Atl.) 11: 14-16.
- 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. Ibid: 2, 401-429.
- Bensley, B. Arthur, 1901. Report on the sardine industry in relation to Canadian herring fisheries. Contrib. Canadian Biology, pp. 59-62.
- Bigelow, Henry B. 1927. Physical oceanography of the Gulf of Maine. Bull. U.S. Bur. Fish., 40(2): 511-1027.
- Bigelow, Henry B. and William C. Schroeder, 1953. Fishes of the Gulf of Maine. U.S. Dept. Interior, Fish and Wildlife Service, Fishery Bulletin 74, 577 pp.
- Craigie, E. Horne and W. N. Chase, 1918. Further hydrographic investigations in the Bay of Fundy. Contr. Can. Biol. (1917-18): 127-136.
- Davidson, Viola M. 1925. An investigation of the autumn maximum of diatom growth at St. Andrews, N. B. Fish. Res. Bd. Canada, MSS 345: 50 pp.

Davidson, Viola M. 1926-27. The causation of diatom maxima.

(a) Report for 1926. (b) Report for 1927. Fish. Res. Bd.
Canada, MSS 437: 29 pp.

Davidson, Viola, and A. G. Huntsman, 1926. The causation of
diatom maxima. Trans. Roy. Soc. Canada: 3(20), Sect. V.

Davidson, V. M. 1929. The relationship between the abundance of
diatoms and sunlight intensity in the vicinity of Passamaquoddy
Bay for four consecutive years. Ibid: 8(28).

----- 1930. Fluctuations in the abundance of planktonic
diatoms in Passamaquoddy region, New Brunswick. Contr.
Canadian Biol. Fish. N.S. 7(28).

Dawson, W. Bell, 1908. Tables of direction and velocity of
currents and time of slack water in the Bay of Fundy. Ottawa,
15 pp.

Fish, Charles J. 1936a. The biology of Pseudocalanus Minutus
in the Gulf of Maine and Bay of Fundy. Biol. Bull. 70(2):
193-215.

----- 1936b. The biology of Calanus Finmarchicus
in the Gulf of Maine and Bay of Fundy. Biol. Bull. 70(1):
118-141.

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.

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

- Gran, H. H. and Trigve Braarud, 1935. A quantitative study of the phytoplankton in the Bay of Fundy and Gulf of Maine (including observations on hydrography, chemistry and turbidity). J. Biol. Bd. Canada, 1(5), 279-467.
- Hjort, Johan, 1915. Investigations into the natural history of the herring in the Atlantic waters of Canada, 1914. Canada, Dept. Naval Service, Suppl. Fifth Ann. Rep. for fiscal year ending March 31, 1915: 1-38.
- Hachey, H. B. and A. G. Huntsman. Factors determining the hydrography of the Passamaquoddy region. Fish. Res. Bd. Canada, Original MSS #431.
- Hachey, H. B. Circulation of the waters of Passamaquoddy Bay from drift bottle experiments, 1927. Fish. Res. Bd. Canada, Original MSS #430.
- Hachey, H. B. and J. M. Morton. Seasonal variations in the phosphate content of the waters of Passamaquoddy region. Fish. Res. Bd. Canada, Original MSS #223.
- Hachey, H. B. 1934. Probable effect of tidal power on Bay of Fundy tides. Jour. Franklin Inst. 217(6): 747-756.
- 1934. Replacement of Bay of Fundy waters. J. Biol. Bd. Canada, 1(2): 121-131.
- 1935. Tidal mixing in an estuary. J. Biol. Bd. Canada, 1(2): 171-178.
- 1952. The general hydrography of the waters of the Bay of Fundy. (Revised by H.B. Hachey and W.B. Bailey). Fish. Res. Bd. Canada, MSS #455: 62 pp.

- Hachey, H. B. 1955. Water replacements and their significance to a fishery. Deep Sea Research, Suppl. to Volume III: 68-73.
- Harvey, J. M. 1929. The action of light on marine copepods, 1925. Contr. Canadian Biol. Fish. 5(4).
----- 1929. The action of light on marine copepods, 1926. Contr. Canadian Biol. Fish. 5(4).
- Hughes, C.J.A. Report on various intensities of light as a factor in determining the vertical distribution of DIAPTOMUS MINUTUS, 1930. Fish. Res. Bd. Canada, MSS #24: 5 pp.
- Huntsman, A. G. Herring investigations: spawning, and behaviour and growth of the young, summer of 1917. Fish. Res. Bd. Canada, MSS #352: 23 pp.
----- The Passamaquoddy power project. Fish. Res. Bd. Canada, Original MSS #492.
----- The effect of temperature on the availability of herring. Ibid: Original MSS #496.
----- The relative importance of the Passamaquoddy mechanism. Ibid: Original MSS #497.
----- The effect of dams on the Passamaquoddy mechanism. Ibid: Original MSS #498.
----- Conditions in Passamaquoddy Bay. Ibid: Original MSS #499.
----- Passamaquoddy dams and the fisheries. Ibid: Original MSS #500.
----- Effect of strong tidal currents on climate. Ibid: Original MSS #501.

- Huntsman, A. G. Report on spawning area for herring at Grand Manan, Province of New Brunswick. Atl. Biol. Sta. Original MSS #508, 3 pp.
- 1919. Growth of young herring (so-called sardines) of the Bay of Fundy. Canada, Dept. Naval Service, Canadian Fisheries Expedition, 1914-15: 165-171.
- 1928. The Passamaquoddy Power Project and its effect on the fisheries. Saint John, 45 pp.
- 1931. Temperature and the Passamaquoddy fishery. Biol. Bd. Canada, Prog. Rept. (Atl.), No. 2: 14-15.
- 1933. Heat and cold make herring seasons in Passamaquoddy Bay. Ibid: No. 7, 3-6.
- 1933. Mackerel invade the herring nursery. Ibid, No. 8: 4-6.
- 1934. Herring and water movements. James Johnstone Memorial Volume, University of Liverpool, pp. 81-96.
- 1938. International Passamaquoddy fishery investigations. J. du Conseil, 13: 357-369.
- 1952. How Passamaquoddy produces sardines. Reprinted from "Fundy Fisherman", Nov. 26, 1952. pp. 1-8.
- 1952. The production of life in the Bay of Fundy. Trans. Roy. Soc. Canada, Ser. III, 46, Sec. V:15-38.
- 1953. Movements and decline of large Quoddy herring. J. Fish. Res. Bd. Canada, 10(1): 1-50.
- Johnson, W. H. 1935. The food and feeding of the herring (Clupea, Harengus). Fish. Res. Bd. Canada, MSS #195: 60 pp.

- Johnson, W. H. Changes in the vertical distribution of the common free-swimming copepods of Passamaquoddy Bay, New Brunswick. Fish. Res. Bd. Canada, MSS #137: 24 pp.
- 1940. Effects of light on movements of herring. J. Fish. Res. Bd. Canada, 4: 349-354.
- 1940. Feeding of the herring. Ibid, 4: 392-395.
- 1942. Effect of light on copepods as food for Passamaquoddy herring. Ibid, 5: 365-376.
- Ketchum, B. K. and D. J. Keen, 1953. The exchange of fresh and salt waters in the Bay of Fundy and in Passamaquoddy Bay. J. Fish. Res. Bd. Canada, 10(3): 97-124.
- King, Hazel M. 1931. On the occurrence of silica in the waters of the Passamaquoddy Bay region. Contr. Canadian Biol. Fish. N.S. 7(11):
- Klugh, A. B. 1926. The biotic effect of light. Ecology, 6.
- 1930. Light penetration into the Bay of Fundy and Chamcook Lake, New Brunswick. Can. J. Research, 2.
- Leim, A. H. 1943. Seasonal variation in the fatness of "sardine" herring. Fish. Res. Bd. Canada, Prog. Rept. (Atl.), No. 34: 17-19.
- 1956. Review of literature on Bay of Fundy herring. Fish. Res. Bd. Canada, MSS #612: 66 pp.
- Marmer, H. A. 1926. The tide. New York, 282 pp.
- Mavor, J. W. 1922. The circulation of the waters in the Bay of Fundy. Part I. Contr. Can. Biol. N.S. 1: 103-124.
- 1923. Ibid: Part II: 355-375.

- MacFarlane, W. E. 1930. Distribution and migrations of the Bay of Fundy herring, summer 1930. Fish. Res. Bd. Canada, Original MSS #193.
- The distribution and movements of the herring of the Bay of Fundy. Fish. Res. Bd. Canada, Original MSS #445.
- MacGregor, D. G. and H. J. McLellan, 1951. Current measurements in Grand Manan Channel. Fish. Res. Bd. Canada, MSS #432, 13 pp.
- McLellan, H. J. 1951. A survey of water conditions in the Grand Manan Channel in September, 1950. Fish. Res. Bd. Canada, MSS #433, 10 pp.
- 1952. A survey of the water conditions in the Grand Manan Channel in April, 1952. Fish. Res. Bd. Canada, MSS #502, 8 pp.
- Moore, H. F. 1898. Observations on the herring and herring fisheries on the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. Rept. U.S. Fish. Comm. 22: 387-442.
- Morton, J. M. Phosphate content of Passamaquoddy water. Fish. Res. Bd. Canada, Original MSS #404.
- Odell, Emma C. The correlation between light intensity and the bathymetric distribution of marine copepods. Fish. Res. Bd. Canada, MSS #89: 17 pp.
- Stevenson, J. A. 1933. The daily vertical distribution in St. Croix River zooplankton. Fish. Res. Bd. Canada, MSS #197: 18 pp.

- Vachon, A. 1918. Hydrography in Passamaquoddy Bay and vicinity
New Brunswick. Contr. Can. Biol. (1917-18): 295-328.
- Watson, E. E. 1930. Water movements in Passamaquoddy Bay.
Fish. Res. Bd. Canada, Original MSS #193.
- 1930. The probable effect of the Cooper Dam on
the Passamaquoddy region. Fish. Res. Bd. Canada, Original
MSS #316.
- 1936. Mixing and residual currents in tidal waters
as illustrated in the Bay of Fundy. J. Biol. Bd. Canada,
2: 141-208.
- Wright, Nelda E. Report on Calanus Finmarchicus 1928. Fish.
Res. Bd. Canada, Original MSS #324.
- 1925-26. The copepod food cycle. Fish. Res. Bd.
Canada, MSS #87: 33 pp.
- 1926-27. Diatoms - an attempt to determine
their fate. Fish. Res. Bd. Canada, MSS #81.
- 1927-28. The place of the copepod in the food
cycles of the sea. Fish. Res. Bd. Canada, MSS #42: 24 pp.

1900

1901

1902

1903

1904

1905

1906

1907

1908

1909