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Long Term Changes in Hydrography and Fluctuations in Fish Stocks.

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The climatic changes, for series of years so variously manifested all over the world, in particular since the middle of the nineteen-twenties in the arctic, the subarctic, and the temperate areas in and around the North Atlantic ocean, present the most important general problem of present day fishery investigations in the said oceanic areas owing to the influence of the changes on the fluctuations in certain very important fish stocks.

The main question in fishery research and in fishery itself is whether the change in the marine climate as observed in our times will persist over a long series of years, or whether by now it has already passed its peak and is returning to the conditions principally ruling for a century or more, and thus regarded as the normal state. As to this, however, one significant point should be given due consideration, namely: whereas the present warm period evidently is a secular, long term phenomenon, it is important to note that much shorter, irregular variations in temperature, lasting a few years or affecting a certain season in one year only, may show much larger amplitudes than long term variations, and that therefore, temporarily, they may in much greater measure affect, for instance, the production of one or more year classes of cod, and thus in time affect the yield of the fishery to a very high degree.

With a view to setting up a program for research on the correlation between variations in the marine environment and the long term fluctuations in the stocks of the commercially more important species of fish in the North Atlantic, it would be appropriate to look into the following questions: -

What recent changes in the stocks, as regards stock size, migration, etc., may be solely due to long term climatic changes?

What simultaneously observed hydrographic conditions may be considered directly the cause of these changes?

Are there any records available of similar changes in fish stocks and hydrographic conditions from the last two hundred years which yield some information on the duration and frequency of such changes?

What biological and hydrographic observations afford the possibility of future forecastings of good or bad secular periods in the fishery?

The northward shift and the simultaneous increase over a series of years of the magnitude of the stocks of commercially important species of fish must be deemed a surer proof of a climatic maritime improvement than many of the isolated finds of rare exotic fishes and other marine animals. The fact is that for economic reasons fishery has always had on open eye for a rising stock of commercially useful fish in the border areas, and during these past few

generations, at least, fishery has been ready to pursue the fish into the northern areas, when the stocks make an appearance there, and to make the best use of any possible increase. Fishery statistics accordingly yield excellent information upon this subject in spite of obvious deficiencies, particularly in earlier times.

However, the northward dispersion of several southerly species is in many instances so noticeable and the phenomenon so well established that in consequence many data of great value have been recorded during this past generation and have proved that in this concern faunistic information on the appearance of rare exotic animals may be very valuable.

We may mention here, in brief, a few examples taken from the practical fishery to show certain changes that have occurred among commercially important species of fish. The cod is the classical example. The increase in the stock of cod at Greenland in present times is a wellknown fact, reflected therein that the annual yield, for a few years just before the year 1920, approximately amounted to only 350 tons per year (caught by Greenlanders), whereas the catch in 1951 amounted to 168,650 tons (of which about 18,000 tons was caught by Greenlanders). Furthermore, the area of the cod fishery at West Greenland has gradually expanded far northwards pursuing the progress of the fish. Now, moreover, the propagation of the cod largely takes place at Greenland, avoiding the previously recorded migration to the Icelandic spawning grounds. On the eastern side of the Atlantic Ocean the cod fishery also has been extended northward, indicating an increase. Thus, while the catch per hour of British trawlers in the Barents Sea in the period of 1924-1928 yearly averaged 16.5 tons, the corresponding average for the period of 1947-1951 was 72.6 tons. In the Baltic the cod fishery also increased enormously, more so in the last half of the 'thirties; and in this area a total of 10 million kilos was caught in 1935, while in 1949 the total catch by fishermen of all nations was 65 million kilos. Also other economically important species of fish have appeared in increasing number in northern waters; and so an extension of fishery in the direction of the current has occurred. Thus, from the north-eastern area (the Barents Sea, etc.) Haddock and Redfish may be mentioned; at Norway, in the Baltic Sea, and at Greenland an increase in the stock of herring; and in the North Sea an increase in the stock of Sole (the Danish fishery increased from about 200 tons in the 20's to about 3,000 tons in 1951). The fact that certain overfished stocks, at the same time, on account of the increasing fishery has decreased in certain waters, makes no difference to the above observations.

Next, if we consider purely faunistic records made during these past 30-40 years, relating to the northern parts of the Atlantic Ocean and areas adjacent thereto, changes in the fauna are evident; though it must not be overlooked that opportunities for observations on the rarer species, especially in the northern areas, have been augmented with the increasing navigation in these waters and with the easier access to publication of faunistic observations. Even so, there are numerous facts which clearly indicate that southern species have made their way far to the north, while northern (arctic and subarctic) species have lost ground at their recent southern limits and have been forced to retreat further northwards. The conditions have been explored principally at Greenland (by Ad. Jensen and Paul M. Hansen), at Iceland (by B. Sæmundsen and Arni Fridriksson), and at Norway (by S. Johnson). Certain species are

so peculiar or of such size, e.g., the Basking Shark (Cetorhinus), that, if they had been there at all, their earlier appearance in the areas where they have been observed in our days would have been recorded. Hence, since the presence of the mentioned giant among all fishes in our time has been observed, e.g., at East Iceland, at West Greenland, and in Danish waters so far as the western Baltic Sea, while for these last 150-200 years there are no such records from these areas, this fact must be regarded as certain evidence of a great change. Furthermore, when at the same time, the hydrographic observations indicate that the conditions in the invaded areas have come close to the requirements of the said species with regard to the temperature and salinity, the contributory causes seem to be obvious. Many other similar examples may be offered, thus: the occurrence south of Iceland of the Velella; the Caranx, in great quantity at Iceland and the Faroe Islands, and, for the first time, the Alosa finta, the Xiphias, the Gadus pollachius, and others, at Iceland, et cetera. On the other hand, the decline in arctic species should be noted, e.g.; the retreat of the White Whale (Delphinapterus) from certain of the southern areas of West Greenland, and also the Greenland Shark (Somniosus) and other species from these waters.

However, the rising temperature has not been effective only as to distribution, spawning places etc. of the stocks. The influence is noticeable also in the morphology of the fishes. Thus, e.g., in various populations of fish the so-called "racial characters" have undergone a change during the past generation; thus, in certain varieties of herring, which on account of the rise in temperature now possess a lower average number of vertebrae compared with thirty years ago. This phenotypical change, naturally, will change back to the normal state when the environment again becomes normal; and perhaps in the future the phenomenon may be used as an indicator to changes occurring in the sea.

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As is well known, the changes which have taken place in the ecological conditions coincide with rather great changes in the hydrography of the North Atlantic Ocean. Thus, e.g., when the average air temperature at Spitzbergen in the winter has risen about 10°C., and approximately the same at Jacobshavn in North Greenland, then the temperature of the sea has increased by 0.5°C. to about 3°C.; this rise is observed mainly in the northern regions, but also southwards to the sources of the Gulf Stream; and not only at the surface but also in some areas at depths down to 600-800 m. a rise in temperature has been observed. At the same time, the arctic ice has diminished in thickness, and the arctic ice front in the ocean has retreated far to the north, in particular in the Barents Sea and to the east thereof, at Spitzbergen and at Greenland, where the eastern coast was free of ice south from Angmagssalik for some time in the late summers of certain years in the 'thirties.

In this connection the well-known fact should be stressed that almost the entire masses of Atlantic water which reach West Greenland (and for that matter, the arctic regions of the Atlantic Ocean on the whole) pass northwards between Ireland and a position somewhere about 100 n.m. WSW of Ireland at Lat. 50°N. Long. 30°W.

This is the water which carries that increased warmth to the fishing banks of West Greenland, which has produced the rich fishery of recent times. It would therefore seem ideal to commence continuous hydrographic researches in this area, and at the fishing banks north of Lat. 50°N, with the aim to keep under observation the annual and the secular variations occurring in the current of warm water supplied through this ocean gate.

However, here is not the place for details on the hydrographic changes in the North Atlantic Ocean, as such may be found widely in recent hydrographic reports from this area. Up till now we have only slight knowledge of the significance to biological changes of hydrographic factors other than those of temperature, salinity, and such nutrient salts as phosphates and nitrates.

Nor is here the place for details on the various instances where the effect of climatic marine changes has been observed far into smaller waters neighbouring the North Atlantic Ocean. However, also in such adjacent waters considerable and striking effects are observable. With the increased circulation in the Atlantic waters, no doubt caused by an increase in the atmospheric circulation, salter and warmer waters rounding the British Isles to the north have passed into the North Sea, and from there through the Danish waters into the Baltic Sea. E. Goedecke (1952) has observed a rise in temperature of about 0.3°C. to about 1°C in the North Sea, principally in the summer and autumn seasons in the period of 1931-1950 compared with 1901-1930. For the south-eastern part of the North Sea this phenomenon is in some measure due to the simultaneous temperature rise on the neighbouring continent.

It is reasonable to assume that the arctic ice conditions, on broad lines, may be taken as fairly significant indicators of warm or cold periods in the North Atlantic Region. At any rate, we have no other, or only a very few other, reliable facts from earlier times on the oceanic hydrographical conditions than the information gained from the forward and backward movements of the ice front; and only with the hydrographic observations of modern times a more reliable foothold has been obtained. Only very scattered hydrographic observations exist from the first 75 years of the ningteenth century; inter alia, from expeditions of entirely different purpose from that of oceanographic exploration. Consequently, where the problem is the study of changes in the environments in earlier times, there are not many facts to rely on. Surface temperatures recorded since the time when such data on the conditions in the northern seas were more systematically collected, may yield some information; and (according to Jens Smed, among others) there is evidence from several parts of the North Atlantic Ocean that somewhat warmer conditions existed about the period of 1875-1883, and that the present rise in temperature did not properly commence until about 1917-1922, and more markedly after 1925. These, and many other observations (mentioned by Scherhag, Slocum, Sverdrup, H. Thomsen, a.o.), plainly show a rise in temperature in the ocean in recent times coincidental with changes in the stocks of fish and invasions into the northern waters of numerous southerly marine animals. However, the facts from this period are well-known and require no further elaboration.

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For practical reasons it is considered convenient here to summarize the physio-chemical factors which during the present climatic fluctuations have evidently most contributed to changes in the size of the fish stocks, in their migrations, et cetera, and to render a brief account of the direct ecological effects from these factors. Thereby it may be possible to decide on the fields in which future exploration should be planned to take place in particular.

I. The rise in temperature in the sea has, no doubt, been of the utmost importance and may, in effect, have had the following results: -

a. The locality of the spawning places of the fish may in various ways affect the various species: 1. The intensity of spawning at the southern limit of the normal area of distribution of the species may have diminished or even have ceased entirely. 2. The intensity of spawning at the northern limit of the normal area of distribution of the species may have increased, or quite new spawning grounds to the north may have been invaded (e.g., as for cod at Greenland). 3. A rise in the temperature in the deep sea, as has been observed in northern waters down to a depth of no less than 200-600 m., may produce changes both in the locality of the spawning grounds and in the distribution of semi-oceanic or purely oceanic fish stocks, such as, e.g., the Redfish.

b. Nursery grounds of very large northward extent have been opened by the rise in temperature (cf. the dispersion of cod in the Spitzbergen-Bjørnø area and in the Barents Sea, as also at West Greenland). This space factor, undoubtedly, has immensely affected the increase in the stock of cod and has caused changes, as well, in the migration and dispersion of the cod.

c. The increase in food brought about by the rise in temperature affords great opportunities for increased growth of young fish in the northern, warmer areas, inasmuch as food in greater quantity over a large area is of much greater benefit to the species of fish than a particularly heavy increase of food in a smaller, normal area. Increased spawning within the normal spawning area of a species and with normal dispersion possibilities brings about a numerous though slow-growing year class, whereas increased spawning from which the fry may spread over a nursery area much larger than the normal one, affords the year class opportunities of extremely rapid development.

d. The growth period is prolonged by a rise in temperature, especially in the northern regions, and this may further contribute to the improvement of a year class.

e. The lethal threshold of tiny fish larvae is of particular importance to the stocks of fish in arctic-subarctic areas. For various species of fish a certain temperature limit exists, below which the tiny fry are unable to ingest food (probably their muscular activity is impeded) so that they gradually die. For cod this limit seems to lie close to 1.8°C., and now, evidently, in certain spawning areas, temperatures below this limit near the lethal threshold of the species have not so often been the rule as in the cold periods, wherefore several

excellent year classes have cropped up in areas which the cod previously did not use for permanent spawning grounds (e.g. at West Greenland).

II. Variations in the course, velocity and water transport of the oceanic currents are, in conjunction with the temperature factor, of extremely great importance. With a more rapid transport of the water masses, in an otherwise favourable period, the fry and the young fish will be carried to new nursery areas with ample food earlier in the season than in a normal period, when the area of dispersion in the vicinity of the spawning area will be over-populated early in the season (cf. the cod at West Greenland, Spitzbergen, and in the Barents Sea). With the quicker and more voluminous water transport many southern boreal and sub-tropical species have been carried far to the north, where they have displaced the more northern species.

III. It is probable that, with the increasing masses of Atlantic warm water, important nutrient salts, such as nitrates and phosphates, in greater quantity than formerly have been put into circulation in the production in the northern seas and in inner waters, such as, e.g., the Baltic Sea.

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When in order to bring light to bear on the present warm period, we now raise the question whether similar warm periods of importance to fishery are known from former times, this question, as is well known, can be answered in the affirmative. However, the first accounts of any value, with reference to important changes in fishery, derive from a period near the close of the nineteenth century and the time thereafter, and, unfortunately, not until the eighteen-seventies have more detailed, simultaneous hydrographic observations been recorded, as a matter of fact, almost only covering these last fifty years. It is from the arctic-subarctic areas, principally, that clear or fairly clear observations are available.

From the North Atlantic area (according to Ad. S. Jensen, a.o.) we have mainly records of the cod fishery, proving fluctuations in the occurrence of cod along the West Greenland coast. These reports have been further added to in recent times by valuable observations from Norway-Spitzbergen. The warm periods thus accounted for naturally have been of importance not only to the stocks of cod, but also to other commercially valuable fish and to the marine fauna in general.

Some time in the period of 1810-1823, cod is said to have been particularly numerous at West Greenland, along the entire coastal region from Julianehaab to Disko Bay. There is various evidence to the fact that this period must have been mild in the North Atlantic Ocean; thus, some southern species of fish were observed at Iceland about that time.

The next period falls between 1845-1849, when catches of cod made by British fishing vessels were said to be good even so far north as the Disko Bay. There is no certainty whether this and the earlier mentioned period were results of temperature rises in the sea equal to the one prevailing now; but those shorter warm periods were probably less effective than the present one. During the first half of the nineteenth century (in particular about 1840-1854), the spread of ice at Greenland was less than during the last half of the century, when the presence of heavy masses of ice was the rule in most of the years. On the whole, the nineteenth century was richer in ice than this present century.

We have no reports from the last half of the nineteenth century covering periods with striking occurrences of cod at West Greenland. American fishermen, it is true, found Halibut on the banks in great quantity during 1866-1881, but cod, at any rate, was not abundant there (Scudder). However, various observations of temperature, made in the Greenland area, indicate that in the 'seventies and 'eighties a warmer period prevailed (Kiilerich, Dunbar). On the other hand, from this period, more particularly in 1873-1882, the cod fishery afforded rich catches in the Spitzbergen area. And other known records of southern animals appearing about this time in the north prove that in the Atlantic Ocean at any rate, and perhaps particularly there, warm water in richer supply than the normal was experienced. It may be added that the Northeast passage was navigated for the first time during that period.

The period, especially in the years 1873-1884, is known to have been warm in the southern part of the North Sea. Those years were followed by a period of lower temperatures, which changed again about the year 1915, and especially about the year 1931, into the present warm period (Goedecke 1952). In good agreement with the statements from the Spitzbergen fishery is the fact that the fishery at Lofoten (on spawning fish grown up in northern waters) during the period of 1865-1897, approximately, was a rich one, which again was followed by a poor period, until the present rich period began to show up, in particular since 1927. In the Spitzbergen area was no cod fishery during the period 1883-1925, whereupon a rich fishery began again. It is not known, however, when exactly the cod again invaded the Spitzbergen area in the present century. The present favourable period began at West Greenland about the year 1917, when, as we know, a specially good year class was born. An increase was particularly noticeable, however, from the year 1926, when the unusually rich year class of 1922 dominated in the catches of the Greenlanders.

Thus it seems evident that in the course of the previous century we had three warm periods in the North Atlantic area; i.e., about 1810-1923, about 1840-1850, and about 1873-1882, and that the longer and warmer period of our present century, which from a meteorological point of view, perhaps, was traceable initially one and a half century ago, or more, first became noticeable about the year 1915, increased in the 'thirties - 'forties, and now perhaps is on the wane. Important data on the chronology of the periods are available in scattered faunistic records (on fishes, birds, etc.). Very many records of southern indicator species in northern areas incidentally occur just in the periods stated; thus at Iceland, Norway, and Greenland.

It may be added here that in this century (in particular after the year 1910), the ice masses at East Greenland, down south and round Cape Farewell to the west coast, are so much diminished that we have to look back largely to the period of 1400-1600 for evidence of similar conditions.

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When the author, being a fishery biologist, now has to propose a long term programme for observing or, as the case may be, forecasting the periods of fluctuation in the great northern fisheries, more particularly for the cod fishery, he may perhaps suggest, with reference to the above account, that the hydrographic observations be so planned that changes in temperature, at any rate in the upper 500 m. of the open sea, should be observed in the region where the Atlantic waters west of Ireland (between Ireland and a position about Lat. 50°N. Long. 30°W) flow northwards and disperse over the eastern and western areas of the North Atlantic Ocean. Observations in this particular region, it would appear, is the most essential part of a programme aiming at exploring climatic changes in the North Atlantic Ocean. Also changes in the water masses to the north of Lat. 50°N. should be observed in sections across all the important fishing banks; and, at the same time, changes in the important cold currents (the Labrador current, the East-Greenland current, and the East-Iceland polar current) should also be explored. Quarterly observations would probably be sufficient for this purpose, and it is considered that observations on temperature, salinity, contents of phosphates and nitrates, currents and ice conditions will be necessary.

By carrying on the fixed long term programmes of recent years, and by improving the fishery statistics, the fishery biological part of the programme will, no doubt, be adequately covered.

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More than twenty years have passed since fishery biologists first realized that evidently a warm period was becoming a fact. However, whether this period, as some people think, is now petering out, or whether it will continue, nobody knows just now with any degree of certainty. At any rate, we have not in the past century and a half had a better opportunity of closer studying the effect of such a warm period on the distribution of the fish, their migrations, growth, etc. Whether, therefore, we are at the close of a warm period, or in the middle of it, or whether it will continue into the distant future, it may be of far-reaching importance to future exploration in this field, if we now endeavour to follow the course of events, both by comprehensive hydrographic observations and by observing the effects on the distribution, life history, etc. of fish and other marine animals. Whereas much research is being done in the latter field, possible of application to the elucidation of the influence of climatic changes, there seems to be lacking such co-ordinating forces in the hydrographic observations as may enable marine biologists sooner or later to determine the exact physio-chemical causes, both in the coastal areas and in the open northern Atlantic Ocean; causes which -

by short term as well as long term changes - may have produced the observed fluctuations in the stocks of fish, changes in the course of migration, etc.; hence, matters of the greatest importance to fishery which, in future, to some extent may make it possible for fishery biologists to predict changes in the great fisheries of the utmost importance to the economy of the subarctic fisheries of several countries and to the fishery policy of these countries.

It would badly serve to repeat the fatal error committed at the beginning of this century by The International Council for the Exploration of the Sea (ICES), when after a few years they discontinued the scheme of quarterly sections of stations, which had been established over the North Atlantic Ocean for the very purpose of keeping watch on the changes. Anyone who has been working in this area for many years, has no doubt often wished that this systematic work has been continued in one form or other. We should then have known considerably more than we do now, inter alia on the causes of some of the great fluctuations in the fisheries.

- THE END -