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Water replacements and their significance to a fishery

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Summary—Attention has been directed to some of the major and more apparent effects that water replacements may have on various fisheries. It has been indicated that such interchanges may be responsible for the destruction of a fish population or the extension of others. The loss of larvae to scallop and haddock areas has been considered as the result of movements of a water mass, and it is suggested that the availability and catchability of certain species is effected by certain water replacement phenomena. When consideration is given to the cycle of life in the sea, it will be quite evident that many indirect effects may follow from these water replacements. While the processes of long-term replacements are not too well understood, wind action is one of the more apparent major casual factors in short-term replacements.

INTRODUCTION

While the changing characteristics of a water mass, such as temperature and salinity, are followed in detail in the study of a fishery, the replacement of one body of water by another is a process which, generally, only attracts attention when the characteristics of the water bodies concerned are in considerable contrast.

Whether it be of the estuary, a coastal area, or the open ocean, the particles of a water mass are never at rest, being subjected to the internal and external forces of gravity, pressure, wind, tide and the Coriolis force. The resultant movements of the water particles under these forces bring about the flushing of estuaries, the replacement of water masses in a bay or coastal area, the removal of water masses from a fishing bank, and the transportation of large masses of ocean water from one location to another.

The flushing of estuaries has been given considerable attention during recent years, due to the need of considering the many problems of pollution. The principles derived from such studies furnish an insight into the mechanism involved in the replacement of waters in a comparatively small area, almost completely land-bound. In contrast, and on an ocean-wide scale, Cooper (1954, 127), has called attention to the large variations in the phosphate content and biological productivity of the English Channel in the last thirty years. He seeks an explanation in the replacement processes involving the replenishing of deep Atlantic water by potentially rich northern waters, these deep Atlantic waters eventually upwelling to determine the nutrient supply of the coastal waters of north-eastern Europe.

Attention is directed herein to many of the direct consequences to a fishery of the various processes of replacement.

THE DESTRUCTION OF A FISHERY

Bigelow and Welsh (1925) describe the disaster to the tilefish, which first came to light in March, 1882, when multitudes of dead fish were observed floating on the surface between the latitudes of Nantucket and Delaware Bay on the Atlantic coast. The area of destruction was at least 170 miles long by 25 miles broad, and covered the entire zone inhabited by the tilefish north of Delaware Bay. It is estimated that at least a billion and a half dead tilefish were sighted. There is evidence to indicate that the destruction of this fishery was caused by a sudden temporary flooding of the bottom by abnormally cold water. It has been shown that the tilefish of the Atlantic coast occupies a very definite environment, for it lives only along the upper part of the continental slope where the water temperatures are approximately 10° C, and never ventures into the lower temperatures on the shoaling bottom nearer land. We have in BIGELOW and WELSH's account of the disaster to the tilefish, a well-documented record of the significance of a temporary incursion of waters of contrasting temperature, which in this case brought disaster to a fishery.

On the basis of present knowledge, the source of the abnormally cold water responsible for such a flooding is to be found to the eastward. A study of the slope water off the Scotian Shelf (MCLELLAN, *et al.*, 1953), has shown that, between the northern boundary of the slope water and the continental slope, there is found in varying quantities a body of cold water, less than 0·0° C off the Grand Banks, and less than 4·0° C east of Sable Island. The quantity of such water, acting as a cushion between the slope water and the continental slope, decreases with westward progression until the slope water generally makes contact with the continental slope to the westward of Emerald Bank. Northerly and southerly migrations of the northern edge of the slope water regime, and westerly progressions and easterly withdrawals of the colder waters along the continental slope, provide the mechanism for producing sharp and sudden changes in the water temperatures on the continental slope and over the outer areas of the continental shelf. While the disaster to the tilefish was of major import, and the westerly progression of cold water must have been greater than normal, similar phenomena on a less spectacular scale have been noted in recent years.

THE EXPANSION OF A FISHERY

In contrast, both as to time and extent, to the temporary incursion of colder waters, bringing about the destruction of a fishery over a limited area, is the historical record of the expansion of the Greenland fishery in recent years with the strengthening of the Atlantic influence in northern latitudes.

Passing over earlier history, about 1820, cod were known to be present in enormous quantities in West Greenland waters, as far north as Disko Bay (JENSEN and HANSEN, 1931). Thereafter, they were absent for a long period of years. Between 1845 and 1849, cod were again plentiful in the Greenland area and then entirely disappeared. From 1917 there was a marked upward tendency in the fishery. The catch increased from approximately 1,000 tons in 1925 to greater than 12,000 tons by 1945, and this fishery has persisted to the present. In dealing with the state of the West Greenland Current up to 1944, DUNBAR (1946) points out that, by 1928, the waters for the west coast of Greenland were considerably warmer than in the preceding period, and that the peak warm year was reached within the period 1930-40. The increasing Atlantic influence however was clearly evident in Latitude 72° N in 1942. A comparison of oceanographic conditions in Hudson Bay and Hudson Strait, as observed in 1930, with those of 1948 (BAILEY and HACHEY, 1951) has shown that the observed higher temperatures and salinities of 1948 are indicative of the increasing Atlantic influence in northern waters generally. A meteorological study of Sherbog (DUNBAR, 1946), has suggested that the warming of the Arctic and sub-Arctic regions from Greenland to Siberia, which has taken place in recent years, is one manifestation of a large scale climatic cycle of a period of about 225 years, which has presumably passed its maximum. It must be stressed here that the expansion of the Greenland cod fishery is associated with the extension of warmer Atlantic waters into more northerly latitudes, although such an extension is probably associated with the climatic cycle.

THE LOSS OF LARVAE

Studies on the replacement of Bay of Fundy waters were initiated some years ago (HACHEY, 1934), and it became evident that the main factors involved in the replacement of these waters were land drainage, wind, and tide. Other things being equal, an excess of south-westerly winds favoured the retention of surface waters within the Bay and thus nullified the normal dynamic tendency for surface outflow and renewal of the waters at greater depths. Under such conditions a type of " closed circulation " is set up within the Bay, as opposed to an " open circulation " when surface waters are carried out of the Bay to be replaced by inflowing deeper waters. During the summer months the " closed circulation " favours higher surface water temperatures, and the surface temperatures, as well as the temperature gradient in the upper layer, can be used as an indication of the type of circulation prevailing. DICKIE (1955) has made use of the temperature data for the Bay of Fundy to show that successful year classes of scallop are produced in those years when the " closed circulation " prevails. Not only do the warmer surface waters hasten development of the scallop larvae to the setting stage, but the " closed circulation " favours the retention of the larvae within the Bay where they settle and grow on suitable scallop bottom. Under the " open circulation " system, as indicated by lowered surface temperatures, the larvae are carried out of the Bay and are lost to the Bay of Fundy scallop fishery.

The replacement of Bay of Fundy waters is not necessarily a regular progressive process, even when the " open circulation " system prevails. KETCHUM and KEEN (1953) have worked out various mean flushing times and exchange ratios for various parts of the Bay of Fundy, and they point out that although their conclusions were based upon the distribution of river water, the same exchanges may be expected for any material or organism transported by the water. KETCHUM and KEEN calculated an average flushing time of 74 days for that part of the Bay of Fundy between Cape Chignecto and a line south of Grand Manan. BAILEY (1953) has shown that within the period October 6th, 1952, and November 21st, 1952, the waters of the Bay of Fundy were almost completely replaced, a replacement that only became apparent when it was found that the salinity throughout a section had increased by more than $0{\cdot}5\,^{\circ}/_{\circ\circ}$ within the period. It might be emphasized that within this period of forty-six days (or less), practically all free-moving larvae in the surface layers would have been carried out of the Bay of Fundy. So too would all free-swimming forms which were feeding at random. The higher salinities as found on November 21st indicate that the replacement involved the inward movement of waters originating from sub-surface depths, and these waters would necessarily carry into the Bay non-swimming forms, and free swimming forms which were feeding at random.

According to WALFORD (1938) the survival of the eggs and larvae of the haddock on Georges Bank is dependent on the variations in the current system in this area, these variations being controlled to a large extent by winds (BIGELOW, 1927, 857). He suggests that the loss of the eggs and larval population in 1932, which occurred some time after the first week of March, was due to the removal by currents. Similarly

Bigelow (1926, 77) wrote: " at the time of our March and April visits (to the north-eastern part of Georges Bank) in 1920, the presence of newly spawned eggs in abundance right out to the 1,000 metre contour proved that a drift out to sea was then taking place from the southern point of the Bank." Walford (1938, 49) states: " there was a very important difference between the circulatory picture in the season of 1932 and that of the corresponding period in 1931. While in 1931 the water movements were such as to permit the bulk of the eggs to remain on the bank and hatch there, in 1932 there were currents carrying eggs off the northern and southern edges into deep water where they were probably lost to Georges Bank." In summary, Walford (1938, 55) points out that a change in the circulatory system on Georges Bank may be disastrous to the haddock brood, and consequently, may be an important cause of fluctuations in abundance.

Carruthers, *et al.* (1951) have directed attention to the variations in brood strength in the North Sea haddock in the light of relevant wind conditions, and the results of these studies have directed considerable effort to the analysis of wind systems as related to other North Sea Fisheries.

AVAILABILITY OF THE FISH

The displacement of surface waters on a grand scale by wind is amply demonstrated by the great ocean currents of the North Atlantic, and the fundamental principles have been thoroughly outlined in the classical work of Ekman (Sverdrup, *et al.*, 1942, 492). Ekman has shown on a theoretical basis that a surface current set up by wind is directed 45° to the right of the wind direction in the northern hemisphere, and this has been shown by observation to be a satisfactory approximation in deep water. In shallow water the deflection of the surface wind current is smaller. A wind blowing parallel to a coast is thus effective in transporting surface waters towards the coast, when the coast is to the right of the wind (*cum sole* from the wind direction) in the northern hemisphere, and away from the coast when the coast is to the left of the wind.

The capture of young herring along the open coasts of the Bay of Fundy and the Gulf of Maine is chiefly dependent upon fixed shore weirs. Huntsman (1934) states: " that the herring are to a considerable extent quite near the surface during the twenty-four hours of the day is not only a matter of direct observation, but a requisite for successful operation of the weirs." Huntsman also states (1934, 96) that " the herring may be treated as a planktonic form ". It then becomes evident that herring in the surface waters, and considered as a planktonic form, will be moved on or off the shore with the varying direction of the wind. This is particularly pertinent on an open coast, such as that of Maine, and the south coast of New Brunswick, where the availability of the herring to the shore-fixed weirs must be determined in part by the varying strength of the prevailing south-west winds during the summer months.

TEMPORARY ADJUSTMENTS IN A FISHERY

Large scale water replacements of a temporary nature sometimes bring about sharp and sudden changes in water temperature, the changes in environment being sufficient to cause a body of fish to either:

(a) move away from a fishing ground, or

(b) cease feeding and thus fail to be attracted to the bait.

The water replacements in the Halifax area associated with the formation and subsequent movement of a tropical cyclone have been described (HACHEY, 1934), and it has been shown that bottom water temperatures in some of the inshore areas increased from 2·0° C to greater than 15·0° C in less than one week. Under these circumstances, in these areas, all fishing for cod and haddock ceases, and does not resume until temperatures return to more normal values (HACHEY, 1934; MCKENZIE, 1934; VLADYKOV, 1933).

Incursions of warmer slope water over the Scotian Shelf have been observed (HACHEY, 1953), when bottom temperatures reached values as high as 12·0° C, about five degrees above normal seasonal temperatures. While no records of fishing effort are available for periods in which such incursions have been observed, it is well known that such bottom water temperatures are unfavourable to cod and haddock, the groundfish probably moving out of the areas subjected to the incursions of waters of such temperatures.

BARREN SEA FLOOR

In the Gulf of St. Lawrence comparatively extreme variations in temperature and salinity have been observed at depth during the summer months (LAUZIER, 1952) brought about by oscillations of the various water layers of contrasting characteristics on a gradually shoaling sea floor. It has been pointed out by LAUZIER that organisms which cannot tolerate these sudden changes in temperature and salinity will not form important populations along the margins of the Magdalen Shallows, and HUNTSMAN (1918) has shown that there are bands of the sea floor between Cape Breton and the Magdalen Shallows which are comparatively barren. The oscillation of these water layers of contrasting temperatures is probably responsible for the periodic complete destruction of scallop beds which become temporarily established and fishable under marginally satisfactory conditions in the Magdalen Shallows (Annual Report for 1953, Fisheries Research Board of Canada, 34).

MARGINAL FISHERIES

In Canadian Atlantic waters, which are contained in the area of confluence of three current systems with waters of contrasting characteristics, extreme contrasts in water characteristics, chiefly temperature, are to be observed. Very sharp boundaries, both vertically and horizontally, are thus encountered, and various marine organisms suitable to one environment (frigid) or another (temperate) exist on a marginal basis. A small vertical or horizontal change in the margin sometimes exerts a very pronounced effect on a fishery.

With progressive warming of the waters during recent years we have witnessed the northerly expansion of successful oyster production in the Gulf of St. Lawrence, and the northerly extension of the green crab to the Bay of Fundy (Annual Report for 1953, Fisheries Research Board of Canada, 25). As mentioned earlier in this paper, the expansion of the west Greenland cod fishery is probably the most outstanding result of the increased Atlantic influence in northern waters. It is to be expected that a downward trend of temperatures would bring about a recession of these extensions.

In some cases, man is responsible for changes in environmental conditions, and this is particularly true in estuaries where pollution problems arise with present-day industrial developments. Of a different nature are the possible changes in the environment of Georges Bay, between Cape Breton and the Nova Scotia mainland, which may follow from the completion of the Canso Causeway. By cutting off the interchange between Gulf waters and those of the open Atlantic through Canso Strait, the strong possibility exists that the waters of Georges Bay will be warmer than heretofore. Slight upward changes in the water temperatures in this area may be sufficient to exert some influence on the lobster populations, and to bring about a southward extension of the oyster populations of neighbouring areas.

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