SECTION

H

H-1

RECENT CHANGES IN THE BENTHOS OF THE WEST SPITSBERGEN FISHING GROUNDS

By

R.W. Blacker[1]

INTRODUCTION

In 1957 the writer published some of the results of the examination of benthos collected by the R/V *Ernest Holt* during research cruises to Svalbard in the period 1949-55. (Svalbard is the Norwegian name for the area including Spitsbergen, Bear Island and Hope Island). These data showed that there were many benthic species which were characteristic of one or the other of the two main water types, Atlantic and Arctic. Several hundred benthic species were identified. Of those most commonly caught in the trawl or most likely to be caught, seven were selected as being indicators of Atlantic conditions and nine were selected as indicators of predominantly Arctic conditions. The seven Atlantic water indicators were: the sponge *Geodia barretti* Bowerbank; the decapod crustacea *Lithodes maia* (Linnaeus) and *Sabinea sarsi* Smith; and the echinoderma *Ceramaster granularis* (Müller), *Pseudarchaster parelii* (Düben and Koren), *Hippasteria phrygiana* (Parelius) and *Gorgonocephalus lamarcki* (Müller and Troschel). The selected indicators of Arctic conditions were: the crustacea *Sabinea septemcarinata* (Sabine) and *Sclerograngon ferox* (Owen) and the echinoderma *Heliometra glacialis* (Leach), *Poliometra prolixa* (Sladen), *Hymenaster pellucidus* Thomson, *Lophaster furcifer* (Düben and Koren), *Gorgonocephalus eucnemis* (Müller and Troschel), *G. arcticus* Leach and *Ophiopleura borealis* Danielssen and Koren.

Plotting the recent distribution of these species up to 1955 clearly showed the areas where the Atlantic water of the West Spitsbergen Current was the predominant hydrographic influence. When this chart was compared with one showing the distribution of the same animals compiled from research cruises made between 1878 and 1931, it was found that Atlantic species had spread northwards along the west coast of Spitsbergen as far as 78°N and that few Arctic species were caught on banks where previously they had been recorded as abundant.

RECENT RESULTS FROM WEST SPITSBERGEN

The results from 1949 to 1955 showed that striking changes had taken place in the benthos off West Spitsbergen, but too few stations had been worked to determine the full extent of the changes. From 1955 to 1959 records of the selected indicator species were obtained from about one hundred additional positions off West Spitsbergen, on the banks northwards from 76°N lat to 80°09'N on the Norske Bank.

These new records show that by 1959 the ranges of *Geodia, Lithodes* and *Hippasteria* extended to at least 79°30'N and that *Sabinea sarsi* had reached 80°09'N. North from 79°N the edge of the bank between 100 and 200 fathoms has not been fished because it slopes steeply and is rough. Two attempts to survey this area in the summers of 1957 and 1958, using underwater cameras, were unsuccessful because of bad weather and ice conditions.

Nesis (1959) gives the results of Russian work off West Spitsbergen during the period 1946-58, adding the material from 155 stations to the present author's published data (Blacker, 1957). Using 23 boreal species and 42 Arctic species, his records show that the Atlantic species *Sabinea sarsi* and *Lithodes maia* (amongst others) occurred as far north as 80°55'N, 17°12'E at a depth of 477 m (261 fathoms). *Gorgonocephalus eucnemis* and other Arctic species occurred at the same station. Nesis states that "only a few of the more hardy north-boreal species penetrate further to the east". Figure 1B summarises the records of indicator species for the period 1949-59 (Russian stations are not included). Comparison with Fig. 1A, which summarises the period 1878 to 1931, shows

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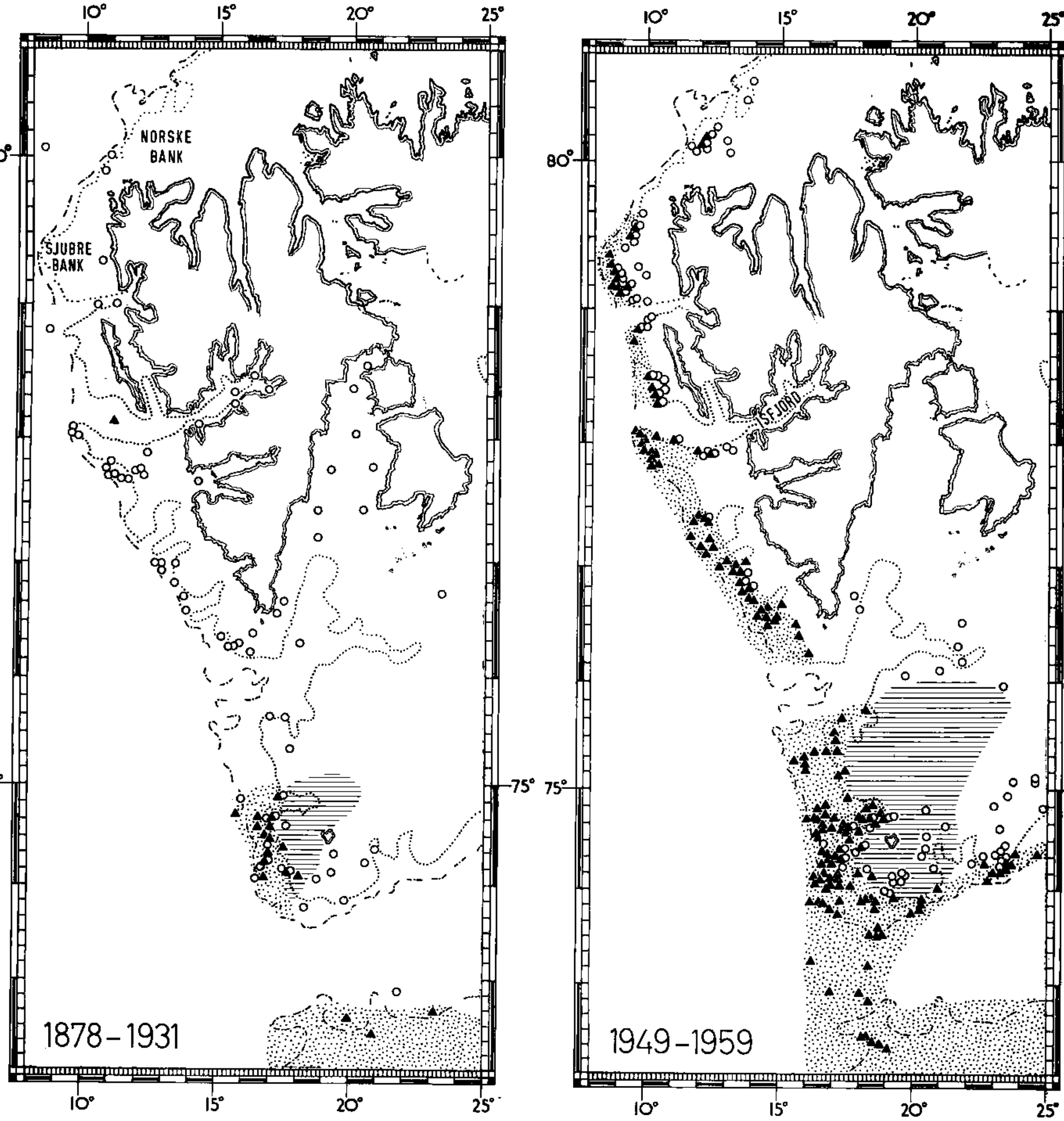

Fig. 1. Summary charts of the distribution of Atlantic species (▲) and Arctic species (O). A. All past records, 1878-1931. B. Present records, 1949-1959 (excluding recent Russian data).

The stippled area indicates the bottom where Atlantic conditions predominate, as deduced from the occurrence of Atlantic species. Comparison of A and B shows how much the Atlantic influence has increased since 1931. The hatched area covers places where conditions may vary from Atlantic to extreme Arctic; similar areas may occur in shallow water off Spitsbergen.

a 300-mile northward spread of Atlantic species along the course of the West Spitsbergen Current during the past 30 years. In addition, from Norwegian researches there are records of the boreal species *Sabinea sarsi* (in 1958) and *Lithodes maia* (in 1960) from the entrance to Isfjord where they had never been found before (Christiansen and Christiansen, 1962).

DISCUSSION

It must not be inferred from the latest data that the spread of Atlantic species northwards has gone on since the period 1949-55. This may have happened, but the data from that period only showed that a change had taken place and they were insufficient to give a basis for inferring a continuation of the warming-up process. As before, the latest records include a number of anomalous ones from the northernmost banks where Arctic species, in particular *Sabinea septemcarinata*, *Heliometra* and *Gorgonocephalus eucnemis*, were found in water warmer than 2°C. From depths greater than 80 fathoms the anomalous records are of small specimens, few in number, and thus are of little significance. However, in shallower depths, especially on the Norske Bank, these Arctic species are abundant where high temperatures have been recorded. All these records have been obtained during July to October when the water temperatures reach their summer maximum, so it is probable that the shallower parts of these banks are covered with warm water for only a short season each year. There are no hydrographic observations from the winter months, when warm temperatures would perhaps indicate that a change to predominantly Atlantic conditions was taking place. The presence of breeding *Sabinea sarsi* on the Norske Bank shows a considerable Atlantic influence there but insufficient work has been done to determine its full extent. There may be some Atlantic benthos all the way along the edge of the shelf from the Norske Bank to about 81°15'N near Northeast Land, where the West Spitsbergen Current flows away from the continental shelf over the deep cold water of the Arctic Basin. It is here that the benthos should first show signs of a general cooling of the Arctic.

How long it takes for cooling down to affect the benthos is not known. The mechanism by which the recent changes in the distribution of the benthos could have been produced, by variations in the strengths of the warm West Spitsbergen Current and the cold East Spitsbergen Current, was fully discussed in the earlier paper (Blacker, 1957). Nothing new has been found out about the ability of the indicator species to withstand adverse conditions produced by changes in the currents. It may take only a matter of months for some of the species to be killed, while the less sensitive ones may perhaps survive for a year or longer apparently unaffected.

From recent hydrographic observations there are indications that the warming-up of the Arctic has stopped and that cooling may have started. According to Timofeyev (1961) the mean annual temperature of the Atlantic water entering the Arctic Basin was less than average from 1957 to 1960 and in the latter year the discharge of Atlantic water and heat into the Arctic Basin was the lowest on record for the period 1933-60. It is hoped therefore that a more detailed survey of the benthos of the critical area on the northern banks will be carried out before any major change takes place. As ice conditions there make regular hydrographic observations in winter difficult or impossible to obtain, basic data for the detection of changes in the distributions of the indicator species are important.

SUMMARY

1. The results of a benthos survey of the Svalbard region from 1949 to 1955 showing changes in the distribution of selected species during the past thirty years are reviewed.

2. Summary charts for the periods 1878 to 1931 and 1949 to 1959 are given, showing the spread northwards of Atlantic species since 1931.

3. Anomalous results from the northernmost part of the area are discussed.

4. The importance is stressed of surveying the northernmost part of the area soon, before any major climatic change takes place.

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H-2

ANOMALIES OF SEA TEMPERATURE AT STATION 27 OFF CAPE SPEAR AND OF AIR TEMPERATURE AT TORBAY-ST. JOHN'S

By

Wilfred Templeman[1]

ABSTRACT

Average yearly and part-yearly sea temperatures for 1950-62 at Station 27, 176 m deep, 2 nautical miles off Cape Spear, near St. John's, were expressed as anomalies of mean temperatures during this period. For the yearly means, the general trend in the upper water layers was that of higher than average temperatures in the years at the beginning and end of the period with an intervening period of lower than average temperatures. Over the whole period there was a slight downward trend which was more evident at the deeper than at the shallow levels. For January-May there was a slight but definite downward trend in temperatures from the beginning to the end of the period. In June-December temperatures at the shallower levels were equally high toward the beginning and end of the period with low temperatures in intervening years and no declining trend. In the deeper water there was a declining trend. Mean sea temperatures especially at the surface generally agreed extremely well with air temperatures in the same year at Torbay-St. John's.

At Torbay-St. John's mean yearly air temperatures rose from a low level in the 1880's and showed only a very slight decline from 1890 to the mid-1920's although there were many fluctuations. Mean annual temperatures have been generally above average since the 1930's and were highest in the early 1950's. December-April air temperatures rose until about 1890, remained approximately the same until the early 1900's and then gradually fell until the 1920's. Temperatures have risen again to above average since the late 1920's with the highest temperatures of the period in the early 1950's. May-November air temperatures fell from the 1870's to the early 1900's and then gradually rose to above average in most of the period since the early 1920's. Temperatures in the 1930's were the highest of the period.

The relationships of these air-temperature trends with trends in air and surface temperatures of neighbouring sea areas are discussed.

INTRODUCTION

Intermittently since 1946 and regularly at least once or twice a month from 1950 onward temperatures at standard depths from surface to bottom have been taken at Station 27 which is situated 2 nautical miles off Cape Spear, near St. John's, Newfoundland at 47°31'50"N, 52°35'10"W in 176 m. Occasionally a monthly observation is missed when the area is covered with ice but usually on such occasions the whole water column is at a low temperature both before and after the arrival of the ice and it is possible to interpolate temperatures with considerable accuracy. The research vessels used were the *Investigator II*, the *A.T. Cameron* and the *Marinus*.

The average temperature picture at this Station for the years 1950-62, the basic period taken for the averages used in calculating the temperature anomalies, is shown in Fig. 1. In calculating the anomalies the whole yearly period was taken and also the period January-May, the coldest period in the sea at Station 27 and the time when cod fishing on the east coast of Newfoundland is at its lowest level, and June-December when cod are more generally available near the east coast.

Mean daily, expressed as mean monthly, air temperatures for the St. John's and the neighbouring Torbay Airport stations have been obtained for recent years from the published monthly records of meteorological observations in Canada and for earlier St. John's records directly from the Office of the Meteorological Branch of the Department of Transport at Torbay. Also, since air temperatures are available for Torbay-St. John's back to 1872 but sea temperatures only since 1950, a comparison with Torbay mean air temperatures has been made during the 1950-62 period based on anomalies of the

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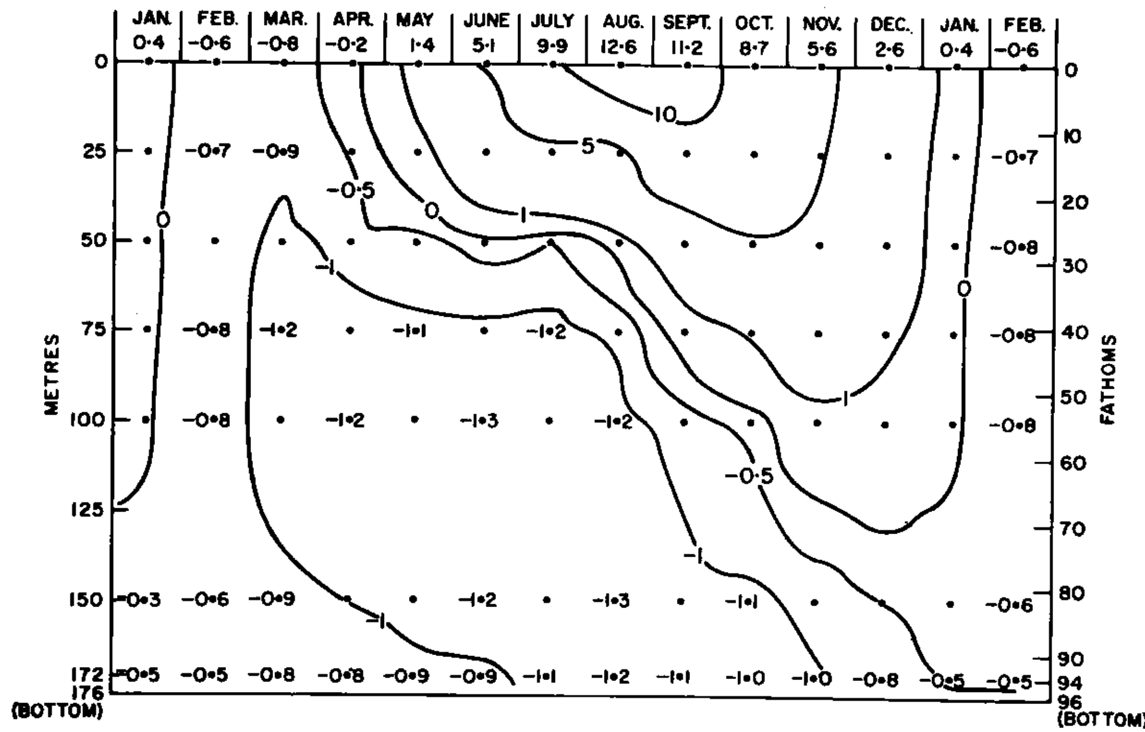

Fig. 1. Average sea temperatures (°C) at Station 27, 2 nautical miles off Cape Spear, near St. John's, Newfoundland. (Average mid-monthly temperatures at the depths indicated, for 1950-62. Position of station, 47°31'50"N, 52°35'10"W, 176 m).

average air temperature during this period and, based on the 1872-1962 average air temperature, anomalies of air temperature Torbay-St. John's back to 1872. The recent records of air temperature on which the 1950-62 average is based are from Torbay Airport, about 5 km from St. John's, and complete daily records of mean temperatures are available for Torbay for 1942-62. Consequently the 1942-62 mean air temperatures used are Torbay temperatures. Since 1942 there have been 9 years when complete records of mean daily temperature for both Torbay and St. John's are available. Comparison of the average temperature for those 9 years shows the St. John's yearly (and also the December-April and May-November) average temperature to be 0.56°C (1.0°F) higher than that of Torbay and the St. John's mean temperatures prior to 1942 have been reduced by this amount to convert them to the Torbay level before calculating anomalies.

In practice both for Station 27 and the air temperatures the mean monthly temperatures have been used and the mean yearly temperatures calculated directly from these without allowance for the differing number of days in the months. For air temperature summaries for comparison with the averages for Station 27, because air temperatures can be expected to have a delayed effect on water temperatures, averages have been made for the whole year and from December of the previous year to November of the year under consideration. Also to compare with the Station 27 January-May and June-December averages air temperature averages have been made from December (of the previous year) to April, the coldest air months, and from May to November.

Temperatures on the same date are needed for comparison and Station 27 could usually be occupied only at varying dates on the outward and inward passages of research vessels. Hence mid-monthly temperatures at the various standard levels were obtained from graphs of temperatures throughout the year at each level.

Temperatures of 25 m water columns have been used in obtaining averages. These water column temperatures have been obtained by averaging the shallower and deeper temperatures of each 25 m column. Thus temperatures at the surface and at 25 m have been averaged to give an average temperature for the 0-25 m column and similarly temperatures were derived for the 25-50 m and each additional 25 m column. A mid-monthly temperature at the 125 m level was interpolated. The average temperatures of the 25 m water columns were used in calculating the average yearly temperatures in the various water columns of Fig. 2-4. For some purposes such as development of pelagic eggs the surface and upper-layer temperatures may be of most importance whereas for adult inshore cod of the east coast over most of the June-December period the 25-50 and 50-100 m levels are most important. Anomalies in temperature are therefore provided for various portions as well as the whole of the water column.

ANOMALIES OF WATER TEMPERATURE AT STATION 27

In Fig. 2-4, apart from the greater amplitude of the anomalies at the surface and in the shallower water columns, the various portions of the water column at Station 27 usually have similar relative temperature anomalies and trends.

For the whole year (January-December) all portions of the water column (Fig. 2) had higher than average temperatures for 1951-53 and 1958, and lower than average temperatures in 1954, 1957 and 1959. For 1960-61 temperatures were somewhat higher than average in the shallower water columns and slightly below average in the water columns including the deepest water. Temperatures in 1955-56 were below average in the shallower and slightly above average in the deeper water columns. The year 1950 was generally slightly below average. The general trend at the shallower levels was that of higher than average temperatures in the years at the beginning and end of the period with an intervening period of lower than average temperatures. Over the whole period there was a slight downward trend which was more evident at the deeper than at the shallow levels.

The January-May anomalies (Fig. 3) provide the same general year by year picture as for the whole year, the most noticeable yearly difference being the distinctly below average temperatures in 1961. There was also a slight but definite downward trend in temperatures with no significant recovery toward the end of the period.

In June-December (Fig. 4) temperatures at the shallower levels were equally high toward the beginning and end of the period with low temperatures in intervening years and no declining trend. In the deeper water a declining trend is evident. The yearly temperatures for this period, however, usually followed the same trends as those of January-May (Fig. 3) with the notable exception that temperatures in 1961 were well above average from June to December and well below average from January to May. The relative differences at different levels between the anomalies in these colder and warmer months in 1961 are responsible for the yearly temperatures in this year being above average at the shallower depths and average or slightly below average when the deeper parts of the water column are included.

Also 1960 was well below average, except in the surface layer, in June-December and average or slightly above average in January-May. Over the whole year this results in somewhat above average temperatures in 1960 in the surface layer and below average temperatures in the deeper and whole water columns.

ANOMALIES OF AIR TEMPERATURE AT TORBAY-ST. JOHN'S

Years 1950-1962

For the period, both for January-December and December-November air temperatures there was a fairly close agreement with temperatures of the upper layers of the sea (Fig. 2). For the whole water columns, also, there was some agreement with air temperatures but the pattern of agreement was not so close as for the surface layers. Air temperatures showed a slight downward trend during the period.

In most years December-April air temperatures showed a close agreement with the average temperatures of the surface and of all water columns in January-May (Fig. 3).

For May-November air temperatures generally followed the same yearly trend as water temperatures in June-December at Station 27 (Fig. 4). Agreement was best with temperatures at the surface and at the upper water levels. Although in December-April air temperatures showed a definite downward trend over the period, for May-November air temperatures held level with equally high levels at the beginning and end and low temperatures in the middle of the period.

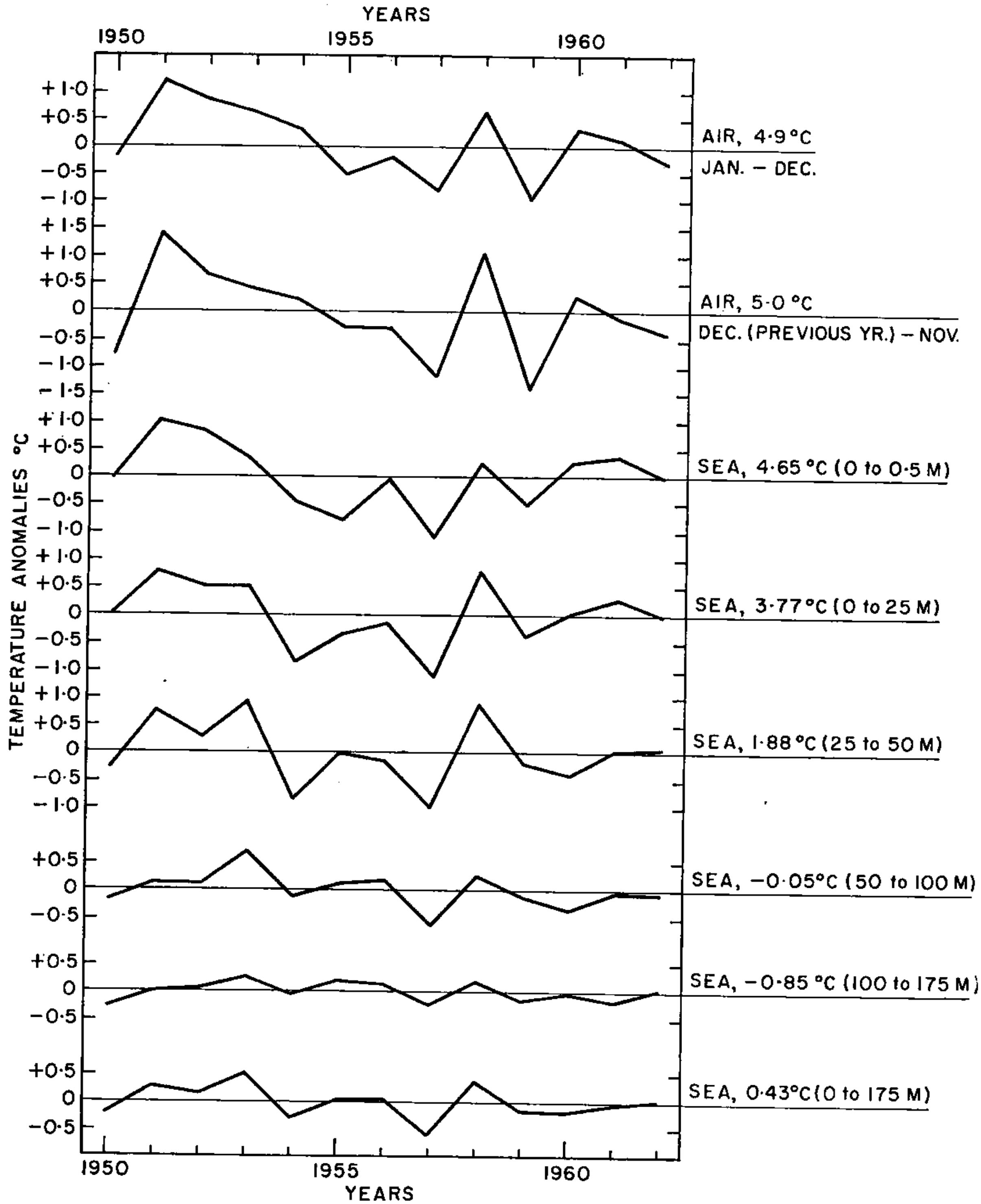

Fig. 2. Anomalies of yearly sea-surface and water column temperatures at Station 27 and of air temperatures at Torbay-St. John's, from average yearly sea and air temperatures, respectively, for 1950-62.

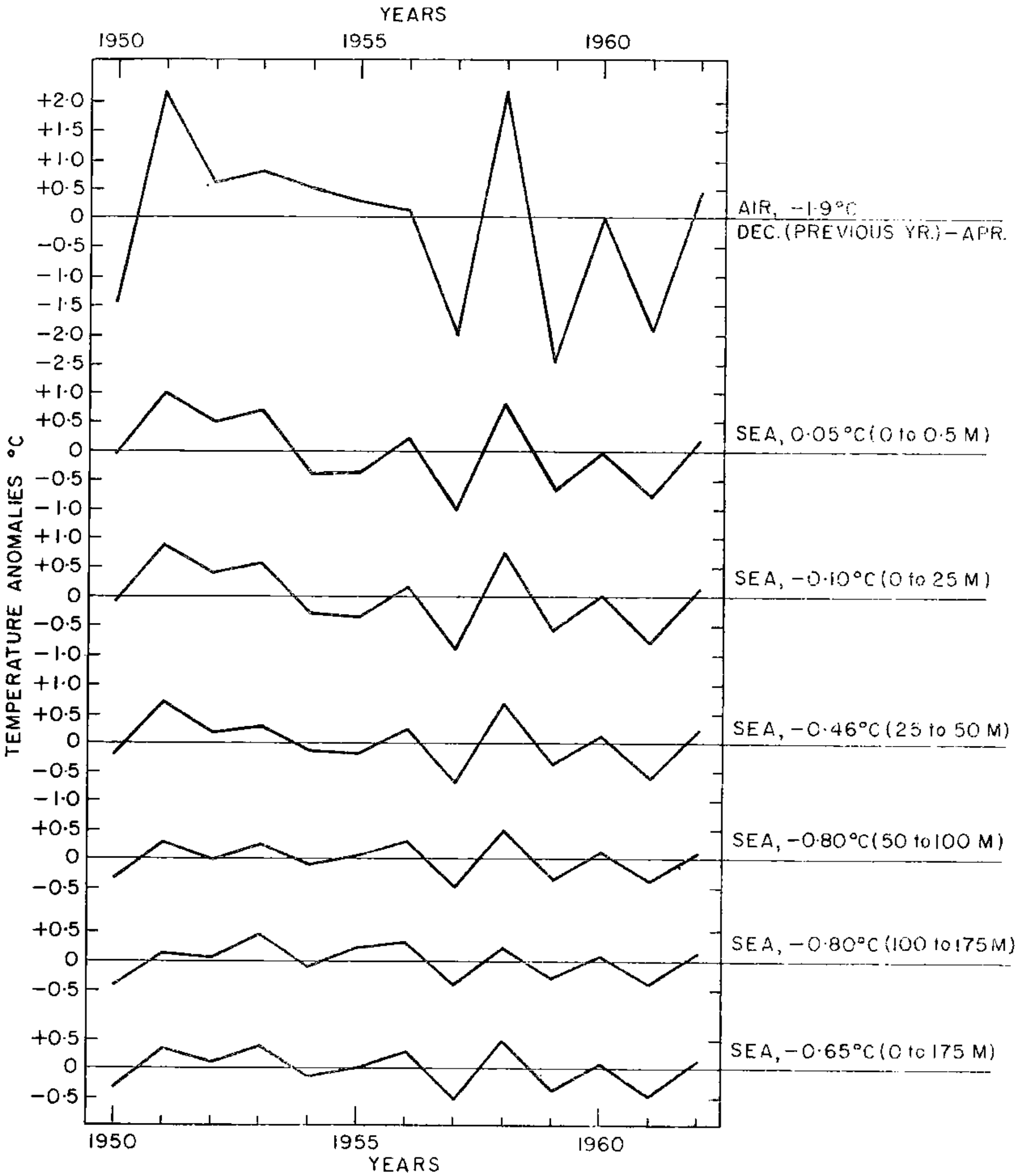

Fig. 3. Anomalies of yearly January-May sea-surface and water column temperatures at Station 27 and of December (of previous year) — April air temperatures at Torbay-St. John's, from average temperatures during these periods for 1950-62.

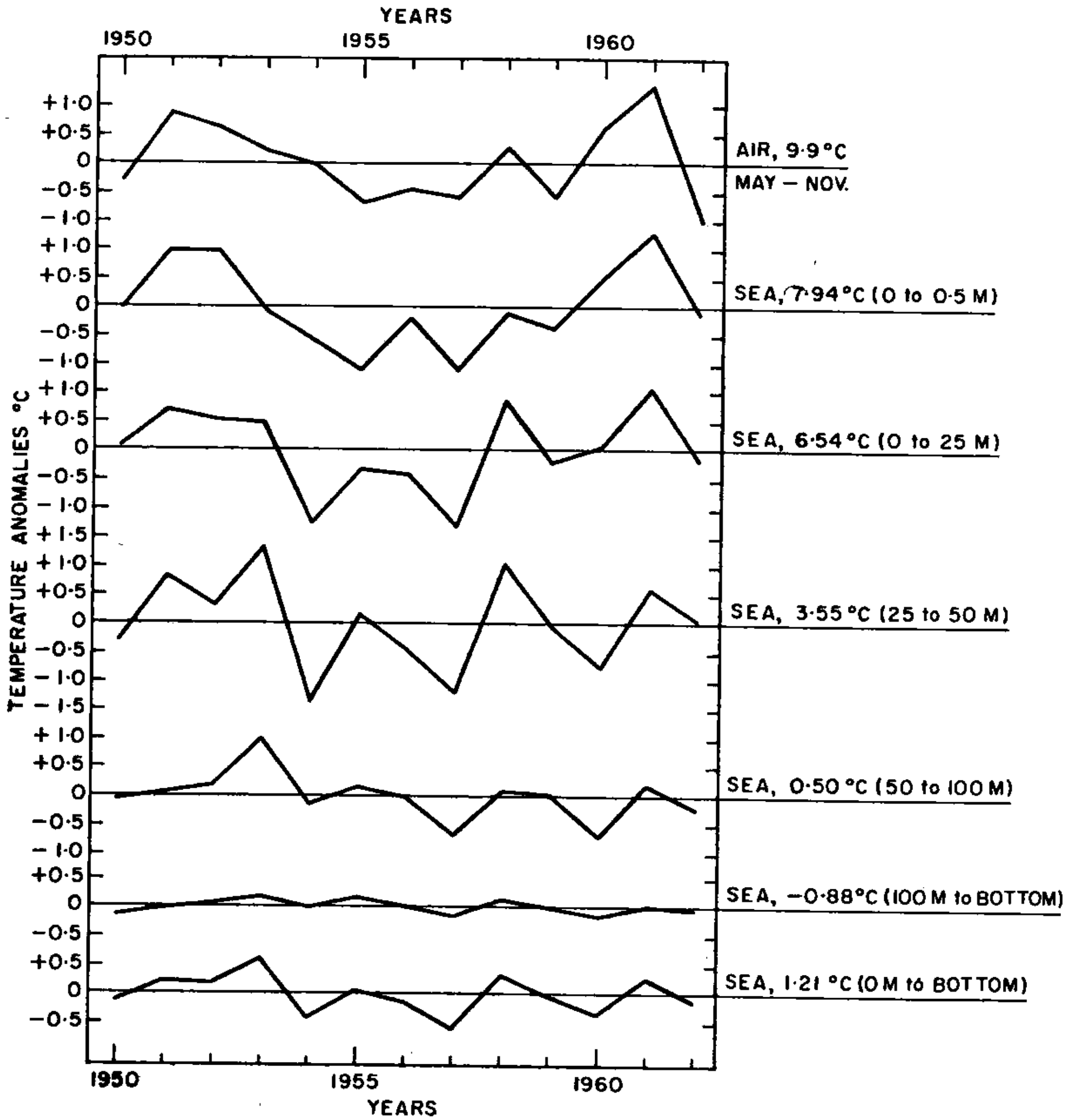

Fig. 4. Anomalies of yearly June-December sea-surface and water column temperatures at Station 27 and of May-November air temperatures at Torbay-St. John's from average temperatures during these periods for 1950-62.

In air temperatures as in the sea, 1961 had higher than average temperatures during the warmer months (Fig. 4) and lower than average temperatures during the colder months (Fig. 3).

In comparing sea and air temperatures it is better to follow trends in a series of years than to compare within individual years above or below the average line. Sea temperatures at Station 27 are limited in a downward direction at about -1.8°C whereas the lower values for air temperatures are much more variable. Also in a station so close to shore the prevalence of onshore and offshore winds will have a great influence regardless of the air temperature. Station 27 is also taken relatively infrequently compared with daily mean air temperatures.

Years 1872-1962

With all the possibilities for disagreement it is surprising how well the air and sea temperatures for 1950-62 followed the same pattern. Thus it appears worth while to study the pattern of air temperatures of Torbay-St. John's back to 1872 as being generally representative of sea temperatures, at least in the surface layers (Fig. 5). Mean yearly air temperatures rose from a low level in the 1880's and showed only a very slight decline from 1890 to the mid-1920's although there were many fluctuations. Temperatures have been generally above average since the 1930's and were highest in the early 1950's.

December-April air temperatures rose until about 1890, remained approximately the same until the early 1900's and then gradually fell until the 1920's. Temperatures have risen again to above average since the late 1920's with the highest temperatures of the period in the early 1950's.

May-November temperatures fell from the 1870's to the early 1900's and then gradually rose to above average in most of the period since the early 1920's. Temperatures in the 1930's were the highest of the period.

DISCUSSION AND CONCLUSIONS

Air and Sea-surface Temperature Trends in the North Atlantic

Many authors including Ahlmann (1949), Jespersen (1949) and Taylor et al. (1957) have shown gradually increasing annual air temperatures in areas bordering the North Atlantic since the latter, and often, especially for winter temperatures, the earlier part of the nineteenth century. The greatest increase has been during the colder part of the year.

Smed (1949) for surface temperatures in various areas of the North Atlantic, 1876-1939, demonstrated that a temperature increase began about the mid-1920's.

Goedecke (1952) for most of the Stations on the Norwegian Coast and in the area between Scotland, Iceland and Norway showed sea-surface temperatures declining at some stations slightly, and at others steeply, from the 1880's to the late 1910's and early 1920's and beginning to rise rapidly in the later 1920's or early 1930's. A decline occurred in the late 1930's and early 1940's followed by a further rise continuing to at least 1950. In the southern North Sea surface water temperatures probably declined from the 1880's to the early 1910's with a slow rise to about 1930 and a more rapid rise thereafter to at least 1950 after a decline in the late 1930's and early 1940's.

Stefánsson (1954) has shown increases in mean sea-surface temperatures off northern Iceland dating from the beginning of the twentieth century, with a more rapid increase beginning in the 1920's and a decline in the 1940's.

Hermann (MS, 1961) has reported for West and South Greenland sea-surface temperatures (April-September and April-October respectively) declining slightly in a series of fluctuations from 1876-80 to the early 1920's and thereafter increasing rapidly to a peak in the late 1920's and early 1930's and declining to a lower but still above average level in the intervening period to 1956-60.

Air and Sea-surface Temperature Trends in the Eastern Canadian Area

For areas more closely related to the St. John's area, Thomas (1955) found for the southeastern Atlantic Coast of Canada annual air temperatures declining from the late 1890's to the early 1920's and from then increasing to the 1950's but with a recession from the late 1930's to the early 1940's. The decrease to a low in the 1920's and the increase to a high in 1950 were both greater in winter than in summer.

Both winter and summer trends in these Nova Scotian area air temperatures are generally similar to those for the colder and warmer periods at Torbay-St. John's (Fig. 5). For the warmer months, however, in the Nova Scotian area there was a slight decline in temperature between the early 1900's and about 1918 with a rise thereafter whereas in the Torbay-St. John's data (for a longer series of months) the rise began about 1903. As a result the Nova Scotian yearly temperatures show a definite decline from the 1900's to the early 1920's but the Torbay-St. John's yearly temperature curve is relatively level or shows only a very slight decline during this period.

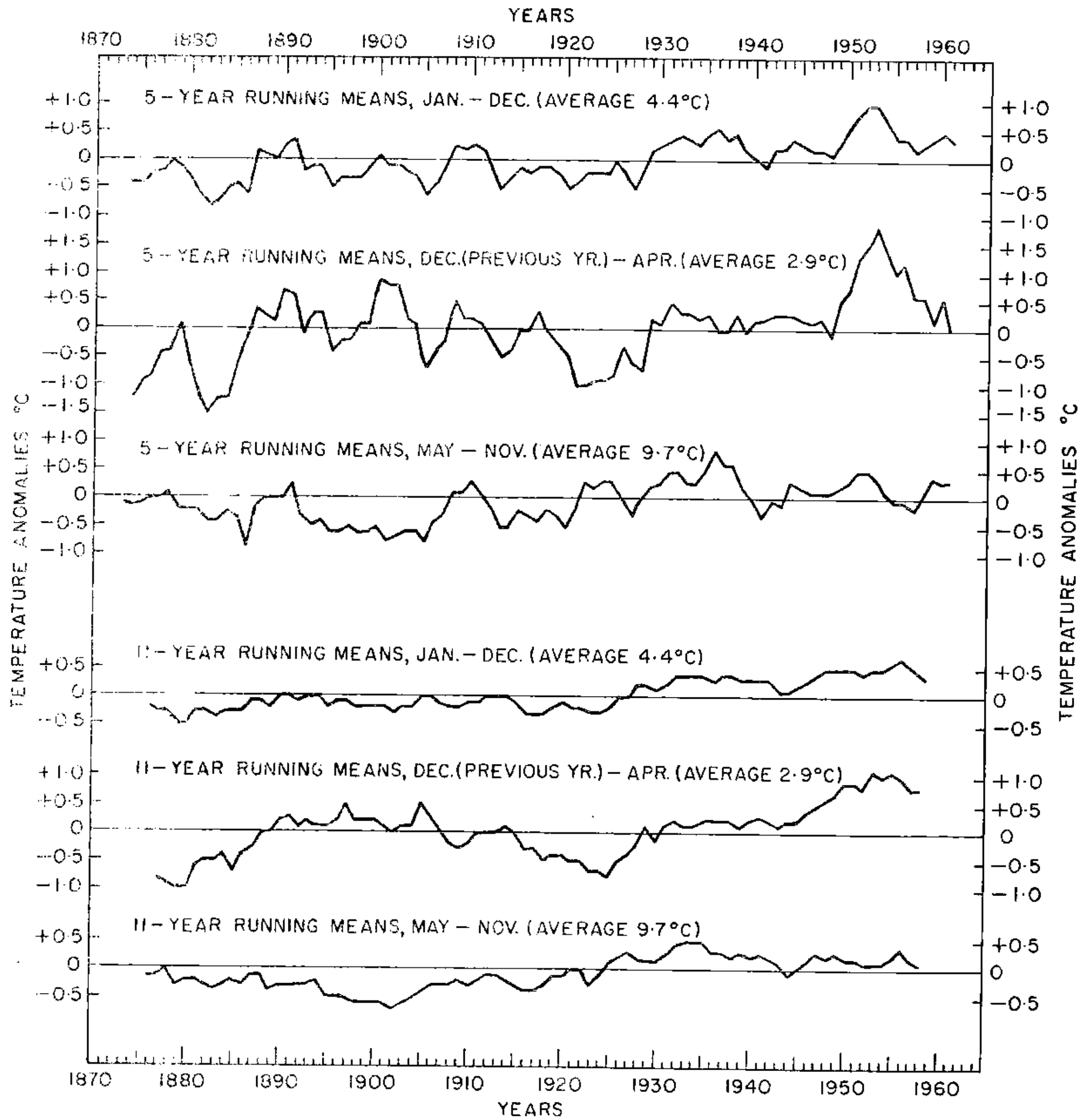

Fig. 5. Five-year and eleven-year anomalies of running means of air temperatures at St. John's-Torbay from the averages for 1872-1962. (The running means are attributed to the median year.)

Torbay air temperatures, 1942-54 were similar in trend and yearly pattern to those of Sydney and Sable Island with a fairly good but lesser resemblance to the air temperatures at Halifax and Yarmouth. In the recent period 1940-54 there were differences between air temperature trends in different years between the group of stations from Torbay, Newfoundland south to Yarmouth, Nova Scotia and the group from Belle Isle northward along the Labrador and Baffin Island coasts.

Temperatures of the surface water at St. Andrews, New Brunswick have been observed since 1922 and have shown a gradual, although fluctuating increase since the late 1920's with highest temperatures between 1949 and 1954 (Lauzier, 1958; Hachey, 1961). The general trends over the short period since 1950 are similar at St. Andrews and at Station 27 (Fig. 2) but anomalies of individual years are not always in agreement.

Riehl (MS, 1956) used all available data to compute monthly and yearly means of sea-surface temperatures of the North Atlantic, 1887-1936, summarizing the data by 5° lat, 5° long rectangles. Because Riehl's important manuscript is not generally available for comparison his graphs relative to the rectangles nearest to the Newfoundland and Newfoundland bank areas, and from which water passes from or enters this area have been reproduced in comparison with air temperatures at St. John's (Fig. 6). Although data on the number and location of observations in each rectangle are not available there is enough agreement in pattern within each group of the two different types of temperature pattern as to allow some confidence to be placed in the data.

In the area 45-50 (Fig. 6) which includes St. John's the sea temperature pattern was usually very similar to that of the St. John's air temperatures. Sea-surface temperatures in 45-50, 45-45 and 45-40 (of which the two former receive the full impact of the Labrador Current and the latter extends eastward from Flemish Cap and is beyond the influence of the colder part but is affected by the warmer part of the Labrador Current) show differences in pattern from those in areas between 40 and 45°N (40-40 to 40-65). In 45-50 surface temperatures, after remaining fairly level for the 1890-1910 period, fell strongly in 1911-16. In 45-45 temperatures were below average and generally declining from the early 1900's to at least 1916 with rising temperatures in the 1920's. In 45-40 the decline began still earlier in the late 1890's and temperatures declined to a low point in the early 1900's. Temperatures gradually rose from this point reaching levels strongly above average in the 1920's and 1930's. Temperature trends in this offshore rectangle are intermediate between those for 45-45 and those of the rectangles between 40 and 45°N.

Especially in the seaward rectangles between 40 and 45°N (40-40 to 40-55) sea-surface temperatures rose strongly from the 1890's to the 1930's. In rectangles 40-60 and 40-65 including part of the coasts and continental shelves of Nova Scotia, Maine and New England the rise in temperature since the 1890's was less and there was a severe drop in temperature to a low for the period in 1917 with below average temperatures in 1916-19. There was another severe low in 40-65 in 1922-24. The year 1917 is however, missing from all the other sea-surface graphs of Fig. 6 but it was a year of higher than average air temperatures at St. John's.

Brown (1963) for the sea area 42-44°N, 50-55°W (in the northern part of 40-50, and immediately south of the St. John's area, 45-50, of Fig. 6) has extended the period of analyses of sea-surface and air temperatures from the 1880's to 1959. For this area both sea and air temperatures showed a downward trend from the 1890's to the 1912-21 period, a warming trend till 1937 (information lacking, 1940-45), a rising trend to 1950-54 and a decline from this to 1959. These trends are most similar to those in 45-45 of Fig. 6. For the more southern part of 40-50 (40-42°N, 50-55°W) Brown found an increasing trend of sea and air temperatures from 1890 (as in Riehl, 40-50, Fig. 6) to the early 1950's with a falling tendency from 1951-52 to 1959.

Interrelationships of Trends in Air and Sea Temperatures at St. John's, and in other Eastern Canadian Localities and Neighbouring Sea Areas

The air temperature trends for the Nova Scotian area (composite of Sydney, Sable Island, Halifax and Yarmouth) and also for Sable Island separately (Thomas, 1955, Fig. 1 and 2) showed a declining trend from the 1890's to the early 1920's similar to Riehl's (1956) data for the northern area 45-45 (Fig. 6). In this same period the sea areas 40-55, 40-60 and 40-65 of Fig. 6, closest to the Nova Scotian area, showed rising surface temperatures.

Lauzier and Hull (MS, 1961), however, showed an extremely close relation in trend between 10-year running means of surface water temperatures from the 1920's to the 1950's at St. Andrews, N.B. and of air temperatures for the same period at Sable Island and Halifax.

Lauzier (1952) found that surface water temperatures at St. Andrews and at the Sambro Lightship, off Halifax, followed the same trends and were closely related in yearly pattern.

Lauzier and Hull (1962) showed that, for the period 1950-60, yearly surface water temperatures at St. Andrews followed a significantly downward trend similar to that at the Lurcher Lightship off southwestern Nova Scotia, and at the Sambro Lightship. On the other hand surface temperatures at Port Borden, Prince Edward Island and at Entry Island, Magdalen Islands (both in the southern part of the Gulf of St. Lawrence), and also in Halifax Harbour had trends more similar to those at Station 27, with higher temperatures at the beginning and toward the end and lower temperatures in the middle of the period.

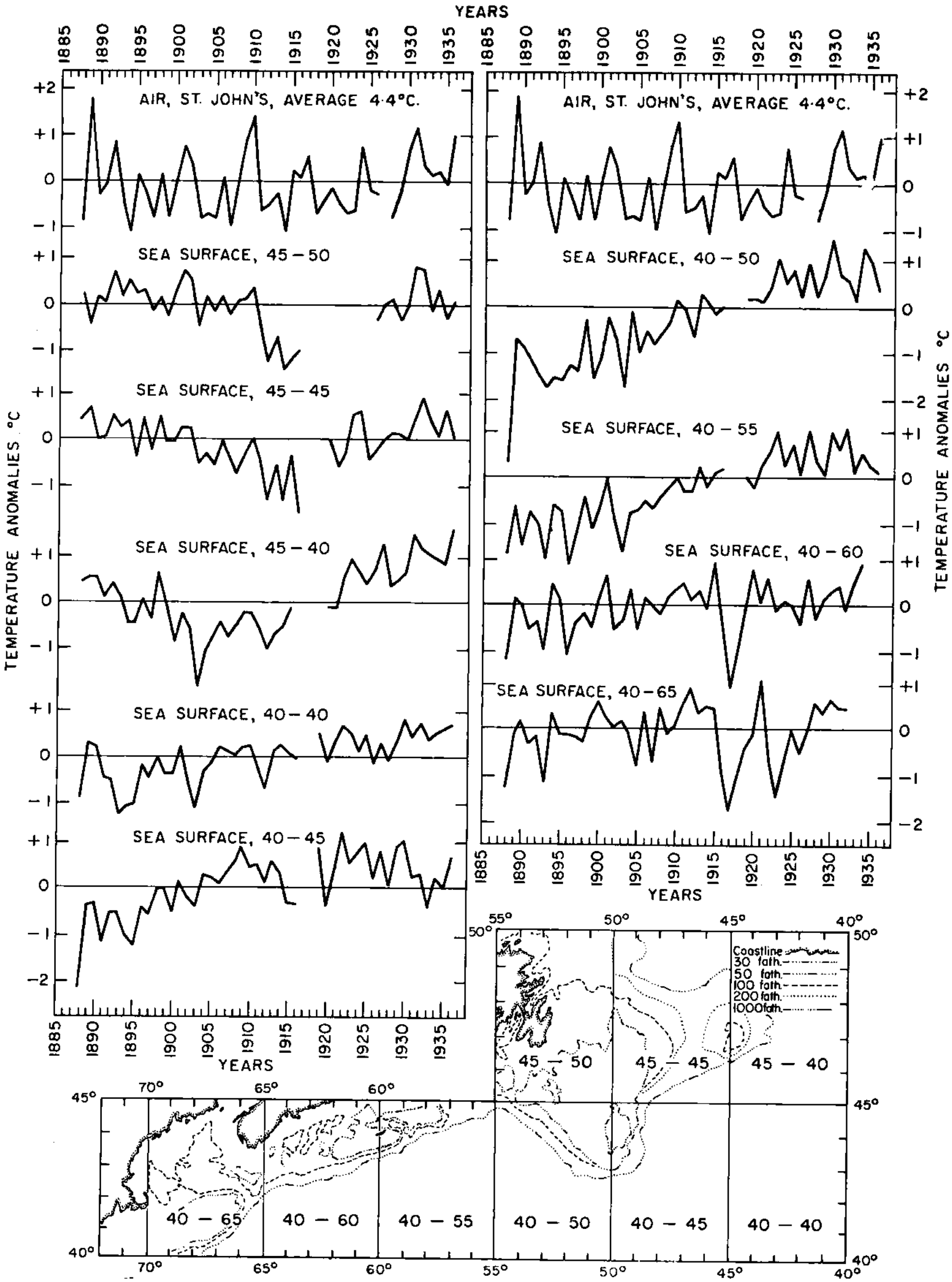

Fig. 6. Anomalies of yearly air temperatures at St. John's (converted to Torbay level) compared with anomalies of average sea-surface temperatures in 5° rectangles to the east and south (after Riehl, MS, 1956). (Each 5° rectangle is designated by the latitude and longitude coordinates of its southeast corner. The anomalies of yearly air temperatures were obtained by comparison with the average air temperature at St. John's (converted to Torbay) for 1888-1936.)

Thus in the earlier decades of the twentieth century there was a much lesser trend toward lower yearly temperatures in the St. John's than in the Nova Scotian coastal air temperatures, with an unexpected relationship of Nova Scotian air temperatures with distant rather than local sea-surface temperatures. More recently there was agreement in almost every year in the air temperature trends between St. John's-Torbay and Nova Scotian coastal stations particularly those of Sable Island and Sydney which are most surrounded by water. Also since the 1920's sea-surface temperatures at St. Andrews have been closely related in trend to air temperatures at Sable Island on the Scotian Shelf and to sea-surface temperatures off Halifax. During the period 1950-60, however, trends in sea-surface temperatures in the southern part of the Gulf of St. Lawrence were more like those at Station 27 off St. John's than at St. Andrews. In recent years as in former years, also, there is a close relationship in trend year by year between air temperatures at Torbay-St. John's and surface temperatures of the neighbouring sea area. This relationship is naturally closer with sea temperatures at Station 27 near St. John's than with the larger 45-50 area of Fig. 6.

No complete explanation can be offered at present for these alternating agreements and disagreements in regional air temperatures and with local air and sea-surface temperatures. The yearly average, however, is a composite of the warmer and the colder periods of the year which, as seen in Fig. 2-5, may have different trends and degrees of divergence from the yearly average. The relative degrees of seasonal divergence, as influenced by the nearness of a continental land mass and of resulting more extreme summer and winter temperatures, may result in different yearly trends.

Riehl's surface temperature data for 40-60 and 40-65 include not only part of the Scotian Shelf which is considerably under the influence of the southward flow from the Labrador Current and the Gulf of St. Lawrence, but also more seaward areas occupied by slope and Gulf Stream water. It is very likely that temperatures of the actual Scotian Shelf water declined in the latter part of the nineteenth and the early part of the twentieth centuries as did air temperatures in this area and sea temperatures in the area affected directly by the Labrador Current. The rise shown in Riehl's data during this period in 40-55 and 40-60 may have been due to most of his temperatures for these rectangles being from the offshore slope and Gulf Stream water where the temperature trend was evidently upward at this time. In this regard it may be noted (Fig. 6) that the rise in sea-surface temperatures during this period was considerably greater in 40-55 which included only a small portion of Shelf and still greater in 40-50 and 40-45 which are less subject to land influences as compared with 40-60 and 40-65 which include more shelf and coast.

Brown's (1963) results (in which, for the latter part of the nineteenth and the early parts of the twentieth centuries, the Labrador-Current-type downward trend was present in the northern part of rectangle 40-50, dominated by bank water and bank-related slope water, and the Gulf Stream type upward trend in the southern part of the same rectangle dominated by the more seaward slope water and the Gulf Stream), provide additional evidence that differing trends existed in these contrasting water types. Riehl's yearly trends for the whole rectangle were strongly upward during this period. It is also evident from Brown's results, compared with those of Riehl for the 40-50 rectangle, that 5° lat, 5° long rectangles are too large for studying temperature trends in areas where highly contrasting water bodies and water temperatures exist. The water of highly differing origins and temperatures in different parts of the rectangle may have different trends and also the averages from the whole rectangle are unlikely to be derived from an equal number of records from all types of water.

ACKNOWLEDGEMENTS

I am extremely grateful to Mr A.G. Kelland and to the many biologists and technicians of the St. John's Station who over the years have gathered the data for Station 27.

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H-3

LONG-TERM TEMPERATURE VARIATIONS IN THE SCOTIAN SHELF AREA.

By

L.M. Lauzier[1]

ABSTRACT

Surface water temperature observations at St. Andrews, N.B. during the last four decades are compared with other temperature series, surface and bottom temperatures, over the Scotian Shelf and along the Atlantic Seaboard. Short- and long-term temperature variations are generally uniform over the area. Study of temperature trends is extended back to 1880, based on the relationship between air and water temperature variations. Long-term temperature variations from the Scotian Shelf area follow some of the ocean temperature fluctuations.

INTRODUCTION

Bjerknes (1959, 1963), Brown (1963), Neumann (1960), Rodewald (1963) and Smed (1948 to 1962) have shown that the fluctuations of the marine climate are far from being uniform throughout the North Atlantic. However, the variations in fluctuations are linked together and could be explained by theories which provide an interim answer to some of the problems of interactions between sea and air.

The variability of the fluctuations may be expected to increase in the coastal areas (over the Continental Shelf) of the Western North Atlantic, where the interchange of properties between the atmosphere and the sea is more variable than over the open ocean, and where the continental drainage plays an important part in the replacement of the waters as well as in their stratification. Another important characteristic of the coastal waters, over the Continental Shelf, is their large annual amplitude and year-to-year variability as compared to the waters of the open ocean.

Temperature trends of the Canadian Atlantic waters have been studied previously by Hachey and McLellan (1948), McLellan and Lauzier (1956), Lauzier and Hull (1962) and Rodewald (1963) who considered the surface temperatures and also by Bailey (1953), McLellan (1955), and Lauzier and Trites (1958) who showed changes in temperatures at depths. Climatic trends in coastal areas adjacent to ICNAF Subarea 4 (Bay of Fundy, Scotian Shelf and Gulf of St. Lawrence) have been considered by Templeman and Fleming (1953), Templeman (1955), Rodewald (1956), and Taylor *et al.* (1957).

Our task here is to investigate the fluctuations of the marine climate of part of the southern end of the ICNAF area, the Scotian Shelf area (Fig. 1), as reflected by long-term changes in either surface water or air temperatures and to show the variations of the marine climate at depth, mainly on some of the fishing areas.

DATA

Twice daily observations of surface water temperatures at St. Andrews, N.B., which began in 1921, are the basis of the longest continuous series of water temperature along the Canadian East Coast. This 43-year series is considered here as a reference point for comparison with other series of shorter durations. The annual mean temperature is derived from the twelve monthly means. Unless otherwise indicated, other water temperature series were obtained from the records at the Biological Station of the Fisheries Research Board of Canada in St. Andrews, N.B.

The meteorological data from Halifax, N.S. and Sable Island, N.S. come from Longley (1954) and from the Meteorological Records published by the Meteorological Service of Canada.

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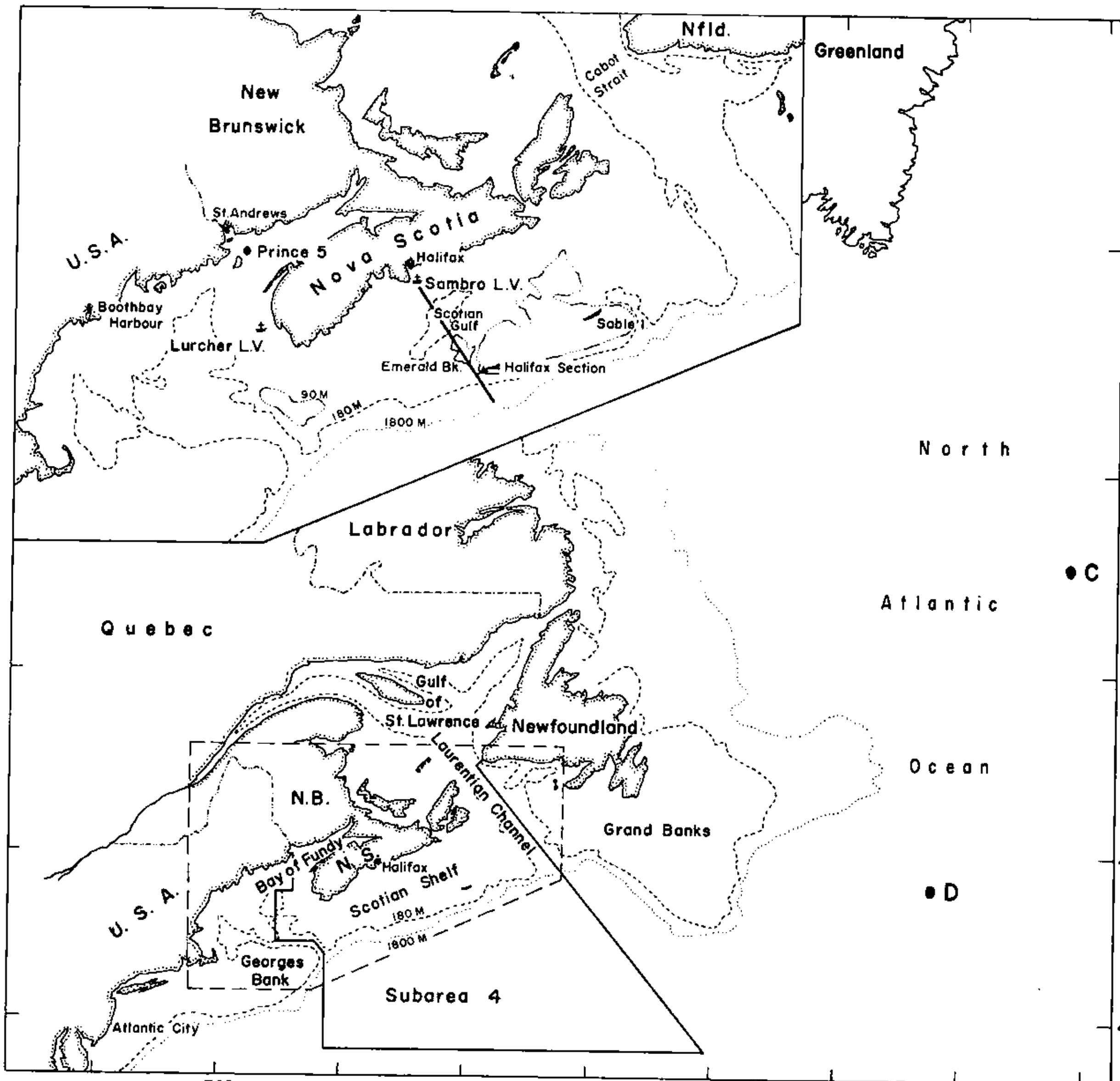

Fig. 1. ICNAF Subarea 4 and details of Scotian Shelf.

LONG-TERM VARIATIONS

Surface water temperatures

The St. Andrews series is represented in Fig. 2 showing both the year-to-year variations and the long-term fluctuations. The annual mean temperature for St. Andrews is 7.0°C. The lowest and the highest annual temperatures were 5.4°C in 1923 and 8.5°C in 1951 respectively. We see that the temperature was below the average in 10 of the first 15 years of the series and that it was above the average in 10 out of the last 15 years of the series. The 10-year moving average, eliminating short period variations, indicates an upward trend of the surface temperatures from the 1920's to the 1950's with a secondary maximum and minimum in the middle 1930's and early 1940's respectively.

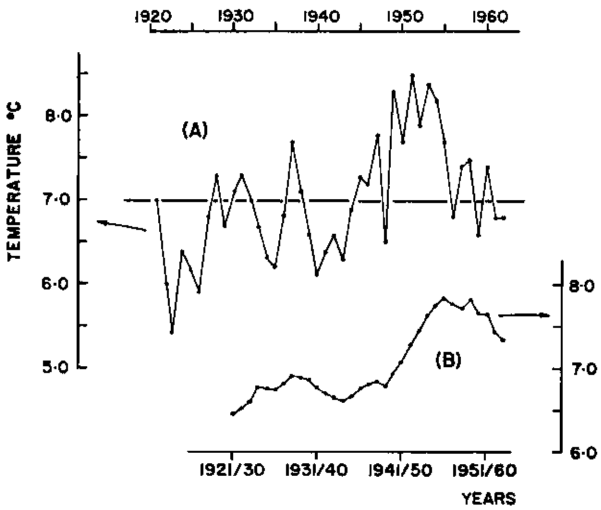

Fig. 2. Surface water temperatures at St. Andrews, N.B.; (A) annual means, (B) ten-year moving averages of annual means credited to the last year of the period.

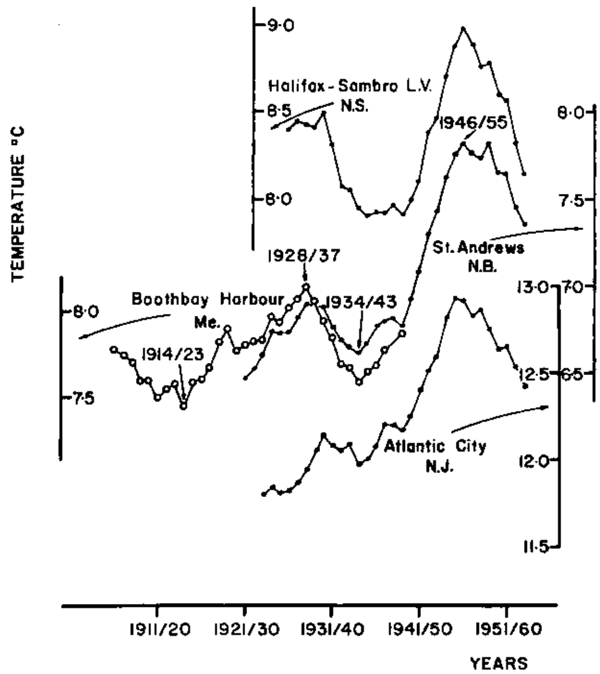

Fig. 3. Surface water temperatures at Halifax-Sambro L.-V., N.S.; St. Andrews, N.B.; Boothbay Harbour, Me.; Atlantic City, N.J. Ten-year moving averages of annual means credited to the last year of the period.

The 10-year averages increased from 6.4°C for 1921-30 to 7.8°C in 1946-55. One important feature of this series is the reversal of the trend from the middle of the 1950's to the present time, the 10-year average for 1954-63 is 7.2°C.

Other surface temperature series, two of them taken outside the Scotian Shelf, are represented as 10-year moving averages in Fig. 3. They are: Halifax Harbour - Sambro Light-vessel, 1926-62; Atlantic City, N.J., 1924-62 and Boothbay Harbour, Maine, 1906-48. The St. Andrews curve is repeated for comparison and adjoined to the Boothbay Harbour series. Atlantic City data to 1958 have been published by U.S. Coast and Geodetic Survey (1960) and the unpublished data from recent years were obtained through the kindness of the Director of the Survey. Boothbay Harbour data were listed in Taylor *et al.* (1957). Halifax Harbour data for the period 1926-35 have been adjusted to the Sambro Light-vessel level, based on the relationship Halifax-Sambro for the years following 1936. The similarity between the temperature series implies that the warming trend from the 1930's to the 1950's followed by cooling from the middle of the 1950's is a widespread phenomena over the Continental Shelf from at least the Laurentian Channel to New Jersey Coast.

The adjoining of St. Andrews and Boothbay Harbour series allows us to visualize a water temperature series for a relatively long period, for almost 6 decades. These combined curves suggest that the St. Andrews series commenced when the warming trend had already started. From Fig. 3, it seems that the general warming started around 1920, reached a secondary maximum and minimum in the middle 1930's and early 1940's respectively and thereafter progressed to a peak attained in the middle 1950's. The secondary maximum seems to be more pronounced in Halifax-Sambro area than at the other three stations.

Shorter temperature series of surface water in the Gulf of St. Lawrence (Lauzier and Marcotte, 1964) indicate local short-term variations superimposed to the long-term variations generally accepted for continental Shelf waters. The warming seemingly continued until 1960 in part of the Gulf of St. Lawrence.

Air temperatures

It is our intention here to use air temperatures as comparative series because the periods of

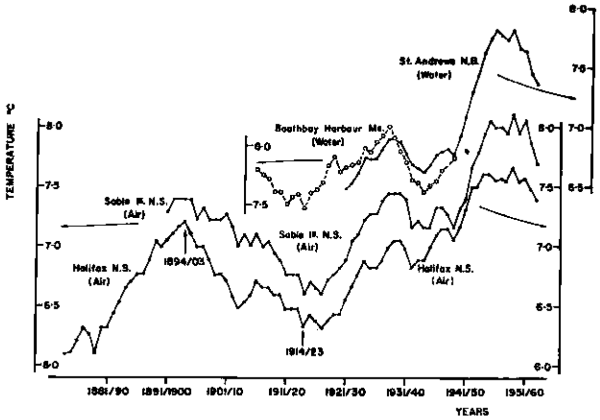

Fig. 4. Surface water temperatures at St. Andrews, N.B. and Boothbay Harbour, Me. Air temperatures at Sable Island and Halifax, N.S. Ten-year moving averages of annual means credited to the last year of the period.

observations are longer than those of the water temperatures. Air temperature series from Sable Island, 1891-1962, seems to be the ideal series because of the oceanic location of the Island, 90 miles south of Nova Scotia, almost at the edge of the Continental Shelf. Halifax, N.S. temperature series, one of the longest in Eastern Canada, started in 1874. Figure 4 shows Halifax and Sable Island air temperature variations as ten-year moving averages along with the St. Andrews-Boothbay Harbour curve repeated from Fig. 3.

Because of the close relationship between the three curves during the last six decades, we are probably justified in assuming that the longer air temperature records tell us approximately what the trends of water temperatures were between 1875 to 1905. The temperature curves in Fig. 4 indicate a warming period from at least the 1880's to the beginning of this century, a cooling period during the first two decades of this century. A long warming period from the 1920's to the 1950's was momentarily interrupted by a secondary minimum in the early forties. The last eight years are those of a cooling period.

Bottom temperatures

Bottom water temperature series from points on the Scotian Shelf and vicinity are much shorter and discontinuous as compared to those of surface temperatures. These series are compared, on a quarterly basis, to St. Andrews series (Fig. 5). Quarterly deviations of the St. Andrews surface temperatures are shown in curve C. In all curves of Fig. 5, short-term variations are more apparent than long-term fluctuations. The important point here is to show the general features of the bottom temperature series as compared to the reference series, from which the long-term fluctuations are inferred.

Bay of Fundy-Gulf of Maine Area

The bottom temperature series at Prince 5 station is the longest in our records. Located on the north side of the Bay of Fundy (Fig. 1), this station (depth: 90 m) has been visited once a month since 1924. Because of the vigorous tidal mixing in the Bay of Fundy, reducing the stratification to a small value, a very close relationship is expected in the variations between St. Andrews surface temperatures and Prince 5 station bottom temperatures, as shown by curves A and C of Fig. 5. The long and short periods of warming and cooling are approximately the same for both series.

At Lurcher Light-vessel, daily bottom (at 95 m) temperature observations commenced in 1950. The annual range of bottom temperatures is less at Lurcher than at Prince 5 station, and the average summer temperature gradient is also less at Lurcher than at Prince 5 station showing a greater oceanic influence on the temperature variations at Lurcher. Temperature trends of the bottom waters, at Prince 5 and at Lurcher, shown in curves A and B of Fig.5, are very similar. However, the cooling period of the 1950's seemed to have started earlier at Lurcher than at Prince 5 station and at St. Andrews. The rate of cooling during the 1950's and the beginning of the 1960's is somewhat more pronounced within the bottom waters at Lurcher and Prince 5 than for the surface waters at St. Andrews.

Halifax-Emerald Bank area

The waters of this area have a different temperature structure than those of the Bay of Fundy-Gulf of Maine area. The temperature stratification is such that a minimum temperature layer located at an average depth of 50-60 m persists during most of the year, except during the winter. Under such

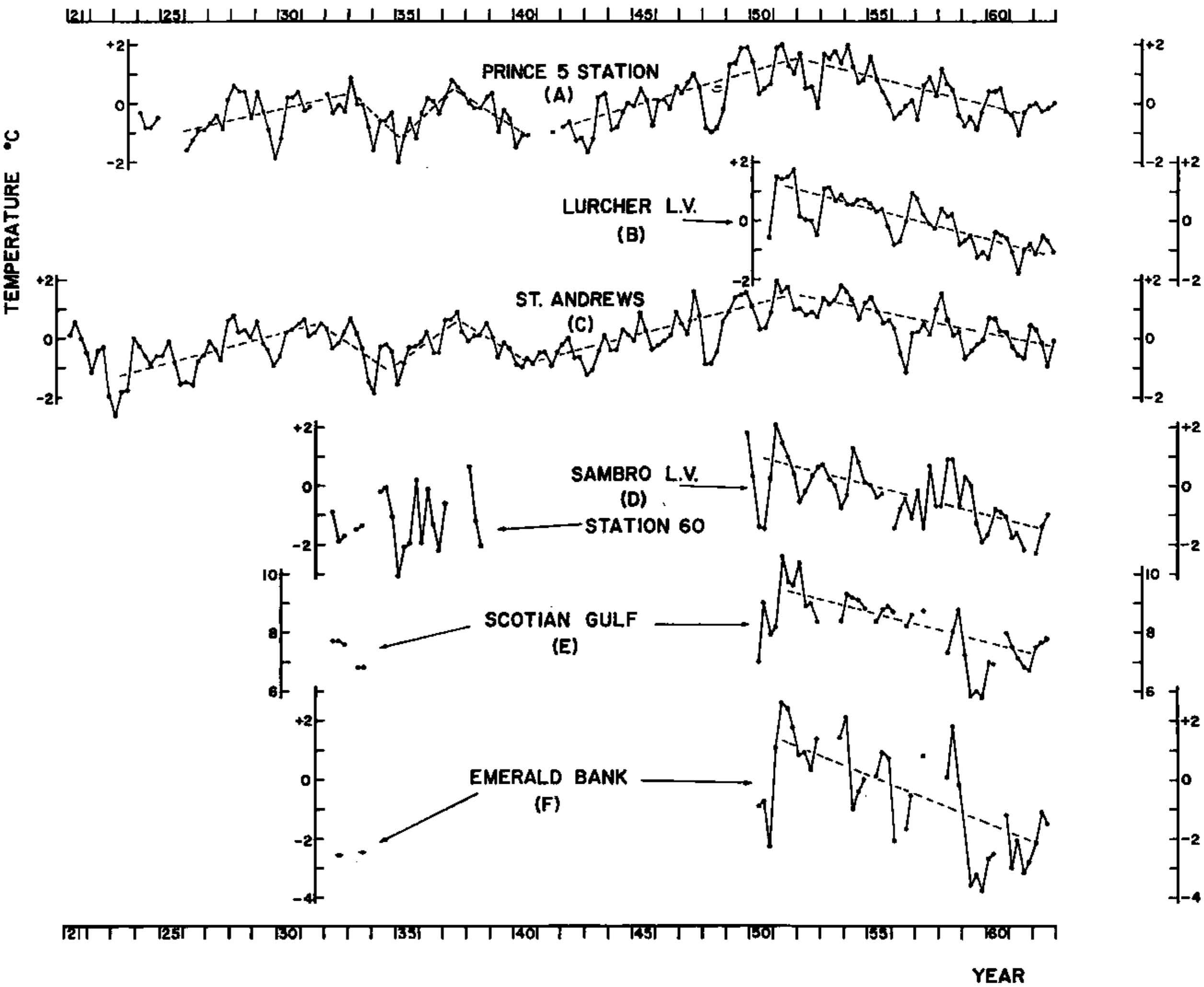

Fig. 5. Quarterly deviations of water temperatures: (A) Prince 5 Station, bottom temperatures average 1924-1960; (B) Lurcher L.-V, bottom temperatures, average 1950-1959: (C) St. Andrews, surface temperatures, average 1921-1960: (D) Sambro L.-V., bottom temperatures, average 1949-1959: (F) Emerald Bank, bottom temperatures, average 1950-1959. Maximum temperatures within bottom layer of Scotian Gulf, curve (E). The dash lines represent temperature trends.

conditions the bottom waters, where the depth of water is greater than 60 m, are those of a relatively warm layer as compared to the mid-depth layer. These waters generally have a higher salinity than those of the Bay of Fundy area, at the same depth, indicating a greater oceanic influence in their formation, (a greater slope water component in their mixture). The annual amplitude of temperature of bottom waters, at depths greater than 60 m, is much reduced as compared to the waters of the Bay of Fundy area. It is on the average 2.7°C at Sambro Light-vessel (at a depth of 85-90 m) as compared to 6.3°C at Lurcher and 8.1°C at Prince 5 station.

In 1949, twice daily bathythermograph (BT) cast observations commenced at Sambro Light-vessel to be continued to the present time. Through the courtesy of Mr R.E. Banks of Naval Research Establishment, the unpublished bottom temperature data for Sambro Light-vessel were put at the author's disposal. Quarterly deviations of bottom temperatures at Sambro are shown in Fig. 5 (curve D). As for Lurcher, the cooling trend in the fifties seemed to have started earlier than at St. Andrews and at Prince 5. A slight warming in 1957 and 1958 is noticeable at Sambro

Light-vessel. The general cooling trend of the 1950's was of the same order of magnitude at Sambro and at Lurcher but the short-term variability seemed to be greater at the former. During the 1930's, bottom temperatures were observed during frequent cruises at Station 60, which is located alongside Sambro Light-vessel. These temperatures were approximately 1.4°C lower than those of the 1950's at Sambro. Because of the large variations of the deviations during the thirties, it is difficult to assess the extent of the cooling and warming, if any, during that period which would correspond with those observed at St. Andrews and at Prince 5 station.

A series of seasonal cruises on the Scotian Shelf covering the Halifax Section from the coast southward over the Scotian Gulf and Emerald Bank commenced in 1950. The maximum temperatures recorded in the deep layer of the Scotian Gulf are shown in curve E of Fig. 5. The deviations from seasonal averages of the bottom temperatures on Emerald Bank are shown in curve F of Fig. 5. These two series show a cooling trend during the 1950's comparable to the trend already described for the other series. On Emerald Bank, however, the variability of deviations seems to be greater than at the other points and the cooling trend seems to be more intense, 3.2°C per 10 years, as compared to 2.0°C at Sambro Light-vessel.

The observations of temperatures in the 1930's at the same locations as in the 1950's (Scotian Gulf and Emerald Bank) indicate only that the temperature level was then lower than at the peak (about 1951) but approximately the same as in 1961, almost in line with the St. Andrews series.

Laurentian Channel

Lauzier and Trites (1958) have considered the long-term trends in the deep waters of the Laurentian Channel. Their study included data up to 1957. More observations have been taken every year since then. A total of 17 cruises has been made between 1958 and 1962 in the Cabot Strait area where the Laurentian Channel is the only entrance of deep warm waters to the Gulf of St. Lawrence. In Fig. 6, the temperatures of two isohalines, 33.0 and 34.0°/oo and of the core of the deep layer (maximum temperature) are plotted against time. For comparison, annual temperatures at St. Andrews have been included in Fig. 6. The general warming from the 1920's through the 1930's until the 1950's has been observed in the deep layers of the Laurentian Channel. However, the warming from the 1930's to the 1940's is minimum, 0.3°C, for the 33.0°/oo water and maximum, 0.9°C, for the core of the deep layer. Frequent temperature observations during the 1950's indicate that these waters, while warmer than in previous years, stayed warm longer than those of the Scotian Shelf. The deeper the waters, the later the peak temperature occurred in the 1950's. The 33.0°/oo water experienced a definite cooling in the last ten years, while the 34.0°/oo water did not show any trend and large variations at the core make it difficult to detect any appreciable trend during the last 10 years.

The definite lag in reaching a peak temperature is reflected in the warming and cooling of some of the surface waters in the Gulf of St. Lawrence (Lauzier and Marcotte, 1964).

General features

The comparison of surface and bottom temperature variations and trends for different areas of the Continental Shelf for periods of varying lengths leads us to believe that the water masses on the Continental Shelf from the Laurentian Channel to the Bay of Fundy have been subjected to long-term variations of temperatures of fairly uniform character. Furthermore because of the close relationship between trends of air and water temperature variations, we are probably justified in assuming that the longer air temperature records tell us approximately the trends of water temperatures over a longer period than that of actual sea temperature measurements.

To summarize: the long-term trends of water temperature in the Shelf part of ICNAF Subarea 4, from 1880 to 1962, were as follows: a warming period for the first 20 years, a cooling period from about 1900 to the beginning of the 1920's, a warming period between approximately 1922-24 and 1953-55 with secondary maximum and minimum centered in the middle 1930's and the beginning of the 1940's respectively. The trend from 1953-55 to 1962 exhibits a fairly intense cooling, except in the very deep waters of Cabot Strait area.

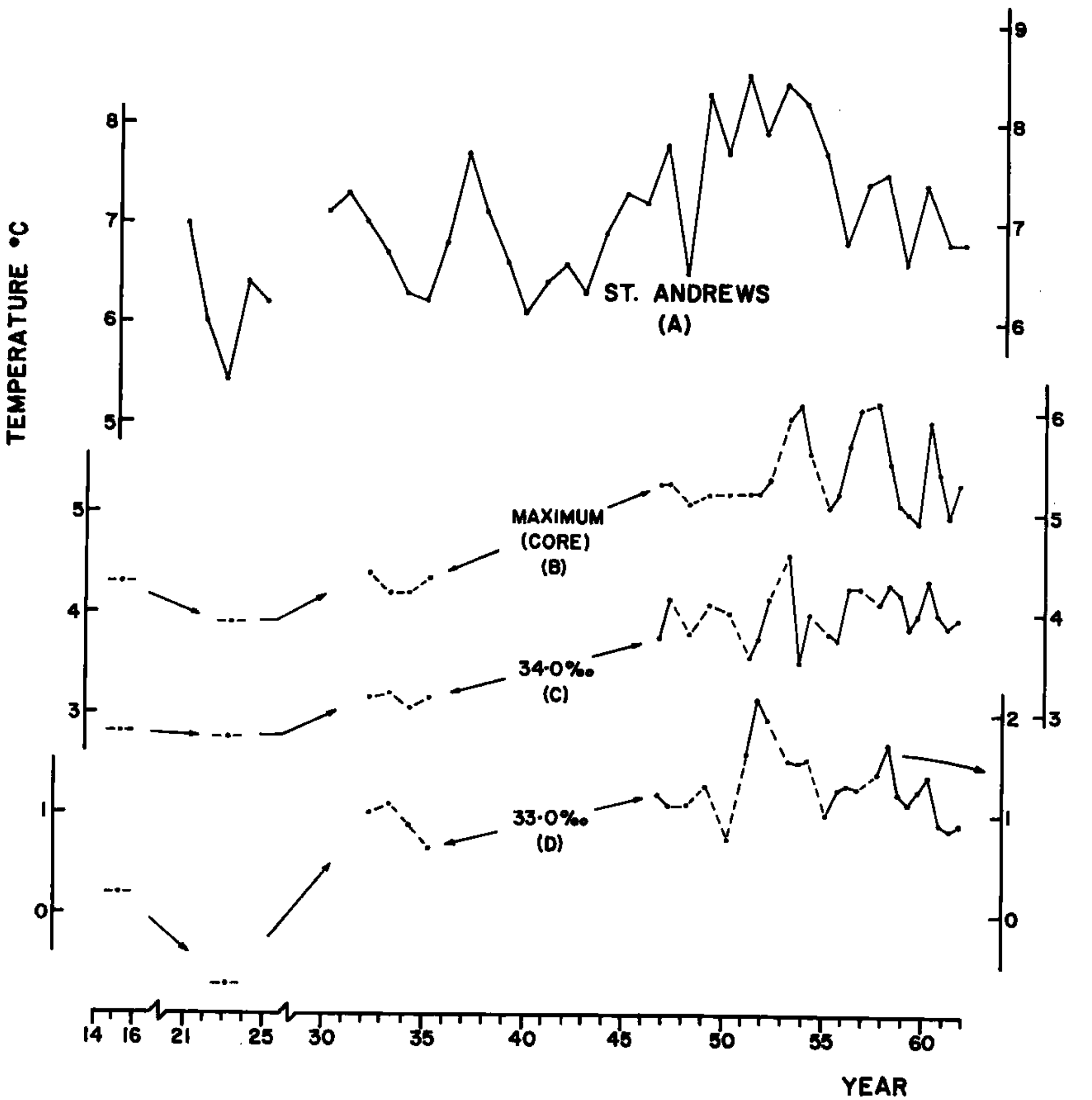

Fig. 6. Temperature variations of surface water at St. Andrews, N.B. (annual means) curve (A), and of waters of the deep layer in Cabot Strait, Laurentian Channel, (semi-annual means) at the core, curve (B); at isohaline 34.0°/oo, curve (C); at isohaline 33.°/oo, curve (D).

DISCUSSION

We cannot explain the long-term variations of temperatures described previously. We should point out however the difference in the temperature variations of the Scotian Shelf area as compared to those of the surrounding Northwest Atlantic and also some of the problems related to the hydrography of the Scotian Shelf area.

Northwest Atlantic

The temperature trends of the waters over the Scotian Shelf have striking similarities with those of the surface waters northeast of the Grand Banks and just north of the Gulf Stream. However, these trends are different from those of the waters in the main North Atlantic gyre.

The surface waters located over the northeast corner of the Grand Banks (45-50°N, 45-50°W) have experienced an intense cooling from 1890 to approximately 1915-25, followed by warming until the 1950's (Riehl, 1956 and Schell, 1957). Temperature data from Weatherships C and D, east of this area, indicate a cooling trend during the 1950's (Rodewald, 1963). For an area located just north of the Gulf Stream (42-44°N, 50-55°W), Brown (1963) shows a cooling trend from approximately 1890 to the period 1912-21 followed by a warming trend until 1937. An increase of temperature during the late 1940's and early 1950's was followed by a fall of temperature of nearly 2.5°C in the late 1950's (Brown, 1963). From the northern half of the main North Atlantic gyre, surface temperature data indicate a warming trend, with a maximum change along the Gulf Stream, from 1890 to 1950, followed by a cooling tendency during the 1950's (Riehl, 1956; Bjerknes, 1959; Brown, 1963).

The most successful explanation of climatic variations of the North Atlantic surface waters emphasized the effect of changes in the atmospheric circulation (intensification of westerlies) on the internal adjustment of the water masses of two large vortices, associated with the Bermuda-Azores High and Icelandic Low respectively. Processes involved in the variations about the normal heat balance of the surface waters of various regions were also given some attention.[2]

Scotian Shelf area

During the last 17 years we have experienced general warming followed by cooling superimposed on alternation of warm and cool years (Fig. 2). Should the problems of warm and cool years be investigated further before we are able to give a sound explanation to the long-term fluctuations? An analogy between the short-term variations and the long-term fluctuations would be fruitful. More information on the circulation, water mass production and heat budget is essential. Little is known about the first two and less about the last one.

Short-term changes in annual temperatures seem to be associated with variations in intensity of the westerlies along the Canadian Atlantic coast. This relationship indicates that lower temperatures are associated with stronger westerlies in 1948, 1959 and 1961, and that higher temperatures are associated with weaker westerlies in 1949, 1951 and 1953. Stronger westerlies may a) maintain a certain amount of upwelling along the coast, keeping the surface temperature at a low level during the summer, and somewhat higher level in the winter; b) bring over the water, during the winter, cold dry air masses increasing then heat loss to the atmosphere which would counteract the warming effect of upwelling. The resulting surface cooling may increase vertical mixing on the Shelf area as well as to the east and therefore increase the production of the intermediate temperature layer that would occupy a large volume during the spring and summer. Hachey (1937) has considered the effect of upwelling on the Scotian Shelf during the summer. Such relationship or association may only indicate a small scale phenomenon. We still have to know more about the circulation at the surface and at depths, over and beyond the continental Shelf. In our opinion a very important aspect of the problem is the production of water masses. We know from previous studies that the water masses in the area possibly result from the mixing of Labrador water, Slope water, and low salinity "inshore" waters. Water masses could be identified but the mixing mechanism is still unknown. Finally the consistency of property distributions within a "component" water mass like the Slope Water and the Labrador water may be questionable. If they vary from year-to-year, from a cold period to a warm period, how are these variations going to affect the mixing mechanisms and the resulting "mixture"?

SUMMARY

1. Long-term surface temperature variations at St. Andrews, N.B. show a warming trend from the 1920's to the 1950's with a secondary maximum and minimum in the middle 1930's and early 1940's respectively. A cooling trend has been observed from the middle 1950's to the present time.

2. Trends of surface water temperatures at St. Andrews, N.B. are representative of surface temperature variations over a large area of the Atlantic Seaboard from, at least, Halifax, N.S. to

[2] This over-simplification does not do justice to the work of Bjerknes (1959, 1963), Neumann (1960) and Rodewald (1963). The readers are therefore encouraged to study their contribution, as well as the contribution by Lamb and Johnson (1959) to the general subject of climatic variations, and the account by Malkus (1962) of large scale interactions between sea and air.

Atlantic City, N.J. Temperature variations at Boothbay Harbour, Me. are used as an extension in retrospect of temperature trends from the 1920's to 1905.

3. Bottom temperature variations and trends on the Scotian Shelf, in the Bay of Fundy area, and deeper layer temperature variations in the Laurentian Channel, are similar to those of surface temperatures at St. Andrews with minor differences. This similarity indicates that the temperature fluctuations occurred within the water masses as well as at the surface.

4. Air temperature trends at Halifax and Sable Island, N.S. are closely related to the trends of surface water temperatures observed at St. Andrews, N.B. and Boothbay Harbour, Me. during the last 6 decades. Trends of air temperatures from longer series starting around 1875 are taken as indicative of trends of water temperatures between 1875 and 1905.

5. In general, the long-term trends of water temperature in the Shelf part of ICNAF Subarea 4, from 1880 to 1962 were as follows: a warming period for the first 20 years, a cooling period from about 1900 to the beginning of the 1920's, a warming period between approximately 1922-24 and 1953-55 with a secondary maximum and minimum centered in the middle 1930's and the beginning of the 1940's respectively. The trend from 1953-55 to 1962 exhibits a fairly intense cooling.

6. No explanation for the temperature trends on the Scotian Shelf is offered. Comparison is made between the trends on the Shelf and the large scale fluctuations over the North Atlantic.

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H-4

EFFECT OF LONG-TERM TEMPERATURE TRENDS ON OCCURRENCE OF COD AT WEST GREENLAND

By

Paul M. Hansen[1] and Frede Hermann[1]

ABSTRACT

The seasonal variation in temperature at different depths and different localities off the West Greenland coast is illustrated by selected hydrographic stations and compared with available information about the occurrence of cod at different seasons.

OCCURRENCE OF COD AT WEST GREENLAND

As is well known the occurrence of cod has been periodical at West Greenland. The two best known cod periods are the period from about 1845 to 1851 and the present cod period which started about 1920 and still continues.

In the first period both English and Danish vessels were fishing cod at the West Greenland banks and coastal waters. The stock of cod decreased however rather suddenly from 1849 and the fishery stopped. In the long period from about 1850 to 1920 there were only small local stocks of cod in some fjords and at some localities in South Greenland the cod appeared for a short time only during the summer. Faroese and Danish fishery expeditions in 1906, 1908 and 1909 found almost no cod on the West Greenland banks.

In 1917 the cod appeared in greater shoals at Frederikshåb at 62°N. In 1922 the cod occurred north to Sukkertoppen at 66°N and in 1928 the northern limit of the stock of cod had reached Disco Bay at 69°N. In the early 1930's the cod reached as far north as Upernavik district at about 73° N.

After about 1950 the northern limit of the cod stock had again moved southward and only small quantities of cod are now caught north of 69°N. Figure 1 showing the yield of the Greenlanders cod fishery gives a good illustration of how suddenly the stock of cod has increased in the 1920's.

VARIATION OF SEA TEMPERATURE OFF WEST GREENLAND

Figure 2 gives the variation of the surface temperature anomalies for West Greenland and South Greenland respectively presented as five-year running means. Figure 3 shows the areas West Greenland (A_1) and South Greenland (B) as established by Smed (1947-62).

The most pronounced feature in both curves is the strong and sudden increase of temperature in the 1920's. In the late 1930's the temperature decreased again and in the post-war years the temperature has been about 0.5° lower than its maximum value about 1930. In the late 1950's and the beginning of the 1960's the temperature has again been increasing.

The increase of the stock of cod occurred almost simultaneously with the rise in temperature, and it seems reasonable to assume that it is the climatic improvement which has made it possible for the cod to extend its northern limit further northward at West Greenland. The strong decrease of the cod fishery experienced in late years north of 69°N may be a consequence of the drop of temperature after about 1940.

It is worth mentioning that a drop in temperature of only about 0.7°C from the value in 1946-50 would have brought the temperature back to the levels for the years before 1920 when almost no cod was found in the Greenlandic area. We have possibly been very near a catastrophe for the West

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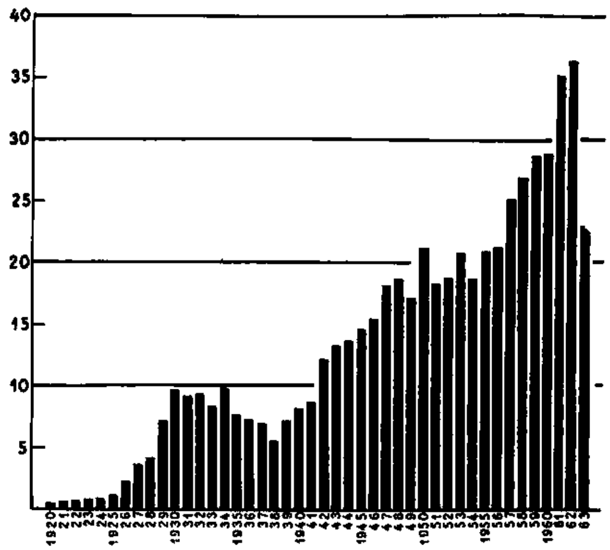

Fig. 1. Yield of Greenlanders cod fishery in thousand tons 1920 to 1963 (1963 estimated from catch until November).

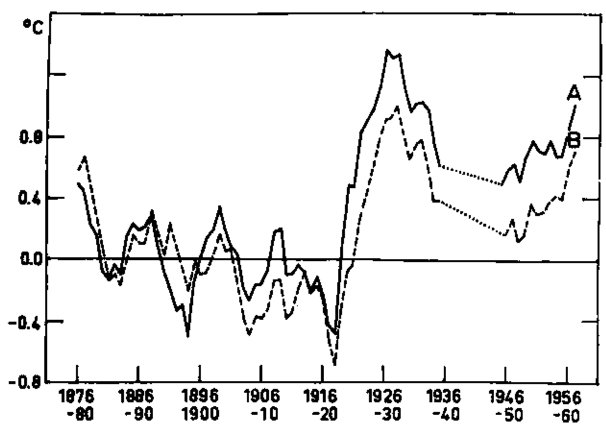

Fig. 2. Five years running means of surface temperature anomalies.
Curve A: for Smed's area A_1 mean April - September.
Curve B: for Smed's area B mean April - October.

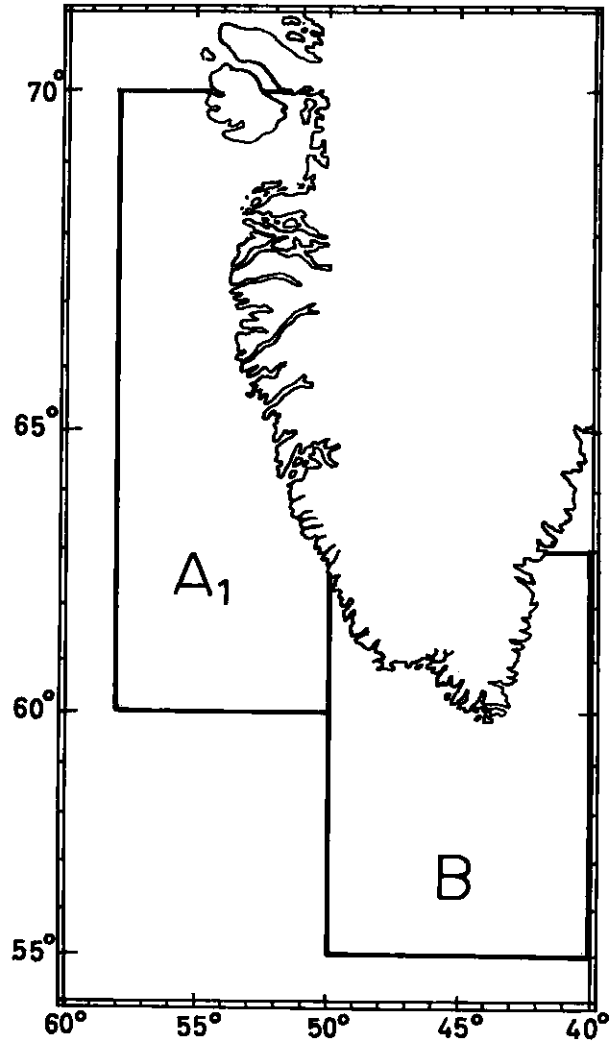

Fig. 3. Location of areas A_1 and B.

Greenland cod population, but fortunately the temperature now seems to be increasing again.

It must be borne in mind that in this paper five-year means of surface temperatures were used. The year-to-year fluctuations in surface temperature are to a high degree averaged out and it is probable that these averages represent fairly well the variation of temperatures also in the deeper layers where the cod lives.

Subsurface temperature observations are rather few in the years before 1920, but they indicate that a considerable warming of the deeper layers has occurred. This has been discussed by Ad. S. Jensen (1939).

VARIATION IN ICE CONDITIONS OFF WEST GREENLAND

Direct measurements of sea temperature are only available from West Greenland waters for the past 87 years, but information on the amount of the Polar ice (Storis) carried by the East Greenland Polar Current to West Greenland is available for a considerably longer period. Speerschneider (1931) collected information about Storis from log books of ships visiting Greenland and since 1901 the Danish Meteorological Institute has published maps of the distribution of ice in West Greenland waters. Since there is assumed to be a close connection between sea temperature and the presence of Storis a consideration of the ice conditions can be expected to yield information concerning climatic changes in the sea.

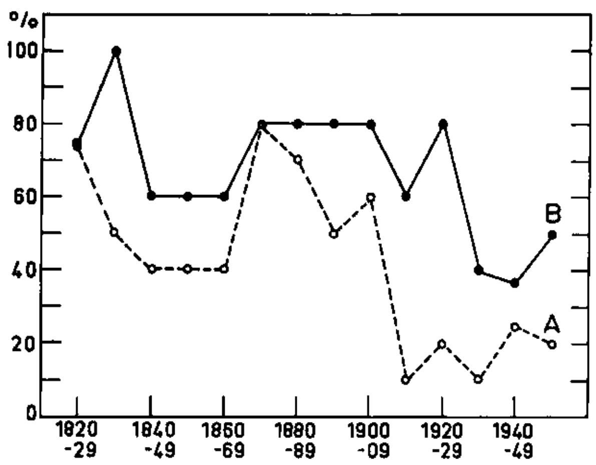

Fig. 4. Frequency of years in which the Storis reached as far north as Godthåb: (A broken line) and to Fiskenaesset (B full line).

Speerschneider (1931) produced in tabular form a summary of the maximum extension of ice along the west coast of Greenland. On the basis of this summary and the material published in "Nautisk Meteorologisk Årbog" and from unpublished information from the Danish Meteorological Institute, Fig. 4 has been drawn. The points for curve A give, for each decade, the percentage of the year in which Storis reached at least to the neighbourhood of Godthåb (64°N), while those for curve B give the analogous curve for Fiskenaesset (63°N). The most striking features in the curves are the strong decrease in the frequency of Storis off Godthåb from about 1910 and off Fiskenaesset from about 1930. Furthermore, there seems to have been a period with relatively favourable ice conditions from about 1840 to 1870.

It is remarkable that the rich cod period from about 1845 to 1851 lies in this interval where favourable ice conditions make it probable that the sea temperatures were also relatively favourable.

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H-5

VARIATION OF THE TEMPERATURE OF THE SURFACE WATER IN AREAS OF THE NORTHERN NORTH ATLANTIC, 1876-1961

By

Jens Smed[1]

ABSTRACT

For a number of areas covering most of the region 50°N-67°N, 0°-58°W the variation of the surface temperature from year to year during the period 1876-1961 is illustrated. Regional differences with regard to magnitude of temperature changes are considered.

Since 1876 observations of surface temperatures have been made regularly in the northern North Atlantic by Danish and Icelandic commercial vessels. The data for the years 1895-1961 have been published in the annual publications of the Danish Meteorological Institute (1896-1963) in the form of half-monthly or monthly means for one degree squares. Based on the data for the years 1876-1915, Ryder (1917) published monthly means of surface temperature in one degree squares over this period. The mean values for this 40-year period will in the following text be called the normal values.

For each month of the period 1876-1961 and for each one degree square the difference of the monthly mean from the normal value for the month has been calculated and for each month these anomalies have been averaged over each of the areas shown in Fig. 1. Finally, for each area and year, a yearly anomaly was calculated by averaging the monthly anomalies. These monthly and yearly anomalies for the areas in Fig. 1 were published in the Annales Biologiques (Smed, 1947-64).

For the various areas, the yearly anomalies have been plotted in Fig. 2 and 3. A conspicuous feature of these figures is the preponderance of positive anomalies from about the middle of the 1920's in all areas except the southeasternmost one, area N.

The main tendency of the temperature variation becomes still more conspicuous in Fig. 4 where the yearly anomalies have been smoothed out by calculation of 5-year overlapping means. From Fig. 4 it appears that there is a decrease of temperatures from the start of the observations in the 1870's to a minimum in the 1880's. From this minimum there is an increase to a maximum which is reached at the end of the 1880's or in the 1890's. Then comes a long period of fluctuations. The main tendency during this period is towards slightly lower values. The minimum is reached at about 1920. From this time there is for most areas a rapid increase to a maximum which in the western areas was already reached in the late 1920's or in the 1930's, whereas in the eastern areas it seems to have been reached in the 1940's. The ensuing decrease lasts until about 1950 when it is followed by a slight increase.

It might be mentioned here that a study (Smed, 1943) of the observations of the salinity of the surface water during the years 1902-39 in a number of areas of the northern North Atlantic showed during this period a variation of the salinity rather parallel to the variation of temperature illustrated above.

With regard to the two southernmost areas, E and N, the above general picture of the variation of temperature is only partly valid. For these areas the high temperatures in the late 1880's have not later been reached. The somewhat diverging course of temperature in these areas, especially in area N, appears from Table 1 also.

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[1] ICES Hydrographic Service, Charlottenlund, Denmark.

TABLE 1. ANOMALIES OF SURFACE WATER TEMPERATURE (°C) IN THE AREAS A_1 TO N IN THE PERIODS INDICATED.

Area / Period	A_1	B	C	D	E	F	G	H	I	J	K	L	M	N
1876-1900	0.1	0.1	0.3	0.2	0.3	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.2	0.3
1901- 25	0.0	-0.2	-0.2	-0.2	-0.3	-0.4	-0.3	-0.2	0.0	-0.2	-0.1	-0.2	-0.3	-0.2
1926- 50	0.7	0.3	0.6	0.3	0.0	0.2	0.4	0.3	0.7	0.4	0.3	0.3	0.2	-0.1
1951- 61	0.7	0.3	0.8	0.4	0.3	0.3	0.8	0.6	1.1	0.7	0.5	0.6	0.3	0.0

Table 1 compares the temperature anomalies, for the various areas, averaged over the 25-year periods 1876-1900, 1901-25 and 1926-50 and finally over the recent shorter period 1951-61. The table shows that, averaged over the period 1876-1900, the temperature is normal or slightly above in all areas, the average anomalies varying from 0.0° to 0.3°. From this period to that of 1901-25 a decrease takes place, varying from 0.0° in area I to 0.6° in area E, so that for the last mentioned period the average temperature is normal or slightly below in all areas.

From the period 1901-25 to that of 1926-50 Table 1 shows a rise of temperature in all areas. The increase differs considerably from one area to another, however, and the geographical distribution of the values shows a clear picture. The increase is small in the southernmost areas N and E, 0.1° and 0.3°, respectively. It is somewhat higher, *viz.* 0.4° -0.6°, in the central areas (B, D, F, H, J, K, L, M). And the increase is high, *viz.* 0.7° -0.8°, in the northernmost areas (A_1, C, G, I). Averaged over the period 1926-50 the temperature is above normal in all areas except the two southernmost ones, N and E.

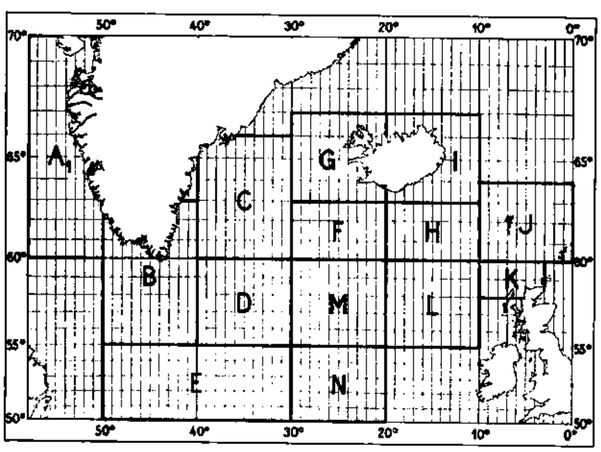

Fig. 1. Location of areas.

Table 1 shows furthermore that the temperature has continued to increase although somewhat slower, from the period 1926-50 to the recent period 1951-61, except in the two areas to the west and south of Greenland, A_1 and B, where the average temperature has remained constant. The greatest increase, 0.4°, took place in the areas surrounding Iceland, G and I.

Comparing the period of lowest temperatures, 1901-25, to that of highest temperatures, 1951-61, we find a temperature rise from about 0.5° in the south (excepting the area N where the rise is 0.2° only) to about 1° in the north.

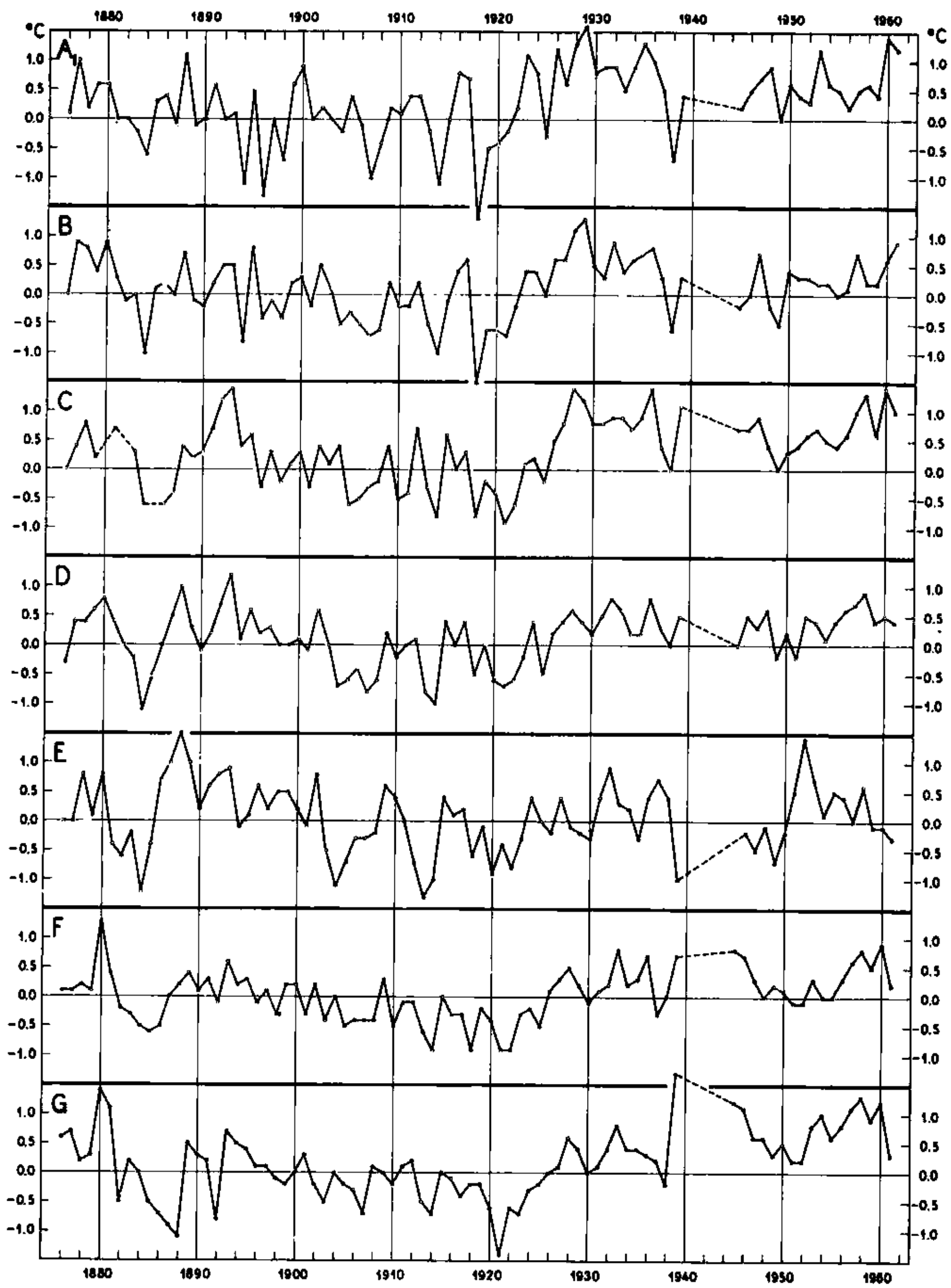

Fig. 2. Yearly anomalies of the temperature of the surface water in the areas A_1 to G.

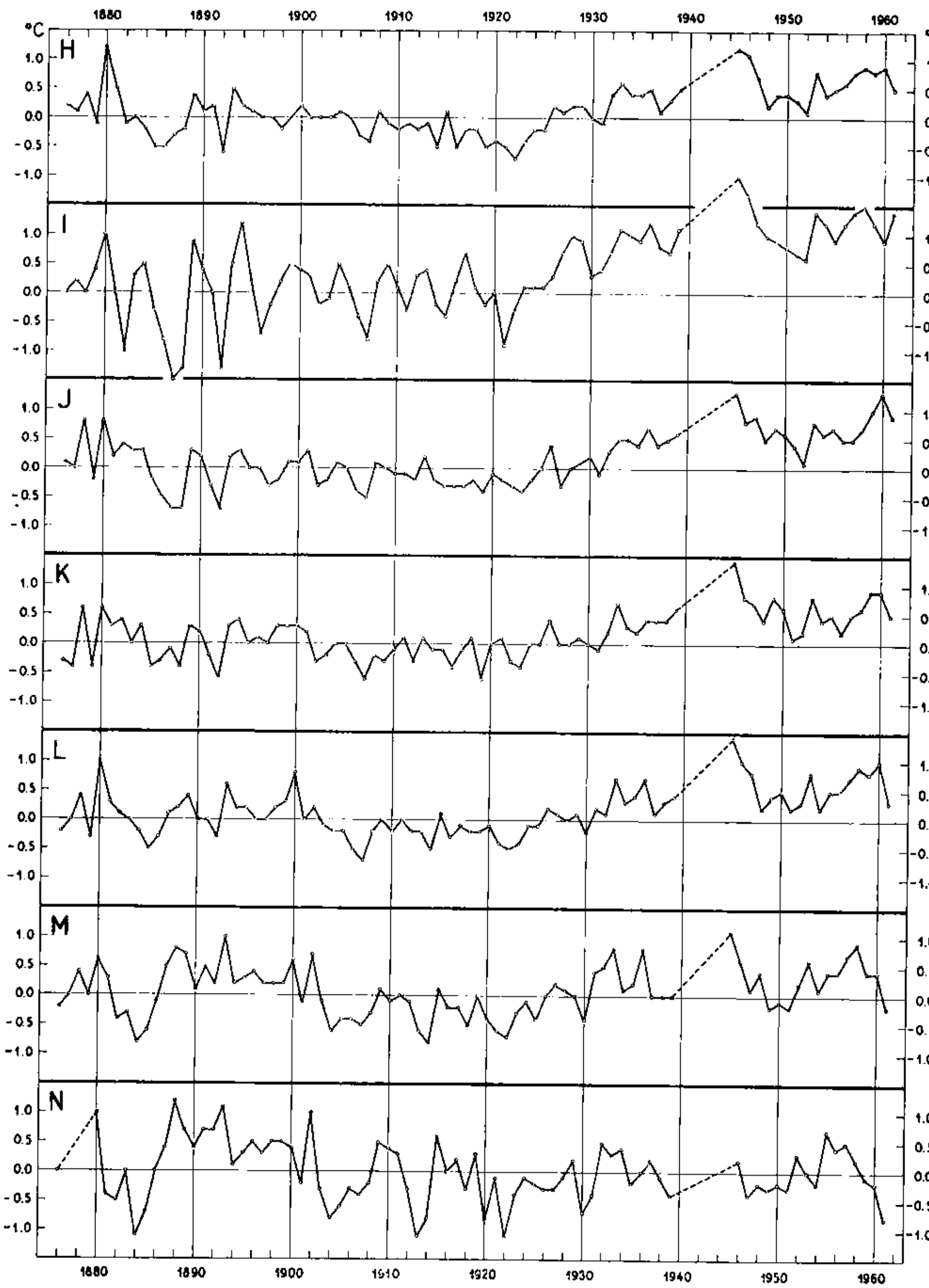

Fig. 3. Yearly anomalies of the temperature of the surface water in the areas H to N.

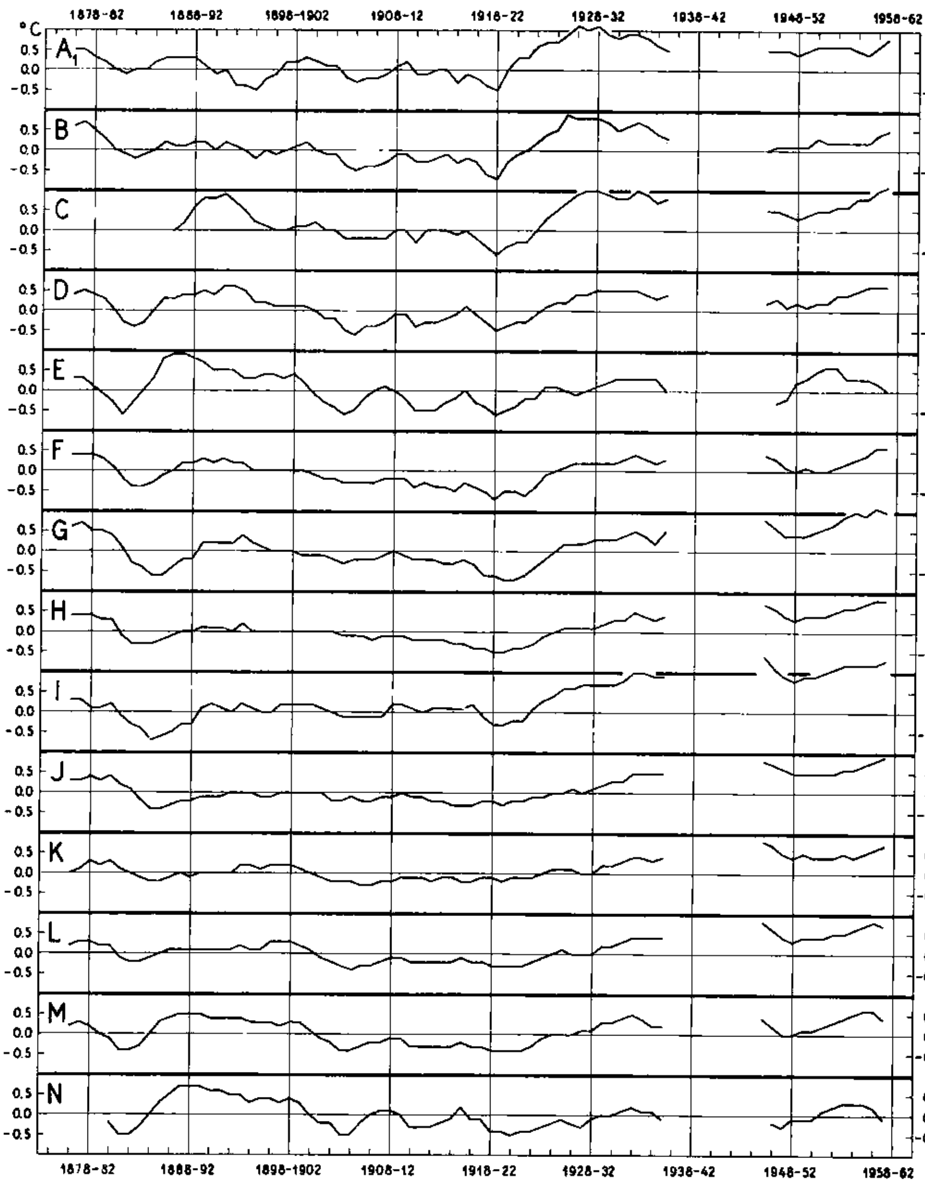

Fig. 4: Overlapping 5-year means of anomalies of surface water temperature in the areas A_1 to N.

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H-6

LONG-TERM VARIATIONS OF OCEANOGRAPHIC CONDITIONS AND STOCKS OF COD OBSERVED IN THE AREAS OF WEST GREENLAND, LABRADOR AND NEWFOUNDLAND

By

A.A. Elizarov[1]

ABSTRACT

Variations of oceanographic conditions along West Greenland, Labrador and Newfoundland coasts are considered. These variations are assumed to reflect relaxation or strengthening of the polar water masses. Water temperatures are used as the indicator of fluctuations in the oceanographic conditions. Commercial productivity of the sea and relative fluctuations of fish stocks in the area are also considered. Izhevsky's method for estimating relative indices of variations of cod stocks gave good results for the Labrador and Newfoundland areas.

Annual variations of temperature conditions in the sea are considered, in many papers, to be the main cause of fluctuations in the groundfish yield. Hermann (1953) showed that an increase of water temperature in the area of Fyllas Bank is related to an increase of the yield of the West Greenland cod and a fall of water temperature results in decrease of the yield.

Kislyakov (1961), having studied the variations of hydrological conditions and annual fluctuations of the cod yield in the Norwegian and Barents Seas, concluded that the highest and lowest intensity of currents is correlated with productive and nonproductive years respectively. The increase in intensity of currents is related to a rise of water temperature, the fall to a decrease of temperature.

Thus fluctuations in the yield of cod are related to annual variations of temperature. In the present case we deal with both causal and mediate relationships. Undoubtedly, water temperature directly influences the formation of fish resources of the sea. A rise of temperature hastens growth and development of eggs and larvae, intensifies the processes of albumen metabolism of different aged fish, and influences the formation of food conditions for fish. The role of water temperature as the indicator of the oceanographic regime of the sea should, however, be noted to be more significant.

Izhevsky (1961) showed first that heat supply in the seas of Northern Europe and the inland seas of the USSR appears to be the indicator of a number of physical processes which finally determine the commercial productivity of the sea. It will be shown below that the same is true of the fishing areas of the Northwest Atlantic.

Fishing areas of the Northwest Atlantic are located meridionally and are influenced by the system of regular warm and cold currents — the Labrador, West Greenland and North Atlantic. Variations of mean temperatures in the active layer of the sea in the areas of Newfoundland and Labrador are related to the strengthening or weakening of the intensity of the Labrador current, as well as to the increase or decrease of the outflow of cold polar water masses (Elizarov, 1962). The polar water moving southward along the continental slope interacts with the relatively warm water masses of the temperate latitudes of the Atlantic Ocean. A decrease or increase of the inflow of polar water masses causes a corresponding extension or reduction of the relatively warm water masses of Atlantic origin. An increase or decrease in the intensity of the West Greenland current and its warm component causes variations in temperature and hydrochemical regimes on fishing banks themselves and on the continental slope.

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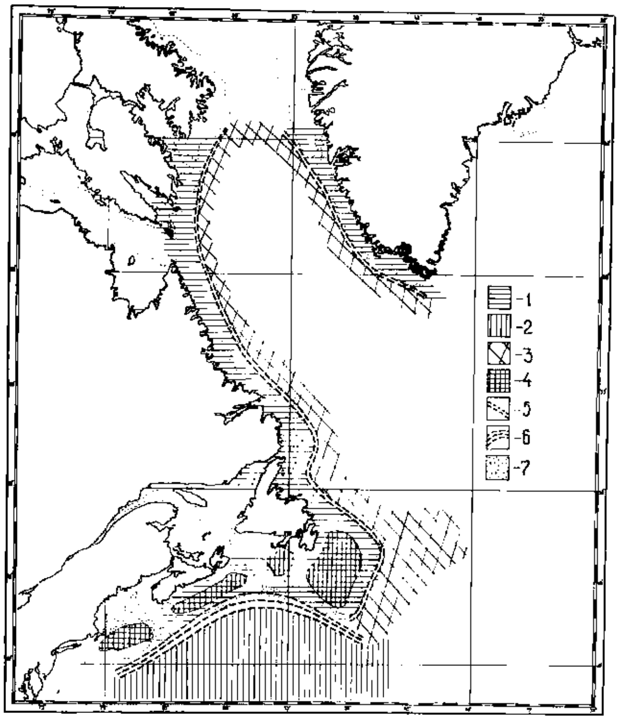

Fig. 1. Water masses and fronts: 1-polar waters, 2-tropical waters, 3-water of moderate latitudes of the Atlantic, 4-bank waters, 5-secondary polar front, 6-polar front, 7-waters of slope.

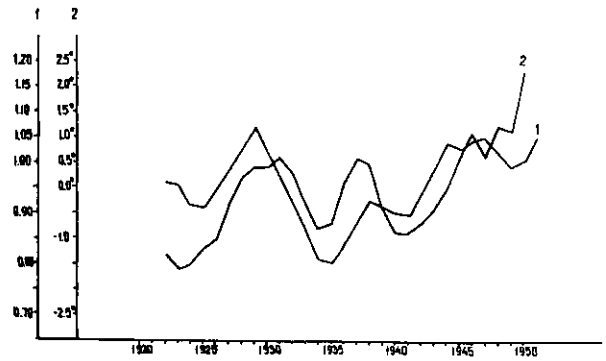

Fig. 2. Long-term variations of the discharge and water temperature (in three-year sliding average). 1-Discharge of St. Lawrence, 2-water temperature on the sea surface in St. Andrew's, Canada.

The analysis of data obtained during long-term observations showed that variations in water temperature and salinity in the areas of West Greenland, Labrador and Newfoundland had a high correlation coefficient (over 0.60). The correlation decreases in the inshore waters where the influence of continental discharge and transport of water out of the Hudson and Belle Isle Straits is found. Over the long term there is a correlation between the St. Lawrence River discharge and the sea surface temperatures at St. Andrews, N.B. (Fig. 2), indicating that a warm climate is associated with greater river flow. Thus during warm periods, higher salinities are found in offshore waters due to the wide distribution of the Atlantic water masses, and lower salinities are found in inshore waters resulting from increase of river discharge. An increase in the amount of Atlantic water as indicated by a rise of temperature in the 0-200 m layer, is associated with a corresponding rise of salinity in all the areas investigated. The fact that the variation of temperature in the area is closely connected with fluctuations in the supply of the upper productive layers with biogenic elements proves to be very important.

As shown by Adrov (1962), enrichment of the water masses of the West Greenland banks with nutrient salts takes place due to an influx of relatively warm deep Atlantic waters flowing up along the slope. In the Frederikshaab area (West Greenland) the correlation coefficient between temperature and phosphorus was 0.67, and between temperature and silicate 0.65. Thus, in a warm year, nutrient salts in the productive layer increase and *vice versa*. Observations of the distribution of biogenic elements over the Newfoundland and Labrador Banks in March-April of 1960 showed that the content of phosphorus and silicates increased, in general, from west to east, *i.e.* from the area of the cold, low salinity polar waters towards the warmer, high salinity waters of the Atlantic origin (Ponomarenko and Istoshina, 1962). The above fact does not mean that waters of Atlantic origin are richer with biogenic elements than the Arctic ones. The Atlantic water masses represent deep waters (their core is located between 200-400 m) which tend to rise into the upper layers near the continental slope. The core of the polar water transported by the Labrador current moves near the surface of the sea, is heated from the top and in the process of photosynthesis partially loses its saturation with nutrient salts.

On the basis of the data obtained during surveys conducted in March-April 1960, a direct relation was found between water temperature and content of phosphorus on different sections of the Grand Newfoundland Bank. On the northern slope of the Bank where the surface heat and the development of phytoplankton has not begun the correlation coefficient for the 0-1000 m layer was 0.94.

On the sections farther to the south along the main stream of the Labrador current the correlation decreases gradually. The correlation coefficient for the 100-500 m (and 100-1000 m) layer did not however drop below 0.60.

Thus, temperature conditions in the fishing areas of the Northwest Atlantic are indicative of the oceanographic phenomena and processes. As a rule, a warm year is characterized by the following conditions which are of great importance for the yield:

1. General increase of heat supply in the sea.

2. Rise of near-bottom temperatures on the shelf.

3. Increase in salinity in the larger part of the area (excluding coastal waters).

4. Increase in river discharge and corresponding growth by providing the coastal zone with biogenic elements.

5. Extension of the relatively warm Atlantic water, which involves an increase of biogenic elements, in the productive layers near the fringe of the shelf.

Quite opposite processes are characteristic of a cold year.

As mentioned previously, definite temperature conditions are related to a definite level of the cod yield. Hermann's data and ours are compared with the stronger year-classes of West Greenland cod (ICNAF, 1951-1960) in Fig. 3. In general, productive years correspond to the maximum temperatures and the nonproductive years to minimum temperatures. The year 1941, an extremely warm one, represents the only exception as the 1941 year-class did not distinguish itself in the fishery.

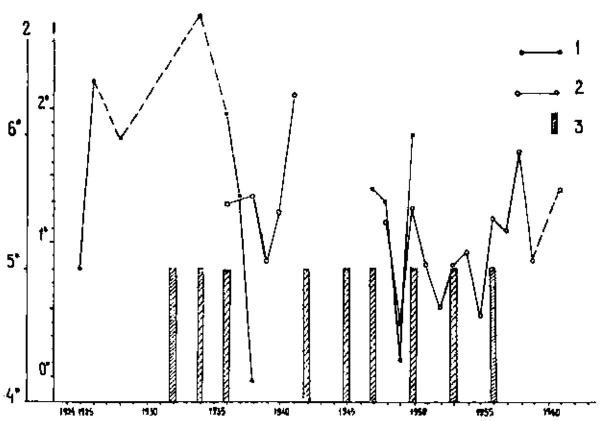

Fig. 3. Strong year-classes of cod in the area of West Greenland (indicated with columns) and mean water temperatures by months
1-in near-bottom layer on the Fyllas Bank in June, according to Hermann.
2-in the 0-200 m layer on the standard section southwest of the Cape Farwell in July, according to Elizarov.

From this correlation an estimate of the year-class size can be made by knowing the oceanographic conditions for the year. The water temperature of the active layer of the sea (0-200 m) estimated on the basis of standard hydrological sections with reduction to a definite date can be assumed as the index of oceanographic conditions for the year.

A similar method was first worked out and used by Izhevsky (1961) for the seas of Northern Europe. The results showed that there was good agreement between the estimated and actual values of catch.

Analogous results were obtained by us for the fishing areas of Labrador and Newfoundland. Water temperature on standard sections in the areas of Labrador and Newfoundland estimated with the help of equations of the relationship of these sections with the Kola meridian section (Elizarov, 1962) are assumed as basis of curves 1 and 2 (Fig. 4). It was taken into account when estimating that cod at age 6-9 was the base of fishing. The high level of 1954-1956 is due to large cod catches per hour of trawling in the area of Newfoundland Banks (Fig. 5). Decline of fishing conditions in the Labrador and Newfoundland areas are shown in Fig. 4. Table 1 shows the data on fishing of cod in the area of Newfoundland Banks. In 1958 the greatest decline in cod stocks was observed.

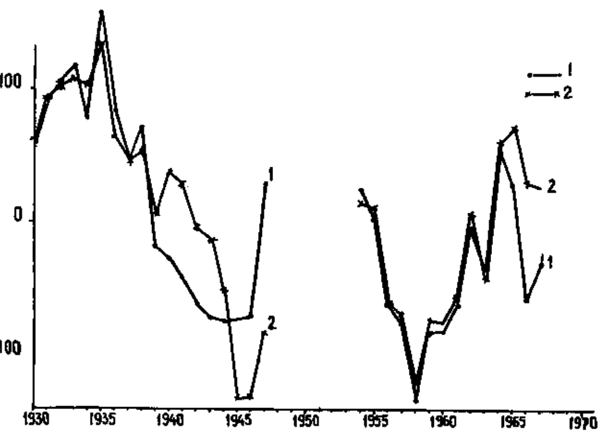

Fig. 4. Fluctuations of cod stocks estimated by means of the index of water regime (mean temperature of the 0-200 m layer): 1-in the area of Labrador, 2-in the area of Newfoundland.

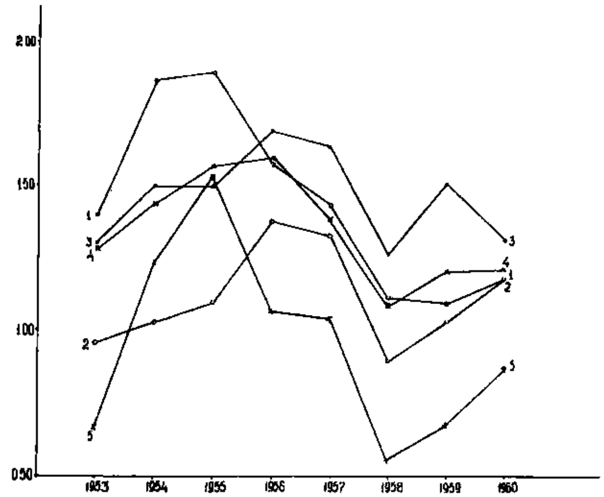

Fig. 5. Mean catches per hour of trawling in the Newfoundland area.
1,2-catches of medium and large-size Spanish trawlers:
3,4-catches of medium and large-size Portuguese trawlers:
5-catches of Canadian trawlers.

During the first half of 1961 the Soviet fleet in the areas of Newfoundland and Labrador fished mainly for cod, catch per unit of fishing effort reached maximum values (to 1,750 kg per hour of trawling).

TABLE 1. CATCHES OF COD IN THE AREA OF NEWFOUNDLAND

Years	Catch of cod ('000 tons)	(as % of the total catch of groundfish)
1957	454	73.7
1958	293	54.8
1959	433	59.9
1960	509	72.9

Thus, there is a good coincidence between cod stocks, estimated with the help of indices of the water conditions, and catches per hour of trawling.

CONCLUSIONS

1. Variations observed in intensity of the currents of the Northwest Atlantic cause changes both in temperature and hydrochemical regimes in the zones of the shelf and continental slope. A decrease of the polar water outflow and a corresponding rise of water temperature is related to an increase of salinity in the offshore part of the area (excluding coastal sections) and a rise of biogenic elements. Increase of river discharge is characteristic of periods of warm years in the onshore areas.

2. Fluctuations of water temperature are closely related to variations of other elements of the regime which, in total, determine the commercial productivity of the sea. In addition, water temperature appears to be one of the elements of the water situation which directly regulates the intensity of biological processes. Thus water temperature can be used as the indicator of annual fluctuations of oceanographic conditions.

3. Analysis of the data concerning water regime and reproduction of cod obtained over a long

period of time showed that the increase of the cod yield in the Northwest Atlantic coincides, as a rule, with the warm years, and decrease of the yield to the regime of cold years.

4. Correlations existing between variation of oceanographic conditions and the level of reproduction of groundfish permit us to calculate relative fluctuations of fish stocks with the help of indices of the water regime. Izhevsky (1961) summarized for each year the temperature conditions under which each year-class in the fishery was produced. Application of this method for the Labrador and Newfoundland areas gave good results: variations of cod stocks estimated by relative indices with the help of the water regime conformed to the actual variations of cod catches per hour of trawling.

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H-7

VARIATION IN RECRUITMENT OF COD (*GADUS MORHUA* L.) IN SOUTHERN ICNAF WATERS, AS RELATED TO ENVIRONMENTAL CHANGES

By

W.R. Martin[1] and A.C. Kohler[2]

ABSTRACT

Long-term trends and annual variations in recruitment of cod to the commercial fisheries of the southern ICNAF area are negatively correlated with sea surface temperatures during the first year of life. This recruitment-temperature association is described for New England, Western Nova Scotia and Gulf of St. Lawrence areas. Similarities between cod and haddock in the occurrence and distribution of dominant year-classes suggest that environmental conditions during the early pelagic life of these species have important effects on recruitment. The association of temperature and recruitment is interpreted to mean that temperature and water transport are limiting factors in the survival of cod eggs and larvae for recruitment to fisheries.

INTRODUCTION

Effects of long-term climatic changes on the abundance of cod in the northern part of the ICNAF area, off West Greenland, have been described in a series of published papers including Jensen (1939), Hansen (1949), and Hermann (1953). The most recent conclusions concerning the importance of high water temperatures in the production of large year-classes of cod at West Greenland are reported by Hansen and Hermann (1964) and by Hermann, *et al.*, 1964).

As a corollary to the positive correlation between year-class survival and temperature observed for ICNAF Subarea 1, year-class strength and resultant fishing success might be expected to be negatively related to temperatures at the southern end of the cod range. This paper examines the hypothesis that weak year-classes are associated with above-average temperatures during early development and strong year-classes with below-average developmental temperatures in ICNAF Subareas 4 and 5.

Sea temperature observations have been taken twice daily since 1921 by the Fisheries Research Board of Canada, at St. Andrews, N.B. Lauzier (1964) has shown that annual variations and trends in the average temperature observed at St. Andrews are representative of changes in the marine climate over the continental shelf adjacent to Nova Scotia and New England. These environmental data are examined in relation to long-term series of statistics and year-class observations for landings of cod from ICNAF Subareas 5 and 4. Annual landings of cod from New England grounds (Subarea 5) for the whole 42-year period of temperature observations are available in ICNAF Statistical Bulletins (Anon., 1952-63). More detailed information on landings by year-classes, and in some cases on landings in relation to fishing effort, has been collected since 1946 by the Biological Station at St. Andrews, N.B., from representative grounds in Subarea 4.

Results of analyses are reported in four sections, and interpretations are considered in the Discussion. The locations of places and areas mentioned in the text are shown in Fig. 1.

TEMPERATURE AND RECRUITMENT VARIATIONS

New England

Annual data on St. Andrews mean water temperatures and landings of cod from Subarea 5 are presented for the period 1921 to 1962 in Table 1. The long-term trend is from low temperatures and

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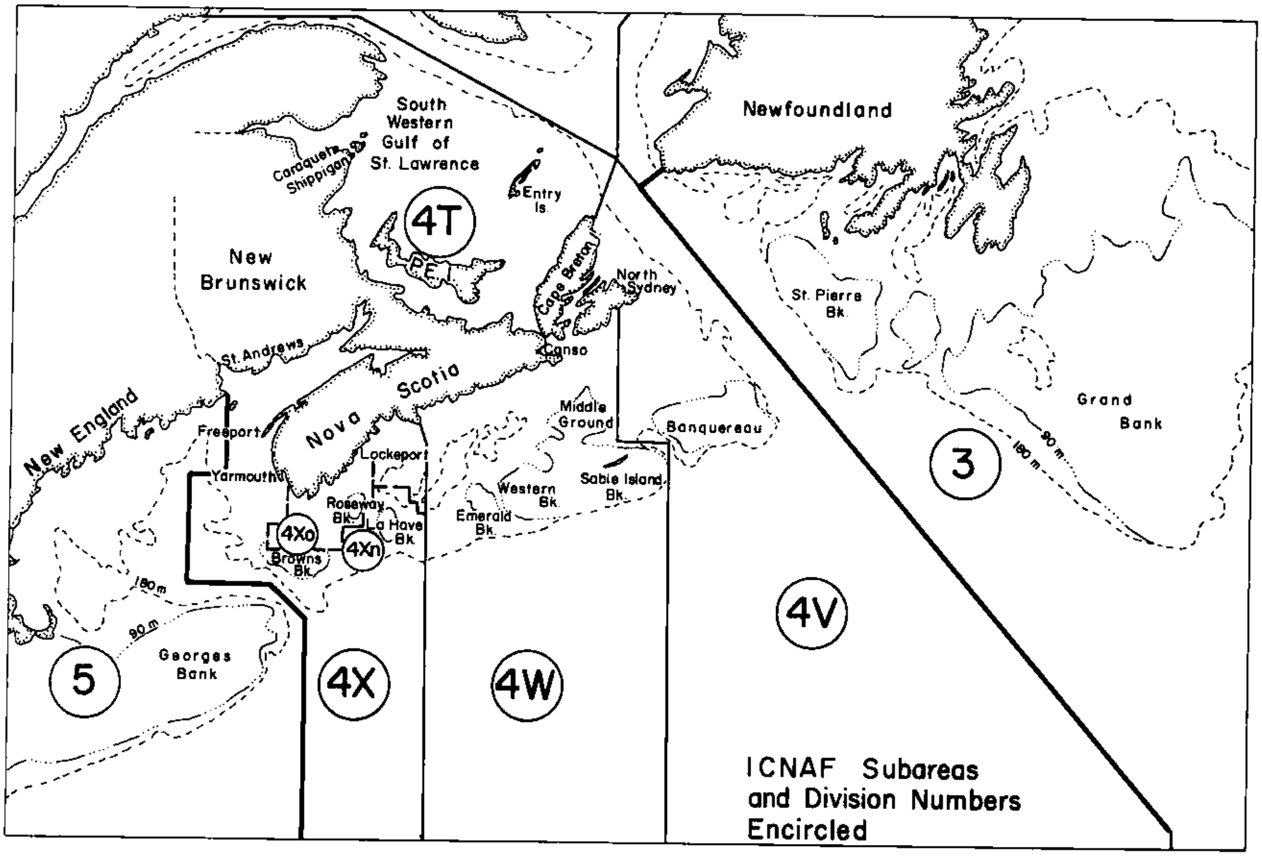

Fig. 1. Chart of the southern ICNAF area.

high landings in the late 1920's to high temperatures and low landings in the early 1950's. Recently the trend has been reversed; lower temperatures and higher landings have been observed.

Age-composition data for Subarea 5 cod landings were not available to provide an assessment of the association between temperatures and the size of year-classes produced at these temperatures. However, an attempt to learn something about this relationship has been made by calculating correlation coefficients between temperatures and total cod landings made up to 7 years later. The results are tabulated in Table 2 and a sample plot of the data for a time lag of 4 years is shown in Fig. 2. It is noted that the highest correlations (-.72 and -.75) are for landings made 3 to 4 years following the year of the temperature measurements. Schroeder (1930) has described the fast growth of Subarea 5 cod and the dominance of 3- and 4-year-old fish in catches for tagging experiments. If year-class strength is determined at the egg-larval stage of development, and landings are in fact largely 3- and 4-year-old fish, the best correlations would be expected for a 3 to 4 year time lag between temperature observations and landings. The high correlations, even with a lag of 7 years, when very few cod are left in the fishery, probably result from the high auto-correlation observed in the temperature series.

Consideration has been given to the possibility that the high correlations result from common trends rather than a causal relationship between temperature and cod catches. To eliminate the effect of possible trends, straight lines have been fitted to both the temperature and cod landings data; and secondly, third degree polynomials have been fitted to these data. Landings and temperatures have been calculated as deviations from the respective "trend" lines, and correlation coefficients have been calculated between landings and temperature residuals. The resultant correlation coefficients are shown in columns 3 and 4 of Table 2. Correlation coefficients between temperatures and landings 4 years later have been reduced by about -.40, but they are still significant. This would be expected if there is a good relationship between temperature and strength of year-classes.

TABLE 1. ANNUAL COD LANDINGS FROM ICNAF SUBAREA 5 AND ANNUAL MEAN SEA SURFACE TEMPERATURES AT ST. ANDREWS, N.B. (LANDINGS IN METRIC TONS, ROUND, FRESH).

Year	USA	Canada	Other	Total	Mean sea surface temp.°C
1921	32859			32859	7.0
1922	31632			31632	6.0
1923	31274			31274	5.4
1924	33469			33469	6.4
1925	35193			35193	6.2
1926	41122			41122	5.9
1927	42807			42807	6.8
1928	40749			40749	7.3
1929	43294			43294	6.7
1930	48380			48380	7.1
1931	39082			39082	7.3
1932	36154			36154	7.0
1933	37491			37491	6.7
1934	32404			32404	6.3
1935	36178			36178	6.2
1936	36373			36373	6.8
1937	46387			46387	7.7
1938	37445			37445	7.1
1939	31897			31897	6.6
1940	28297			28297	6.1
1941	32257			32257	6.4
1942	29172			29172	6.6
1943	31226			31226	6.3
1944	33549			33549	6.9
1945	33702			33702	7.3
1946	35160			35160	7.2
1947	27533			27533	7.8
1948	29374			29374	6.5
1949	28867			28867	8.3
1950	24251			24251	7.7
1951	19077			19077	8.5
1952	14886			14886	7.9
1953	11226	4		11230	8.4
1954	12237	0		11237	8.2
1955	12457	20		12477	7.7
1956	13238	8		13246	6.8
1957	13160	21		13181	7.4
1958	16252	64		16316	7.5
1959	16218	132		16350	6.6
1960	14282	148	USSR	14430	7.4
1961	17669	241	55	17965	6.8
1962	18226	7935	?	26161	6.8

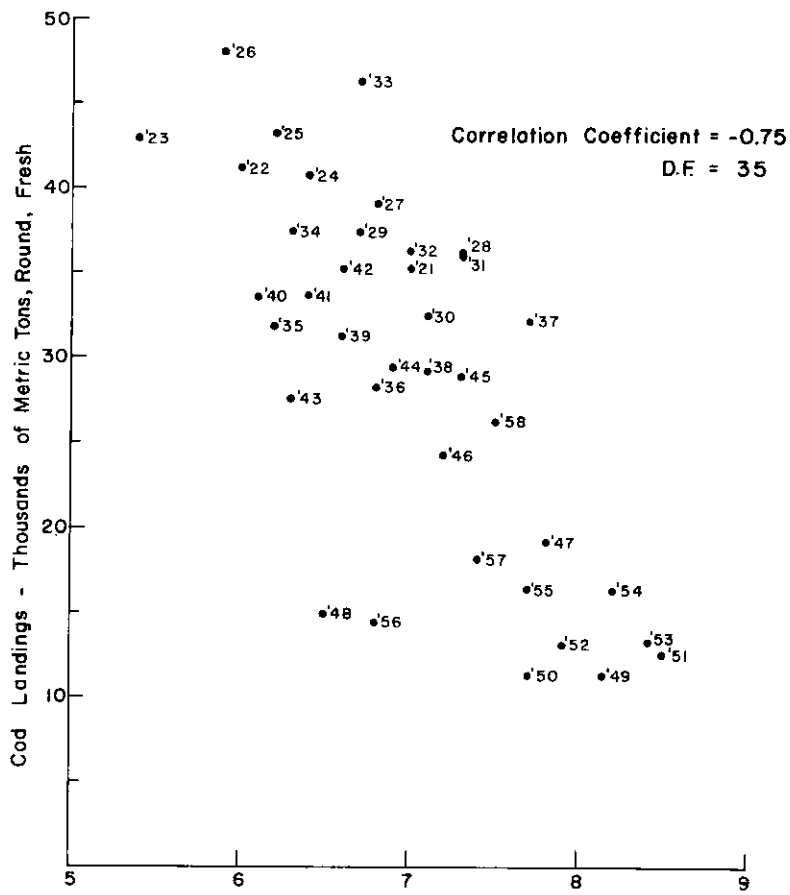

Fig. 2. Relationship of annual mean sea surface temperatures at St. Andrews, N.B., and Subarea 5 cod landings 4 years later. Years for temperature data are shown.

TABLE 2. CORRELATIONS BETWEEN ICNAF SUBAREA 5 COD LANDINGS AND TEMPERATURE DATA (TABLE 1). CORRELATIONS ARE GIVEN FOR TEMPERATURE AND LANDINGS 0 TO 7 YEARS LATER.

Lag (years)	Correlation coefficient	Correl. coeff. eliminating possible linear trend	Correl. coeff. eliminating possible third degree polynomial trend
0	-.40[a]	.00	.03
1	-.53[a]	-.12	-.08
2	-.65[a]	-.23	-.18
3	-.72[a]	-.30	-.25
4	-.75[a]	-.38[a]	-.34[a]
5	-.68[a]	-.33[a]	-.31
6	-.65[a]	-.34[a]	-.33[a]
7	-.63[a]		

[a]significant at 95% level

The dangers in concluding that low temperatures are the cause of high landings of cod in ICNAF Subarea 5 are fully appreciated. Changes in effort and landings for the haddock fishery in Subarea 5 (Graham, 1952) parallel the cod landings data in Table 1 for the years up to about 1945. There have been changes in market preference for haddock over cod, and changes in gear and depths fished. The long-term increase in fishing effort by otter trawlers may have been an important factor affecting the trend toward decreased landings of cod. However, it is difficult to understand how this trend in fishing practices could account for the recovery from very low landings in the 1950's. Changes in landings appear to be more closely related to fluctuations in environmental conditions.

The significant negative correlations between annual mean temperatures and landings of cod from ICNAF Subarea 5 are consistent with the hypothesis that small year-classes are associated with above-average temperatures, and large year-classes with below-average temperatures, at the southern end of the cod's geographic range in the western North Atlantic.

Western Nova Scotia

Cod data for western Nova Scotia (unit areas o and n of ICNAF Division 4X) are only available for a shorter period (1946 to 1962). However, the availability of information on fishing effort in relation to landings, and on age composition of landings, permits a more precise assessment of the temperature-year-class strength relationship during this limited time series.

Cod landings from the 4Xo-n area are shown in Table 3. Most of the catch has been taken by Canada. Both Canadian and United States 4Xo-n landings follow the same long-term trend toward lower landings that we have observed for Subarea 5.

TABLE 3. COD LANDINGS FROM UNIT AREAS O AND N OF ICNAF DIVISION 4X (IN METRIC TONS, ROUND).

Year	USA	Canada	Total
1946	1254	10139	11393
1947	1295	8285	9580
1948	1276	8203	9479
1949	802	7622	8424
1950	895	9386	10281
1951	833	8230	9063
1952	1036	9233	10269
1953	460	6924	7384
1954	660	8009	8669
1955	505	7341	7846
1956	305	6938	7243
1957	183	7815	7998
1958	467	6669	7136
1959	107	6246	6353
1960	425	6127	6552
1961	627	6519	7146
1962	335	7277	7612

Most of the Canadian catch has been taken by baited longlines fished from inshore boats. Sampling of landings by this fishery has been carried out at Lockeport, N.S. Abundance has been measured by average landings per tub of longline gear (each containing eleven 50-fathom (91.4 m) lines with about 50 baited hooks per line). Sampling of the landings for age composition has provided a breakdown of these abundance data by year-classes (Table 4).

The relative strength of year-classes has been measured by totalling catches per tub over ages 3 to 7 for each of the year-classes 1944-51. The figures thus obtained have been correlated with sea temperatures during the year of spawning and early development. The St. Andrews temperatures listed in Table 1 have been used as an index of temperature changes in the 4Xo-n area.

TABLE 4. RELATIVE STRENGTH OF YEAR-CLASSES OF COD FROM THE 4XO-N AREA AS MEASURED BY NUMBERS OF FISH LANDED PER TUB OF TRAWL AT EACH AGE.

	Age												
Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1947	1	6	11	4	4	5	5	1	-	1	-	-	-
1948	1	5	9	8	2	2	2	3	1	1	1	-	-
1949	2	8	8	7	8	-	1	2	1	-	-	-	-
1950	2	8	11	6	5	5	-	-	1	1	-	-	-
1951	1	10	8	8	3	2	3	-	-	2	-	-	-
1952	1	4	15	10	6	4	2	2	1	-	-	-	-
1953	-	3	8	10	5	2	1	1	1	-	-	-	-
1954	-	3	9	7	7	3	1	1	1	1	-	-	-
1955	-	6	9	7	5	4	2	1	1	1	-	-	-
1956	-	1	12	5	4	3	3	1	-	1	1	-	-
1957	-	1	2	9	2	3	2	3	2	-	1	1	1
1958	-	3	6	5	7	1	1	1	1	-	-	-	-

Year-class	Total numbers per year-class for ages 3 to 7
1944	29
1945	26
1946	35
1947	34
1948	46
1949	27
1950	26
1951	20

Although based on only 6 degrees of freedom, a significant correlation coefficient of -.75 was calculated. The correlation does not necessarily imply cause and effect. However, the high negative correlation is again consistent with the hypothesis that small year-classes are associated with above-average developmental temperatures and large year-classes with below-average temperatures at the southern end of the cod's distribution in the Northwest Atlantic area.

Southwestern Gulf of St. Lawrence

The cod fishery in the southwestern Gulf of St. Lawrence has been studied since 1946. The development of a Canadian dragger fishery and European otter-trawler exploitation of this stock have substantially increased landings of Division 4T cod. The greatly increased fishing effort obscures any effect that climatic changes may have had on landings.

Our examination of the temperature-cod recruitment relationship is based on mean surface temperatures taken daily during the months of May to October at Entry Island (Lauzier, 1953; Lauzier and Hull, 1961), and on sampling of Canadian cod landings for age composition at fishing ports in northern New Brunswick. The average temperatures and the year-classes which were dominant in landings for more than one year are listed in Table 5.

Temperatures were observed to be below the average annual temperature of 11.9°C during 8 of the 21 years. Five dominant year-classes of cod were observed in this period, and 4 of these year-classes were spawned in below-normal sea temperature years.

These rather superficial observations concerning the relationship between temperatures and cod abundance are again consistent with the hypothesis that large year-classes are associated with below-normal developmental temperatures in ICNAF Subareas 4 and 5.

TABLE 5. COMPARISON OF MEAN SURFACE TEMPERATURES (°C) FOR MAY TO OCTOBER AT ENTRY ISLAND AND DOMINANT YEAR-CLASSES OF SOUTHWESTERN GULF OF ST. LAWRENCE COD.

Year	Mean surface temperature °C	Temp. below average (11.9°C)	Dominant year-class	Year	Mean surface temperature °C	Temp. below average (11.9°C)	Dominant year-class
1937	12.2			1948	11.2	X	
1938	12.1			1949	12.2		
1939	11.3	X		1950	11.8	X	X
1940	11.3	X		1951	12.8		
1941	10.5	X	X	1952	12.6		
1942	12.9			1953	12.0		
1943	11.4	X		1954	11.4	X	X
1944	11.9			1955	11.9		
1945	12.1			1956	11.7	X	X
1946	11.9			1957	11.9		
1947	12.3		X				

Distribution of Dominant Year-Classes

It is of interest to examine the relationship of the dominant year-classes of cod observed off Western Nova Scotia and in the Western Gulf of St. Lawrence to dominant year-classes observed in adjacent areas and in a related species, haddock (*Melanogrammus aeglefinus* L.).

Sampling of Canadian landings for age composition has been carried out at representative fishing ports in Nova Scotia, New Brunswick and Prince Edward Island since 1946. The age-composition data, assigned to area fished, are on file at St. Andrews. The Gulf of St. Lawrence data have been published by Kohler (1964). The dominant year-class for each annual set of samples from each fishing ground is the one having the greatest individual percentage in the sample and is listed for cod in Table 6. The general pattern of distribution of dominant year-classes is summarized by groups of fishing grounds which roughly correspond with the distribution of stocks of cod in ICNAF Subarea 4 (Martin, 1953) in Fig. 3.

Similar treatment of haddock samples to show dominant year-classes is summarized in Table 7 and Fig. 4. The haddock data have been extended to Georges Bank (Subarea 5) by adding observations by Graham (1953-1961) and to St. Pierre and Grand Banks (Subarea 3) by adding information reported by Templeman (1953-1961). Table 7 also includes data for Browns Bank and Inshore Lockeport (Hennemuth, Grosslein and McCracken, 1964; Kohler, 1958; and Wise, 1957).

An examination of Fig. 3 and 4 shows that dominant year-classes commonly extend over a broad geographic range. It is particularly noteworthy that the largest year-classes are dominant over a wide area as well as remaining for several years in the fishery. In most cases dominant year-classes are distributed over contiguous areas rather than in a discontinuous distribution pattern. In some cases a dominant year-class appears in only one area, but these are the exceptions rather than the rule. Some dominant year-classes are found only in inshore areas and others are confined to off-shore banks; some are found on western grounds, and others have an easterly distribution.

It is of special interest that cod and haddock year-classes are often dominant for the same years and the same areas. The 1943 and 1952 year-classes were particularly strong in both species and in both cases were distributed from Cape Breton to Georges Bank. The 1945, 1948, and 1950 year-classes were dominant in both species and they had similar distributions over the western part of the area. The 1947 and 1949 year-classes were dominant in both species and were distributed over eastern Nova Scotia grounds. The similarities in the occurrence and geographic distribution of dominant year-classes in these two species suggest that common factors are operating during very early stages of development in the determination of year-class survival for recruitment to fisheries. This appears reasonable in view of the late winter and early spring spawning of Nova Scotian populations of both species (Grosslein, 1962; Templeman, 1962), and the common pelagic life of eggs and larvae.

TABLE 6. DOMINANT YEAR-CLASSES OF COD IN COMMERCIAL LANDINGS. DATA ARE TAKEN FROM FILES OF THE GROUNDFISH INVESTIGATION, FISHERIES RESEARCH BOARD OF CANADA, BIOLOGICAL STATION, ST. ANDREWS, N.B. DASHES INDICATE NO DATA.

Year	Freeport grounds	Yarmouth grounds	LeHave Bk.	Roseway Bk.	Lockeport grounds	Western Bk.	Sable Is. Bk.	Middle Ground	Banquereau	Canso grounds	N. Sydney grounds	SW Gulf St. Lawrence
1946	'43	'43	'43	-	'43	'39;'42	-	'38;'39	'39	'41	'39	'35
1947	'44	'43;'44	'43	'43	'43	'39	'43	'39;'41	'39	'39;'41	'39	'41
1948	'45	'43;'44	'43	'43	'44	'43	'39	'43	'39;'43	'43	'41	'41;'42
1949	'45	'45;'46	'43	'44	'43;'45	'39	'39;'43	'41;'43	'43	'43	'41	'41
1950	'47	'45	'43;'45	'46	'46	'43	-	'43	'43	'43	'43	'41
1951	'48	'48	'43	'46	'43;'46	'43	'41	-	'43;'45	'46	'43	'46
1952	'48	'48	'48	-	'47;'48	-	'49	'47	'43;'47	'47;'48	'43;'47	'47
1953	'48	'50	'48	-	'48	-	-	-	'47	'47;'49	'47	'47
1954	-	-	'50	-	'50	-	'46	-	'49	'47	'47	-
1955	'52	-	'50	'52	'52	'47	-	-	-	'49	-	'50
1956	-	-	'51	'52	'52	'49	'49;'51	-	'52	-	'52	'50
1957	-	-	-	-	'52	'49	-	'49	'49	-	'49	'50
1958	-	-	-	-	'54	'49;'55	-	'52	'52;'55	-	'49;'52	'53
1959	-	-	-	-	'54;'55	'52	'53	-	'54	-	'52	'54
1960	-	-	'54	-	-	'55	-	-	'55	-	'54	'54
1961	-	-	'56	-	'56	'52	'56	-	-	-	'56	'56
1962	-	-	'57	-	'58	-	-	'58	'56	-	'56	'56;'57

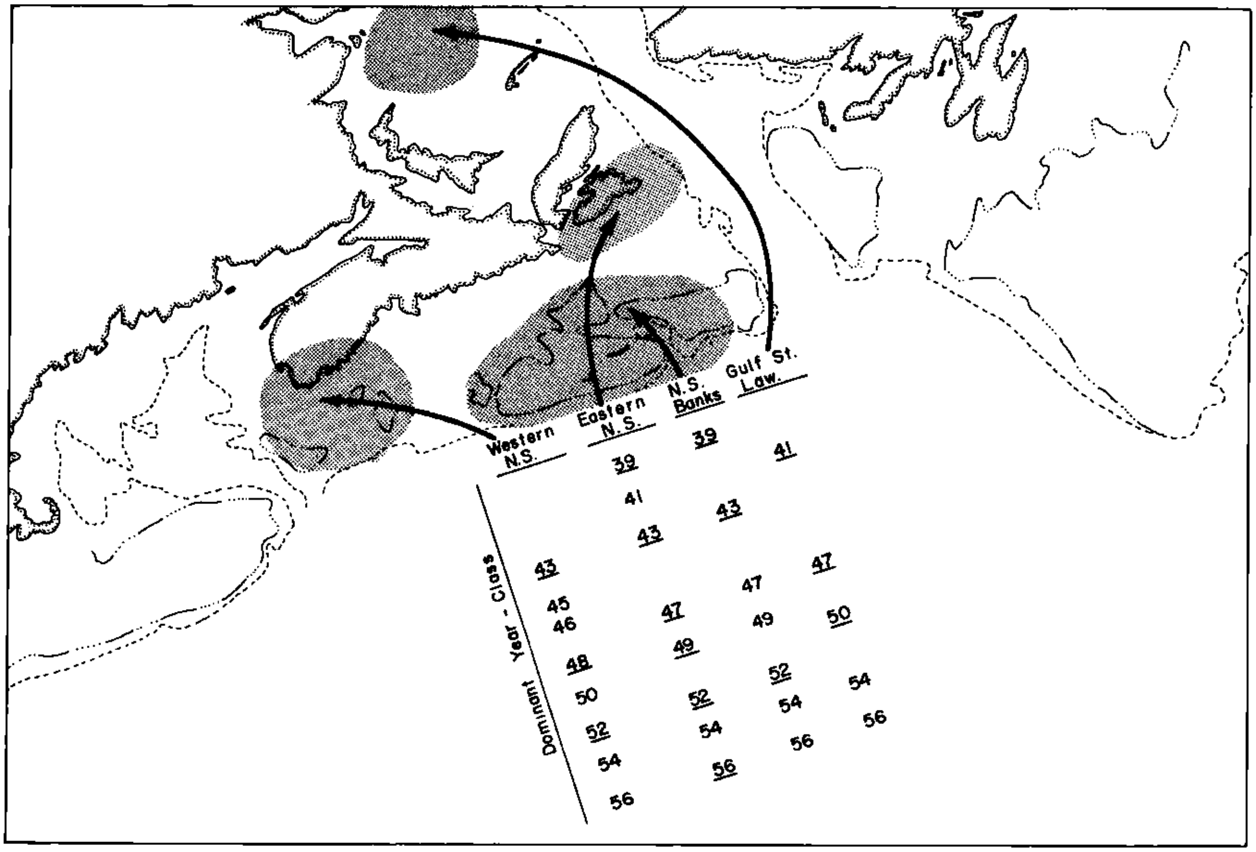

Fig. 3. Dominant year-classes in cod landings for the years 1946-1962. Extra strong year-classes are underlined.

The early summer spawning stocks of Gulf of St. Lawrence cod and St. Pierre Bank haddock produce dominant year-classes which differ from one another and often from the dominant year-classes found on Nova Scotia Grounds.

DISCUSSION

Many papers have been written on variations in year-class strength for cod and other species in the North Atlantic area, with interpretations of the importance of temperature, water transport, wind direction and intensity, and planktonic food as factors affecting year-class survival.

Frost (1938) and Dickie (1955) have examined the relationship between year-class strength and temperature for Subarea 3 cod and Division 4X sea scallops, respectively. In both cases the apparent effect of temperature on survival was interpreted as the effect of water transport on both temperature and transport of pelagic eggs and larvae.

Colton and Temple (1961) and Steele (1963) have written two of the most recent papers on the relation between water circulation and the transport of fish eggs and larvae in ICNAF Subarea 5 and Division 4X. They contend that most haddock and pollock eggs and larvae are swept away from spawning areas, and that only a small fraction is retained in the counter-clockwise eddy of the area to settle and produce year-classes which are large enough to support commercial fisheries.

Carruthers, *et al.* (1951), Chase (1955), and Hill and Lee (1958) have described the apparent relation of wind to brood strength of haddock and cod through its effect on surface-water transport.

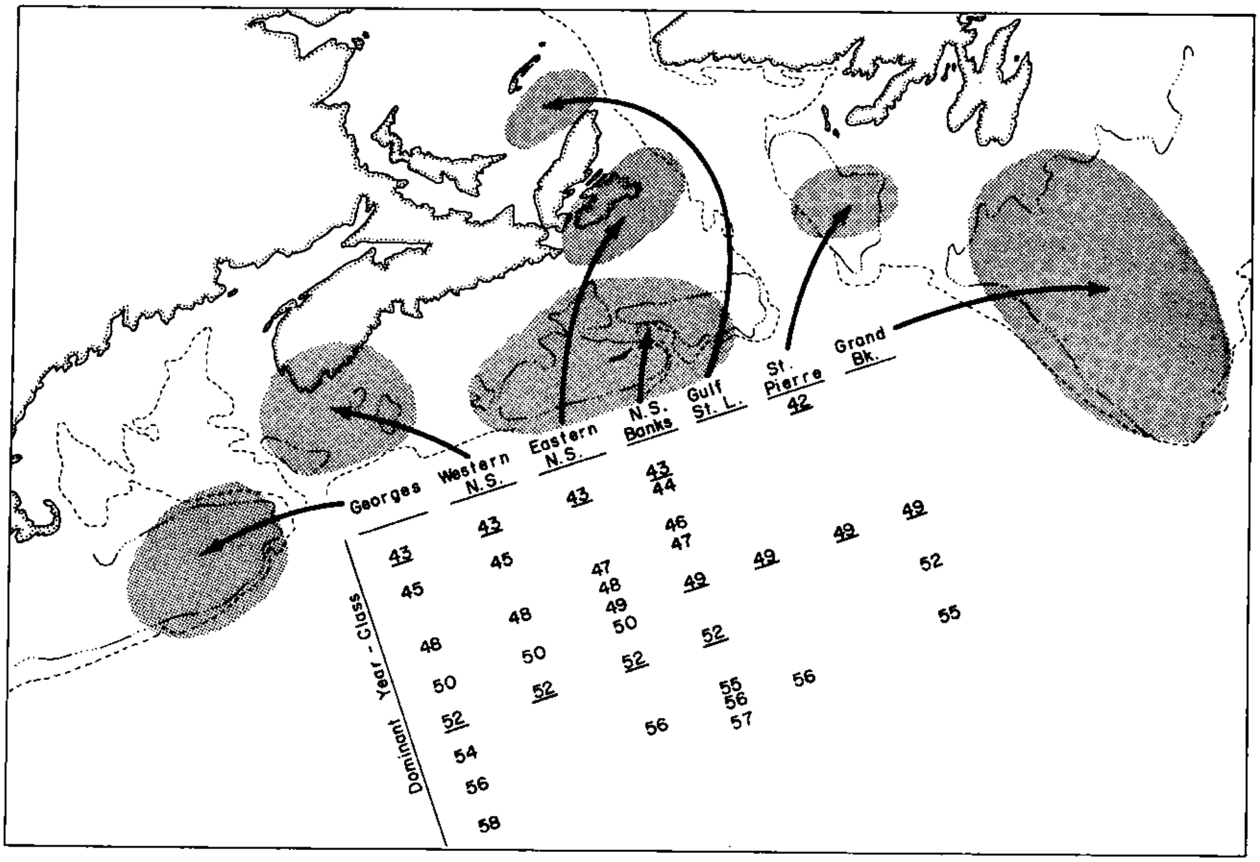

Fig. 4. Dominant year-classes in haddock landings for the years 1946-62. Extra strong year-classes are underlined.

Poulsen (1930), Dannevig (1947), Wiborg (1957) and Corlett (1958) refer to the importance of availability of planktonic food for the survival of cod in the Northeast Atlantic area. In these papers the effects of physical factors, such as temperature and wind, on plankton and cod larvae production are discussed.

All of these physical variables, wind, water transport, and sea temperatures, appear to be interrelated and related in one way or another to abundance of plankton, including fish eggs and larvae. It is concluded therefore that the consistent negative correlations between temperature during early development and cod abundance do not necessarily imply cause and effect. Changes in sea temperatures may directly affect plankton production and year-class survival, or they may simply reflect the direct effects of changes in water transport on the distribution of plankton and fish eggs and larvae. The possible mechanics of these interpretations are considered further.

Temperature must be a limiting factor in the survival and well being of plankton crops, including fish eggs and larvae. The water temperatures of ICNAF Subarea 1 and Subarea 5 sometimes appear to be sufficiently extreme to drastically reduce the numbers of cod eggs and larvae in these subareas. Year-class strength is more variable at either end of the species range than in the central areas.

In southern waters, low temperature may prolong the spawning period and the pelagic life of larvae, thereby providing greater opportunities for suitable feeding conditions to permit good survival and growth of large lots of larvae.

TABLE 7. DOMINANT YEAR-CLASSES OF HADDOCK IN COMMERCIAL LANDINGS. DATA ARE TAKEN FROM GRAHAM (1953-1961), HENNEMUTH, GROSSLEIN AND MCCRACKEN (1964), KOHLER (1958), TEMPLEMAN (1953-1961), AND WISE (1957). DASHES INDICATE NO DATA.

Year	Georges Bank	Browns Bank	Freeport Grounds	Yarmouth Grounds	LaHave Bank	Roseway Bank	Lockeport Grounds	Emerald Bank
1946	'43	-	'39;'43	'43	;40	-	'39;'43	'41
1947	'43;'45	-	'43	'43	'40	'43	'43	'40:'41;'42
1948	'45	-	'43	'43	'43	'43	'43	-
1949	'45;'46	-	'43	'43	'43	'43	'43	'43;'44
1950	'48	-	'44;'45	'43	'43	'43	'43;'45	'43
1951	'48	-	'45;'47	'45	'43	-	'45	-
1952	'50	-	'46;'48	'46;'48	'46;'47	-	'46;'48	-
1953	'50	-	'48	'48;'49	'47;'48	'48	'48	'47;'48
1954	'50;'52	-	-	'48	'48;'49	'49	'48	-
1955	'52	-	-	-	'49;'50	'50	'50	-
1956	'52	'50	-	-	'50;'52	-	'50	'50;'52
1957	'52;'54	'52	-	-	'52	-	'52	'52
1958	'54	'52	-	-	-	-	'52	'52
1959	'56	'54	-	-	-	-	'52	'52
1960	'58	'54	-	-	-	-	'56	'55
1961	'58	'56	-	-	-	-	-	'56
1962	'59	-	-	-	-	-	-	'56;'57

TABLE 7. CONTINUED.

Year	Western Bank	Sable Is. Bank	Middle Ground	Banquer-eau	Canso Grounds	N.Syd-ney Grounds	SW Gulf St.Law.	St.Pierre Bank	Grand Bank
1946	'41	-	'40	'39	'40	-	'43	'39	-
1947	'41	'43	'43	'43	'43	'43	-	'42	-
1948	'43;'44	'44	'43	'43	'43;'44	'43	-	'42	-
1949	'44	'44	'44	'43	'43	'43	-	'42	-
1950	'44;'46	-	-	'44	-	'43	-	'42	-
1951	'46	'46	-	'46	'45	'46	'46	-	-
1952	'46;'47	'47;'49	'47;'49	'46;'47	'47	'47	'47	'47	-
1953	'47	'47	'48	'47	'48	'47	'48;'49	'46;'47	-
1954	'47;'49	'52	-	'49	'48	'49	'49	'49	'49
1955	'49	'52	'49	'49	'49	'48	'49	'49	'49
1956	'49;'52	'52	'52	'49	-	'50	'49	'49	'49
1957	'52	'51	'52	'50;'52	-	'52	'52	-	'49;'52
1958	'52	'55	'52	'52;'54	-	'52	'54	-	'52
1959	'52	'55	'55	'54;'55	-	'52	'54	-	'55
1960	'55	'56	-	'56	-	'56	'56	-	'55
1961	'56	-	-	-	-	-	'56	-	-
1962	'56;'57	'56;'57	-	'56;'57	'57	-	-	-	-

Sandström (1919), Trites and Banks (1958) and Bigelow (1928) have described the circulation of surface waters in the Gulf of St. Lawrence, Nova Scotia Banks, and Gulf of Maine areas, respectively. The pattern of circulation over each fishing area can account for the retention of sufficient pelagic eggs and larvae to permit adequate settling of young fish to bottom on grounds which are suitable for continued survival.

Hachey (1934), Day (1958), Bumpus (1960) and Colton and Temple (1961) refer to annual variations from the general circulation patterns. In some years, water transport appears to carry fish eggs and larvae from one fishing area to another, and often completely away from suitable bottom habitats. Annual variations in water transport are believed to be of great importance in the determination of year-class strength. The transport is presumably affected by relative contributions of major ocean currents, such as those of Labrador and the Gulf Stream, and by wind. Annual variations in water transport are probably reflected in the annual temperature changes observed at monitoring stations.

Trites and Banks (1958) have described the transport of water from east to west along the Nova Scotia coast, and from west to east over offshore Nova Scotia Banks. Net drift was observed to be 2 to 4 miles per day. Annual variations in the timing and duration of pelagic life of fish eggs and larvae could result in the annual variation in distribution of dominant year-classes illustrated in Fig. 3 and 4. Young fish may settle to bottom on inshore, western, offshore, or eastern grounds, or on combinations of these areas. Some year-classes are carried away almost completely during pelagic life, and this would appear to be particularly common for certain populations such as St. Pierre (Templeman, 1961) and Georges Bank (Colton and Temple, 1961) haddock.

Long-term trends and annual variations in recruitment of cod to the southern part of the ICNAF area are negatively correlated with water temperatures during the first year of life. The correlations are interpreted to mean that temperature has a direct effect on survival, and that temperature is an indirect measure of effects of wind and water transport on plankton, including cod eggs and larvae. Colder water could imply greater water transport from east to west, which would result in the appearance of strong year-classes on western grounds.

A continuation of the types of observations described in this paper, and the addition of oceanographic studies of water transport and zooplankton, together with laboratory experiments on factors affecting survival of cod eggs and larvae, are needed to provide a better understanding of the effects of the changing environment on recruitment to cod fisheries.

ACKNOWLEDGEMENTS

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H-8

CHANGES IN THE HYDROGRAPHY OBSERVED ALONG THE EAST COAST OF THE UNITED STATES

By

D.F. Bumpus[1] and Joseph Chase[1]

ABSTRACT

Daily temperature and salinity measurements at lightships along the Atlantic seaboard of the United States over a period of seven years have revealed a number of short-term changes. These are compared with previous observations of longer periods in order to show the recent trends. The returns from drift bottles along this same coast have also indicated changes and may in some instances be associated with changes in the runoff from adjacent watersheds.

INTRODUCTION

This paper is being presented at the session in the ICNAF Environmental Symposium having to do with the effect of long-term trends. We shall discuss some changes in the hydrography off the east coast of the United States, changes which undoubtedly have their effects on the biota which we are not presently prepared to discuss. This is more of a warning to ecologists that, while the seasonal effect of the cycles of wind, temperature and river runoff continue to prevail in influencing the marine environment, relatively minor changes in these parameters may cause marked changes in the hydrography and circulation, at least off the east coast of the United States.

We shall limit our discussion to some of the data developed from our lightship program (Fig. 1) which was commenced in late 1955. Daily temperature measurements with a bathythermograph and surface salinity samples have been taken at 12 lightships off the east coast. Surface temperature observations have been made at some selected shore stations. In late 1958 we began to release two drift bottles daily at many of the lightships. Through these observations we have sensed some changes in the hydrography which may be pertinent.

RECENT TRENDS IN WATER TEMPERATURE OFF THE EAST COAST OF THE UNITED STATES.

The general upward trend in air temperatures covering, approximately, the hundred years ending about the middle of this century (Veryard, 1963; Mitchell, 1963) has been paralleled, to some extent, by rises in sea water temperatures (Bjerknes, 1959; Rodewald, 1956). More recently, downward trends have been recorded in air temperature (Mitchell, 1963) and in surface water temperatures in some areas (Rodewald, 1963; Lauzier and Hull, 1961).

A program of daily bathythermograph observations at lightships along the east coast of the United States was begun in 1956 under a contract between the US Fish and Wildlife Service and the Woods Hole Oceanographic Institution (Bumpus, 1957; Day, 1959 *a* and *b*, 1960, 1963; Chase, 1964). Although the data from this program do not yet constitute in themselves a long enough record for long-term climatological study, they do extend the previous record of Bumpus (1957*a*) of surface water temperatures. It is the purpose of this study to examine these records for trends and to compare them with records of air and water temperatures from stations on the coast.

New England.

Typical of the trends during this century is the curve of 5-year means of winter (December, January, February) air temperatures at Boston, Massachusetts, and New Haven, Connecticut, combined

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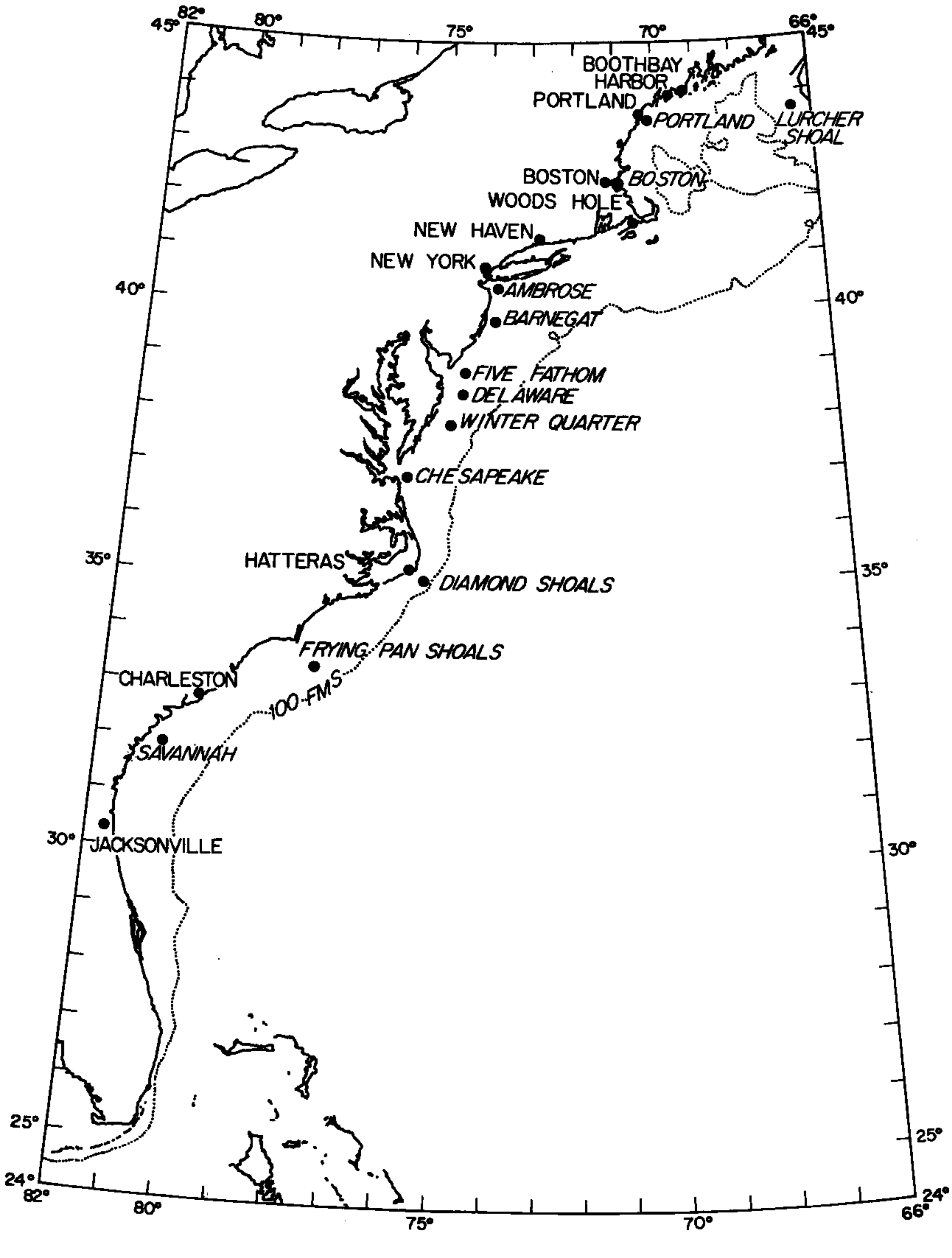

Fig. 1. East Coast of the United States.

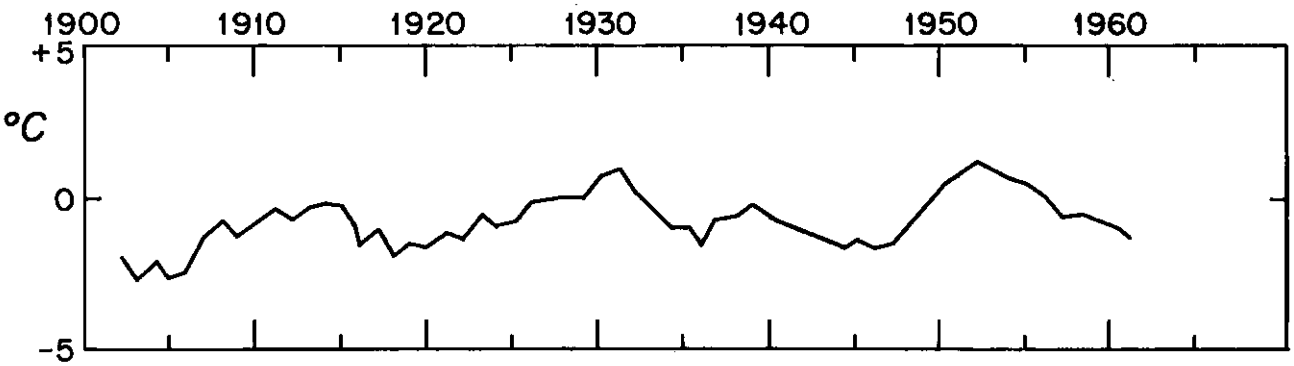

Fig. 2. Five-year means of winter (December, January, February) air temperature at Boston, Massachusetts and New Haven, Connecticut, combined.

(Fig. 2). The curve rises gradually to 1931. A second maximum occurred in 1952. The low values between the peaks and again in recent years are about normal for this century but higher than the general level of values for the last half of the nineteenth century. For the summer months over this same period there has been very little change in southern New England (Taylor, *et al.*, 1957). Water temperatures at Boothbay Harbor, Maine for February and for the year (Fig. 3) parallel the air temperatures of Fig. 2. The rise in February values is more than that of the winter air temperatures. The maxima of 1931 and 1953 occurred at about the same time as those in air temperature. The August record shows little long-term change although there was a prominent maximum in 1951. The drop during the past decade is clear in all three curves.

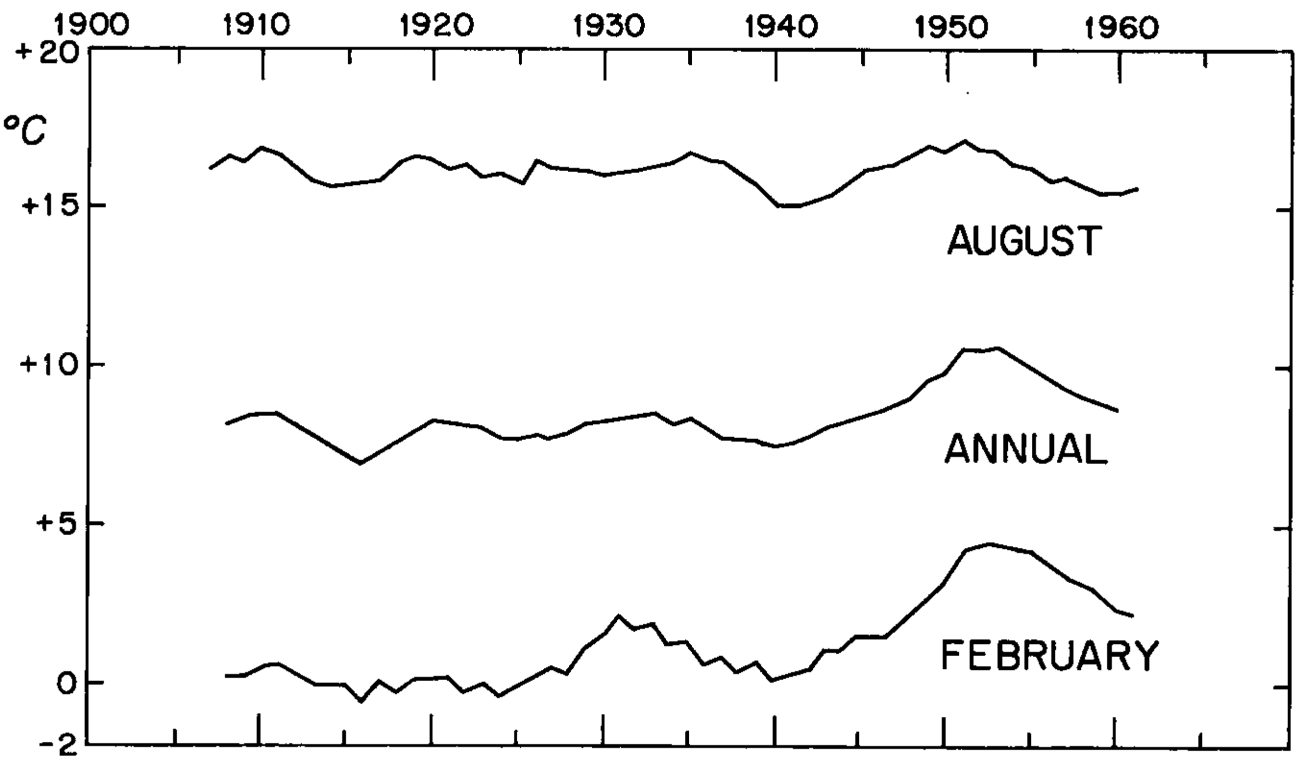

Fig. 3. Five-year means of water temperature at Boothbay Harbor, Maine for August, the year, and February.

Surface water temperatures have been recorded at Woods Hole, Massachusetts since 1880. The annual averages show a maximum near 1950. The level of an indicated maximum in the early 1930's is uncertain due to gaps in the record of observations. The change is in the winter data. Five-year means in February, for example, show a minimum of -1.3°C for the period 1901 through 1905 and a maximum of 2.1°C for 1949-53. The general level before the minimum was about 0°C. The highest February value since 1953 is 1.5°C (1960) and for the last three years the average is -0.7°C.

Typical of the warmer months is August with a five-year minimum of 20.3°C (1901-05) and a maximum of 22.2°C (1948-52). The average for the three years 1880, 1883 and 1885 (no data available for August of 1881, 1882 and 1884) is 22.2°C.

At Portland Lightship, which is well offshore and thus far removed from the local influence of cities (Duckworth and Sandberg, 1954; Swartz, 1956), there was also a rise in winter temperatures culminating in about 1950 and a small decline since then. Three-year means indicate a previous maximum about 1928. There is little change apparent in the summer temperatures since the beginning of observations in 1925.

At Boston Lightship, the old record comprises data for 1925 to 1941. The observations made since 1956 indicate no significant trends in any season and the values are about the same as those of the old record. There was a small maximum in the winter temperatures about 1932.

New York to Cape Hatteras

Rodewald (1956) noted the rise in January air temperatures at New York City from the decade ending in 1888 to a maximum for the decade ending in 1937 and the occurrence of another maximum in the decade ending in 1953. The gain in summer temperature over the same 65 years was less than half that of winter. From his examination of later values and of past trends he conjectured a return to lower winter values which has in fact been borne out by later observations along the coast.

At Hatteras, North Carolina, the air temperatures have undergone similar trends. There were winter maxima in 1929-34 and 1948-53. The principal minimum was in the years 1900-05.

There are six lightships along this stretch of coast which participate in the bathythermograph program. The southernmost of these, Diamond Shoals Lightship, is subject to so much variation in water temperature due to advection as to defy analysis of its data for climatic trend until a much longer record has been made. Three of the others, Barnegat, Five-Fathom Bank and Chesapeake Lightships, show a decrease in winter water temperatures in recent years after a maximum in about 1950. The records for the other two, Ambrose and Delaware (with Winter Quarter) Lightships are too irregular for complete analysis but at least these records do not contradict the general trends for the area. Chesapeake Lightship which has the longest temperature record (begins in 1928) experienced a marked winter maximum in about 1931-32 and another maximum near 1950. Apparently there were no significant trends in summer.

Cape Hatteras to Jacksonville

The air temperature record at Charleston, South Carolina (Fig. 4) shows maxima in winter five-year means in about 1933 and 1951 that are only slightly higher than maxima around 1882 and 1892.

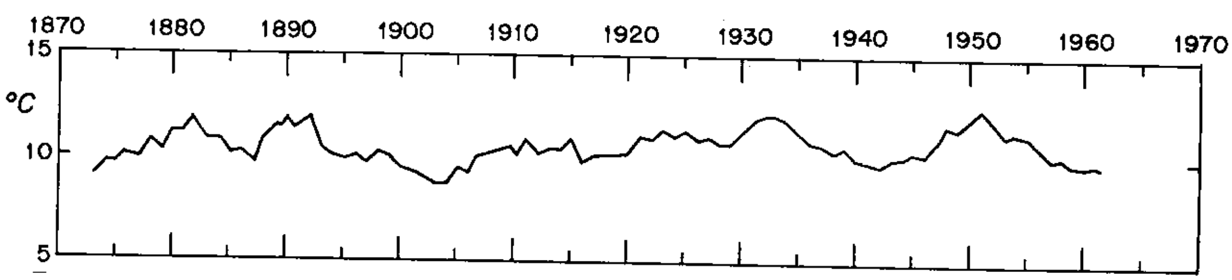

Fig. 4. Five-year means of winter (December, January, February) air temperature at Charleston, South Carolina.

The minimum centered about the winter of 1902-03 had a value of 8.7°C as compared with 12.3°C for the maximum centered about 1950-51. The summer temperatures show no significant trends.

At Jacksonville, Florida, the air temperature record reveals winter maxima and minima at nearly the same times as at Charleston and the summer data reveal no significant trends.

The two lightships off this part of the coast which participate in the bathythermograph program are Frying Pan Shoals and Savannah Lightships. Both have experienced a decline in winter surface water temperatures since 1956 (although the exceptionally low values for February and March of 1958 are probably due to advection of colder water rather than to climatic change). Both observation posts have previous records dating from 1947 which indicate maximum winter temperatures around 1950 and in addition a short record of observations at Frying Pan Shoals from 1930 through 1934 indicates a winter maximum there around 1932. Again no summer trends are apparent.

THE CIRCULATION

The general circulation in the Gulf of Maine at the surface comprises an anticyclonic gyre in the Gulf and a cyclonic eddy over Georges Bank (Bigelow, 1927) which develop during the spring months of the year and begin to deteriorate during the summer (Day, 1958). During the winter the southern side of the gyre and the Georges eddy appear to be absent. From Nantucket Shoals southwestward the surface circulation is southwesterly as far as Cape Hatteras where it turns offshore. South of Hatteras the surface circulation is northeasterly off the Carolinas, and reversing off Georgia and Florida being northerly during the winter and southerly during the late summer and autumn. However, through the use of drift bottles, we have noted certain departures from the norm.

Runoff effect in northern Gulf of Maine

The non-tidal drift at the surface from Lurcher Lightship near Yarmouth, Nova Scotia is northerly into the Bay of Fundy. During the whole year 1957 there were no exceptions to this rule except for the return of a few drift bottles in November which apparently were caught up in a back eddy and were found on the western coast of Nova Scotia south of their point of origin. However, during the first three months of 1958, the majority of those bottles which were recovered from Lurcher Lightship releases, were from the coast of Massachusetts having been carried at speeds as great as 13 km/day. Following this period, the circulation returned to normal (Bumpus, 1960). This remarkable change in the circulation was supported by the return of drift bottles released in Passamaquoddy Bay during this same period. It became quite obvious when one examined the runoff from rivers emptying into the Gulf of Maine that, for a period of nine months, the runoff was much below normal followed by a period, December 1957 and January and February 1958, when the runoff was substantially greater than normal, thus producing the dynamic impetus for a vigorous anticyclonic circulation around the perimeter of the Gulf of Maine. We have looked further into the drift bottle returns from Lurcher Lightship and discovered that it is not at all uncommon for drift bottles released at that location to be found on the shores of New England but we have not seen them make the traverse in such large numbers or at such great speeds as in early 1958. The year 1962 was an exception; a very small number crossed to New England in March of that year. Also 1957 was exceptional in that the circulation was persistently, except as noted for November, directed northerly into the Bay of Fundy where, as in other years (1959, 1960 and 1961), it was not uncommon for the current to send a branch westward across the southern end of the Bay of Fundy and so on southwesterly along the coast of New England.

Now if we look at this southwesterly flow at the location of Portland Lightship we find that during the first four months of the year the non-tidal drift is predominantly southerly but that during the remainder of the year it falters and many bottles will drift northerly into Casco Bay or even easterly across the southern end of Casco Bay.

However, during the latter part of 1958 and much of 1959, the runoff from New England rivers was much below normal and the drift bottle data exhibit the consequential weakening of the close inshore anticyclonic drift during that period.

The effect of the runoff can be graphically displayed by comparison of the departures from the mean of the runoff of the Pemigewasset River and the surface salinity as observed at Portland Lightship (Fig. 5). The relationship is remarkably good considering that the river is gagged many miles upstream and debouches into the sea south of the lightship.

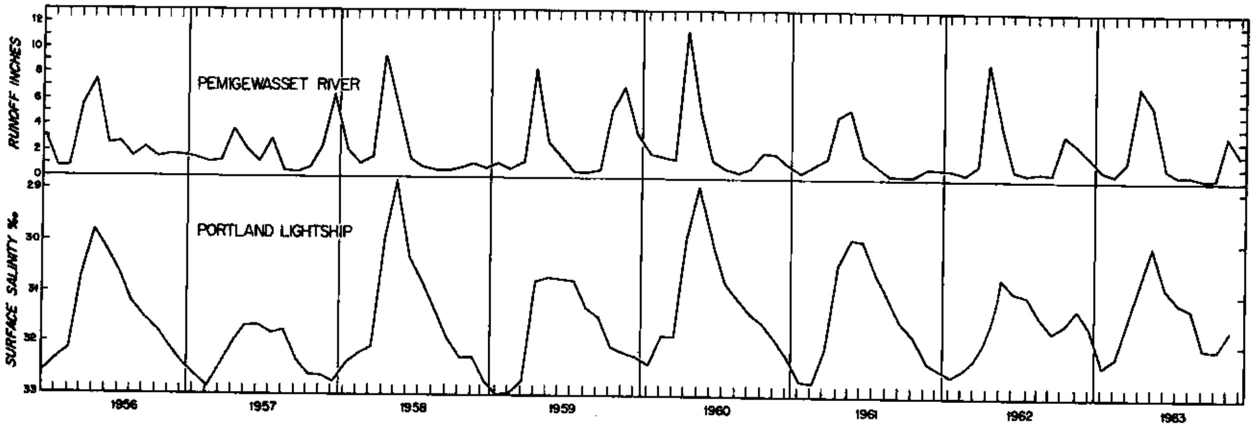

Fig. 5. Runoff of the Pemigewasset River and surface salinity at Portland Lightship.

Reversal off South Atlantic States

One change in the hydrography, which does not properly come under the heading of long-term trends, is a seasonal one but it is mentioned here because we doubt the general awareness of it. That change is the reversal in direction of the non-tidal drift on the continental shelf between North Carolina and Florida.

During the months of December, January and February no drift bottles are recovered from Frying Pan and Savannah Lightships. They presumably drift offshore and get caught up in the Florida Current. During March, April and May the drift is northerly. June appears to be a transition period. During July through October and occasionally November the drift is consistently southerly. Are there other coastal areas where a similar alternation in non-tidal drift has been observed?

SUMMARY

In recent times surface water temperatures at lightships off the United States East Coast have in general followed the trends in air temperature along the coast.

Most of the climatic change in both air and water temperatures has taken place in the winter months rather than in the summer.

Two peaks in winter temperature in about 1931 and 1950 are apparent in all the coastal air temperatures studied and in the water temperatures at the lightships (except Diamond Shoals) within the limits of the available data. A general downward trend is apparent in more recent winter data.

North of Cape Hatteras there was a warming of the air since sometime in the nineteenth century to near the middle of this century. South of Cape Hatteras a minimum occurred near the beginning of this century.

While drift bottles are not very sensitive devices for studying currents, a continuous release of them at discrete locations can reveal some patterns. Anomalous current patterns have been observed in the northwestern part of the Gulf of Maine associated with periods of drought followed by high precipitation and runoff. A periodic reversal in the coastal circulation between South Carolina and Florida have been observed now for three years.

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H-9

INFERENTIAL BIOLOGICAL EFFECTS OF LONG-TERM HYDROGRAPHICAL TRENDS DEDUCED FROM INVESTIGATIONS IN THE FAROE-SHETLAND CHANNEL

By

J.B. Tait[1] and J.H.A. Martin[1]

ABSTRACT

Five different water-masses, only one of which is permanent, occur in the region of the Faroe-Shetland Channel. Three of these are cold, low salinity, water-masses, while two are warm and relatively highly saline.

When they occur, one of the warm and two of the cold masses are intrusive respectively into the two masses which normally characterise the region, namely, the upper, warm and permanent layer, and the lower, cold, semi-permanent layer. The semi-permanence of the latter stems from the fact that, on occasions, one or other or both of the cold water intrusions totally displace it as the bottom water-mass of the Faroe-Shetland Channel.

Of one kind or the other, that is, warm or cold, the intrusions usually occur in groups of from about four to six or seven consecutive years, waxing to maximum intensity in the mid-period of their occurrence and waning to extinction at the end.

A clearly established association has become apparent between the above-mentioned cold water intrusions, which are of Arctic origin, and fish stocks bordering upon the Faroe-Shetland Channel region. As reflected in commercial catches, the annual herring fishery of the Minch area for example, over the 39 years from 1920-59, have been high, medium, or low, according as Arctic water influence in the Faroe-Shetland Channel has been strong, moderate, or non-existent, three years earlier. The summer herring fishery alone (June-September) shows the same relationship with Arctic water influence. When this is eliminated, however, these same catches reveal fluctuations in correspondence with meteorologically cool or warm summers.

Similar trends, apparently more closely linked with sea temperature than with Arctic water influence, are discernible for haddock catches in the Faroe Islands neighbourhood.

It was necessary, first of all, to define the nature of the long-term trends in question.

The Faroe-Shetland Channel region is roughly that enclosed within the relevant coasts and artificial sea boundaries indicated on Fig. 1. This region, particularly the northern part of it between Faroe and Shetland, has been relatively often and to some extent regularly investigated, especially hydrographically but also biologically, during the present century, by successive research ships attached to the Marine Laboratory at Aberdeen. Less frequent investigations of a similar kind in the same region have been made from other countries, notably Norway and Denmark, and more recently, the USSR.

When it came to be realised in the 1920's that an almost necessary counterpart of these mainly hydrographical researches in the northern part of the Channel were similar and, where possible, concurrent investigations at its southern end, in the region between the Butt of Lewis and Faroe Bank, such investigations were thereafter carried out with varying but, after 1946, increasing frequency, and since the observational material for this period had not previously been worked up in detail, a particular study was made of the years from 1927 to 1952, excluding the war period, 1940-46 inclusive (Tait, 1957).

[1] Marine Laboratory, Aberdeen, Scotland.

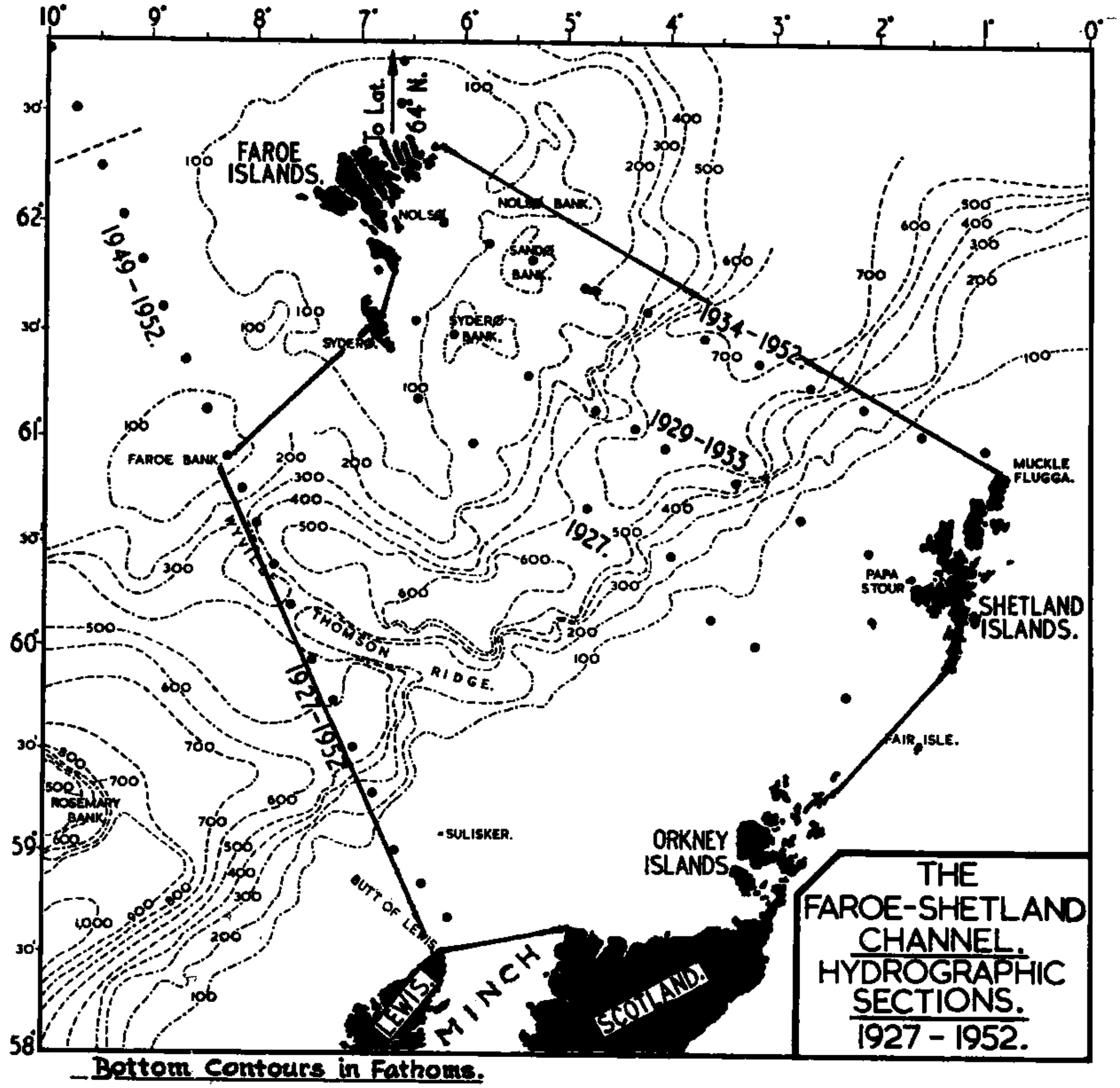

FIG. 1.

This study revealed that, besides the two main water-masses previously recognised as being characteristic of the Faroe-Shetland Channel, at least three more distinctive water types intrude from time to time into the region.

Only the oceanic water-mass, recognised chiefly (in the Channel area) by its salinity of from about 35.25 $^{o}/oo$ to a maximum of 35.44 $^{o}/oo$, is a permanent feature of the region, approximately and normally in its uppermost 300-500 m layer.

Bottom Norwegian Sea water, of salinity between 34.90 $^{o}/oo$ and 34.94 $^{o}/oo$, but relatively steady at 34.92 $^{o}/oo$, while normally characteristic of the deeper Channel to over 1,400 m depth, is not strictly a permanent feature since it can on occasions be more or less totally displaced by one or other, or both, of the intrusive types mentioned below.

In a long series of many hundreds of salinity determinations from within the oceanic water-mass, a distinct hiatus occurs between values of up to 35.45 $^{o}/oo$, representing the maximum salinity of the oceanic water-mass proper, and salinities of upwards of 35.50 $^{o}/oo$ which clearly signify water of a specifically different geographical origin. Its biological content is also distinctive, and from this aspect, Fraser (1955, 1961) has named it Lusitanian water. Its origin would seem to be the vicinity of the deeper Mediterranean Sea outlet into the Atlantic Ocean through the Strait of Gibraltar. Its appearance within the oceanic water-mass of the Faroe-Shetland Channel is usually in disrupted or disintegrated form, an effect apparently of impingement on the southern slope of the Wyville Thomson Ridge, the threshold of the Faroe-Shetland Channel from the North-Eastern Atlantic Ocean. Even so, Lusitanian water seldom if ever occurs in the immediate surface of the Channel, which is probably significant in relation to the depths (800-1,200 m) of the Mediterranean efflux at the Strait of Gibraltar. Sometimes the only evidence of its occurrence in or near the area is in more or less isolated traces. This feature, however, is linked with a further characteristic of this and other intrusions into the main, permanent or semi-permanent, water-masses of the Faroe-Shetland Channel region.

When these intrusions occur in other than mere traces, in obvious isolation from a parent water-mass, they are not as a rule limited to a single year, but pertain to a group of four to six or seven consecutive years. From quantitatively small beginnings in a particular year, they wax to maximum intensity in two to three years, and thereafter wane to extinction, so far as the Faroe-Shetland Channel is concerned, in the next two to three years.

In addition to the above-mentioned Lusitanian (or Gulf of Gibraltar) water intrusion, via the oceanic water-mass, the foregoing characteristics apply also to two Arctic water-mass types which penetrate the Channel region from time to time within the bottom Norwegian Sea water-mass, sometimes displacing the latter from the deeper parts of the Channel at the peak of the phenomenon. These types are (i) intermediate (depth) Arctic water of salinity 34.85 $^{o}/oo$ to 34.89 $^{o}/oo$, and (ii) surface Arctic water with salinity ranging from 34.77 $^{o}/oo$ to 34.84 $^{o}/oo$.

During the period, namely, 1927-52, which has been subjected to closest study so far, although these are discernible in other periods significant evidences of similar circumstances, there were two periods of marked intrusion of (a) Lusitanian water on the one hand, namely, between 1931 and 1938, and (b) Arctic water on the other, between 1946 and 1952. There was evidently, however, a resurgence of the latter influence in 1953-56, and earlier records than those which have been under such close study to date indicate a similar degree of the same influence in 1920-26.

Subsequent investigation by one of us, in collaboration with biological colleagues, has revealed what would appear to be a clearly established association between these intrusive hydrographical phenomena, particularly the Arctic water intrusion, and fish stocks bordering the Faroe-Shetland Channel region. Taking as an example the annual herring fishery of the Minch area just outside the Faroe-Shetland Channel proper, and subdividing the entire period from 1920 to 1959 according to the degree of Arctic water influence as gauged by the mean minimum salinity of the bottom water-mass of the Channel, the following table strikingly indicates the association of this influence, with the Minch herring fishery:

Arctic Influence			Herring Catches	
Period	Degree	Mean Salinity	Period	Average no. crans per landing
1949-56	Strong	34.86 $^{o}/oo$	1952-59	22.50
1920-26	Moderate	34.88 $^{o}/oo$	1923-29	12.92
1944-48	"	34.90 $^{o}/oo$	1947-51	12.36
1956-59	"	34.90 $^{o}/oo$	1960-61	17.66
1927-36	None	34.92 $^{o}/oo$	1930-39	7.87

The postulate is that Arctic water in the Faroe-Shetland Channel is conducive of increased productivity of the oceanic water-mass by admixture, leading to better fish recruitment in "Arctic" years and this is reflected in commercial catches three years later.

The summer Minch herring fishery (June-September) by itself shows the same sort of trend in relation to Arctic water influence as the annual fishery, but on the other hand, eliminating this trend from the summer fishery by the use of moving averages, it also becomes apparent that meteorologically warm summers are associated with depressed catches per landing. This is true for all the warm summers in that region since 1947, namely, 1947, 1949, 1950, 1953, 1955 and 1959.

These deductions, however, take no account of the differential abundance of spring as distinct from autumn spawning herrings. Since the 1920's, it is evident from biological records that there has been a general replacement in the Minch, and other nearby regions, of spring spawners by autumn spawners, and this replacement appears to reflect both the above environmental factors, namely, Arctic influence in conjunction with increased sea temperature. There would seem on the one hand to be a case for assuming that this sub-Arctic species, *Clupea harengus* has, since the 1920's, retired northward in face of a general temperature increase, and on the other hand, that the partial recovery of spring spawners during Arctic periods is not merely a case of increased productivity but of the promotion of a favourable environment for replenishment of Hiberno-Caledonian herring stocks by extension southwards of the Atlanto-Scandian stock, the influence of Arctic water on the thermal structure of the Norwegian Sea being so very great. In non-Arctic periods, as in the 1930's, there takes place a northwards recession of the Atlanto-Scandian herring stock.

It would appear, therefore, that only a marked reversal of the temperature trend will bring about a recession of southerly (autumn spawning) in favour of northern (spring spawning) stocks, although a decrease in the abundance of the former is likely unless Arctic water influence increases markedly with accompanying increased productivity. By the same token the substantial reappearance of spring spawning herrings in the Minch may not be expected until a further strong intrusion of Arctic water into the Faroe-Shetland Channel takes place.

Similar trends, somewhat more closely linked, however, with sea temperature than with the fact of Arctic water influence, is discernible for haddock catches in the neighbourhood of the Faroe Islands.

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