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PART I. TEXT (and figures)

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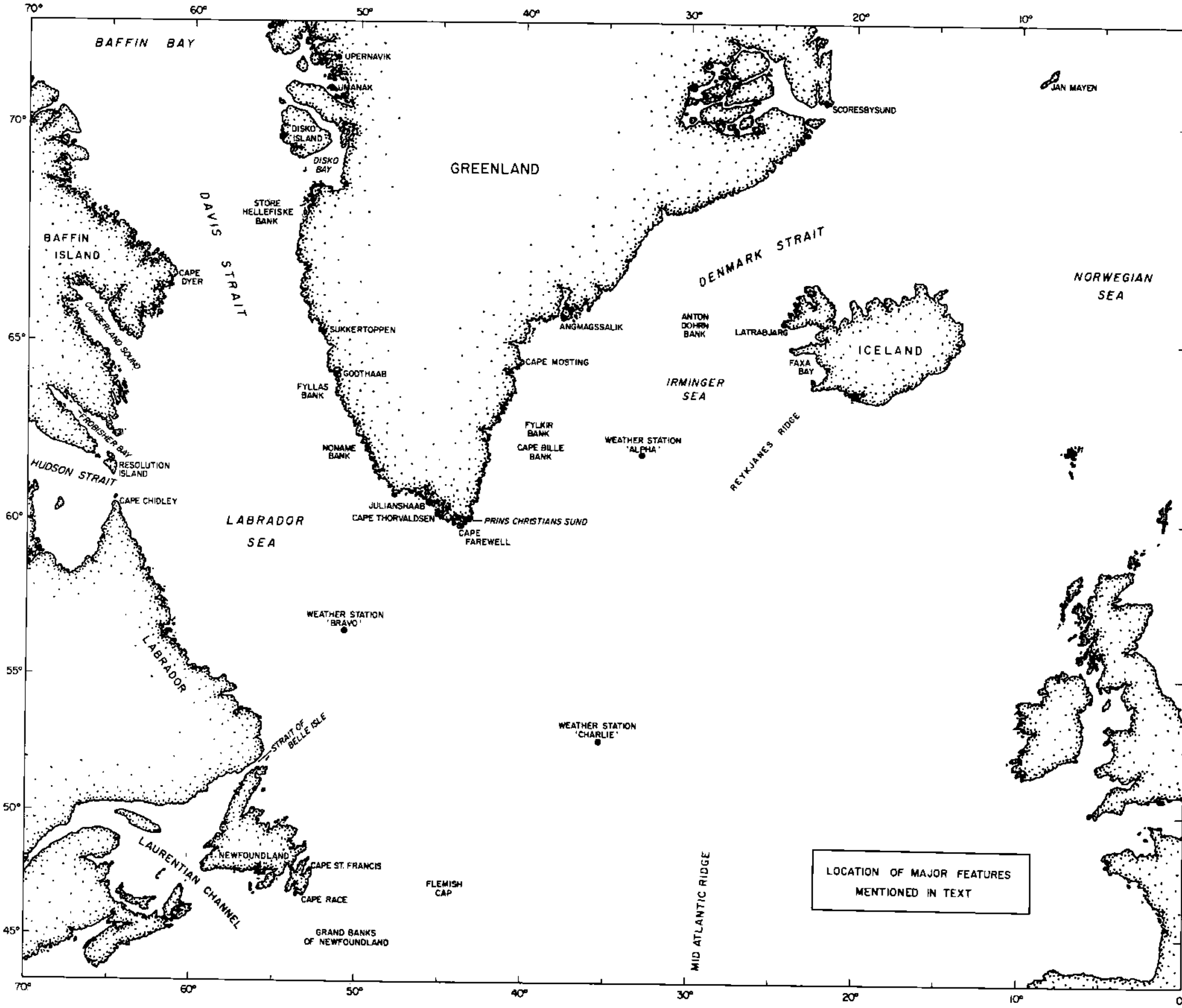
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60°
50°
40°
30°
20°
10°
0°
65°
55°
45°

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Preface

The NORWESTLANT Surveys took place during April-July 1963. The dates of the three surveys which were carried out were as follows:

NORWESTLANT 1: 31 March-9 May;
NORWESTLANT 2: 30 April-30 June;
NORWESTLANT 3: 30 June-3 August.

(In the report, dates which have the year omitted should be regarded as referring to 1963.)

The following research vessels took part in the surveys:

NORWESTLANT 1:	*Thalassa*	France
	G. O. Sars	Norway
	Ernest Holt	UK
	Topseda	USSR
	Academician Knipovich	USSR
NORWESTLANT 2:	*Sackville*	Canada
	Baffin	Canada
	Dana	Denmark
	Anton Dohrn	Federal Republic of Germany
	Aegir	Iceland
NORWESTLANT 3:	*Dana*	Denmark
	Ernest Holt	UK
	Explorer	UK
	Academician Knipovich	USSR

In addition, other vessels provided relevant data, especially the Norwegian, French, British, and American weather ships that occupied Ocean Weather Stations *Alfa* and *Bravo*, the U.S. Coast Guard cutter *Evergreen*, U.S.S. *Atka*, and the ships which carry out the Continuous Plankton Recorder Survey for the Oceanographic Laboratory, Edinburgh, Scotland. On behalf of the group of scientists that planned and executed the NORWESTLANT Surveys, I would like to thank the officers, scientists and crews of all these ships for their contributions to the surveys.

The report on the surveys consists of four parts as follows:

Part I — Text;
Part II — Atlas;
Part III — Physical and chemical oceanographic data;
Part IV — Biological data.

All parts have been bound in such a way that the reader can rearrange them into a loose-leaf system should he so wish. It also allows him to compare charts by superimposing one on the other. The base chart was kindly provided by the Institut für Meereskunde der Universität, Kiel, Federal Republic of Germany and is in on Delisle's conical projection. The International Council for the Exploration of the Sea is using the same projection for its atlas of the North Atlantic Polar Front Survey carried out during the International Geophysical Year (IGY). Thus, the results of the NORWESTLANT Surveys can be relatively easily compared with those obtained during the IGY.

The preparation of Parts I, II, and IV has been carried out under my supervision and I wish to express my thanks to the Reporters who have written the various sections of the report, to the members of the Coordinating Groups who have contributed material relevant to those sections, and to

my colleagues at this laboratory and in the ICNAF Secretariat who have helped so greatly with the editorial work, particularly John Corlett who has done most of the work in preparing Part IV for publication.

Part III is in three volumes and has been compiled by the Canadian Oceanographic Data Centre, Ottawa and ICNAF thanks this organization and in particular its former Director, Charles Sauer, for the very large amount of valuable work which has been done on its behalf.

I also wish to acknowledge the important contribution made to the NORWESTLANT Surveys by the Oceanographic Laboratory, Edinburgh in marrying the data collected by the research vessels to those provided by its Continuous Plankton Recorder Survey. In this way, it has been possible to compare some of the information collected during NORWESTLANT 1-3 with a long time series.

Arthur Lee,
Fisheries Laboratory, Lowestoft.

Introduction

By

C. E. Lucas[1]

In March 1961, I had the honour and pleasure of convening, at the request of the International Commission for the Northwest Atlantic Fisheries (ICNAF), an ICNAF Working Party in the Marine Laboratory, Aberdeen. This group had been appointed to advise the Commission on a number of questions concerning environmental research in the Commission's area, which had been posed by the Research and Statistics Committee. The group officially comprised: Dr Graham, Mr Hermann, Dr Krefft, Dr Lauzier, Mr Lee, Dr Marty, and myself, but we also had the help of Mr Corlett, Mr Glover, Mr Parrish, and Dr Tait for different items of the Agenda. I am most indebted to all of them for their assistance in that meeting, and for their continuing assistance in furthering ICNAF environmental research thereafter.

In particular, ICNAF had requested advice on:

a) the effects of the environment on the survival of the eggs and larvae, growth, long-term abundance and distribution, of cod in particular, but also of redfish and haddock;

b) how studies of such matters might be directed so as not only to provide evidence of associations and correlations but also to lead to prediction;

c) what fundamental studies requisite for such investigations and not already proceeding should be initiated; and

d) how plans could best be laid for holding an Environmental Symposium.

The detailed report which resulted was substantially adopted at the Woods Hole meeting of ICNAF in May and June 1961, and is set out on p. 61-89 of the ICNAF Redbook for 1961. Among other things, it can fairly be said to have stimulated environmental research generally in the ICNAF area. In particular, it laid the foundations for the Environmental Symposium which was held in Rome in 1964, the report of which has now been published as *Spec. Publ. int. Comm. Northw. Atlant. Fish.*, No. 6, 1966, and it also outlined proposals for a scheme of international environmental research within the shelf waters of the ICNAF area, with special reference to the survival of the eggs and larvae of the principal species of commercial importance.

This last proposal was approved in principle at the 1961 meeting of ICNAF, where it was decided to concentrate work first on Subarea 1, the West Greenland area, with special reference to the effects of the "climatic hazard" on cod year-class strengths; redfish were also to receive attention. Despite the agreement, there was a general feeling that the project would be a formidable one, and member countries were simply asked to consider the feasibility of initiating such a programme in the spring of 1963. A meeting of those likely to be concerned was held in Copenhagen in October 1961, through the courtesy and common interest of the International Council for the Exploration of the Sea (ICES). The striking thing was the enthusiasm with which the scientific representatives of the member countries of both bodies set about this task. By the time of the ICNAF meeting in Moscow in May and June 1962, a detailed programme had been prepared, with the quite specific aims of establishing the distribution and drift of cod eggs and larvae, and redfish larvae, in relation to specific environmental factors. There were to be three conjoint surveys from April to July 1963, over Subarea 1 and adjacent waters (extending to Iceland in the east and the Grand Banks in the south). By October 1962, at another meeting held in Copenhagen through the courtesy of ICES, firm promises of research vessel time had been secured from Canada (*Sackville* and *Baffin*), Denmark (*Dana*), Federal Republic of Germany (*Anton Dohrn*), France (*Thalassa*), Iceland (*Aegir*), Norway (*Johan Hjort*), UK (*Ernest Holt* and *Explorer*), USSR (*Academician Knipovich* and *Topseda*). There were promises of

[1] Marine Laboratory, Aberdeen, Scotland.

personnel and assistance from other countries; in particular, there was an undertaking from Canada to process and publish the physical and chemical oceanographic data at the Canadian Oceanographic Data Centre in Ottawa. Further, arrangements were being made to coordinate with this survey an intensification of work in the relevant region of the Continuous Plankton Recorder Survey organized by the Oceanographic Laboratory in Edinburgh.

The preliminary plans are set out in p. 19-29 of the ICNAF Redbook Part I for 1962, which records the establishment of a group, under the leadership of Mr A. J. Lee, to coordinate the activities of the various scientists and research vessels. It was this coordinating group which had the task of setting out the project in much greater detail, in the "blue" book of NORWESTLANT[2], as the survey came to be called. In such relatively difficult waters, everything was to depend on the care with which the work was planned. Once the survey had been completed this group also had the responsibility for coordinating the working up of material collected. At meetings held at the time of the ICES meetings in Madrid in October 1963, and in Copenhagen in September 1964, and at the ICNAF meetings held in Hamburg in May 1964, and in Halifax, Nova Scotia in May and June 1965, the guide-lines for the processing and analysis of this material, for the writing of the report which follows, for the compilation of the atlas and for the publication of the data were worked out. The results reviewed in the following pages thoroughly justify the effort entailed. If further justification is needed it can be found in the consideration now being given by ICNAF to organizing another cooperative survey, this time in the area of Georges Bank. In 1962, I handed responsibility for this project with the greatest confidence, and relief, to Mr Lee and his colleagues. As always, some aspects of the environment were against them, and perhaps few could be said to be wholly with them. Mr Lee and all concerned are to be congratulated most sincerely on the results they obtained, and perhaps especially on the demonstration that, despite the many difficulties, such a coordinated research effort was indeed possible. I know that they will wish to join me in hoping that its successors will be even more successful.

[2] International Commission for the Northwest Atlantic Fisheries: Studies of the environment and planktonic stages of cod and redfish: Guide Book to Surveys NORWESTLANT 1-3, April to July 1963. This book was issued to all participants in the surveys but has not been published. The master copy is held by the Executive Secretary of ICNAF.

Bottom Topography of the Northwest Atlantic

By

B.D. Loncarevic[1] and K.S. Manchester[1]

INTRODUCTION

The Northwest Atlantic was explored by some of the earliest civilized voyagers and yet our knowledge of the configuration of the ocean floor in that area is meagre. The first modern description of the bathymetry was contained in the report of the Marion and Green Expeditions (Smith *et al.*, 1937). The bathymetric map contained in this report was still referred to as late as 1954 (Hachey *et al.*, 1954). About this time the US Navy prepared a series of contoured bathymetric plotting sheets at a scale of 4 inches per degree of longitude, but these were not declassified and generally available until the early 1960's. The latest review of the general hydrographic aspects of the area was prepared by Dietrich (1965) who described the bottom morphology of the northern Atlantic shown in a chart prepared by Ulrich (1962).

In addition to charts issued by the various national hydrographic services, several detailed charts of surrounding continental shelf areas have been published by Soviet scientists (Litvin and Rvachev, 1962; Rvachev, 1964; Avilov, 1965). These charts indicate a considerable knowledge of the detailed bathymetry of the continental shelves and slopes in the Northwest Atlantic area. Unfortunately the published reproductions are at a scale too small for inclusion in other bathymetric charts.

BATHYMETRIC CHART

The bathymetric records of the NORWESTLANT Survey represent important new data contributing to the charting of the world oceans. Copies of the sounding plotting sheets resulting from this survey have already been submitted to the organizations responsible for the production of the General Bathymetric Chart of the Oceans (GEBCO) and this new data has been included in the recently produced GEBCO Sheet B-1, 4th edition, which was published in Paris on 1 December 1966 by the National Geographical Institute on behalf of the International Hydrographic Bureau. This chart, which covers the North Atlantic area between 46°40'N and 72°N lat and 0°W and 90°W long at a scale of 1:10,000,000 at the equator, includes the complete NORWESTLANT Survey area and is the most recent bathymetric chart of the complete survey area that is available at the present time.

The data of this GEBCO chart, sheet B-1, has been transferred to a 1:3,500,000 scale Delisle's conical projection chart (Chart 1) to conform in scale and projection to the other charts included in this special publication. The bathymetry has been contoured at the 200, 500, 1,000, 2,000, 3,000, 4,000, and 5,000 m intervals enabling all the major physiographic provinces of the area to be identified. Only the areas covered by the NORWESTLANT Survey will be discussed although much more bathymetric data of surrounding areas is included on the charts. The original sounding records of the Canadian ships CSS *Baffin* and CNAV *Sackville*, which took part in the NORWESTLANT Survey, have been examined as well as the original sounding records of the Canadian ships CCGS *Labrador* BIO 12-63 cruise; and the CSS *Hudson* cruises BIO 24-65, BIO 02-66, and BIO 02-67 that have taken place more recently in the NORWESTLANT Survey area. Chart Nr. 256 FL., published in 1967 by the German Hydrographic Institute in Hamburg, was also used to update the bathymetric data of the East Greenland shelf and the corrections are included in Chart 1. The reference to the original sounding records of the above-mentioned Canadian ships has made it possible to discuss some of the more detailed bathymetric features present in the survey area, although they are not clearly shown on Chart 1.

[1]Bedford Institute, Dartmouth, Nova Scotia, Canada.

DESCRIPTION OF PHYSIOGRAPHIC PROVINCES.

The area covered by the NORWESTLANT Survey is bounded on the north between West Greenland and Baffin Island at 68°N lat in northern Davis Strait and between Iceland and East Greenland at about 67°N lat in Denmark Strait; in the south by 50°N lat; in the east from southern Iceland southwest along the eastern flank of the Reykjanes Ridge and in the west by Canada. This survey area is bounded by bathymetric highs or land masses in all directions except the south and even this direction is partially restricted by the Grand Banks of Newfoundland and the westward bulge of the junction of the Reykjanes Ridge and the Mid-Atlantic Ridge proper.

Davis Strait is a sill with a maximum depth of 650 m that separates Baffin Bay and southern Davis Strait. Similarly, Denmark Strait is a sill with a maximum depth of also about 650 m dividing the deeper Greenland Sea and the northeastern Labrador Basin. The eastern boundary of the survey area coincides with the eastern flank region of the Reykjanes Ridge.

The north central section of the chart is covered by the land mass of Greenland. Flint (1963) gives the following brief summary of the Greenland physiography:

"Greenland has the shape of an elongated inverted dish with a central dome reaching a maximum altitude of 3,200 to 3,300 meters and a lower southern dome; both domes lie east of the median axis of the ice sheet (see Chart 1). The margin of the ice sheet is very irregular because of the presence of mountains along the east and west coasts; the inland parts of these mountains are buried beneath the ice sheet. Those on the east coast are higher than the mountains on the west coast with Alpine summits reaching altitudes of 3,700 meters. Through deep valleys transecting them, ice discharges as outlet glaciers as large as 10 km in individual width; many of these reaching the sea."

The western boundaries of the survey area are the Canadian coasts of Baffin Island, Labrador, and Newfoundland. The southeast coast of Baffin Island is bordered by high mountains of crystalline rock that have been cut by the large inlets of Cumberland Sound and Frobisher Bay and many smaller fjords. Hudson Strait with maximum depths of over 900 m near its eastern end separates Baffin Island from the Labrador coast to the south. The Labrador coast is also primarily comprised of pre-Cambrian crystalline rocks. There are several deep inlets in this coast but generally the coast has fewer long fjords and inlets than the Baffin Island or West Greenland coasts.

The major physiographic divisions of the submarine topography into continental shelf, continental slope, ocean basin floor, and mid-ocean ridges (Heezen *et al.*, 1959) are clearly visible in the chart and will be discussed in that order.

CONTINENTAL SHELVES

The earth's continental shelves are water covered areas adjoining the continental coastlines and are generally less than 200 m deep. The depth of the outer edge of the West Greenland shelf varies between 60-360 m, whereas the edge of the East Greenland shelf lies more consistently at 370-380 m. The West Greenland shelf edge in the Davis Strait sill area is usually 160-180 m, whereas all the southern section of the West Greenland shelf is generally deeper with a shelf edge depth of 230-240 m (Rvachev, 1964).

The shelf area between Cape Dyer and Hudson Strait along the southeastern Baffin Island coast is little known in comparison to the other Northwest Atlantic, Labrador Sea, and Davis Strait shelves. This is undoubtedly because of a lack of commercial fishing interests and the more extended period of annual ice cover. The shelf edge depth of this region is very difficult to determine but appears to range between 200-600 m. This area has been undoubtedly greatly modified by Quaternary glacial action and the easterly offshore continuation of the complex tectonic history of southeastern Baffin Island. The area is unique in the northwestern Atlantic as it has three large northwest-southeast trending depressions in the Pre-Cambrian Basement. In two of these, Frobisher Bay and Cumberland Sound, the depressions are suspected to be grabens; in the third case, Hudson Strait, the origin is unknown (McGill University, 1963).

The depth of the outer edge of the shelf along the Labrador and Newfoundland coasts is also variable with depths varying from 50 to 450 m, depending on whether the edge passes along a bank or is gouged out by the estuary of a transverse trough (Litvin and Rvachev, 1962). The depth of the shelf along the northeasterly part of the Grand Bank varies between 200-300 m (Avilov, 1965).

It is apparent from the above examples that the edge of the continental shelves is not consistent in the Davis Strait, Labrador Sea, or Northwest Atlantic areas. The boundary between the continental shelf and slope that has been used in the previous discussion is that portion of the sea floor where there is a marked increase in the slope of the topographic profile with the increased slope continuing towards the abyssal depths.

The width of the continental shelves in the Northwest Atlantic is interesting because of its economic significance. Avilov (1965) points out that of the west coast of Greenland the width of the shelf decreases abruptly from north to south. Whereas off Disko Island depths of less than 500 m extend 115-145 km from the coast, in the south the width of the shelf is less than half that distance. In contrast, the width of the shelf off Labrador more than doubles from north to south, *i.e.* from about 130 km along northern Labrador to more than 325 km in width on the Grand Banks of Newfoundland. The East Greenland shelf is similar to the West Greenland shelf in that it also decreases in width from north to south. The increase in width of the southern Greenland shelves going north undoubtedly is related to the presence of the sill between Baffin Island and West Greenland and also of a similar sill between East Greenland and Iceland.

The topography of the continental shelves in the survey area has been greatly modified in the past by tectonic and erosional forces. Tectonic uplifts that formed the highland and mountain areas inland from the coasts of East and West Greenland and Labrador took place prior to the Quaternary glaciation. The faults and fractures of the crystalline bedrock of the continental shelves produced by the tectonic action were later gouged out by the erosional force of the glacial ice. During the glacial periods the sea level was much lower and the outlet glaciers from the continental icecaps were much more numerous and active than at the present time. With the rise of sea level following the glacial periods the glacially modified topographic features were completely covered by the transgressing sea, and the process of marine erosion and deposition continued the modification. All these factors have resulted in the present day continental shelf morphology where generally shallow smooth top banks are separated from each other by deeper longitudinal and transverse troughs.

Rvachev (1964) and Avilov (1965) have described in detail the morphology of the West Greenland and Labrador shelves. The Labrador and West Greenland shelves have similar morphological features but all the topographic features of the Labrador shelf are more subdued in relief and accordingly have gentler gradients than those of the Greenland shelf.

One unusual bathymetric feature common to the shelves of East and West Greenland and Labrador has been previously pointed out by Dietrich (1965). On these shelves one finds a small rise close to the outer shelf edge with deeper water occurring closer to the shoreline. Dietrich (1965) states that the outer rises are obviously terminal moraines of the Pleistocene glaciers of Greenland and Labrador.

O. Holtedahl (1950), H. Holtedahl (1958), O. Holtedahl and H. Holtedahl (1961) have noted in many parts of the world that have undergone Quaternary glaciation, including among these the Labrador and West Greenland shelves, the presence on the inner shelves of deep longitudinal channels parallel to the coastline, so separating the shallower outer banks from the coast. They have interpreted these particular features as being an indication of the presence of crustal fractures, most likely fault lines associated with the Cenozoic (mainly tertiary) uplift of the high land near the coasts. These channels were then carved out of the faulted and fractured bedrock, principally when the sea level was lower, by river and glacial action. Rvachev (1954) has pointed out the difference in morphology between the transverse and longitudinal troughs on the West Greenland shelf. He states that the transverse troughs bear marks of being worked by ice when the shelf was glaciated and the troughs are glacial valleys. Their slopes are smooth and have a steepness of 14° to 15°. Figure 1, Section B-C, shows a cross-section profile of one of the transverse channels on the West Greenland shelf. A broken relief is characteristic for the longitudinal canyons, the steepness of their slopes being as much as 20° to 22°. Grant (1966) made a transverse profile with a small continuous seismic profiler across a large longitudinal trough on the east coast of Labrador at the break in the profile E-F in Fig. 3. The profile showed exposed irregular crystalline rock on the inshore side of the trough. As the seaward side of the trough was crossed, the topography became much smoother with nearly flat lying sedimentary strata being present. No real proof of a fault along the trough was apparent from this data and there is nothing in the magnetic or gravity profiles of Fig. 3 to indicate a fault. The transverse trough in profile B-C of Fig. 1 has possibly a gravity and magnetic anomaly associated with it but this is not sufficient evidence to justify a fault structure for their origin.

Geophysical observations over the Northwest Atlantic continental shelves are not very extensive.

Shipborne gravimeter and magnetometer profiles collected by CSS *Hudson* in 1965 are shown in Figs. 1, 2, and 3 as an illustration of the typical geophysical anomalies observed in the region. Figure 1 shows a portion of the continental shelf near the entrance to Hudson Strait (A) and near Southwest

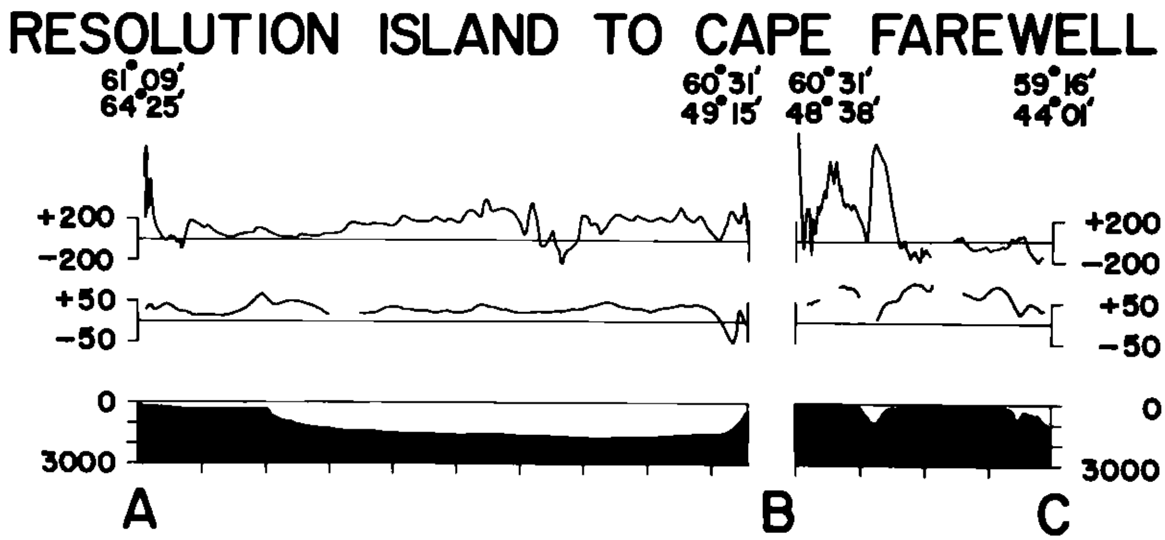

Fig. 1. Resolution Island to Cape Farewell. Top profile is the total field magnetic anomaly after removal of the regional magnetic gradient. Scale units ± 200 gamma (1 gamma = 10^{-5} oersted). The middle profile is the free air gravity anomaly. Scale units are ± 50 milligal (1 gal = 1 cm/sec^2). The bottom profile is depth. Scale units 0-3,000 fathoms (1 fathom = 1.829 m). The ticks along the bottom represent the distance along the ship's track in 100 km intervals. The location of the profile is shown on Chart 1.

Greenland (B-C). Both of these sections show higher frequency magnetic anomalies closer inshore suggesting shallower crystalline basement. It is interesting to note the change in character of the magnetic anomaly on crossing the transverse trough. This change might be due to a difference in lithology of the underlying basement rocks. The gravity profile shows a broad gravity low over

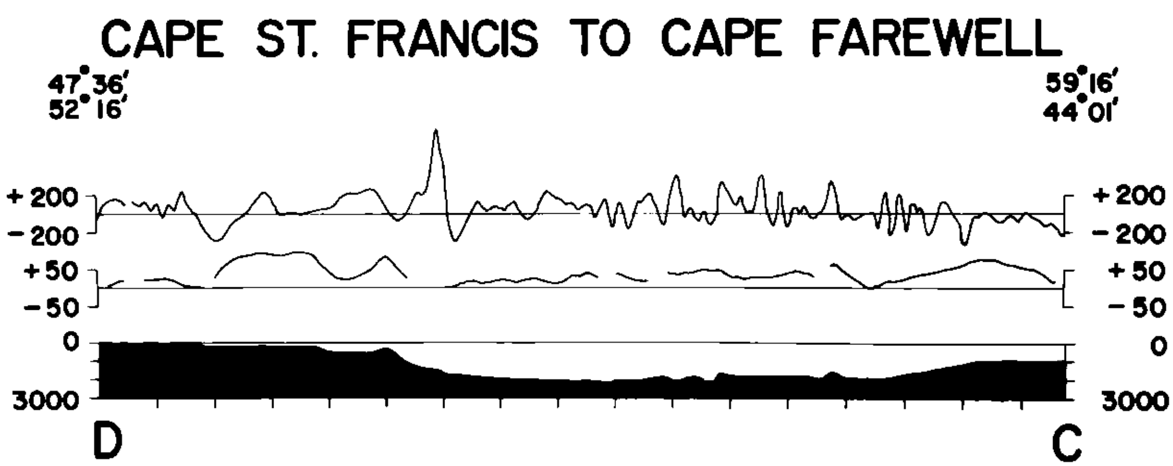

Fig. 2. Cape St. Francis to Cape Farewell. For explanation see caption to Fig. 1.

the continental shelf near Hudson Strait entrance suggesting a possible accumulation of sediments. The gravity high immediately to the east of this low is a typical feature associated with the deeper structure of the continental margins. The gravity profile over the Southwest Greenland shelf shows a considerable relief suggesting large variations in near-surface geology (for Bouguer anomaly variations over the adjoining land area, see Svejgaard, 1959).

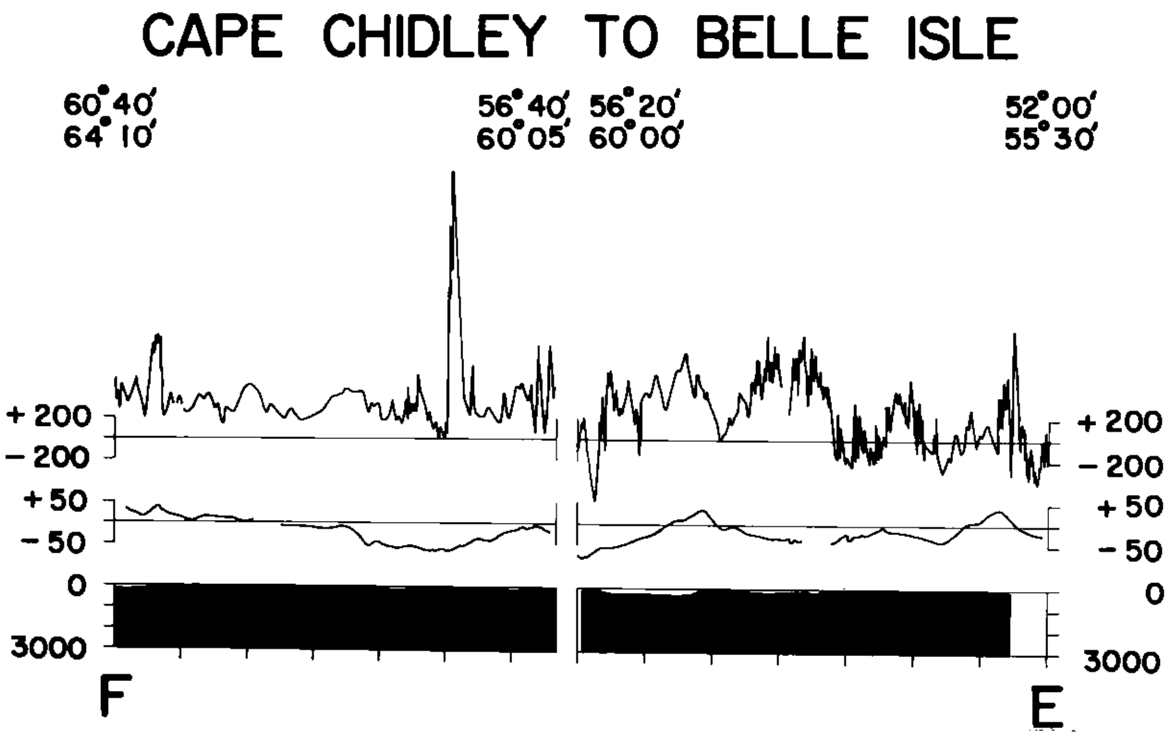

Fig. 3. Cape Chidley to Belle Isle. For explanation see caption to Fig. 1.

Figure 3 shows the magnetic and gravity anomaly profiles and the bathymetric profile along the Labrador continental shelf from Newfoundland to Hudson Strait (Chart 1). It is apparent from Fig. 3 that the bathymetry is relatively constant; that the free air gravity anomalies are broad and predominantly negative; that the magnetic anomalies vary considerably in both frequency and amplitude. The bathymetry is relatively constant because the complete profile shown is on the continental shelf where the depths vary only a few hundred meters maximum. The change in the magnetic character can be broadly correlated with the structural provinces as given in figure 1 of Stockwell (1965). Starting from Belle Isle Strait, there is approximately 450 km of track across the offshore extension of the Grenville province. This section is characterized by very high frequency magnetic anomalies superimposed on broader regional anomalies. The next 200 km can be correlated with the Eastern Nain structural province and is distinguished by the absence of high frequency anomalies. The next province occupying approximately 350 km of track is the Western Nain province. In this portion of the track local anomalies (characterized by sharp peaks of large amplitudes) equal or exceed the regional anomalies. The next 250 km of track crosses the East Nain province again. The anomalies are smallest in this section and high frequency anomalies are almost completely absent. The final 150 km of track just south of Hudson Strait crosses the Western Nain, or Churchill provinces, or both, and is characterized by the reappearance of larger amplitude anomalies.

The long period gravity anomalies may be caused by a difference in the thickness of the sediments overlying the Canadian shield or they may be broad basement anomalies characteristic of shield regions. Gravity anomalies do not show as clear correlation with the structural provinces as is seen in the magnetic profile. In a general way there appears to be a gravity low associated with the central part of the various provinces. The boundaries between the provinces seem to be characterized by gravity highs.

CONTINENTAL SLOPES

The characteristics of continental slopes are related to those of the adjoining shelves. Slopes off wide shelves are in general smooth, broad, and dip towards the ocean floor at a smaller angle than the slopes off narrow shelves.

At the bottom of the slope off Southwest Greenland is a trench approximately 200 m deep that extends north to 64°N lat (Manchester, 1964). This trench is evident in the original sounding records of profile A-B in Fig. 1. The free air gravity anomaly over this trench is -50 mgal and the overall gravity anomaly is -90 mgal (near B in Fig. 1). No obvious magnetic anomaly is associated with the trench. Dietrich (1965) presents bathymetric profiles that show a similar trench-like feature along the Southwest Greenland slope. The trenches on either side of southern Greenland may be caused by the isostatic adjustment of Greenland due to changes in the size of the Greenland icecap.

South of Cape Farewell at the bottom of the continental slope is a rise extending southwesterly as far south as 58°N lat (see Chart 1 and Fig. 2). Opposite the rise on the Greenland slope is a similar large northeasterly trending rise on the Labrador slope. One could possibly expect a connection between these rises on the slopes in the form of a sill or buried ridge across the Labrador Sea that would be parallel to the Reykjanes Ridge to the east of it. This connection might be a continuation of the Grenville subprovince across the Labrador Sea to Southwest Greenland. Isotope dating evidence supports this continuation of the Grenville subprovince (Eardley, 1962) and bathymetric studies of the Northwest Atlantic Mid-Ocean canyon profile indicate that an interconnecting rise may be buried in the deeper part of the Labrador Sea (Manchester, 1964).

Another interesting feature of the continental slope is a large magnetic anomaly at the bottom of the slope off the Northeast Newfoundland coast. This anomaly was detected on airborne magnetometer surveys conducted by the Dominion Observatory, Ottawa, in 1954 and 1960 (Manchester, 1964). This large anomaly begins on the southern Labrador shelf, then continues southeasterly down the slope and approximately along the 2,000-m contour northeast of Newfoundland. This anomaly is clearly seen on the profile C-D in Fig. 2. It probably marks the northern end of the Appalachian structure and its junction with the oceanic crust (Fenwick *et al.*, in press).

OCEAN BASINS

The deep ocean basin present in Chart 1 is referred to as the Labrador Basin and is restricted in all directions except the south. The greatest depth in the south-central part of the basin is about 4,600 m. From here the depth gradually decreases towards Davis Strait with a bottom gradient of 1:2,000 and towards Denmark Strait with a gradient of 1:1,000 up to the 3,000-m contour.

An interesting feature of this basin floor is the Northwest Atlantic Mid-Ocean canyon which starts at about 61°N lat in the middle of the southern Davis Strait and continues southeast to the southern limit of Chart 1 (Manchester, 1964). This canyon is not a large enough feature to appear on Chart 1. However, it was plainly visible on the original sounding records of the CCGS *Labrador*, CSS *Hudson*, CSS *Baffin*, and CNAV *Sackville* that we had access to.

MID-OCEAN RIDGES

The NORWESTLANT study area is bounded by the Reykjanes Ridge on the east. To the north this ridge is terminated by a large volcanic eruption which appears above the sea surface as Iceland. The ridge strikes in the southwesterly direction from Iceland and appears to be terminated at approximately 52°N lat by a possible east-west fracture zone. Starting from the southwest, and going towards the northeast, the ridge width increases and the water depth decreases. A number of profiles and other characteristics have been discussed by Ulrich (1960). His main conclusion is that the topography of the ridge is extremely complicated, especially the crest region, while the flanks of almost every section are steep but less complicated.

More recent geophysical studies over the Reykjanes Ridge have been carried out by the Lamont Geological Observatory (Heirtzler *et al.*, 1966). Using aeromagnetic profiles, they showed a remarkable lineation of magnetic anomalies over the ridge. From the study of these anomalies, Vine (1966) and others have deduced a very fast rate of ocean floor spreading, amounting to 4.5 cm/year.

CONCLUSIONS

Structural Relationships

The most important and widely debated question in geophysics today is that of continental drift. The geophysical studies of ocean floors over the last 20 years have produced evidence which could be interpreted as a support for the continental drift hypothesis. One of the important areas for verifying this hypothesis is the Northwest Atlantic.

The mid-ocean ridges have been used as key evidence in support of continental drift. Assuming continental drift, Wilson (1963) predicted that a mid-ocean ridge would be found in Labrador Sea. The existence of that ridge is still considered very doubtful by the present authors in spite of the interpretations of available geophysical data supporting its existence (Drake *et al.*, 1963; Godby *et al.*, 1966). Neither the present bathymetric chart nor any sounding rolls from Labrador Sea available to the authors show any topographic expression on the ocean floor which could be traced over sufficient length to merit the name "ridge". It has been proposed by Drake *et al.* (*loc. cit.*) that the ridge is buried under the sediments. However, all of the Labrador Sea is deeper than 1,500 fathoms while most of the Mid-Atlantic Ridge is less than 1,500 fathoms. Therefore, if there were a fully developed ridge in the Labrador Sea, it would be above the level of the ocean floor. If the ridge is not fully developed and its peaks not sufficiently high to project through the ocean floor sediments, then the key evidence can be collected by gravity measurements. Such gravity measurements were made in 1965 on board CSS *Hudson* and the result for crossing from Cape Farewell, Greenland, to Cape Francis, Newfoundland, is shown in Fig. 2. The free air gravity anomaly profile shows small variations of the order of 10-20 mgal over the central section of the Labrador Sea, while larger anomalies occur closer to continental margins. This profile shows no evidence of unusual structure underlying the central Labrador Sea. Since the depth of water is fairly uniform, if the ridge composed of volcanic rocks was buried under lighter sediments, the density contrast would have resulted in a positive anomaly over the ridge.

Godby *et al.* (*loc. cit.*) have tried to use aeromagnetic data as evidence for the Mid-Labrador Sea ridge. The Mid-Atlantic and Carlsberg ridges have a well developed magnetic anomaly associated with the central portion of the ridge. This large central anomaly is flanked by magnetic lineations which form a symmetrical pattern around the central anomaly (Heirtzler *et al.*, 1966). Referring again to Fig. 2, the magnetic anomaly profile traversing the alleged ridge does not show the expected characteristic anomaly in the centre, though it is possible to argue that the magnetic pattern is symmetrical around the proposed ridge. Therefore, both magnetic and gravity profiles fail to show convincing evidence in support of the proposed Mid-Labrador Sea Ridge.

Because of the complexity of the geomorphology and structural relationships, the area described in the present report is not well understood. The majority of geophysical observations collected in the past have been of a reconnaissance nature and have served only to outline the problems. For a meaningful reconstruction of the continental drift in the North Atlantic, more systematic observations are required. It is important to stress the great need for new data and the contribution that could be made towards better geological understanding as a by-product of any future fisheries investigations.

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Meteorological Conditions During NORWESTLANT 1-3

By

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GENERAL CIRCULATION OVER THE NORTH ATLANTIC OCEAN

The Atmospheric Circulation Preceding the NORWESTLANT Surveys (January-March 1963)

In order to judge the meteorological conditions in the survey area during the NORWESTLANT Surveys, we have to study the preceding atmospheric circulation. For this information we have used the maps of Deutscher Wetterdienst (1963*a*). They contain the deviations of the monthly means of atmospheric pressure from the long-term means (1899-1939). The observations of the air and surface temperature made at the Ocean Weather Stations A, B, and C are compared with the 10-year means, 1951-60, which were published by Pflugbeil and Steinborn (1963). Moreover, normal values were taken from Rodewald (1952) in order to compute the deviations of the surface temperatures.

In January 1963 (Chart 2), the mean pressure distribution shows a large anticyclone in the British Isles, South Scandinavia, and Iceland area with its centre of 1,030 millibars (mb) north of Scotland. On the other hand, there is a depression of 1,010 mb in the Hudson Strait area. This results in a strong positive pressure anomaly in the area of the North Atlantic and the Norwegian Sea, including the area west of Greenland, with its maximum of +28.5 mb near the south coast of Iceland (Chart 3). This means much more wind from southeast to south in the Irminger Sea which, in the Denmark Strait area, turns to southwest. In the area west of Greenland the "additional wind" blows from southeast-south. The additional wind is computed according to the method of Rudloff (1960).

In February 1963 (Chart 4), the blocking anticyclone has moved away from Faroes-Iceland to eastern Greenland. During this movement the pressure has declined from 1,030 mb to 1,020 mb. A trough of 1,000 mb extends from the Davis Strait and the Labrador Sea to west of Ireland. In spite of this deviation in the average pressure from January to February, the whole NORWESTLANT area around Greenland remains in the sphere of the positive pressure anomaly with its centre of +13.4 mb near Scoresbysund (Chart 5). The highest values of the negative anomalies are found on the eastern coast of Labrador (-7.1 mb) and on the northwestern coast of Spain near La Coruna (-11.2 mb). From this distribution of the anomalies there results an easterly additional wind component to the long-year mean for the Denmark Strait area to Cape Farewell and a southeast-south component for the Labrador Sea and the Davis Strait.

In March 1963 (Chart 6), the circulation had completely changed. In the distribution of mean pressure the whole North Atlantic, including the area west of Greenland up to Baffin Bay, is covered by an extended depression with its centre of 991 mb south of the Irminger Sea (55°N, 30°W). The East Greenland anticyclone has abated and moved towards the polar region. On the average, the Atlantic depression was so deep that the deviation from the normal value (Chart 7) shows a negative anomaly covering all the North Atlantic including the NORWESTLANT area. The centre of this anomaly is surrounded by a weak positive anomaly over Labrador and Scandinavia. From this situation there results a northwesterly additional wind component for the northern Denmark Strait and the Labrador Sea, and a weak northerly additional component for the Davis Strait.

The Atmospheric Circulation During the NORWESTLANT Surveys (April-July, 1963)

In April 1963 (Chart 8), the mean distribution of pressure shows an extended depression system covering the North Atlantic with one centre of 1,002 mb near Newfoundland and a second of 1,004.5 mb south of Iceland. On the other side, there is an anticyclone of 1,023.3 mb over North Greenland

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with a wedge of 1,020 mb extending to southeastern Greenland. Chart 9 shows a positive anomaly from the Norwegian Sea to Greenland and Canada, with a primary maximum of +5.6 mb over East Greenland and a secondary one of +3.5 mb over Baffin Land. The North Atlantic is covered by a negative anomaly, the minimum of which is -11.3 mb, and situated southeast of Cape Race. Therefore, the additional wind components are similar to those of the last month.

In May 1963 (Chart 10), the zonal westerly weather situation was prevailing in the North Atlantic area. This is well shown by the mean pressure distribution chart with an average depression of 1,001.7 mb over Iceland, and a depression branch of 1,007.8 mb extending from South Greenland to the Davis Strait. The central Atlantic is covered by a large anticyclone with its centre of 1,030 mb near the Azores. The distribution of the pressure anomalies is similar (Chart 11). The centre of the negative anomaly shows -12.3 mb over Iceland. The maximum of the positive anomaly with +10.3 mb is situated north of the Azores. The whole NORWESTLANT area is influenced by the higher westerly wind current over the North Atlantic with an additional component from between west and northwest.

In June-July 1963 (Charts 12, 13), the mean pressure is similar in the 2 months. Therefore, the distribution of pressure and the deviations from the normal values for the 2 months have been combined. The total survey area on the average is covered in both months by a weak depression area. Its minimum of 1,010 mb is found near Belle Isle. This weak depression is surrounded by an extended anticyclone with its primary centre of 1,023 mb southwest of the Azores, and a secondary one of 1,015 mb over East Greenland. The deviations from the average pressure are very small. An additional wind of a definable direction is not to be found.

The Mean Monthly Wind Vectors at the Ocean Weather Stations A, B, and C

The Ocean Weather Stations A and B are situated within the NORWESTLANT area while Station C is pointed at its southern periphery (Chart 2). Therefore, the wind vectors of these three stations show well the mean of the monthly circulation situations. Especially great variations of direction of the three wind vectors exist if the stations are in the centre of a depression or near it. These variations may be seen especially in February, April, and June. Only in May does the westerly component prevail at all the three stations. Table 1 shows the mean monthly wind vectors which have been calculated from the observations made every 3 hr. All wind observations for a month are combined in the mean vector according to their direction and speed.

TABLE 1. Mean monthly wind vectors (in degrees and m/sec).

1963	Ocean Weather Station A			Ocean Weather Station B			Ocean Weather Station C		
	degree	m/sec	N[a]	degree	m/sec	N	degree	m/sec	N
January	170	2.6	246	179	3.9	246	55	4.1	247
February	68	4.2	221	168	1.8	215	254	2.6	223
March	43	3.9	247	332	5.0	242	321	1.3	243
April	25	5.7	238	30	4.0	232	152	1.2	236
May	293	3.6	248	247	4.3	246	247	4.9	245
June	108	1.8	239	40	1.5	234	180	2.2	237
July	14	1.0	233	-	-	-	-	-	-

[a] N = number of observations

Other Information of the Wind Situations at the Ocean Weather Stations in the NORWESTLANT Area

Tables 2 and 3 also comprise the observations made every 3 hr at the Ocean Weather Stations. Table 2 shows the most frequent wind direction and all other frequent directions are included in the mean wind speeds regardless of their direction. In Table 3 the same observations are given as the percentage frequency of strong winds and gales. In January and February the mean wind speed is generally low in the NORWESTLANT area, while in March and April the mean is mainly lower than that for 1951-60 (Table 2). Nevertheless, the frequency of strong winds at the three Ocean Weather Stations in February is greater than the average for the years 1951-60. In other months it is only above average, in January at Station C, in March at Stations A and B, and in April at Station B (Table 3). In January 1963 the frequency of gales is even higher than that of the strong winds. During the NORWESTLANT Surveys (April-July) the mean of the wind speed was a little above the average at Stations A and B. The frequency of strong winds was nearly always higher than the 10-year average at these stations. The frequency of gales was only sometimes higher.

TABLE 2. Prevailing winds (degrees) and mean monthly wind speeds (knots) as well as their deviations from the decadal average 1951-60 (Pflugbeil and Steinborn, 1963).

1963	Ocean Weather Station A most frequent wind direction (degrees)	Station A mean wind speed (knots)	Station A deviation from 1951-60 (knots)	Ocean Weather Station B most frequent wind direction (degrees)	Station B mean wind speed (knots)	Station B deviation from 1951-60 (knots)	Ocean Weather Station C most frequent wind direction (degrees)	Station C mean wind speed (knots)	Station C deviation from 1951-60 (knots)
January	140	18.8	-5.6	250	24.5	-0.3	90	22.0	-2.0
February	40	22.1	-0.9	140	22.6	-0.9	250	20.0	-2.7
March	30	22.1	-0.2	360	21.6	-0.8	290	25.3	+2.8
April	30	20.0	+0.3	90	18.1	-1.8	90	18.1	-1.5
May	230	22.7	+4.9	290	17.7	+0.5	230	15.7	-1.8
June	170	14.6	0.0	70	16.1	+1.0	140	15.2	-0.8
July	250	14.1	+0.5	-	-	-	-	-	-

TABLE 3. Monthly frequencies of strong winds (22-33 knots/hr) and gales (more than 33 knots/hr) and their deviation from the decadal averages 1951-60, given as a percentage.

1963	Station A strong wind %	Station A strong wind dev. %	Station A gale %	Station A gale dev. %	Station B strong wind %	Station B strong wind dev. %	Station B gale %	Station B gale dev. %	Station C strong wind %	Station C strong wind dev. %	Station C gale %	Station C gale dev. %
January	27.6	- 6.4	9.4	-13.0	26.0	-12.4	28.4	+ 7.2	40.1	+ 3.5	10.5	- 9.3
February	44.4	+10.8	10.0	- 7.3	38.2	+ 2.1	14.4	- 3.7	31.4	+ 1.1	9.0	- 8.4
March	49.4	+15.0	6.1	- 9.7	41.7	+ 7.8	9.5	- 6.6	37.4	+ 3.5	24.2	+ 9.8
April	31.2	+ 2.0	13.1	+ 3.4	29.8	+ 1.2	7.3	- 4.3	28.7	- 2.7	4.6	- 3.4
May	33.9	+ 7.1	14.5	+ 9.7	32.2	+ 8.1	3.3	- 1.8	19.6	- 4.5	2.6	- 2.9
June	18.8	- 0.1	0.0	- 1.1	16.3	+ 0.8	6.8	+ 3.4	16.0	- 4.8	0.0	- 1.9
July	19.7	+ 6.8	0.0	- 1.5	-	-	-	-	-	-	-	-

The Sea Surface Temperatures and the Air Temperatures at the Ocean Weather Stations A, B, and C

From January through March 1963, the monthly mean values for the water temperature and for the air temperature show a high positive anomaly in the Irminger Sea at Weather Station A. The water temperatures in January and February are only a little below the highest mean values for the years 1951-60 (Pflugbeil and Steinborn, 1963), while in March they exceed them by +0.3°C. Probably, the atmospheric circulation had intensified the Irminger Current. This intensification seems to have caused the high positive anomalies of water temperatures, also found in April, while the air temperatures have decreased to the 10-year average in this month. The atmospheric circulation completely changed in May and the positive anomalies of water temperature declined. The final result of this reduction is to be seen in June (Tables 4, 5). Though in January and February there were additional winds with southeasterly directions, the monthly means of air and water temperatures differed only slightly from the means for the years 1951-60 (Pflugbeil and Steinborn, 1963) in the Labrador Sea (Ocean Weather Station B) during the first 4 months of 1963. In May and June the air temperature had a small positive anomaly. The water temperature newly corresponded to the average for these months. Only in January were the air and water temperatures well above the normal values at Ocean Weather Station C. In February the mean of air temperature decreased below the mean of the 10 years; the water temperature did the same 1 month later.

TABLE 4. Mean monthly surface temperatures (°C) at the Stations A, B, and C, as well as their deviation from the decadal averages 1951-60 and from the normal values (Rodewald, 1952).

	Ocean Weather Station A			Ocean Weather Station B			Ocean Weather Station C		
	water	deviation		water	deviation		water	deviation	
1963	temp. °C	1951-60 °C	normal °C	temp. °C	1951-60 °C	normal °C	temp. °C	1951-60 °C	normal °C
January	5.7	+0.5	+0.8	3.2	0.0	+0.5	7.4	+0.7	+0.3
February	5.6	+0.5	+0.9	2.9	+0.3	+0.9	6.6	+0.2	-0.2
March	5.9	+0.8	+1.2	2.9	0.0	+0.9	6.1	-0.9	-0.7
April	6.0	+0.6	+0.8	3.6	+0.4	+1.1	6.9	-0.2	-0.7
May	6.5	+0.1	+0.4	4.1	-0.1	+0.1	7.5	-0.5	-1.5
June	7.6	-0.6	+0.4	5.7	0.0	-0.1	9.4	-0.2	-1.1
July	9.1	-0.8	+0.4	-	-	-	-	-	-

TABLE 5. Monthly means of air temperature (°C) at the Stations A, B, and C and their deviations from the decadal average 1951-60.

	Ocean Weather Station A		Ocean Weather Station B		Ocean Weather Station C	
1963	air temp. °C	dev. °C	air temp. °C	dev. °C	air temp. °C	dev. °C
January	3.4	+1.3	-1.5	0.0	6.4	+1.0
February	3.9	+1.2	-1.5	-0.6	4.1	-1.2
March	4.4	+1.2	0.0	-0.2	4.8	-0.7
April	3.9	+0.1	2.1	+0.4	6.8	0.0
May	4.8	-1.0	3.7	+0.2	7.8	-0.5
June	7.5	-0.2	5.2	+0.4	9.7	-0.3
July	8.6	-0.8	-	-	-	-

WEATHER CONDITIONS DURING THE NORWESTLANT SURVEYS

Since the NORWESTLANT Surveys covered a period of 4 months it seemed practical at times to combine all days with analogous development into single "weather sections". The data for such "sections" were taken from Duetscher Wetterdienst (1963*b*). For each of these "weather sections" we draw a map showing the mean pressure distribution in the NORWESTLANT area. The wind arrows and figures in these maps correspond to the mean wind direction and the mean speed of the wind in knots; they were estimated according to the method of Rudloff (1960). The given speeds of wind were estimated from the gradient of pressure (taking into consideration the geographical latitude) and the curvation radius of the isobars. The local luff-, lee-, and jet-effects around the coasts of Iceland and Greenland were not taken into consideration. Some preliminary remarks, however, should be made on these effects which are described in detail by Rodewald (1951, 1955); Walden (1959). According to these authors the wind increases at the southwest coast of Iceland while the wind is weak and turning at the northeast coast if there is a depression in the area of the Irminger Sea and southeast of Greenland, and an anticyclone in the area of the Azores, *i.e.*, a southeasterly air drift. The reverse situation is found in an easterly to northeasterly air drift, *i.e.*, if there is an anticyclone over Greenland and a depression in the area of the eastern Atlantic.

In the Denmark Strait, the general coastline causes an intensification of a southwesterly air drift, but a northeasterly drift is intensified far more. The coastal mountains of Greenland bring about the intensification of the northeasterly air drift over the Anton Dohrn Bank and in the Irminger Sea. Cape Farewell is a defined meteorological limit. If deep depressions are moving between the middle of the North Atlantic and the Irminger Sea and an anticyclone is situated over Greenland, extraordinarily heavy northeast winds arise in the area along the southeast coast of Greenland to as far as Cape Farewell. This is the result of corner-, jet-, and so-called "press-effects". At this time mostly typical lee-effects with partial calms are to be found on the west coast of Greenland. If a depression is moving from the western Atlantic northwards to the Labrador Sea and the Davis Strait, the speed of southerly to southeasterly winds is intensified at the west coast of Greenland. Then the southeast coast has lee-effect with low wind speeds.

In the following discussion of the individual weather sections, we try to show all peculiarities of the daily weather conditions. The charts for the sections are shown in Chart 14.

In the weather section of 1-5 April, low pressure was characteristic for the western North Atlantic and the Labrador Sea to Davis Strait area. On the average the eastern limit was formed by an anticyclone of 1,020 mb in the British area with a ridge of 1,015 mb extending via eastern Iceland to eastern Greenland. This caused in general a strong southerly air drift in the southeastern part of the survey area. West of Iceland and south of Greenland this drift turned to southeast. This southeasterly drift reached its highest intensification in the coastal area of southwest Greenland. Strong northerly to northwesterly wind was predominant in the Labrador Sea, coming from the Davis Strait. The mean pressure distribution consisted of a storm centre which dispersed near West Greenland and several gale force depressions which moved from Newfoundland towards Cape Farewell. More than once these centres caused gale speeds in the strong current fields which are marked in the average map.

In the weather section of 6-8 April, the ridge which was formerly directed towards East Greenland had intensified itself to an anticyclone of 1,030 mb over the Rosegarden (Iceland-Faroe Ridge) and southern Greenland. Opposite to this there was a medium depression of 995 mb over Newfoundland. The result of this configuration was a strong easterly wind in the North Atlantic, which turned to southeast in the Labrador Sea east of Newfoundland, and nearly to south in the Davis Strait. It reached gale forces east of Newfoundland as can even be seen in the average map. Particularly on 6 and 7 April, strong to stormy winds from east to southeast prevailed in the North Atlantic and the Labrador Sea at the east flank of the Newfoundland depression.

In the weather section of 9-12 April, the mean high pressure had somewhat decreased over Greenland. Low pressure was found again in the area of Newfoundland. The deep depression over the British Isles and the Rosegarden caused a gale from the southeast in the Iceland area through all days. Southwest of Iceland the gale turned to north. In the southwestern part of the NORWESTLANT area around Newfoundland, strong to stormy east winds occurred on 9, 11, and 12 April. R/V *Ernest Holt* reported good weather from 9 to 11 April in the area south of Cape Farewell. The northeast gale, which lasted 24 hr on 10 and 11 April between Cape Farewell and Cape Møsting, must have been of local nature, because it is not to be found in the daily weather map. R/V *G. O. Sars* reported a south to southeast gale in the area west of the Noname Bank on 12 April. This gale developed from a secondary depression near West Greenland and a ridge directed from the anticyclone over Greenland to the Irminger Sea. For a short time the area of strong winds extended nearly from Cape Thorvaldsen to Godthaab.

In the weather section of 13-21 April, there predominated a strong cyclonic motion over the North Atlantic with centres south of Iceland and west of the British Isles. The high pressure over Greenland still continued. Even the average map for this section shows a strong northeast wind drift from the Denmark Strait and Iceland to Newfoundland/Labrador. During this time the highest wind speeds were encountered in the Iceland/Greenland area. On the northern periphery of the depressions which regenerated themselves more than once south of Iceland, the northeast to east gale continued nearly all the time. On the other hand, in the southern Labrador Sea and near Belle Isle, *i.e.*, on the northern flank of a Newfoundland gale centre, a storm was only found from 13 to 15 April. From 12 to 20 April R/V *Ernest Holt* reported wind from north to east with speeds of no less than 20 knots, but in general of more than 25 knots in the Cape Farewell/Cape Møsting area. The gale caused three interruptions of observations: the longest was 3 1/2 days between 16-19 April. From 16 to 18 April R/V *Thalassa* had to take shelter from a northeast gale (8-11 Bft) in the Faxa Bay. At the same time the R/V's *Academician Knipovich* and *Topseda* which were operating south of Cape Farewell and Ocean Weather Station B only reported northeast winds of 6-7 Bft.

The weather section of 22-25 April was characterized by a medium depression of 995 mb southeast of Newfoundland with a secondary one of 1,000 mb south of Iceland and by a medium anticyclone of 1,025 mb over Scandinavia with a ridge of 1,015 mb extending to Greenland and the Davis Strait. Therefore, east to northeast winds prevailed in the NORWESTLANT area. The highest average speed was found in the Denmark Strait and in the Labrador Sea. Through the whole period the gale depressions were very intensive in the area south of Newfoundland, causing northeast winds of 6-7 Bft in the areas east of Newfoundland and in the southern Labrador Sea. In the Iceland region the frequency of cyclones was only effective on 22 and 23 April with an area of strong winds from the Denmark Strait to the Irminger Sea. No disturbances of work caused by meteorological conditions occurred during this period.

During the weather section of 26-30 April, the centre of the low pressure moved to the area of the Ocean Weather Station A with a weak trough directed to the Norwegian Sea and another to the West Greenland area. The anticyclone over Greenland increased, and also over Labrador a medium anticyclone was to be found. The highest average wind speed (23-25 knots) was observed between the Ocean Weather Stations C and I, directed from the Denmark Strait to the Irminger Sea. The speed of wind, however, was essentially higher if single days are considered. From 26 to 28 April two gale depressions were moving from the area east of Newfoundland to the Irminger Sea and Iceland. On 26 April they caused northeast to north winds of 7-8 Bft in the southern Labrador Sea and near Belle Isle, and south to southeast winds of 6 Bft near the Ocean Weather Station C. While the north wind in the Labrador Sea abated on 27 April, the speed of wind was intensified to 8-9 Bft in the Cape Farewell/Cape Møsting area as the centres of the cyclones approached the Irminger Sea. On 28 April the increasing wind force also extended to the Denmark Strait and lasted until 29 April. During this time strong southwest winds blew in the area from Ocean Weather Station C to Iceland. From the evening of 26 April to the morning of 28 April, R/V *Ernest Holt* reported a north gale at Cape Møsting. On 29 April, weather conditions around Iceland prevented R/V *Thalassa* from accomplishing her research programme. From 28 to 30 April a strong depression, not to be found in the average map, moved from the Hudson Strait to South Greenland and caused strong to stormy south to southeasterly winds at the western coast area of Greenland on 29 April.

In the weather section of 1-5 May, the centre of the low pressure had moved eastward to the Iceland and the Norwegian Sea areas. High pressure extended over the middle North Atlantic. A weak ridge over Cape Farewell united this anticyclone with the high pressure, which had moved in the meantime to East Greenland. The strongest average wind speed was on the periphery of the depression near West Iceland. The wind speed reached 27 knots from the northeast in the Denmark Strait and 26 knots from the northwest in an area to the northeast of Ocean Weather Station C. The 3 and 4 May have to be specially noted because on these days the northeast gale probably reached a wind speed of 40-60 knots in the Denmark Strait and on the Anton Dohrn Bank. In the area of the Ocean Weather Station A, the wind turned to northwest and had still a speed of 30-40 knots. On 5 May the northerly gale area had moved to Iceland with a little weakening. From 2 to 15 May *Aegir* had only 2 days with good weather for work in the area west of Iceland. Most of the time the wind speed varied between 20-40 knots and decreased rarely to 15 knots. On the 4 and 5 May *Aegir* had to interrupt the programme because of weather conditions.

In the weather section of 6-13 May, the centre of the low pressure was situated by deepening in the area of the Ocean Weather Station I south of Iceland. Weak to moderate high pressure was again over Greenland. Therefore, the whole observation area between Iceland and Greenland lay mainly in a northeastern current, whereas in the Labrador Sea the average wind direction was north to northwest. During this period (6-13 May) the wind direction and the wind speed were very changeable, especially in the eastern area where sometimes the weather was terrible. The beginning of a gale centre south of the Irminger Sea, and its moving in the direction of the Rosegarden and deepening to 950 mb south of Mehlsack on 12 May, caused a strong increase of the wind speed in the hitherto quiet survey area. On 11 May the wind blew from the north with 5-6 Bft in the Davis Strait, from north-northwest with 8 Bft in the Labrador Sea and from east to northeast with 8-9 Bft in the area between the Ocean Weather Station A and Cape Farewell. On 12 May the latter gale zone extended over the whole area between southeastern Greenland and Iceland and brought winds from northeast to north with a wind speed of 8-12 Bft, combined with rain and bad visibility. The north and northwest wind lulled in the sea area off western Greenland and in the Labrador Sea. On 13 May the northeasterly and northerly winds decreased in the Denmark Strait, the Irminger Sea and later also west of Icelar . From 12 to 13 May *Aegir* had to interrupt her research because of the weather.

In the mean map of the weather section of 14-18 May, the centre of the low pressure had moved into the area of Iceland-Faroes-Jan Mayen with a weaker trough over South Greenland to the Davis Strait and the Labrador Sea. North of the Azores a powerful anticyclone had pushed into the Bay of Biscay. Around Iceland moderate average wind was observed coming in the Denmark Strait from the northeast, in the Irminger Sea and west of Iceland from the northwest, and south of Iceland from the west. South of the Ocean Weather Station I even the mean of 5 days' wind speed gives the high value of 26 knots. On the other hand, only on 16 and 18 May did strong wind with 6 Bft appear locally in the Labrador Sea. On nearly all days 6 Bft, and once 8 Bft, were observed south of the Irminger Sea and in the sea areas west and south of Iceland.

The average map of the weather section from 19 to 22 May shows only weak pressure gradients between Iceland and South Greenland as well as in the sea areas west of Greenland around a depression south of the Ocean Weather Station A. Opposed to it a zone of stronger westerly winds extended from Newfoundland over the Ocean Weather Station C in the direction of South Ireland. Only on 19 May did the sea area east of Cape Farewell have bad weather: the wind was northeast 7-9 Bft. On 21 May the coast area of Southwest Greenland had south to southeast winds of 6 Bft. West of Iceland *Aegir* announced good working conditions with easterly wind between 0 and 4 Bft. Compared to this *Dana* had nearly consistently poor weather, especially in the area of Cape Farewell from 20 May to 14 June. Therefore, many planned observation stations had to be wiped out.

During the weather section from 23 to 27 May in the average map, the centre of low pressure has extended by moving to the sea area between South Greenland and Iceland. The main wind zone ran with a westerly wind component between 50° and 60°N from Labrador/Newfoundland to the Ocean Weather Stations I and J. There the zone turned north directly to Iceland. On 25 May strong southerly winds blew into the coast area of West Iceland. On 26-27 May these winds turned to southwest. Especially on these days in the sea area south of the Ocean Weather Station A, there was strong to stormy westerly wind. There was also a westerly gale from 25 to 27 May around Cape Farewell. In the sea area off West Greenland, there were only unimportant disturbances. In the Labrador Sea on 25 May, there was very inclement weather with westerly winds of 7-8 Bft.

The map of the weather section from 28 to 31 May shows an average depression of 1,005 mb in the area of the Anton Dohrn Bank and near Angmagssalik. It is surrounded by an anticyclone of 1,030 mb in the middle North Atlantic with a wedge of 1,020 mb to the sea area off West Greenland and a ridge to the anticyclone of 1,030 mb over Scandinavia. At this time the strongest wind zones were from Cape Farewell to the area north of the Ocean Weather Station C with northwesterly to westerly winds. The zone was then directed to Iceland with southwesterly winds, as well as along the southeastern coast of Greenland with northeasterly winds and in the Irminger Sea with northerly winds. From 28 to 30 May the weather situation was especially unfavourable between Southeast Greenland and Iceland including Cape Farewell because a gale depression moved from the Irminger Sea to Iceland. The gale zone reached from Cape Farewell to Iceland. Its southern edge lay nearly in 57°N. On 29 and 30 May *Anton Dohrn* observed westerly winds of 7-8 Bft with wave heights of 6 m between the Ocean Weather Station C and Cape Farewell. In contrast to that, strong to stormy northeasterly to northerly winds blew on the southeastern coast of Greenland. From 30 May strong to stormy southerly to southeasterly wind encroached from the west onto the Labrador Sea and the Davis Strait and influenced the western coast area, especially on 31 May. From 21 May to 16 June *Baffin* reported very bad weather conditions from West Greenland. Also the *Sackville* frequently met terrible weather in the Labrador Sea and especially around Cape Farewell.

In the weather section from 1 to 4 June, there were only few contrasts in the average pressure in the research area. In front of West Greenland a weak trough was opposite to an anticyclone of 1,025 mb over the North Atlantic. The zone with very bad weather, which had influenced the coast area of West Greenland with strong southerly and southeasterly wind on 31 May, moved to Cape Farewell and the Irminger Sea on 1 and 2 June and then dispersed itself. The northeasterly gale, which was connected with the movement of the zone of bad weather into the Irminger Sea, brought rain and snow with very poor visibility and much ice, forcing *Anton Dohrn* to interrupt her research near Cape Farewell. Only on 4 June could observations begin again in the Irminger Sea.

In the weather section from 5 to 8 June, low pressure over the centre of the North Atlantic was opposite to an anticyclone of 1,025 mb in the Norwegian Sea. This brought an average east component of the air current. Therefore, the coast effect of South Greenland was completely effectual, so that the wind between Cape Møsting and Cape Farewell was turned away in a northeasterly direction and increased to gale especially on 7 and 8 June. Strong easterly winds of 6 Bft also covered the Labrador Sea on 8 June west of the Ocean Weather Station A. *Anton Dohrn* sometimes observed wind of 6 Bft on 5 June.

In the weather section from 9 to 13 June, the weather situation became very bad in the survey area. In the average map high pressure near Iceland is opposite to a depression of 990 mb over the Belle Isle Strait. Even in the average a very strong easterly air current is found near South Greenland and over the Labrador Sea. During the whole weather section a gale depression, which moved slowly from Newfoundland to the Labrador Sea, predominated. At the south and southeast periphery of that depression, secondaries were directed to South Greenland. Therefore, during this period an easterly to northeasterly gale blew around Cape Farewell, and there was a southeasterly gale with short interruptions from Cape Farewell to Cape Thorvaldsen. In the northern coast area of West Greenland strong northerly to northeasterly wind blew from 9 to 12 June, whereas over the Labrador Sea an easterly gale was observed from 9 to 11 June. Around the 10 June *Sackville* reported wind speeds of 55 knots and wave heights of 22 ft.

From 14 to 25 June the mean map of the weather section exhibits low pressure south of Iceland with a low trough over South Greenland to the Davis Strait. During this period the strongest average winds were northeasterly in the Denmark Strait, and westerly in the area west of the Ocean Weather Stations I and J. On 14 and 15 June a gale depression, which moved from Cape Farewell to Iceland, brought moderate to strong northerly to northwesterly wind in the Davis Strait and the Labrador Sea. East of Cape Farewell this depression had caused a northeasterly gale, which succeeded in moving from Cape Farewell over the Irminger Sea to the Denmark Strait between 14-16 June. *Anton Dohrn* crossed the gale area on 14 June in the Irminger Sea with northeasterly to northerly wind speeds of more than 40 knots. On 15 and 16 June east of Cape Farewell, the research was still handicapped by northeasterly swell of 4-5 m. Between 55° and 60°N a strong to stormy west wind was on the southern side of the east-moving gale depression. On 18 June in the area of a depression, which quickly moved from Newfoundland to the British Isles, the wind increased to more than 6 Bft between 50° and 55°N. On 19 and 20 June to the northeast of the Ocean Weather Station C, *Anton Dohrn* was obliged to omit the plankton catches with the ringtrawl because the sea was too rough. On 25 June a depression, which drifted through the Hudson Strait eastwards, caused a south to southeast gale on the western coast of Greenland.

In the weather section from 26 to 30 June, the average pressure situation contains a large trough over the western Greenland Sea and the Labrador Sea with the centre of 1,005 mb near Cape Thorvaldsen and an anticyclone of 1,025 mb directed from the Azores up to the area south of Iceland. The zone of the strongest air current ran northwards over the Ocean Weather Stations C and A and then turned to the Denmark Strait. During this period the worst weather was east of Cape Farewell, in the Irminger Sea, in the sea area west of Iceland, and in the Denmark Strait.

In the weather section from 1 to 7 July, the whole eastern survey area was influenced by an anticyclone, whereas low pressure lay over the east coast of Labrador. The southerly air current between these pressure systems was partly directed to the Davis Strait and partly to the Irminger Sea up to the Denmark Strait. On 1 July in the area of the Ocean Weather Station A, there was a strong southwesterly wind, and between Cape Farewell and Cape Thorvaldsen one from south to southeast. On 2 July near Cape Farewell, the wind turned to northeast only for some hours. From 2 to 4 July extensive fog fields lay near the eastern and especially southeastern coast of Greenland. From 2 July *Explorer* reported good weather in the area 55° to 60°N, 30° to 40°W, whereas it was foggy near Greenland. Later *Explorer* changed her research position southward because near Cape Farewell the weather was unfavourable. From 5 to 6 July on the west coast of Greenland, the south to southeast air current increased once more to 6-8 Bft.

During the weather section from 7 to 12 July, the average centre of high pressure was situated in the area of Ocean Weather Station C with a ridge of 1,020 mb directed to Greenland. The strongest gradient to the low pressure lay on the northeastern side of the ridge in direction to the Norwegian Sea. Here some depressions moved southeastwards and caused strong winds, sometimes gales, between west and north in the area between South Greenland and Iceland. Because of the weather *Ernest Holt* had to interrupt her research on 9 July between Faxa Bay and East Greenland. Another change, to worse weather, took place in the Labrador Sea on 11 July and moved on 12 July to the area between Ocean Weather Station C and Cape Farewell, where the wind speed increased to gale force. At the Cape the wind was again turned away from southeast to northeast. At the same time the wind blew at storm force from northwest to west in the Davis Strait and the Labrador Sea.

In the weather section from 13 to 19 July, the centre of the low pressure had encroached from the Norwegian Sea to the North Atlantic near Ocean Weather Station C. This brought an average northeasterly air current along the coast of East Greenland and over Iceland to Ocean Weather Station C. This extension of the average low pressure zone to the southwest was mainly caused by a gale depression, which moved northward from 13 to 14 July to the southern side of the research area. At the same time this depression caused strong and stormy northeasterly wind between Iceland and South Greenland. *Ernest Holt* was forced to interrupt her work again in this area because of the bad weather. *Explorer* reported a northeasterly gale with very poor working conditions on 13 and 14 July from the area north of 60°N and between 30° and 40°W. From 15 July research could be carried out under normal conditions. At the same time at the coast of West Greenland, there was a short deterioration.

From 20 to 23 July, the weather section brought an average increase in the air current over the Labrador Sea from the south. This was caused by a depression over Labrador and an anticyclone near Cape Thorvaldsen. In the area of Iceland, along the coast of East Greenland, and in the Irminger Sea, the northeasterly component of the air current continued in this period. No remarkable handicap due to the weather was reported. In the Labrador Sea and near the west coast of Greenland, the wind increased from the south to 6-7 Bft, but only for a short time. The same was to be found west of Iceland with winds from north to northwest.

In the weather section from 24 to 26 July, the whole pressure system drifted eastward. Now the depression off Labrador lay near South Greenland, whereas the anticyclone moved to the sea area west of Iceland. Contrary to the weak pressure gradients in the average map, several days showed a gale pressure, which moved south of Cape Farewell and eastward and brought on 25 and 26 July in the sea area east of Cape Farewell strong to stormy northeast and later north wind.

From 27 to 31 July the weather section was characterized by a low pressure in the area of Ocean Weather Station A, with a strong northeasterly air current from the Denmark Strait to Cape Farewell and a similar strong southwesterly current west of the British Isles. Several gale depressions, which went to the Irminger Sea and to Iceland, caused strong to stormy wind from the south and southwest in these areas. As the wind directions remained steady, a complete wind sea and high swell resulted.

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Ice Conditions in Greenland Waters During January–July 1963

By

Hans H. Valeur[1]

Generally, it can be stated that the extent of the ice in Greenland waters (around Cape Farewell and adjacent areas) was about normal. Normal here is understood to be the 50% probability of ice during 1919-42 as given by Deutsches Hydrograpisches Institut and based mainly upon the ice-yearbooks of the Danish Meteorological Institute. This information is based almost entirely upon ships' observations. Due to the low height of the observer, the ships' observations are often rather pessimistic in that the observer is liable to exaggerate the concentrations of the ice. Also, in most cases, he will not be able to state whether he is dealing with a continuous icebelt or just a belt or string separated from the main belt. Therefore, the information given on the average ice conditions may be regarded as exaggerated, and some caution is recommended when comparing actual conditions with these average values.

To supplement the text, 15 maps (Charts 15-29) are given for the period 19 March to 2 August. These maps are primarily based upon air reconnaissances, but information from ships is also included. I wish to thank the following ships for their contributions: *Academician Knipovich*, USSR; *Anton Dohrn*, Federal Republic of Germany; *Sackville*, Canada; *Baffin*, Canada; *Dana*, Denmark; *Ernest Holt*, UK; *G. O. Sars*, Norway; *Aegir*, Iceland; *Topseda*, USSR; *Thalassa*, France. Information has not yet been received resulting from American ice-reconnaissance flights and the picture may be changed to some extent when these are received.

With these reservations the ice conditions were as follows.

January. The extent of the ice off southern Greenland was slightly above normal. On 17 January the width of the icebelt off Prins Christians Sund (approximately 60°N) was about 160 km, *i.e.* well above normal, but farther northwards the belt narrowed about 30 km near Angmagssalik, which is below normal.

February. The extent of the ice off southeastern Greenland was or slightly below normal, while in Julianehåb Bay the extent was above normal, though with only scattered concentrations.

March. The extent off southeastern Greenland was below normal. In Julianehåb Bay the extent was slightly above normal, but the concentrations were negligible. On the west coast the conditions were about normal, Disko Bay being entirely covered with fast ice.

April. The occurrences off the east coast (south of 66°N) were below normal. At Cape Farewell the ice conditions were about normal. In the northwestern part of Julianehåb Bay the ice sometimes exceeded the normal, reaching its highest point from 21 to 26 April. On the west coast the conditions were about normal.

May. Except off Disko, the extent of the ice was at or below normal in all areas. The west ice extended nearer the coast than normal.

June. Both the polar ice (the ice along the east coast and around Cape Farewell) and the west ice were below normal.

July. From the beginning of the month the ice increased its extent. During the first half of the month all ice occurrences were more or less above normal. Later the occurrences decreased again, the extent of the polar ice being at or slightly below normal, while the west ice was above

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normal north of 66°N and below normal south of this latitude.

EDITOR'S NOTE

Chart 30 has been added to Mr Valeur's contribution. It is based on the Monthly Ice Charts (M.O. 759) compiled by the Marine Division, Meteorological Office, Bracknell, England and it shows the ice distribution off the Canadian coast in the Labrador Sea and Davis Strait at the ends of each of the months April-July 1963.

NORWESTLANT Surveys: Physical Oceanography

By

Arthur J. Lee[1]

DATA AND METHODS

The serial oceanographic data on which this report is based were collected mainly by the research vessels participating in the NORWESTLANT Surveys. These research vessel data have been published in Part III of the NORWESTLANT Report (*Spec. Publ. int. Comm. Northw. Atlant. Fish.*, No. 7, Part III, Vol. I-III, 1968). These publications also contain details of the observational and laboratory procedures employed, the precision of the observations, and a description of the machine-generated data record as prepared by the Canadian Oceanographic Data Centre, Ottawa (CODC). They also contain a report on the intercalibration of the gear and methods used during the surveys and the bathythermograph data collected by the various participating vessels.

In addition to the data collected by the participating research vessels, oceanographic data were also collected by ocean weather ships and other vessels which were operating in the NORWESTLANT area, or in adjacent regions, but which were not taking part specifically in the surveys. These data we have designated as being peripheral, and they have been used in preparing this report. They have been published in Part III of the NORWESTLANT Report and as follows:

(1) Report of the International Ice Patrol Service on the North Atlantic Ocean (Season of 1963). U.S. Treasury Department, Coast Guard Bulletin No. 49, Washington, D.C., 1964.

(2) Mariner's Weather Log, Vol. 8, No. 3, May 1964, p. 99.

(3) Cahiers Océanographiques, XVI^e Année, No. 2, 157-162, février 1964, Service Hydrographique de la Marine, Paris.

Some additional stations were worked by the USSR fishery research vessel *Pobeda* off Labrador during March-May. They are not considered in this report but are dealt with in the paper by A.I. Postolaky "On the life-cycle pattern of Labrador cod", to be found in the section of the volume dealing with "Cod eggs and larvae". Furthermore, some observations were made by Icelandic investigators to the north of Iceland in June. These have been reported upon by Jónsdóttir (1965) and have been considered below in the section of this report dealing with NORWESTLANT 2.

The oceanographic stations on which this report is based are shown survey by survey in Charts 31-33. The ships working them are shown and the stations have been given the CODC consecutive numbers used in Spec. Publ. int. Comm. Northw. Atlant. Fish., No. 7, Part III, Vol. I-III, 1968. The serial numbers and letters of the various hydrographic sections referred to in this report are also given. If a section was worked on more than one survey, it has been given a serial number. If it was worked once only, it has been given a letter.

Each institution participating in the surveys constructed such vertical sections and horizontal charts showing the distributions of temperature, salinity, dissolved oxygen, nutrient salts, *etc.* as it could, using the data collected by its own research vessels. These sections and charts were drawn in accordance with guide lines laid down at various meetings as described in the Introduction, and they were then sent to the Fisheries Laboratory, Lowestoft, England where the final set of figures was drawn under the leadership of Mr A. R. Folkard.

To obtain the distributions of geostrophic velocity at the sea surface and of the geostrophic mass transport between that surface and 1,000-m depth, charts showing the geopotential topography of

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the sea surface and of the distribution of the potential energy anomaly at the sea surface have been constructed, using the machine-generated data. The pressure surface at 1,000 m has been taken as the reference surface, so that the geostrophic velocities and mass transports are relative to that level. In areas where the depth is less than 1,000 m, the method of Helland-Hansen (1934) has been used to obtain the geopotential topography of the sea surface.

GENERAL CIRCULATION

The main features of the surface circulation in the Irminger Sea have been described by Hermann and Thomsen (1946) and those of the Labrador Sea and Davis Strait by Smith, Soule, and Mosby (1937). The northern major branch of the North Atlantic Current flows eastwards from the Grand Banks of Newfoundland between 49° and 52°N lat. At 23° to 27°W long, in the region of the Mid-Atlantic Ridge, some of this current turns towards the north and as the Irminger Current it flows along the coast of Iceland. Part of the Irminger Current turns eastwards along the north coast of Iceland. The remainder turns west and then south in the Denmark Strait and flows along the edge of the East Greenland Shelf parallel to the cold East Greenland Current, which is of Polar origin and which occupies much of the shelf area. Between the north-going current over the Reykjanes (Mid-Atlantic) Ridge and the south-going current along the East Greenland coast is an area occupied by two cyclonic eddies. The East Greenland Current and the western branch of the Irminger Current, round Cape Farewell, flow along the west coast of Greenland as the West Greenland Current. This eventually divides, part going over the Davis Strait Ridge into Baffin Bay and part flowing westwards, south of the Davis Strait Ridge, and joining the Arctic water flowing out of Baffin Bay and Hudson Strait to produce the Labrador Current which flows south to the Grand Banks of Newfoundland. Part of the southerly flow east of Labrador eventually turns in a general northeasterly direction and flows along the northwestern borders of the North Atlantic Current.

WATER MASSES

The water masses in the Irminger Sea have been classified by Dietrich (1957) as follows:

Northeast Atlantic Water ..... 9.5°C, 35.35°/₀₀;
Irminger Sea Water .... 4.0°C, 34.90°/₀₀;
East Greenland Water .... -1.8°C,<34.50°/₀₀.

The Northeast Atlantic Water is supplied by the North Atlantic Current and eventually becomes the Atlantic Water of the Irminger Current. The East Greenland Water originates in the North Polar Basin and is supplied by the East Greenland Current. The Irminger Sea Water is the product of winter vertical convection in the Irminger Sea. Dietrich also lists a fourth type, Arctic Bottom Water, with the values -0.6°C, 34.90°/₀₀. This water fills the bottom of the basin of the Norwegian Sea and overflows the Iceland-Greenland Ridge into the Irminger Sea.

The water masses of the West Greenland Current in the Davis Strait are derived from the Northeast Atlantic Water and the East Greenland Water. Smith, *et al.* (1937) regard the water of the branch of the West Greenland Current, which turns westwards in the Davis Strait, as having the values 3.5°C, 34.98°/₀₀. On the Canadian coast they find:

Canadian Arctic Water .... -1.75°C, 33.20°/₀₀.

This water flows out of Baffin Bay and the Hudson Strait. The curve on a T-S diagram joining the points 3.5°C, 34.98°/₀₀ and -1.75°C, 33.20°/₀₀ is indicative of the Labrador Current. They also identify three other water masses in the Labrador Sea:

Intermediate Water .... 3.2°C, 34.88°/₀₀;
Deep Water .... 2.2° to 2.9°C, 34.94-34.98°/₀₀;
Bottom Water .... 1.3° to 2.2°C, 34.91°/₀₀.

The Intermediate Water occupies the central parts of the Labrador Sea below 500 m and above the Deep Water at about 2,000-m depth. It is said to be the product of the mixing in winter of the Deep Water with a fresher component contributed by the Labrador Current, the East Greenland Current and fresh water from melting ice, land drainage, and precipitation. The Deep Water occurs below 2,000 m and above the Bottom Water and is regarded as a mixture of Bottom Water and North Atlantic Water from the Irminger Sea which has progressively sunk as it has circulated cyclonically around the Labrador Basin. The Bottom Water is thought to be formed intermittently by winter cooling and consequent vertical convection of the surface, Intermediate, and Deep Waters in the northern part of the Labrador Basin about midway between Greenland and Labrador.

More recently Lee and Ellett (1965, 1967), on the basis of data collected during the International Geophysical Year, have shown that the Intermediate Water is equivalent to the Labrador Sea Water of Worthington and Metcalf (1961) and that it occurs throughout the Labrador Basin and the Irminger Sea. In the northern part of the latter it is somewhat modified and has a higher salinity. There is no evidence for the existence of Dietrich's Irminger Sea Water and the modified Labrador Sea Water takes its place. The Deep Water is really Northeast Atlantic Deep Water, which originates as the overflow of the Scotland-Iceland Ridge by the Norwegian Sea Deep Water of Mosby (1959), particularly through the Faroe Bank Channel. This deep water crosses the Reykjanes Ridge and fills the Irminger Sea and Labrador Sea between 1,500- and 2,500-m depth. It lies under the Labrador Sea Water and above the Northwest Atlantic Bottom Water. The latter is equivalent to the Bottom Water of Smith, *et al.* (1937) and is the product of the overflow of the Iceland-Greenland Ridge by cold water whose precise origin is as yet unknown.

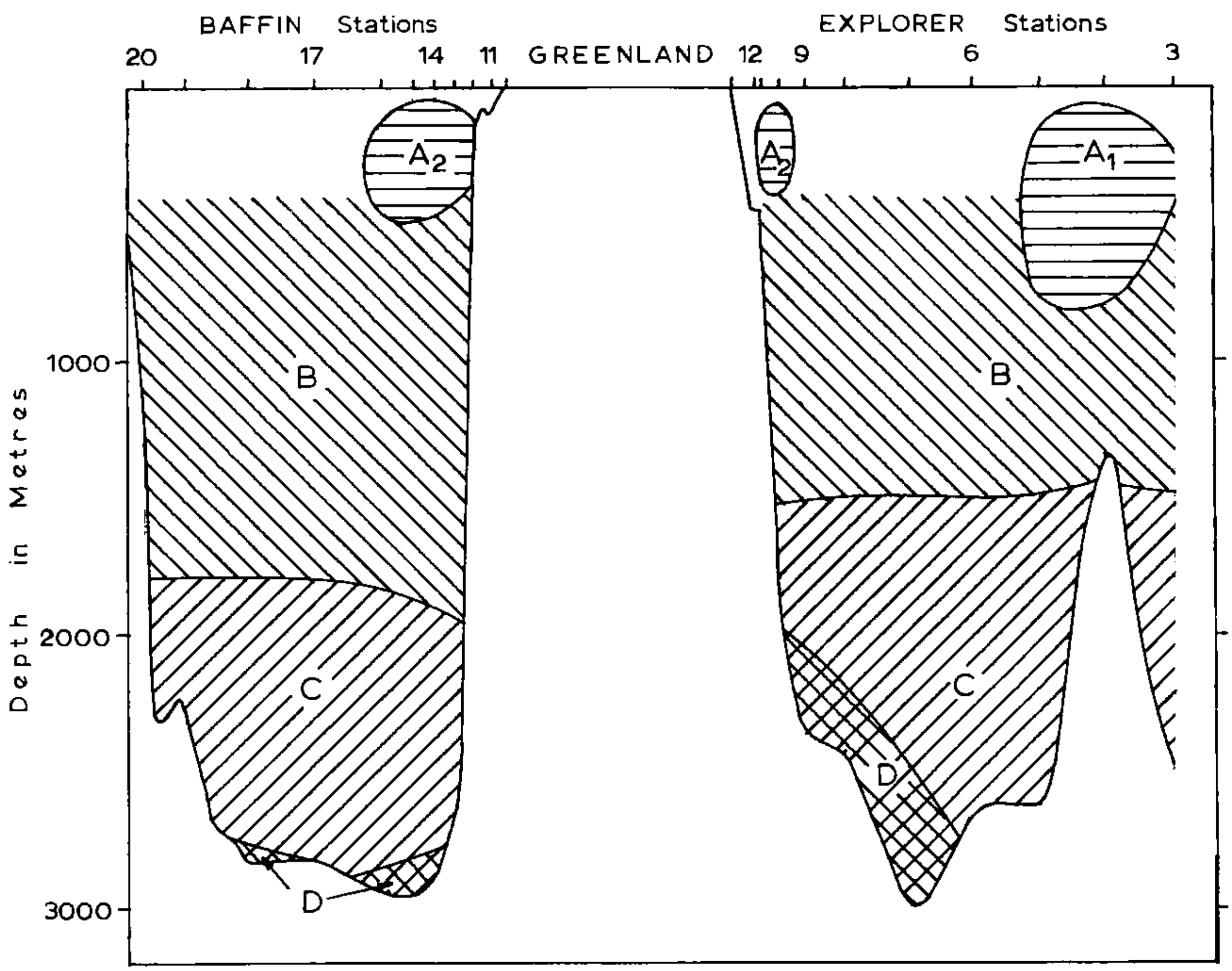

Fig. 4. Cross-section of the Labrador and Irminger Seas showing the approximate regions occupied by water masses A-D mentioned in the text. The section is based on *Baffin* Section 10 NORWESTLANT 2 and *Explorer* Section 5 NORWESTLANT 3.

The arrangement of the water masses in the deeper parts of the Irminger and Labrador Seas is shown schematically in Fig. 4. There are four main masses:

- A $\left\{ \begin{array}{l} A_1 \text{ Northeast Atlantic Water} \\ A_2 \text{ Irminger Atlantic Water} \end{array} \right.$
  - A_1 Northeast Atlantic Water .... 9.5°C, 35.35°/oo,
  - A_2 Irminger Atlantic Water .... 4.0° to 6.0°C, 34.95-35.10°/oo;
- B Labrador Sea Water .... 3.4°C potential temperature, 34.89°/oo;
- C Northeast Atlantic Deep Water .... 3.0°C potential temperature, 34.95°/oo;
- D Northwest Atlantic Bottom Water ...... 0.8° to 1.5°C, 34.91°/oo.

To these we can add for the shallower regions:

- E East Greenland Water .... -1.8°C, <34.5°/oo;
- F Canadian Arctic Water .... -1.75°C, 33.2°/oo;
- G Denmark Strait Overflow Water .... 0.5° to -0.5°C, 34.8-34.9°/oo.

These seven water masses are shown as a temperature-salinity diagram in Fig. 5. Type G is the water found near the bottom and overflowing the Iceland-Greenland Ridge. It has rather variable characteristics and we have tried here to show their range. The Labrador Sea Water, Type B, becomes modified to the extent of having a salinity of 34.94°/oo in the northern Irminger Sea. In Fig. 4 we have shown it extending nearly to the surface and have not given it a definite upper limit. This is meant to indicate that the low salinity water of the surface layers found in the Labrador and Irminger Seas in summer becomes Labrador Sea Water in winter, when the surface layers are mixed by convectional overturn due to cooling.

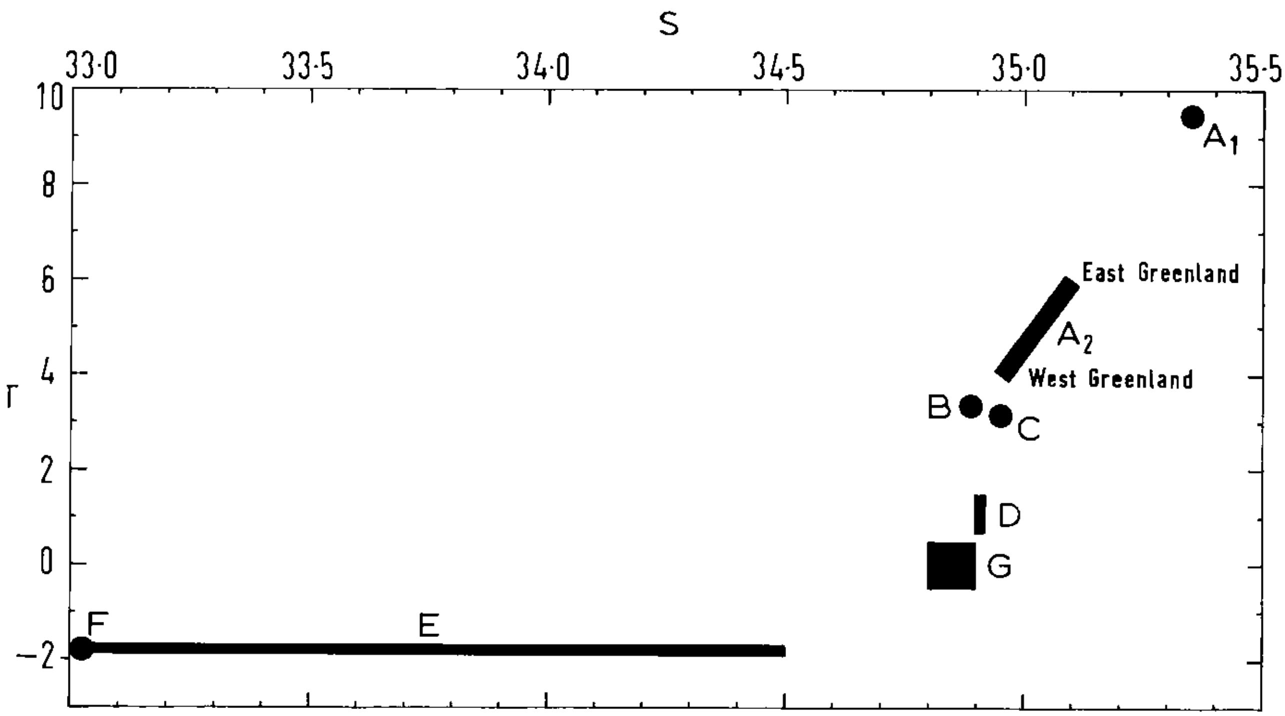

Fig. 5. Temperature-salinity relationships of the main water masses in the Irminger and Labrador Seas. A_1 — Northeast Atlantic water; A_2 — Irminger Atlantic water; B — Labrador Sea water; C — Northeast Atlantic deep water; D — Northwest Atlantic bottom water; E — East Greenland water; F — Canadian Arctic water; G — Denmark Strait overflow water.

NORWESTLANT 1

This survey was carried out from 31 March to 9 May and the stations occupied are shown in Chart 31. The charts and sections showing the horizontal and vertical distributions of temperature and salinity form Charts 38-67.

General Circulation

Charts 34 and 35 show the dynamic topography of the sea surface and the mass transport respectively; both are based on the reference level being taken as the pressure surface at 1,000-m depth. The general circulation described earlier is clearly apparent. It can be seen that the speed of the North Atlantic Current does not exceed 6 cm/sec, but that those of the East and West Greenland Currents reach 15 and 20 cm/sec respectively, while that of the Labrador Current reaches 15 cm/sec. In the central part of the survey area the topography is flat and the current speed nearly zero. A feature of Charts 34 and 35 is the complicated current pattern in the Denmark Strait. Here there seems to be two areas of northeast-going current, separated from each other by a southwest-going current and flanked on the west by the East Greenland Current and on the east by a current flowing south along the edge of the Icelandic Shelf. Another complicated current pattern indicating eddy motion is found to the west of Cape Farewell.

GEK observations were made in the Irminger Sea by RV's *Ernest Holt* and *Thalassa*. These are shown in Chart 36, but whereas in the case of *Thalassa*'s observations the electrode signal was measured at particular points on each of two courses at right angles to each other, *Ernest Holt*'s measurements were made on single courses only as the ship proceeded along Sections 4-6. The results of the *Ernest Holt* observations are therefore shown as arrows which represent the current component normal to the ship's track on these sections. The *Thalassa* measurements are shown as arrows which give the direction of flow relative to geographic coordinates at each of the observation points. To convert the electrode signals into knots, a K factor of 2.6 has been used over the East Greenland Shelf area. This was derived from two comparisons between electrode signal and ship's drift made by *Ernest Holt* in April 1962 and during NORWESTLANT 3 respectively. In the deep sea away from the Shelf, a K factor of 1.1 has been used, following von Arx (1962). The magnetograms of the Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, England for the periods of NORWESTLANT 1-3 have been examined to ensure that disturbances in the earth's magnetic field did not invalidate any of the GEK records.

The GEK observations made by *Ernest Holt* are broadly in agreement with the dynamic topography, except over the eastern half of Section 5. This section was worked after at least 24 hr of strong west-northwest winds and these may have been responsible for much of the increased southwest-going flow found over most of this section as compared with the other two sections, which were worked after spells of northeast-east winds. The observations made by *Thalassa* also agree on the whole with the dynamic topography, although some notable exceptions do occur. They do show the existence of cyclonic eddy to the southwest of Iceland and suggest that there is a south-going current to the west of the Iceland Shelf. They also indicate a flow away from the East Greenland Shelf between 64° and 65°N lat, but a movement on to the Shelf further south. The flow away from the Shelf was found at a time when the wind was causing a rapid easterly movement of the ice edge. The GEK observations indicate speeds of flow of up to 100 cm/sec on the East Greenland Shelf and of up to 60 cm/sec in the deep Irminger Sea. The dynamic topography gives much slower rates of flow, 6 cm/sec at the most in the Irminger Sea.

To get some idea of the current speeds to be expected on the East Greenland Shelf, two parachute drogues were tracked over a period of 13 3/4 hr in the Fylkir Bank area from *Ernest Holt*. The tracks of the drogues were determined by radar fixes on the East Greenland coast. The two drogues were at a depth of 29 m and they were released at 0930 hr GMT on 29 April in position 62°34'N, 40°36.5'W where the bottom depth was 210 m. With the exception of the period 1500-1800 hr, the two drogues moved steadily to the southwest. The average drift over the whole period was 46 cm/sec (0.9 knots) towards 217 °(true), a speed which is in agreement with the GEK results.

A total of 584 drift bottles were released from both *Ernest Holt* and *Thalassa*, and to date 23 bottles have been recovered. The positions at which bottles were liberated and recovered are shown in Chart 37. The tracks of the recoveries are in agreement with the dynamic topography in that bottles liberated near East Greenland (Positions G and H) travelled southwards, rounded Cape Farewell and were recovered in Disko Bay, and that bottles liberated further to the east in the Irminger Sea (Positions A, B, and D) travelled north-eastwards and were recovered in Iceland. Of the bottles recovered in Disko Bay, taking the one recovered after the shortest time out, we obtain a speed of drift of 5.0 nautical miles/day (10 cm/sec) from East Greenland, assuming that it followed the shortest possible route and that it was found as soon as it stranded. Of the bottles recovered in Iceland, proceeding in the same way, we obtain a speed of drift of 2.8 nautical miles/day (6 cm/sec) from a position southeast of Cape Farewell. These speeds agree with those obtained from the dynamic topography.

Some of the bottles released on this survey travelled very long distances. The release positions off East Greenland (G and H) giving recoveries in Disko Bay also produced a recovery in the British Isles after 669 days. The positions to the east and southeast of Cape Farewell (A-F) producing returns from Iceland also gave recoveries in Newfoundland after about 800 days, and from the British Isles and Norway after about 600-800 days. Positions to the west and southwest of Iceland (K, L, and O) produced two returns from Norway after about 1 year and others after 550-700 days. The returns from Europe after about a year probably followed a more or less direct route. All those that were recovered after 550-800 days probably travelled at first in an anticlockwise direction around the Irminger and Labrador Seas and then joined the North Atlantic Drift to proceed eastwards to Europe. The two bottles found at Newfoundland after about 800 days may have spent some time locked in the ice of Baffin Bay.

North Atlantic Current

This current occupied the eastern and southern parts of the area of the Survey. Its temperature was generally above 6°C at the sea surface and above 5°C at 200 m, and in the area to the south of Iceland temperatures were the highest in all the NORWESTLANT area, above 9°C at the surface and above 7.5°C at 200 m. The warmest water of the current can be seen at the southeastern ends of Sections 2 and 3, that is over the summit of the Reykjanes Ridge and to the east of it, where temperatures above 7°C extend down to 650-m depth. Water with temperatures above 6°C was found over a wide area to the west of the Ridge, down to 500 m on Section 2 and to 300 m on Section 3. The warm water of the current can also be seen at the southeastern ends of Sections 4-6 and at the southern end of Section 7. In the latter region the surface temperature was above 7°C and water above 4°C occurred down to 500 m.

The maximum salinity of the North Atlantic Current was found in the region south of Iceland, with values higher than 35.2‰ at the surface and above 35.15‰ at 200 m. At the southeastern ends of Sections 2 and 3, salinites higher than 35.15‰ occur down to 650 m, and to the west of the Reykjanes Ridge, salinities higher than 35.05‰ are found down to 500 m over a large part of Section 2, while on Section 3, a considerable area has salinity values above 35.00‰ down to 300 m. This area, particularly in the neighbourhood of Section 2, was the region where the purest form of Northeast Atlantic water was entering the NORWESTLANT area. To the south of it, salinity values declined: in the upper 200 m they were between 34.7 and 35.0‰ and in the region between the southeastern end of Section 6 and the southern end of Section 7 they were below 34.9‰ down to 300- to 450-m depth.

Irminger Current

Along the west coast of Iceland temperatures were above 6°C close to the coast and at the edge of the Shelf, but below 6°C on the Shelf itself, as can be seen from Section 1. The highest salinities, above 35.1‰, were along the edge of the Shelf. In this region, part of the Irminger Current turns westwards and then southwards to flow along the edge of the East Greenland Shelf. The charts of the horizontal distributions between the surface and 200 m show this turning. From the surface to the 200-m depth the current was warmer than 5°C and more saline than 35.0‰ to as far as Cape Farewell. On Sections 1-7 it can be clearly seen just off the East Greenland Shelf, with the temperature and salinity of its core decreasing as it progressed southwards. On Section 2 the core is warmer than 6°C and more saline than 35.05‰ down to 400 m but on Section 3 the 6°C isotherm occurs at 275 m. By Section 4 there is no 6°C water, but water warmer than 5°C and more saline than 35.0‰ extends down to 400 m; by Section 6 the 5°C isotherm is at 300 m, and by Section 7 there is no 5°C water. In the region of Sections 4 and 5 the current widened and split into two branches with a cooler area between them some 50 nautical miles from the Continental Slope. This division does not appear on Section 6.

On Sections 1-3 a branch of the Irminger Current can be seen over the East Greenland Shelf. It is to some extent overlain by the East Greenland Current. The existence of this branch has already been noted by Krauss (1958).

East Greenland Current

The charts of the horizontal distributions show this cold current flowing southwards on the East Greenland Shelf to the westward of the Irminger Current. At the surface it was colder than -1°C and less saline than 33.2°/₀₀. On Section 1 the cold water of the current is only 50-m thick and it overlies warmer water of Atlantic origin. The thickness of this cold layer increased as the current proceeded southwards and by Section 3 it has doubled. The East Greenland Current was not sampled on Sections 4 and 5 but on Section 6 it is still 100-m thick and overlies warmer water on the bottom in 200-m depth. By Section 7, however, it is much thicker and the water column at the edge of the Shelf was now almost homogeneous to the bottom in 200-m depth.

West Greenland Current

The Irminger Atlantic component of this current had a temperature higher than 4.5°C and a salinity above 34.95°/₀₀ to as far north as 60°N lat at the surface. At 200-m depth the component was somewhat more pronounced. In the vicinity of Cape Farewell it appeared to divide into two branches, one following the Continental Slope and the other moving first west and then northwest, eventually to flow parallel to the first branch but separated from it by colder and less saline water. This division is clearly shown in Sections 8 and 9 and the last vestiges of it appear in Section 10. These sections also show how the warmer, saltier water became confined to the subsurface levels as it proceeded northwards in the Davis Strait. On Section 8 water warmer than 4.5°C extends from the surface to 500 m, but on Section 9 there is only a very little 4°C water at the surface, yet two marked cores of 4.5°C water at 200-300 m. On Sections 10-12 the upper 4°C isotherm is found at progressively greater depths, from 100 m on Section 10 to 275 m on Section 12. Similarly, the 34.9°/₀₀ isohaline is found at progressively greater depths. Furthermore, the lower limit of the warmer water got deeper as it went northwards and, on Section 11, 4°C water is found as deep as 1,400 m. This, presumably, was due to an increase in vertical convectional overturn as the water moved into the colder northern part of the Labrador Sea.

The East Greenland component of the West Greenland Current was found at the surface along the whole of the West Greenland coast as water with a temperature below 0°C and a salinity below 33.5°/₀₀. At 200-m depth it was found as water cooler than 2°C and less salty than 34.2°/₀₀. Sections 8-12 all show it as giving rise to some stratification of the vertical water column over and to the west of the West Greenland Shelf area, the degree of layering being more pronounced than on Section 7 in the region of Cape Farewell.

Part of the West Greenland Current turned westwards in the Labrador Sea and then southward to flow parallel to the Labrador Current. The charts of the horizontal distributions of temperature and salinity down to 200 m show this flow as tongues of water warmer than 3.5°C immediately eastward of the cold Labrador Current. This water is also clearly shown in Sections 9 and 10, its extent dwindling as it proceeded southwards between the two sections.

Labrador Current

The charts of the horizontal distributions show this as water colder than -1°C on the western side of the Davis Strait. In the north it reached well over to the Greenland side of the Strait and on Section 12 it appears as water colder than -1.5°C and less saline than 33.6°/₀₀ at the western end. This cold, low salinity water also appears at the western ends of Sections 10 and 11 but with its temperature and salinity now somewhat higher. Further south, off Labrador, the current is still shown by water colder than -1°C at depths down to 200 m on the horizontal distribution charts, and it is to be seen at the western ends of Sections 8 and 9, to some extent overlying warmer water along the Continental Slope.

Central Parts of the Irminger and Labrador Seas

Sections 2-6 show the deeper parts of the Irminger Sea to have consisted very largely of water with a temperature of 3.5° to 4°C and a salinity in the region of 34.95°/₀₀. The temperature distributions along these sections show this water to have formed a thermal dome, and this is also apparent on Section 7 and on the horizontal distribution charts, particularly that for temperature at 200 m. The salinity distributions were more complicated, and only on Section 4 is a similar dome apparent. On Sections 6 and 7 the situation is confused by the presence of low salinity water, below 34.75°/₀₀ in places, from the surface down to 400 m. This water extended northeastwards to Section 5, and it is also seen in Section 8 in the Labrador Sea where it lies above the Labrador Sea water, which has a salinity between 34.85 and 34.90°/₀₀ and a temperature between 3.0° and 3.5°C and which occupies most of the central region and the area south of Cape Farewell down to about 1,500-m depth. The low salinity water in the upper layers is not present, however, further north on Section 9. Its origin would seem to lie in the Labrador Current and the heavy precipitation over the Labrador Sea.

Section 1 ran along the Iceland-Greenland Ridge: at the bottom of the channel which breaks through the Ridge, overflow water with a temperature below 2°C and a salinity below 34.9°/oo was found below 600-m depth. The course of this overflow along the East Greenland Continental Slope as it descends to form the bottom water in the Irminger Sea and the Labrador Sea can be seen on Sections 2-4 where it appears as water below 3°C at depths greater than 1,600 m. Its presence as bottom water in the Davis Strait can be seen in Sections 9 and 10 where water colder than 2.5°C occurs at 3,000-m depth. Over all the survey area the water above the bottom water and below the Labrador Sea water had a component of Iceland-Scotland overflow origin, *i.e.*, of Northeast Atlantic Deep Water.

Stability

In Chart 48 the difference in sigma-t value between 0 and 50 m is shown: this is a measure of the stability of the surface layers. There was little stability over the area as a whole, except in the northern half of the Labrador Sea and off the coasts of Greenland and Labrador. In the northern Labrador Sea and Davis Strait, the stability was brought about by a surface layer of low salinity water; off Greenland and Labrador it was due to cold, low salinity currents tending to override warmer, high salinity water. A consideration of the difference in sigma-t value between 0 and 200 m, not charted here, shows that a homogeneous or unstable water column could be found in a band just off the Continental Shelf stretching along the East Greenland coast and around Cape Farewell. It could also be found in the centre of the southern part of the Labrador Sea.

NORWESTLANT 2

This survey was carried out from 1 May to 18 June and the stations occupied are shown in Chart 32. The charts and sections showing the horizontal and vertical distributions of temperature and salinity form Charts 70-116. Those showing the distribution of temperature at 20-, 50-, and 100-m depth have been extended around the north of Iceland to take in the observations of Jónsdóttir (1965) made from 12 to 19 June.

General Circulation

Charts 68 and 69 show the dynamic topography of the sea surface and the mass transport respectively. As was the case for NORWESTLANT 1, the general circulation described earlier can be seen, and the complicated circulatory pattern in the Denmark Strait is once more apparent, particularly the south-going flow along the Iceland Shelf. Now, however, additional eddies are found along the East Greenland Shelf. Further, two prominent eddies are clearly to be seen in the North Atlantic Current; the most westerly of these is consistent with the northern one in the two gyre system described by Worthington (1962). Current speeds in parts of the North Atlantic and Irminger Currents reach 20 cm/sec, as do those of the East Greenland and Labrador Currents. The West Greenland Current has speeds in excess of this in places.

North Atlantic Current

This current again had a temperature generally above 6°C down to 200 m on this survey. The maximal temperatures from the surface down to 200 m were above 10°C; these occurred in the extreme south at the southern end of Section 7. Immediately to the north of this region, lower temperatures occurred but further north again, to the south of Iceland, warmer water was entering the NORWESTLANT area. This can be seen at the eastern end of Section F where water warmer than 7°C occurs down to 650 m as on NORWESTLANT 1. As one proceeds southwards from Section F to Section 6, one can see the extent of the 7°C water diminishing. Conditions at the southeastern ends of Sections 4, 6, and 7 show little difference from those on the corresponding sections for NORWESTLANT 1, but on Section 5 the warmer water seems to extend further west during NORWESTLANT 2.

The North Atlantic Current down to 200-m depth had a salinity greater than 35.0°/oo in the extreme south and east only. In the southeastern part of the survey area salinities below 34.9°/oo occurred. This water of lower salinity is found at depths down to 500 m over most of the southern end of Section 7 and the southeastern end of Section 6, and at depths down to 200 m at the southeastern end of Section 5. On Sections F and 4, however, salinity values above 35°/oo are found in the southeast down to 1,000 m. The core of maximal salinity on Sections F and 4-6 is always located at 400-600 m. Thus, as on NORWESTLANT 1, the purest form of Northeast Atlantic water was entering the survey area to the south of Iceland. There are no significant differences between the salinity distributions along the parts of Sections 4-7 furthest from Greenland and the corresponding sections for NORWESTLANT 1.

Irminger Current

In drawing the charts showing the horizontal distributions of temperature and salinity along the west coast of Iceland, a certain amount of difficulty has been met owing to the fact that Section B was worked first on 15 and 16 May and again on 30 and 31 May. Comparison of these two sections shows a major difference in the area off the Iceland Shelf. Here a wave in the isotherms, possibly caused by an eddy, was found when the section was first worked but not when it was repeated. A second wave in the region of the Continental Slope on the second working does not appear on the first, but this may have been caused by the different spacings of the stations. Again, the surface layers appeared to have warmed up between the two workings of the section. As the first working was closer in time to that of the other sections in this area, and as some of the salinity observations made on the second working have been found to be in error and have had to be omitted, the observations made on the first working have been preferred as far as the preparation of the horizontal charts is concerned.

Immediately to the south of the Reykjanes Peninsula, in the southwest corner of Iceland, water warmer than 7.5°C was found down to 100-m depth. On Section A the 7°C isotherm is at about 750-m depth and the 6°C isotherm at 925 m. Along the west coast of Iceland, temperatures above 6°C occurred over most of the Shelf area off Faxa Bay, but further north, water colder than 5°C was found on the Shelf; no marked stratification was apparent. Sections B and C show that there was a tendency for temperatures to decrease towards the edge of the Shelf and then to increase again in the warm current off the Shelf. Here the depth to which 6°C water was found seemed to increase at first as one went northwards but then to decrease rapidly; it is found down to 750 m on Section B, 900 m on Section C, 800 m on Section D, and 400 m on Section 1. The reason for the decrease in the thickness of the warm current between Sections A and B is not clear; it was even more marked when Section B was worked for the second time. Furthermore, water warmer than 7°C was not found at the surface on this section when it was first examined, but it was found on the sections further north and when Section B was reoccupied. The sections worked on NORWESTLANT 2 in this area are not easily comparable with the observations made on the previous survey, but they do seem to show a slight increase in the temperature of the core of the warm current in the surface layers and also over the Shelf generally.

To the south of the Reykjanes Ridge, the warm current had a salinity greater than 35.2°/₀₀ down to 650 m. Off the Shelf along the west coast of Iceland the salinity in its core was higher than 35.1°/₀₀, but the cooler water found along the edge of the Shelf on Sections B and C gave rise to a slightly reduced salinity there. Eastwards, on the Shelf itself, the salinity values increased again, but in the area very close to the coast much lower values, below 34.95°/₀₀, were found.

In the Denmark Strait that part of the Irminger Current which flows southwards off East Greenland had a temperature above 7°C at the surface and above 6.5°C at 200-m depth. By the time it had reached Cape Farewell, its temperature had fallen to 5°C at all levels from the surface to 200 m, but at 20 m and 50 m this 5°C water appeared as a patch to the south of Cape Farewell detached from the main area of 5°C water situated further north. Likewise, the salinity of the current at 0-200 m decreased, from over 35.1°/₀₀ to between 34.9°/₀₀ and 34.95°/₀₀, as it proceeded southwards. Sections 3-7 and F show this progressive decrease in salinity and temperature. On Section 3 the 6°C water reaches to 250 m and 5°C water to 500 m, but on both Sections 4 and 5, the 6°C isotherm is at 50 m and the 5°C isotherm is at 400 and 325 m respectively. On Section F there is no 6°C water and the 5°C isotherm is at 50 m, but on this section the stations were widely spaced near the Continental Slope, and so the 5°C water may not have been properly sampled. On Section 6 the 5°C appears as a core at 75- to 200-m depth and on Section 7, it extends from the surface to 250 m. Similarly, water with a salinity above 35.0°/₀₀ reaches to 550-m depth on Section 3, is reduced to a core at 125-275 m on Section 5, and is not observed on the sections further south.

Over the Shelf area, on Sections 3 and E, the branch of the Irminger Current observed on the previous survey can be seen as a core of warm high salinity water at about 150-m depth. It is separated by cooler, less saline water from the main part of the Irminger Current which is to the east of the Shelf.

Temperature conditions in the northern part of the Irminger Current during NORWESTLANT 2 were different from those found during NORWESTLANT 1. The isotherms on Section 3 are all about 200 m deeper than those on the corresponding section for the earlier survey. Further south, however, there had been some warming of the surface layers between the two surveys, but otherwise, there is little difference between the sections for the two surveys, except near Cape Farewell. Here the core of the current at all depths from the surface to 200 m was located some 50 nautical miles further south on NORWESTLANT 2 than on NORWESTLANT 1. The displacement is shown by the vertical and horizontal salinity distributions as well as by the temperature distributions.

East Greenland Current

This current appears on the horizontal charts for 0 and 20 m with a minimal temperature below -1°C and a minimal salinity below 33.0°/₀₀ in the Denmark Strait and off Southeast Greenland. It is also apparent on the other charts down to 200 m. It can be seen as cold, low salinity water at the northwestern ends of Sections 1-7 and F, its extent varying from section to section. This water is least apparent on Section 4, but on Section 6 it is particularly noticeable between the surface and 50-m depth and it overlies the core of the Irminger Current, suggesting an offshore movement of part of the current in the area to the south of Cape Farewell.

West Greenland Current

The Irminger Atlantic component of this current had a temperature higher than 4°C from the surface down to 50-m depth to as far north as 61°N lat. At 100 and 200 m the 4°C isotherm was found much further north, at 62°30'N and 64°N lat respectively. Similarly, the 4.5°C isotherm at 0-50-m depth did not extend far beyond Cape Farewell, but at 100 m it reached to 61°N lat and at 200 m to 62°30'N lat. The salinity distributions had the same pattern. There was much more water with a salinity above 34.9°/₀₀ at 100- and 200-m depth along the west coast of Greenland than at 0-50 m. Thus, as on the previous survey this component was less pronounced in the surface layers. There is no evidence on this occasion, however, of its splitting into two branches in the vicinity of Cape Farewell. This may, to some extent, be an artefact because the section running southwestwards from Cape Farewell was not sampled on this survey, but nevertheless, there is no sign of a split on Section 9 such as there was on the corresponding section on the previous survey.

The Irminger Atlantic component can easily be followed along the west coast of Greenland from section to section by considering the water warmer than 4.5°C. This is found at 100-200 m on Section 9, but on Section 10, it occupies a greater area and is found at 100-400 m. On Section K it is at 300-550 m, and on the two workings of Section 11, it is at 400-500 m on one occasion, and at 675 m on the Continental Slope on the other. There is nothing incompatible between the two versions of Section 11, if one bears in mind the differences in the station spacings. On Sections 12 and 13, the 4.5°C water is at 500-m depth. None occurs on Section 14, but water warmer than 2°C can be seen against the Continental Slope on this section and Section 15. A consideration of the distribution of water saltier than 34.95°/₀₀ shows a similar trend. This water is not present on Section 9 but it is observed on Sections 10-13, its amount decreasing northwards. Thus, the Irminger Atlantic component, as on NORWESTLANT 1, was confined to the subsurface layers in the Labrador Sea. Comparison with the corresponding sections on NORWESTLANT 1 also shows that in the region of Section 9, there was less water of temperature greater than 4.5°C on this occasion. Further north, however, to as far as the region of Section 13, the temperature of the component was a little higher than on the previous survey. The salinity distributions show the same trends between the two surveys as the temperature distributions, there being a decrease in salinity in the southern part of the Labrador Sea and an increase further north.

The East Greenland component of the current was found as water with a temperature below 0°C, from the surface to 50 m extending along the West Greenland coast to as far north as Section 10. It then became gradually warmer, so that by the time Section 11 was reached, no water of less than 1°C was observed. The salinity of the component showed the same trend. Water less saline than 33.5°/₀₀ was present to as far north as the region of Section 11 but not beyond, although there is some difficulty in interpreting the salinity data, since those from *Dana* gave lower values in the East Greenland component than those from *Baffin*. At greater depths, 100-200 m, the influence of the component was still apparent, the temperatures being 1° to 3°C and the salinities 33.5-34.5°/₀₀. The temperature of the component to as far as the vicinity of Section 10 was similar to that on the previous survey, but further north, it was now higher by about 1°C. There seems to have been little difference in salinity between the two surveys.

The horizontal distributions for 0-50 m show the general movement westwards across the Labrador Sea of part of the West Greenland Current. Those for 100 and 200 m show a more pronounced turning of part of the current in the region of 62°N. Sections 9 and 10 clearly show this effect, with water above 4°C and a salinity greater than 34.9°/₀₀ present to the east of the Labrador Current. This water was 0.5°C higher in temperature than that of the corresponding water encountered on the previous survey.

Labrador Current

The charts of the horizontal distributions from the surface to 100 m show this as water with a temperature below -1°C and less saline than 33.5°/₀₀ on the western side of the Davis Strait. At 200 m it appears as water colder than 0°C and less saline than 34.0°/₀₀. At 0-50 m the current is coldest in the north off Baffin Island where it emerges from Baffin Bay; here it is colder than -1.5°C to as far south as Cape Chidley. From this point its temperature increases but its salinity decreases, indicating some modification by an outflow from Hudson Strait.

The current can be seen as cold, low salinity water at the western ends of all the sections worked in the Davis Strait, reaching well over to the Greenland side of the Strait on Sections 12-15. On Sections 10 and 11 it extends well to the eastward too. It can also be seen at the western ends of Sections G-J, but as it progressed south its surface layers became warmer; on the two most southerly sections its cold core is situated at 75- to 100-m depth. Its low salinity made its influence felt far to the eastward, particularly on Sections G and J, and the horizontal charts of salinity distribution show that this influence extended to the region south of Cape Farewell and was the cause of the low salinity values there, which were discussed above in the section on the North Atlantic Current during NORWESTLANT 2.

Central Parts of the Irminger and Labrador Seas

As on the previous survey the deeper parts of the Irminger Sea consisted largely of water with a temperature of 3.5° to 4°C. The temperature distributions along Sections F, 4-7, and J show a thermal dome, as does that along Section 9 in the Labrador Sea. This dome is apparent from the horizontal distributions as well, and on all the sections, the surface layers above it show signs of warming since the previous survey.

On Sections G and J water with a salinity below 34.9°/₀₀ can be seen extending down to 1,400-m depth. This is Labrador Sea Water and it is also readily apparent on Section 7 to the south of Cape Farewell and on Section 9 in the Labrador Sea. Its influence was also felt on Section 10 further north in that sea and on Sections 5, 6, and F in the Irminger Sea.

Evidence of cold water with a temperature below 0.5°C overflowing the Iceland-Greenland Ridge can be seen on Section 1, and its southward extension along the Continental Slope off East Greenland in Sections D, 2, and 3. This overflow did not consist entirely of Norwegian Sea Deep Water, because on Section 1 a large part of it has a salinity below 34.9°/₀₀. This indicates that entrained into the overflow of Norwegian Sea Deep Water on this occasion was either a water formed by the mixing of Northeast Atlantic Water and East Greenland Water in the region of the Continental Slope or Arctic Intermediate Water as defined by Helland, *et al.* (1909). This entrainment effect can also be seen on Section D, but it is particularly well illustrated on Section 2. The sections further south in the Irminger Sea were not sampled to a depth great enough to allow the overflow water to be followed beyond Section 3, but as on the previous survey, it can be seen in the Davis Strait after it has rounded Cape Farewell, this time on Sections 9 and 10 at the bottom. Furthermore, in all parts of the survey area the water above this overflow water and below the Labrador Sea Water again contained a component of Iceland-Scotland overflow origin.

Stability

The difference in sigma-t value between the surface and 50 m is shown in Chart 80. It is obvious that zones of surface layer stability again existed all around Greenland and off Labrador and Newfoundland, but that they were more extensive than during NORWESTLANT 1. Stability was also high in the northern part of the Labrador Sea and the Davis Strait, as during NORWESTLANT 1, but by the time of NORWESTLANT 2, a zone of stability had developed as well in the extreme east of the survey area, namely in the North Atlantic Current. The difference in sigma-t value between 0 and 200 m, not charted here, shows that by the time of this survey the zones with a homogeneous or unstable water column lay southwest of Iceland and southeast of Cape Farewell.

NORWESTLANT 3

This survey was carried out from 30 June to 3 August and the stations occupied are shown in Chart 33. The charts and sections showing the horizontal and vertical distributions of temperature and salinity form Charts 120-153.

General Circulation

The dynamic topography of the sea surface and the mass transport are shown in Charts 117 and 118 respectively. As on the previous surveys the general circulation described earlier is to be seen. The complicated pattern in the Denmark Strait during NORWESTLANT 1 is to some extent absent, but the south-going flow along the edge of the Iceland Shelf is still present and there are indications of at least one large eddy off the Greenland Shelf. In the region of the North Atlantic Current the circulatory pattern is similar to that found on NORWESTLANT 2, but the area surveyed is now smaller. West of Cape Farewell an eddy similar to that observed during NORWESTLANT 1 is again present. Current speeds in the East and West Greenland Currents and the Labrador Current are seen to reach 20 cm/sec once more, but the northeast-going current in the Irminger Sea is no faster than 10 cm/sec.

GEK observations were made by *Ernest Holt*, and on this occasion the electrode signal was measured at particular points on each of two courses at right angles to each other, so that the results are shown as arrows giving the direction of flow relative to geographic coordinates. The K factors used were as for NORWESTLANT 1 in the East Greenland Shelf area and over the deep Irminger Sea. Over the banks west of Iceland, a K factor of 1.5 was used, following the experience of von Arx (1962) on Georges Bank and of Vaux (1965) in the North Sea and Barents Sea. The current directions as determined by GEK are shown in Chart 119. Over the deep sea they agree on the whole with the dynamic topography. Over the East Greenland Shelf, where the dynamic topography cannot be determined, they present a complicated picture, which taken as a whole shows a narrow southwest-going East Greenland Current with a northeast-going countercurrent on its western side close to the ice-edge and a number of eddies on its eastern side between it and the Irminger Current. In the area to the west of Iceland the observations must contain a tidal component in the region of the shallower banks; but as on NORWESTLANT 1 westward of these banks, there does seem to be a south-going flow along the edge of the Iceland Shelf. On the East Greenland Shelf the GEK observations indicate speeds of 130 cm/sec and of 200 cm/sec in one locality near the Anton Dohrn Bank; over the Irminger Sea they indicate speeds up to 60 cm/sec. These speeds are much higher than those derived from the dynamic topography. The high speeds observed near the Anton Dohrn Bank were the same as those derived from observations of the ship's drift, and they occurred in an area where parachute drogue tracking by *Ernest Holt* in April 1962 had yielded speeds of 150-200 cm/sec.

Drift bottles were again liberated by *Ernest Holt* during NORWESTLANT 3, and the recaptures are shown in Fig. 9. Out of 457 bottles released, 11 have been recovered. One bottle liberated off East Greenland at position I in about 64°N lat was recovered in Disko Bay 123 days later; this gives a speed of drift of 8 nautical miles/day (17 cm/sec), if we make the same assumptions as when discussing the drift bottles released during NORWESTLANT 1. As on NORWESTLANT 1, some of the bottles travelled very long distances. Some released at positions off East Greenland (I, M, N, P, and Q) reached Europe in about 620-760 days, and it is interesting to note that it was position I which produced the return from Disko Bay. Others from position J, in the middle of the Irminger Sea, spread even wider, reaching Newfoundland in about 700 days and the British Isles in 550 days. The routes followed by these long-distance bottles were probably the same as those suggested for similar recoveries from the releases made during NORWESTLANT 1.

North Atlantic Current

Once more this current had a temperature generally above 6°C down to 200 m, but no 6°C water was observed at 200 m on the section running southwards from Cape Farewell on this occasion, because it did not extend as far south as on the previous survey. Warming of the surface layers down to 50- to 100-m depth had occurred since NORWESTLANT 2, so that at the surface temperatures above 9°C were found from south of Cape Farewell to the west coast of Iceland, and maximal temperatures of over 11°C were observed in the region south of Iceland. At the 200-m depth temperatures were higher than 5°C in the south of the survey area and higher than 8°C south of Iceland. The cooler area southeast of Cape Farewell found on NORWESTLANT 2 was now absent. The current can be seen at the southern and southeastern ends of Sections 2-7. The depth of the 7°C isotherm on Section 3 is somewhat shallower than on the previous two surveys but, as before, as one proceeds southwards from Section 3 to Section 6 the extent of the 7°C water diminishes. Particularly noticeable in this connexion is the change in depth of the 5°C isotherm over the Reykjanes Ridge, from 800 to 1,000 m on Section 2 to

600 m on Section 6, but on the whole the temperature distribution at depth is similar to that found earlier.

The salinity of the current at the surface exceeded 35.0°/₀₀ only in the eastern part of the survey area, and maximal salinity values of more than 35.15°/₀₀ occurred south of Iceland. In the south and southeast of the survey area the surface salinity was lower than on the previous survey, and in the extreme south surface salinity values of less than 34.5°/₀₀ were observed. At the 200-m depth there was more water more saline than 35.0°/₀₀ than at the surface, and the maximal salinity value observed was greater than 35.2°/₀₀. This occurred to the south of Iceland. The low salinity water of the upper layers extends to the 400-m depth on Section 7, to 200 m on Sections 5 and 6, but not even to 100 m further north on Section 4. On Sections 6 and 7 there is more of this water than on the previous survey, but there seems to have been little change in the amount of water with a salinity greater than 35.0°/₀₀ on any of the sections. The purest form of Northeast Atlantic Water was again entering the survey area to the south of Iceland.

Irminger Current

To the west of Iceland there had been seasonal warming of the 0- to 50-m layer, as is shown by Section 1, and surface temperatures above 10°C were found near the coast but they decreased westward. The 200-m temperature distribution shows that the Irminger Current was carrying water warmer than 7°C to the west of the Shelf, but that on the Shelf itself cooler water below 7°C occurred, as is seen in Section 1. Near the coast, however, temperatures increased again. The salinity distribution to the west of Iceland was in conformity with the temperature distribution and the salinity was generally higher than 35.0°/₀₀.

Where the Irminger Current ran along the East Greenland Shelf, the surface temperature was generally above 8°C, and 7°C water reached Cape Farewell. At the 200-m depth water warmer than 5°C reached beyond that point. The depths of the 6° and 5°C isotherms on Sections 2-7 show the progressive decrease in temperature of the current as it proceeds southwards: on Section 2 they are at 450 and 750 m respectively, while on Section 7 they are at 75 and 250 m. All these sections show seasonal warming in the 0- to 75-m layer. The surface salinity over most of the current was low; in the Denmark Strait it was above 35.0°/₀₀, but elsewhere it was below 35.0°/₀₀ and at Cape Farewell it was 34.8°/₀₀. This low salinity water was confined to the 0- to 50-m layer in the north, as is shown by Sections 2 and 3, but it was thicker further south and reaches to 75-100 m on Sections 4-7. At the 200-m depth the salinity of the current even at Cape Farewell was 35.0°/₀₀ and in the Denmark Strait it exceeded 35.1°/₀₀. The salinity distributions on Sections 2-7 parallel the temperature distributions, and there is a progressive decrease in salinity as the current goes south. Thus, the 35.0°/₀₀ isohaline is at the 850-m depth on Section 2 and at 350 m on Section 6, but no 35.0°/₀₀ water is found on Section 7.

Compared with NORWESTLANT 2, temperature and salinity conditions on this survey do not show much change as far as Sections 2 and 3 are concerned. However, Section 4 shows more 6°C and Sections 5-7 more 5°C water. The salinity distributions show the presence of more 35.0°/₀₀ water on Sections 4-6 and higher salinities on Section 7. The current was also much wider in the region of Cape Farewell than on the previous survey, and the core of the current was now 50 nautical miles further north and back in the position in which it was found on NORWESTLANT 1. As on NORWESTLANT 2, there was an indication that an offshoot of the current was proceeding over the East Greenland Shelf in the Denmark Strait. This shows as an area of higher temperature and salinity over the Shelf on Section 3, but Section 2 did not run sufficiently far over the Shelf to show whether or not it also existed there on this occasion.

East Greenland Current

This current had a minimal temperature below 0°C in the surface layers all along the East Greenland coast from the Denmark Strait to Cape Farewell, and as deep as 200 m it had temperatures below 2°C in the Denmark Strait and below 3°C at Cape Farewell. The surface layers had a minimal salinity below 31°/₀₀ in the Denmark Strait and below 33°/₀₀ near Cape Farewell, and at 200 m the current gave rise to salinity values of less than 34.8°/₀₀ all along the East Greenland coast. The current can be seen to a greater or lesser extent at the northwestern ends of Sections 1-7. Its main influence is seen in the 0- to 100-m layer and it overlies the western edge of the Irminger Current, but on Sections 1, 3, 5, and 7 the influence of its low salinity can be seen extending to the 500-m depth at the edge of the Shelf.

West Greenland Current

The Irminger Atlantic component of this current showed a marked increase in temperature since NORWESTLANT 2. Whereas previously the 5°C surface isotherm did not reach far beyond Cape Farewell, it now stretched to nearly 63°N lat, and the 4°C isotherm was at 65°N lat, 240 nautical miles further north than on NORWESTLANT 2. Similarly, at 200 m some 5°C water was now found at 61°N lat, whereas on NORWESTLANT 2 it did not round Cape Farewell. The surface salinity distribution did not show a similar change, low salinity water being found in the surface layers: off southwestern Greenland values below 34.7°/₀₀ were observed and further north they were below 34.5°/₀₀. There had, in fact, been a decrease in salinity in these layers since the previous survey. At 200 m, however, there had been an increase in salinity and the 34.95°/₀₀ isohaline contained a much bigger area than before, reaching to 63°N lat.

Water with a temperature above 5°C can be seen on Section 8 to a depth of 300 m and on the following sections to as far as Section 10, where it appears at 150-250 m; water above 4.5°C can be traced to as far as Section 12, where it is found at a depth of 500 m. The influence of the warm component of the West Greenland Current can, in fact, be seen on the northernmost section, Section 15, in the water warmer than 2.5°C. Similarly, water with a salinity above 35.0°/₀₀ is seen on Section 8, and salinity values above 34.95°/₀₀ are prominent in all the sections to as far north as Section 13. Sections 9-13 all show warmer and more saline conditions than on the corresponding NORWESTLANT 2 sections. For example, they all have more water warmer than 4.5°C and more saline than 34.95°/₀₀. On Section 14 in the warm core at 300- to 400-m depth, the temperature has risen by 1°C and the salinity has undergone a corresponding increase.

The horizontal distributions again show the westward movement of the warm component of the West Greenland Current across the Labrador Sea; its influence along the eastern boundary of the Labrador Current can be seen from Sections 8 and 9, but the structure of the component itself as it flowed along the Continental Slope off southwestern Greenland had a considerable streakiness, which is apparent in the same two sections.

The East Greenland component in the Labrador Sea is shown in the horizontal distributions to have had its maximal influence off southwestern Greenland. Here temperatures below 0°C and salinities below 32.0°/₀₀ were observed in the surface layers, and temperatures below 1°C and salinities below 34.0°/₀₀ at 200 m. This cold component can be seen at the eastern ends of Sections 8-10 and L, to some extent overlying the warm component. From Section 10 northwards, although low salinity water with minimal values below 33.5°/₀₀ occurred along the West Greenland coast, the temperature of the surface layers progressively increased, water warmer than 4°C being found at 65°N lat. Further, the temperatures at the sea-bed along the Shelf in this northern area were generally above 1.5°C. Although there had been little change in the salinity level in this region since NORWESTLANT 2, the temperatures over the Shelf area north of Section 11 had risen by 1° to 2°C.

Labrador Current

This current was observed in two localities: where it leaves Baffin Bay and off Labrador. In the former area it had a minimal temperature below -1°C and a minimal salinity below 32.5°/₀₀ in the surface layers, and even at the 200-m depth it gave rise to temperatures below 2.5°C and salinities below 34.5°/₀₀. It can be seen at the western ends of all sections from Section 8 northwards and its cold core is usually located at 50- to 100-m depth, there having been some warming of the surface layers. Off Labrador the current gave rise to a minimal temperature below 1°C and a minimal salinity below 29°/₀₀ at the surface. In the extreme south close to the Labrador coast there had, however, been considerable warming of the 0- to 20-m layer and in places the surface temperature exceeded 6°C. Below this thin warm layer the cold core of the current, with temperatures below -1°C, was found at 75- to 100-m depth. At the 200-m depth the temperature was still below 1°C and the salinity below 34.0°/₀₀.

Central Parts of the Irminger and Labrador Seas

As on NORWESTLANT 1 and 2 the deeper parts of the Irminger Sea, Labrador Sea, and Davis Strait consisted of Labrador Sea Water down to the 1,500-m depth, of water of Iceland-Greenland overflow origin at the bottom, and of water with an Iceland-Scotland overflow component in between. The Iceland-Greenland overflow can be seen on the Continental Slope off East Greenland from the Denmark Strait to Cape Farewell on this occasion; it appears on each of Sections 1-6 as water below 2°C, getting progressively deeper as it moves south. The sections in the Labrador Sea were not sampled to a great enough depth for it to be observed there.

The surface layers in the central areas showed seasonal warming everywhere down to 50- to 75-m depth, the least amount being in the Labrador Sea in the region of Section 9. There were higher temperatures in the surface layers in the Irminger Sea than elsewhere. The upper layers over the entire central area showed the presence of low salinity water, and the horizontal salinity distribution charts for 0-200 m indicate that the Labrador Current in 55°N lat was the source of much of the low salinity water found in the region to the south of Cape Farewell and in the southern part of the Irminger Sea. On Section 7 this water can be seen reaching down to as deep as 400 m south of Cape Farewell. The East Greenland Current was also making some contribution to the low salinity of the central regions, but it was a much smaller one.

Stability

The difference in sigma-t value between 0 and 50 m, as shown in Chart 130, demonstrates that there was a certain amount of stability in the surface layers over most of the survey area. As during NORWESTLANT 2, it was greatest off the coasts of Greenland, in the northern part of the Davis Strait and in the North Atlantic Current. The amount of stability in these regions had increased, except off West Greenland. In addition, a zone of higher stability occurred off Southwest Iceland. There were indications also of stratification in the surface layers of the Irminger Sea and the Labrador Sea. The biggest area of low stability lay in the deep water area around Cape Farewell.

SUMMARY OF CHANGES IN CONDITIONS OVER THE COURSE OF THE SURVEYS

The charts of the dynamic topography of the surface and of the mass transport show that in the Irminger Sea the north-flowing offshoot of the North Atlantic Current increased in strength between the first and second surveys and then decreased again by the third, but not back to the level found on NORWESTLANT 1. During the second and third surveys there was a notable contribution from the east to this flow; the area surveyed during NORWESTLANT 1 was not great enough to show whether or not it existed then. On the other hand, the mass transport of the Irminger Current flowing southwards along the East Greenland coast and of its component off West Greenland both declined between the first and second surveys and then increased to a maximum during NORWESTLANT 3. The speeds of the East Greenland Current and its component off West Greenland increased between the first two surveys and then remained steady until the third. Coverage of the Labrador Current was not sufficient over the three surveys to allow conclusions to be drawn about changes in its flow. Two areas of very complicated flow appear on the charts for all three surveys, one in the Denmark Strait and the other from south to west of Cape Farewell. In the former the main features of the flow pattern are more or less the same over the whole survey period, but in the latter marked differences occur. During NORWESTLANT 1 the dynamic topography and the mass transport indicated a large eddy in the deep water off the coast of Southwest Greenland. This was not apparent during NORWESTLANT 2, but the station network during that survey was not so comprehensive and the existence of the eddy then cannot be ruled out. It does appear on the NORWESTLANT 3 charts, but on this occasion a closer station network was the result of two ships operating in the area at slightly different times and we cannot tell whether the eddy shown on the charts was the result of changes in space or of changes in time. A further feature is that on NORWESTLANT 2 an increase occurred in the combined width of the East Greenland and Irminger Currents; rounding Cape Farewell by NORWESTLANT 3 it was narrower again but still wider than during NORWESTLANT 1.

Turning to the changes in the temperature distribution, between the first and second surveys there was little change in the North Atlantic Current, but in the area to the west of Iceland there was a slight increase in temperature and the warm water reached a greater depth. In the Irminger Current, apart from some warming in the surface layers, there was also little change to as far as Cape Farewell. Here, however, there was a southwards displacement of the core of the current at all depths down to 200 m; on NORWESTLANT 2 it lay 50 nautical miles further south than on NORWESTLANT 1. Off Southwest Greenland the Irminger component was colder on the second survey, but further north in the Davis Strait it was warmer, as was that part of the West Greenland Current which turns to the west. Over most of the survey area there had been some warming of the surface layers by NORWESTLANT 2, except in the cold East Greenland and Labrador Currents. Between the second and third surveys there was again little change in the North Atlantic Current beyond warming in the surface layers down to 100 m. Likewise, the Irminger Current showed warming down to 50-75 m west of Iceland and along the East Greenland Slope. Off Southeast Greenland, however, this current was much wider than on NORWESTLANT 2 but with the core no longer displaced to the south. Furthermore, the influence of the Irminger component off West Greenland showed a great increase, and the rise in temperature at depth off the whole of the West Greenland Slope after the second survey indicates marked advection of warm water into this area, in agreement with the increase in current velocity and mass transport noted above. Seasonal warming was apparent everywhere in the surface layers on NORWESTLANT 3 except in the core of the East Greenland Current. Even the surface layers of the Labrador Current showed it, particularly down to 20 m in its southern parts.

The salinity changes from survey to survey tend to reflect the temperature changes, but this tendency is to some extent masked by the fact that the salinity of the upper layers over the whole survey area decrease progressively from NORWESTLANT 1 to NORWESTLANT 3. This decline is not sufficient to obscure an event like the increase in salinity at depth off the West Greenland Slope between the second and third surveys, when the influence of the Irminger component was increasing. Such a general decline is a common phenomenon in Arctic seas in summer and is due to a combination of two factors: the addition of low salinity water of melt-water origin by the East Greenland and Labrador Currents, and the addition of precipitation to the surface layers above the seasonal thermocline.

As far as stability of the surface layers is concerned, the first survey showed zones of stability situated along the seaward edges of the East Greenland and Labrador Currents and in the northern part of the Labrador Sea. As the surveys progressed, these zones extended in area, until by NORWESTLANT 3 virtually the whole survey area had a certain amount of stability in the uppermost layers of the water column. In the original zones the degree of stability increased with time, but off West Greenland there was a tendency to a decrease in stability in certain parts by the last survey. Frede Hermann, in the appendix to this report, shows that during this survey upwelling of water was taking place along the western edge of the West Greenland banks: such a process would give a zone of reduced stability.

The oceanographic observations made at Ocean Weather Station *Alfa* during the survey period provide a good record of the changes in temperature and salinity over the course of time*. They also provide a prelude to the surveys in that they show the conditions prevailing in the months preceding them. From 1 January to 20 July, 1963 Station *Alfa* was occupied by Norwegian, French, and English weather ships. The Norwegian Ocean Weather Ships *Polarfront I* and *II* served at the station from 1 January to 13 April. From these ships 55 hydrographic stations were worked, 23 in January, 19 in February, 5 in March, and 8 in April; from 27 February to 23 March no stations were worked because of damage to the hydrographic winch aboard the ship. From 14 April to 4 June Ocean Weather Ships *France I* and *II* served at Station *Alfa* and two hydrographic stations were worked, with samples down to 2,000 m. The salinity values of these stations seem, however, to be too high. The English Ocean Weather Ships *Weather Monitor* and *Weather Adviser* occupied the station from 5 June to 20 July, and eight hydrographic stations were worked.

Ocean Weather Station *Alfa* has the position 62°00'N, 33°00'W, and the depth to bottom is approximately 3,000 m. This position is situated in the boundary area between two different water bodies; to the east of the station Northeast Atlantic Water flows northwards, while to the west there is a cyclonic vortex of Labrador Sea Water. Thus, there is warm and saline water to the east and colder and less saline water to the west. Relatively small east-west movements of the water masses may therefore involve great variations of temperature and salinity in the upper 500-600 m. However, it has been possible to construct average profiles of temperature and salinity to 1,000-m depth for the following four periods: January, February, 23 March-13 April, and 5 June-20 July. These are shown in Fig. 6.

The curves for February show the lowest values for both temperature and salinity at all depths from the surface to 1,000 m. Except in the upper 300 m, the highest salinity values occur in January. Below 550 m January exhibits also the highest temperature. From 23 March to 13 April the absorption of radiation from the sun was increasing and this may account for the fact that the mean surface temperature was more than 1°C higher than in January and February. The surface salinity was, however, also very high in this period and it is therefore possible that some of the warm water had been transported into the area by the North Atlantic Current. In June-July the effect of solar radiation is more pronounced and the mean surface temperature reached 8°C, even though this period had the lowest surface salinity.

The bathythermograph observations made at Ocean Weather Stations *Alfa*, *Bravo* and *Charlie* during the NORWESTLANT Surveys have been summarized as temperature isopleth diagrams in Fig. 7. In March the profile of Station *Bravo* shows an increase in temperature with increasing depth: by April this temperature gradient has reversed and become similar to that at Station *Charlie*. At both stations the temperature in the uppermost 100 m shows an increase throughout May and June and the decrease of temperature with depth becomes more marked, so that by July there is evidence of thermal stratification in the 0- to 75-m layer. At Station *Alfa* there were no observations made until June. The temperature gradient at that time is seen to be similar to that at the other stations, but during the month it steepens and in July stratification is apparent.

* I am indebted to Mr J. Blindheim for the analysis of temperature and salinity conditions at Ocean Weather Station *Alfa*.

Certain observations were made off East Greenland after NORWESTLANT 3 had been completed and these allow us to follow the course of events even later into 1963. For example, Blindheim and Bratberg (1964) give a series of temperature sections worked by RV *Johan Hjort* from Cape Farewell

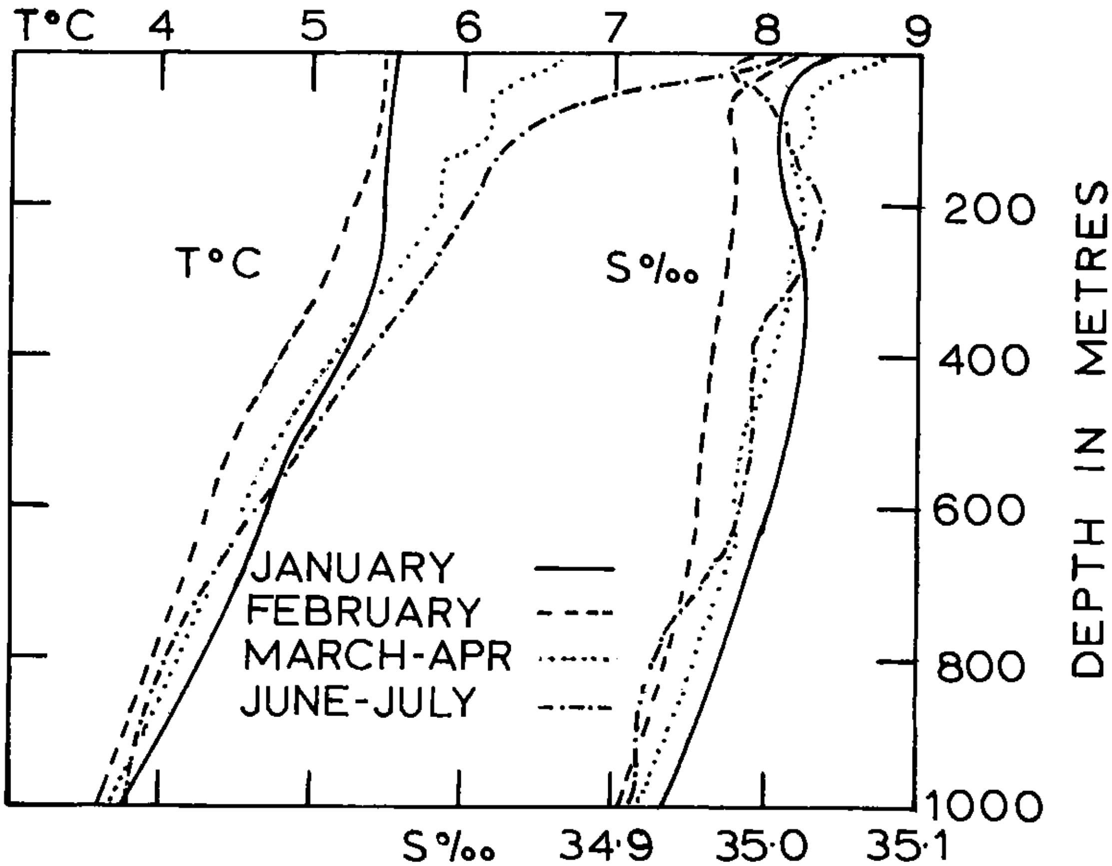

Fig. 6. Ocean Weather Station *Alfa*; average temperature and salinity profiles for January-July 1963.

to the Denmark Strait at the end of August: Gade, Malmberg, and Stefánsson (1965) give sections in the Denmark Strait worked at the beginning of September. The sections of Blindheim and Bratberg show that by the end of August the surface layers in the area to the east of the East Greenland Shelf had increased in temperature by 1° to 2°C and that off southeastern Greenland the temperature of the deeper water of the Irminger Current had increased as well, the 5°C isotherm lying up to 100 m deeper than it did during NORWESTLANT 3. In the Denmark Strait, on the other hand, the sections of Gade, Malmberg, and Stefánsson show the reverse situation, with the isotherms in this current 100 m shallower than on NORWESTLANT 3. Charts 154 and 155 show the temperature distributions at 0 and 200 m as derived from these two papers.

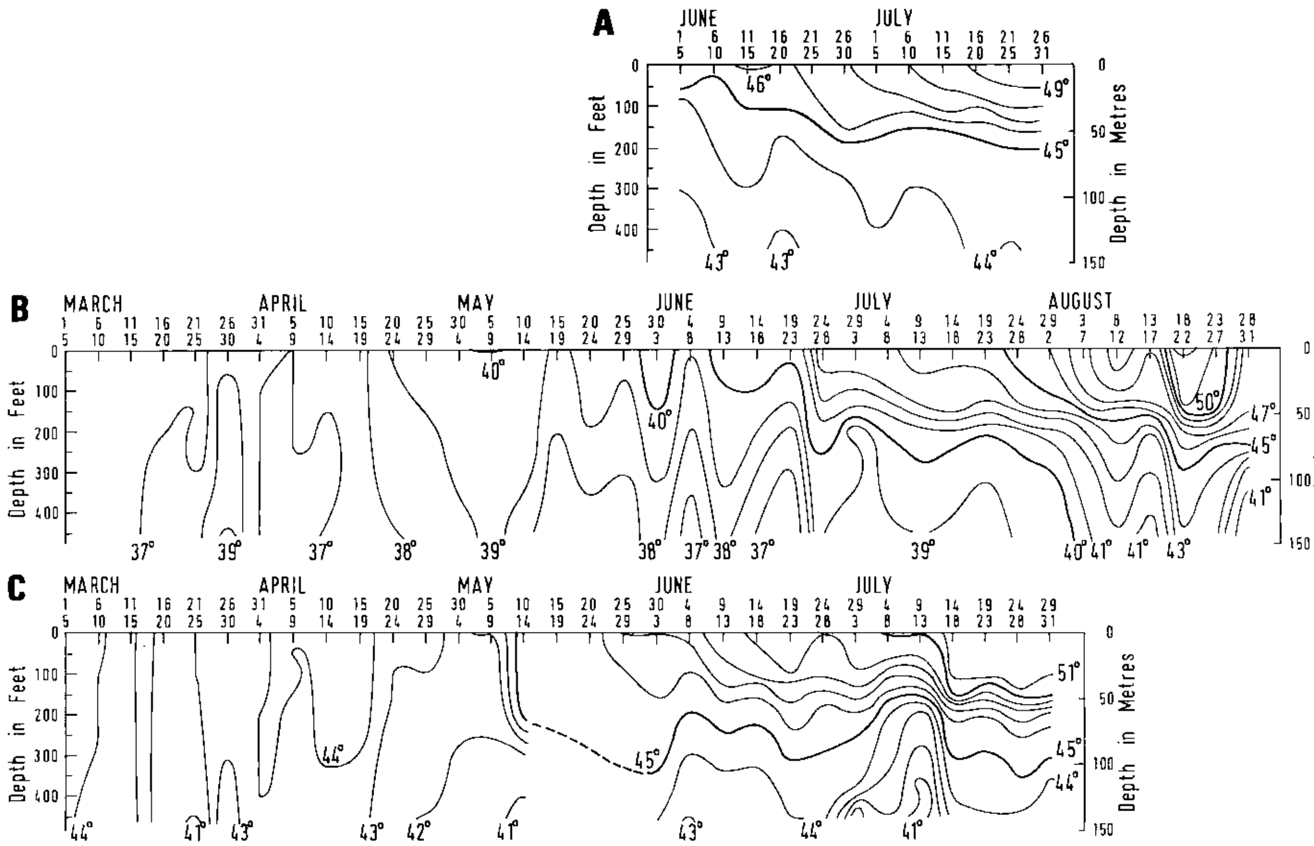

Fig. 7. Temperature isopleth diagrams for Ocean Weather Stations *Alfa*, *Bravo*, and *Charlie*; March-July 1963.

COMPARISON WITH CONDITIONS IN PREVIOUS YEARS

The NORWESTLANT Survey area has not been investigated on a very great scale in the past, and previous observations are so relatively few that it is virtually impossible to say how far the year 1963 was typical of the normal regime. All that we can do is to compare the NORWESTLANT observations with those of the few surveys that have been made at a comparable time of the year in the past.

As far as the general circulation is concerned, Dietrich (1957) shows the dynamic topography of the surface in the Irminger Sea in June 1955. Its pattern is the same as that shown in Chart 68 for NORWESTLANT 2, except that in the eastern part of the Irminger Sea in June 1955 the north-going current appears to have had a uniform speed of 6-10 cm/sec across its whole width and there was a strong east-going current to the south of Iceland. During NORWESTLANT 2 there was a streak of higher velocities, up to 15 cm/sec, at the core of the north-going current and there was little east-going current. The complicated flow found in the Denmark Strait on all the NORWESTLANT Surveys was also present in June 1955 and there is great similarity between the pattern given by Dietrich and those shown here. Dietrich shows a south-going current to the west of the Iceland Shelf as found by us. Gade, Malmberg, and Stefánsson (1965) show the dynamic topography in the Denmark Strait in September 1963; in the deep water they use a reference level of 1,000 dbar, in the shallow water they use one of 300 dbar, and in the Slope area they omit the topography. This different treatment of the data means that the south-going current found by Dietrich and by us does not appear, nor does the north-going current off the East Greenland Slope. Gade, Malmberg, and Stefánsson point out that the true current pattern in this area can only be established with certainty by direct current measurements; these authors have already started such work. One of their few sets of measurements does show a south-going current in the area where such a flow is indicated by our charts of dynamic topography; the GEK observations described above in this report also show such a flow.

A large number of observations were made in the NORWESTLANT area during the International Geophysical Year (IGY), and Dietrich (1964) shows the dynamic topography of the sea surface in the late summer of 1958. The topography derived from the observations made in spring 1958 is not yet available. The chart for late summer 1958 only covers the area deeper than 1,000 m. A feature of it is a flow into the Irminger Sea from the east in the vicinity of position 55°N, 30°W. Such a flow was deduced by Dietrich and Stefánsson (1963) from the temperature and salinity observations made between the surface to 200 m during the 1961 redfish larvae investigations carried out by Iceland and Germany. It is certainly shown by the NORWESTLANT 2 and 3 Surveys, and it appears in the current chart of the Irminger Sea given by Hermann and Thomsen (1946) on the basis of drift bottle studies and other hydrographic investigations.

TABLE 6. Mean temperature and volume transport of the West Greenland Current near Cape Farewell 1950-63 (based on U.S. Treasury Department Coast Guard Bulletins Nos. 36-49).

Year	Mean Temp. °C	Total volume transport $10^6 m^3/sec$	Volume transport Irminger component $10^6 m^3/sec$	Volume transport East Greenland component $10^6 m^3/sec$	Dates
1950	4.26	7.76	3.58	4.18	31 July - 5 Aug.
1951	3.77	4.50	1.12	3.38	18-23 July
1952	3.79	5.93	1.53	4.40	17-20 July
1953	3.86	7.23	2.08	5.15	16-20 July
1954	4.95	8.95	6.82	2.13	25 Aug. - 4 Sept.
1955	4.74	5.66	3.79	1.87	15-18 July
1956	4.10	7.32	2.86	4.46	15-20 July
1957	4.15	9.74	4.01	5.73	26-29 July
1958	4.48	8.36	4.63	3.73	1- 6 July
1959	4.29	7.56	3.57	3.99	5- 9 Aug.
1960	4.95	6.09	4.64	1.45	10-13 July
1961	4.69	5.98	3.88	2.10	8-11 July
1962	4.26	6.10	2.80	3.30	13-17 July
1963	4.71	2.44	1.60	0.84	17-21 July

The International Ice Patrol Service has regularly worked a section from Labrador to Cape Farewell in the summer months over a long period of years. In 1963 it occupied this section between 17 and 21 July and the results are given in U.S. Treasury Department Coast Guard Bulletin No. 49. The volume transport of the West Greenland Current off Cape Farewell is calculated as 2.44 x $10^6 m^3/sec$, as compared with the seasonal normal of 5.84 x $10^6 m^3/sec$. Its cold East Greenland component had a volume transport of 0.84 x $10^6 m^3/sec$ as compared with the seasonal normal of 2.89 x $10^6 m^3/sec$, and its warm Irminger component had a volume transport of 1.60 x $10^6 m^3/sec$ as compared with the seasonal normal of 2.95 x $10^6 m^3/sec$. Thus, the circulation around Greenland during NORWESTLANT 3 would appear to have been more than 50% below normal.

Temperature and salinity conditions in the Irminger Sea in April-July 1963 can be compared with those prevailing in April-May 1961 as described by Dietrich and Stefánsson (1963), with those in March-April 1958 as described by Dietrich (1964), and with those in June 1955 as described by Dietrich (1957). In April-May 1961 the temperature was higher than during NORWESTLANT 2 by 0.5° to 1°C from the surface down to 200 m over most of the Irminger Sea and the Denmark Strait. An exception occurred in the vicinity of Cape Farewell, where the Irminger Current was slightly warmer in 1963 than in 1961. Of the IGY data for March-April 1958, the 200-m temperature observations are the only ones available in chart form at the present time. They show similar temperature levels to those observed during NORWESTLANT 1, but slightly colder conditions in the Irminger Current near Cape Farewell. As for 1955, surface temperatures in June over the whole of the Irminger Sea were

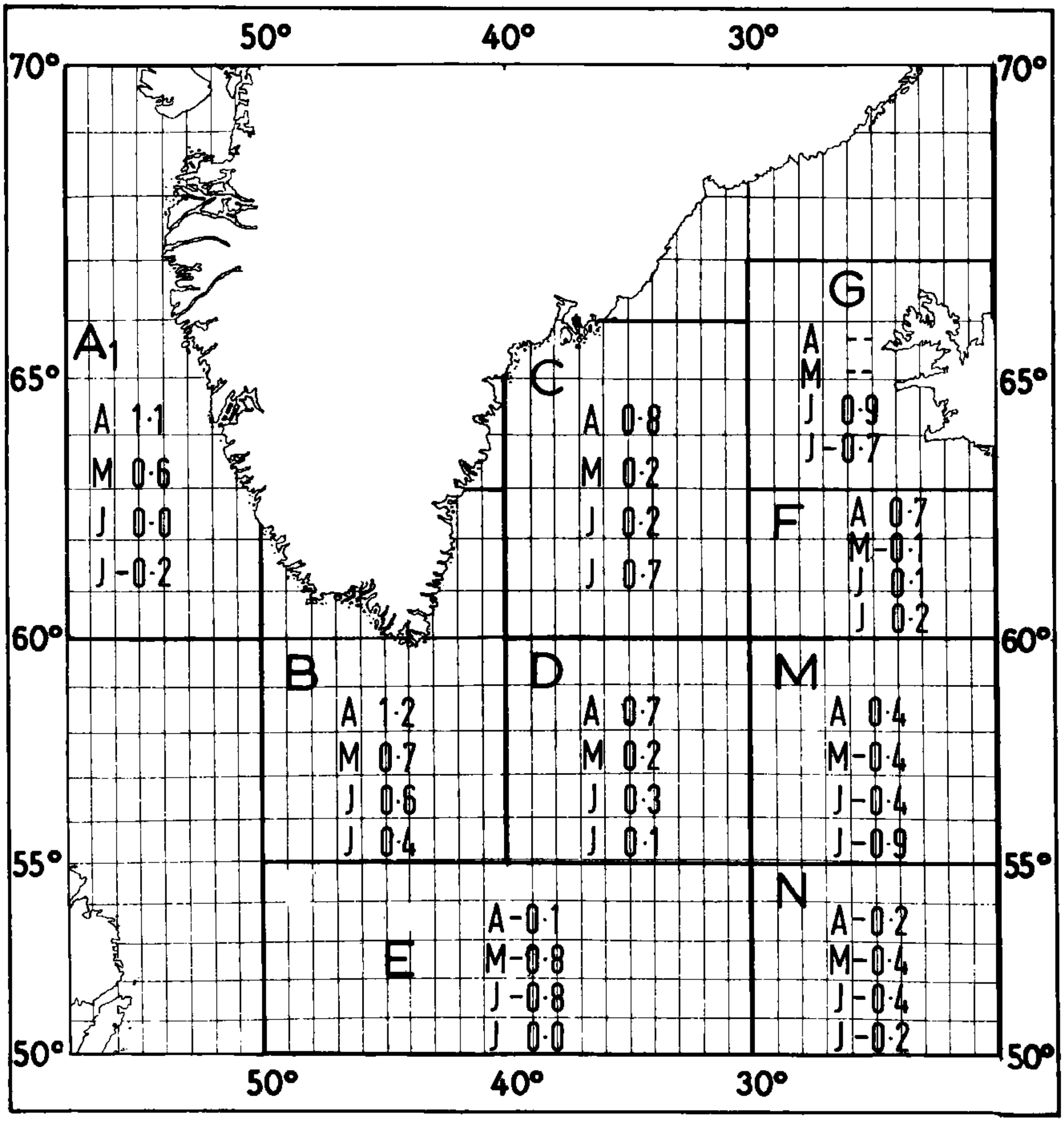

Fig. 8. Monthly surface temperature anomalies for April-July 1963 in various regions in the NORWESTLANT area.

1° to 2°C higher than during NORWESTLANT 2, but at 200 m they were the same. In none of the 3 years 1955, 1958, and 1961 was there a displacement of the Irminger Current to the south of Cape Farewell, similar to that found on NORWESTLANT 2.

In April-May 1961 salinities in the Irminger Sea were 0.05-0.1‰ higher than during NORWESTLANT 2. Further south the west-east tongue of lower salinity water in the vicinity of 53°N lat,

TABLE 7. Sea surface temperature anomalies for various parts of the NORWESTLANT area. For positions of the regions, see Fig. 8. (Based on contributions by Jens Smed in various volumes of the Annales Biologiques, International Council for the Exploration of the Sea.)

Year	Region A_1				Region B				Region C				Region D				Region E				Year
	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July	
1950	0.5	0.8	0.8	0.2	0.8	0.7	0.5	0.6	0.2	-0.1	0.8	1.0	0.0	0.3	0.5	0.6	-1.1	0.0	0.5	-0.6	1950
1951	0.2	0.6	0.7	0.3	0.0	0.6	0.8	1.1	-0.2	0.4	0.8	0.8	-0.2	0.3	0.5	0.5	0.6	0.8	1.4	1.0	1951
1952	0.1	0.6	0.5	-0.1	-0.5	0.3	0.3	-0.1	0.1	-0.2	0.1	0.1	-0.2	0.1	0.2	-0.1	-0.7	1.3	2.1	1.7	1952
1953	2.2	1.5	1.0	1.1	0.9	1.6	0.8	0.2	0.2	1.0	0.9	1.3	0.5	1.1	0.6	0.2	0.8	0.9	0.4	0.4	1953
1954	-0.3	0.7	0.9	0.4	-0.5	0.5	0.7	0.6	0.4	0.1	0.9	1.0	0.1	0.1	0.6	0.6	-0.1	0.3	0.5	0.3	1954
1955	1.2	1.2	1.2	-0.4	0.6	0.5	0.9	-0.7	0.9	0.8	1.3	0.4	0.5	0.7	1.2	-0.1	0.8	1.1	0.4	0.0	1955
1956	0.5	0.4	0.0	0.7	1.9	0.7	-0.2	0.1	0.7	0.3	0.3	0.8	1.2	0.1	0.0	0.0	0.1	-0.4	-0.2	0.0	1956
1957	0.6	0.3	0.7	0.9	0.6	0.7	0.6	0.9	0.4	0.9	0.8	1.6	0.4	0.6	1.2	1.1	-0.5	-0.4	-0.2	0.0	1957
1958	0.2	0.7	0.9	1.0	0.0	0.7	0.9	0.9	1.1	0.8	1.5	2.7	0.6	0.8	1.4	1.6	0.4	1.1	1.3	0.9	1958
1959	1.0	1.5	0.8	0.7	0.4	0.7	0.5	1.2	0.9	0.7	0.6	1.2	0.6	0.7	-0.1	0.4	-1.5	0.5	-0.9	0.4	1959
1960	1.5	1.2	1.2	1.6	0.4	0.8	0.9	1.0	0.3	0.7	1.3	1.7	0.6	0.6	0.3	0.2	-1.0	-0.2	-0.9	0.1	1960
1961	1.8	0.6	0.9	1.6	1.2	1.6	1.2	0.8	0.6	2.0	1.4	0.9	0.8	1.1	0.8	0.0	0.0	0.7	-0.6	0.0	1961
1962	0.7	1.1	1.1	1.1	0.9	1.1	0.8	1.0	0.4	0.3	0.5	0.6	0.8	0.8	0.5	0.5	-0.4	0.1	-1.0	0.4	1962
1963	1.1	0.6	0.0	-0.2	1.2	0.7	0.6	0.4	0.8	0.2	0.2	0.7	0.7	0.2	0.3	0.1	-0.1	-0.8	-0.8	0.0	1963
1964	0.6	0.8	0.7	0.2	0.2	1.3	0.7	-0.1	1.5	1.2	1.6	0.7	0.7	1.1	1.4	-0.1	0.3	0.3	0.1	-0.2	1964

Year	Region F				Region G				Region M				Region N				Year
	April	May	June	July	April	May	June	July	April	May	June	July	April	May	June	July	
1950	0.0	0.2	0.0	0.6	0.3	1.1	0.2	0.4	-0.8	0.4	0.5	0.3	-0.3	0.1	0.9	-0.1	1950
1951	-0.6	0.1	0.8	0.4	-1.0	0.2	1.0	0.1	-0.8	0.3	0.4	0.7	1.5	0.3	–	–	1951
1952	-0.1	-0.3	-0.3	0.3	0.4	0.3	0.5	0.2	-0.8	-0.5	0.0	0.1	-1.7	–	–	1.9	1952
1953	-0.4	0.5	0.6	1.3	-0.6	0.8	1.1	1.4	0.0	0.7	0.9	0.9	-0.3	–	–	–	1953
1954	0.3	0.5	1.0	0.2	1.4	0.4	1.7	0.5	0.5	0.5	0.2	0.0	0.8	0.8	-0.2	0.3	1954
1955	0.7	0.4	0.8	0.2	1.1	0.7	1.4	0.0	0.8	0.8	1.0	0.3	1.1	0.9	0.7	1.4	1955
1956	0.6	0.6	0.2	0.1	0.4	0.9	0.5	0.1	1.1	0.5	0.0	-0.5	1.1	-0.5	-0.4	-0.8	1956
1957	0.3	0.9	1.0	1.1	1.2	1.0	1.1	0.9	0.7	0.8	1.0	0.8	-0.1	0.4	1.2	0.2	1957
1958	0.7	0.5	1.0	1.6	0.8	0.8	1.8	1.6	1.0	0.6	0.6	1.5	0.5	0.2	-0.6	–	1958
1959	0.5	0.6	0.2	0.3	0.4	0.9	1.1	0.5	0.2	1.3	-0.1	0.0	-0.1	0.0	-0.6	-0.6	1959
1960	0.4	1.0	0.9	0.9	–	–	1.4	1.1	0.2	0.2	0.2	0.5	-0.6	-0.4	-0.8	-0.4	1960
1961	0.5	0.9	0.3	-0.1	–	–	1.4	0.2	-0.3	0.7	-0.1	0.0	-1.0	-2.1	0.0	0.6	1961
1962	0.2	0.2	0.2	-0.1	2.7	2.4	0.6	0.3	0.0	0.3	-0.2	0.3	-0.6	-0.2	-0.7	0.6	1962
1963	0.7	-0.1	0.1	0.2	–	–	0.9	-0.7	0.4	-0.4	-0.4	-0.9	-0.2	-0.4	-0.4	-0.2	1963
1964	0.8	0.9	0.6	0.0	–	–	2.2	0.2	0.5	0.6	0.3	-0.2	1.2	-0.5	0.8	-0.1	1964

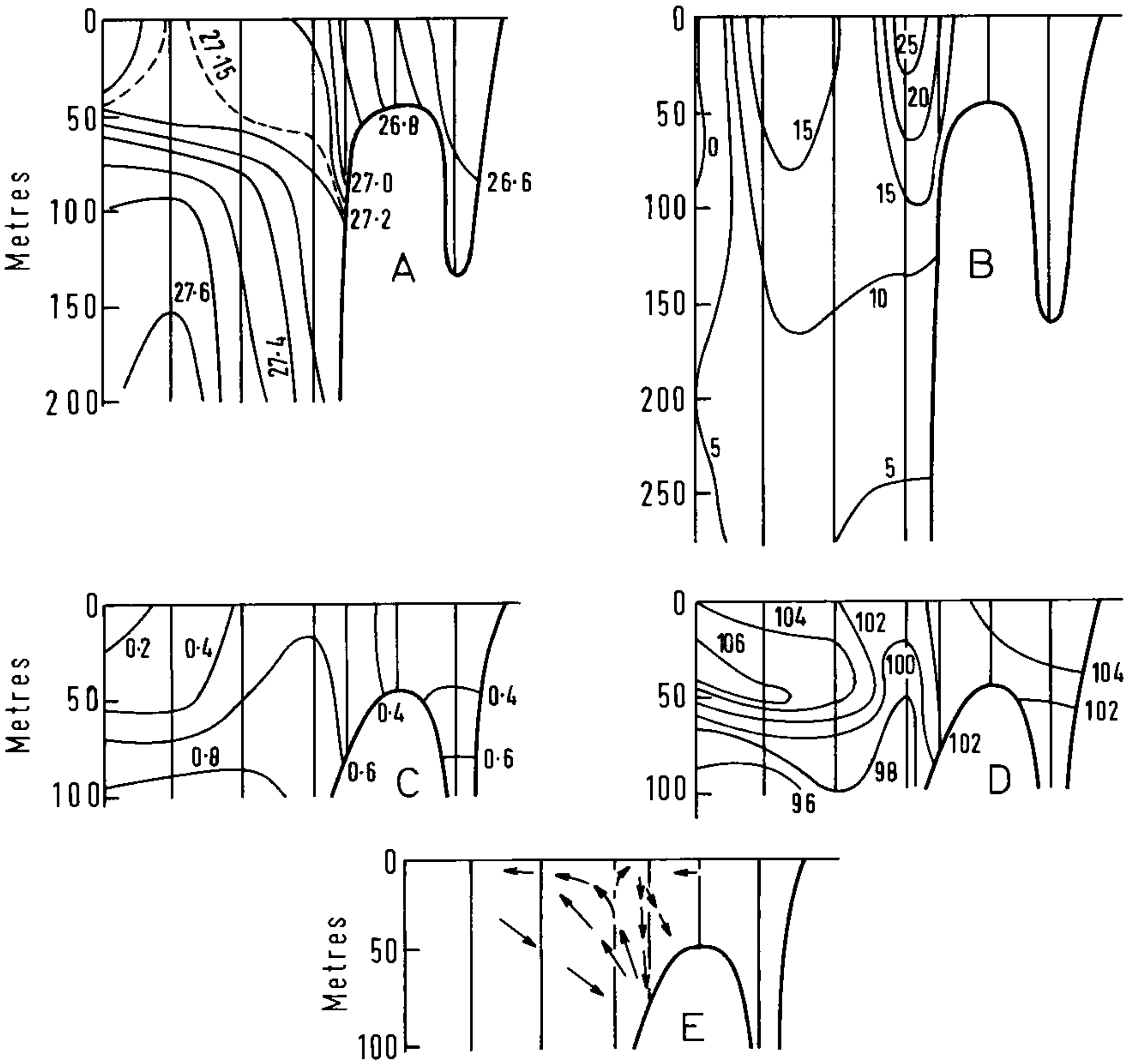

Fig. 9. NORWESTLANT 3. Section 11; 6-7 July. A — Sigma-t; B — Currents normal to the section (all are north-going); C — PO_4-P(μg at /l); D — Dissolved oxygen content (percent, saturation); E — Vertical water movements.

which was found during the NORWESTLANT Surveys, was again present and it had a somewhat lower salinity than in 1963. It was also present in June 1955 when it had the same salinity as in 1963, as did the rest of the 0- to 200-m layer in the Irminger Sea. The details of the salinity distributions at the surface in June 1955 and during NORWESTLANT 2 have a remarkable similarity, such small features as a tongue of low salinity water eastward of the Irminger Current in the vicinity of Cape Farewell appearing in both distributions.

Conditions off West Greenland during NORWESTLANT 1 can be compared with those found by Norwegian investigators in 1959-65 and reported upon annually in ICNAF Redbooks. Other countries have also made investigations in this area and these are reported in the Redbooks too, but the Norwegian observations form the only set which allows a comparison of conditions in April-May to be made from year to year. They show that 1961 was warmer at the surface than 1959 and 1960. However, 1962 showed a return to colder conditions which got progressively more severe, as far as the surface layers are concerned, in 1963 and 1964. In 1965 surface temperatures rose again. The year 1961 had a stronger Irminger component than 1960. In 1962 and 1963 this warm current was weak but in 1964 and 1965 it was strong again. Hermann, Hansen, and Horsted (1965) show that during NORWESTLANT 2 the mean temperature of the 0- to 45-m layer over the Fyllas Bank was 0.4°C below normal (2.0°C). It was higher than in 1956 and the same as in 1959, but lower than in 1953, 1954, 1957, 1960, and 1961. It was also lower than in 1964 according to Hermann (1966). The U.S. Treasury Coast Guard Bulletin No. 49 puts the mean temperature of the West Greenland Current during NORWESTLANT 3 at 4.71°C compared with the seasonal normal of 4.36°C. The volume transports of both its Irminger and East Greenland components were, however, much below normal. The temperature and volume transport of the current as obtained by the U.S. Coast Guard since 1950 are given in Table 6.

The anomalies of air and sea surface temperature at Ocean Weather Stations *Alfa*, *Bravo*, and *Charlie* are dealt with in the section of this report concerned with Meteorology. Further, Jens Smed (ICES) has published in the Annales Biologiques the anomalies of surface temperature for various regions in the NORWESTLANT area over a number of years. The regions are shown in Fig. 8 and the anomalies for the months April-July from 1950 to 1964 are given in Table 7. It can be seen that in April 1963 there was a positive anomaly over the whole NORWESTLANT area north of 55°N lat, and that this anomaly ranged from about 1°C off West Greenland and Cape Farewell to 0.4°C in the east of the area. South of 55°N lat there was a slight negative anomaly. In May there was a marked decrease in the positive anomaly: it was still about 0.7°C off West Greenland and Cape Farewell, but elsewhere it was less than 0.2°C, and in the extreme south and east of the Survey area there was a negative anomaly of 0.4° to 0.8°C. In June the anomalies were everywhere the same as in May, except off West Greenland where temperatures were now normal: west of Iceland there was a positive anomaly of about 1°C. July saw a change to negative anomaly off West Greenland and a further decrease in the positive anomaly south and southeast of Cape Farewell. In the extreme east there was now a marked negative anomaly of nearly 1°C, and there was a negative anomaly of 0.7°C off the west coast of Iceland. In the extreme south, however, the temperature was normal or a little below, and off East Greenland it was 0.7°C above normal.

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POSTSCRIPT

Since this report went to press, a paper by Blindheim (1968) has been published describing hydrographic conditions in the Irminger Sea in the years 1954-64. Observations have been made in various years by Norwegian research vessels in the branch of the Irminger Current flowing southwards along the edge of the East Greenland Shelf during the latter part of August and early September. They have also been made by Norwegian weather ships at Ocean Weather Station *Alfa*, mainly during June-December. Blindheim shows that in 1954-56 only small amounts of Atlantic water were observed, but that the Atlantic inflow then increased until 1959-60: since 1961 the amount has decreased again.

A. J. L.

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Vertical Water Movements in the Polar Front Along West Greenland

By

Frede Hermann[1]

VERTICAL WATER MOVEMENTS IN THE POLAR FRONT ALONG WEST GREENLAND

The polar front around East and West Greenland consists of a relatively narrow boundary area between two water masses differing greatly in density. In Greenland waters the densities in the upper layers are mainly a function of the salinity. The light water component of the West Greenland Current is the polar East Greenland component found nearest the coast and the heavy water component is the Irminger Current found off the Slope of the Shelf. The front is generally sharper off East Greenland than off West Greenland. The front area is an area with great horizontal turbulence, as is clearly seen on the surface thermograph, when one sails on the warm water side of the front. Patches of cold water are often found several miles off the front. It is probable that this strong horizontal turbulence is also found in the subsurface layers.

Figure 9*a* shows the vertical distribution of density on Section 11 (the Fyllas Bank Section) worked by M/S *Dana* in July 1963 during NORWESTLANT 3. The isosteric surfaces in the front area over the western slope of the bank are strongly inclined to the horizontal and the horizontal density gradient is strong. Figure 9*b* shows the current perpendicular to the section, calculated from dynamic height anomalies assuming zero current at 1,000 m or along the bottom. It is questionable how well these currents represent the real currents, especially over the shallow part of the section. It is, however, supposed that the main features west of the bank are correct. As shown in the figure, a maximum of current is found in the front area over the western slope of the bank. If the horizontal turbulence is strong, there will also be strong friction where the horizontal velocity gradient is strong. In the core of the current this friction will tend to reduce the velocity, with the result that the Coriolis force will become smaller than the pressure gradient perpendicular to the current direction. This will result in a westward movement of the water in the current core. This movement will, however, not be horizontal, but will follow the isosteric surfaces, which are inclined upwards towards the west. We can thus expect to find in the core of the current an upwelling of mixed water, which will tend to flow westward in the surface layers over the heavier water masses of the Irminger component of the current. By a similar argument we find that the water masses on both sides of the core of the current will tend to sink and move eastward along the isosteric surfaces.

On the section discussed, dissolved oxygen and phosphate were measured in the 0- to 100-m layer. The vertical distributions are shown in Fig. 9*c* and *d*. Both sections indicate upwelling of phosphate rich, oxygen poor, deep water at the core of the current. In the western part of the section there is an indication of a movement towards the east and downwards of oxygen rich water, as expected. The water movements discussed here are shown schematically in Fig. 9*e*. Chart 158 shows the horizontal distribution of phosphate at 20-m depth off West Greenland based on the Danish observations made during NORWESTLANT 3. A maximum of phosphate is found in the front area and just west of the front. This maximum is probably caused mainly by the upwelling in the front of mixed water, which spread out over the surface layers of the heavy Irminger component of the West Greenland Current.

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The Distribution of Phosphate, Silicate and Dissolved Oxygen in the 0- to 100-m Layer During NORWESTLANT 1-3

By

P.G.W. Jones[1] and A.R. Folkard[1]

REVIEW OF PAST LITERATURE

The first nutrient estimations in the area were made during the 1928 Godthaab expedition (Hagen, 1936). Phosphates were measured from Cape Farewell in the south to Smith Sound in the north. Observations were made in the Labrador Sea and Davis Strait between the end of May and the beginning of July. Surface values of approximately 0.5 μg atom PO_4-P/l were recorded off the coast of Labrador and Baffin Island. The concentration of phosphate fell to zero towards parts of the West Greenland coast. The vertical sections showed that the concentration of phosphate increased through the first 100 m. The results of the NORWESTLANT Surveys, however, show that the distance between stations on the Godthaab expedition were too great to show the detailed distribution of phosphate.

Hermann (1953, 1954, 1955, 1956) measured the phosphate content of the water at 20 m off the West Greenland coast during July 1953-56. The basic pattern was similar on all the surveys. A band of high phosphate values extended offshore from Cape Farewell to the west of the Fyllas Bank. The range of phosphate concentration encountered showed some year to year variations. Adrov (1963) measured phosphate, silicate, and nitrite in the same area during the spring and summer of 1958-60. His observations extended from the surface to 500 m. Fedosov and Andreev (1961) measured phosphate on three sections in the eastern Davis Strait. Mean values only were recorded for each section. Corwin and McGill (1963) measured total phosphorus, inorganic phosphate, nitrate, and silicate in the Labrador Sea during July 1962. They were mainly concerned with the distribution of nutrients in the deep water. However, some data for the first 100 m are available in their report. McGill and Corwin (1964*a* and 1965) made similar observations in the Labrador Sea during the summer of 1963 and 1964, and McGill and Corwin (1964*b*) measured total phosphorus, inorganic phosphate, nitrate, and silicate in Baffin Bay and Kane Basin during the summer of 1963.

Kalle (1957) measured phosphate in the Irminger Sea during June 1955. At the surface, an area of water situated to the south and east of Iceland had values below 0.5 μg atom PO_4-P/l. Along the whole East Greenland coast the phosphate content of the water was below 0.5 μg atom PO_4-P/l. Weichart (1963) has already reported upon phosphate in the surface water of the Irminger Sea as measured by means of an automatic continuous recording technique during NORWESTLANT 2.

Dissolved oxygen estimations were made during the 1928 Godthaab expedition in sea areas to the west of Greenland (Riis-Carstensen, 1936). Recent surveys which have included similar measurement are those of Soule, Franceschetti, and O'Hagen (1963); Soule, *et al.* (1963); Franceschetti, *et al.* (1964); Franceschetti (1964); and Kollmeyer, *et al.* (1965). Observations, extending to the bottom, were made in the Labrador Sea and adjacent areas during the summers of 1961-64. Fedosov and Andreev (1961) measured dissolved oxygen from the surface to 1,000 m in the eastern Davis Strait and Adrov (1963) measured it down to 500 m off the west coast of Greenland. Data for the Irminger Sea are more sparse although Kalle (1957) reported dissolved oxygen values for his survey of June 1955.

NORWESTLANT 1-3 — TREATMENT OF MATERIAL

The data and methods used were the same as those described in the section on Physical Oceanography. The analyses of the results of the intercalibration experiments have shown that differences in data between vessels often occurred. However, there was no definite evidence that the discrepancies observed during these tests introduced large errors into the charts showing the distribution of phosphate, silicate, and oxygen.

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Horizontal charts of the distribution of phosphate and silicate at 20 m have been prepared for NORWESTLANT 1-3 (Charts 156-161). This depth was selected in preference to the surface since most of the phytoplankton data refer to 20 m. Moreover, phosphate contamination of some surface samples has been reported. Horizontal charts of phosphate and silicate at 100 m are given for NORWESTLANT 1 (Charts 162 and 163). This depth is below any thermocline and is a guide to the winter distribution of phosphate and silicate in the surface and subsurface water. Vertical sections showing the distribution of phosphate and silicate from the surface to 100 m are given for each of the three surveys (Charts 164-169). Surface values suspected of contamination have been rejected. Chart 170 shows the distribution of dissolved oxygen in terms of % saturation at 100 m on NORWESTLANT 1. The distributions of oxygen at 20 m on NORWESTLANT 1-3 are shown in Charts 171-173. Vertical sections showing the distribution of oxygen from the surface to 100 m are presented in Charts 174-176.

The text is based on descriptions of the horizontal charts. References to the vertical sections are chiefly confined to outstanding features not shown by the horizontal charts. The location of hydrographic sections on each of the three surveys are given in the description of the Physical Oceanography (Charts 31-33).

PHOSPHATE AND SILICATE

NORWESTLANT 1

Phosphate — 100 m

A large area of water with a phosphate content greater than 1 µg atom PO_4-P/l was situated offshore in the Irminger Sea. A narrow band of this water extended around Cape Farewell into the eastern Labrador Sea. The phosphate distribution of the water to the west of Iceland was complex. To the southwest of Iceland a tongue of Northeast Atlantic Water was evident with a phosphate concentration below 0.75 µg atom PO_4-P/l. Other features of this area were, however, more difficult to relate to the water masses present and the East Greenland and Irminger Currents were not clearly differentiated by their phosphate content.

In the eastern Labrador Sea the phosphate content of the water fell towards the West Greenland coast and a value below 0.25 µg atom PO_4-P/l was recorded at the eastern end of Section 10 in the West Greenland Current. The presence of ice along both the West and East Greenland coasts prevented sampling close inshore. It is therefore difficult to say whether this low phosphate water extended along the whole coast or whether it was an isolated occurrence. Phosphate values from the western Labrador Sea were rather sparse. However, Section 8 shows values to have been above 1 µg atom PO_4-P/l across the Labrador Current.

Phosphate — 20 m

This distribution had many features in common with that at 100 m. A large area of water existed in the Irminger Sea with a phosphate concentration greater than 1 µg atom PO_4-P/l. At 20 m this water extended further to the north than at 100 m, but it did not extend to the west of Cape Farewell. To the south of Iceland, the water with a phosphate content of less than 0.75 µg atom PO_4-P/l represented the incursion of Northeast Atlantic Water into the Irminger Sea. The extent of this water was rather greater than at 100 m (see Section 3). There were no clearly defined structures in the distribution of phosphate along the East Greenland coast that differentiated the East Greenland Current from the Irminger Current.

In the southeastern Labrador Sea a tongue of water with a phosphate content above 1 µg atom PO_4-P/l extended northwards to about 60°N lat. Further north the phosphate content of the water declined. A bifurcation of the 0.5 µg atom PO_4-P/l contour suggests a division of the Irminger Current component. Values below 0.25 µg atom PO_4-P/l were found along the West Greenland coast and in the northeast of the survey area. Sections 11 and 13 show that the phosphate content of the water increased with depth in this area. The concentration of phosphate along the western part of Section 8 in the Labrador Current was similar to that at 100 m (< 1 µg atom PO_4-P/l).

Silicate — 100 m

A broad band of water with a silicate content above 8 µg atom SiO_3-Si/l extended northeastwards into the Irminger Sea from Cape Farewell. One arm of this water branched eastwards towards Iceland and another extended into the Denmark Strait. The inshore stations along the East Greenland coast showed silicate values below 8 µg atom SiO_3-Si/l, but there were no clearly defined structures that could be used to distinguish the East Greenland Current from the Irminger Current. South of Iceland there was an incursion of Northeast Atlantic Water with a silicate content below 6 µg atom SiO_3-Si/l.

The distribution of silicate in the Labrador Sea was more complex than in the Irminger Sea. The main feature shown in the eastern Labrador Sea was an area of water with a high silicate content in the south and a general decrease in concentration northwards. In the southern part of the Davis Strait, however, there was an indication of a north-going tongue of water across Sections 11 and 12 with a silicate content above 8 µg atom SiO_3-Si/l. In the western Labrador Sea the silicate content of the water showed a north to south decrease in concentration.

Silicate — 20 m

In the Irminger Sea the 8 µg atom SiO_3-Si/l contour did not extend so far north as that at 100 m. Northeast Atlantic Water (> 6 µg atom SiO_3-Si/l), however, was evident to the south of Iceland in approximately the same position as at 100 m.

In common with the situation at 100 m the greatest complexity was shown in the Labrador Sea. An area of high silicate existed in the eastern Labrador Sea to the southwest of Cape Farewell, but with a detailed structure more complex than that at 100 m. The silicate content of the water decreased towards the Davis Strait and towards the Greenland coast. Sections 11 and 12 show that silicate increased with increasing depth in this area. A tongue of water with a higher silicate content extended northwestwards parallel to the West Greenland coast and appeared to represent the Irminger Current component. The distribution of silicate in the western Labrador Sea at 20 m was similar to that at 100 m.

Discussion

The main features of the silicate and phosphate distribution were very similar. Apart from in the Davis Strait there was little clearly defined stratification. The distribution of both phosphate and silicate showed the greatest complexity in the Labrador Sea. Differentiation of the water masses by means of their phosphate and silicate content was often difficult. Phosphate and silicate did not satisfactorily delineate the East and West Greenland Currents or the Irminger Current. However, the Northeast Atlantic Water south of Iceland appeared to be distinguished by a relatively low phosphate and silicate content. The Labrador Current was apparent by its high silicate content, but with a north to south decrease in concentration.

NORWESTLANT 2

Phosphate — 20 m

The dominant feature of this distribution was a very large area of water with a phosphate content above 0.75 µg atom PO_4-P/l extending from Section 9 in the Labrador Sea, round Cape Farewell to beyond Section 4 in the Irminger Sea. At 20 m this water mass had a core south of Cape Farewell at approximately 57°N, 45°W, with values above 1 µg atom PO_4-P/l. The vertical sections show that water with a phosphate content of over 1 µg atom PO_4-P/l was far more extensive in the deeper water than at 20 m. Sections 4, 5, 7, 9-11, G, and H all show values of over 1 µg atom PO_4-P/l at 100 m or less. The highest concentration of over 1.25 µg atom PO_4-P/l occurred on Section G.

The main areas of water with a low phosphate content were close to the ice-edges, that is around the east and west coasts of Greenland, in the northwest part of the Davis Strait and in the western Labrador Sea. Weichart (1963), using his continuous phosphate recording technique, has clearly illustrated the surface boundary between the low phosphate East Greenland Current and the high phosphate Irminger Current.

The vertical sections show that most low values were confined to the upper layers. For example, Section 5 shows that whereas surface values at Station 24 off the east coast of Greenland were 0.25 µg atom PO_4-P/l, values approaching 0.75 µg atom PO_4-P/l were recorded at 100 m. Similarly, on Section 9 across the Labrador Sea, values were near or below 0.25 µg atom PO_4-P/l in the upper layers, whereas at 100 m they were mostly between 0.75-1.00 µg atom PO_4-P/l.

A general examination of all vertical sections shows a number of structures which seem to indicate vertical movement. This was especially marked to the west of Fyllas Bank where Sections 10 and 11 show an upwelling of phosphate rich water from below 100 m up to 20-30 m.

Silicate — 20 m

A large area of water was situated in the southern Labrador Sea with silicate values above 9 μg atom SiO_3-Si/l. A smaller core of water with values above 10 μg atom SiO_3-Si/l appeared to be centred over Station 4 on Section 9. Unfortunately, the rather large gap between Sections J and 9 prevents an accurate evaluation of the detailed horizontal and vertical structure of this water mass.

The concentration of silicate showed a decrease towards the Davis Strait, through the Irminger Sea, and towards the coastline. The vertical sections show that the lowest values tended to occur in the upper layers, although a considerable complexity of structure is often apparent. Section 11, for example, shows that at 100 m values of over 6 μg atom SiO_3-Si/l occurred, that at 30 m the silicate concentration was in the region of 3 μg atom SiO_3-Si/l, but that within the top 10 m values between 6-7 μg atom SiO_3-Si/l were found. Sections 10 and 11 also show upwelling in a number of tongues of water rich in silicate coming from below 100 m.

Another interesting phenomenon is the silicate content of the water in some coastal regions. On Section 4, for example, the silicate content of the water in the upper layers fell towards the East Greenland coast, reaching a minimum of 1 μg atom SiO_3-Si/l at Station 14. At Station 13, however, the silicate content of the water was between 4-5 μg atom SiO_3-Si/l. A similar phenomenon occurred at the landward end on Section 6 off Cape Farewell, and at the western end of Section 14 in the Davis Strait. The end of the latter section was close to the ice-edge although some distance from the coast. The full significance of this phenomenon cannot be evaluated since the distance of the innermost station to the coastline was often limited by the presence of ice. Indeed, the western end of Section 14 was against the ice-edge but 100 miles east of Baffin Island. It is therefore possible that the phenomenon may be associated with the proximity of the ice-edge rather than the coastline.

Discussion

The distributions of phosphate and silicate were similar to one another in that the highest values at 20 m occurred in the Labrador Sea. However, the core of this water was situated further to the east with respect to phosphate than to silicate.

Both phosphate and silicate often showed well-marked stratification, the lowest values generally occurring in the surface layers. This presumably reflected plankton growth. The vertical distribution of silicate was often more complex than that of phosphate. Moreover, there was no clearly marked increase in the concentration of phosphate at the ice-edge as was often the case with silicate.

No attempt has been made to correlate either phosphate or silicate with the water masses present. It is considered that biological activity had modified the distribution of nutrients to an extent that make identification of water masses by their phosphate or silicate content unreliable.

The complexity in distribution of both phosphate and silicate in the Labrador Sea appears to have been less marked on NORWESTLANT 2 than on NORWESTLANT 1. However, this may be a result of the large gap in the observations between Sections J and G on the former survey. Both nutrients show greater stratification on NORWESTLANT 2 compared with NORWESTLANT 1, and this is presumably a result of greater biological activity during the second survey.

NORWESTLANT 3

Phosphate — 20 m

The main feature of this distribution was a large U-shaped area of water with phosphate values mainly above 0.75 μg atom PO_4-P/l extending from the Labrador Sea, around Cape Farewell into the Irminger Sea. Relatively small areas with values above 1 μg atom PO_4-P/l were situated in the Labrador Sea and in the Irminger Sea. Sections 4, 6, and 7 show that at 100 m the area of water with values above 1 μg atom PO_4-P/l was considerably larger than at 20 m.

The phosphate content of the water fell towards the Greenland coast and reached values below 0.25 μg atom PO_4-P/l off the west coast and off the northeast coast, the lowest values occurring in the surface waters as, for example, on Sections 3 and 10. The vertical sections as a whole show that stratification over the survey area was generally well marked.

A tongue of water extended northwards into the Davis Strait from the region of high phosphate concentration in the Labrador Sea. The tongue was characterized by a relatively high phosphate content with maximal values in the deep water as on Section 12.

The two other main features of the 20 m distribution were the large area of water with values above 0.75 g atom PO -P/l in the western Labrador Sea, and the area of water with values of below 0.5 g atom PO -P/l to the south of Iceland and protruding into the Irminger Sea.

Silicate — 20 m

The area surveyed differed from that for phosphate in that the northern Labrador Sea, the Davis Strait and an area near Cape Farewell were not covered. A U-shaped area of water with a relatively high silicate content extended from the Irminger Sea, around Cape Farewell to beyond the survey limit in the Labrador Sea. At 20 m the highest values were above 7 µg atom SiO_3-Si/l to the south of Cape Farewell. Section 7 shows that this value rose to above 9 µg atom SiO_3-Si/l at 100 m.

All the vertical sections show that stratification of silicate was well developed over most of the survey area. The lowest values at 20 m occurred off the Greenland coast and over a large area to the south of Iceland. The highest value recorded was 15 µg atom SiO_3-Si/l in the Labrador Sea at 75 m on Section 8.

Discussion

The horizontal and vertical distributions of phosphate and silicate were very similar. High concentrations of both nutrients were distributed in a U-shaped area extending from the Irminger Sea into the Labrador Sea. The lowest concentrations of phosphate and silicate occurred in coastal waters and to the south of Iceland. The distribution of the two nutrient salts showed some small differences. At 20 m the highest silicate values occurred in an area to the south of Cape Farewell, whereas the maximum phosphate concentrations of about 1 µg atom PO_4-P/l occurred in both the Labrador Sea and in the Irminger Sea.

As in the case of NORWESTLANT 2, it is considered that plankton growth had influenced the distribution of nutrients in the surface layers to such an extent that a correlation of phosphate and silicate with the water masses present would be unreliable.

The distribution of phosphate and silicate during NORWESTLANT 3 was mainly similar to that of NORWESTLANT 2. However, differences in the areas covered prevent a complete comparison. There were two main differences in the distribution of phosphate at 20 m between the two surveys. On NORWESTLANT 3 the area of water in the Labrador Sea with values above 0.75 µg atom PO_4-P/l was less extensive than on NORWESTLANT 2. Also, the area to the east of the Labrador coast showed values above 0.75 µg atom PO_4-P/l during NORWESTLANT 3, whereas the concentration of phosphate was below 0.25 µg atom PO_4-P/l in the same locality during NORWESTLANT 2. Similarly, the area enclosed by the 7 µg atom SiO_3-Si/l contour in the Labrador Sea was considerably less extensive on NORWESTLANT 3 compared with NORWESTLANT 2. The sparseness of silicate data from off the Labrador coast for NORWESTLANT 3 prevents a reliable comparison with the previous survey. It does appear, however, that silicate values were higher than during NORWESTLANT 2.

NORWESTLANT 3 is comparable in time to the July surveys by Hermann off the west coast of Greenland. The distribution of phosphate in the southern part of the area during NORWESTLANT 3 differed somewhat from Hermann's surveys. The area of water with high phosphate values off the southwest coast became bifurcated towards the north. Hermann found a continuous band of high values running parallel to the coast. Upwelling of the type described by Hermann in the appendix to the section on Physical Oceanography was found in the area on all the NORWESTLANT Surveys, but it was most pronounced on the second and third surveys. Hermann attributes the phenomenon to be a result of turbulence in the subsurface Irminger Current lifting deep water, rich in nutrients, towards the surface. There are no silicate data in this region for NORWESTLANT 3. On NORWESTLANT 2 (*e.g.*, on Section 10) upwelling was common to both phosphate and silicate. It is interesting to note that the phenomenon occurred as a number of tongues across the whole section and was not confined to the coastal region.

The surface distribution of phosphate in the Irminger Sea found by Kalle during June 1955 is basically similar to the 20-m chart for NORWESTLANT 3. Low values were found to the south of Iceland and along the East Greenland coast with a relatively high concentration of phosphate in the central part of the Irminger Sea. Kalle's survey is more comparable in time to NORWESTLANT 2, for which phosphate data in the northern Irminger Sea are missing. The pattern in the southern Irminger Sea on NORWESTLANT 2 is, however, basically similar to both NORWESTLANT 3 and Kalle's survey.

DISSOLVED OXYGEN

NORWESTLANT 1

100 m

At 100 m the dissolved oxygen saturation was near 100% over the whole survey area.

20 m

The main feature of this chart is the high percentage saturation values off the west coast of Greenland in the northern part of the Davis Strait (Sections 11 and 12). Over the remainder of the area there was little difference from the 100-m chart.

NORWESTLANT 2

20 m

In the Irminger Sea most dissolved oxygen values were between 95-110% saturation, except for the inshore stations on Sections 4 and E, where values rose above 120%. Reference to Section 4 shows that these high values were confined to the upper 40 m.

The main feature of interest in the Labrador Sea is the high values off the Labrador coast with the inshore oxygen saturation amounting to 140%. Reference to Sections H, J, and 9 shows that the area of high saturation extended down to as far as approximately 30 m. Two areas of relatively low saturation values occurred in the southern part of the Labrador Sea near the boundary between the North Atlantic Current and the Labrador Current. Other areas of low values were found off the northeast coast of Labrador and off the southwest coast of Greenland. Section 10 shows sharp vertical gradients in the percentage saturation of oxygen extending from the surface to at least 100 m off the northeast coast of Labrador. However, in Section 9, off the southwest coast of Greenland, the saturation contours are very complex and marked horizontal and vertical gradients both occur: on Stations 8 and 9 many values have not been contoured owing to their complexity and the reported values have been inserted at the appropriate depths instead. Off the west coast of Greenland the percentage saturation of oxygen at 20 m was also rather complex, with a wide range of values. All the vertical sections in this region show the high saturation to have been confined to the shallower water.

NORWESTLANT 3

20 m

On this survey the percentage saturation of oxygen at 20 m ranged between 100-115% over most of the area. A small region of saturation above 120% occurred off the East Greenland coast on Section 2 and a value of less than 95% was recorded in the West Labrador Sea. The latter observation was made by USCG *Evergreen* on a non-standard section and does not appear in the vertical sections.

DISCUSSION

The most interesting feature shown by the dissolved oxygen surveys is the high saturation values recorded during NORWESTLANT 2. Fedosov and Andreev (1961) observed oxygen saturation up to 119-125% off the west coast of Greenland during May-June 1958. They attributed the phenomenon to a very high rate of phytoplankton production. Franceschetti (1964) recorded oxygen saturation up to 136% in the surface water of the Kane Basin during July 1963. The high values were thought to have resulted from air trapped in the ice passing into solution as the ice melted. The high saturation observed during NORWESTLANT 2 could have been caused by both mechanisms. High values were often encountered in the vicinity of ice, as, for example, off the south coast of Labrador. A comparison of the general distribution of phosphate and silicate at 20 m on NORWESTLANT 1 and 2 suggests that biological activity was greatest on the second survey. It is therefore reasonable to assume that a high rate of phytoplankton production then had also resulted in high oxygen saturation. The region investigated by Fedosov and Andreev coincides with the area of saturation values above 115% in the Davis Strait centred on 63°N, 55°W. Reference to Chart 76 shows that this water was of relatively high salinity and therefore away from the influence of melting ice. It is therefore probable that here was an example of high oxygen saturation caused by phytoplankton activity. The general absence of high saturation values on NORWESTLANT 3 points to a diminution in the rate of phytoplankton production between the second and third surveys.

The distribution of percentage saturation of oxygen on the three surveys did not give any clear indication of the water masses present. This is to be expected, since in surface waters the exchange of oxygen between the atmosphere and water occurs readily and biological activity is at a maximum.

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Ammonia and Organic Carbon During NORWESTLANT 2

By

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During NORWESTLANT 2 R/V *Anton Dohrn* undertook investigations of the ammonia and of the organic carbon at all hydrographic stations from all depths inside the region from 53° to 63°N lat and from 26° to 43°W long.

The mean vertical distribution of ammonia (Method: Gillbricht, 1961) is given in Fig. 10. Some surface values were extremely high and were not used because they were obviously influenced by the ship. Down to 200 m we have a steady gradient, below this depth there is a more or less constant value. But we must always have in mind that this "ammonia" method, in fact, also determines organic nitrogen compounds (*i.e.* amino acids).

The vertical sections (Chart 177) show a distinct structure only near the polar front on their left hand sides. For the other irregularities it is difficult to decide whether or not these values are real. Such a complicated method is easily disturbed. Again, at the surface we must expect to have a thin film with much more ammonia and so on. Using a bucket we will catch a variable quantity of this film and in this way get a range of values. Therefore it would be better to use a water bottle half a meter or so below the surface instead of taking direct surface samples.

The organic carbon was determined with a simple permanganate method (Gillbricht, 1957). The mean vertical distribution compared with the situation during the International Geophysical Year (IGY) (R/V *Anton Dohrn*, August-September 1958) is given in Fig. 11. While the values near the surface are practically the same in both years the gradient is a steeper one in 1958. This indicates a smaller turbulence during the IGY than during NORWESTLANT 2. This can also be seen by means of the density gradients and of the gradients of phosphate and oxygen.

The vertical sections are given in Chart 178. It is difficult to describe these diagrams because the organic carbon is a relatively stable substance on the one hand but on the other, it is produced by the phytoplankton near the surface (Fig. 11). Because the hydrographic condition was a very confused one, we must expect to find at least the same situation for the organic carbon but complicated for the reasons given above with regard to ammonia.

We can say a little more about organic carbon and ammonia if we investigate the correlations and the multiple correlations between these substances and other measurements (depth, T°, S°/₀₀, phytoplankton, zooplankton) using only samples from the surface to 20-m depth and from one water body. In this way we get three groups of samples:

a) Stations 13 to 18 (except Station 16; surface),
b) Stations 18 to 21 (except Station 21; 10 m),
c) Stations 27 to 32 (except Station 27; surface).

Testing the different possibilities I found that the following solutions best describe the situation:

C = organic carbon	n = number of measurements
N = ammonia nitrogen	r = correlation coefficient
phy = phytoplankton	R = multiple correlation coefficient
S = salinity	

a)	n = 23	C = f(phy)	r = +0.547	$p < 0.05$
b)	n = 15	C = f(N)	r = +0.572	$p < 0.05$
c)	n = 23	C = f(N)	r = +0.456	$p < 0.05$

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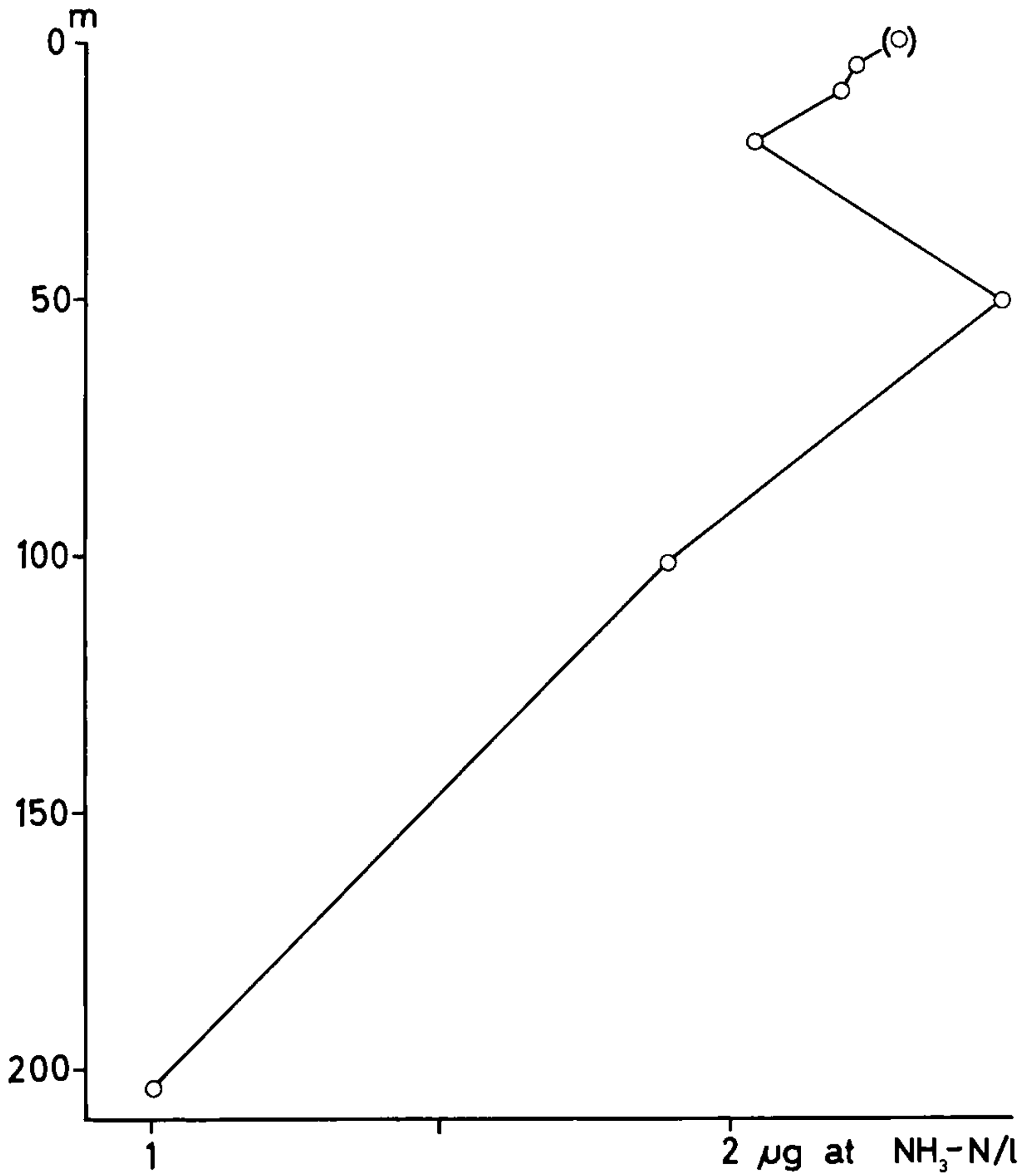

Fig. 10. Mean values of the vertical distribution of the ammonia during NORWESTLANT 2 (R/V *Anton Dohrn*).

a) No correlation between N and any variable,
b) N = f(S, C) R = 0.756 $p < 0.01$
c) N = f(C) r = +0.456 $p < 0.05$

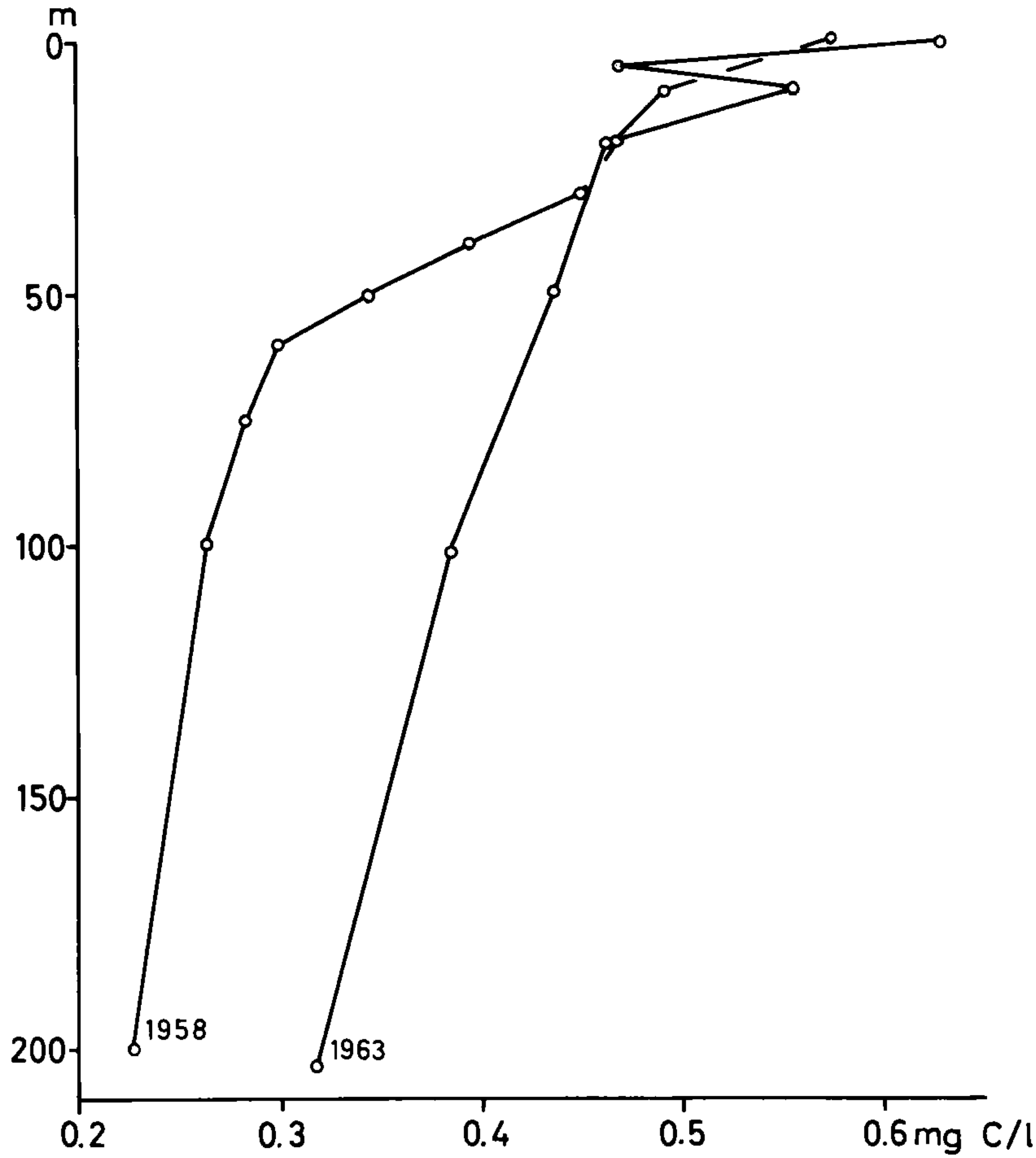

Fig. 11. Mean values of the vertical distribution of organic carbon (permanganate consumption) during IGY 1958 (R/V *Anton Dohrn*) and during NORWESTLANT 2 1963 (R/V *Anton Dohrn*).

Figures 12 and 13 show the connections between the calculated values obtained by means of these correlations and the observed values of organic carbon and ammonia.

For groups (b) and (c) organic carbon is seen to be a function of the ammonia content. Therefore,

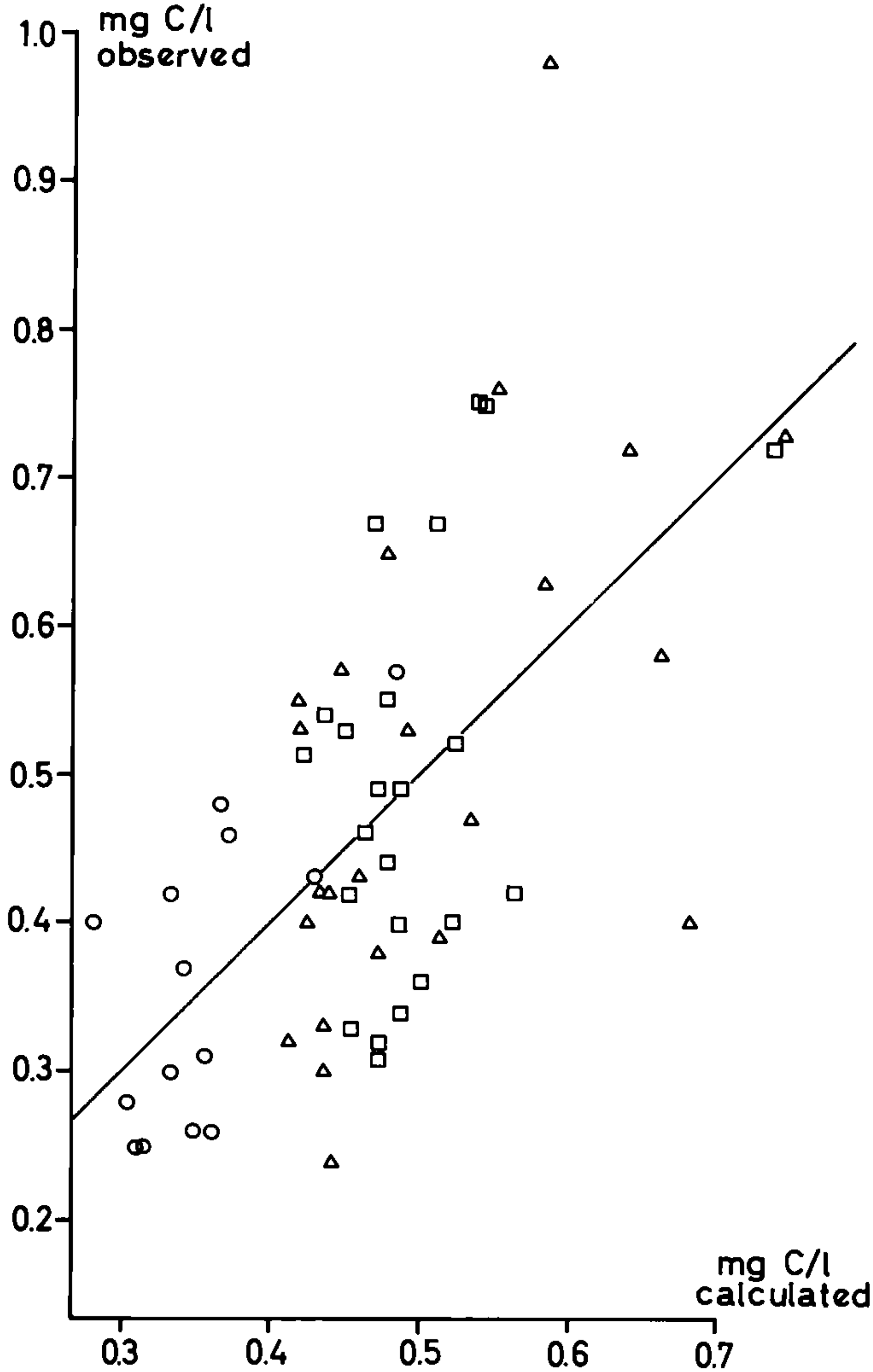

Fig. 12. Organic carbon: Correlation between calculated and observed values (Δ — Stations 13-18; O — Stations 18-21; □ — Stations 27 to 32).

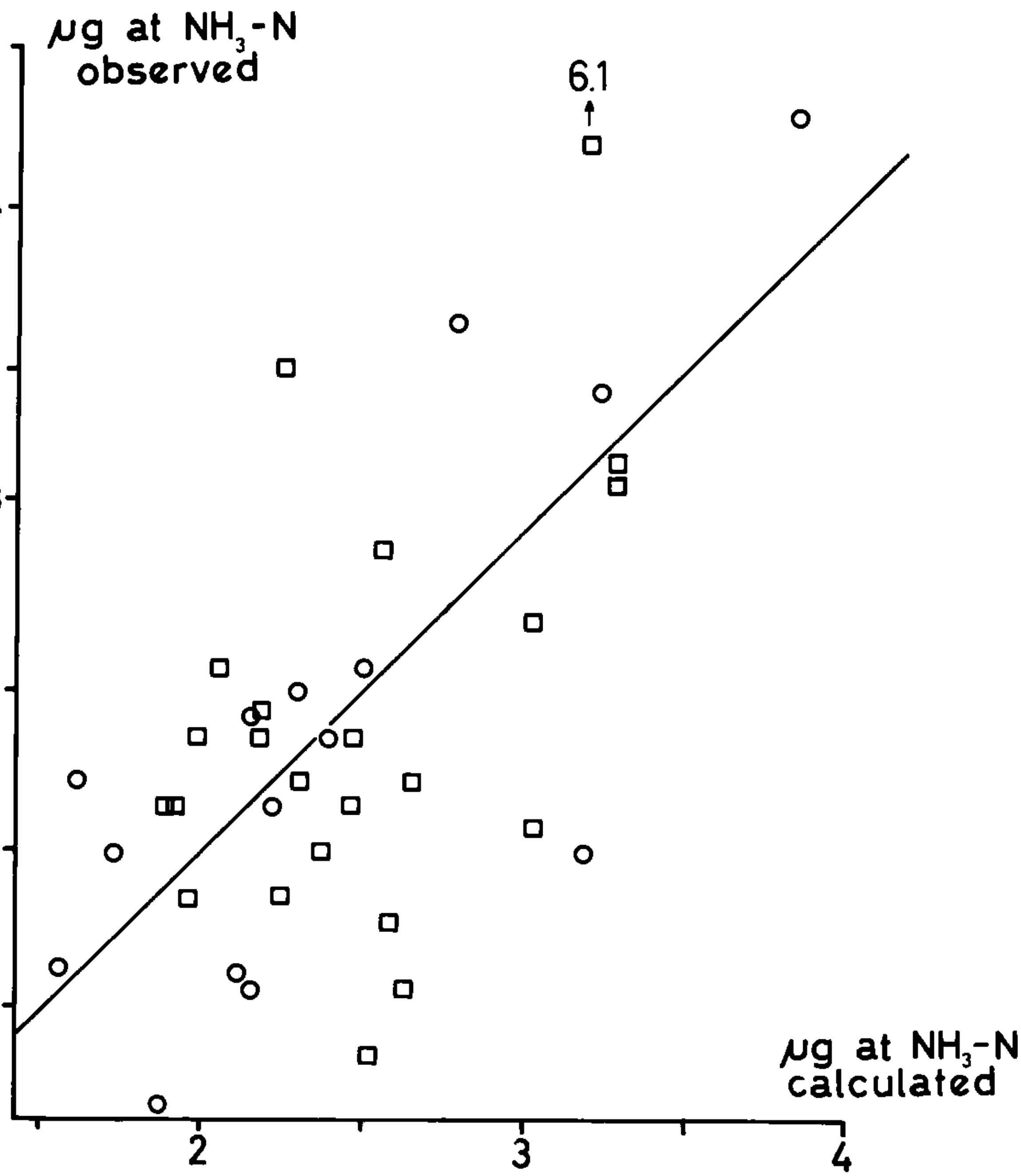

Fig. 13. Ammonia: Correlation between calculated and observed values (Δ — Stations 13-18; O — Stations 18-21; □ — Stations 27-32).

we can investigate what relation exists between ammonia and organic carbon (Fig. 14 A). The three lines

a) $r = +0.342$ $p > 0.05$
b) $r = +0.572$ $p < 0.05$
c) $r = +0.456$ $p < 0.05$

indicate, that the quantity of ammonia which corresponds to 1 mg of organic carbon, is also a

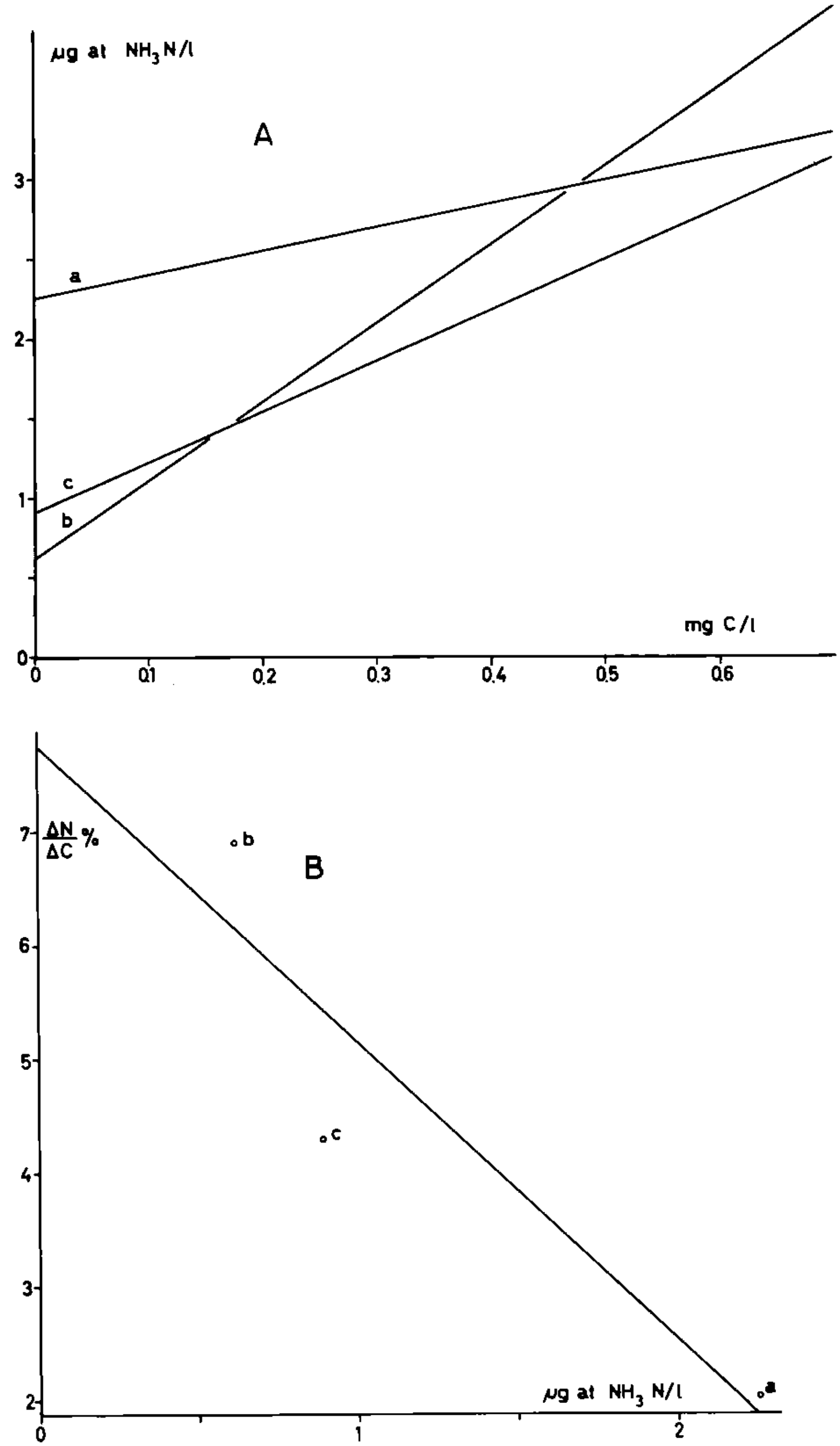

Fig. 14. A: Regression lines between organic carbon and ammonia for different water bodies.

B: Correlation between the ammonia content if there is no organic carbon and the change of ammonia with the organic carbon for different water bodies (for explanation, see text).

function of the ammonia content without any carbon being present. This is easy to understand because the oxidation of ammonia is faster if the quantity is a greater one. This means that the true and highest value can be seen only if we have the situation where no ammonia exists in the absence of organic carbon. In our case (Fig. 14 B) we get the maximum value

$\frac{\Delta N\%}{\Delta C\%} \approx 8\%$, where ΔN is the increase in ammonia for an increase in organic carbon, ΔC, in Fig. 14 A.

Such a calculation has a small accuracy, of course, but we can at least see the range. This value would mean that about 25% of the organic substances given off consist of amino acids and so on (a reasonable quantity), assuming that all ammonia comes out of organic substances. Amino acids would also be determined directly by the ammonia method used.

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The Phytoplankton During NORWESTLANT 1-3

By

M. Gillbricht[1]

OISTRIBUTION OF THE TOTAL PHYTOPLANKTON

During the NORWESTLANT cruises of 1963, water samples for phytoplankton analysis were taken at all stations from 10 m and also at depths to 600 m at selected stations. The volumes of the samples varied from 60 to 250 cc. As 1,573 samples had to be analyzed in a short time, the fast counting method described by Gillbricht (1959*b*) was used. This meant that all the samples could be analyzed by one person and that they were all treated and counted in exactly the same way. Only 20-25 cells per sample were counted and for this reason it is impossible to describe the distribution of the rare forms. The method was designed to give a picture of the seasonal and geographical distribution of the total phytoplankton as µg carbon per litre. As there can be considerable heterogeneity in phytoplankton distribution (Gillbricht, 1962) this information is more reliable when obtained from the analysis of a large number of samples using the fast counting method rather than by analyzing a few samples more thoroughly.

To compare the plankton data with chemical determinations (organic carbon, etc.), the numbers of each species per sample were converted into plankton (plasma) volume (Lohmann, 1908) using one average cell size for each species. However, the cell volumes of individual species may vary within a wide range (diatoms 1,000:1) and different populations of the same species often have different mean volumes. For these reasons the measure of total carbon calculated from cell volume will not be very precise, but it will give a better assessment of the phytoplankton biomass distribution than that given by numbers alone. The conversion factors from plasma volume to dry organic matter (Banse, 1956) and from dry organic matter to carbon (Cushing, *et al.*, 1958) are not so variable and are unlikely to cause any significant errors in the conversion to the final values of total carbon per sample.

The phytoplankton was collected on three surveys, NORWESTLANT 1 in April, NORWESTLANT 2 in May-June, and NORWESTLANT 3 in July. The area under investigation was divided into four regions:

a) NW — North of 60°N, West of 45°W;
b) SW — South of 60°N, West of 45°W;
c) NE — North of 60°N, East of 45°W;
d) SE — South of 60°N, East of 45°W.

There is one point near Cape Farewell common to all four regions. A comparison of the mean values of the total phytoplankton (given as µg carbon per litre) in the surface samples (0 to 20 m) from these four areas is given in Fig. 15. In the waters east of Greenland the phytoplankton increased from April to July while in the waters west of Greenland it decreased, suggesting that the spring maximum had already ended there. The warming of the water in spring started earlier in the waters west of Greenland and the water column was stabilized to allow the beginning of a phytoplankton bloom. The spring phytoplankton outbreak can start as early as March even in high northern latitudes (at least up to the polar circle) if the water column is stable enough. The southern regions showed curves typical of a spring outbreak. The figures obtained for the SW region for NORWESTLANT 2 are probably too high as only a few samples were taken near Cape Farewell then.

Chart 179 shows the intensity of the sampling during the NORWESTLANT cruises in one degree squares. Most samples were taken in the coastal waters of Greenland and Iceland where the greatest heterogeneity was expected. The results were, in fact, very complicated in these regions; to simplify the results so that contour lines could more easily be drawn, the charts were constructed by calculating the mean value of carbon per litre for each one degree square. The necessity for doing this suggests that single samples are not sufficient for drawing distribution charts. The

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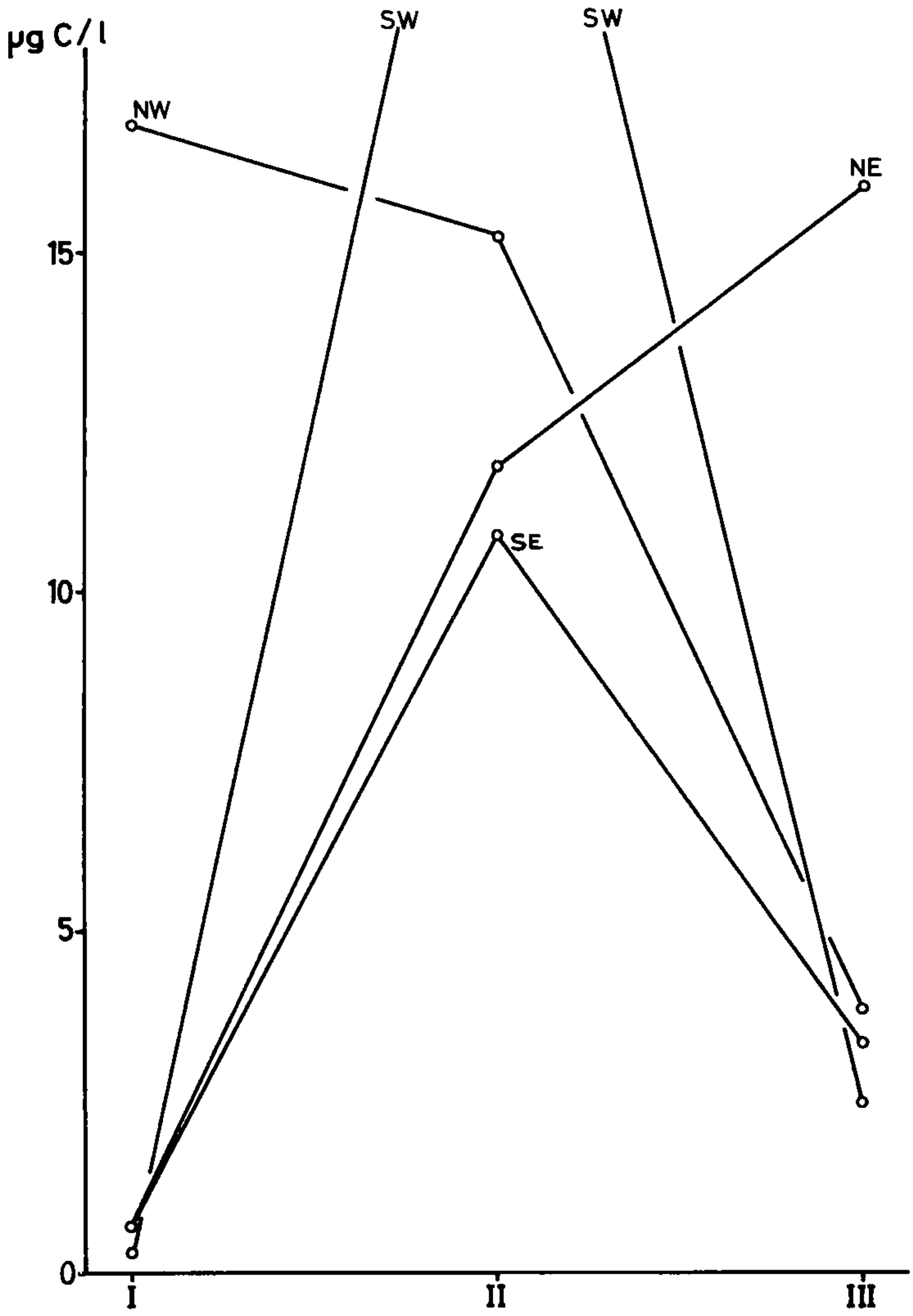

Fig. 15. Graphs showing the mean values of phytoplankton in µg carbon per litre for each area during NORWESTLANT 1-3 (see text).

even distribution in the open sea may be a function of the small number of samples taken there rather than the true distribution. It is not known if the distributions would have been more complicated if more samples had been taken, so that the charts give only a general picture of phytoplankton distribution and cannot be correct in fine detail.

NORWESTLANT 1 (Chart 180)

Phytoplankton was abundant in the coastal waters west of Greenland from the northern boundary of the area investigated (67°N) to Cape Farewell, with a maximum (50 µg carbon/litre) at 64°N.

NORWESTLANT 2 (Chart 181)

There were two areas of maximum production (ca. 50 µg carbon/litre) in the waters west of Greenland at 62°N and 67°N. The isolines are more or less parallel to the coast. In the waters east of Greenland there were three centres with abundant phytoplankton with values up to 100 µg carbon/litre: Greenland coastal waters, Icelandic waters, and to a lesser degree the open sea.

The vertical distribution of phytoplankton for three sections southeast of Greenland has been given for this survey (Chart 182). In the southernmost section (c) there were two areas with rich plankton, one near the coast and the other in the warmer Atlantic water. In the most northern section (a) three centres of high production can be seen, one near Greenland, one in the Irminger Sea, and in Atlantic water. The distribution in the middle section (b) appears to be intermediate.

NORWESTLANT 3 (Chart 183)

There were some weak populations off the west coast of Greenland which appeared to spread out from the shore. Phytoplankton was scarce near the east coast but large numbers had drifted in from the east and the north. The high mean value at this time was caused by an inflow into this area and not the result of growth there.

The general impression of the phytoplankton distribution was of high values in coastal areas, cold polar waters and water of the North Atlantic Drift, but low numbers in the Irminger Sea.

The distribution in 1963 can be compared with earlier observations which are summarized in Table 8.

TABLE 8. Earlier observations taken in the regions of the NORWESTLANT Survey.

Reference	Year	Season	Region	Conclusions
Braarud (1935)	1929	June-August	Denmark Strait	Well defined limits to the distributions of different species (e.g. *Fragilaria oceanica* and *Achnanthes taeniata* near Greenland); phytoplankton development started with the disappearance of the ice-cover; seasonal maximum lasted from the end of June until August; the polar current with *Detonula confervacea* was extremely stable and had a short phytoplankton season (no renewal of nutrients).
Steemann Nielsen (1935)	1899	September	East of Greenland	Much phytoplankton.
	1903	June	West of Iceland	Phytoplankton bloom.
	1932	June	Gulf Stream	Phytoplankton maximum (the maximum was later than May in 1934).
	1932	August	Reykjanes Ridge	Upwelling with much phytoplankton. Normally phytoplankton production is maximal in May and June.

- continued

TABLE 8. (continued)

Reference	Year	Season	Region	Conclusions
Grøntved and Seidenfaden (1938)	1928	May-October	West of Greenland	65°N - 70°W, *Ceratium arcticum*, *Peridinium* spp., *Chaetoceros* spp., *Rhizosolenia hebetata* var. *semispina* were abundant. Southwest of Greenland, *Nitzchia* spp., and *Phaeocystis* were numerous while *Coscinodiscus* spp. were dominant near the Canadian coast.
Holmes (1956)	1950-51	January-December	56°30'N 57°00'W	Two phytoplankton maxima, one in June and the other in September. Only a small number of species (*Fragilaria nana*, *Corethron hystrix*, *Rhizosolenia hebetata* var. *semispina*, *Glenodinium* sp., *Gymnodinium* sp., *Goniaulax* sp. and *Bodo marina*).
Steeman Nielsen (1958)	1954	July-August	Greenland	Highest production at the boundaries of the currents; maxima east of the East Greenland Current, in the coastal waters west of Greenland up to 67°N and in the centre of the Davis Strait (similar results in 1955, 1956 and 1957).
Fraser (1959)	1957	Spring	Near Iceland	Vernal bloom later than April-May.
Gillbricht (19[illegible])	1955	June	Irminger Sea	Much phytoplankton east of Greenland (*Phaeocystis*, *Rhizosolenia*, *Chaetoceros*); the spring maximum had finished near the Reykjanes Ridge.
Thordardóttir	1958	May-June	Northwest of Iceland	High production.
Steemann Nielsen and Hansen (1961)	1958	July	West Greenland	More phytoplankton than normal; more chlorophyll than 1957 especially.
Hansen (1961)	1954-58	Summer	West of the Reykjanes Ridge	Low production.
	1954-58	Summer	East Greenland	High production always at the boundary of the East Greenland Current and the Irminger Current.
	1954	Summer	Reykjanes Ridge	Similar production to 1957. Two to three times production found in 1955 and 1956.
Gillbricht (1961)	1958	March-April	Irminger Sea	Low values.
	1958	August-September	Irminger Sea	High numbers near East Greenland; medium numbers in the central part.
Thordardóttir (unpublished)	1959-62	May	West and northwest of Iceland	Highest productivity in 1960. Low production near the ice border.
	1959-61 1963-64	June	West and northwest of Iceland	Higher production in June 1959 and 1961 than May while values were already low in 1963 and 1964.

- continued

TABLE 8. (continued)

Reference	Year	Season	Region	Conclusions
	1961	July	West and northwest of Iceland	Production much lower than in preceding two months.
	1961 1963	September	West and northwest of Iceland	Similar production as found in July.

Generally, the previous investigations confirm the distributions observed during the NORWESTLANT Surveys, except that there is no information about the early spring outbreak of phytoplankton in the waters west of Greenland. It is especially interesting to note that there can be great differences in plankton production from year to year. It is important to know whether the production in 1963 was high, normal, or low, compared with observations made in other years. The stability of the water column, one of the fundamental factors influencing the growth of phytoplankton, was unusually low in 1963 (Table 9).

TABLE 9. Production in the Irminger Sea.

	R/V *Anton Dohrn*[a]		NORWESTLANT (NE Region)	
	1955	1958	1963	1963
	June	August-September	May-June	July
Phytoplankton (µg C/l)	38	15	13	16

[a] Gillbricht, 1959*a*, 1961.

Plankton values and stability were both low in 1963 compared with 1955. A comparison with 1958 is difficult because the samples were taken later in the year than NORWESTLANT 3, but as the phytoplankton maximum is usually over before August, it is probable that numbers were higher in 1958 than 1963.

SPECIES DISTRIBUTIONS

The hydrographic situation in 1963 was very complicated and is reflected in the distributions of individual species which were not well-defined. The abundance and composition of the phytoplankton differed from station to station making it very difficult to draw distribution charts.

NORWESTLANT 1 (Chart 184)

Diatoms (*Chaetoceros* spp. and *Thalassiosira* spp.) were abundant in the waters west of Greenland. *Phaeocystis* sp. was present in the extreme north.

NORWESTLANT 2 (Chart 185)

Diatoms and *Phaeocystis* spp. were still present west of Greenland and there was also a small zone of *Fragilaria oceanica* and similar forms (*Achnanthes taeniata*) around Greenland. *Nitzchia* spp. and other pennate diatoms were found over a large area of the Irminger Sea and there was a region where *Gymnodinium* spp. and other flagellates were dominant. *Rhizosolenia* spp. and *Chaetoceros* spp. were also present in the coastal waters of Greenland and *Skeletonema costatum* and *Asterionella japonica* near the coast of Iceland.

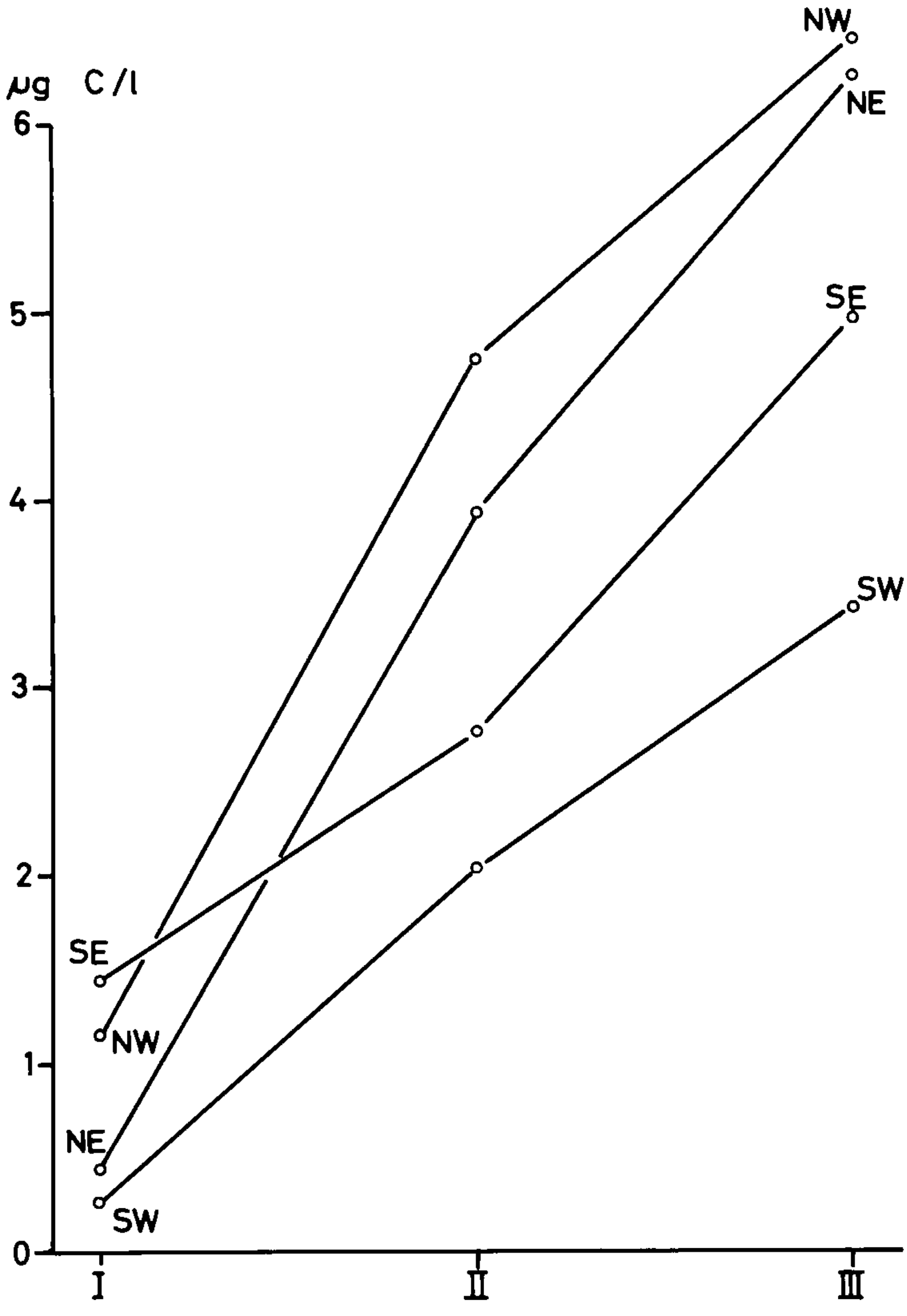

Fig. 16. Graphs showing the values of zooplankton in µg carbon per litre for each area during NORWESTLANT 1-3 (see text).

NORWESTLANT 3 (Chart 186)

Gymnodinium spp. and other flagellates were found in the waters west of Greenland and also associated with *Chaetoceros* spp. and *Nitzchia* spp. in the Irminger Sea near Greenland. The high numbers found northwest of Iceland consisted of *Chaetoceros* spp., *Nitzchia* spp., and other pennate diatoms.

SMALL ZOOPLANKTON

The distribution of the members of the zooplankton caught with the water bottle is summarized in Fig. 16. The counts have been transformed into µg carbon per litre. They consisted of species or forms not usually caught in net samples (ciliates, etc.) and their distributions might be related more to the phytoplankton rather than the larger animals. It may be that different size ranges of zooplankton have different geographical distributions. The results are given for the four main regions and these all showed a steady increase in microzooplankton during the NORWESTLANT Surveys. The development was much slower than that of the phytoplankton and it seems unlikely that there is a direct relationship between the two. Growth was faster in the northern regions and this might be associated with more phytoplankton and a lower respiratory rate because of the lower temperature. However, numbers of small zooplankton in the northwest region did not increase earlier than the other regions in spite of the earlier spring outbreak of phytoplankton there. This may have been because the water was too cold at that time.

ORGANIC PARTICLES

Besides the plankton, organic particles were abundant in most samples. These particles were probably derived from decomposed plankton and naked nannoplanktonic forms which are usually destroyed during fixation. They must surely form a source of food for many small animals so that some assessment of their biomass should be of ecological interest. The counts have been converted into µg carbon per litre and the results are presented for the four main areas (Fig. 17). Values were higher for the eastern regions, especially during NORWESTLANT 2. The significance of these distributions is not understood.

VERTICAL DISTRIBUTIONS

The mean vertical distribution of the phytoplankton, the zooplankton, and the organic particles during the three surveys showed the expected logarithmic decrease from the surface to 100 m (Table 10).

TABLE 10. Changes in distribution of phytoplankton, zooplankton, and organic particles with depth.

	Decrease in % per metre depth	
	North of 60°N	South of 60°N
Phytoplankton	3.4	2.1
Zooplankton	2.1	1.5
Organic particles	2.0	1.2

The gradient was steeper in the north compared with the south and there were different vertical gradients for the three components indicating possibly different rates of sinking and decomposition. The distribution of the microzooplankton was correlated more with the organic particles than the phytoplankton.

The three components may also be compared by means of selected surface sections.

NORWESTLANT 1 (Fig. 18)

The phytoplankton distribution was similar to that shown in Chart 180, *i.e.* abundant in the coastal waters west of Greenland. The zooplankton was usually less abundant that the phytoplankton while the organic particles were particularly numerous in the south and east.

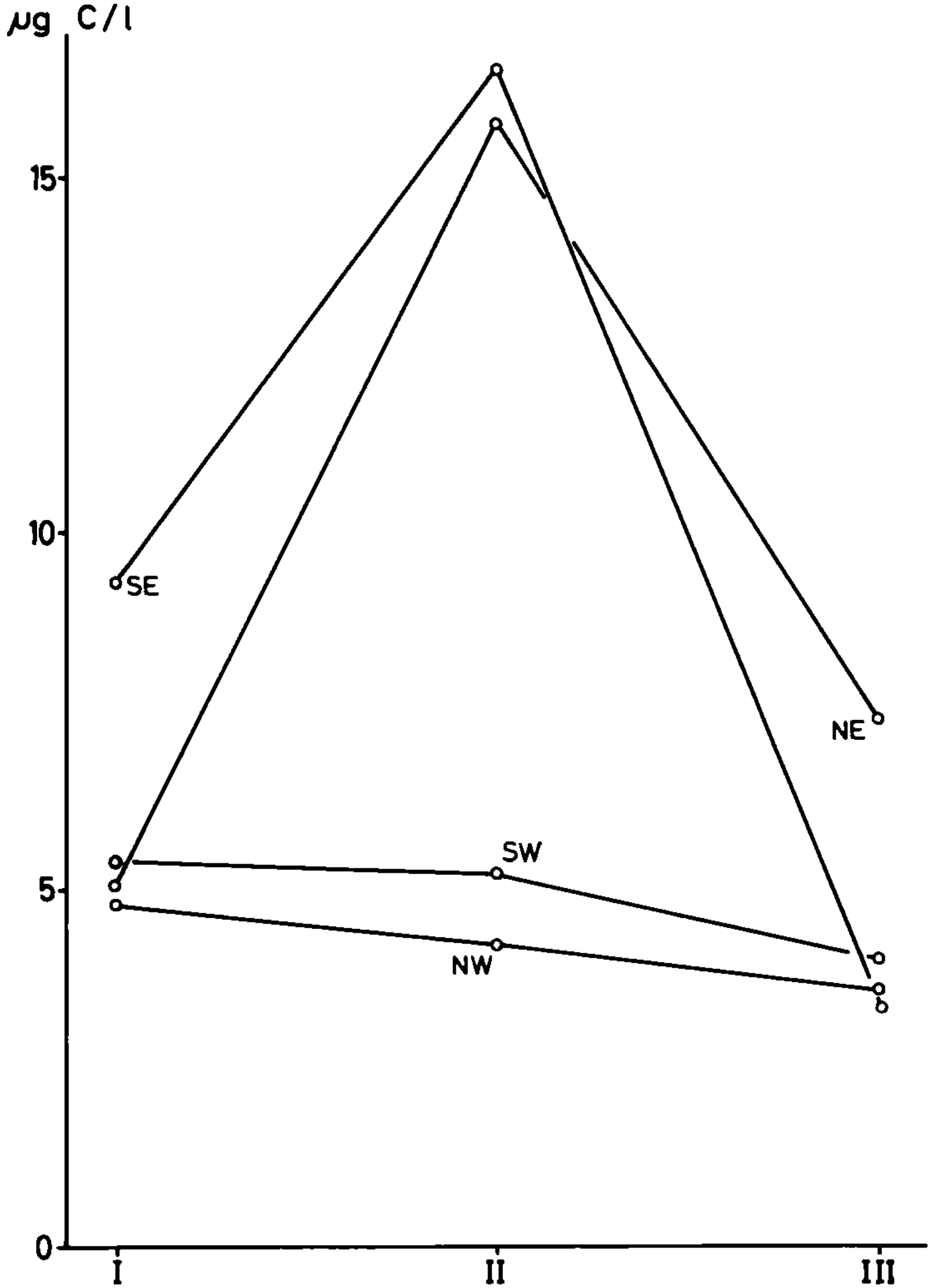

Fig. 17. Graphs showing the values of organic particles in µg carbon per litre for each area during NORWESTLANT 1-3 (see text).

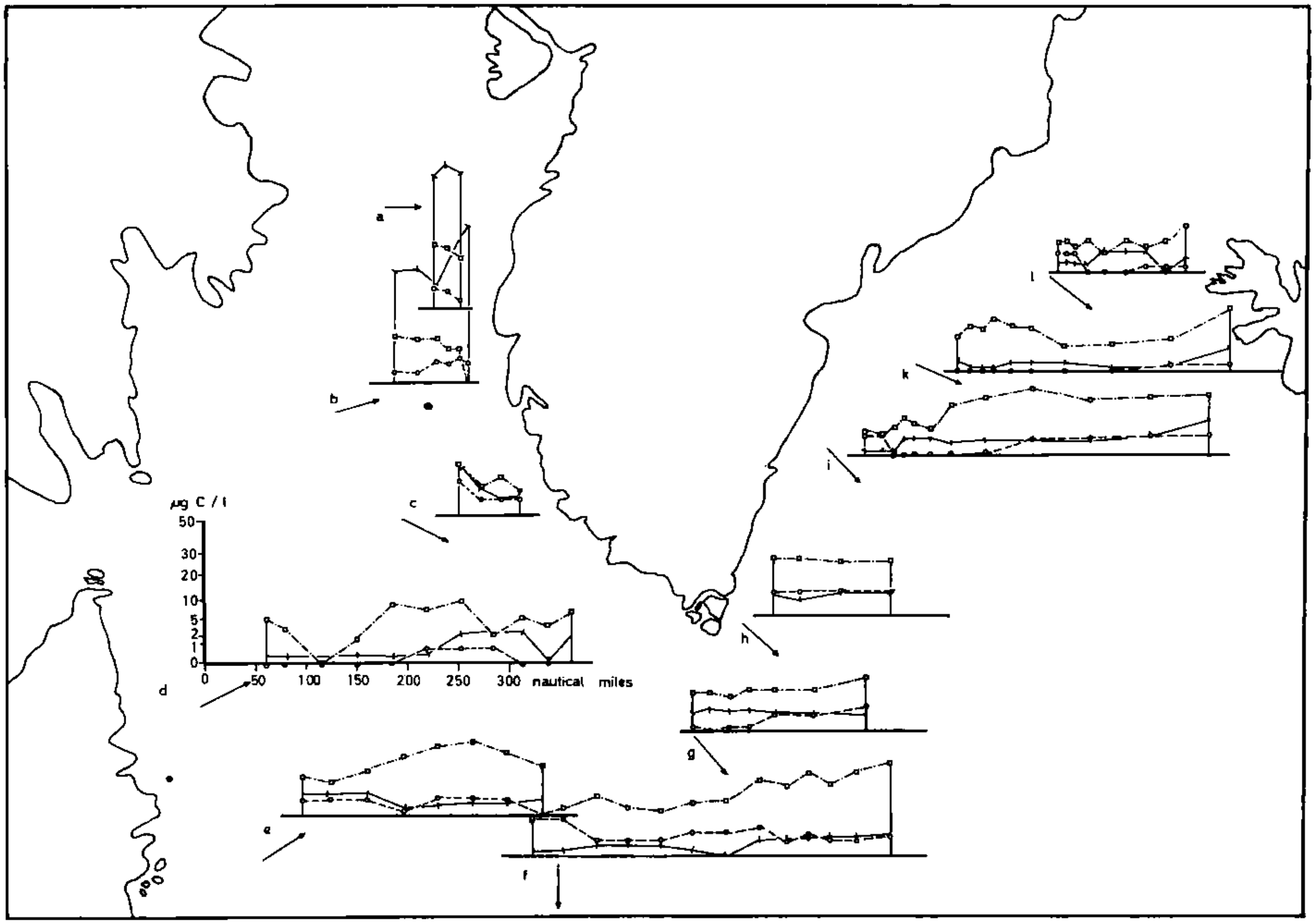

Fig. 18. Graphs showing the surface distributions in µg carbon per litre (0 to 20 m mean value) of phytoplankton ———, zooplankton -----, and organic particles -.-.-, in selected sections sampled during NORWESTLANT 1.
The arrows indicate the directions of the sections. The abscissa is given in nautical miles and the scale of the ordinate has been shortened by using the square root of the phytoplankton values, which were obtained by taking three-station running means.

NORWESTLANT 2 (Fig. 19)

The phytoplankton was richer in the coastal waters of Greenland with values decreasing towards the open sea and then increasing again in the Atlantic water. Zooplankton and organic particles were more numerous than during NORWESTLANT 1. Sections g, h, and i, were also given in Chart 182 respectively.

NORWESTLANT 3 (Fig. 20)

In some of the area (sections g, i, and k) the biomass of phytoplankton, microzooplankton, and organic particles was similar, but west of Greenland the zooplankton was now more abundant than the phytoplankton, probably indicating the end of the phytoplankton bloom there.

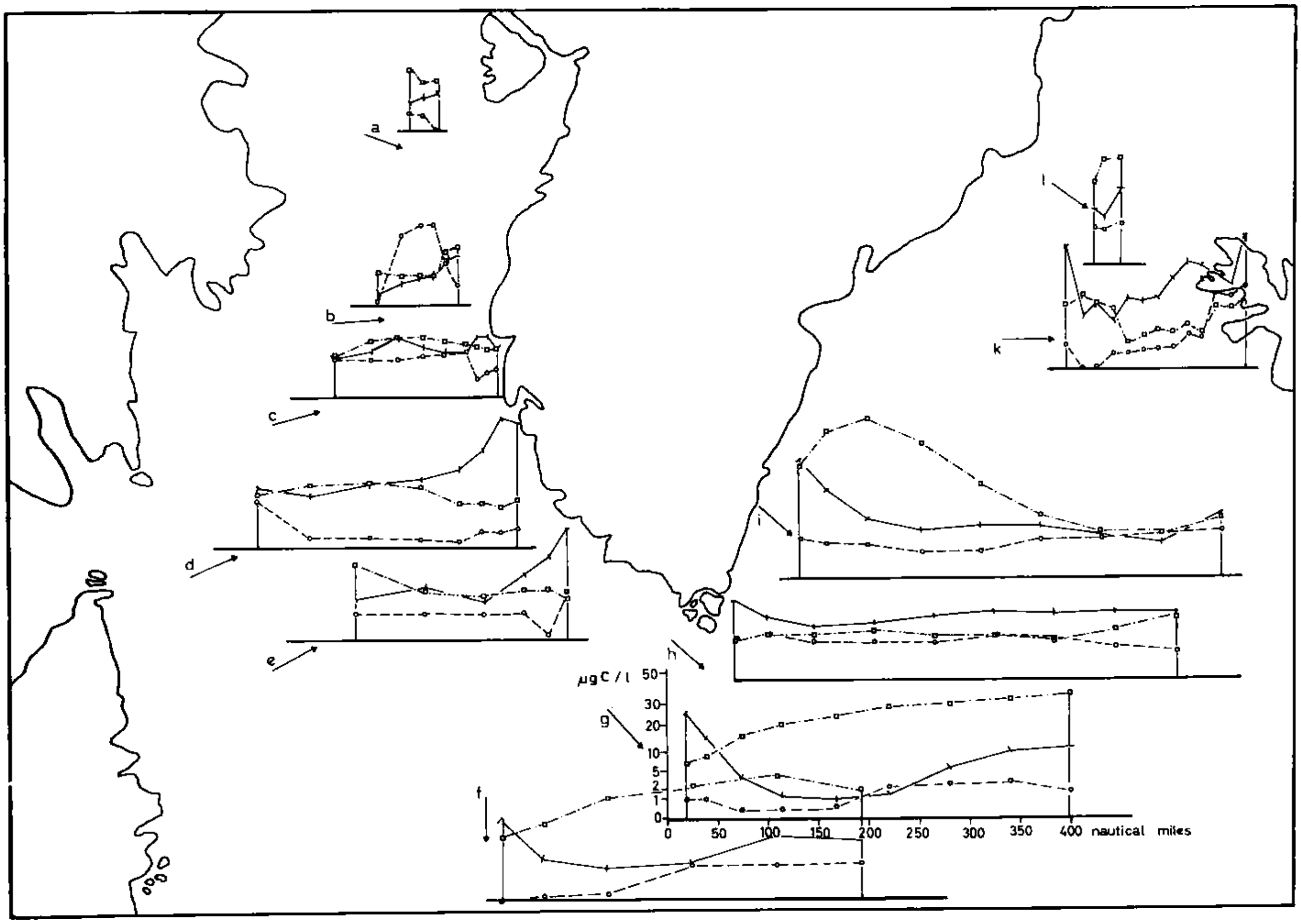

Fig. 19. Graphs showing the surface distributions in µg carbon per litre of the phytoplankton, zooplankton, and organic particles, in selected sections sampled during NORWESTLANT 2. For further details see Fig. 18.

SUMMARY

1) The distribution of the total phytoplankton (as µg carbon per litre) showed that production started earlier in the coastal waters west of Greenland than elsewhere. Generally, high values were obtained in coastal areas, cold polar waters, and water of the North Atlantic Drift but low values in the Irminger Sea. The distribution in 1963 is compared with earlier observations.

2) The distributions of the individual species were complicated and not well-defined.

3) The distribution of the small zooplankton caught by water bottles did not show any direct relationship with the phytoplankton distribution.

4) Organic particles were abundant, especially in the eastern parts of the survey.

ACKNOWLEDGEMENTS

The author would particularly like to acknowledge the help of K. Banse (USA), G. Berge (Norway), A. S. Bursa (Canada), J. H. Fraser (UK), E. H. Grainger (Canada), G. A. Robinson (UK), J. H. Steele (UK), E. Steemann Nielsen (Denmark), and T. Thordardóttir (Iceland), in the preparation of this paper.

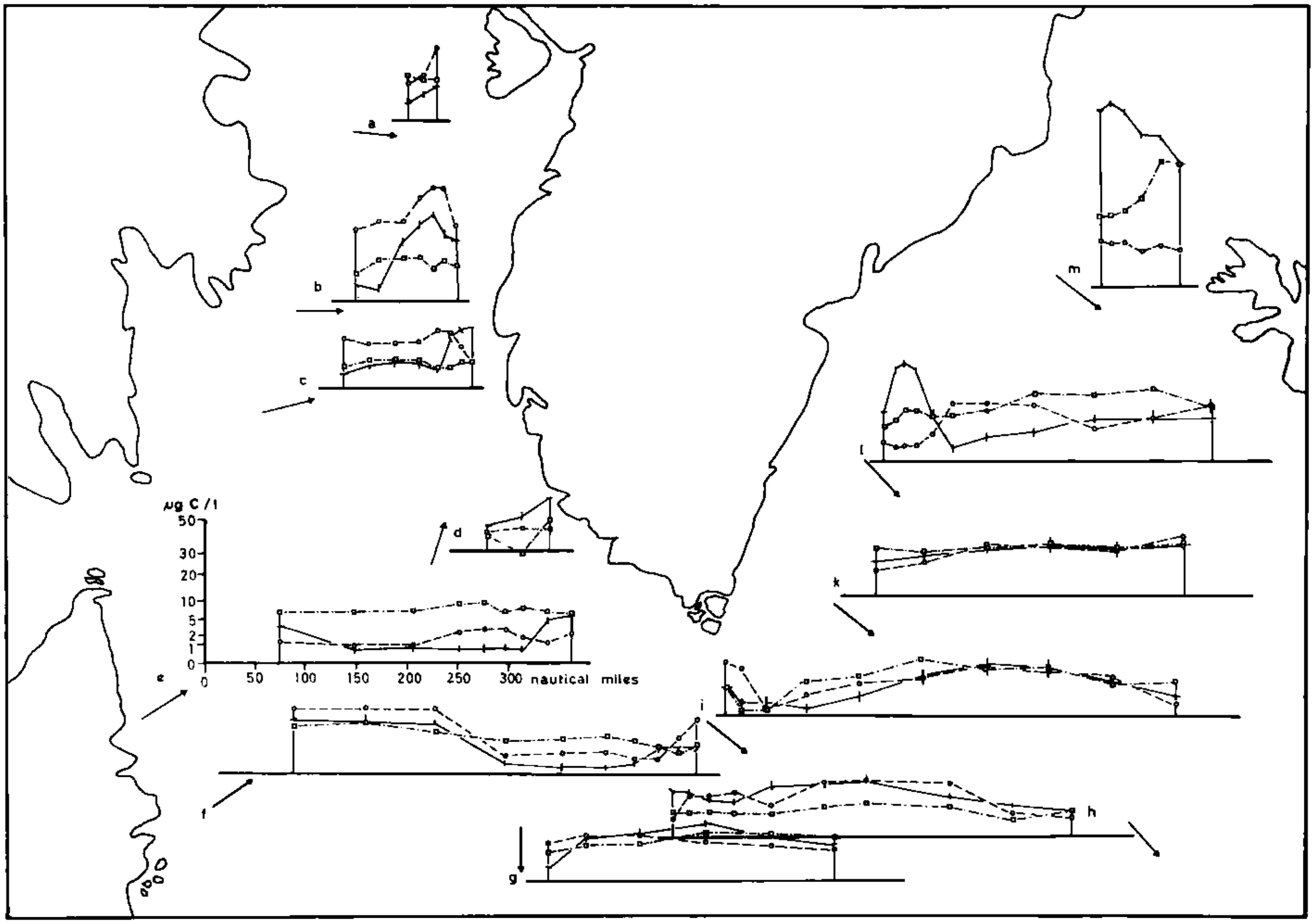

Fig. 20. Graphs showing the surface distributions in µg carbon per litre of the phytoplankton, zooplankton, and organic particles, in selected stations during NORWESTLANT 3. For further details see Fig. 18.

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Chlorophyll *a* Distributions

By

J.H. Steele[1]

During the NORWESTLANT cruises estimates of chlorophyll *a* concentration at 10 m were made by Canada, Denmark, Germany, and UK. The German and UK material was analyzed in the Marine Laboratory, Aberdeen, and I am grateful to Dr Gillbricht, Mr Corlett, Mr Lee, and Dr Johnston for collecting the samples. The Canadian and Danish data were collected and analyzed by Dr Pearre and Dr Vagn Hansen respectively who have kindly provided their results for this summary.

Except for Denmark the plant pigments were extracted in 90% acetone. For the samples analyzed in Aberdeen the chlorophyll *a* was estimated using the factor:

$$E663 = 89 \text{ l/g cm (SCOR-UNESCO, 1964).}$$

The Canadian samples were treated ultrasonically and the factor was:

$$E665 = 89 \text{ l/g cm (Parsons and Strickland, 1963).}$$

The Danish material was extracted in methanol with ultrasonic treatment. The conversion factor was:

$$E665 = 86 \text{ l/g cm (Laessøe and Hansen, 1961).}$$

Since the data are used only to indicate broad regional and seasonal changes, the differences in methods should not be significant.

On NORWESTLANT 1 samples were collected by the R/V *Ernest Holt* to the southeast of Greenland. The values were all low, within the range 0.07-0.59 µg/l, indicating that no significant phytoplankton growth was occurring. For this reason the data have not been charted. The results for NORWESTLANT 2 and 3 are shown in Charts 187 and 188. Roughly, concentrations less than 1.0 µg/l indicate negligible phytoplankton growth, 1.0-3.0 µg/l slight to moderate growth, and greater than 3.0 µg/l "bloom" conditions.

During NORWESTLANT 2, although there is some production over nearly all the area surveyed, the main region of growth is near Greenland. A comparison with the hydrographic data show that this latter area corresponds to the East Greenland Current with its fresher surface layer, higher stability and lower phosphate concentration. In particular, the westward spread of high chlorophyll *a* concentration on the west side of Greenland corresponds to the hydrographic features in this area.

On NORWESTLANT 3 the general level of chlorophyll *a* concentration has decreased. In particular, although the strip off East Greenland has slightly higher values than the offshore waters, the bloom appears to have ended. The only rich areas are found in small patches inshore and in the extreme northeast.

This summary supplements the more detailed survey of the phytoplankton by Dr Gillbricht and shows that the same general features are distinguishable in the chlorophyll *a* data.

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On Primary Production in the Northwest Atlantic[1]

By

M.V. Fedosov[2] and I.A. Ermachenko[2]

Most commercial sea organisms represent heterotrophs, *i.e.* organisms needing organic nutrition for their existence. Two organic substances serve as the sources of organic nutrition in sea water:

1) Organic material formed by phytoplankton in the process of photosynthesis and the assimilation of mineral biogenic substances;
2) Organic material provided from continents, remainders of animal and vegetable organisms on the land.

The first source of primary organic nutrition exceeds the second in quantity. In coastal areas, however, organic substance brought from the land can somewhat increase its amount in sea water. A fair number of organic substances can be accumulated in the photic layer of the sea water masses adjacent to the land, and their concentration in a unit volume of sea water usually appears to be the highest here; it has a positive meaning in trophic relations in the sea.

Investigations carried out in 1963 on the Soviet R/V *Academician Knipovich* and *Topseda* reveal the influence of hydrochemical and thermal factors on the intensity of photosynthetic process. Examinations of the intensity of the formation of phytoplankton organic material were made in April and July in the Labrador Sea and the adjacent areas of the northwestern part of the Atlantic Ocean. The period from the time of field work to the present moment being short, we use only a part of the material collected. This, however, permits us to consider the chemical base of the productivity investigated.

Observations on temperature permitted the determination of its influence upon the biochemical processes characteristic of sea water. To examine these, observations on the content of dissolved oxygen in sea water were made. The data on changes in the dissolved oxygen content during a day in the photic layer, which characterize the intensity of biological processes in the upper layers of the sea, proved to be especially valuable. The phosphorous and silicon contents of the sea water were determined, and changes in P and Si from April to July were recorded. Observations made on the biochemical consumption of oxygen permit the assessment of the character and quantity of organic material.

Numerous analyses of the content of biogenic elements allowed us to work out new characteristics of the waters investigated and supplement estimations on their primary productivity.

Over-oxygenation of the sea water in the process of photosynthesis permits the definition of regions with various degrees of phytoplankton vegetation during the investigations. The process of over-oxygenation of water above 100% begins in spring and coincides with the time phytoplankton began blooming. This well-known fact allows us to judge the time and intensity of the photosynthetic activity of phytoplankton. However, to the result of the analyses it is necessary to introduce corresponding corrections for possible over-oxygenation of the water masses on account of rapid warming of the sea.

The investigations and estimations made suggested a sub-division of the investigated waters into regions (Fig. 21) according to the magnitude of the photosynthesis of organic material, the primary nutrition for heterotrophs. On the basis of the over-oxygenation rate of the subsurface sea water column, the thickness of the photic "productive" layer was determined. The value of the surplus

[1] This paper was originally submitted to the ICNAF Symposium, "The Influence of the Environment on the Principal Groundfish Stocks in the North Atlantic", held in Rome, 27 January-1 February 1964. It is published here rather than in *Spec. Publ. int. Comm. Northw. Atlant. Fish.*, No. 6, as it deals with primary production during the NORWESTLANT Surveys.

[2] All-Union Research Institute of Marine Fisheries and Oceanography, VNIRO, Moscow, USSR.

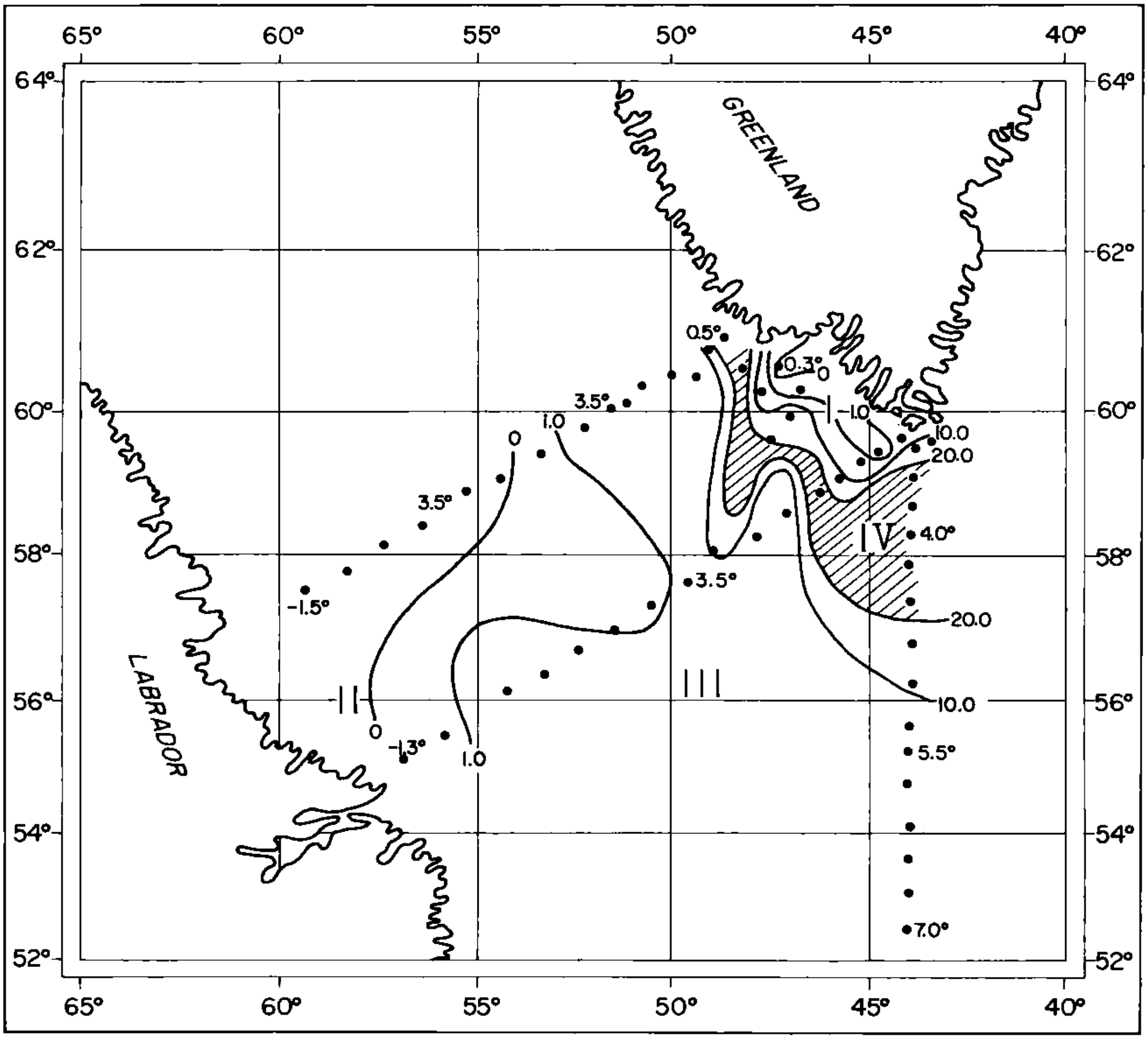

Fig. 21. The Labrador Sea. Four regions with different intensities of photosynthetical formation of new organic matter in April 1963. Contours show excess of dissolved oxygen in the photic layer as litres/m^2. Typical temperatures are given.

of oxygen in the photic layer characterizing the rate of the intensity of photosynthesis and expressed in litres of oxygen under a square meter of water surface, was taken as the basis for the division into regions of the water masses investigated in April 1963 (Fig. 21). The results of the analysis of the data on the daily increase of oxygen and the biochemical consumption of oxygen confirmed the reliability of this method of division. Mean values of water temperature characteristic of the photic layer in each region are shown in Fig. 21. Within the areas with low water temperatures off Labrador (Region II) and the southwest coast of Greenland (Region I), effective photosynthesis was nil or very small.

The highest photosynthetic over-oxygenation (more than 20 l O_2/m_2) was observed in waters of Region IV located to the south and southwest of Greenland (Fig. 21), the temperature of the water being 3.5° to 4°C. The areas over-oxygenated more than 20 l O_2/m_2 represent the areas with the

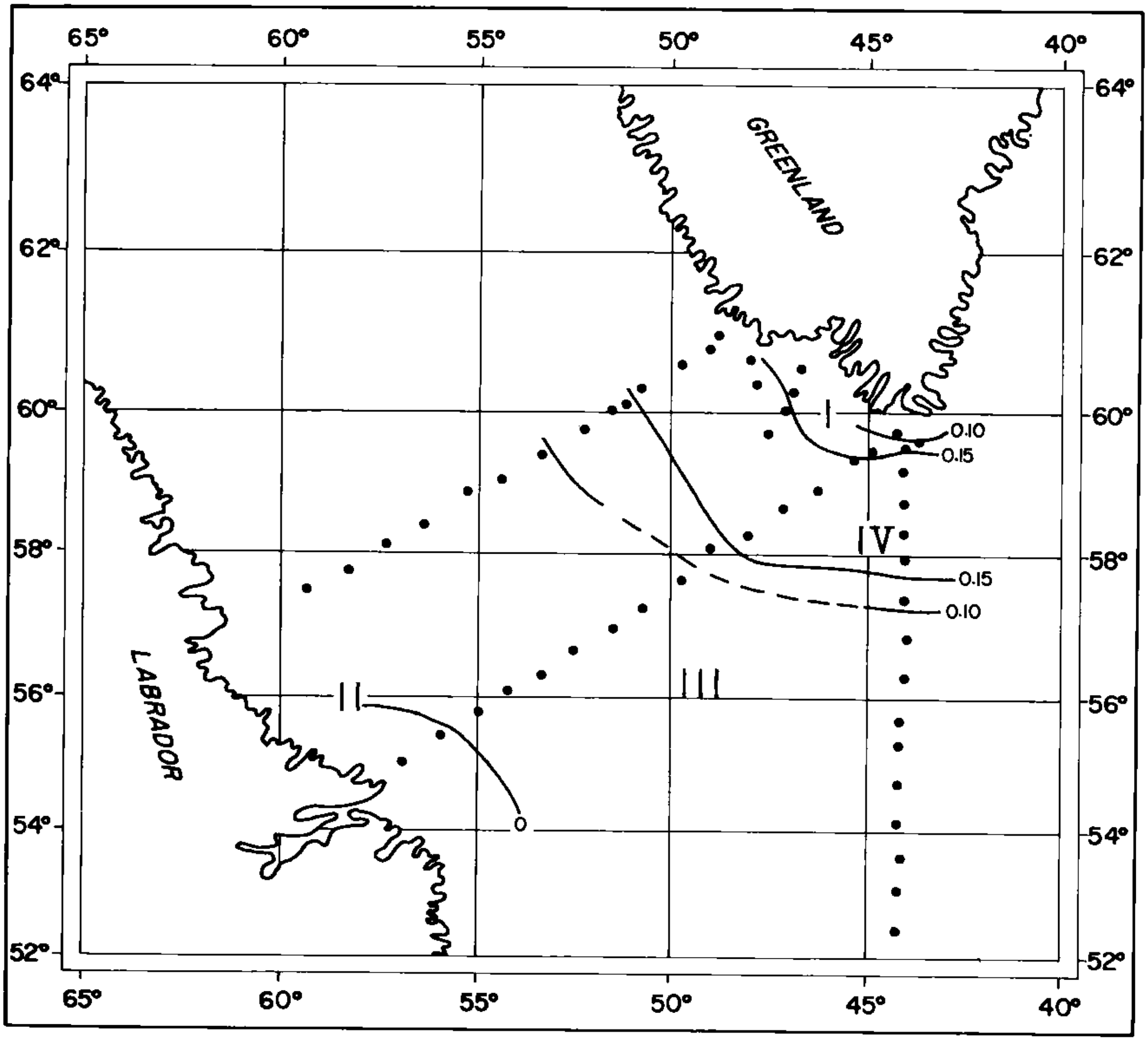

Fig. 22. The Labrador Sea. Values of daily production of vegetable organic matter in mg per day in April 1963. Regions mentioned in the text are shown.

highest daily intensity of photosynthesis registered on the basis of daily changes of dissolved oxygen content in the photic layer of the sea.

The value of oxygen surplus under a square meter indicates the amount of photosynthesis during the whole period from the beginning of growth until the time of its observation. The daily fluctuations in the content of oxygen in the photic layer of sea water shows directly the amount of synthesis of organic matter during the period of the observations. The results confirm the division of the area into regions.

Four regions of the waters investigated were clearly distinguished in April 1963: the Labrador region (Region II), the central part of the Labrador Sea (Region III), the region along the southwestern coast of Greenland (Region I), and an area between Regions I and II to the south of Cape Farewell (Region IV, Fig. 22).

Observations made on the intensity of biochemical consumption of oxygen as a result of oxidation of dissolved organic matter provided additional characteristics of the primary production of the water masses in different regions of the investigated part of the Northwest Atlantic Ocean. The intensity varies from place to place depending upon the distribution of the most recently formed organic material. The investigations on the intensity of biochemical consumption of oxygen in the upper layers of sea water masses made by R/V *Academician Knipovich* confirm the diagram of organic matter distribution (Figs. 21, 22) in the area surveyed.

Table 11 shows the results of these experiments. In southern waters (Region IV) this process is noted as being very intensive even in April. In areas with cold waters (Regions I and II) the process of biochemical consumption of oxygen was quite small in April 1963. As in May 1958 (Fedosov and Andreev, 1961) biochemical consumption of oxygen in the lower layers of the waters in the Labrador Sea at the depth of 120-130 m was 0.002-0.004 ml O_2/l for 24 hr. In July 1963 newly-formed organic matter was subjected to consumption and dissociation and gave rise to a higher consumption of oxygen. In July this process did not increase in the southern region (Region IV), on the contrary it became somewhat slower. When biological spring starts off the Labrador coast and the southwestern coast of Greenland, the increasing intensity of biochemical oxidation of organic material indicates its increasing formation as well.

TABLE 11. Average daily biochemical consumption of oxygen (ml O_2/l) in April and July 1963 (t° of thermostat 5° to 6°C).

Regions	Depth (m)	April Average from 2-3 experiments	July Average from 2-3 experiments
South of Greenland (Region I)	0	0.020	0.087
	50	0.011	0.055
	120	0.008	0.040
The Labrador area (Region II)	0	0.012	0.109
	50	0.014	0.089
	300	0.004	0.004
South of Cape Farewell (Region IV)	0	0.039	0.039
	50	0.084	0.039
	500		0.010

During the growing period effective photosynthesis occurs. At that time the new formation of organic matter exceeds its biochemical oxidation in the process of consumption and dissociation.

In connection with it a more intensive consumption and assimilation of biogenic mineral substances occurs. A decrease of biogenic mineral substances in the photic productive layer compared with their amount in the lower layers of the water is observed within the photic layer of the sea. Analysis of the data obtained by the expedition allowed us to obtain the following picture of the distribution of the characteristics of this process.

The most intensive consumption and assimilation of phosphates and monosilicates were observed in the southeast of the area investigated (Regions III and IV).

A very intensive consumption of biogenic mineral substances in the process of formation of phytoplankton organic matter, however, occurs even in a less powerful photic layer off the southwestern coast of Greenland.

Changes in the amounts of phosphates and monosilicates (both in the surface photic and the lower active layers) indicate the rate of photosynthesis in the water. The mean values of the content of phosphates and monosilicates in corresponding layers were estimated for every month by regions.

Approximately 1,000 analyses were made during NORWESTLANT 1-3. Consideration of the data shown in Table 12 suggests the following conclusions in addition to those stated earlier.

In April almost absolute homogeneity in the quantity of phosphates and monosilicates (to some extent) was registered in the photic and lower layers of the water masses off the Labrador coast and in the central part of the Labrador Sea.

The difference in quantity of phosphate observed between two layers (off the southwestern coast of Greenland and south of Cape Farewell) amounted to 0.16-0.19 µg-at P/l. The difference was caused by assimilation during the process of photosynthesis which was going on in the photic layer.

In April the decrease of monosilicates in the photic layer in comparison with the lower layer averaged 1.8 µg-at Si/l in all regions.

During the second period (July) of the investigations, the decrease of phosphates in the photic layer caused by their photosynthetical assimilation reached 0.42 µg-at P/l (0.32-0.48 µg-at P/l). Changes in the amount of phosphates in the lower layers of water did not exceed 0.06 µg-at P/l from April to July. Taking into consideration the above changes in assimilation of phosphates in the photic layer of all the regions is assumed to have increased by 0.32-0.36 µg-at P/l during the above period. By July, assimilation of phosphates had reached its peak in two regions: the Labrador coast, 0.36 µg-at P/l; the central part of the Labrador Sea, 0.42 µg-at P/l, where it was insignificant in April (0.03 µg-at P/l).

TABLE 12. Change in quantity of phosphates and silicates in the photic layer caused by their assimilation.

Water layer	Depth (m)	P(µg-at /l) April	P July	P April to July	P Lower and photic layers April	P Lower and photic layers July	Si(µg-at /l) April	Si July	Si April to July	Si Lower and photic layers April	Si Lower and photic layers July
Region I. The Southwest Coast of Greenland											
The photic layer	0- 50	0.77	0.55	-0.22	0.17	0.45	9.2	2.1	-7.1	1.8	7.1
The lower layer	100-250	0.94	1.00	+0.06			11.0	9.2	-1.8		
Region II. The Labrador Region											
The photic layer	0- 30	1.13	0.77	-0.36	0.06	0.33	9.2	5.0	-4.2	2.6	3.9
The lower layer	50-500	1.19	1.10	-0.09			11.8	8.9	-2.9		
Region III. Central Part of the Labrador Sea											
The photic layer	0-100	1.10	0.68	-0.42	0.03	0.45	10.0	4.3	-5.7	1.00	5.3
The lower layer	100-500	1.13	1.13	0			11.0	9.6	-1.4		
Region IV. South of Cape Farewell											
The photic layer	0-100	0.90	0.65	-0.15	0.20	0.48	9.6	4.6	-5.0	1.8	5.4
The lower layer	100-500	1.10	1.13	+0.03			11.4	10.0	-1.4		

Assimilation of monosilicates during the period from April to July averaged 5.3 µg-at Si/l (from 3.9 to 7.1 µg-at Si/l); the decrease of the quantity of monosilicates in the lower layers averaged 1.8 µg-at Si/l (1.4 to 2.8 µg-at Si/l).

Taking into consideration the fact (Fedosov and Andreev, 1961) that 150 times as much vegetable organic substance can be synthesized in the process of the photosynthetical assimilation of one phosphate unit in oceanic conditions, one can judge the new formation of vegetable organic matter in the waters investigated (Table 13).

TABLE 13. Yield of organic matter of phytoplankton in g/m^3 (estimations based on consumption of phosphates).

Water masses of the photic layer		Salinity (°/oo)	April (from winter) (mg/l)	July (from April) (mg/l)
Region I.	The Southwest coast of Greenland	< 34.8	~ 0.5	~ 1.0
Region II.	The Labrador coast	< 34.8	0.0	~ 1.6
Region III.	Central part of the Labrador Sea	≥ 34.8	0.0	~ 1.9
Region IV.	South of Cape Farewell	≥ 34.8	~ 0.6	~ 1.2

Taking into consideration the different depths of the photic layer in the above regions and various durations of the vegetative period under investigation, the picture will be as shown in Table 14.

TABLE 14. Yield of organic matter of phytoplankton in g/m^2 (estimations based on consumption of phosphates).

Water masses of the photic layers		Depth of the photic layer (m)	Period of production observed (months)	Value of newly-formed vegetable organic matter (g/m^2)
Region I.	The Southwest coast of Greenland	50	4	75
Region II.	The Labrador coast	30	3	48
Region III.	Central part of the Labrador Sea	100	3	190
Region IV.	South of Cape Farewell	100	4	180

Comparisons and estimates concerning the content of monosilicates give an analogous picture, allowing for the fact that the quantity of silicon in phytoplankton is 15 times greater than the quantity of phosphorus (Table 15).

The coincidence of estimations resulting from the change of phosphate quantity in the productive photic layer with the results of the analogous calculations concerning the content of monosilicates permits us to conclude that during the first half of the productive period, the southern regions of the waters investigated appear to be more productive. Water masses in the Labrador region where production of phytoplankton began much later are less productive. The gross value of primary production off southwestern Greenland is less than in regions of open waters.

Taking into account, however, the column of water in the photic layer in different regions, one can see that the concentration off the southwestern coast of Greenland of newly-formed organic

TABLE 15. Yield of organic matter of phytoplankton in g/m^2 (estimations based on consumption of silicon).

		(g/m^2)
Region I.	The Southwest coast of Greenland	100
Region II.	The Labrador coast	33
Region III.	Central part of the Labrador Sea	150
Region IV.	South of Cape Farewell	150

matter as well as its accessibility as food for heterotrophs is the same as the one observed in southern regions (Table 13).

The influence of thermal conditions in coastal regions and of areas with intensive intermingling of water masses on the course of the biochemical processes forming the primary productivity of water masses is shown in the paper. It should be noted that the region with the increased intensity of newly-formed organic matter (Region IV) coincides with the region of the increased vertical mixing of water masses (Mamaev, 1960).

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Continuous Plankton Records During the NORWESTLANT Surveys, 1963 – Phytoplankton

By

G.A. Robinson[1]

MATERIAL AND METHODS

The principal features of the Continuous Plankton Recorder Survey have been described by Glover (1962). Recorders are towed by merchant ships and ocean weather ships, every month where possible, along a number of standard routes, sampling at a depth of 10 m and filtering the plankton on silk of 60 meshes to the inch. From 1948 to 1955 the survey was confined to the North Sea and the eastern North Atlantic; thereafter, the survey has been extended progressively westwards across the North Atlantic. The routes in use in 1963 are shown in Fig. 23*a*. The survey was supported by H.M. Treasury through a grant from the Development Fund and by contract N62558-3612 between the Office of Naval Research, Department of the United States Navy, and the Scottish Marine Biological Association. This report is intended to provide a background to the distributions of the common species from that part of the North Atlantic which was sampled in the region of the NORWESTLANT Surveys.

The methods of analysis of Recorder samples have been described by Colebrook (1960). For the routine treatment of data the counts of organisms in individual samples are transformed using $y = \log_{10}(x + 1)$. The area is divided into rectangles (2° long × 1° lat) and the logarithmic mean number per sample is calculated for each organism in each rectangle in each month. These rectangle means are averaged to provide, for each month, the mean number per sample in each of the standard areas shown in Fig. 23*b*. Phytoplankton colour is assessed visually according to the intensity of the green colour of the silk. This gives a crude estimate of the abundance of the phytoplankton as a whole.

DISTRIBUTION AND ABUNDANCE

The distributions of the colour estimates are given month-by-month from April to August 1963 in Fig. 24. The spring outbreak of phytoplankton was well advanced in April in two shallow coastal areas off West Greenland and Newfoundland. Production was just beginning in Icelandic coastal water, but there was no evidence of any phytoplankton over the deeper water beyond the continental shelves. In May, phytoplankton was again abundant in the coastal waters and had begun to increase in oceanic waters south and southwest of Iceland and east of Newfoundland. The spring outburst reached its peak in oceanic waters in June but it was short-lived and there was a very sharp decline in July. In August phytoplankton appeared to be confined to an area east of Labrador, but the sampling coverage was most unsatisfactory in this month.

The fluctuations in abundance of eight species (or groups of species) of diatoms and one dinoflagellate as well as the green colouration of the silks are given in Fig. 25. The mean number per sample in each of the standard areas is shown as a histogram for each month from April to September 1963; the principal features of the phytoplankton distribution in the Northwest Atlantic can be described by considering this period only. In most of the areas it has been possible to calculate long-term means for each month; these are shown as line graphs. They were calculated by combining all the results obtained with Plankton Recorders during the 7 years 1958-64 and provide a measure of the "normal" seasonal cycle for each organism. Because of the progressive westward extension of the survey in recent years, there is considerable variation in the available data for the different areas. The long-term means are shown as continuous lines for those areas which have been sampled for at least 5 of the last 7 years (areas B6, B7, C7, and C8). Areas B6, C8, and D7 were sampled for 3 or 4 years and the long-term means are shown as broken lines. Sampling in area B8 started in 1962 and it is not possible to give a long-term mean for this area.

[1] Oceanographic Laboratory, Edinburgh, Scotland.

Results for the remainder of 1963 and for other organisms and also from other areas sampled by the Continuous Plankton Recorder in the North Atlantic and its neighbouring seas will be provided on application to the Oceanographic Laboratory, Craighall Road, Edinburgh 6, Scotland.

The green colour of the silks, when compared with the long-term mean, showed that phytoplankton was relatively scarce everywhere; area C6 was the only area where the colour in 1963 was close to the long-term average. However, in May in the coastal waters west of Greenland (area B8 for which there is no long-term average), phytoplankton was abundant; a similar growth was found in 1962 in this area although the spring ourburst was then about a month later. Evidence from the rest of the area suggests that the spring bloom, although much weaker than usual, was close to its normal timing. In the oceanic areas, it started in May in areas B6, B7, C6, D7, and D8, but not until June in C7 and C8. Phytoplankton is normally less abundant in the central Atlantic areas C6, C7, and D7 than

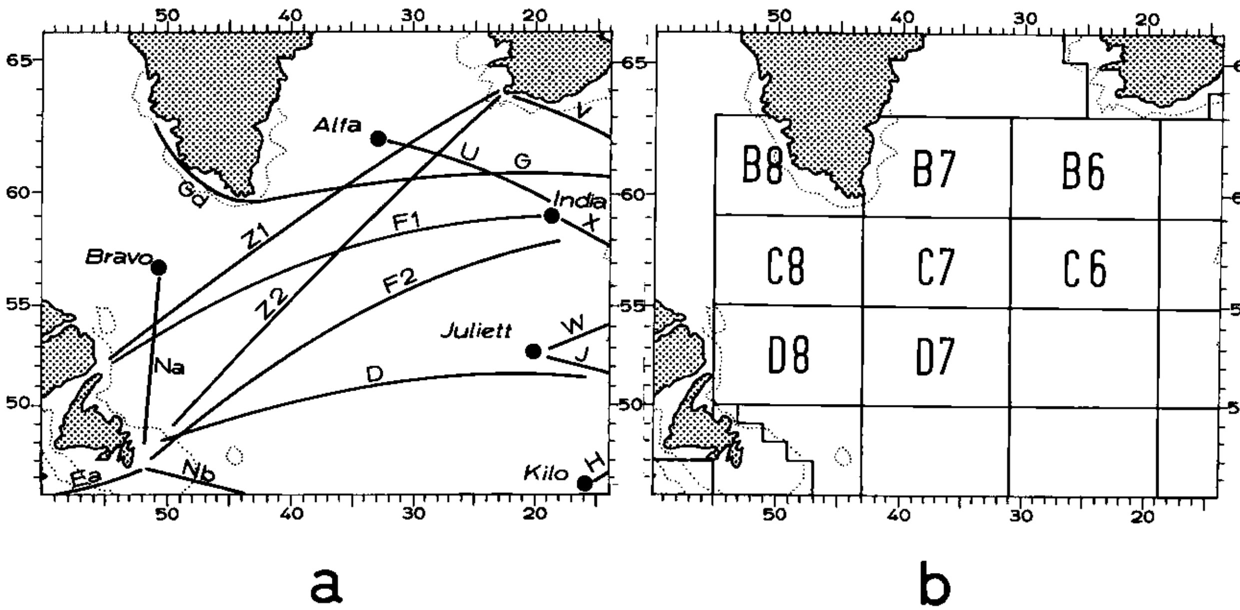

Fig. 23*a*. Chart showing the standard positions of the Continuous Plankton Recorder routes in 1963. The ships' courses varied slightly from month to month and two ships followed different routes in summer (F1 and Z1) and winter (F2 and Z2).

b. Chart showing the area sampled by the Continuous Plankton Recorder west of 19 W. The area has been divided into standard areas (see text).

the surrounding areas.

The abundance of the individual species (Fig. 25) confirms the results of the colour analysis, suggesting that phytoplankton was scarce in 1963. *Thalassiosira* spp. were exceptional in being more numerous than usual in all areas (except areas C7 and C8). They were extremely abundant in the coastal waters west of Greenland (area B8). *Nitzschia seriata* was the only other widely distributed species that was more numerous than usual (central Atlantic areas B6, B7, and C6 in May and June). It was also abundant, together with *Hyalochaetes* and *Phaeocerids*, in the West Greenland coastal waters in July. These last two groups of species, together with *Thalassiothrix longissima*, were found in numbers considerably lower than usual in areas B6 and B7, but were closer to average in area C6 and the western oceanic areas C8, D7, and D8.

R. styliformis and *R. hebetata* var *semispina* were never abundant, although *R. styliformis* was

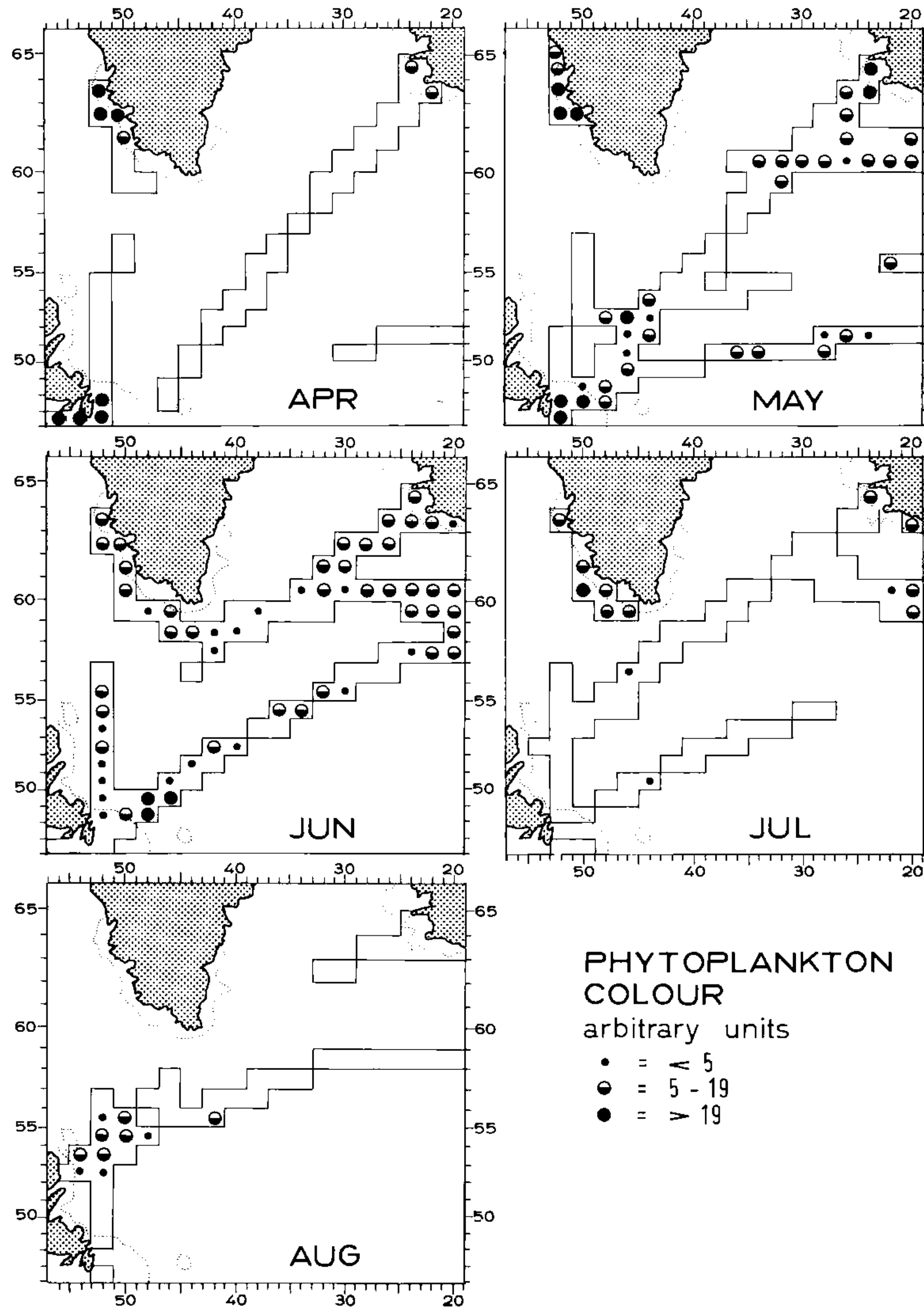

Fig. 24. Charts showing the distribution of the phytoplankton (from colour analysis) on the Continuous Plankton Recorder silks from April to August 1963 in the Northwest Atlantic.

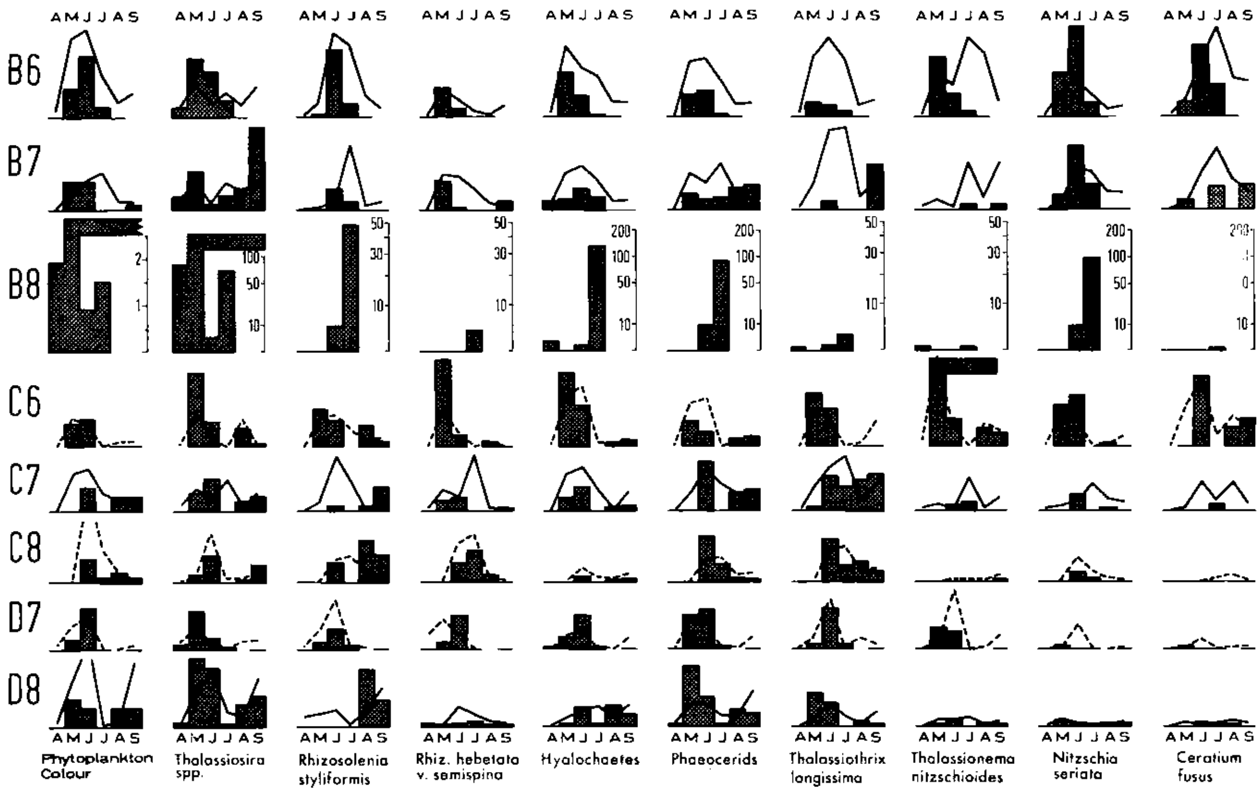

Fig. 25. Histograms showing a month-by-month estimate of the phytoplankton from April to August 1963. The colour estimate is based on visual assessments of the green colour of Recorder silks and the numbers of the individual species are given as the average number per Recorder sample. The letters and numbers (B6, B7, etc.) refer to the areas shown in Fig. 23*b*. A break in the base-line indicates that there was no sampling in that month. The line graphs show the long-period mean in all areas, except B8, based on a combination of all Records in these subareas from 1958 to 1964 (see text).

more numerous in July 1963 in the coastal waters west of Greenland than in July of 1962 or 1964, whereas *R. hebetata* var. *semispina* was less numerous in July 1963 than in the other 2 years.

Areas B6 and B7 have been sampled in almost every month since 1958, and the data therefore permit more detailed comparisons of seasonal and annual variations in distribution from that time. The standing crop as depicted by "colour analysis" was well above average in these two areas in 1958 and 1959, about average in 1960, and has been low from 1961 to 1964. The species affected by this reduction of standing crop were chiefly the dominant spring diatoms *Thalassiothrix longissima* and *Chaetoceros* spp. Gillbricht (this volume, p. 73) also suggests that conditions for plankton production in these oceanic areas were poor in 1963 compared with 1955 and 1959.

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Norwegian Particle Distribution Studies

Editorial Note

Owing to illness, Mr Grim Berge has been unable to prepare a report on these studies, but he has been able to produce Chart 189 showing the relative concentration of particles recorded by R/V *G. O. Sars* during NORWESTLANT 1 between 10 and 21 April, and Charts 190 and 191 showing the relative concentrations in 1964, firstly from 2 to 22 April, and secondly, from 22 April to 14 May. The measurements were made with a recording transparency meter described in Berge (1963). It was his intention to calibrate them against pure cultures of *Chlorella*, but this has not been possible.

Assuming that there was no difference in instrument performance between 1963 and 1964, the charts as they stand suggest that phytoplankton production was heavier and earlier in 1963 than in 1964.

Arthur Lee.

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The Zooplankton of the NORWESTLANT Surveys

By

V. Bainbridge[1] and J. Corlett[2]

INTRODUCTION

The object of this report is to give an account of aspects of the distribution of zooplankton during NORWESTLANT 1-3 which may be relevant to the distribution and survival of cod and redfish larvae. It has been compiled from data sent to us by J. Beaudouin (France), E. Bratberg (Norway), J. H. Fraser (Scotland), E. H. Grainger (Canada), I. Hallgrimsson (Iceland), A. Kotthaus (Germany), E. Smidt (Denmark) and E. A. Pavshtiks (USSR), as well as from work done in our own laboratories. J. B. L. Matthews and L. T. Jones of the Oceanographic Laboratory, Edinburgh, played a large part in the analysis of samples collected during the Danish and German cruises. We wish to thank these people for their assistance in sending us data and we have greatly benefitted from their advice both in correspondence and discussions, but we must accept responsibility for the presentation and interpretation of the results. The report concerns a very wide area and is not intended as a comprehensive review of the zooplankton. More detailed studies of individual species and groups are possible with the data available but only in limited areas during NORWESTLANT 2 and 3.

MATERIALS AND METHODS

Methods of sampling

The original plan called for the use of three standard nets for the collection of fish eggs and larvae, and zooplankton. All ships were to use the standard Hensen net at each station on the hydrographic sections and on the grids planned for cod eggs and larvae, and redfish larvae. At each station on the egg and larval grids oblique hauls were also to be made with a 2-m-stramin net and with the Icelandic High Speed Sampler. The specifications of the nets and the methods of hauling them were described in the Guide Book to Surveys NORWESTLANT 1-3 which was issued to all participants. The more important details are listed below:

Hensen Net. Diameter 72 cm. No. 3 silk. Hauled vertically at 1 m/3 sec from 100 m to the surface or from a few metres off the bottom to the surface at those stations less than 100 m in depth;

Stramin Net. Diameter 2 m. Mesh 500 threads/m. Hauled obliquely from 50 m to the surface at 1.5 knots. Duration of hauling time about 30 min;

Icelandic High Speed Sampler. Hauled obliquely from 50 m to the surface at 5 knots. Duration of hauling time about 30 min.

In their reports on the surveys to the Annual Meeting of ICNAF in June 1964, each country reported on the methods actually used and on the deviations from the original plan. Only a summary of these differences is reported below.

NORWESTLANT 1. *Thalassa* did not use the High Speed Sampler and *Ernest Holt* was unable to use either of the towed nets because of bad weather. On some stations of the egg and larval grid *Ernest Holt* substituted a 1-m-silk net for the Hensen net. The Nansen net was used for vertical hauls at a few of the hydrographic stations. *Akademician Knipovich* and *Topseda* used the stramin net at only half of the stations and *G.O. Sars* did not use the High Speed Sampler;

[1] Oceanographic Laboratory, Edinburgh, Scotland.

[2] Fisheries Laboratory, Lowestoft, England.

NORWESTLANT 2. *Aegir* did not use the stramin net, and High Speed Samplers were towed horizontally at three depth intervals, 2-5 m, 15-18 m, and 25-30 m, instead of obliquely from 50 m. From *Anton Dohrn* a Helgoland larval net or a Nansen net replaced the Hensen net for the vertical hauls, the stramin net was raised in three steps at 50 m, 25-30 m, and 5-10 m, and the High Speed Sampler was used at only three stations. The High Speed Sampler was used by *Dana* only for a series of comparative tows with the 2-m-stramin net;

NORWESTLANT 3. *Ernest Holt* used the High Speed Sampler at a few stations only and the Nansen net was used for extra vertical hauls on some of the hydrographic stations. On *Explorer* difficulty was experienced with the 2-m-stramin nets and at about one third of the stations a 1-m. net made of silk of 26 meshes per inch was substituted. *Akademician Knipovich* had to omit the stramin-net hauls at about one quarter of the stations, and *Dana* did not use the High Speed Sampler. *Baffin* used the stramin net at about one third of the stations and the High Speed Sampler at about half, and *Sackville* did not use either of the towed nets.

From the above account it will be seen that the most complete coverage on all surveys was with the vertical hauls using the Hensen net, and that the Icelandic High Speed Sampler was only used regularly by a few of the ships.

Analysis of samples

The methods used for sorting and counting the samples in the various laboratories have not been reported in detail, but it is clear that the usual procedure followed was to pick out and count the larger animals before removing an aliquot subsample to count the smaller and more numerous animals. In a few cases much of the counting was done at sea and some countries (particularly Iceland) used the short-cut method described by Hallgrimsson (1958) for all or some of the samples. In this method the subsample consists of 100 or 200 animals and the results are expressed as percentage occurrences of each species or stage. The total number of animals in each sample were later estimated so the percentages could be converted to numbers. Usually, samples from the vertical nets and the High Speed Sampler were analyzed in most detail, while only the larger animals were reported from the stramin-net samples.

The animals in the samples from the vertical hauls were expressed as numbers under 1 m^2 of sea surface within the top 100 m, conversion factors being derived from the dimensions of the mouths of the nets and assuming 100% filtration. The factor used for the conversion of the Hensen net samples was usually 2.6 but varied from 2.46 for the Canadian data to 2.93 for the Norwegian data since the effective diameters of the nets used were slightly different. Counts on the samples from the Helgoland larva net and Nansen net were converted to numbers under 1 m^2 using the factors 0.62 and 2.4 respectively. Data from the stramin-net samples were standardized to numbers per 30-min haul. Results from the High Speed Sampler catches were variously reported.

At a meeting of representatives of the countries concerned in Madrid in October 1963 it was agreed that:

> "In working-up and reporting upon the zooplankton caught by the 2-m-stramin net and IHSS priority would be given to determining the total numbers of those organisms that provide the food of cod and redfish larvae, viz. *Calanus* species (stage VI), *Spiratella* species, *Thysanoessa longicaudata* and *Meganyctiphanes norvegica.* If countries have time and manpower available second priority would be given to indicator organisms, viz. *Halopsis*, *Periphylla*, *Aglantha*, *Sagitta maxima*, *Eukrohnia*, and *Spiratella* and any other species which appears dominant when a country works up its material. Third priority would be given to the predators of cod eggs and larvae and redfish larvae."

The species given first priority were reported by all countries, but not necessarily from all the nets, so gaps in the data will be apparent in the sections on the separate species. On the other hand, some countries greatly exceeded the basic requirements and we have been unable to use all the data provided by them. The species referred to in the report are listed with authorites in Appendix Table II.

Since the displacement volumes of most samples from the vertical hauls had been measured it was decided to ask every country to do so and to include information on plankton volumes in this report. The method used varied from one country to another, but not sufficiently for correction factors to be necessary. In Canada the "wet weight" of the Hensen net samples were determined and these have been regarded as equivalent to displacement volumes.

Presentation of results

In preparing this report the first task was to draw charts of the distribution on each survey of the species listed as priorities and then of as many other species and stages of species as were reported by most countries. All those given first and second priority in the list were selected for inclusion together with as many others as seemed to be useful in providing a background for the studies on fish larvae. Most of the charts selected refer to data from samples taken with the Hensen and other vertically hauled nets since these gave the widest coverage for all three surveys and the results of the analyses could be transformed with reasonable accuracy to a common basis. The High Speed Sampler data were generally neglected because very few samples were taken, except during the second survey, and the results were not compatible with those for the stramin net. In a series of hauls for comparison of the two nets the Danes found a wide variation in the proportions of the different species: for example, the proportion 2-m-stramin/High Speed Sampler was 5/1 for *Pandalus* larvae, 13/1 for fish larvae, 118/1 for crab larvae, and 164/1 for fish eggs. However, the data from all nets proved useful in that the results obtained from one net could be used to help interpret the patterns of distribution shown by another net.

Only two sets of data have been deliberately excluded from most of the charts because they were so much earlier or later than the rest as to distort the synoptic picture. These were the first part of the *Aegir* cruise (Stations 1-81) which was 1-3 weeks earlier than the rest of NORWESTLANT 2, and the last hydrographic line of *Dana* (Stations 12064-12075) which was 2-3 weeks later than the rest of NORWESTLANT 3.

The preparation of contoured charts raised several problems since there was sometimes considerable variation between the numbers of certain species at closely adjacent stations. After several tests, the contour levels used by Fleminger (1964) in the plankton atlas produced by California Cooperative Oceanic Fisheries Investigations were adopted since they gave the clearest presentation for the majority of species and groups. The levels are based on the logarithmic series 50, 500, 5,000, 50,000, etc. and generally gave fairly equal areas between successive contours. However, on the charts showing the distribution of plankton volumes, it was convenient to use contour levels at 10, 30, and 100; the same series as used for the Plankton Recorder Survey (Colebrook, *et al.*, 1961).

L. T. Jones and J. B. L. Matthews have made a detailed study of the distribution of the Euphausiacea and Copepoda during NORWESTLANT 2 and have found that distinct diurnal variations occurred in the numbers of all euphausiids and several copepods, especially *Calanus hyperboreus* and *Euchaeta norvegica*, taken by the stramin nets. These variations were presumably due to diurnal variations either in the vertical distribution of the animals or in their ability to avoid the nets. Using a technique similar to that developed by King and Hida (1954) and Legand (1958) they have applied correction factors to mitigate the effects of night-to-day differences on the distribution patterns. The mean number of each species per 30-min-stramin haul was calculated for each of six 4-hr intervals, regardless of the region of sampling, and in all cases, the greatest numbers were caught during darkness. From the smoothed diurnal curves a correction factor was applied by dividing the maximum value by the value at each quarter-hour interval. Each sample for each species was then multiplied by the ratio obtained for its collection time, on the assumption that the population of the species behaved uniformly throughout the area. Contoured charts showing the distribution and abundance of the euphausiid *Thysanoessa longicaudata* during NORWESTLANT 2 using uncorrected and corrected data are shown in Charts 211 and 212. There are obvious differences in detail, but the wide contour levels chosen show the same broad features in the pattern of distribution in both corrected and uncorrected data. In the following account only the main patterns of distribution shown by the principal species and groups are discussed, and it should be noted that some of the irregularities shown by the contours could be due to diurnal variations in the catch.

In addition to the contoured charts, standard areas have been used to present the geographical and seasonal distributions of the more important animals. The data were processed in a similar way to that adopted for the Continuous Plankton Recorder Survey (Glover and Robinson, this volume, p. 125). The area of the NORWESTLANT Surveys was divided into rectangles of 2° long by 1° lat and the mean number per m^2 of sea surface was calculated for each rectangle. These rectangle means were then averaged to give area means for the seven standard areas defined in Chart 192. The 2° x 1° rectangles were the same as those used in the Recorder Survey but the standard areas were chosen so that the comparisons could be made with the phytoplankton data described by Gillbricht (this volume, p. 75). In addition to Gillbricht's four main divisions, the shelf waters off Iceland and East and West Greenland are considered separately. The standard areas are not identical to those used by Bainbridge and McKay (this volume, p. 187), but nevertheless, allow comparisons to be made with their work in the feeding of cod and redfish larvae.

THE ZOOPLANKTON DURING THE THREE SURVEYS

NORWESTLANT 1

The pattern of stations plotted in the chart of Chart 193 shows that there was good coverage around the Greenland Shelf, from the Denmark Strait to about 66°N off West Greenland. Ice restricted work over the East Greenland Shelf between 65° and 66°N and to a lesser extent further south to Cape Farewell, and also in the Davis Strait between 63° and 67°N. Almost all the plankton samples were collected during the last 3 weeks of April.

During this survey the quantity of zooplankton in the upper 100 m was generally low over the whole area as is typical of the late winter and early spring season. Chart 194 shows that the volume of plankton in the vertical nets was lowest in a band over the Greenland Shelf which included the cold water of the East Greenland and West Greenland Currents. Quantities of plankton were also low in the Labrador Sea south and west of Cape Farewell. There was a fairly well defined band of higher volumes off the edge of the shelf in the Irminger and Labrador Seas. The bulk of the plankton over the whole area was made up of *Calanus finmarchicus* in stages V and VI. *Spiratella retroversa* was second in abundance numerically, although *Thysanoessa longicaudata* was second in terms of volume over most of the survey area outside the continental edge and constituted a particularly large part of the stramin net catches.

The distribution of *Calanus finmarchicus* is illustrated by three charts. Stages V and VI are shown separately in Charts 196 and 197 while the total numbers of earlier copepodites (stages I-IV) are shown in Chart 195. The numbers of *Calanus* in the *Thalassa*'s area have been estimated from both the stramin net and Hensen net catches and so are not strictly comparable with those in the rest of the area. During NORWESTLANT 1 (31 March-9 May 1963) the grouping of stages I-IV included both overwintering stage IV copepodites and stages I and II from the spring spawning. The patches of larger numbers over the Irminger and Labrador Seas were of stage IV copepodites, while the patch over the East Greenland Shelf between 62° and 63°N (Fylkir Bank and Cape Bille Bank) consisted of stage I and II copepodites, indicating early spawning there. Pavshtiks (1964) reported *Calanus* eggs and nauplii in the plankton near the south coast of Greenland during this survey indicating the onset of spring spawning, and there were a few early copepodites along the edges of the West Greenland Shelf north of 63°30'N.

The distributions of *Calanus* stages V and VI (Chart 196 and 197) were broadly similar to the distribution of plankton volumes in that the largest numbers were found on the edges of the shelf around East and West Greenland. Adult *Calanus* were the dominant stage over a wide area of the Irminger and Labrador Seas, suggesting that some spawning had started or was imminent. The pattern of distribution over the East Greenland Shelf was rather confused and was not closely related to sea temperature, although generally there were fewer *Calanus* in the colder water.

In order to provide maximum coverage of the euphausiids with the limited data available two charts are presented; Chart 198 based on samples from the vertically hauled nets and Chart 199 based on those from the towed nets. These charts showed similar patterns of distribution with highest numbers over deep water. Around the coast of Greenland numbers were low in the cold water, but the group was more abundant where tongues of warmer Atlantic water extended over the shelf such as in the region southeast of Angmagssalik (Fig. 8, in Physical Oceanography Section). *Thysanoessa longicaudata* was usually the dominant species, while *Meganyctiphanes norvegica* had a widespread distribution in the Irminger Sea and West Greenland waters, being the commonest euphausiid at several stations west of Faxa Bay, Iceland. The great majority of specimens caught during NORWESTLANT 1 were adults.

The pteropod, *Spiratella retroversa*, (Chart 200) had a similar distribution to that of *T. longicaudata*, with the largest numbers over the deep water of the Irminger Sea, only moderate numbers over the outer part of the shelf, and few or no specimens at stations in the cold water of the East and West Greenland Currents. The pattern of distribution shown by the Hensen net catches was broadly confirmed by the stramin net, although some of the stramin net catches off Angmagssalik and in the Labrador Sea contained very large numbers of *Spiratella*.

In addition to species which at some time during their life history form the food of young cod and redfish, information was available on two groups, the medusae and Chaetognatha, which include species known to be useful as indicators of certain water masses. By far the commonest medusa in the survey area was *Aglantha digitale* and its distribution is shown in Chart 201. Only a few specimens were caught in each Hensen-net haul so the distribution in the *Thalassa*'s area is based on the stramin-net data. *Aglantha* was widely distributed around the Greenland coast but was absent on the Icelandic Shelf and at many stations in the Labrador Sea. The two other species of medusae which should have been reported were *Periphylla periphylla* and *Halopsis ocellata*. Neither species was caught by the *Ernest Holt* and they were evidently not included in the analysis schedule for the Norwegian and Russian samples. The French recorded *Halopsis* as widespread along the East Greenland Shelf and on the Icelandic Shelf, but no specimens of *Periphylla* were present in the samples from the sector surveyed by *Thalassa*.

Two species of Chaetognatha, *Sagitta maxima*, and *S. elegans*, have been plotted on Chart 202 since these were the two species identified by most countries. The chart shows the presence or absence of both species in samples from all types of net. *S. elegans* was found chiefly over the Greenland Shelf and was absent off Iceland. Its distribution was not confined to the coldest water and it probably also extended into mixed water with an East Greenland Current component. *S. maxima* was found over deep water with the fringe of its area of distribution in places overlapping the outer part of the shelf. In the Denmark Strait and over the Fylkir Bank the presence of *S. maxima* suggests the penetration of oceanic water onto the shelf. The third common chaetognath species, *Eukrohnia hamata*, had a similar distribution to *S. maxima* off Southeast Greenland, but was not found in the Denmark Strait or over the Icelandic Shelf.

Other species recorded from the samples varied from country to country. Among the more noteworthy were *Fritillaria borealis* which was found in large numbers at several of the *Ernest Holt* stations in the cold water of the East Greenland Current. The small copepods *Pseudocalanus minutus* and *Oithona similis* were quite widespread in the *Ernest Holt* samples, particularly over the shelf, and *Oithona* was reported in many of the samples taken from *Thalassa*.

NORWESTLANT 2

Sampling was more extensive during this survey than on the other two, giving a particularly good coverage of the Irminger Sea as well as of the coastal waters around Greenland (Chart 203). However, the survey lasted almost 2 months since the *Aegir*'s cruise took place during May while other ships worked mostly from mid-May to mid-June. Conditions had changed considerably between the early part of the *Aegir*'s cruise and the latter part of the other vessels' cruises, so the results of the first half of the *Aegir*'s cruise in early May have not been included in the charts of distributions.

Plankton volumes were generally higher than on NORWESTLANT 1 except in the coastal waters of West Greenland and in some regions off the East Greenland coast (Chart 204). The high volumes observed between Angmagssalik and Cape Mosting off the coast of East Greenland were due to phytoplankton; and the numbers of the various animals suggest that zooplankton volumes were generally low in the cold water of the East and West Greenland Currents. Highest plankton volumes were found over the deep water in the southeastern part of the survey area, but there were a number of small patches with high volumes off the Greenland and Icelandic Shelves.

The plankton samples of NORWESTLANT 2 have been analyzed in greater detail than those of the other surveys and, since most of the early larvae of cod and redfish were found during this survey, it is useful to give a general account of the composition of the plankton as a whole before describing the charts of the distribution of the principal species and groups.

The average numbers per square metre of sea surface of various groups taken by the vertically hauled nets in each of the standard areas were calculated as described previously and are given in Table 16. Coepods were by far the commonest group and the majority of the species reported are listed individually in Table 16.

Calanus finmarchicus was the predominant species over the entire survey area and of the remaining copepods only *Pseudocalanus minutus*. *Scolecithricella minor*. *Euchaeta norvegica* and *Oithona similis* were both widespread and fairly numerous. *Calanus glacialis*, which in this area has been shown to coincide with Polar water (Grainger, 1961), and *Calanus hyperboreus* were common in the Davis Strait (areas GW and NW in Chart 192) and present in the East Greenland Current (area GE), but generally rare or absent elsewhere. *Rhincalanus nasutus* and *Euchirella rostrata* were mainly confined to the warmer waters found in the southeastern part of the survey area (area SE). *Metridia lucens* was only recorded over the eastern half of the survey area. Samples taken near Iceland (area Ic) were characterized by high numbers of *Pseudocalanus minutus* and *Acartia* spp. while Greenland Shelf waters contained many *Oithona similis*. *Temora longicornis* and *Centropages* sp. were found only in Icelandic waters during this survey, but a few specimens of *C. hamatus* were recorded off West Greenland during

TABLE 16. NORWESTLANT 2. Average numbers of animals under 1 m^2 from vertical net samples in the areas shown in Chart 192 (- not included in analysis schedule; + less than 1).

ENTITY	West Greenland (GW)	Davis Strait (NW)	Labrador Sea (SW)	East Greenland (GE)	Irminger Sea (north) (NE)	Irminger Sea (south) (SE)	Iceland (Ic)
COPEPODA							
Calanus finmarchicus	15,697	33,616	8,951	3,127	6,037	7,177	4,304
Calanus glacialis	280	1,936	3	1	0	0	-
Calanus hyperboreus	55	920	65	36	8	3	0
Pseudocalanus minutus	356	300	18	97	122	69	1,352
Rhincalanus nasutus	0	0	0	0	1	13	0
Euchirella rostrata	0	0	+	0	0	14	0
Euchaeta norvegica	40	37	61	62	221	468	50
Scolecithricella minor	32	23	147	42	197	171	17
Centropages spp.	0	0	0	0	0	0	8
Temora longicornis	0	0	0	0	+	0	8
Metridia lucens	0	0	0	0	11	12	10
Metridia longa	8	4	14	21	8	3	0
Heterorhabdus norvegica	1	0	1	+	0	4	0
Acartia spp.	5	0	0·	0	3	0	206
Oithona spp.	1,335	108	407	1,075	112	464	13
Total Copepods	17,809	36,944	9,667	4,461	6,720	8,398	5,068
OTHER SPECIES AND GROUPS							
Cladocera	0	0	0	0	+	+	50
Euphausiacea	1,629	3,016	500	231	361	773	79
Amphipoda	11	73	80	7	33	101	2
Ostracoda	97	419	411	63	195	376	0
Spiratella retroversa	98	49	578	129	142	667	0
Clione limacina	1	0	1	1	59	41	-
Larvacea	2,017	6,196	167	121	399	232	-
Tomopteris spp.	8	11	42	10	67	261	-
Aglantha digitale	4	10	12	5	5	107	-
Chaetognatha	24	39	102	30	548	140	5
Cirripede larvae	643	50	0	0	1	0	485
Decapod larvae	7	6	0	2	14	+	78
Echinoderm larvae	598	50	0	7	1	0	11

NORWESTLANT 3. Several copepods, including *Microcalanus pygmaeus*, *Scolecithricella ovata* and *Oncaea borealis* were occasionally reported but have not been tabulated since counting was not consistent. *Oncaea borealis* was mainly found in Greenland waters.

In addition to the Copepoda, the Euphausiacea, with *Thysanoessa longicaudata* as the principal species, were well represented throughout the entire survey area. Most of the remaining groups listed in Table 16, although widespread, showed definite regional differences in abundance. The Amphipoda (mainly *Parathemisto gaudichaudi*) and the Ostracoda (mainly *Conchoecia obtusata*) tended to be more frequent in the oceanic areas (NW, SW, NE, and SE) while the Chaetognatha (mainly *Eukhronia hamata*), the two pteropods *Spiratella retroversa* and *Clione limacina* and the polychaete *Tomopteris* (mainly *T. septentrionalis*) were most numerous in the open Atlantic (SW, NE, and SE). The Larvacea (*Oikopleura* spp. and *Fritillaria* spp.) were clearly most abundant within the Davis Strait (areas NW and GW) while the Cladocera (*Evadne nordmanni* and *Podon leuckarti*) were virtually limited to Icelandic waters (area Ic). As might be expected the larvae of benthic invertebrates were most plentiful in coastal waters, especially cirripede nauplii and decapod larvae off Iceland, and both cirripede and echinoderm larvae off West Greenland. Very few specimens of the larvae of any benthic animals were recorded off East Greenland. The presence of cirripede and echinoderm larvae in the central part of the Davis Strait is noteworthy and in agreement with the westerly extension of the West Greenland Current.

Some of the differences in the plankton observed between the regions are due to real differences in the distribution of the species; e.g., *Temora longicornis* has never been recorded from West Greenland coastal waters (Jespersen, 1934). Others are due to differences in timing; e.g., the numbers of Larvacea off East Greenland had greatly increased by NORWESTLANT 3.

The Canadian samples were analyzed in considerable detail and E. H. Grainger (unpublished) found that a number of the species fell clearly into two groups: those characteristic of Davis Strait and the Southwest Greenland coast, and those typical of the Labrador Sea and South Central Davis Strait (Table 17). In his report he notes that members of the first group are known elsewhere as cold-water species and are reported from near-surface waters of the high Arctic regions of the world, while those of the second group are relatively warm-water forms characteristic of the waters of the North Atlantic. Plotting the occurrence of members of the two groups in the Canadian samples showed remarkably little overlap. The northernmost stations appeared to support predominantly Arctic species and most of the offshore waters of the Labrador Sea appeared to contain only members of the warm-water group. There was mixing of the two groups in the Central Davis Strait and off Southwest Greenland. The northernmost limit of 3°C water coincided well with the apparent farthest extension of the unmixed warm-water forms.

Charts 205-207 show the distribution of *Calanus finmarchicus* during NORWESTLANT 2. The distributions of adults and stage V copepodites were similar in that highest numbers were found over deep water and lowest numbers in the vicinity of the Greenland Shelf. Very few were present north of 63°N off West Greenland, and at many stations close to the coast in this region both stages were absent. Chart 205 shows that *Calanus* copepodites I-IV had rather the converse distribution to the older stages with high numbers in the Davis Strait and near the Fylkir Bank off East Greenland, suggesting that the main spring spawning had occurred some weeks previously in these regions. Copepodite stages I-IV were fairly common in the southern part of the Irminger Sea, but there was a prominent band of low numbers beyond the edge of the shelf off East Greenland.

Grainger (unpublished) found that in the Canadian samples the ratio of *Calanus finmarchicus* to *C. glacialis* showed a more or less gradual trend from Atlantic to Arctic waters. Exclusive occurrence of *C. finmarchicus* was restricted largely here to water of 3°C or warmer, and the greatest proportions of *C. glacialis* were found in water of 1.5°C and colder.

The total numbers of euphausiids taken with the stramin nets (and Icelandic High Speed Sampler in the northeast part of the area) have been plotted in Chart 210. The distribution was extremely patchy, but numbers were generally highest in the Irminger Sea and lowest in the Denmark Strait and Davis Strait. A clearer picture is shown by the calyptopis and furcilia stages taken by vertical nets (Charts 208 and 209). Furcilias were most numerous in the Irminger Sea and the central part of the Davis Strait, but only occasionally found in the shelf waters around Greenland. By contrast, calyptopis stages were common over the Greenland Shelf as well as in parts of the Irminger Sea, and highest numbers were present in the Davis Strait. Considering the distribution of these developmental stages, it would appear that the spring generation was more advanced in the Irminger Sea and in the central part of the Davis Strait than in the colder waters around Greenland.

TABLE 17. The two groups of species distinguished in the Canadian samples: (a) cold water forms; (b) warm water forms.

(a) Davis Strait and off SW Greenland	(b) North Atlantic
COPEPODA	COPEPODA
Microcalanus pygmaeus	*Scolecithricella ovata*
Euchaeta glacialis	*Euchaeta norvegica*
Acartia longiremis	*Heterorhabdus norvegicus*
	Eucalanus elongatus
	Rhincalanus nastutus
	Euchirella rostrata
AMPHIPODA	*Pseudaetideus armatus*
	Metridia lucens
Apherusa glacialis	
Gammarus wilkitzki	
Parathemisto abyssorum	
Parathemisto libellula	AMPHIPODA
	Lanceola clausi
OSTRACODA	
Conchoecia borealis maxima	OSTRACODA
	Conchoecia obtusata
CHAETOGNATHA	*Conchoecia elegans*
Sagitta elegans	
	EUPHAUSIACEA
	Thysanoessa longicaudata
PTEROPODA	
Spiratella helicina	
	CHAETOGNATHA
	Sagitta maxima

Thysaneossa longicaudata was the dominant euphausiid over much of the area sampled and the numbers of adults and furcilias in the stramin-net samples are given in Charts 211 and 212, which have already been discussed in relation to day and night variations. In his report on the Canadian samples, E. H. Grainger (unpublished) observed that, in the Davis Strait, *T. longicaudata* ranged north to about the limit of 3°C water and showed little overlap with the larvae of other *Thysanoessa* spp. (*raschii* and *inermis*) which were largely limited to the colder water. The presence or absence of the other species recorded are indicated in Chart 213. *Meganyctiphanes norvegica* was the commonest of these and was found most frequently over and to the east of the Reykjanes Ridge and in the vicinity of Iceland. Small numbers were observed in the Irminger Sea west of the Reykjanes Ridge, and to the southeast and southwest of Greenland. *Thysanoessa inermis* was mainly limited to shelf waters and was present off Iceland and in the Davis Strait, but it was found at only a few stations off East Greenland. Two other species were occasionally recorded: *Thysanopoda acutifrons* over deep water mainly to the south and east of the Reykjanes Ridge, and *Thysanoessa raschii* over shallow water in the Davis Strait. *Thysanopoda acutifrons* is a bathypelagic species and was normally found as early furcilias in the night samples.

Chart 214 shows the distribution of the pteropod *Spiratella retroversa*, a common species in the open ocean. Highest numbers were found in the southeast of the survey area and it was rare or absent in the vicinity of the Greenland coasts. The absence of the species at inshore stations off West Greenland is clearly shown, and in the northern part of the Davis Strait it was replaced by the cold water species *Spiratella helicina*.

The medusa *Aglantha digitale* was a regular member of the plankton, with highest numbers over deep water, and especially in the southeastern part of the survey area (Chart 215). A few specimens of *Halopsis ocellata* were found off the coasts of Southeast and Southwest Greenland, while *Periphylla periphylla* was recorded from several stations in the Irminger Sea and off Southwest Greenland (Chart 216).

Chart 217 shows the distribution of two species of *Sagitta*. *S. elegans* was found only over the shelf, while *S. maxima* was widely distributed over deep water in the Irminger and Labrador Seas and only occasionally extended over the shelf.

NORWESTLANT 3

Most of the sampling during NORWESTLANT 3 was carried out during the first 3 weeks of July and the pattern of stations is shown in Chart 218. Again there was good coverage over and in the vicinity of the Greenland Shelf from the Denmark Strait in the east and around Cape Farewell to 68°N on the western seaboard. Sampling in the Irminger Sea and Labrador Sea was confined to the hydrographic sections.

The main features of the distribution of the plankton volumes (Chart 219) are the high values in a band along the continental edge off Southeast and Southwest Greenland and off Labrador. Volumes were low west of Iceland between 63°30' and 65°30'N, over the West Greenland Shelf north of 61°N, and over the East Greenland Shelf. As during the previous surveys, *Calanus finmarchicus* formed the bulk of the plankton, with furcilia stages of *Thysanoessa longicaudata* taking second place by volume. Euphausiids sometimes made up the bulk of the stramin-net samples, although *Calanus* still accounted for the largest number of animals.

The distribution of *Calanus finmarchicus* is shown in Charts 220-222. Comparison with NORWESTLANT 2 indicates that the numbers of adult *Calanus* had decreased since the previous survey, (compare Charts 207 and 222) and adults had almost disappeared from the waters over much of the shelf around Greenland. The largest numbers were still to be found in the Irminger Sea suggesting prolonged spawning in this region. Chart 220 shows that copepodite stages were abundant over most of the sampled area, and were particularly numerous around the edge of the shelf east, southeast, and southwest of Greenland. On the eastern side, stage II copepodites were usually most numerous in the colder water near the ice edge, stage III over the rest of the shelf, and stage IV over the deeper water at the continental edge. Stage V *Calanus* were also abundant off the edge of the shelf south and east of Greenland and in the central part of the Irminger and Labrador Seas (Chart 221). Pavshtiks (1964) comments that over the deeper water of the Labrador Sea *Calanus* stage V constituted over 80% of the population and that nauplii and stages I-III were quite scarce; while on the shelf off the southwest coast of Greenland these early stages made up more than 80% of the *Calanus* population.

The distribution of young stages of euphausiids from the Hensen-net samples shown in Chart 223 presents rather a confused pattern. Calyptopes were common though patchy over the shelf around Greenland. This suggests that spawning was more prolonged in the colder waters than over the warmer deeper waters of the Irminger Sea, where there were no calyptopes during this survey. The Hensen net caught mainly early furcilia stages and these were most numerous in a band around the edge of the Greenland Shelf (Chart 224). Over most of the area the majority of the early furcilias were of *Thysanoessa longicaudata*, while off West Greenland there were very few at the stations nearest the coast, and north of about 64°N the early furcilias were mostly *T. inermis* but some *T. raschii*. Adult and furcilia stages were not always separated in the counts made on stramin-net samples, so they have been combined in Charts 225 and 226. Large numbers of the oceanic species *T. longicaudata* dominated the stramin-net catches in the Irminger Sea and Labrador Sea. Few were found over the shelf, except along the edge and in places where the oceanic water penetrates such as in the Denmark Strait. The difference in numbers between Charts 225 and 226 represents the euphausiid species other than *T. longicaudata* and it can be seen that they were most important proportionately off West Greenland, north of about 63°N. The distribution of these species as presence or absence is shown in Chart 227. *Thysanoessa inermis* was confined to the shelf around Greenland and *T. raschii* was only found off West Greenland north of 63°N, while *Meganyctiphanes norvegica* was widespread in the Irminger Sea and extended to 64°N off West Greenland.

Spiratella retroversa was most abundant southwest and southeast of Greenland and over the Irminger Sea (Chart 228). It was absent from most of the vertical-net samples taken in the vicinity of the Icelandic Shelf and the Denmark Strait and also from the West Greenland area north of 65°N.

Chart 229 shows the distribution of *Aglantha digitale* to have been common on the outer part of the shelf off Iceland, Southeast Greenland, and West Greenland, and most abundant in the Davis Strait north of 65°N. It was surprisingly absent from many stations in the Labrador and Irminger Seas. Chart 230 shows that *Halopsis* was widespread all along the shelf and also over deep water in the Davis Strait to about 63°N where it may have been carried by the westerly branch of the West Greenland Current. Records of *Periphylla* were scattered all around the edge of the shelf and over the Irminger Sea.

The distributions of the two species of *Sagitta* are shown in Chart 231. *S. elegans* was confined to stations over the shelf, while *S. maxima* was widespread in the Irminger Sea and along the edge of the shelf, both east and west of Greenland. The distribution of the commonest chaetognath, *Eukrohnia hamata*, is not shown on the chart but it was rather similar to that of *S. maxima*.

By far the commonest of the small copepods during NORWESTLANT 3 was *Oithona similis* which was widely distributed and particularly abundant on the East Greenland Shelf in the Cape Bille area, in the southern part of the Irminger Sea, and over the West Greenland Shelf north of about 65°N. *Pseudocalanus minutus* was the only other common small copepod present at most stations west of Greenland and was also present at many stations in the eastern part of the survey area when included in the analysis schedules.

VARIATIONS IN THE ABUNDANCE OF ZOOPLANKTON

The timing of the seasonal development of the main species and groups from April to July was strikingly different in the different regions surveyed. In order to simplify the description of these changes, the seven standard areas delimited in Chart 192 were selected and the average numbers of the various groups, species, or stages were calculated by the method described previously. The choice of areas was determined by many factors and, although they allow some broad comparisons with oceanographic features, it should be emphasized that there is no exact correspondence between these features and the boundaries of the standard areas.

Calanus finmarchicus

Since *Calanus* is both the dominant herbivore and the principal food consumed by cod and redfish larvae in the seas around Greenland, the seasonal development of this species will be considered in detail. Average numbers of each copepodite stage per m^2 of sea surface have been calculated for each survey in the seven standard areas using data from the Hensen-net samples. The averages obtained are shown as a series of histograms in Fig. 26. The six copepodite stages are, of course, not caught with equal efficiency by the nets used; e.g., stage I is not adequately sampled since it can pass through the No. 3 silk of a Hensen net (Cushing and Tungate, 1963). Subject to this limitation and the complications posed by water movements, some deductions can be made from the succession of copepodite stages in the different areas.

In regions such as the Clyde, Norwegian Sea, and East Greenland fjords, *Calanus* overwinters in deep water, mainly as late copepodite stages. During the spring, these copepodites ascend towards the surface, moult to become adults and spawn, and die soon afterwards (Marshall and Orr, 1955; Ostvedt, 1955).

During NORWESTLANT 1, completed in April, the population of *Calanus* in the top 100 m was mainly represented by adults (Fig. 26). Early copepodites were very scarce but the presence of slightly higher numbers of stage I than stage II, in areas such as the Davis Strait (NW) and East Greenland waters (GE), suggests that a little spawning had taken place.

By NORWESTLANT 2, all three western areas (sampled in June) had very high numbers of early copepodites, stage I being predominant. There was no indication that spawning had been earlier in the south; indeed, copepodites were more abundant in the Davis Strait (NW) than in the Labrador Sea (SW). In the two eastern oceanic regions (NE and SE) adult *Calanus* remained the commonest stage. During both May and June there was a marked scarcity of early copepodites in the northern Irminger Sea (NE) and the persistence of adult *Calanus* from the overwintering generation suggests that the main spring spawning had been delayed considerably in this area. The southern Irminger Sea (SE), sampled mainly in June, had a peculiar stage-composition with highest numbers of stages III and VI.

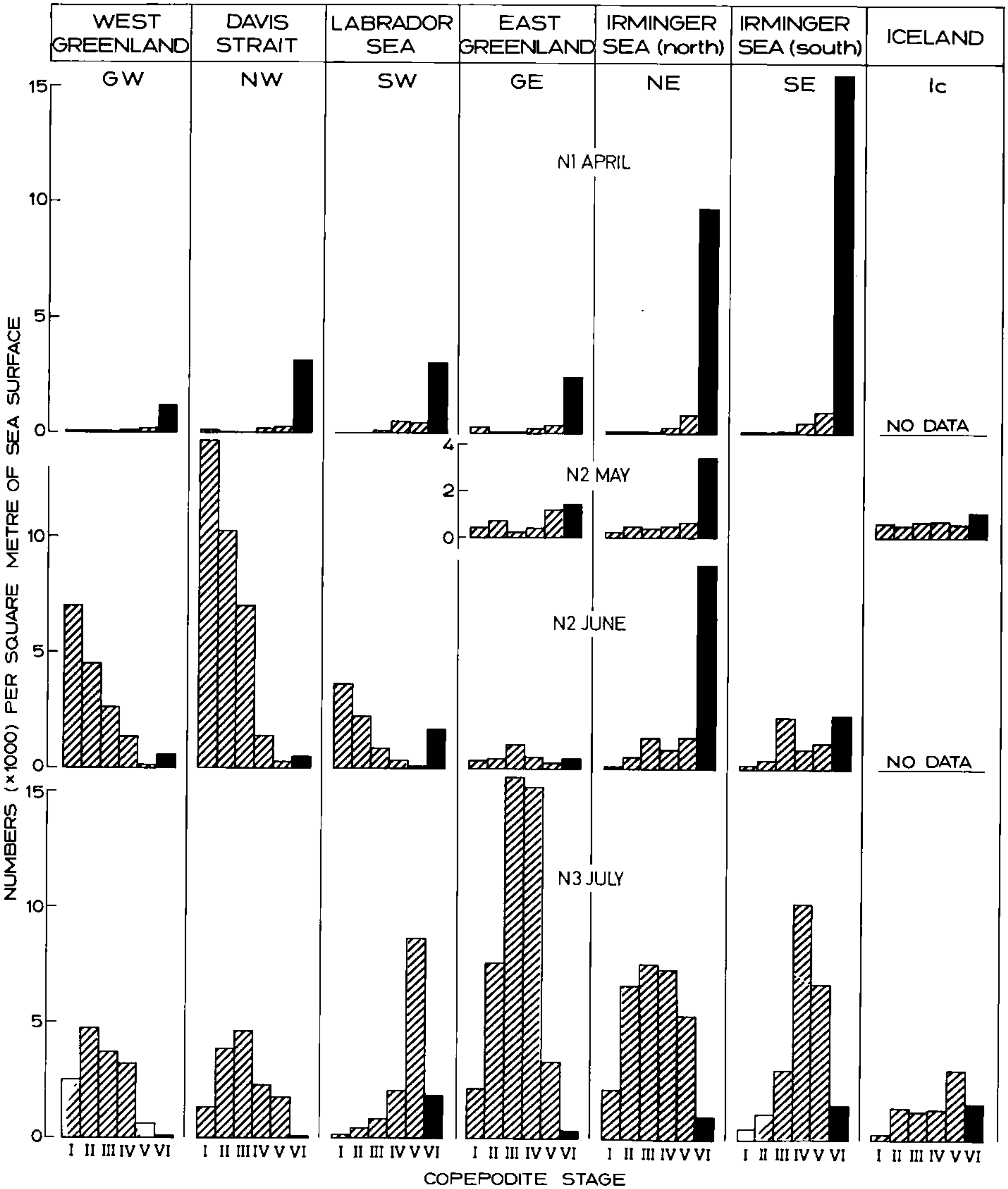

Fig. 26. NORWESTLANT 1-3. Average numbers of the adult and copepodite stages of *Calanus* under 1 m^2 in areas shown on Chart 192.

More detailed examination of the data revealed that most of the stage III copepodites were confined to a small part of the area and that over most of the southern Irminger Sea there was little evidence of the products of the spring spawning reaching early copepodite stages. East Greenland waters (GE) were sampled in May and June during NORWESTLANT 2. Adults were predominant off East Greenland in May but by June these had declined considerably and stage III was the most abundant copepodite, suggesting that the spring generation was a little more advanced than in the neighbouring northern Irminger Sea area. The average numbers of *Calanus* in Icelandic waters (Ic) sampled in May during NORWESTLANT 2 have been included in Fig. 26. Numbers were spread fairly evenly throughout the six copepodite stages and are difficult to interpret in terms of the life history since comparable data were not available for NORWESTLANT 1.

The stage-composition observed during NORWESTLANT 3 (July) indicates that the rate of development of the spring generation must have varied considerably throughout the survey area. In the western areas, stage V was numerically superior in the Labrador Sea (SW), stage III i n the central Davis Strait (NW) and stage II in the colder West Greenland waters. Considering the general similarity of the population structure in these three areas during NORWESTLANT 2, the rate of development would appear to be linked in some way with sea temperature. There were also big differences in the stage-composition of *Calanus* in the eastern half of the survey area with stage V preponderating off Iceland (Ic), stage IV in the southern Irminger Sea (SE) and stage III in both the northern Irminger Sea (NE) and East Greenland waters (GE). As in the western part of the survey area, the *Calanus* population in the south was more advanced than in the north. Despite the delay in the appearance of early copepodite stages in the northern Irminger Sea, evident from the results of the previous survey, the population structure of *Calanus* in this region during NORWESTLANT 3 was similar to that in the central Davis Strait (NW). More rapid growth in the northern Irminger Sea must have allowed the spring generation to catch up with that in the colder waters of the Davis Strait. The results for East Greenland waters during NORWESTLANT 3 are difficult to interpret. Although there had been a phenomenal increase in the total numbers of *Calanus* copepodites, compared with the previous month, very little change had occurred in the population structure and stage III remained the commonest copepodite. Considering that the East Greenland Current is relatively strong, these high numbers of copepodites may have been immigrants from the northeast. Gillbricht (this volume, p. 73) found evidence for a drift of phytoplankton into the area.

In conclusion, the most interesting feature of the seasonal development of *Calanus* revealed by the surveys was that the main period of spawning in the Irminger Sea during 1963 occurred about a month later than in other parts of the survey area. This was an abnormal event since the results of the Continuous Plankton Recorder Survey showed that in the northern Irminger Sea peak numbers of *Calanus* copepodites I-IV occurred a month later than the peak for the long-term mean (Glover and Robinson, Fig. 29, this volume). Geographical variations in the timing and intensity of the spring outburst of phytoplankton provide a possible explanation of the differences observed. Gillbricht (this volume, p. 73) found that in the Davis Strait the standing crop of phytoplankton was highest during NORWESTLANT 1 and declined thereafter reaching a minimum in NORWESTLANT 3. Fluctuations in the Irminger Sea were almost the mirror image with the average quantities of phytoplankton not approaching the NORWESTLANT 1 values for the Davis Strait until the final survey in July. Comparing his results with earlier observations, Gillbricht found that during 1963 phytoplankton values in the Irminger Sea were lower than in other years. The reproduction of *Calanus* is known to depend very closely on the food available. This has been demonstrated experimentally by Marshall and Orr (1964), who also found that seasonal variations of the reproductive rate in the Clyde area could be correlated with diatom increases.

Euphausiacea

In terms of biomass, euphausiids usually formed the second most important group of animals present in the net samples. Bainbridge and McKay (this volume, p.187) found that euphausiid nauplii formed a substantial part of the diet of early cod larvae off Iceland during NORWESTLANT 2 and that the calyptopis and early furcilia stages were frequent items in the guts of the large redfish larvae caught during NORWESTLANT 3.

Specific identifications and counts of the adult and furcilia stages were made on many of the stramin samples taken during NORWESTLANT 2 and 3. Table 18 gives the relative abundance of the different species in some of the standard areas.

The distribution of euphausiid species in the northern North Atlantic has been described by Einarsson (1945) and Dunbar (1964). *Thysanoessa longicaudata* is widespread in the northern North Atlantic and is a characteristic species of the upper layers of the ocean north of about the 10°C

TABLE 18. Average numbers of euphausiids (adults + furcilias) per 30-min-oblique haul (50 to 0 m) with the 2-m-stramin net during NORWESTLANT 2 and 3. The average numbers refer to the standard areas shown in Chart 192 for which data are available.

Species:	*Thysanoessa longicaudata*		*Meganyctiphanes norvegica*		*Thysanoessa inermis*		*Thysanoessa raschii*	
Standard area / Survey:	N2	N3	N2	N3	N2	N3	N2	N3
West Greenland (GW)	402	16	1	1	3	1	2	1
Davis Strait (NW)	43	29	0	0	1	1	0	0
East Greenland (GE)	236	509	4	56	3	0	0	0
Irminger Sea (south)(SE)	508	1,199	385	170	0	0	0	0

surface isotherm for May. In the NORWESTLANT Surveys it was particularly numerous in the Irminger Sea and was also common in the Labrador Sea (Charts 211 and 226). Being a surface oceanic species, it may be carried into shallower regions wherever oceanic water flows over the shelf, and this would account for its presence where the Irminger Current flows over the continental edge off East and West Greenland.

The distributions of some other euphausiids are shown in Charts 213 and 227. Among them is *Meganyctiphanes norvegica*, a species with a wide distribution in the Atlantic, but which seems to be mainly characteristic of slope waters (Einarsson, 1945; Dunbar, 1964). The distribution of *M. norvegica* during the NORWESTLANT Surveys would appear to be related to the sea floor topography, since it was mainly found in the vicinity of the Reykjanes Ridge and along the continental slopes off Iceland and Greenland. Off West Greenland adults and juveniles extended to 66°N, the northern limit of sampling, during NORWESTLANT 1, but during NORWESTLANT 2 and 3 the larval forms present did not occur so far north. The two species of *Thysanoessa* shown in Charts 213 and 227 were mainly limited to the shallow parts of the survey area. *T. inermis* was found over or close to the continental shelves of Iceland and Greenland and was also present over the Holsteinborg Ridge, suggesting that the species may extend across the Davis Strait in this region. Records of *T. raschii* were generally restricted to the cold coastal waters over the West Greenland Shelf in the northern part of the sampled area.

All the remaining euphausiids recorded were very rare with the exception of *Thysanopoda acutifrons* which occurred sporadically over deep water, mainly to the south and east of the Reykjanes Ridge, (but it was not included in the records of all the countries). The adults of this species are bathypelagic but the calyptopis and early furcilia stages may be found in surface waters (Einarsson, 1945).

Since specific identifications of the euphausiids were generally limited to the adult and furcilia stages it is only possible to consider the seasonal development of euphausiids as a group. The average numbers of the various developmental stages for six of the seven standard areas defined in Chart 192 were calculated using data from the vertical net samples. Interpretation of the results, which are shown in Fig. 27, can only be tentative since the nets used were obviously selective, giving a distorted picture of the true quantitative composition of the various stages in the top 100 m.

Adult and furcilia stages were not counted separately in many of the NORWESTLANT 1 samples, but it is clear from the data available that there were few, if any, furcilias present. Highest numbers of adult euphausiids were found in samples from the southern oceanic areas (SW and SE) and the presence of a few calyptopis stages in both regions suggests that some spawning had already occurred. Spawning had also begun in East Greenland waters (GE) since a few eggs and nauplii were found at three stations on Fylkir Bank and at two stations off Cape Farewell.

All the main developmental stages in the life history of the euphausiids were included in the analysis schedules for the majority of the samples collected during NORWESTLANT 2 and Fig. 27 shows that there were big regional differences in the average stage-composition. Eggs and nauplii predominated off West Greenland (GW) and were also common in the central part of the Davis Strait (NW), where calyptopes were the most numerous stage. Intensive spawning had recently occurred in both

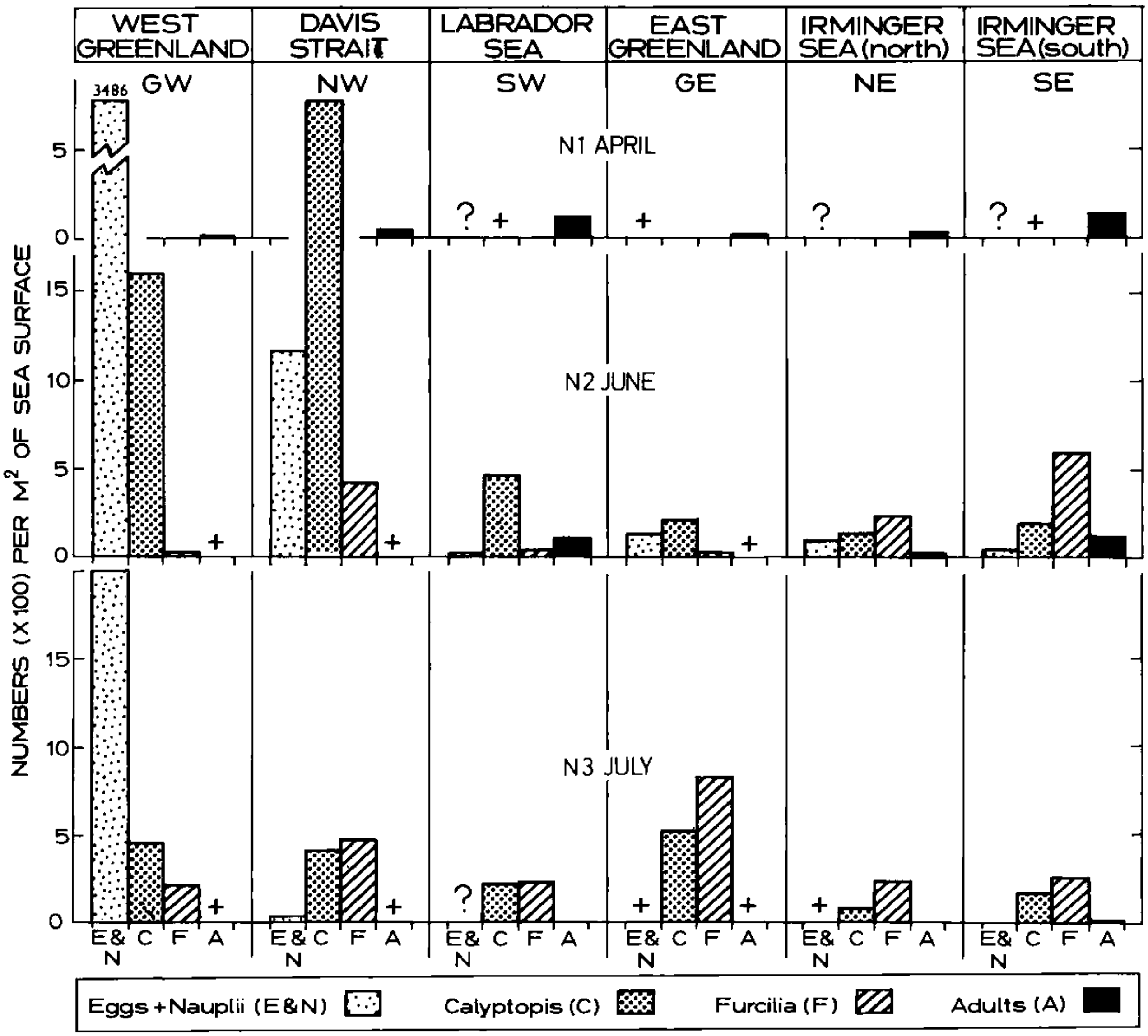

Fig. 27. NORWESTLANT 1-3. Average numbers of the adult and larval stages of euphausiids under 1 m² in areas shown on Chart 192 (+ = present in low numbers; ? = not included in analysis schedule).

areas but analyses were not sufficiently detailed to determine which of the three species of *Thysanoessa* were mainly involved. In the Labrador and Irminger Sea areas (SW, NE, and SE), where *Thysanoessa longicaudata* was dominant, the main spawning had probably taken place before NORWESTLANT 2 as eggs and nauplii were relatively scarce compared with the numbers of caluptopes and furcilias.

Although early stages were not recorded as consistently during NORWESTLANT 3, some data is available for five of the standard areas. Eggs and nauplii remained abundant in the West Greenland area (GW) during July. Largest numbers of nauplii were north of 64°N and eggs were only found north of 65°N. The early furcilias identified in this area were mainly *T. inermis*, but some *T. raschii* were also present. It may be inferred that these two species had continued to spawn at least until mid-July in this region. Both eggs and nauplii were rare or absent in all the other areas considered, including the central part of the Davis Strait, and furcilias were the predominant stage. It is noteworthy that adult euphausiids were very scarce during NORWESTLANT 3. Pavshtiks (1964) suggests that over continental shelves adult euphausiids were living near the bottom in July, since she found them in the stomachs of cod caught off Labrador and redfish caught off Cape Farewell.

To summarize, the main spawning of euphausiids occurred earlier in the relatively warm Atlantic water of the Irminger Sea, where *Thysanoessa longicaudata* and *Meganyctiphanes norvegica* predominate, than in the colder shelf waters where *T. inermis* and *T. raschii* were most common. No relationship was apparent between the breeding of euphausiids and the timing of the main phytoplankton growth.

Spiratella retroversa

The pteropod *S. retroversa* was a common member of the zooplankton and the larvae of this species, with shells in the range 100-150 µ across, sometimes formed an appreciable part of the diet of early redfish larvae (Bainbridge and McKay, this volume, p.187). All three charts of *S. retroversa* (Charts 200, 214, and 228) show that the area of greatest abundance was the Irminger Sea. It was also common where the water of the Irminger Current flows over the shelf off Southeast and Southwest Greenland. The species was generally scarce in the cold waters of the East and West Greenland Currents and very rare in the vicinity of Iceland.

For many of the samples from the vertically-hauled nets only the total numbers of *Spiratella* were estimated. However, in the samples taken by *Dana, Anton Dohrn,* and *Explorer* during NORWESTLANT 2 and 3, "large" and "small" specimens were counted separately. The two size groups were clearly distinct and it may be presumed that the small specimens were of the 1963 generation.

The average numbers of *S. retroversa* in the seven standard areas (Chart 192) are shown in Fig. 28 and when possible the histograms have been subdivided to show the numbers of large and small specimens. In the Irminger Sea (NE and SE) total numbers increased from NORWESTLANT 1 (April) to NORWESTLANT 3 (July) with the greatest increase in the south. Although no quantitative data are available a similar big increase probably occurred in the Labrador Sea (SW), since Pavshtiks (1964) reported that many *S. retroversa* were present in this region during NORWESTLANT 3 and noted that the young were widely distributed. The two standard areas off the Greenland coast (GE and GW), which include the cold East and West Greenland Currents, showed no substantial increase in numbers until after June, i.e. between NORWESTLANT 2 and 3. In both these areas, as in the southern Irminger Sea (SE), the increase of total numbers was entirely due to small individuals, while the numbers of large specimens tended to decline. Off Iceland (Ic) and in the Davis Strait (NW) there were fewer *Spiratella* present during July than in April. The scarcity of small specimens in the Davis Strait during July suggests that there was no significant reproduction of the species in the area. The replenishment of the population in this area may largely depend on the penetration of Atlantic waters.

Medusae

The data available allow the distributions of three species of medusae, *Aglantha digitale*, *Halopsis ocellata*, and *Periphylla periphylla* to be considered in some detail.

Aglantha digitale, a member of the hydromedusae, frequently constituted a substantial part of the total volume of samples taken by all types of net and was obviously one of the more important carnivores of the zooplankton community. Kramp (1959) describes the species as very common in all arctic and subarctic seas with a wide distribution extending into the boreal regions. With reference to the Irminger and Labrador Seas, Kramp (1947) wrote, "at any time between May and August from which material is available, small as well as large specimens were taken". It is not surprising, therefore, that there were few stations on any of the NORWESTLANT cruises where *Aglantha* was absent (Charts 201, 215, and 229). These few stations were chiefly on the Icelandic Shelf west of Faxa Bay and in the central part of the Labrador Sea. The species was most plentiful off the East and West Greenland Shelves where the Irminger Current and East Greenland Current meet and mix, and in the Atlantic water of the southeastern part of the survey area. The distribution during NORWESTLANT 2 (Chart 215) was in marked contrast to that observed by Dietrich, *et al.* (1961) in May and June 1955 when far higher numbers, exceeding 10,000 per m^3 were present in the central part of the Irminger Sea and in the Davis Strait.

In the Guide Book to Surveys NORWESTLANT 1-3 the following note on *Aglantha* was based on Danish experience: "The usual 'white' form occurs almost everywhere in the Davis Strait, but in decreasing

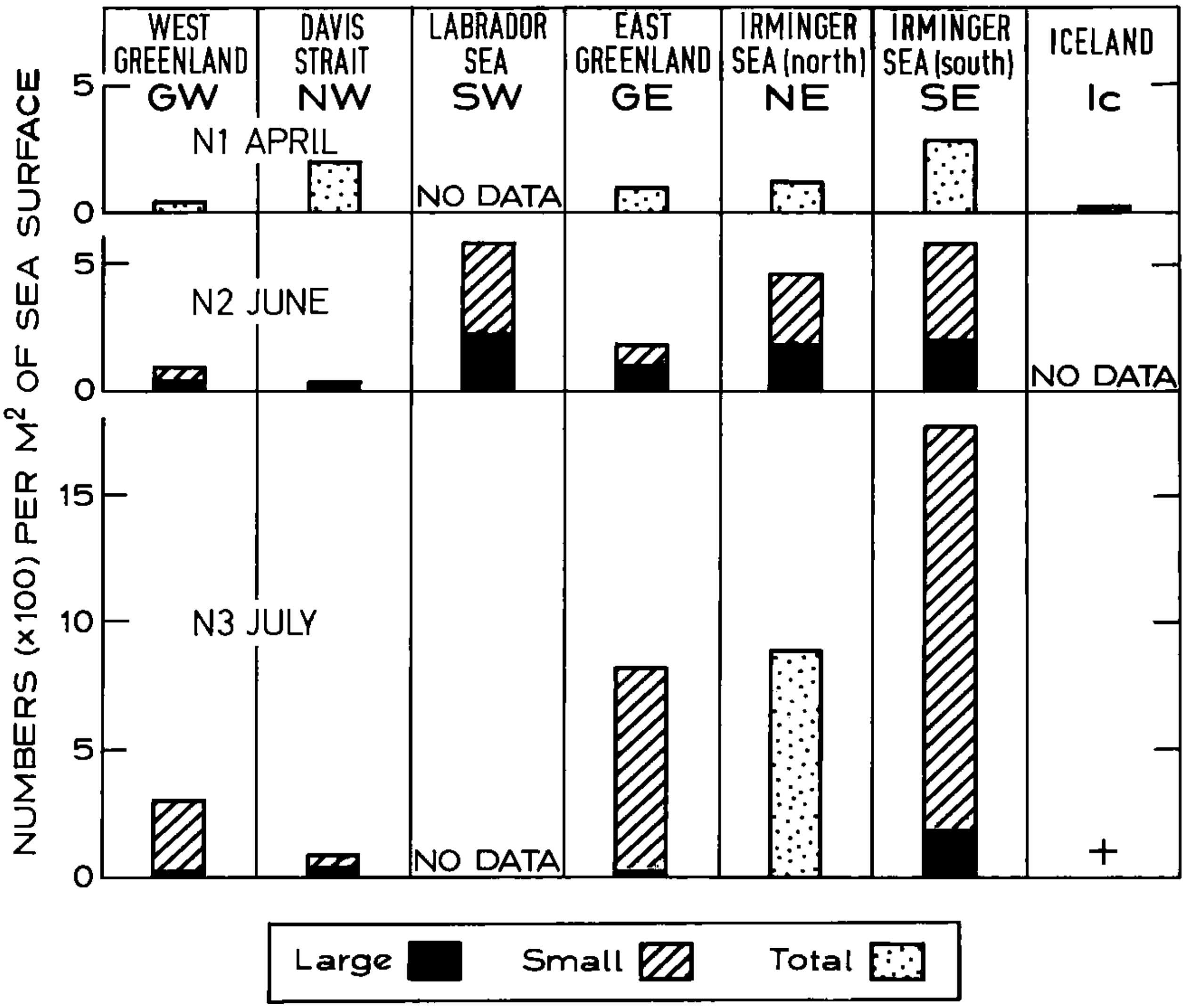

Fig. 28. NORWESTLANT 1-3. Average numbers of large and small specimens of *Spiratella retroversa* under 1 m^2 in areas shown on Chart 192.

numbers the colder the water, and it is replaced by the 'red' form in arctic waters. This latter will, however, lose its red colour very shortly after being caught. It is consequently necessary to determine the percentage composition of red to white *Aglantha* - immediately after they are caught". The only country reporting on the red *Aglantha* was the USSR on NORWESTLANT 3. At two stations close to Cape Farewell and one on Hamilton Inlet Bank "*Aglantha digitale* of orange colour were found, these specimens constituted about 10% of the quantity of usual white *Aglantha digitale*".

The hydromedusa, *Halopsis ocellata*, and the large scyphomedusa, *Periphylla periphylla*, were included in the analysis schedules since it was thought they might prove useful as biological indicators of different water masses.

Kramp (1947) describes *Halopsis ocellata* as a "meroplanktonic, neritic medusa ..... common in the coastal areas of the Northeast Atlantic ..... frequently taken above deep water west of the British Isles and south of Iceland following the circulations of the Gulf Stream system"; and he records it as indigenous in the West Greenland coastal area. In the NORWESTLANT Surveys it occurred over the shelf off Iceland and both East and West Greenland. *Halopsis* was occasionally found beyond the shelf over deep water in the Irminger and Labrador Seas and isolated specimens were recorded well away from the shelf in the Irminger Sea (Charts 216 and 230). The only addition to Kramp's account is in its frequency of occurrence over the East Greenland Shelf from the Denmark Strait to Cape Farewell on Surveys 1 and 3.

Periphylla periphylla is described by Kramp (1947) as a "bathypelagic medusa widely distributed in the deep parts of all the great oceans except the Arctic"; he also notes it "is very abundant in the Atlantic Ocean south of the submarine ridges between Scotland, the Faroes, Iceland, Greenland and Baffinland. It has its main occurrence in the deep and intermediate strata, but it may sometimes ascend towards the surface and be carried considerably farther northwards, but it evidently avoids areas where cold currents prevail". The distributions during the NORWESTLANT Surveys are in general agreement with Kramp's observations since it was found in the upper layers, chiefly over deep water, along the edges of the shelf off Iceland and East and West Greenland (Charts 216 and 230). During NORWESTLANT 2 *Periphylla* was also present at many stations in the Irminger Sea (Chart 216).

No other medusae were recorded regularly, but in his unpublished notes on the Canadian samples from NORWESTLANT 2 E. H. Grainger observes "most of the comparatively rare finds of *Hybocoden*, *Rathkea*, *Leuckartiaria*, *Bougainvillia*, and *Halitholus* were over the Greenland banks". These are all neritic species which have previously been recorded in West Greenland coastal areas.

Chaetognatha

The Chaetognatha have attracted considerable attention as "biological indicators" and were therefore included in the analysis schedules for the NORWESTLANT samples. Specific determinations of the group were normally carried out on the stramin samples and Table 19 shows the average numbers during NORWESTLANT 2 and 3 for the standard areas of Chart 192. *Eukrohnia hamata* was clearly the most abundant of the chaetognaths in all areas for which information was available. *Sagitta maxima* was also found in all these areas, with highest numbers in the southern Irminger Sea (SE), while *Sagitta elegans* was mainly limited to the areas adjacent to the Greenland coast (GE and GW). Only one other species was recorded, *Sagitta serratodentata*, with occasional specimens in the Irminger Sea.

TABLE 19. Average numbers of chaetognaths per 30-min-oblique haul (50 to 0 m) with the 2-m-stramin net during NORWESTLANT 2 and 3. The average numbers refer to the standard areas shown in Chart 192 for which data are available.

Standard area	Species: *Eukrohnia hamata*		*Sagitta maxima*		*Sagitta elegans*	
Survey:	N2	N3	N2	N3	N2	N3
West Greenland (GW)	871	56	80	1	2	3
Davis Strait (NW)	471	174	55	27	0	1
East Greenland (GE)	1,138	284	39	18	46	0[a]
Irminger Sea (south)(SE)	482	1,104	153	713	1	0

[a] Present in Hensen-net samples

The distributions of *Sagitta maxima* and *Sagitta elegans* during the three surveys are shown in Charts 202, 217, and 231. *S. elegans* is probably the most frequently cited indicator species and Fraser (1961) has made some comments on its distribution which are relevant to the NORWESTLANT area. He notes that the species appears to require both coastal (or bottom) influence as well as oceanic. In an area dominated by coastal water it may be considered an indicator of an admixture of oceanic water (e.g., North Sea, English Channel) but where the water is dominantly oceanic it is an indicator of coastal influence (e.g., Faroe Islands, Icelandic Shelf). The position of *S. elegans* as a coastal form off Faxa Bay, Iceland, and in the seas around Greenland was manifest during all three surveys. In the Greenland area it was not strictly confined to the cold water of the East and West Greenland Currents but was also found where the warmer water of the Irminger Current flows over the shelf. Records of *S. elegans* over deeper water in the central parts of the Davis and Denmark

Straits during NORWESTLANT 3 are in general agreement with the pattern of currents shown in the Physical Oceanography section (this volume, p. 31).

Sagitta maxima has been described as a cosmopolitan species associated with the deep- or middle-water layers of the ocean (Alvarino, 1965) while Fraser (1951, 1961) considers it to be a cold-deep-water species in the Scottish area and has also listed it as characteristic of arctic or boreal water found in lower latitudes. On all three surveys substantial numbers of *S. maxima* were present in samples taken within the upper 50 m in the Irminger Sea. It was recorded around the edge of the Greenland Shelf and occasionally over the shelf, although it was rarely found together with *S. elegans*. The two regions at which *S. maxima* was found nearest to the Greenland coast were in the vicinity of Fulkir Bank, East Greenland during all three surveys, and south of Frederikshaab, between 61° and 62°N, off West Greenland during NORWESTLANT 3 (Charts 202, 217, and 231). The isotherms for the surface and 50 m given in the section on Physical Oceanography suggest that the warmer Atlantic water had penetrated close to the Greenland coast in both these regions.

SYNOPSIS AND CONCLUDING REMARKS

The NORWESTLANT Surveys have revealed some distinct regional differences in the composition of the zooplankton of the upper 100 m although one animal, *Calanus finmarchicus*, was predominant throughout virtually the whole of the survey area.

In samples taken over deep water in the Irminger and Labrador Seas the species-composition showed considerable uniformity. *C. finmarchicus* was by far the dominant member of the zooplankton followed by such species as *Euchaeta norvegica*, *Thysanoessa longicaudata*, *Conchoecia obtusata*, *Spiratella retroversa*, *Aglantha digitale*, and *Eukrohnia hamata*. The plankton community was rather similar in the central part of the Davis Strait but, in addition to the dominant *Calanus finmarchicus*, there were substantial numbers of *C. glacialis* and *C. hyperboreus*. Larvaceans, mainly *Oikopleura* spp. were also abundant while *Spiratella retroversa* was scarce compared with numbers in the open Atlantic.

Quantities of zooplankton were lowest in the cold water of the East and West Greenland Currents. Off both coasts *Oithona* spp. (mainly *O. similis*) was second in abundance to *Calanus*, but otherwise there were considerable differences between east and west. Certainly during NORWESTLANT 2, far higher numbers of euphausiids, larvaceans, and the larvae of bottom-living invertebrates were present off the western than the eastern seaboard of Greenland. The zooplankton of Icelandic coastal waters showed a greater diversity of species than is indicated by the averages for the standard area Ic of Table 16. Many of the samples taken close to the coast were not analyzed because of the large quantities of diatoms present, but the few samples in the vicinity of Faxa Bay, for which data are available, contained many small copepods, including *Temora longicornis*, *Pseudocalanus minutus*, *Acartia* spp., and *Centropages* spp. in addition to *Calanus*. Larvae of benthic invertebrates also constituted a large part of the zooplankton in this region.

An interesting feature shown by the NORWESTLANT samples was the geographical variation in the seasonal development of the main groups. In particular, the main spring spawning of *Calanus* had been completed by early June within the Davis Strait but was evidently still proceeding in the Irminger Sea during this month. Euphausiids showed the opposite trend with the evidence pointing to later and more prolonged spawning in the Davis Strait than in the Irminger and Labrador Seas, while *Spiratella retroversa* was relatively scarce in the Davis Strait and little or no reproduction of the species occurred in this region. These regional differences occurred during 1963 and it should be noted that there can be considerable annual variation in the seasonal timing and abundance of *Calanus*, *Spiratella* and Euphausiacea (Glover and Robinson, this volume, p. 123).

The zooplankton investigations described in this report form part of a comprehensive study of the environment of cod and redfish larvae in the seas around Greenland. It is generally accepted that the larval phase in the life history of the fish is critical and two of the main causes of larval mortality are thought to be starvation and predation, both of which will be directly influenced by the abundance and composition of the zooplankton. Young cod and redfish are known to feed mainly on the early stages of copepods so the availability of suitable food will largely depend on how closely the development of the fish larvae is synchronized with the main period of reproduction of the copepods, especially the dominant form *Calanus*. This argument will be considered in greater detail in the report on the feeding of fish larvae (Bainbridge and McKay, this volume, p. 187). Predation losses will depend on the abundance of predators and the length of time the fish larvae remain vulnerable members of the zooplankton ecosystem. Unfortunately, data on the distribution and abundance of several important carnivorous groups did not cover the entire survey area. However, some observations on the abundance of predators within the area of distribution of cod eggs and larvae are given as an Appendix to this paper.

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APPENDIX I

NOTES ON THE ABUNDANCE OF POTENTIAL PREDATORS OF COD EGGS AND LARVAE DURING THE NORWESTLANT SURVEYS

An assessment of the possible intensity of predation on fish eggs and larvae in different parts of the area covered by the NORWESTLANT Surveys is difficult since little is known of the relative importance of the various carnivorous species as predators of young fish. Fraser (1961) cites coelenterates, especially *Aglantha*, together with ctenophores, chaetognaths, and siphonophores as serious predators of fish larvae. Among other forms known to be voracious feeders on a wide variety of zooplankton are the hyperiid amphipods, adult *Meganyctiphanes*, *Euchaeta*, *Tomopteris*, and small cephalopods. Another common carnivorous species in the North Atlantic is *Clione* but this gastropod may be a selective feeder on *Spiratella* (Bigelow, 1924).

Table 16 of the Zooplankton Report (this volume, p.106), which gives average numbers of animals taken by the vertical-net hauls during NORWESTLANT 2, shows that most of these predators were more abundant in the oceanic standard areas (NE, SE, NW, and SW) than in the two areas adjacent to the coast of Greenland (GE, and GW). This suggests that fish larvae over deep water may have been subjected to a greater intensity of predation than those in shallower water around Greenland. Detailed analyses were available for the zooplankton from the stramin-net hauls taken off West Greenland during NORWESTLANT 2 and 3 so a comparison could be made of the average numbers of carnivorous zooplankton at those stations with cod larvae over shallow water (under 300 m) and deep water (greater than 300 m). The averages given in Appendix Table 1 suggest that cod larvae carried over deep water by branches of the West Greenland Current were moving into a more hazardous environment with greater numbers of potential predators.

APPENDIX TABLE 1. Average numbers of predators per 30-min-oblique haul (50-0 m) with the 2-m-stramin net off West Greenland during NORWESTLANT 2 and 3. The averages refer to shallow (< 300 m) and deep (> 300 m) stations with cod larvae.

	NORWESTLANT 2		NORWESTLANT 3	
	Shallow	Deep	Shallow	Deep
Aglantha	49.4	187.8	1,585.1	2,379.0
Other medusae	17.2	3.5	88.2	35.2
Siphonophora	2.3	5.6	0.3	0.2
Chaetognatha	10.0	1,560.4	16.1	29.2
Tomopteris	+	51.8	0.1	0.2
Clione	2.7	3.0	18.4	45.2
Cephalopoda	0.3	1.4	7.8	12.3
Euchaeta	0.9	248.6	0.7	294.3
Hyperiids	18.6	21.7	52.1	2,609.4
Number of stations	13	11	16	15

Since data on the carnivorous members of the zooplankton were rather limited, no satisfactory comparisons could be made between the numbers of possible predators of cod larvae off Greenland and in the vicinity of Iceland. During NORWESTLANT 1 information on some of the larger carnivorous zooplankton was obtained for the northern part of the Irminger Sea and distributions have been discussed by Beaudouin (1967). Chart 201 shows that *Aglantha* was common off East Greenland but absent from stations near Iceland. The scarcity of chaetognaths in the vicinity of Iceland has also been mentioned in the report on zooplankton and is also clearly shown on the charts given by Beaudouin (1967). Cod eggs and larvae present off Iceland would therefore seem to be associated with fewer predators than those from the neighbouring spawning grounds off East Greenland during NORWESTLANT 1.

Unfortunately, there are no data on the abundance of several of the main carnivorous groups in Icelandic waters for NORWESTLANT 2 but by NORWESTLANT 3 *Aglantha* was relatively common in this area (Chart 229). The average numbers of carnivores taken by the vertical-net hauls in the two main regions with cod larvae during NORWESTLANT 3 are given in Appendix Table 2. These averages,

APPENDIX TABLE 2. Average numbers of predators under a m^2 of sea surface during NORWESTLANT 2 calculated from the vertical-net samples. The averages refer to stations with cod larvae in each area.

	Denmark Strait	West Greenland
Aglantha	112.7	3.0
Chaetognatha	16.4	11.4
Tomopteris	31.9	0
Clione	0.4	2.0
Euchaeta	20.5	21.9
Hyperiids	0.2	5.2
Number of stations	38	31

which were obtained using only stations with cod larvae, suggest that more predators were associated with the patch of larvae off Iceland and in the Denmark Strait than with the larvae found off West Greenland. However, the young cod present during NORWESTLANT 3 had a length range from 7 to 61 mm with almost half the population exceeding 25 mm in length (Hansen, this volume, p.127). Most of these young fish would appear to be too large to be captured by the size-range of predators which are normally sampled by vertical-net hauls.

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APPENDIX II

List of species referred to in the report, together with authorities.

MEDUSAE	*Periphylla periphylla*	Peron and Lesueur
	Aglantha digitale	(O. F. Müller)
	Halopsis ocellata	Agassiz
CHAETOGNATHA	*Sagitta elegans*	Verrill
	Sagitta maxima	Conant
	Sagitta serratodentata	Krohn
	Eukrohnia hamata	(Möbius)
POLYCHAETA	*Tomopteris septentrionalis*	Quatrefages
OSTRACODA	*Conchoecia obtusata*	G. O. Sars
	Conchoecia elegans	G. O. Sars
	Conchoecia borealis maxima	G. O. Sars
CLADOCERA	*Podon leuckarti*	G. O. Sars
	Evadne nordmanni	Lovén
COPEPODA	*Calanus finmarchicus*	(Gunnerus)
	Calanus glacialis	Jaschnov
	Calanus hyperboreus	Krøyer
	Eucalanus elongatus	Dana
	Rhincalanus nastutus	Giesbrecht
	Pseudocalanus minutus	(Krøyer)
	Microcalanus pygmaeus	G. O. Sars
	Pseudaetidius armatus	(Boeck)
	Euchirella rostrata	(Claus)
	Euchaeta glacialis	H. I. Hansen
	Euchaeta norvegica	Boeck
	Scolecithricella minor	(Brady)
	Scolecithricella ovata	(Farran)
	Centropages hamatus	(Lilljeborg)
	Temora longicornis	(O. F. Müller)
	Metridia lucens	Boeck
	Metridia longa	(Lubbock)
	Heterorhabdus norvegicus	(Boeck)
	Acartia longiremis	(Lilljeborg)
	Oithona similis	Claus
	Oncaea borealis	G. O. Sars
AMPHIPODA	*Gammarus wilkitzki*	Birula
	Lanceola clausi	Bovallius
	Apherusa glacialis	(H. J. Hansen)
	Parathemisto abyssorum	(Boeck)
	Parathemisto libellula	(Mandt)
	Parathemisto gaudichaudi	(Guerin)
EUPHAUSIACEA	*Thysanopoda acutifrons*	Holt and Tattersall
	Meganyctiphanes norvegica	(M. Sars)
	Thysanoessa longicaudata	(Krøyer)
	Thysanoessa inermis	(Krøyer)
	Thysanoessa raschii	(M. Sars)
GASTROPODA	*Spiratella retroversa*	(Fleming)
	Spiratella helicina	(Phipps)
	Clione limacina	(Phipps)
LARVACEA	*Fritillaria borealis*	Lohmann

Continuous Plankton Records During the NORWESTLANT Surveys, 1963 – Zooplankton

By

R. S. Glover[1] and G. A. Robinson[1]

MATERIAL AND METHODS

Throughout 1963, as in previous years, Continuous Plankton Recorders (Hardy, 1939; and Glover, 1962) were towed at the standard depth of 10 m in the North Atlantic, including the region of the NORWESTLANT Surveys. The routes used during 1963 are shown in Fig. 23*a* of the paper by Robinson (this volume, p. 95). The survey was supported by H.M. Treasury, through a grant from the Development Fund, and by Contract N62558-3612 between the Office of Naval Research, Department of the United States Navy, and the Scottish Marine Biological Association.

The monthly fluctuations in abundance of some of the characteristic zooplankton organisms throughout the year are presented here in order to provide a background to the NORWESTLANT collections. The region including and adjoining the NORWESTLANT Survey is divided into eight areas, according to the standard method of presenting the results of the Plankton Recorder Survey (see Fig. 23*b* of the paper by Robinson, this volume, p. 95).

The histograms in Fig. 29 show the average monthly abundance of the selected organisms; the results for April-August, the period of NORWESTLANT, are stippled. A break in the base line shows that there was no sampling in that month. For details of the method of calculating the average number per sample, see Robinson (this volume). In order to compare the results for 1963 with the "normal" seasonal cycle, the long-term averages are shown as line graphs. These were calculated by combining all the available results for each month from 1955 to 1964. Because of the westward extension of the Recorder survey in recent years, the long-term averages are based on variable periods of sampling. Areas B6, C8, and D7 have been sampled only during the last 3 or 4 years and the long-term means are shown as broken lines. Sampling in area B8 (west of Greenland) started in 1962 and there is insufficient data for the calculation of a long-term mean in this area.

DISTRIBUTION AND ABUNDANCE

In 1963 the numbers of total Copepods were close to the average in most areas, particularly during the NORWESTLANT Surveys, but they were lower than usual for most of the year in area B6 (south of Iceland) and appreciably higher in area D7 (a little to the southeast of the NORWESTLANT area). There were high peaks of abundance in April in areas C7, C8, and D7.

The results for *Calanus finmarchicus*, which was the dominant copepod throughout the whole area, are presented in two series of histograms, one for copepodite stages I-IV, the other for stages V-VI. The young stages were more abundant than usual in most areas, especially in the second half of the year.

Adult *Calanus*, also, were more numerous than usual in most areas during and after the NORWESTLANT Survey, but they were rather below average in May-July in area C8 in the southwestern part of the survey. In area B8 (off the west coast of Greenland) they were less abundant in 1963 than in 1962, the only year for which there are comparable data in this area. In general, the numbers of adults remained high until October and November.

Euchaeta norvegica was the only other copepod that was abundant and widespread but it was absent from the waters west of Greenland (area B8) where it had occurred in May and June of 1962. It was much more numerous than usual in areas B6, B7, C7, C8, and D7. Because of the strong diurnal migrations of this species, the histograms are based on night samples only.

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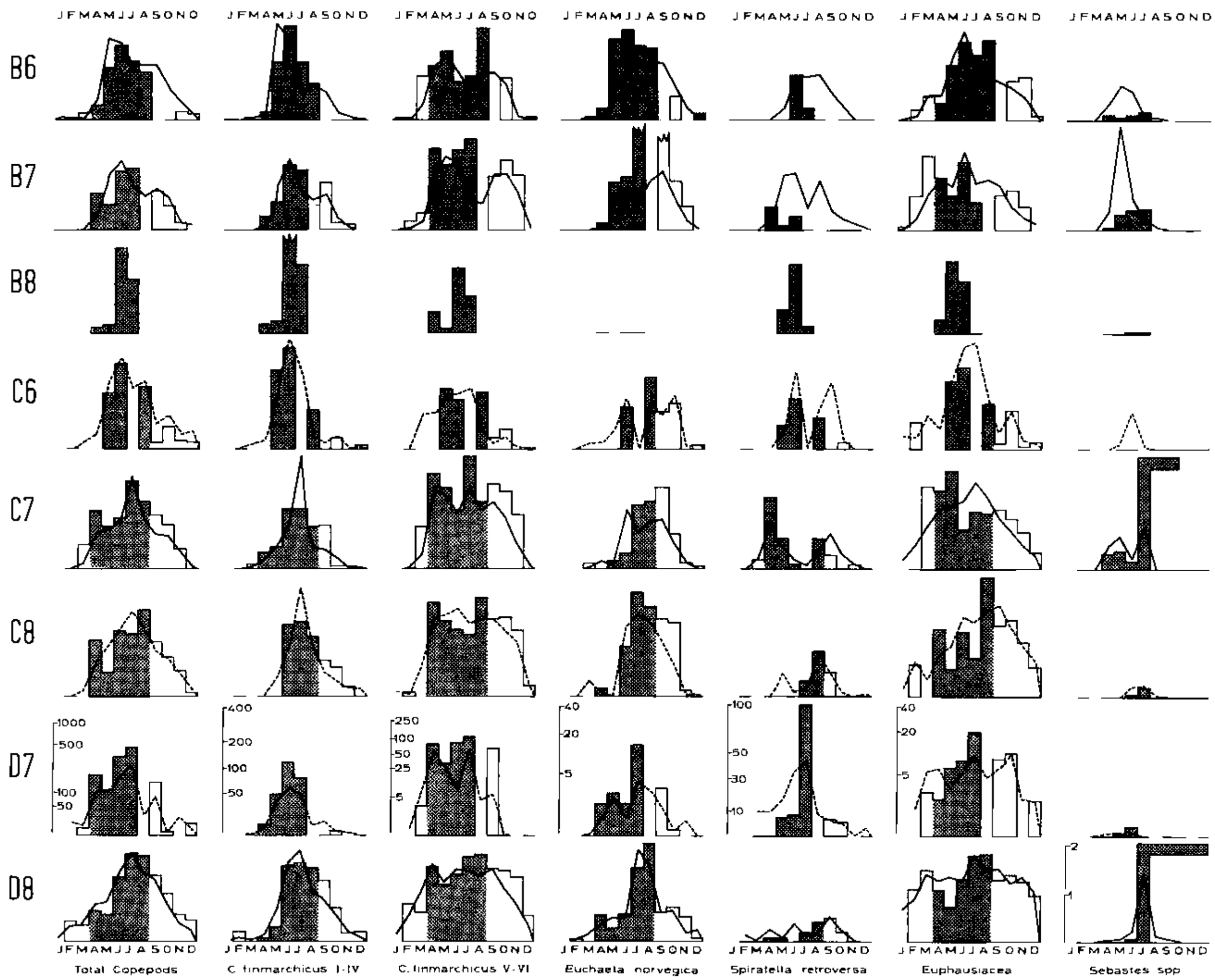

Fig. 29. Histograms showing the average number, per Recorder sample, of total Copepods, *Calanus finmarchicus*, *Euchaeta norvegica*, *Spiratella retroversa*, *Euphausiacea*, and *Sebastes* larvae during 1963. The code (B6, B7, etc.) refers to the subareas shown in Fig. 23*b*. The line graphs show the long-period means based on a combination of all Records in these subareas since 1955. For further details see text.

The pteropod, *Spiratella retroversa*, was unusually scarce. The season was very short and numbers were extremely low in areas B6 and B7 compared with the long-term means, and it was not found at all in these areas in the second half of the year when it is usually abundant. There were short periods of abundance in April in area C7 and July in D7, and it was more abundant in area B8 than in 1962. This species has been rare, also, in the eastern North Atlantic since 1954, although it showed signs of a recovery there in 1963 when it was more abundant than in any year since 1956.

Euphausiids were close to or a little below average on the whole but their numbers fluctuated more erratically than the other organisms. The great majority were *Thysanoessa longicaudata*. Adults were more numerous than usual in spring in areas B7 and C7, to the east and southeast of Greenland; the high numbers in July in area D7 and August in areas B6 and C8 were mostly young stages.

The young stages of redfish (*Sebastes*) were much less numerous than usual, especially at the beginning of their normal season, and were abundant only in July in area D8 (northeast of Newfoundland,

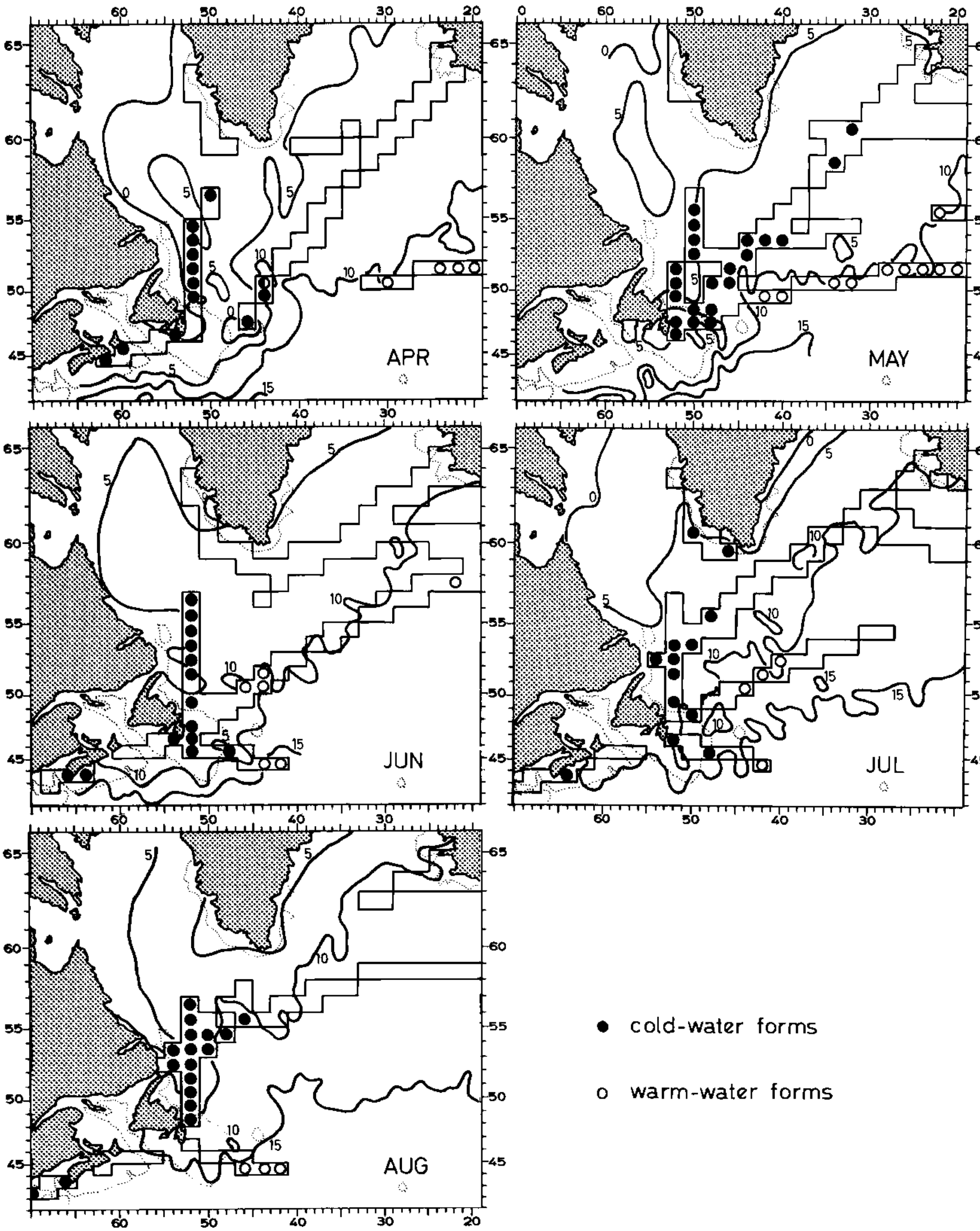

Fig. 30. Charts showing the distribution of warm- and cold-water species in Recorder samples from April to August, 1963 (see text). The surface isotherms for 0°, 5°, 10°, and 15°C are taken from the Monthly Ice Charts produced by the Marine Division of the British Meterological Office (with the permission of the Controller of H.M. Stationery Office).

where the larvae had sub-caudal melanophores) and area C7 (southeast of Greenland, where they did not). Their distribution is discussed in more detail by Henderson (this volume, p.157).

Figure 30 shows the distribution of the characteristic "cold" and "warm" water communities of plankton during the NORWESTLANT Survey, as determined from Continuous Plankton Records. The results are plotted in rectangles of 1° lat by 2° long. The species used to define the two plankton communities are listed below.

Cold-water forms: *Calanus glacialis, Metridia longa, Calanus hyperboreus, Ceratium arcticum.*

Warm-water forms: *Doliolum nationalis, Salpa fusiformis, Doliotetta gegenbauri, Clausocalanus* spp., *Calocalanus* spp., *Mecynocera* spp., *Calanus helgolandicus, Calanus gracilis, Calanoides carinatus, Euchirella rostrata, Euchaeta acuta, Undeuchaeta plumosa, U. major, Pleuromamma abdominalis, P. borealis, P. gracilis, P. piseki, Rhincalanus nasutus, Eucalanus elongatus, Centropages bradyi, Scolecithrix danae, Temora stylifera, Nannocalanus minor, Heterorhabdus papilliger.*

The surface isotherms in Fig. 30 are taken (with the permission of the Controller of H.M. Stationery Office) from monthly ice charts for 1963 issued by the Marine Division of the UK Meteorological Office. They are based on routine observations by merchant ships and naval vessels in the course of their normal meteorological observations.

Clear patches of warm-water species appeared to shift northwards from April to July and, perhaps to August, although the sampling was inadequate in this month. There is an obvious association with the surface temperatures, the 10° isotherm corresponding roughly with the northern boundary of the warm-water species which are presumably associated with the Gulf Stream system. Over the greater part of the area there was a mixed or temperate plankton but the region off the Labrador and Newfoundland coasts was always characterized by cold-water plankton belonging to the waters of the Labrador Current. The boundary between the two major current systems was always evident to the east of Newfoundland.

CONCLUSIONS

Calanus finmarchicus and *Thysanoessa longicaudata* are the two dominant members of the plankton throughout the area of the NORWESTLANT Surveys. They were both present in numbers not very different from the long-term mean, although adult *Calanus* were above average, especially in the second half of the year, and the euphausiids a little below. *Euchaeta norvegica,* always an important part of the plankton in this area, was appreciably more abundant than usual but *Spiratella* was well below the long-term average. The planktonic larvae of *Sebastes* was relatively scarce at the beginning of their normal season but later became abundant (in July).

The Recorder survey has been operated in areas B6 and B7 (between Greenland and Iceland) since 1957. Therefore, it is possible to make more detailed long-term comparisons in these areas. The results show that there is considerable variation in the seasonal timing and abundance of the dominant plankton organisms. Young stages of *Calanus* were very abundant in 1959 and 1962 in area B6. Adult *Calanus* were numerous in 1960, 1962, and 1963 in area B6 (south of Iceland) but in B7 they were more abundant in 1963 and 1964 than in any other year since 1957.

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Report on Cod Eggs and Larvae

By

Paul Hansen[1]

Owing to the importance of the cod for the commercial fishery in Greenland waters, special studies on its propagation have been carried out for many years. These studies included researches on the amount and distribution of cod eggs and larvae in different years in the hope that it should be possible to predict the occurrence of rich year-classes in the stock of cod 5 years before their entering in the commercial catches. One of the items on the programme of the NORWESTLANT Surveys was an extension of this work. The results are shown in Charts 232-236.

The gears used were the 2-m-stramin net, Hensen net, Helgoland net, and Icelandic High Speed Sampler (IHSS). The results for stramin net are given as numbers per 30-min haul, for the Hensen net and Helgoland net as numbers per m^2, and for the IHSS as numbers per m^3. The stramin net yielded by far the best catches, in particular of larvae. The catches from the other gears were rather poor, and the IHSS, especially, gave very small catches. The differences between the catches of the different gears were so irregular that it was impossible to convert them to a common unit.

As the stramin net proved to be the best gear, catches taken with it have been given preference on the charts. For instance, the stramin-net catches of cod eggs during NORWESTLANT 1 are shown in Chart 232 on the large chart, while catches with the Hensen net and IHSS are shown on the two small charts inserted in the right corner. All stations are shown as dots. Hatching is used to indicate catches of eggs in Chart 232, where eggs predominate, while catches of larvae are shown as symbols. In the other three charts, where catches of larvae predominate, the larvae are shown by hatching and symbols are used for eggs.

NORWESTLANT 1

Chart 232 gives the distribution of cod eggs and larvae. Cod eggs were caught at the majority of stations east and west of Greenland. Cod larvae were found at one station close to the south-eastern coast of Iceland (11 specimens) and at five stations near the southeast coast of Greenland (total eight specimens).

Rather dense concentrations of cod eggs were found in many places in the whole area, especially over the offshore banks and over the western slopes of the banks in the Davis Strait. Farther out in the Davis Strait the number of eggs diminished, and in the middle of the Davis Strait very few were caught with the stramin net and none with the Hensen net.

Large concentrations of cod eggs were observed at the stations between 55° and 59°N near the Labrador coast where the Labrador cod stock evidently has its spawning grounds. On the "Godthåb" expedition in 1928 cod eggs were also found near these places. The northern boundary for cod eggs in the Davis Strait was 66°N which is in accordance with previous observations.

South of Cape Farewell between 56° and 57°N some cod eggs were taken with the Hensen net and IHSS. The spawning season for cod in Greenland waters usually starts at the end of March or the beginning of April. NORWESTLANT 1 was carried out practically in the middle or a little after the middle of the spawning season, therefore, it can be assumed that the largest number of the recently spawned eggs had not been transported far by the current, but were still present in the water layers over the spawning places. Therefore, Chart 232 may be considered as showing roughly the cod spawning places in Greenland waters.

Very little is known about the occurrence of cod eggs on the spawning grounds off East Greenland.

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Apparently, a rather heavy spawning takes place west of Iceland over the Anton Dohrn Bank and along the East Greenland coast. The catch of eight cod larvae in a Hensen-net haul east of Cape Farewell is surprising and difficult to explain. Perhaps the larvae had been transported by the current from the Icelandic spawning grounds. There seems to be a rather uniform spawning on both sides of Greenland.

NORWESTLANT 2

The catches of cod eggs and larvae with different gears are shown in Charts 233-235. Charts 233 and 234 show the catches with the stramin net of cod eggs and cod larvae respectively. In Chart 235 the catches of both eggs and larvae with the Hensen net are given: the small insert shows the catches with the IHSS.

The stramin-net catches of cod eggs were very small. More than 10 eggs per 30-min haul were obtained only at two stations off the East Greenland coast (62°N and 62°30'N lat) and at two stations off West Greenland (62°30'N and 63°30'N lat). The western limit for the occurrence of cod eggs in the Davis Strait was 56°W long.

The stramin-net catches of cod larvae were also rather modest. More than 10 larvae per 30-min haul were obtained only at two stations off West Greenland. At most stations only one or two larvae were caught. The western limit was 58°W long.

Catches with the Hensen net revealed concentrations of cod eggs and larvae on the West Iceland Shelf. Between Iceland and East Greenland and off the East Greenland coast, eggs were taken in rather small numbers. Larvae were obtained at two stations off East Greenland, but one specimen only at each station. Around Cape Farewell all stations were negative. Many of the stations in the Davis Strait were negative too, and at the remaining stations the numbers were below 10. In general, the occurrence of cod larvae was much smaller than was expected in view of the rather large amount of cod eggs found in April during NORWESTLANT 1.

NORWESTLANT 3

All catches of cod eggs and larvae were taken with the stramin net. The results are shown in Chart 236. Eggs were still obtained at the three stations off Southwest Iceland, at three stations on the Anton Dohrn Bank and at seven stations between 63°-65°N lat and 35°-39°W long. At all other stations no eggs were found.

Cod larvae were obtained at nearly all stations from Southwest Iceland, over the Anton Dohrn Bank, until about 65°N, 34°W. All stations except three were negative in the area southeast of this position along the Southeast Greenland coast, around Cape Farewell, and in the Davis Strait until 64°N, 52°W. On each of these three stations one single larva was taken. One of the stations was near Cape Farewell, while the other two were rather far out in the Davis Strait nearly half-way between Greenland and Baffin Island. Off West Greenland the cod larvae were concentrated between 64° and 67°30'N, but they were rather few in numbers. The northernmost catch was in 68°N where one larva was caught.

The general impression of the occurrence of cod eggs and larvae in 1963 is that eggs in April were rather evenly distributed over the offshore banks both off West and East Greenland, and between East Greenland and Iceland. The most dense concentrations were on the Iceland and Labrador shelves. In May and June very few cod eggs were taken, and also the numbers of larvae were very small. In July cod eggs were only found off Iceland, on the Anton Dohrn Bank and off Southeast Greenland: in the southern area around Cape Farewell cod larvae were exceedingly few and larvae were found only in West Greenland waters in a somewhat more northerly position than in May and June. The very small number of cod larvae in May-July compared with the rather rich occurrence of eggs in April seems to show a very high mortality either in the egg stages or in the early larval stage.

An interesting phenomenon is the occurrence of cod larvae in April and of cod eggs in July off Southeast Greenland. This early occurrence of larvae and late occurrence of eggs may possibly be due to a long spawning period in the area or perhaps more probably to a drift of larvae and eggs from the Southwest Iceland spawning grounds.

COD EGGS

Size of Eggs

Measurements of sizes of cod eggs have been made only by Canadian scientists who have measured the diameter of all the undamaged cod eggs taken by different nets. The average length of the diameter was between 1.40 and 1.44 mm.

Developmental Stages of Cod Eggs

Samples of cod eggs have been classified according to developmental stages by Canada, France, Norway, UK, and USSR. The systems used by the different nations have been somewhat different. Norway and USSR have used a system with four stages. Canada and France have used another system including five stages, and UK has used a similar system, with stage I divided into two, IA and IB. To make the compositions of the developmental stages in the samples comparable it is necessary to convert all the systems into the most simple one of four stages used by USSR and Norway. These four stages correspond with the stages in the Apstein system (Apstein, 1911) and with the UK, Canadian, and Frerch systems as shown in the following table.

Norway, USSR	Apstein	UK	Canada, France
I	1 - 8	IA + IB	I
II	9 - 11	II	II
III	12 - 19	III + IV	III + IV
IV	20 - 22	V	V

Figure 31 shows the stages I-IV. The numbers 1-22 on the eggs are the numbers used by Apstein.

The results of the analyses of cod eggs according to stages are presented in Fig. 32. The big map insert shows the egg stages off East Greenland and on the Anton Dohrn Bank during NORWESTLANT 3. During NORWESTLANT 1 stage I predominated in 9 out of 15 samples. All cod eggs taken during 10-12 April on the Labrador shelf belong to stage I, which means that spawning had taken place recently and that the place where the eggs were obtained was a spawning place or near the spawning grounds for the Labrador stock of cod. A different composition with a strong predominance of stage II and III reaching about 30% was found several miles to the northeast of this position on 7 April. Off the West Greenland coast the composition of the stages differed, even at places which were not far from each other. Eight samples from a little north of 65°N to Cape Farewell have been analyzed. Three had a strong predominance of stage I, 60 to more than 65%, among them the northernmost sample. Five had a rather even composition of stages, three of them with a predominance of stage II. In the most westerly sample on 61°N, stages I, II, and III were of nearly equal size. The predominance of stages I and II means that the eggs had been recently spawned. Off East Greenland, on Anton Dohrn Bank, and on the Iceland Shelf five analyses were made. In the samples from East Greenland waters and on the Anton Dohrn Bank stage I predominated. In the southernmost sample it lies between 40-50%: in the three other, which were taken during 9-23 April, it amounts to 68, 75, and 79% respectively, which means that the eggs had recently been spawned. The sample on the Iceland Shelf from 22 April is quite different with stage III, forming about 75%. This composition means that the eggs would have been hatched within a short time.

Two samples from NORWESTLANT 3 have been analyzed: one from catches with a stramin net east of Angmagssalik on 15-19 July, and the other from stramin-net catches south of Angmagssalik in about 64°N on 4-9 July. The first sample contained 26 eggs, the other 93 eggs. The two samples are very different. In the first, stage I formed about 84%; in the second, stage IV formed 60%. This means that the first consisted of newly-spawned eggs and the second of eggs just about to hatch.

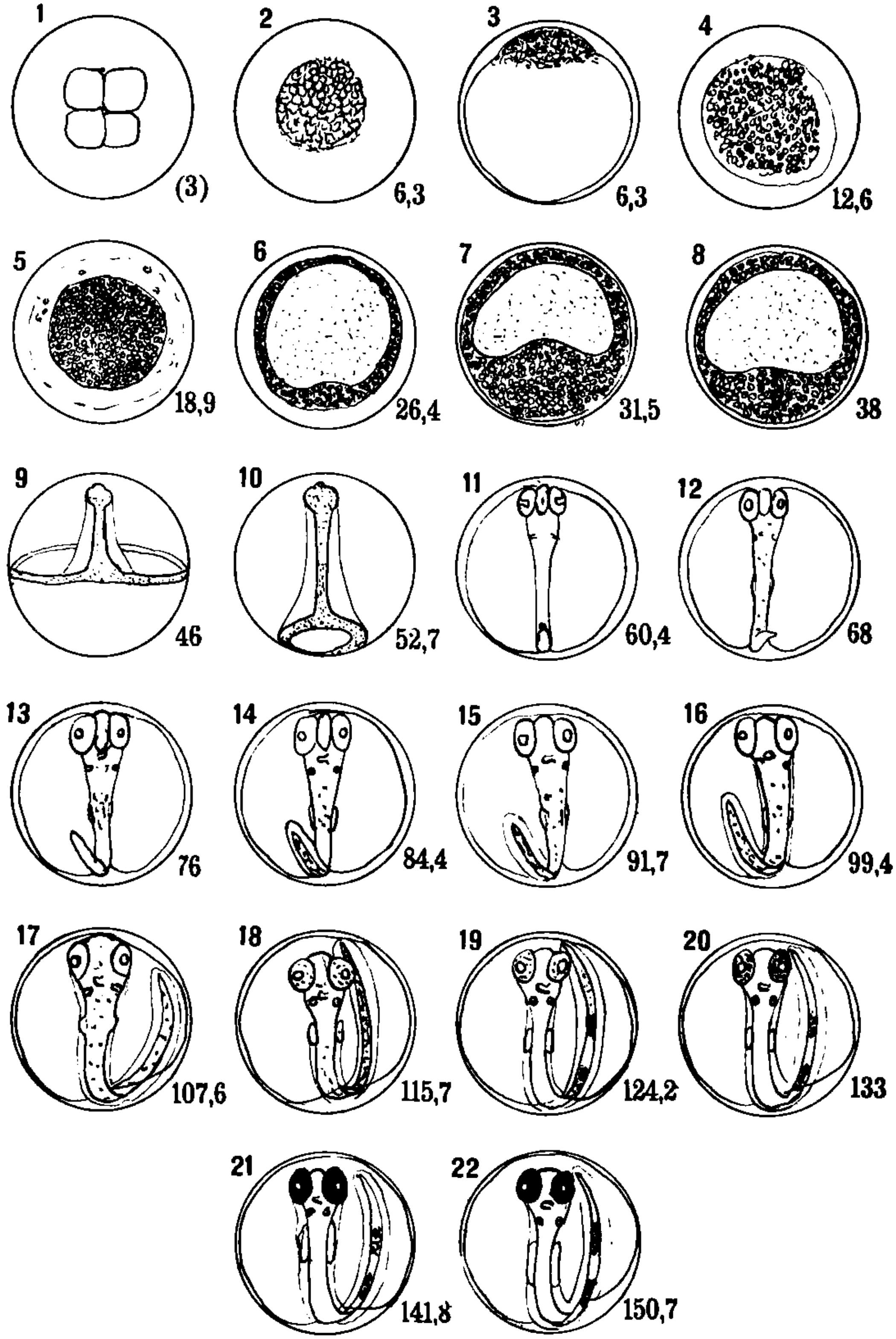

Fig. 31. Developmental stages of cod eggs used for analysis (Apstein, 1911).

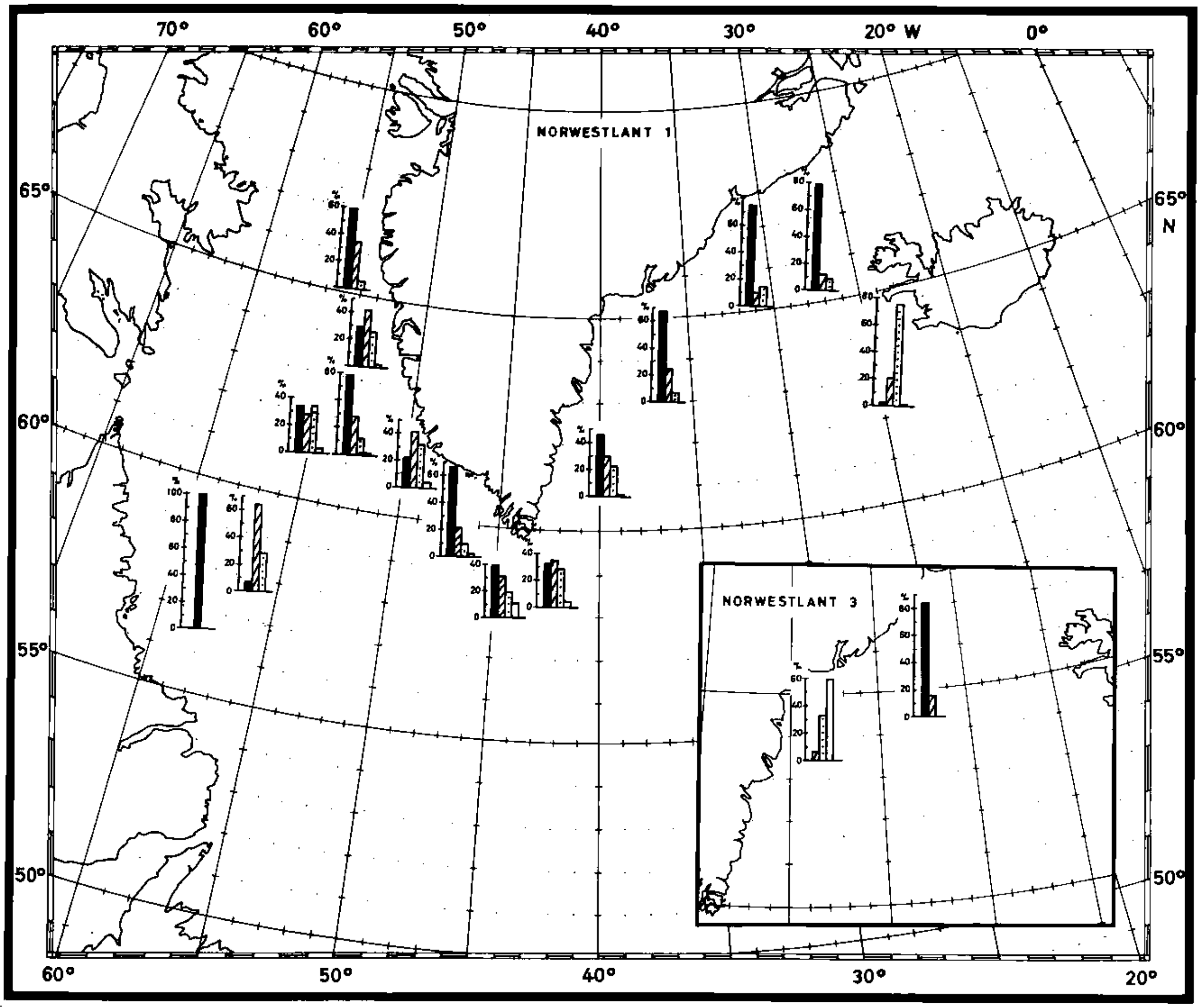

Fig. 32. NORWESTLANT 1 and 3. Percentage composition of cod egg development stages.

COD LARVAE

Growth

Figure 33 shows the length measurement curves for cod larvae from NORWESTLANT 2 and 3. The curve for NORWESTLANT 2 is based on lengths of cod larvae caught in 2-m-stramin-net hauls by *Dana* and *Baffin* in the Davis Strait from 20 May to 16 June; the curve for NORWESTLANT 3 on measurements of cod larvae collected by *Dana* in the same region and by the same gear from 19 June to 31 July. The average lengths for the two samples were 5.6 mm for NORWESTLANT 2 and 10 mm for NORWESTLANT 3. The growth in a month has been between 4 and 5 mm. In 1950 the average size of cod larvae caught in the Davis Strait between 1-10 July was 12.8 mm, which is 2.8 mm more than for NORWESTLANT 3. During NORWESTLANT 3 a total of about 290 larvae were caught between 4-19 July by *Ernest Holt* with a 2-m-stramin net at 40 stations off East Greenland in the area north of 61°20'N. The length distribution of the larvae is shown in Fig. 34. The distribution is quite different from those found in the samples from West Greenland for NORWESTLANT 3. The length curve of the West Greenland larvae is regular and lies between 5 and 15 mm, with a distinct maximum at 9 mm. The length curve of the

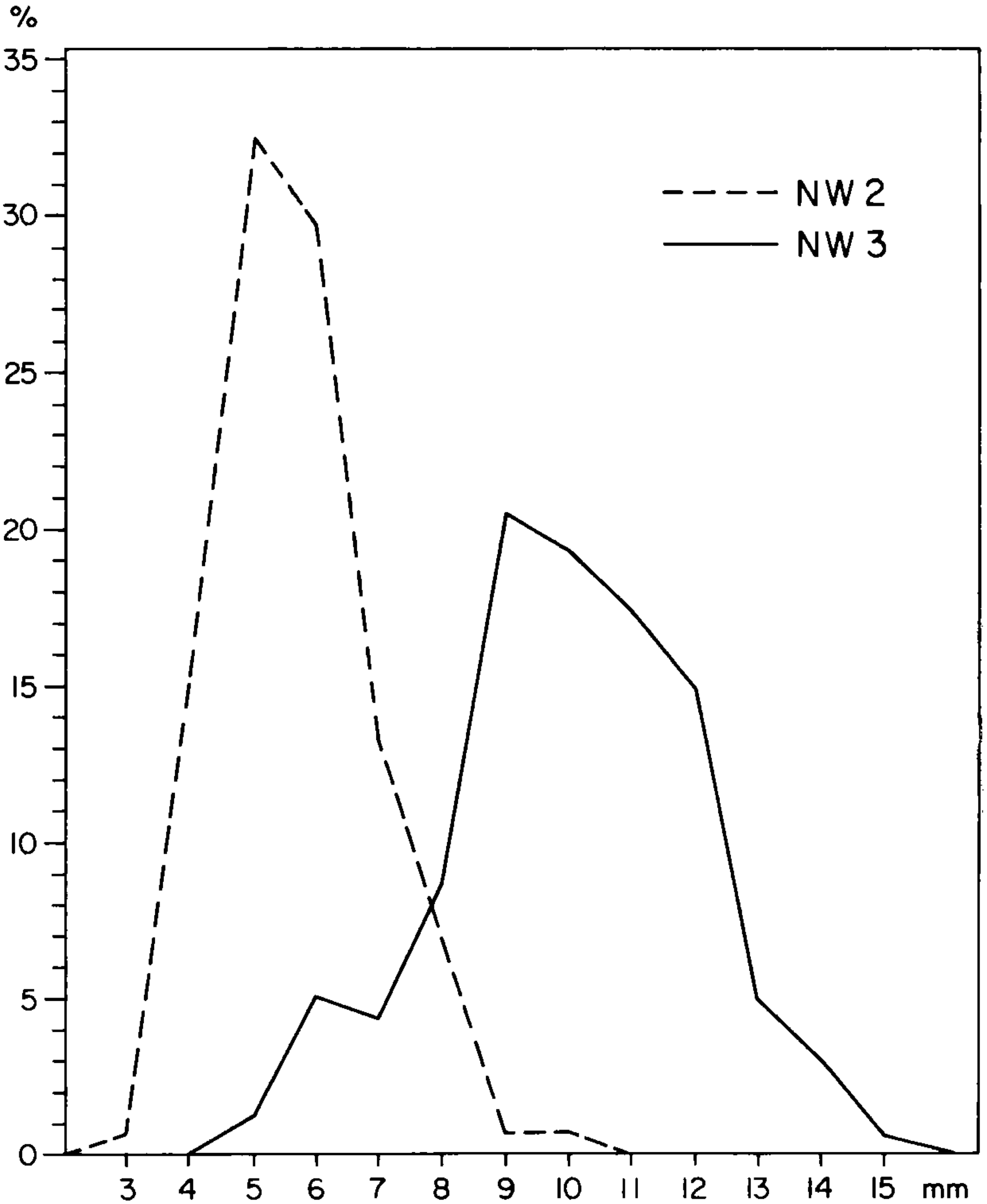

Fig. 33. NORWESTLANT 2 and 3. Length distribution of cod larvae taken off West Greenland.

larvae off East Greenland is from 10 to 43 mm and very irregular, without a real maximum but with many peaks. It looks like a combination of many length curves. When we look at the occurrence of eggs and larvae east of Greenland during NORWESTLANT 1-3, we find eggs and larvae in all periods, which possibly indicates that spawning takes place during several months and that the length curve therefore includes larvae from different spawning periods and different length.

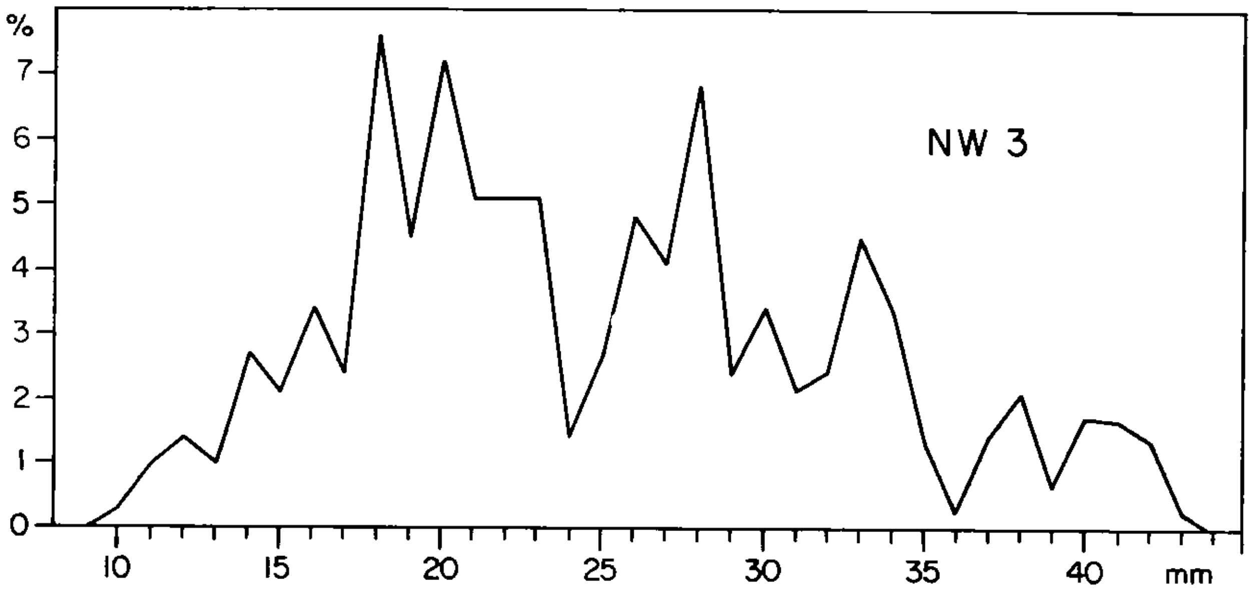

Fig. 34. NORWESTLANT 3. Length distribution of cod larvae taken off East Greenland.

NUMBER OF LARVAE IN DIFFERENT YEARS

Figure 35 shows the average numbers of cod larvae per 30-min haul with a 2-m-stramin net in West Greenland waters in 11 years from 1950 to 1963. It appears very clearly that the number of larvae varies greatly in the different years. The years with the largest occurrence of larvae are 1950, 1953, 1957, and 1961. In all these 5 years rich year-classes with great importance to the commercial fishery were produced. The year 1957, which appears as the year with the largest amounts of larvae, is also the year which gave birth to one of the richest year-classes in West Greenland waters. The year-class 1961 is one of the rich year-classes, and it appeared as small-sized 4-year-old cod in 1965, and is expected to be of importance to the fishery in 1966. The 1960 year-class is also important but unfortunately there was no sampling for cod larvae in 1960 because *Dana* had engine trouble and could not go to Greenland.

The 1963 year-class seems to be rather poor judging from the number of larvae found during the NORWESTLANT Surveys. It remains to be proved in 1968 when it obtains commercial size. There is reason to continue the research on the occurrence of cod larvae because it is of great interest to be able to predict the occurrence of rich year-classes in the stock as early as possible.

In each of the years during which the Danish fishery investigations have been carried on, the annual report has referred to the age-groups which are growing up and will be of importance in the commercial catches in the years to come. These estimates have proved to be correct in most cases. The material used to make these estimates has been eel-seine and shrimp trawl catches of the I, II, and III group, but mainly the II group. Using this age-group it has been possible to predict the occurrence of a rich year-class 3 years before it enters the commercial stock (Hansen, 1949). If the prediction could be made on the numbers of larvae in July, it could be carried out 5 years before recruitment to the stock occurs. It is possible to make such predictions because the differences between rich and poor year-classes in Greenland waters are more strongly pronounced than in most other areas where cod occur.

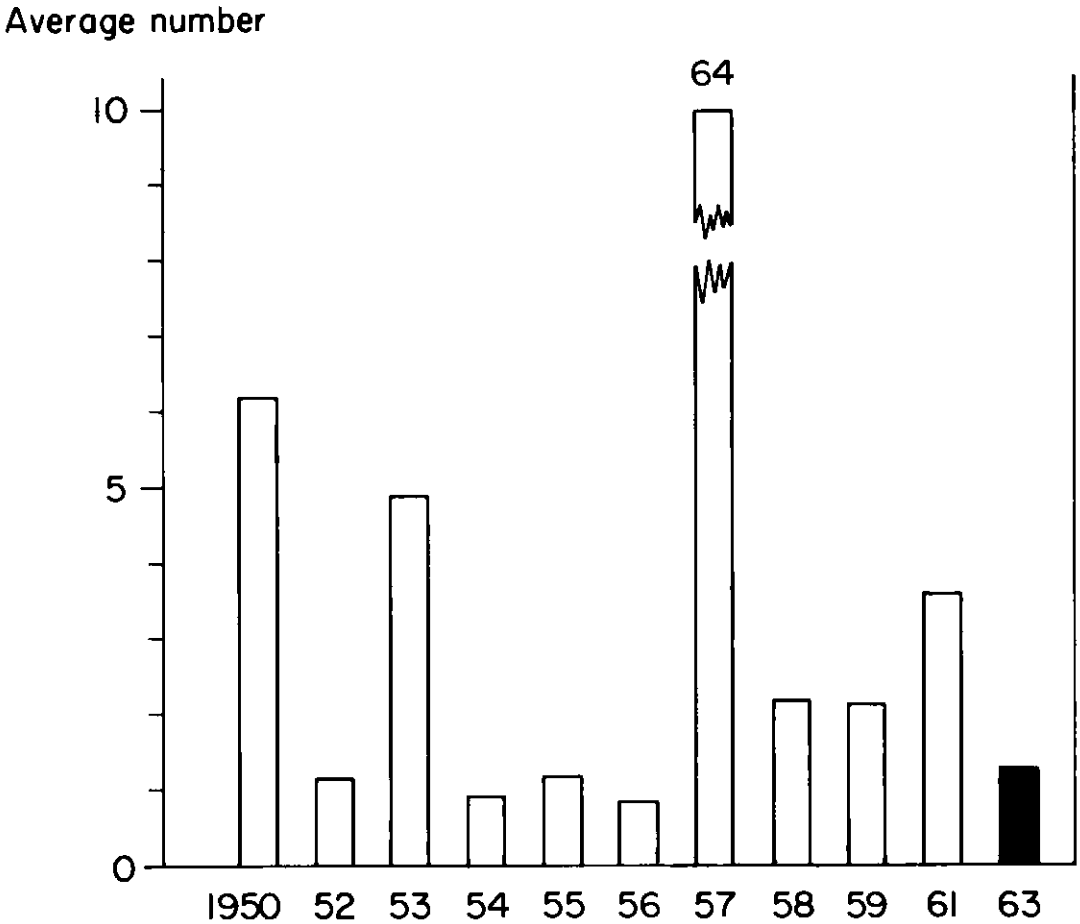

Fig. 35. Average numbers of cod larvae taken per 30-min haul with a 2-m-stramin net off West Greenland from 1950 to 1963.

RESEARCH ON COD LARVAE AND FRY PREVIOUS TO 1963

In 1908 and 1909 the *Tjalfe* expedition carried out the first fisheries research work in West Greenland waters under the leadership of Professor Adolf Jensen. It was in the cold period before the cod became common in Greenland waters. No eggs and larvae were obtained on these two cruises. In the beginning of the warm period when the cod appeared in big shoals which gradually moved from south to north along the coast of West Greenland, Dr Tåning carried out research work from a Danish naval ship in 1924. He found cod larvae in the coastal area and in the fjords but was not sure if they were larvae of *Gadus ogac* or of *Gadus morhua*.

Cod eggs and larvae were found in the Davis Strait for the first time in 1925 on the cruise of *Dana II* under the leadership of Adolf Jensen (Jensen, 1926). Cod eggs were found from 6 to 23 June in inshore and offshore waters from 63°10' to 66°45'N. Cod larvae were found within the same limits.

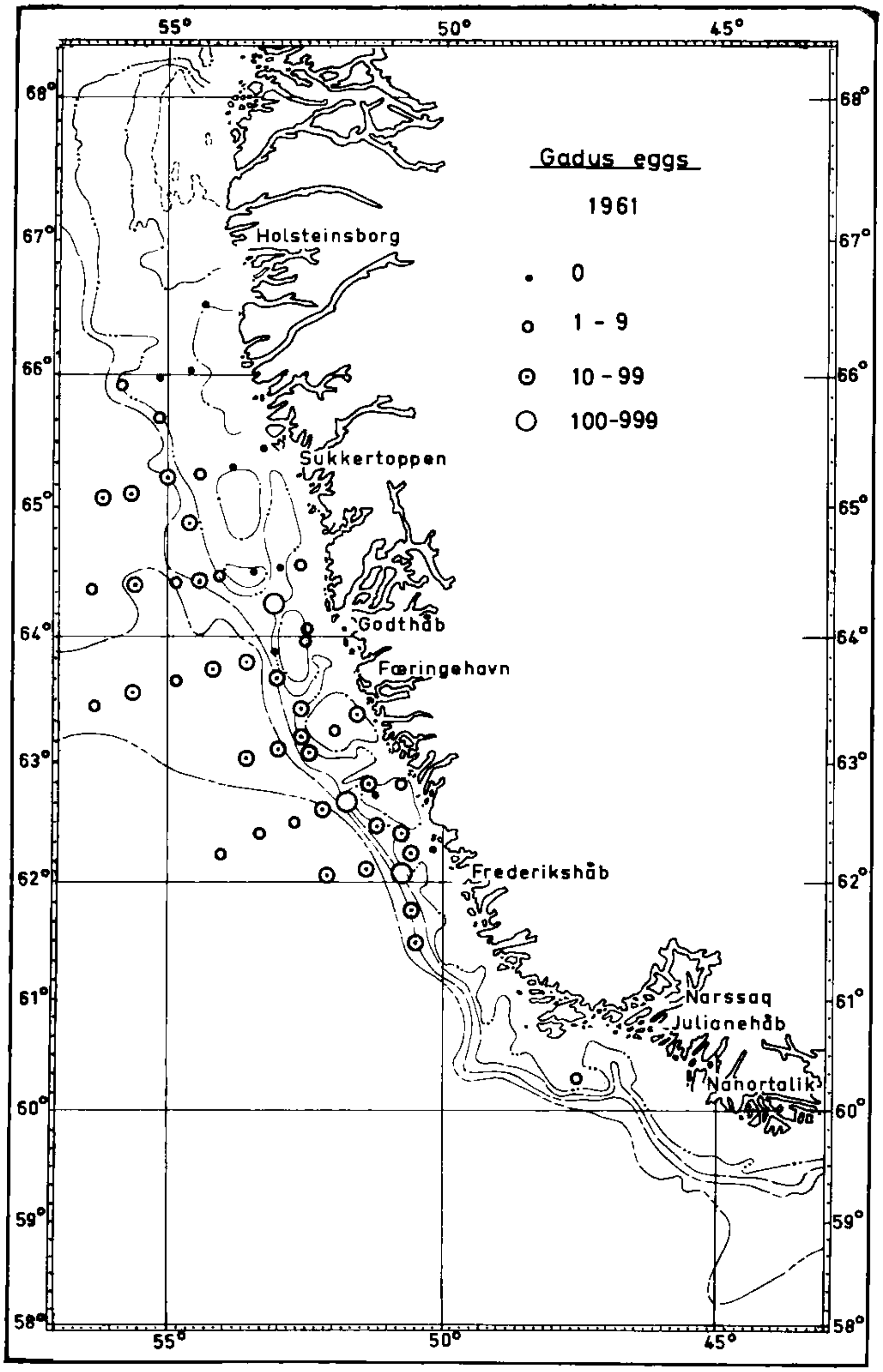

Fig. 36. Distribution of cod eggs off West Greenland (13 April-6 May 1961). Numbers per haul with a 1-m-nylon-egg net.

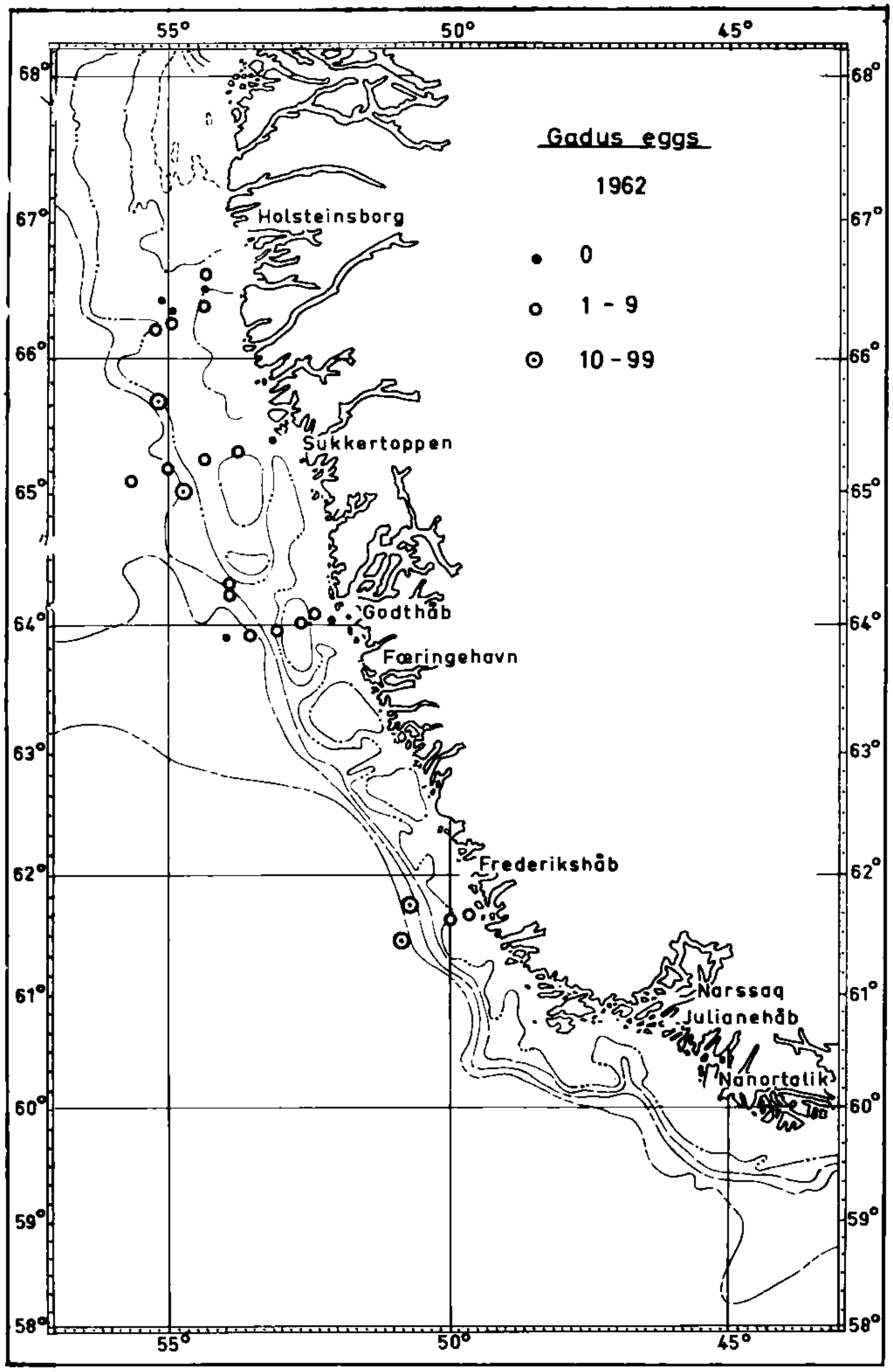

Fig. 37. Distribution of cod eggs off West Greenland (17 April-4 May 1962). Numbers per haul with a 1-m-nylon-egg net.

In subsequent years fisheries research was carried out mainly in inshore waters until 1950 when *Dana III* made a cruise in June and another in July (Jensen and Hansen, 1931). In the following years, except for 1951, 1960, 1962, and 1965, *Dana III* carried out fisheries research work in West Greenland waters in July (Ann. Biol., Vol. VII, IX-XVIII, XX, 21, and 23). In all these years, except one, cod larvae only and no eggs were taken with the 2-m-stramin net. In 1959 a few cod eggs were obtained.

One of the remarkable observations on these cruises has been the occurrence of cod larvae far out in the Davis Strait indicating a transport in the west-going branch of the West Greenland Current over to Labrador. These larvae are lost from the Greenland stock and may possibly be considered as recruits to the Labrador stock.

In most years from 1950 to 1965 hauls with a stramin net have been taken on three stations over Fyllas Bank in March or April (Ann. Biol., Research Reports in Northwestern Area, Vol. I, V-X). The numbers of eggs obtained varied in the different years, but generally, the largest number of eggs were taken in the haul over the western slope of the bank, with a smaller number on the middle of the bank, and only a few between the bank and the mainland. These results are not surprising since the western slope of the Fyllas Bank is a spawning place for cod.

From 13 April to 6 May 1961 and from 17 April to 4 May 1962 Norway has carried out research on the occurrence of cod eggs in the Davis Strait. Figure 36 and 37 show the distributions of cod eggs in these 2 years. A larger number of stations were made in 1961 and the larger number of eggs per station was also obtained in that year. Cod eggs were taken far from the offshore banks over great depths both in the south and north. The northern limit for the eggs was at 66°N in 1961 and at about 66°40'N in 1962.

In May 1961 the Iceland research ship *Aegir* carried out redfish studies in the Irminger Sea. On this cruise the occurrence of cod larvae was also studied. A Helgoland net and the IHSS were used for collecting fish larvae. The greatest concentration of cod larvae was found on the Iceland Shelf off Reykjanes. Over the East Greenland Shelf and its slopes, between 60° and 63°N, cod eggs were taken at almost all stations. The greatest density was found between 61° and 63°N. On the northern stations very few eggs were found. In the same region small numbers of newly-hatched cod larvae were found on seven stations. By studying the occurrence of the different stages of cod eggs and taking the velocity of the East Greenland Current into consideration, it was assumed "that no remarkable concentrations of cod larvae could be expected on the East Greenland banks, except when there has been heavy spawning in the northernmost region or there has been a strong drift from the spawning grounds off Iceland" (Magnusson, *et al.*, 1965).

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The Life-Cycle Pattern of Labrador Cod, *Gadus morhua L.*, in ICNAF Subarea 2[1]

By

A. I. Postolaky[2]

In 1963 some research works of the Polar Institute were carried out to detect the spawning grounds of Labrador cod, *Gadus morhua L.*, in ICNAF Subarea 2. Spawning grounds were searched for, with due regard for the hydrological conditions of the Labrador Sea, and proceeded from certain assumptions on the drift migrations of the young.

In March-May 1963 waters adjacent to Labrador were surveyed by the research fishing vessel *Pobeda*. In mid-March some concentrations of pre-spawning and spawning cod were found in Division 2G at depths from 280 to 350 m, the temperature being 2.0° to 3.5°C. Post-spawners were observed in the same area in April. The catches of spawning cod were of a commercial nature.

Table 20 shows the data on the maturity stages of cod in the Labrador area and adjacent slope of the Newfoundland shallows in March-May. Figure 38 shows the size composition of both the immature and mature fish.

TABLE 20. Stages of maturity of cod in the Labrador and northern Newfoundland Bank areas in March-May 1963 (as % of the number of fish analyzed).

Location	Date	Maturity stages						
		II	IV	IV-V	V	VI	VI-II	No.
North Labrador (2G)	18 March	-	20.0	75.8	4.2	-	-	49
	5-19 April	1.2	0.7	22.7	23.8	65.8	5.8	3772
Central Labrador (2H)	20 April	-	-	-	6.8	64.7	28.5	102
Southern Labrador (2J)	1-30 April	28.7	11.1	15.2	26.7	19.3	9.0	1132
	1-30 May	20.5	5.4	0.5	8.6	35.0	29.9	2009
Northern Newfoundland Bank (3K)	29 March	86.0	11.7	0.6	0.3	0.9	0.6	351
	1-30 May	34.5	13.0	0.4	3.1	25.6	23.4	1033

Analysis of the state of maturity of the cod provides a good reason for the supposition that in Div. 2G mass spawning has continued from the middle of March until the end of April. In Div. 2J and in the adjacent section of Div. 3K spawning was observed from the end of March until the beginning of June. It must be noted that in these parts the spawners were encountered in much fewer numbers than in Div. 2G.

[1] This paper was originally submitted to ICNAF Symposium, "The influence of the environment on the groundfish stocks in the North Atlantic", held in Rome, 27 January 1964. It is published here rather than in ICNAF Spec. Publ. No. 6 as it deals with cod eggs in the NORWESTLANT area during the first two surveys.

[2] Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, USSR.

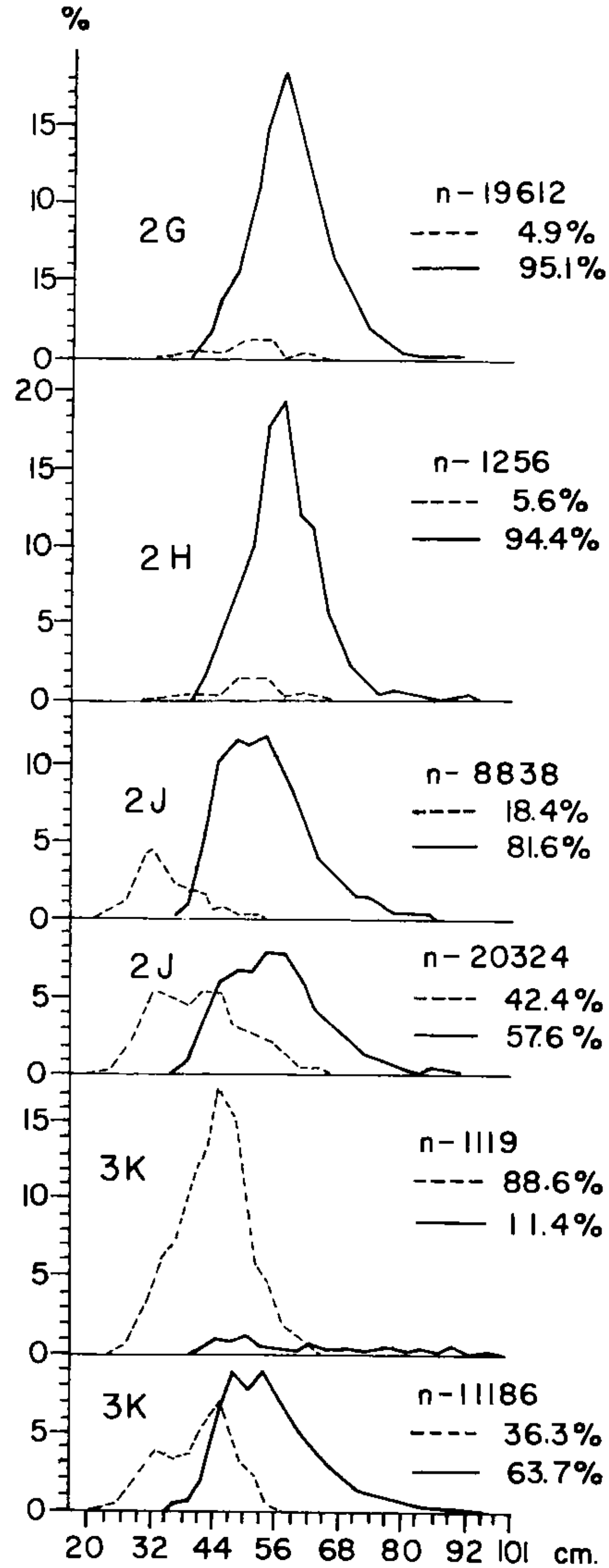

Fig. 38. Size composition of immature (— — —) and mature (———) cod in Divisions: (1) 2G - April; (2) 2H - April; (3) 2J - April; (4) 2J - May; (5) 3K - March; (6) 3K - May.

A considerable number of cod mature at stages VI and VI-II caught in Div. 2J and 3K have apparently come from Div. 2G, as indicated by a small number of post-spawners in this division in the end of April. Southward migration of cod from North Labrador is confirmed by the results of tagging. A cod tagged on 10 April on the spawning ground in the North Labrador area (59°50'N, 60°56'W) was recaptured 8 days later in the Central Labrador area (57°07'N, 50°41'W). Two cod specimens which had also been tagged on 9 and 10 April on the spawning ground (50°28'N, 61°15'W and 59°50'N, 60°56'W) were recaptured after 20 days in the southern Labrador area 380-440 miles from the area of tagging.

The collected data on the eggs of cod indicate their wide distribution in the Labrador and northern Newfoundland Bank areas in April and May (Fig. 39). The sizes of the eggs varied within the range of 1.1-1.8 mm, with sizes of 1.4-1.6 mm predominating. Largest catches of eggs per single vertical haul with an egg-net (diameter of outer opening 80 cm, gauze No. 140) were observed in the North Labrador area (Table 21).

TABLE 21. Data on cod eggs in the Labrador and northern Newfoundland Bank areas in April and May[a].

Location	Date	Embryonic stages of development I	II	III	IV	Average number of eggs per haul in the area	Total number of eggs caught in the area
Northern Labrador (2G)	5-19 April	274.0 / 90.8	26.2 / 8.7	1.5 / 0.5	- / -	301.7	4525 (15)[b] / 100.0
Central Labrador (2H)	20 April	11.0 / 14.7	60.5 / 80.6	3.5 / 4.7	- / -	75.0	150 (2) / 100.0
Southern Labrador (2J)	1-29 April	26.7 / 15.6	26.9 / 15.7	109.0 / 63.4	9.1 / 5.3	171.7	2232 (13) / 100.0
	5-29 May	9.3 / 19.4	6.5 / 13.7	26.5 / 55.3	5.5 / 11.6	47.8	1004 (21) / 100.0
Northern Newfoundland Bank (3K)	8 May-1 June	8.3 / 16.4	9.1 / 18.0	22.5 / 44.4	10.6 / 21.2	50.5	808 (16) / 100.0

[a] Numerator shows the average catch of eggs in a vertical haul; denominator indicates the percentage of the total number of eggs caught in the area.

[b] Number of hauls from which the average value of eggs in different stages per haul was assessed.

As can be seen from Table 21, the maximum number of eggs in stage I (stages were determined according to Rass, 1949) were caught in the North Labrador area whereas in the other areas the number of such eggs was considerably smaller. During April and May the distribution of eggs of different stages of embryonal development in the Labrador and North Newfoundland Bank areas was uneven. While the eggs caught in the North Labrador area were mainly found to be in stage I and those in the Central Labrador in stage II, the eggs in the southern Labrador and northern Newfoundland Bank areas were in stage III. In the latter two areas eggs in stage IV occurred both in April and May.

Cod larvae were observed in May on one station in the southern Labrador area and on three stations of the northern Newfoundland Bank. The sizes of larvae ranged from 3.0 to 6.3 mm.

Eggs in stage II in the Central Labrador area and in stages III and IV in the southern Labrador and northern Newfoundland Bank areas had evidently been carried there from the north by the Labrador Current. According to Smith and Ancellin (Bogdanov, 1959) the average velocity of the Labrador Current at its surface is 0.4-0.5 knots[3]. Judging by this speed, the eggs should be carried from the northern to the southern Labrador area in 30-48 days, and to the northern Newfoundland Bank area in 48-55 days.

[3] According to observations made in April 1963 the average velocity on the sea surface approximated 0.5 knots.

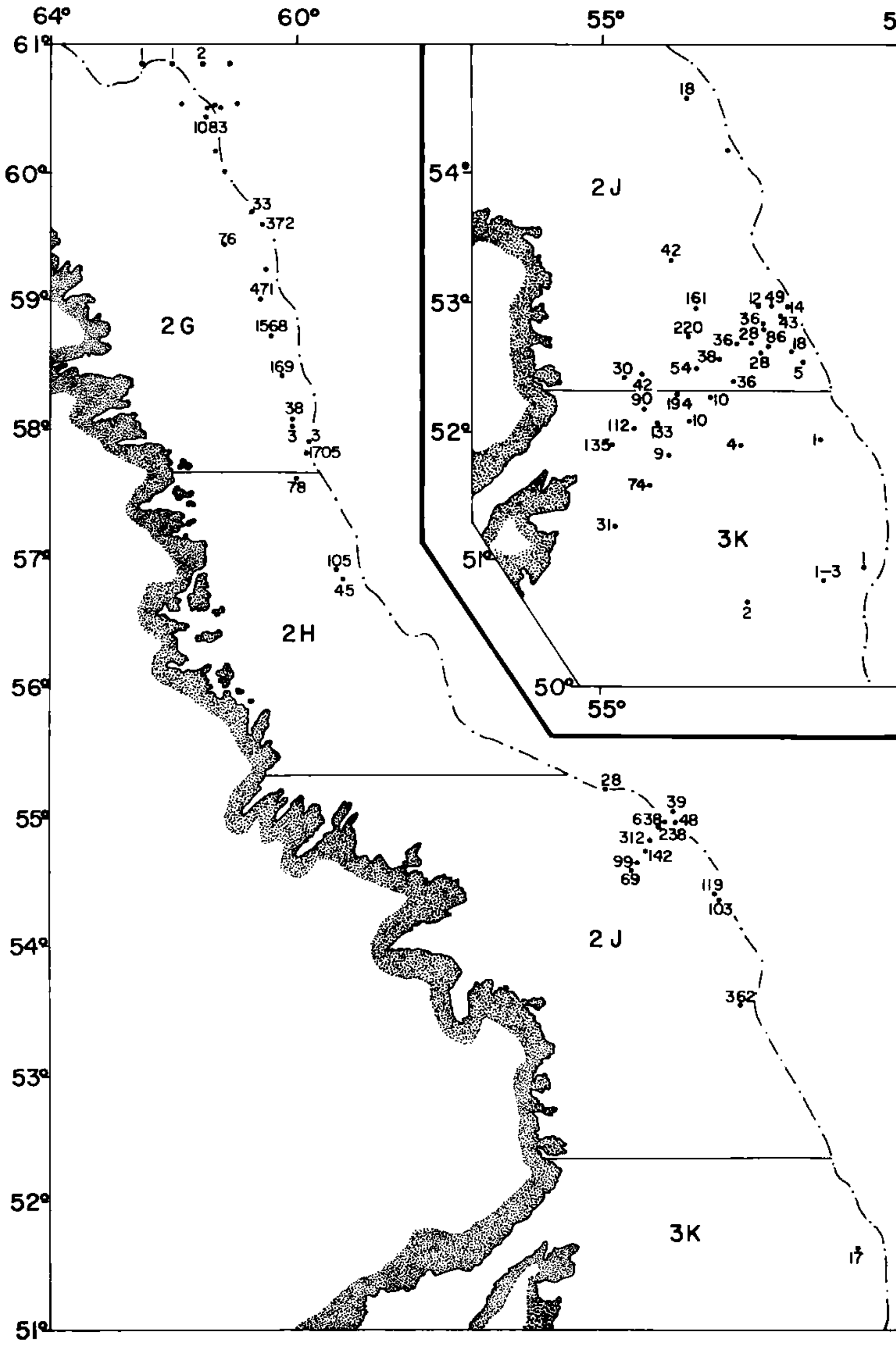

Fig. 39. Distribution of cod eggs in April (A) and May (B) 1963 (stations are marked by dots). Figures near dots indicate the number of eggs caught by egg-net per one total vertical haul.

The temperatures of the upper water layers in March-May remained negative along the whole coast of Labrador. Waters over the slope (500-600 m) presented a single exception, their temperature sometimes exceeding 3°C (Fig. 40). Waters with subzero temperatures occupied the 0-180-m layer with

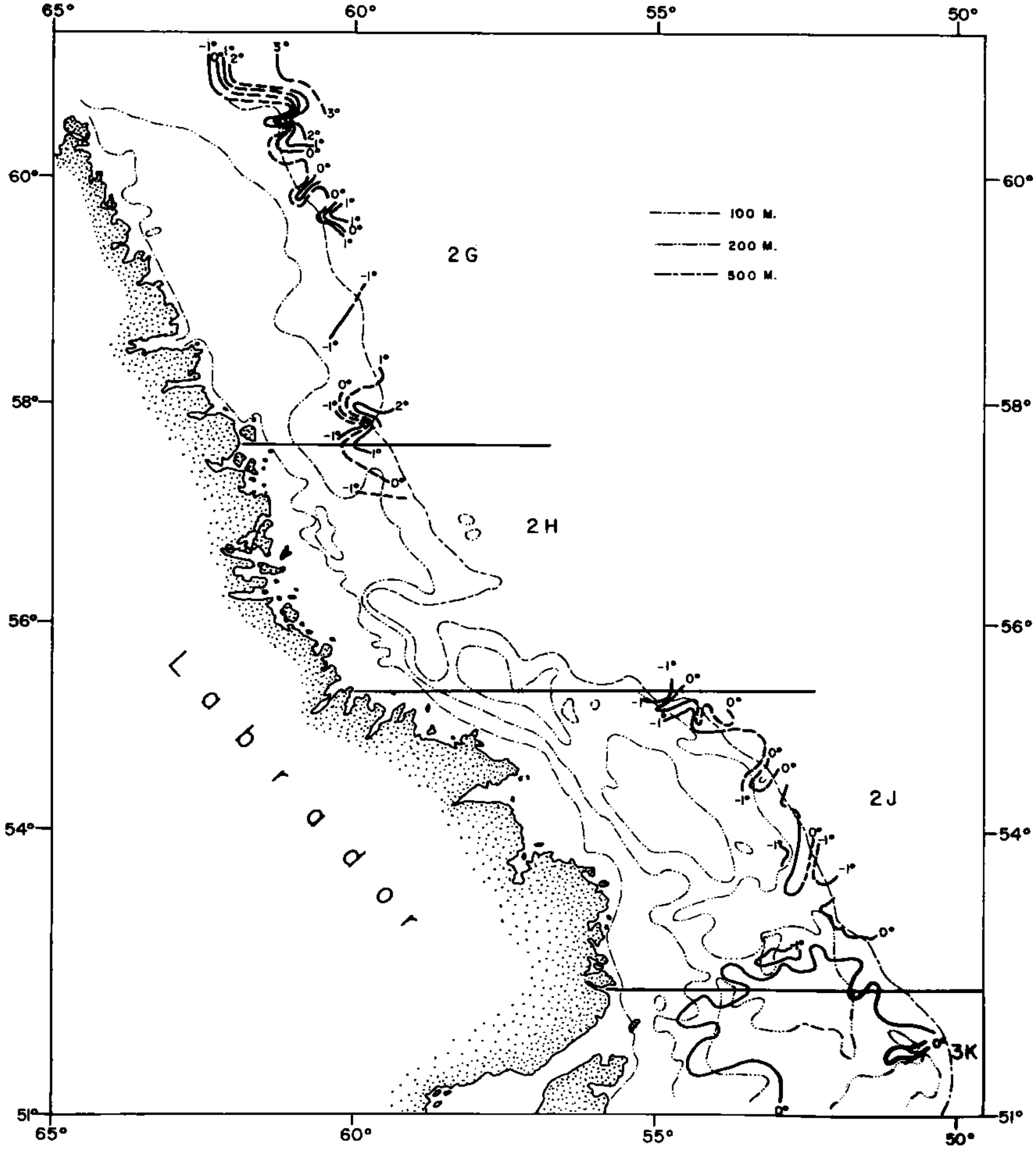

Fig. 40. Surface water temperature in March-May 1963.

temperatures below 1°C being observed in the 100-150-m layer. It must be noted that the eggs of cod in North Labrador were encountered in greatest numbers in the area with depths of 280-350 m and that in southern Labrador and on the northern Newfoundland Bank they were chiefly in the zone with depths of 150-200 m. The surface temperature on the stations where the eggs were observed was in most cases below zero, sometimes as low as -1.80°C.

Thus, it can be supposed that the development of cod eggs in the Labrador and northern Newfoundland Bank areas occurs in subzero temperature range. The time required for the development of cod eggs, according to Apstein (1909), is 43 days if the temperature is 0°C, and 60 days if the temperature is -1°C. To make an egg develop into stage III it takes 22-30 days if the temperature is 0°C, and 30-43 days if it is -1°C. Comparison of the data on the velocity of the drift and on the time of development of eggs under the low temperature conditions suggests that the cod eggs in stages III and IV found in southern Labrador and northern Newfoundland Bank in April and May had been carried there by a current from the northern Labrador area. Part of the eggs in stage II found in the southern Labrador area had probably been deposited in North Labrador waters as well.

As shown by PINRO investigations the young cod are almost entirely absent from the central and northern areas of Labrador, whereas in southern Labrador and on the northern slope of the Newfoundland Bank they occur in great numbers. They probably represent the young cod that spawn in the northern areas of Labrador. The young cod that spawn in the southern Labrador area seem to develop much further to the south.

To summarize, one may suppose that the main spawning grounds of Labrador cod are situated in the northern Labrador area at a considerable depth where the temperature is 2° to 3.5°C. Therefore, the eggs drift southward with the Labrador Current. The development of eggs and larvae in the surface layer proceeds mainly at 0°C and lower temperatures.

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Report on Redfish Larvae, *Sebastes marinus L.*

By

Jakob Magnússon[1]

INTRODUCTION

In this paper the results of the redfish larvae sampling during NORWESTLANT 1-3, in 1963, are discussed.

Redfish larvae were obtained on all three surveys. On NORWESTLANT 1 they were reported from the Irminger Sea only, but on NORWESTLANT 2 and 3 they were also reported from West Greenland. On NORWESTLANT 1 redfish larvae were reported by France, *Thalassa*; UK, *Ernest Holt*; on NORWESTLANT 2 by Canada, *Baffin* and *Sackville*; Denmark, *Dana*; Federal Republic of Germany, *Anton Dohrn*; Iceland, *Aegir*; Norway, *G. O. Sars* (one station); on NORWESTLANT 3 by Denmark, *Dana*; UK, *Ernest Holt* and *Explorer*; USSR, *Academician Knipovich*.

Of all three surveys, both the greatest concentrations and widest distribution of redfish larvae were found during NORWESTLANT 2, mainly in the Irminger Sea and southwards.

MATERIAL, GEAR, AND METHODS

During the surveys the following horizontal towing gears were used: the 2-m-stramin, Icelandic High Speed Sampler (IHSS), and 1-m-silk net. Further, the following vertical sampling gears were used: Hensen net, Helgoland larvae net, 1-m-silk net, Nansen net and the British Ocean weather ship net. The towing time for the 2-m stramin was approximately 20-30 min in an oblique haul from 50 to 0 m, at a towing speed of 1.5-3 knots. The IHSS were operated in the same way by most of the participants at a speed of 3-5 knots. But on the Icelandic *Aegir*, where IHSS were exclusively used instead of the 2-m stramin, this gear was towed for 1.5 nautical miles (at few stations 2.5 nautical miles), at a speed of 6-8 knots in the following depths: 2-5 m, 15-18 m, and 25-30 m, the filtration being about 20 m^3 for each sample for 1.5 nautical miles towing distance. The vertical sampling gears were generally hauled from 100 to 0 m, the Hensen net being the most used gear. Most of the redfish larvae were caught with the 2-m-stramin net and the IHSS by Iceland. Few redfish larvae were reported from the oblique hauls with the IHSS and the vertical sampling gears. In some cases, flow meters were used on the nets. Kelvin-Hughes depth tubes were used by many of the participants for testing the depth of the gears. Of all three surveys, redfish larvae were recorded on 405 stations: i.e., 11.5% of all planktonic stations in NORWESTLANT 1; 56.2% in NORWESTLANT 2, and 37% in NORWESTLANT 3.

The number of redfish larvae per 30-min tow with a 2-m-stramin net ranged from 1 to 1,400; with the IHSS from 0.02 to 3.13 per m^3 (mean for all three sampling levels); and the vertical nets from 0.6 to 180.9 per m^2. Generally, redfish larvae were sorted out of the samples immediately, and in some cases measured. The working up was completed in the laboratories ashore and the number reported as numbers per unit (/30-min tow, m^3, m^2); see tables 77-88 in Part IV (Biological Data) of this publication.

DISTRIBUTION AND ABUNDANCE

NORWESTLANT 1

During NORWESTLANT 1 redfish larvae were only found in the Irminger Sea. Unfortunately, sampling during this survey was not carried out in the Central Irminger Sea, but earlier investigations (Henderson, 1961; Magnússon, 1962; Magnússon *et al.*, 1965) have shown that the heaviest extrusion of redfish larvae is in the central and eastern part of this area. Therefore, sampling during this

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survey was only carried out on the north and west boundary of the previously observed main extrusion area. However, notable numbers of redfish larvae were observed in these boundary areas (Chart 237), indicating that a considerable release of redfish larvae had already taken place in April.

NORWESTLANT 2

The widest distribution of redfish larvae was observed during NORWESTLANT 2. Thus, they were reported from almost the entire Irminger Sea and southwards to as far as observations were made (approximately 52°N). Further, larvae were found in a zone along the West Greenland coast exceeding the 65° lat (Chart 238).

All attempts to find a conversion factor for the results of 2-m-stramin net and IHSS catches failed. Therefore, the abundance of redfish larvae in this survey is given in two maps: Chart 238 for stramin-net results; and in Chart 239 for the IHSS results in the Irminger Sea. These charts show the abundance of redfish larvae was very uneven over the whole area and was split up into areas with relatively high and low densities. The main abundance area of redfish larvae was found to be in a region extending from about 57°N northeastwards to about 65°N in the central oceanic area surveyed. South of this region and west of Cape Farewell, high density zones were touched. Even within one survey the time difference in sampling is considerable, which surely is of great importance for the recorded results and it is not certain to what degree the splitting of the maximum density is due to this fact. Thus, e.g., the observations which were made by ***Aegir*** along the 60°N lat were done at the beginning of May but the following observations to the south of this area were carried out in the latter half of May. The abundance of redfish larvae in the Irminger Sea (Chart 239) can be compared with the results of a cruise covering the same area during the same month in 1961. In both years, the areas of distribution and maxima densities appeared to be in a broad zone west of the Reykjanes Ridge. However, in 1963, the area of greatest abundance appeared to lie somewhat more westerly than in 1961 and it is more split into patches, some reaching farther north than in 1961. The redfish larvae were also more abundant in 1961 in this area than in 1963. Thus, the number of redfish larvae per m^3 per positive station in 1961 was 0.77, but in 1963 it was 0.39. The same sampling technique was used in both years.

NORWESTLANT 3

During NORWESTLANT 3 approximately the same area was covered as in the NORWESTLANT 2 Survey, although the station grid was not as dense in all areas as in the NORWESTLANT 2 Survey (Chart 240). During NORWESTLANT 3 the redfish larvae were mainly found along the continental slopes from West Iceland to approximately 62°N off West Greenland. But farther in the open ocean, redfish larvae were only found to be distributed in scattered and isolated patches. The redfish larvae were by far less abundant than in the previous survey, and no greater concentrations were observed except at a single station off East Greenland, where 448 larvae per 30-min tow with the 2-m-stramin net were recorded and 112 larvae with the 1-m-silk net.

Larvae of *Sebastes viviparus* Krøyer

Larvae of ***Sebastes viviparus*** were only reported by Iceland in NORWESTLANT 2. As usual, they appared in the Icelandic Shelf region and were found in small numbers, with a maximum of 0.18 per m^3 (mean for the three IHSS). No ***S. viviparus*** larvae were observed in the Hensen net samples and none was reported by other participants. The size of ***S. viviparus*** larvae was small, about 90% were of the 4- to 6-mm groups, indicating a recent release.

ABUNDANCE IN RELATION TO TEMPERATURE

In the northern part of the survey area in NORWESTLANT 1, only surface temperatures are reported on the biological stations since the hydrographical observations were carried out earlier. Therefore, a comparison of the distribution and abundance of redfish larvae and temperature is difficult since the surface temperatures are not reliable, in this respect, along the ice border. But the surface temperatures at the stations where redfish larvae were caught ranged from 1.3° to 6.8°C. The bulk of the larvae were found in a tongue of water of 5° to 6°C along the cold water front.

On the very few stations in the southern part of the survey area, where redfish larvae were recorded, the surface temperatures ranged from 5° to approximately 6.5°C.

In the Irminger Sea, in the area surveyed by ***Aegir*** during NORWESTLANT 2, redfish larvae were most abundant in temperatures between 6° and 7°C at 20-m depth. In 1961 the greatest concentrations were found in waters of 7° to 8°C (Magnússon *et al.*, 1965). They were also found in temperatures of 8.5°C which was the highest temperature observed on this cruise. None was found in temperatures below 5°C. In the southern part of the area covered by *Aegir*, there does not seem to be a direct relation between the temperature (in 20 m) and the splitting into the concentrations of redfish larvae abundance which has been mentioned before (Chart 239). On the other hand, this splitting is understandable when compared with the dynamic topography in the 0-m depth. In the northern part, a relation between temperature in 20 m and the abundance of redfish larvae was observed since the splitting of larval concentration is following the two branches of warm water along the cold water front. This correlation is still more underlined by the dynamic topography in 0 m. South of this, in the area covered by *Anton Dohrn* and *Dana*, redfish larvae were mainly found in surface temperatures from 5° to 9°C. None was found in surface temperatures below 4.4°C with one exception (0.6°C) at a station close to the ice. When considering the temperature in the 20-m depth, redfish larvae were abundant mainly in temperatures between 5° and 8°C with the densest zones between 6° and 7°C, which is similar to that found in May 1961 in this area (Kotthaus, 1961). But the contours for the redfish larvae densities did not follow the general direction of the isotherms. Off West Greenland redfish larvae were found in a rather narrow zone along the border of cold and warm water. No larvae were recorded in waters with temperatures higher than about 4°C at the 20-m depth. But there was a close correlation between the dynamic topography and the distribution of redfish larvae in this area.

During NORWESTLANT 3 the redfish larvae were recorded within a rather wide range of temperature, from approximately 0°C (off West Greenland) to almost 11°C (eastern part of the Irminger Sea) at a depth of 20 m. But, as on the previous surveys, redfish larvae were found mainly in water temperatures between 5° and 8°C. A comparison with the dynamic topography in this survey shows a rather good agreement with the distribution of the larvae.

LENGTH

Data on the lengths of the larvae taken at each station are given in tables 77-88 in Part IV (Biological Data) of this publication. A summary by survey and vessel is given in Table 23.

NORWESTLANT 1

The size of redfish larvae in NORWESTLANT 1 was small, the range being from 5 to 13 mm with the majority being 6-7 mm. In the northern part of the area, the larvae were of a smaller size than in the southern part, the mean length being 7.02 mm, that is newly hatched. In the southern part, the mean length was 8.66 mm which indicates that these larvae have been released some time earlier.

NORWESTLANT 2

NORWESTLANT 2 was carried out from 1 May to 24 June, thus extending over a longer period than the other surveys. But the different cruises in this survey were not all carried out simultaneously. Thus, the Irminger Sea area south to 60°N was covered from 1 to 31 May, the area south of it from 27 May to 24 June, and the area west of Cape Farewell from 21 May to 16 June. The time differences are reflected in the size distribution from the corresponding areas. In the first area (Irminger Sea), the size range was from 5 to 12 mm, about 85% being in the 6- to 8-mm groups. The mean length for the area was 7.37 mm which is slightly lower than in 1961, when the mean length was 7.74 mm for the same area in May (Magnússon *et al.*, 1965). In the second area (south of 60°N) the length range was from 4 to 23 mm, the mean being 9.76 mm, 90% in the 7- to 12-mm-size groups. In the third area (West Greenland), the size range was from 5 to 13 mm with about 96% in the 7- to 9-mm-size groups. The mean length was 8.03 mm.

NORWESTLANT 3

All cruises in NORWESTLANT 3 were carried out simultaneously mainly during the first half of July, some additional observations were carried out at the end of July. Thus, as to the time of observations this survey was unique. There were clear differences in the size composition of redfish larvae in the surveyed areas east and west of Cape Farewell, the mean length of the larvae in the western area being some 6 mm smaller than in the eastern area. Further, size differences within the eastern and western part are expressed by the mean length of redfish larvae in the areas covered of the different cruises: *Ernest Holt* — 16.49 mm; *Explorer* — 18.97 mm; *Dana* — 18.98 mm, i.e., in the eastern part arranged from north to south; *Dana* — 10.97 mm; *Academician Knipovich* — 12.68 mm, i.e., in the western part arranged from north to south. The clear difference in the mean length in both areas indicates, with regard to the currents, that the redfish larvae from the area west of Cape Farewell originate to a great extent from another spawning and not the larvae from the area east of Cape Farewell.

West of Cape Farewell, the size range was from 7 to 19 mm, about 87% being in the 10- to 14-mm groups. The mean size for this area was 11.57 mm. East of Cape Farewell, the size ranged from 6 to 35 mm with a peak at 20 mm and minor peaks at 14, and 10-12 mm. Considering the size distribution for the whole survey area, there were two distinct peaks at 11 and 20 mm and a minor one at 14 mm. These two distinct peaks indicate at least two different redfish larvae release periods in this survey area. Larvae from the first period did not occur west of Cape Farewell, but in the second period they were quite numerous.

Small Larvae

In order to get information on the extrusion area of redfish the larvae of 7 mm and smaller were treated separately, since these larvae are supposed to be newly extruded. In NORWESTLANT 1 (April), a notable extrusion had taken place in the northernmost area of the Irminger Sea, since about 95% of the larvae caught were 7 mm and smaller (Chart 241). At this time, no spawning could be observed west of Cape Farewell. These conditions were considerably changed in NORWESTLANT 2, when newly-extruded larvae were observed in the Irminger Sea and around Cape Farewell, north to 65°N off West Greenland as demonstrated in Chart 242. However, the density was very different. Off West Greenland 18.5% of the larvae caught were 7 mm and smaller. In the Irminger Sea north of 60°N (covered by *Aegir*) 64.7% of all larvae caught were within this size category; but in the area south of 60°N (covered by *Dana* and *Anton Dohrn*) it was only 17.7%. Off West Greenland, these small larvae were only observed in minor quantities and were very scattered towards the north but somewhat denser in an area southwest of Cape Farewell. East of Cape Farewell small larvae were observed almost continuously distributed in the entire Irminger Sea south to 60°N. The greatest density was located in the centre of the mentioned area and extended northwards (Chart 242). These findings lead to the assumption that during May small larvae were also abundant in the areas south of 60°N and that the lack of these small larvae in the latter named area during this survey must have been due to the time of observations since all the sections except the southernmost one were carried out in June. The presence of small larvae on the southernmost section which was worked in the last days of May and the considerable quantities of bigger larvae in this area strengthens the assumption of an abundance of small larvae over the whole region in May, such as has been observed earlier (Henderson, 1961; Kotthaus, 1961). Although the heaviest extrusion of redfish larvae was taking place over deep waters in the open ocean, some scattered extrusion seems also to have taken place along and on the shelves of East and West Greenland, as indicated in Chart 242. In July (NORWESTLANT 3), the extrusion period of redfish larvae seemed to be over, since only very few larvae of 7 mm and smaller (0.73%) were observed during the survey (Chart 243). One of these larvae was found far off Cape Farewell, the others in the northernmost part of the survey area along the East Greenland slope.

GENERAL DISCUSSION

A comparison of the distribution and abundance of redfish larvae in all three surveys indicates a general trend in the drift of larvae from the central oceanic areas surveyed towards the slopes of the continental shelves. From West Iceland they drift towards East Greenland and southwards along the East Greenland Shelf and to some extent around Cape Farewell (Tåning, 1949; Einarsson, 1960). At West Greenland the larvae mix together with the larvae originating locally and from the neighbouring areas and then drift northwards along the coast. This drift is generally in accordance with the results of the drift bottle experiments carried out during the surveys. A comparison of the distribution charts for NORWESTLANT 2 and 3 (Charts 238 and 240) shows that the redfish larvae were not distributed as far towards the north off West Greenland during NORWESTLANT 3 as during NORWESTLANT 2, and they seem to have disappeared from this area during the interval between the two surveys. This might be explained by drift. The trend in the drift of larvae as described above is still more underlined when considering the abundance of small larvae in connexion with the general distribution.

The time of observations differed sometimes considerably within each survey since the proposed timing of the survey could not be adhered to by all participants. Due to these alternations in time, sampling was carried out somewhere within the survey area every half month from April to the beginning of August. Therefore, it was thought useful to study the length distribution of redfish larvae in half-month periods. For this purpose, the areas east and west of Cape Farewell are studied separately. Figure 41 shows the percentages for each millimetre-group in half-month periods for the area east of Cape Farewell. From April to mid-May, the majority of larvae caught was within the size category of newly-extruded larvae (7 mm or smaller). But from the second half of May the

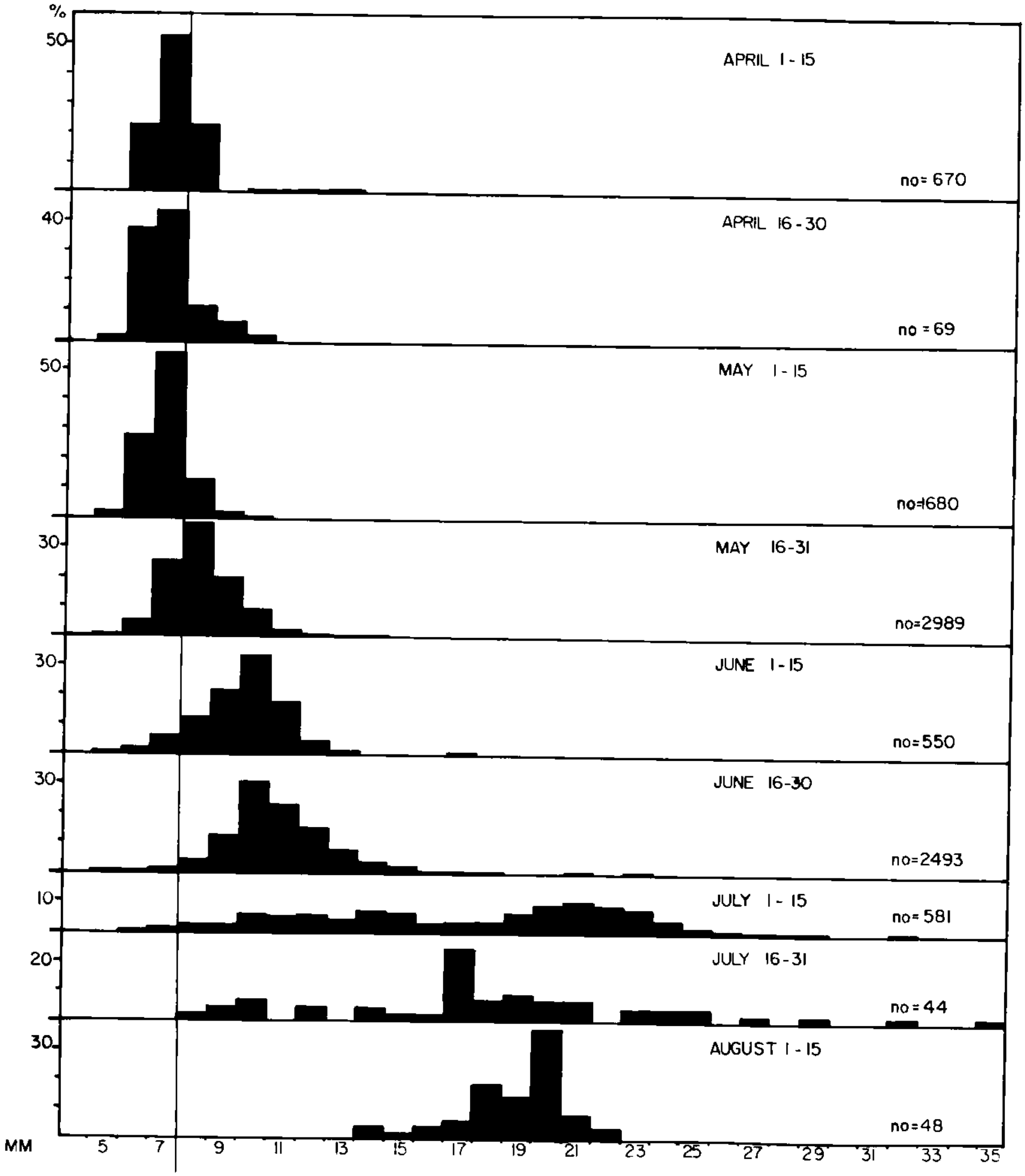

Fig. 41. Diagram showing the size composition of redfish larvae in the area east of Cape Farewell in half-month periods during NORWESTLANT 1-3 (April-August).

larvae showed a wider size range and the bigger larvae were in majority. Newly-extruded larvae were still well represented throughout May but decreased rapidly in number during June. However, they are found as late as in the first half of July. Although no small larvae (7 mm or smaller) have been found in the Continuous Plankton Recorder catches in July from 1955 to 1961 (Henderson, 1961, 1962), some very scarce findings of such small larvae in this area in July have been reported (Einarsson, 1960). These rare findings of small larvae and the findings during the NORWESTLANT Surveys indicate that the extrusion of redfish larvae can last until July in this area. The late findings of newly-extruded larvae during the NORWESTLANT Surveys are most probably due to the more thorough sampling in this area during June and July 1963 than in previous years. A comparison of the NORWESTLANT Survey results and those of the Continuous Plankton Recorders in the years 1955-60 (Henderson, 1961) shows generally a good correspondence. However, there are slight differences which might be due to the type of sampling since the area covered by the Continuous Plankton Recorders only represents a section of the area covered by the NORWESTLANT Surveys. Figure 42 shows the percentage/mm relation in half-month periods for the area west of Cape Farewell. No redfish larvae were recorded until the latter half of May. Newly-extruded larvae make up about 20% of the total larvae from mid-May to mid-June. Then they disappear completely from the catches until mid-July when a single specimen of 7 mm was found at about 55°N, south of Cape Farewell. Thus, the time of extrusion of redfish larvae off West Greenland extends over a much shorter period than east of Cape Farewell. In Fig. 43 the mean length is given for the different half-month periods for both areas east and west off Cape Farewell, with the size range indicated. These mean lengths, of course, do not give the real growth of the larvae, but indicate only the progressive increase in size. Further, it indicates the difference in the mean size east and west of Cape Farewell during these periods. Perhaps the biggest larvae from May to July might give a more true growth picture since the area in question was covered fairly well during NORWESTLANT 2 and 3 and we can therefore assume that the biggest larvae are the oldest ones which represent the size increase during this period.

A comparison of the abundance of redfish larvae between years could not be carried out for the total area because of a lack of comparable material from the previous years except for the area east of Cape Farewell, between 60° and 64°N, for 1961-63 in May. As has already been pointed out (Magnússon *et al.*, 1965) the redfish larvae in 1963 were considerably less abundant than in the other 2 years. Thus, the mean number of redfish larvae per IHSS tow in May was 15.2 in 1961, 15.9 in 1962, and 9.6 in 1963.

As to the distribution of redfish larvae in relation to depth, only the material from the *Aegir* cruise can be used. During the first half of May, in the area between 60° and 64°N, sampler III which samples in a depth of 25-30 m, gave the highest yields. In the second half of May, in the area north of 64°N, sampler III gave only slightly higher yields than sampler II (which samples at a depth of 15-18 m). During the whole cruise sampler I (i.e., 3-5 m) gave the lowest yields. In the same month and area in 1961, sampler I gave the lowest yields, however, the greatest quantities of redfish larvae were caught in sampler II. Thus, in 1963 the redfish larvae were found to be more abundant in deeper layers than in 1961 in the first half of May. This might be due to the inclement weather conditions during this period in 1963. A comparison of this relation for the years 1961 and 1963 is given in Table 22.

TABLE 22. Mean number of redfish larvae per m^3 per positive station in three levels during May 1961 and 1963.

		May 1961			May 1963		
Level	Depth (m)	First half	Second half	Total	First half	Second half	Total
I	3- 5	0.37	0.43	0.39	0.19	0.16	0.17
II	15-18	1.15	1.43	1.25	0.45	0.42	0.43
III	25-30	0.58	0.71	0.63	0.73	0.43	0.58

During the working up of the *Aegir* material, attention was paid to the occurrence of subcaudal melanophores on redfish larvae. On five stations (96-99, and 122), a total of eight larvae with subcaudal melanophores were observed; they were 6-8 mm in size. Further, an abnormality in the pigmentation in some cases was observed. The pigmentation of these larvae differed from the usual chromatophoral arrangement by lack of the dorsal pigment row. These larvae were observed in an

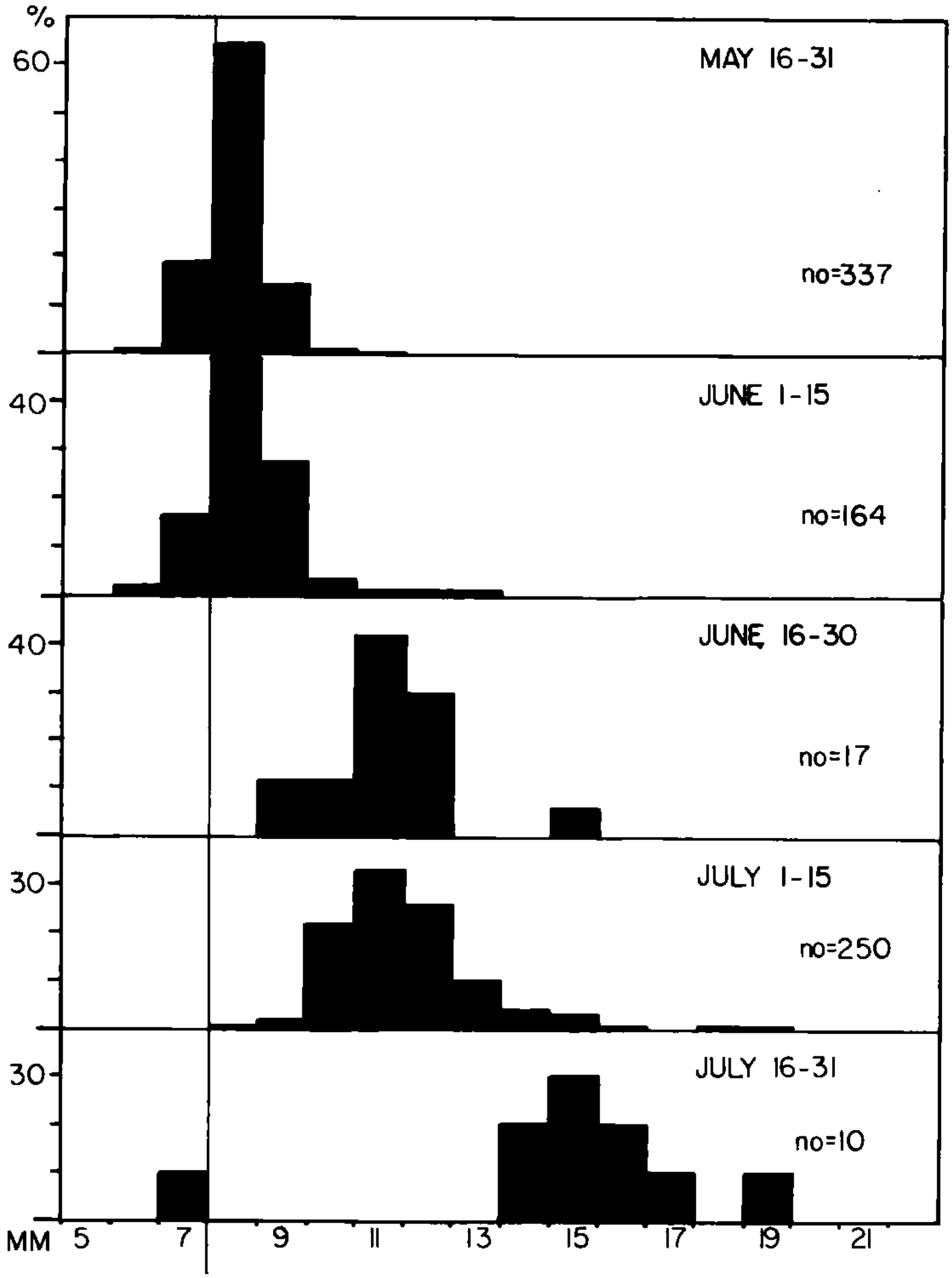

Fig. 42. Diagram showing the size composition of redfish larvae in the area west of Cape Farewell in half-month periods during NORWESTLANT 2-3 (May-July).

TABLE 23. Summarized length of redfish larvae (in millimeters) given by survey and vessel.

Survey	Vessel	Date	Length in mm 4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sub-total ML
NORWESTLANT 1	*Thalassa*	11 April-1 May	–	1	41	109	19	–	2	3	3	1	–	–	–	–	730
		%	–	–	–	551	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 1	*Ernest Holt*	25 April-1 May	–	–	–	1	12	18	1	–	–	–	–	–	–	–	32
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total			–	1	41	110	31	18	3	3	3	1	–	–	–	–	762
Percent			–	0.13		+551 + 96.19		2.36	0.39	0.39	0.39	0.13	–	–	–	–	99.98%
NORWESTLANT 2	*Aegir*	2-31 May	–	32	530	1352	740	298	113	14	1	–	–	–	–	–	3080
		%	–	1.04	17.21	43.89	24.03	9.68	3.67	0.45	0.03	–	–	–	–	–	–
NORWESTLANT 2	*Anton Dohrn*	27 May-23 June	1	5	42	163	303	555	1063	707	420	196	87	54	10	6	3612
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 2	*Dana*	20 May-14 June	–	3	78	320	749	257	40	2	1	1	–	–	–	–	1451
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 2	*Baffin*	27 May-9 June	–	1	3	11	14	10	1	1	–	–	–	–	–	–	41
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 2	*Sackville*	28 May-2 June	–	–	–	1	2	–	–	–	–	–	–	–	–	–	3
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total			1	41	653	1847	1808	1120	1217	724	422	197	87	54	10	6	8187
Percent			0.01	0.50	7.97	22.55	22.08	13.68	14.86	8.84	5.15	2.41	1.06	0.66	0.12	0.07	99.96%
NORWESTLANT 3	*Ernest Holt*	4-23 July	–	–	1	6	15	15	33	24	26	13	14	17	8	15	187
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 3	*Explorer*	2-15 July	–	–	–	–	–	–	1	5	8	12	28	21	10	11	96
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 3	*Dana*	30 June-12 July	–	–	–	–	1	6	48	78	40	5	1	1	–	–	180
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 3	*Dana*	31 July-2 August	–	–	–	–	–	1	–	–	–	–	2	1	2	5	11
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NORWESTLANT 3	*Academician Knipovich*	1-16 July	–	–	–	1	–	–	8	11	29	22	12	9	2	2	96
		%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total			–	–	1	7	16	22	90	118	103	52	57	49	22	33	570
Percent			–	–	0.11	0.74	1.69	2.32	9.48	12.43	10.85	5.48	6.01	5.16	2.32	3.48	60.07%

TABLE [illegible] (continued).

Survey	Vessel	Date	Length in mm 18	19	20	21	22	23	24	25	26	27	28	29	32	35	Grand total ML
NORWESTLANT 1	[illegible]	11 April-1 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	730
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NORWESTLANT [illegible]	[illegible]	[illegible] April-1 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total			-	-	-	-	-	-	-	-	-	-	-	-	-	-	762
Percent			-	-	-	-	-	-	-	-	-	-	-	-	-	-	99.98%
NORWESTLANT [illegible]	Aegir	[illegible]-31 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3080
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NORWESTLANT [illegible]	Anton Dohrn	[illegible]7 May-23 June	1	1	1	-	-	-	-	-	-	-	-	-	-	-	3615
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NORWESTLANT [illegible]	[illegible]	20 May-14 June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1451
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NORWESTLANT [illegible]	Baffin	27 May-9 June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[illegible]	Sackville	[illegible] May-[illegible] June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total			1	1	1	-	-	-	-	-	-	-	-	-	-	-	8190
Percent			0.01	0.01	0.01	-	-	-	-	-	-	-	-	-	-	-	99.99%
NORWESTLANT [illegible]	[illegible] Polt	4-25 July	17	29	38	32	26	20	9	6	5	2	-	-	1	1	373
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	[illegible]	[illegible]-15 July	7	11	18	27	25	28	20	6	1	1	1	2	1	-	244
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[illegible]	[illegible]	30 June-12 July	-	-	-	-	-	-	-	-	-	-	-	-	-	-	180
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[illegible]	[illegible]	31 July-2 August	9	7	19	6	2	-	-	-	-	-	-	1	-	-	55
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NORWESTLANT [illegible]	[illegible]	1-16 July	-	1	-	-	-	-	-	-	-	-	-	-	-	-	97
		%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total			33	48	75	65	53	48	29	12	6	3	1	3	2	1	949
Percent			3.48	5.06	7.90	6.85	5.58	5.06	3.06	1.26	0.63	0.32	0.11	0.32	0.21	0.11	100.02%

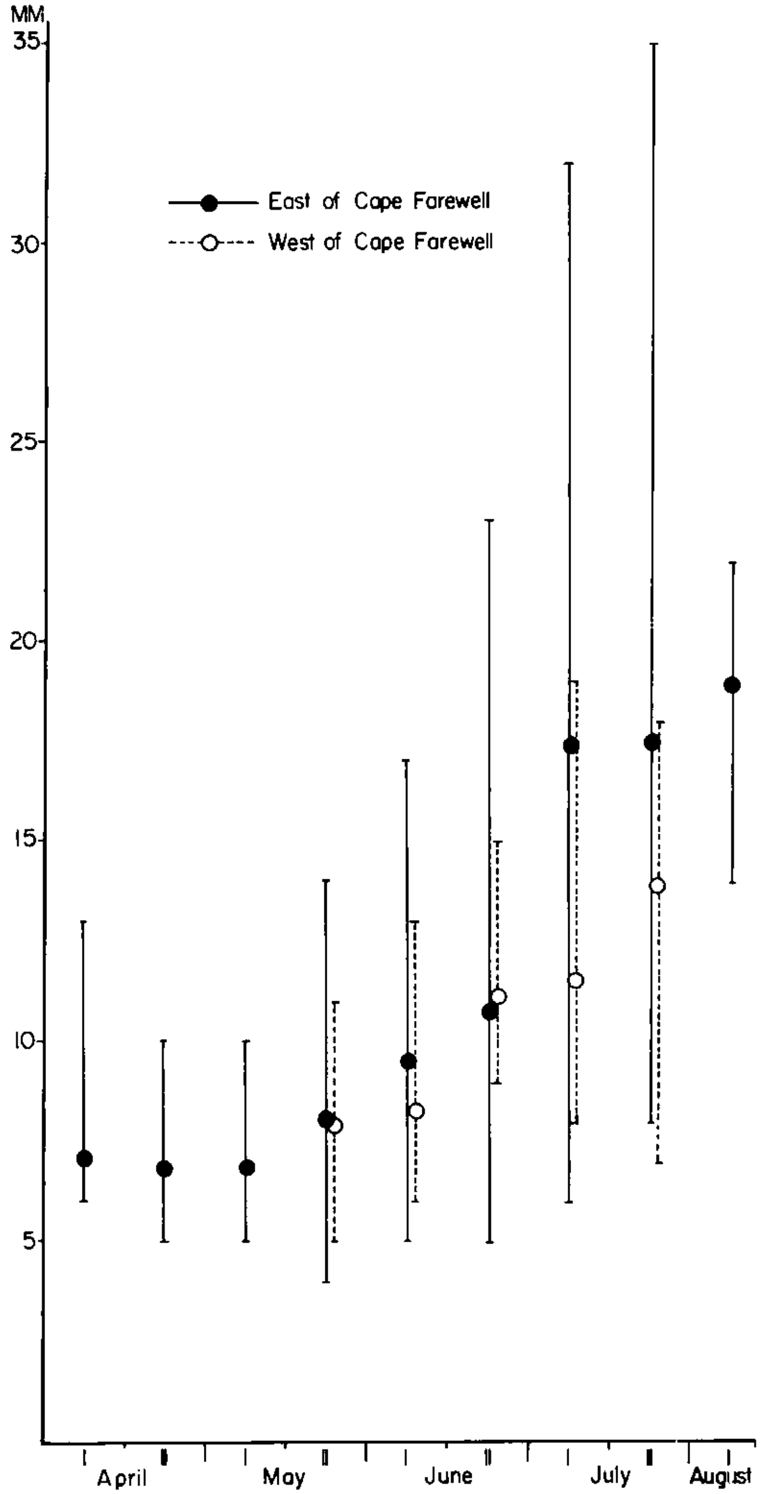

Fig. 44. Diagram showing the mean lengths of redfish larvae in half-month periods during NORWESTLANT 1-3 (April-August) for the areas east and west of Cape Farewell. The size range is indicated by vertical lines.

isolated area between 61° and 62°N, and 22° and 26°W (station numbers 8, and 37-42) and at three stations (148, 178, and 190) along East Greenland. The total number of these larvae was 24 (5-7 mm) with one to five per station. None of the other participants has reported the occurrence of subcaudal melanophores on redfish larvae or abnormalities in the pigmentation.

Finally, the differences in the technical treatment of the material proved to be of great difficulty in combining the results of the different cruises. The necessity of standardization in sampling gear and methods, as well as in working up and reporting the material for such surveys, is an indispensable demand for a successful cooperative work.

ACKNOWLEDGEMENTS

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Continuous Plankton Records During the NORWESTLANT Surveys, 1963 – Young Redfish

By

G. T. D. Henderson[1]

INTRODUCTION

Routine sampling with the Hardy Continuous Plankton Recorder in the North Sea and North Atlantic was carried out throughout 1963. The work was supported by a grant from H.M. Treasury through the Development Fund and by Contract N62558-3612 between the Office of Naval Research, Department of the United States Navy, and the Scottish Marine Biological Association.

Every opportunity was taken to tow Recorders from April to July when the NORWESTLANT Surveys were carried out but in April and May the sampling across the Irminger Sea towards Cape Farewell (Greenland) was rather less than had been expected, whereas in June and July this area was more thoroughly sampled. For details of the standard Recorder routes see fig. 23*a*, this volume p. 96.

In 1955 and subsequent years the Plankton Recorder survey, at the standard depth of 10 m has shown the presence of large numbers of young redfish in the open ocean. The young stages found in this large oceanic area had been considered, in the light of the descriptions available, to be those of the large redfish, *Sebastes marinus* L., distinguished from the other viviparous *Sebastes* species by the absence of isolated melanophores below the root of the primordial caudal fin (Tåning, 1961; Templeman and Sandeman, 1959). However, doubts as to the reliability of this identification are growing (Henderson and Jones, 1964) and in this account all are called *Sebastes*, a distinction being made between young stages without subcaudal melanophores (called "non-pigmented" young) and those with one to three, but mostly with two melanophores (called "pigmented" young). The former are apparently characteristic of the oceanic populations, while young of the latter type have been taken west of Cape Race from 1961 onwards, over the Nova Scotian Banks and in the Gulf of Maine, but only in fairly small numbers. In 1963, however, new routes between Newfoundland and Ocean Weather Stations *Bravo* and *Delta* extended the sampling into areas not previously traversed, and additional populations of pigmented young *Sebastes* were found. Although many of these young redfish were taken outside the area of the NORWESTLANT Surveys, it was considered that a description of the distribution, abundance, and size composition of all the young taken in 1963 might be useful for comparative purposes, particularly as a separation between the non-pigmented (oceanic) stock and the pigmented (non-oceanic) stock is suggested.

DISTRIBUTION

The distribution of young *Sebastes* taken at 10 m from April to July 1963 are shown in Fig. 44. The line drawn through 56°N, 55°W and 48°N, 40°W on all these monthly charts separates the two types of young. All those taken to the north and east of this line were the non-pigmented type, almost entirely in waters where the depths exceed 1,000 fathoms, whereas those taken to the south and west were pigmented, occurring over the shelf or the slope, mainly over depths of less than 250 fathoms.

The non-pigmented (oceanic) young were taken in April 1963 in relatively small numbers between 55° and 61°N, mainly along the line of the Reykjanes Ridge. The numbers were within the limits previously observed for April. Their distribution in May was very similar, over the Reykjanes and Mid-Atlantic Ridges, with some to the east of the Reykjanes Ridge in 60° to 62°N lat, but they were very much less abundant than usual in Recorder collections in May. In June these young were widely distributed in moderate abundance from Iceland to Greenland and as far south as 52°N lat. In July the numbers were greater than in June, and the main area of abundance appeared to lie in an arc from east to south 200-300 miles off Cape Farewell, Greenland, rather to the west of the axes of the Reykjanes and Mid-Atlantic Ridges, but the sampling was inadequate to determine the southeasterly

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limits of this distribution. In August only one specimen was found in these oceanic areas.

The pigmented young were first found in May at the northeast corner of the Newfoundland Bank, west of Flemish Cap, but this patch was not represented in the following months (in which the area was not as well sampled). In June there was a patch on the new route north of the Newfoundland Bank, the northern limit being at the latitude of the Strait of Belle Isle. The numbers were very small, but these larvae appeared to be the precursors of a very large population which was sampled on the same route in July[2], the numbers exceeding 100 per 10 m^3. This population had disappeared in August, except for two specimens near the coast of Newfoundland. On the Nova Scotian Shelf the first specimens occurred in July and this population also had declined to negligible numbers by August.

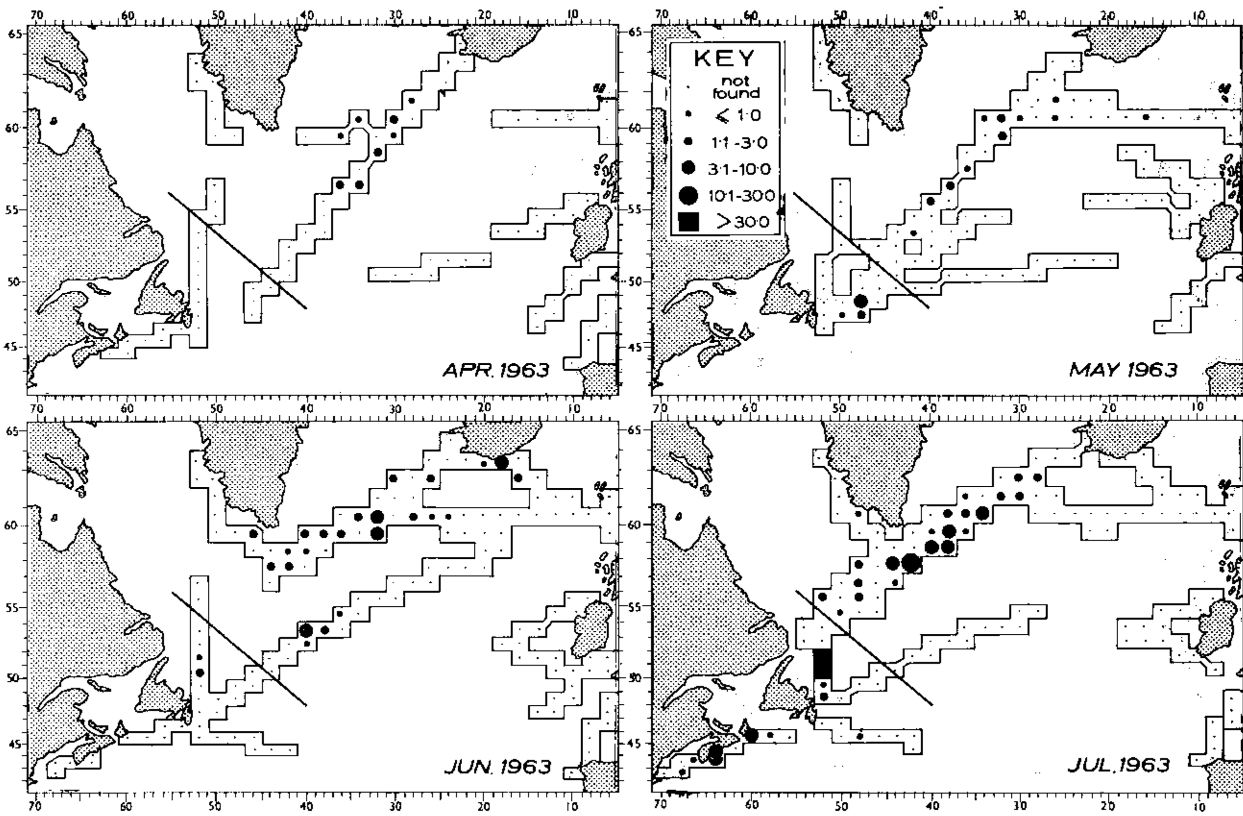

Fig. 44. Charts showing the distribution of young *Sebastes* in Recorder collections from April to July 1963. The symbols indicate the mean numbers per 10 m^3 for all samples within each standard rectangle, 1° of lat by 2° long, which had been sampled. The heavy line separates the "pigmented" and "non-pigmented" young.

This 'pigmented' part of the young redfish population may be separable into two components, a 'slope' population off the Newfoundland Bank, and a 'shelf' population on the Nova Scotian Shelf and in the Gulf of Maine; there appear to be some differences between the size compositions in the two regions (Fig. 45). It seems possible that a line drawn down the centre of the Laurentian Channel may serve as a boundary between these populations, so far as can be determined from the data at present available, but more sampling and much larger numbers of larvae will be needed to investigate this possibility.

Recorder sampling in 1964 supports the distribution pattern shown in this area for 1963.

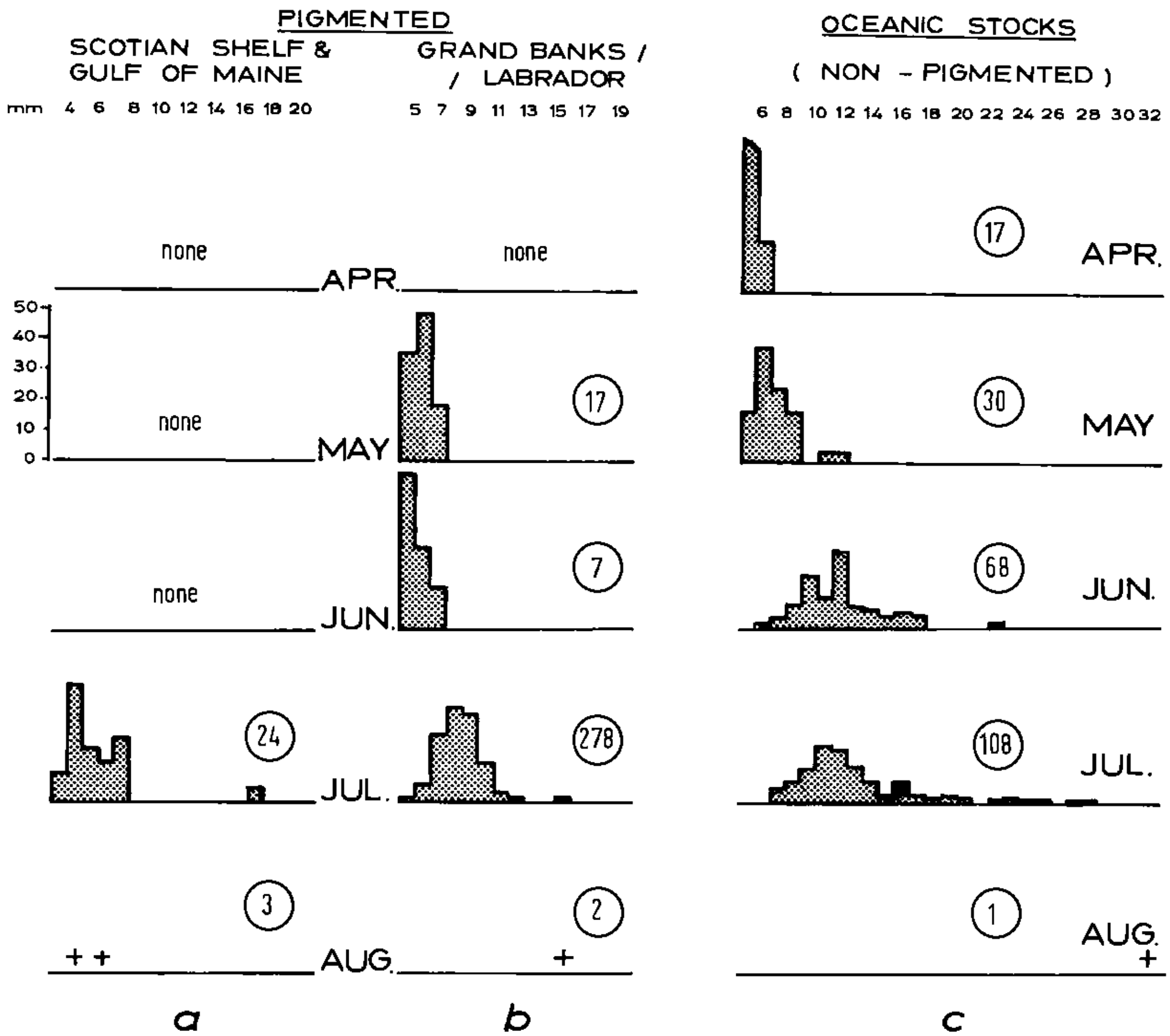

Fig. 45. Histograms showing the percentage size frequency composition of young *Sebastes* from April to August 1963. Separate series of histograms are shown for (a) the stocks on the Nova Scotian Shelf and the Gulf of Maine, (b) the stocks around the Newfoundland Banks, and (c) the oceanic stock. The lengths are shown at the top in millimeters, and the percentage scale is shown at the left side of the May histograms.

SIZE COMPOSITION

It is clearly essential to consider separately the non-pigmented and the pigmented forms. Further, in view of their geographical and temporal separation, it seems advisable to distinguish between the pigmented forms found north of the Newfoundland Bank and those of the Nova Scotian Shelf. The percentage size compositions in 1963 are shown in Fig. 45, where the oceanic non-pigmented young show a size composition very similar to that found in this region in previous years (Henderson, 1961). The stocks off the Newfoundland Bank appear somewhat different in that they apparently commence spawning later, and continue longer, than the oceanic stock, but start and finish earlier than the stock of the Nova Scotian Shelf which did not, apparently, spawn until July, and continued into August. Clearly, however, it is impossible to make any generalizations from a single year's samples, particularly as 1963 seems to have been a rather poor year for the smaller oceanic larvae in May, when formerly they have been very abundant.

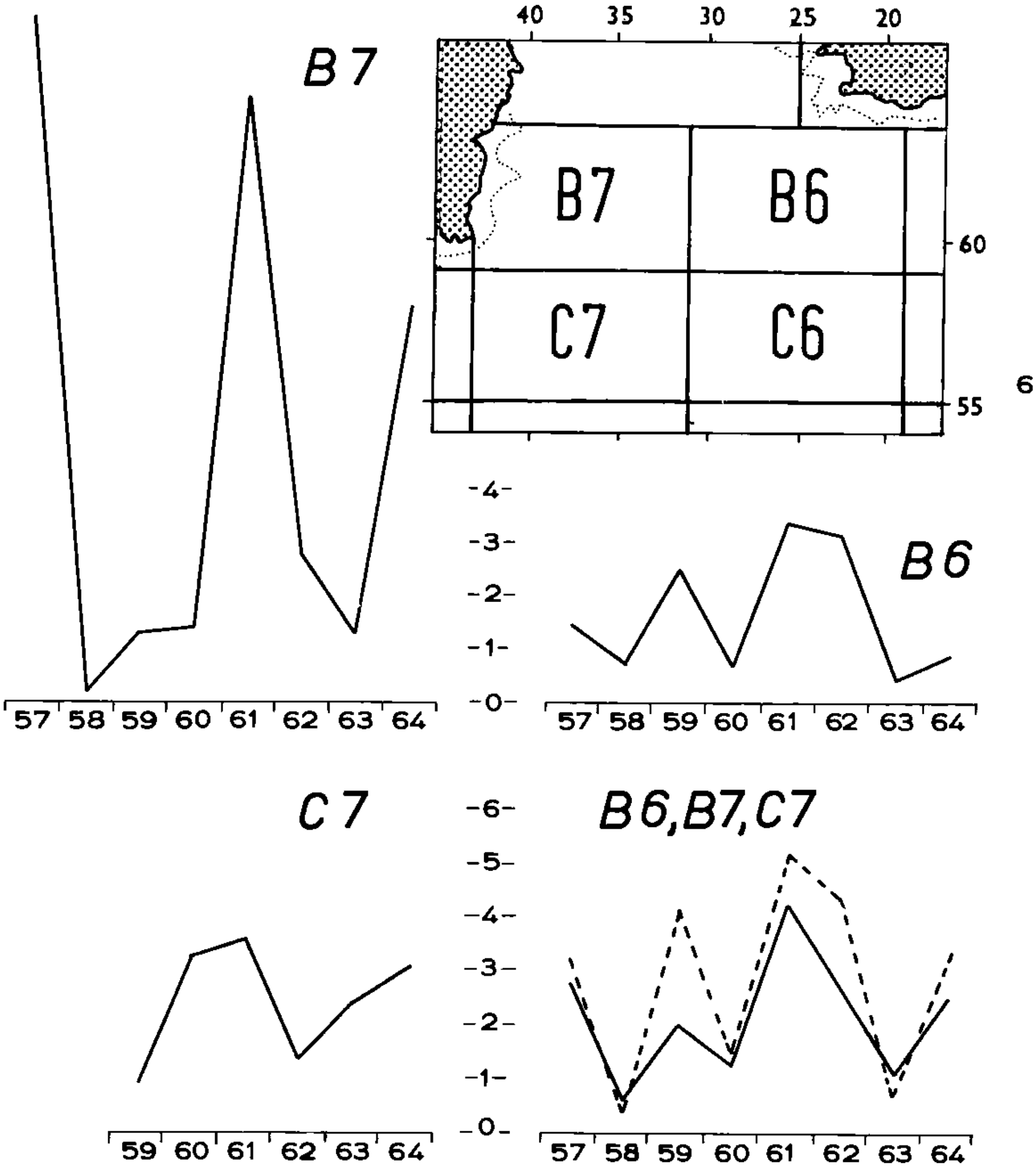

Fig. 46. Graphs showing the annual fluctuations in abundance of young *Sebastes* in the standard areas B6, B7, and C7, and for all three areas combined. The graphs are based on the period April-July, but the results for April and May are also shown in broken lines on the graph for the combined areas. The inset chart shows these standard areas.

ABUNDANCE

In previous years assessments of abundance of the oceanic stock of young *Sebastes* (Henderson, 1961) have been based on the sampling in April and May within a rectangular area to the south and southwest of Iceland. In this paper, and in future, the results will be based on the standard areas used for other organisms in the Recorder survey. The rectangle used previously for *Sebastes* included the standard area B6 and part of B7. The distribution pattern of the oceanic stock, as shown by Recorder sampling, extends over these two areas and into C7, B8, C8, D7, and the northeastern part of D8 (see fig. 23*b*, this volume p.). However, the great majority of the oceanic young stages in the Recorder samples have been found in areas B6, B7, and C7. Figure 46 shows the annual fluctuations in these areas, separately and combined, during the months April-July from 1959 to 1964. It is not possible to give comparable results for other regions or for the pigmented stocks because the survey was extended into these areas only during the past 2 or 3 years.

The most important feature of the graphs in Fig. 46 is the relatively low level of abundance of young *Sebastes* in 1963, comparable with the low figures in 1958. (The results for 1960 in area B6 and for 1961 and 1962 in C7 are probably artificially low, because of poor sampling). The low level of abundance in 1958 appeared to be characteristic of all areas in which young *Sebastes* were found (Henderson, 1961). In 1963, however, the evidence is less clear. For instance, there were larger numbers in June and July than in April and May, the reverse of the usual trend. It is possible, therefore, that the Recorder sampling in April and May did not pass through the main centres of spawning activity. Indeed there is some evidence, from other NORWESTLANT participants, that larger numbers of young were found in these early months to the northwest of the Recorder routes, in the area between Iceland and Greenland. The general conclusion seems to be that, although 1963 was not a very good year for *Sebastes* in the region of the NORWESTLANT Survey, it was probably better than 1958.

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Report on Capelin Larvae, *Mallotus villosus* (Müller)

By

Jutta Magnússon[1]

INTRODUCTION

This paper gives a summary of capelin larvae findings during NORWESTLANT 1-3.

Capelin larvae were reported by six nations: Denmark, France, Germany, Iceland, UK, and USSR. On NORWESTLANT 1, capelin larvae were only obtained on the *Thalassa* cruise (France). On NORWESTLANT 2 they were obtained on three cruises: *Anton Dohrn* (Germany); *Dana* (Denmark); and *Aegir* (Iceland). On NORWESTLANT 3 they were obtained on two cruises: *Ernest Holt* (UK), and *Academician Knipovich* (USSR). Young stages of capelin were exclusively found on the West Iceland and East Greenland shelves during all the three surveys with one exception on NORWESTLANT 3, when young capelin were reported from one station southwest of Cape Farewell.

It should be mentioned here that some of the young stages of capelin reported do not belong to the 1963 brood. However, they will also be discussed in this report as "young capelin", i.e., capelin of 43 mm and larger.

MATERIAL AND METHODS

Sampling Techniques

Capelin larvae were obtained by 2-m-stramin net, Hensen net, and the Icelandic High Speed Sampler (IHSS). The IHSS were used by Iceland instead of the stramin net since this gear cannot be used on the Icelandic research vessel *Aegir*. Capelin larvae were caught both in the IHSS and Hensen net on *Aegir*, but all the other nations reported these larvae for the stramin net. In NORWESTLANT 1 capelin larvae were obtained at seven stations; in NORWESTLANT 2 at 35 stations; and in NORWESTLANT 3 at 22 stations (see tables 89-92 in Part IV, Biological Data, of this publication). The number per 30-min tow with the stramin net ranged from 1 to 75; with the IHSS from 0.1 to 41.3 per m^3 (mean for all 3 sampling levels); and with the Hensen net from 2.4 to 188.0 per m^2.

DISTRIBUTION WITH NOTES ON THE TEMPERATURE CONDITIONS

NORWESTLANT 1

During NORWESTLANT 1 capelin larvae were only obtained off Iceland and then in small numbers (Chart 244). The highest number (75 per 30-min-tow stramin) was obtained at one station near the Icelandic coast region. Here and at the other station near the coast, the only larvae were obtained, whereas off East Greenland young capelin were caught. The larvae were found in temperatures between 5.5° and 6.5°C in 20-m depth.

NORWESTLANT 2

Of all the three surveys the greatest yields of capelin larvae were obtained during NORWESTLANT 2 (Chart 245). Most of them were caught in the Icelandic Shelf area, the densest concentrations being in Faxa Bay and off Látrabjarg. This is in agreement with earlier observations which have shown that capelin larvae are the most common species of the fish larvae west of Iceland in the spring and early summer, when they often occur in great quantities (Schmidt, 1906; Jespersen, 1920; Magnússon, 1965). At East Greenland a few capelin larvae were observed in the more northerly region but young capelin appeared to be scattered along the coast further south (the stations shown in Chart 245 marked with

[1] Hafrannsóknastofnunin, Rekjavik, Iceland.

an "x"). At one station (61°56'N, 40°14'W) a considerable number of young capelin were caught, 68 per 30-min-tow stramin. In the Icelandic region the larvae were found in waters of 5° to 7°C (20-m depth) whereas off East Greenland they were exclusively observed in waters with temperatures below 5°C.

NORWESTLANT 3

On NORWESTLANT 3 the occurrence of capelin larvae was exclusively limited to the northernmost part of the area surveyed in the Irminger Sea, i.e., in the region west of Iceland to Angmagssalik, in temperatures from -1° to 9°C (Chart 246). At a single station off Cape Farewell three specimens of young capelin were caught. No great quantities were recorded and the larvae seemed to occur in more or less isolated patches scattered on the border of the warm and cold water front off East Greenland. This is reflected in the wide temperature range in which the larvae were observed.

LENGTH

Data on the length of the capelin larvae caught at each station are given in Table 25A.

NORWESTLANT 1

Capelin larvae on NORWESTLANT 1 were only obtained at two stations off Iceland. The size range of the larvae was from 6 to 13 mm, the mean length being 7.91 mm which indicates that the bulk of the larvae was relatively newly hatched. The few young capelin which were obtained off East Greenland had a length range of 43-85 mm, the mean length being 52.07 mm.

NORWESTLANT 2

The size range of the capelin larvae on NORWESTLANT 2 was 4-31 mm, with a mean length of 10.57 mm. Larvae taken in the same localities (station number 80 and 81) 16 May, and station number 206 and 208, 31 May, with a 14-day interval) showed a clear difference in the size distribution. The mean length in these localities increased from 10.52 to 16.96 mm. Another feature in the length distribution which has been observed before (Jespersen, 1920; Magnússon, 1962; Magnússon, *et al.*, 1965) was an increase in size with increasing distance from the shore. This is shown in Table 24 where the stations are arranged in offshore direction. As in 1961, the Látrabjarg section (stations 109-106) showed a discontinuity in the size distribution.

TABLE 24. Mean length (millimeters) of capelin larvae on some sections off Iceland.

Station number	Mean length	Station number	Mean length	Station number	Mean length	Station number	Mean length
1	8.18	81	9.74	87	8.24	109	7.21
2	9.61	80	12.41	88	12.69	108	6.97
		79	17.90	89	14.14	107	7.00
		78	18.00			106	12.72

As to the young capelin previously mentioned, the length range was from 44 to 80 mm, the mean length being 56.16 mm.

NORWESTLANT 3

On NORWESTLANT 3 the size of capelin larvae ranged from 11 to 35 mm, the mean length being 22.19 mm. The samples were collected from 6 to 19 July. This time interval seemed to be reflected in the size distribution since the larvae were smaller at the beginning than towards the end of this period. The three young capelin which were caught off Cape Farewell were 63, 65, and 75 mm.

In Fig. 47, the length composition for capelin larvae is summarized and given as percentages for each millimeter group on a month's period base. No larvae were obtained during June.

GENERAL REMARKS

A comparison of the distribution charts (Chart 244-246) and the length composition (Fig. 47) leads to the assumption that all larvae reported in the three surveys originate from the Icelandic spawning grounds. Thus, on NORWESTLANT 1 all capelin larvae were found in the Icelandic Shelf region and the size indicated a new hatching. On NORWESTLANT 2 nearly all capelin larvae were caught in the Icelandic Shelf region. During this survey (May) not only had the area of distribution expanded since April, but concentrations had become denser. Of the larvae captured 55.4% were 10 mm and smaller.

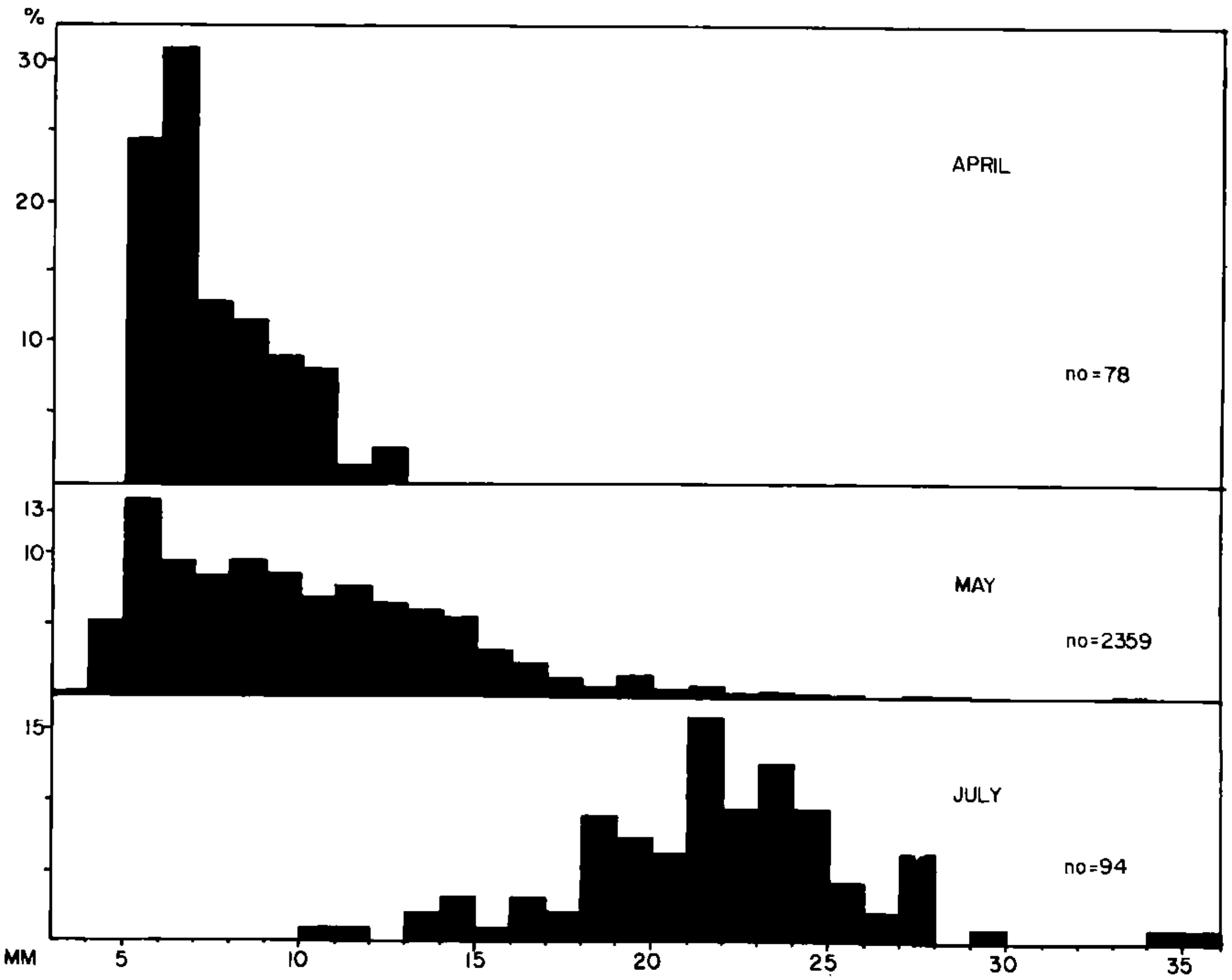

Fig. 47. The size composition of capelin larvae in months during NORWESTLANT 1-3 (April, May, and July).

On NORWESTLANT 3 no heavy concentrations were observed west of Iceland, but the larvae were distributed from Iceland to the Angmagssalik area at East Greenland. Considering the distribution (Chart 246), the current direction in this area, and the fact that all larvae caught in this survey were larger than 10 mm, one can assume that the occurrence of the capelin larvae at East Greenland is due to a drift from the Icelandic Shelf. This drift is also supported by the dynamic topographical

TABLE 25A. Length of capelin larvae (millimeters) given by survey, vessel, and station.

Survey	Vessel	Station number	Date	Length in mm 4	5	6	7	8	9	10	11	12	13	14	15	16	Sub-total
NORWESTLANT 1	*Thalassa*	11P104	20 April	-	-	-	2	1	-	-	-	-	-	-	-	-	3
		1P115	22 April	-	-	19	22	9	9	7	6	1	2	-	-	-	75
Total				-	-	19	24	10	9	7	6	1	2	-	-	-	78
Percent				-	-	24.36	30.77	12.82	11.53	8.97	7.69	1.28	2.56	-	-	-	99.98
NORWESTLANT 2	*Aegir*	1	1 May	-	3	7	44	61	40	15	4	1	1	-	1	-	177
		2		-	-	1	-	1	12	6	1	1	-	-	-	1	23
		78	16 May	-	-	-	-	-	-	-	-	-	-	1	1	1	3
		79		-	-	-	-	-	-	-	-	-	-	-	1	3	4
		80		-	1	-	-	-	6	9	15	26	12	12	6	4	91
		81		1	14	14	8	15	36	57	41	21	10	6	5	-	228
		82	18 May	2	6	63	27	3	8	9	8	17	5	2	1	-	151
		83		-	1	19	13	20	27	21	13	15	15	11	6	5	166
		84		-	-	-	3	6	14	27	12	11	9	26	22	8	138
		85		-	1	1	1	6	14	11	16	22	36	29	25	18	180
		86		-	1	22	12	26	37	22	9	14	13	5	8	2	171
		87	19 May	2	72	63	6	6	7	3	7	7	11	15	12	12	223
		88		-	1	2	4	4	7	1	4	4	4	5	12	6	54
		89		-	-	-	-	1	-	1	-	-	-	1	-	1	4
		106	21 May	-	-	-	-	-	-	4	20	27	21	26	9	-	107
		107		-	1	1	7	-	-	1	-	-	-	-	-	-	10
		108		-	21	82	53	26	4	4	-	3	1	1	3	-	198
		109		-	-	47	46	22	10	4	1	2	1	-	-	-	133
		110		-	-	-	-	-	-	-	1	-	3	-	3	3	10
		111		-	-	-	-	3	1	3	3	1	-	-	-	-	11
		130	23 May	-	-	-	-	-	-	1	-	-	-	-	-	-	1
		134		-	-	-	-	-	-	-	-	-	-	-	1	-	1
		145	24 May	-	-	-	-	-	-	-	-	1	-	-	-	-	1
		154	25 May	-	-	-	-	-	-	-	-	-	1	-	-	-	1
		157		-	-	-	-	-	-	-	-	-	1	-	-	-	1
		206	31 May	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		208		-	-	-	-	-	-	-	-	-	-	-	2	2	4
		209		1	1	4	-	-	2	4	9	10	12	5	14	11	73
Total				6	123	326	224	200	225	203	164	183	156	145	132	77	2,164
Percent				0.25	5.21	13.82	9.50	8.48	9.54	8.61	6.95	7.76	6.61	6.15	5.60	3.26	91.74

TABLE 25A. (continued).

Survey	Vessel	Station number	Date	Length in mm 17	18	19	20	21	22	23	24	25	26	28	29	31	Grand total
NORWESTLANT 1	*Thalassa*	11P104	20 April	-	-	-	-	-	-	-	-	-	-	-	-	-	3
		1P115	22 April	-	-	-	-	-	-	-	-	-	-	-	-	-	75
Total				-	-	-	-	-	-	-	-	-	-	-	-	-	78
Percent				-	-	-	-	-	-	-	-	-	-	-	-	-	99.98
NORWESTLANT 2	*Aegir*	1	1 May	-	-	-	-	-	-	-	-	-	-	-	-	-	177
		2		-	-	-	-	-	-	-	-	-	-	-	-	-	23
		78	16 May	-	1	-	3	1	-	-	-	-	-	-	-	-	8
		79		3	-	-	1	-	1	1	-	-	-	-	-	-	10
		80		1	1	-	2	-	-	-	-	-	-	-	-	-	95
		81		-	-	-	-	-	-	-	-	-	-	-	-	-	228
		82	18 May	-	-	-	-	-	-	-	-	-	-	-	-	-	151
		83		2	1	-	-	-	-	-	-	-	-	-	-	-	169
		84		8	4	1	2	1	-	-	1	-	-	-	1	-	156
		85		9	7	3	2	1	-	-	-	-	-	-	-	-	202
		86		1	2	-	-	-	-	-	-	-	-	-	-	-	174
		87	19 May	5	3	1	1	1	1	-	-	-	-	-	-	-	235
		88		3	1	2	2	-	-	-	-	-	-	-	-	-	62
		89		3	-	-	-	-	-	-	-	-	-	-	-	-	7
		106	21 May	-	1	-	-	-	-	-	-	-	-	-	-	-	108
		107		-	-	-	-	-	-	-	-	-	-	-	-	-	10
		108		1	1	-	-	-	-	-	-	-	-	-	-	-	200
		109		-	-	-	-	-	-	-	-	-	-	-	-	-	133
		110		1	-	-	-	-	-	-	-	-	-	-	-	-	11
		111		-	-	-	-	-	-	-	-	-	-	-	-	-	11
		130	23 May	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		134		-	-	-	-	-	-	-	-	-	-	-	-	-	1
		145	24 May	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		154	25 May	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		157		-	-	-	-	-	-	-	-	-	-	-	-	-	1
		206	31 May	-	-	-	-	-	-	1	-	4	1	2	1	1	10
		208		3	4	3	14	7	10	4	6	2	3	-	-	-	60
		209		15	5	6	9	2	3	-	-	-	-	-	1	-	114
Total				55	31	16	36	13	15	6	7	6	4	2	3	1	2,359
Percent				2.33	1.31	0.68	1.53	0.55	0.64	0.25	0.30	0.25	0.17	0.08	0.13	0.04	100

TABLE 25A. (continued).

Survey	Vessel	Station number	Date	Length in mm 11	12	14	15	16	17	18	19	20	21	Sub-total
NORWESTLANT 3	*Ernest Holt*	41	6 July	-	-	-	1	-	-	-	-	-	-	1
		42		-	-	-	-	-	1	-	-	-	-	1
		48	7 July	1	-	-	-	-	-	-	-	-	-	1
		49		-	-	1	-	-	1	-	-	-	-	2
		50	8 July	-	-	-	-	-	-	-	1	-	-	1
		54		-	-	-	-	-	-	-	1	-	-	1
		55		-	-	-	-	-	-	1	-	-	-	1
		56		-	-	-	1	-	-	-	-	-	-	1
		63	10 July	-	-	-	-	-	-	-	-	-	-	0
		64		-	-	-	-	-	-	-	1	-	-	1
		65		-	-	-	-	-	-	-	-	1	-	1
		69	11 July	-	-	1	-	-	-	-	-	-	-	1
		72		-	-	-	-	-	-	-	-	-	-	0
		74	12 July	-	1	-	1	-	-	-	1	1	-	4
		75		-	-	-	-	-	-	-	1	2	2	5
		77		-	-	-	-	-	1	-	-	-	-	1
		79		-	-	-	-	-	-	-	-	-	-	0
		87	15 July	-	-	-	-	-	-	1	1	1	-	3
		88		-	-	-	-	1	-	-	2	2	3	8
		89		-	-	-	-	-	-	-	-	-	1	1
		111	19 July	-	-	-	-	-	-	-	-	-	-	0
Total				1	1	2	3	1	3	2	8	7	6	34
Percent				1.06	1.06	2.13	3.19	1.06	3.19	2.13	8.51	7.45	6.38	36.16%

TABLE 25A. (continued)

Survey	Vessel	Station number	Date	Length in mm 22	23	24	25	26	27	28	30	34	35	Grand total
NORWESTLANT 3	*Ernest Holt*	41	6 July	-	-	-	-	-	-	-	-	-	-	1
		42		-	-	-	-	-	-	-	-	-	-	1
		48	7 July	-	-	-	-	-	-	-	-	-	-	1
		49		-	-	-	-	-	-	-	-	-	-	2
		50	8 July	-	-	-	-	-	-	-	-	-	-	1
		54		-	-	-	-	-	-	-	-	-	-	1
		55		-	-	-	-	-	-	-	-	-	-	1
		56		-	1	-	1	-	-	-	-	-	-	3
		63	10 July	1	-	-	-	2	-	-	-	-	-	3
		64		-	-	-	1	-	-	-	-	-	1	3
		65		-	-	1	-	-	-	-	-	-	-	2
		69	11 July	-	-	-	-	-	-	1	-	-	-	2
		72		-	-	-	-	-	-	1	-	-	-	1
		74	12 July	1	1	2	2	-	-	1	-	-	-	11
		75		4	1	-	-	-	-	-	-	-	-	10
		77		-	-	-	-	-	-	-	-	-	-	1
		79		3	-	-	4	-	1	-	-	-	-	8
		87	15 July	1	2	4	-	1	1	1	-	-	-	13
		88		3	4	5	1	1	-	2	-	1	-	25
		89		2	-	-	-	-	-	-	-	-	-	3
		111	19 July	-	-	-	-	-	-	-	1	-	-	1
Total				15	9	12	9	4	2	6	1	1	1	94
Percent				15.96	9.57	12.77	9.57	4.26	6.38	6.38	1.06	1.06	1.06	99.98%

TABLE 25B. Length of capelin (young fish) in millimeters, given by survey, vessel, and station.

Survey	Vessel	Station number	Date	Length in mm 43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	Sub-total
NORWESTLANT 1	*Thalassa*	65P58	11 April	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	3
		58P65		-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
		48P74	12 April	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
		40P81	14 April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		26P91	15 April	1	-	-	2	1	-	2	-	-	-	-	-	1	-	-	7
Total				1	-	-	3	1	1	2	1	-	1	1	-	1	-	-	12
NORWESTLANT 2	*Aegir*	157	25 May	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
		173	27 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		186	28 May	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
		187		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
		188		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
	Anton Dohrn	564	3 June	-	1	2	2	3	3	6	3	3	1	2	3	3	4	5	41
	Dana	11899	25 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Total				-	1	2	2	3	3	6	3	4	2	2	3	3	4	5	43
NORWESTLANT 3	*Academician Knipovich*	137	13 July	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Total				-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

TABLE 25B. (continued)

Survey	Vessel	Station number	Date	Length in mm 58	59	60	61	62	63	64	65	70	72	75	76	78	80	85	Grand total
NORWESTLANT 1	*Thalassa*	65P58	11 April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
		58P65		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		48P74	12 April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		40P81	14 April	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	2
		26P91	15 April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Total				-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	14
NORWESTLANT 2	*Aegir*	157	25 May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
		173	27 May	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
		186	28 May	-	-	-	-	-	1	-	1	-	-	-	1	1	-	-	5
		187		-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
		188		-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
	Anton Dohrn	564	3 June	1	6	1	3	2	-	1	-	-	1	-	-	-	-	-	56
	Dana	11899	25 May	-	1	-	-	1	-	-	-	-	-	-	-	-	1	-	3
Total				1	7	1	3	3	1	1	1	2	1	-	2	1	1	-	68
NORWESTLANT 3	*Academician Knipovich*	137	13 July	-	-	-	-	-	1	-	1	-	-	1	-	-	-	-	3
Total				-	-	-	-	-	1	-	1	-	-	1	-	-	-	-	3

observations made during the surveys and is in agreement with Schmidt's and Tåning's observations on the drift of cod larvae in these waters (Schmidt, 1931; Tåning, 1934, 1937, 1939-41, 1943).

Although spawning of capelin at West Greenland has been observed along the whole coast up to Disko Bay (Jensen and Hansen, 1931), no capelin larvae were observed during these surveys in this region. Possibly the spawning takes place in the fjords and the larvae do not seem to be drifted to a great extent into the Labrador Sea-Davis Strait area, as Danish investigations also indicate. Smidt (personal communication) reported capelin larvae in the Godthåb Fjord between NORWESTLANT 2 and 3. Smidt also reported that capelin larvae were very scarce in the Davis Strait although they were numerous in the fjords. Most probably, conditions in this respect are similar to those at East Greenland.

The distribution of young capelin was bound to the Greenland Shelf as can be seen on Chart 244-246. Their number was, however, small and did not exceed five specimens per station with one exception in NORWESTLANT 2 (Chart 245). The lengths of the young capelin are given in Table 25B and it agrees with the size range given by different authors for 1-year-old capelin (Hansen, 1939-41; Templeman, 1948; Hansen and Hermann, 1953). The location of the stations where young capelin were recorded during the different surveys is very interesting. In April, they were only found in the northernmost area of the Irminger Sea. In May and June they were recorded mainly to the south of the previously mentioned area. But in July, they had disappeared from the catches for the whole area with one exception, a station south of Cape Farewell.

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Report on Greenland Halibut and Halibut Eggs and Larvae

By

Erik Smidt[1]

INTRODUCTION

The distribution of eggs and larvae collected in NORWESTLANT 1-3 is shown in Charts 247-249. Symbols for Greenland halibut are circles; for halibut, triangles; and different symbols are used to show the numbers per 30-min haul with a 2-m-stramin net. Catches with other gears, Icelandic High Speed Sampler (IHSS) and Hensen net, are very few, and they are shown without indication of number. Stramin-net stations, where eggs and larvae were absent, are shown as dots. Other stations where they were absent are not shown in the charts, as the chance of catching them with gears other than a stramin net is very little.

GREENLAND HALIBUT, *Reinhardtius hippoglossoides* (WALB.)

NORWESTLANT 1

A few eggs but no larvae were taken with the stramin net in the Davis Strait by *G. O. Sars* from 11 to 19 April. The eggs were taken on seven stations from one to five per 30-min haul.

NORWESTLANT 2

Several larvae, but no eggs, were taken with the stramin net in the Davis Strait by *Baffin* and *Dana* from 26 May to 14 June. They were taken on 39 stations in numbers from one to twenty-four per 30-min haul. One larva was taken with IHSS. In the East Greenland-Iceland area a few larvae were taken off Southeast Greenland on three stramin-net stations by *Dana* from 25 to 31 May in numbers of only one to three per 30-min haul.

NORWESTLANT 3

In the Davis Strait several larvae were taken by *Dana* on 48 stramin-net stations from 1 to 15 July in numbers from one to fifty-four per 30-min haul. South of Cape Farewell two larvae were taken on a stramin-net station by *Academician Knipovich*, and in the East Greenland-Iceland area a few larvae were taken by *Ernest Holt* on seven stramin-net stations in numbers of one to two per 30-min haul.

Eggs

In the Davis Strait the spawning must take place in the deep, warm water south of the submarine ridge which extends from Greenland to Canada almost along the Polar Circle, as the tiny larvae (10-18 mm) are only taken south of that ridge mainly in depths of about 600-1,000 m (Jensen, 1935).

Pelagic eggs are not known from the literature, but Jensen (*loc. cit.*) has found ripe eggs with a diam of 4 to 4.5 mm in three female specimens, and later, in August 1947, ripe eggs with an average diam of 4.5 mm were found in a female taken in a fjord near Holsteinsborg. The eggs had a faintly reddish-brown membrane.

From 1954 to 1962 twenty-eight eggs, which must belong to the Greenland Halibut, have been taken by *Adolf Jensen* (Denmark) with a 1-m-stramin net off Godthåb (64°15'N lat) in coastal water and in the Davis Strait from March to May. They had a reddish-brown membrane and diam from 3.8 to 4.3 mm (average 4.0 mm), and embryos were distingly developed. Seventeen eggs of precisely the same type, also with embryos and with diam from 3.7 to 4.2 mm (average 3.9 mm) were taken on NORWESTLANT 1.

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No other pelagic eggs of this size have been taken in West Greenland waters, and judging from the colour of the membrane, there can be no doubt that these eggs belong to Greenland halibut. As they are considered to be bathypelagic, it is understandable that only few have been taken in stramin nets in the upper water layers. However, on a stramin-net station *Adolf Jensen* got sixteen eggs in 30 min with a 1-m-stramin net and 600-m wire out (about 200 m) west of Fyllas Bank on 27 March 1962.

Nothing is known about the spawning areas in the water between East Greenland and Iceland.

Larvae

The larvae have been described and figured by Schmidt (1904) and Jensen (*loc. cit.*). The tiny larvae were mostly taken in deeper water, but later the larvae rise towards the surface.

The distribution of the larvae as shown in the NORWESTLANT 2 and 3 charts (Charts 248, 249) is typical, as it is in good accordance with data from previous expeditions. In Chart 250 all data from the Danish expeditions since 1908 and from NORWESTLANT are summarized; it is based on 1,281 stramin-net stations, of which larvae were taken on 467. Previously, the distribution of Greenland halibut larvae in the NORWESTLANT areas has been published by Jensen (1926, 1935) and Tåning (1936, 1951).

Chart 250 shows that the densest occurrence of Greenland Halibut larvae is in the Davis Strait as indicated by the hatched area. In this area regular Danish investigations have been made for many years, so that the information is rather secure. However, the western limit of the hatched area is mainly a limit for the investigations and therefore says nothing about the limit of the distribution of the larvae. The densest occurrence is in the zone between 62°30'N and 66°15'N (ICNAF Divisions 1C and 1D), where an average of more than 10 larvae per 30-min-stramin haul was taken in July (biggest number in one stramin haul here was 163 larvae in 30 min in July 1957). In the East Greenland area the larvae are scarce as never more than five larvae per 30-min haul have been taken on a stramin-net station.

It is remarkable that no larvae (and no eggs) have been taken in the West Greenland fjords, where many stramin-net hauls have been taken, and where dense populations of adult fish live. It is also remarkable that no larvae have been taken in stramin-net hauls north of 68°N lat, inspite of very rich populations of adult fish which are fished by the Greenlanders, especially in the Disko Bay and Umanak district. Chart 250 shows that no larvae have been taken in the Polar Current zone near the coast of Southeast Greenland and the southernmost coast of West Greenland. Thus, all data show that the Greenland Halibut only reproduce in relatively warm water, although the adults have a real arctic distribution, as they live as far north as Inglefield Gulf (about 77°N lat) in Northwest Greenland.

The average number of larvae per 30-min-stramin haul in the Davis Strait in the zone between 60°45'N and 68°50'N (ICNAF Divisions 1B-1E) was three in NORWESTLANT 2 (June) and six in NORWESTLANT 3 (July). This presumably means that in the meantime there has been a recruitment of younger larvae from deeper water to surface water.

In Fig. 48 the average number of larvae per 30-min haul in the above-mentioned area in the Davis Strait in NORWESTLANT 3 is compared with catches made by *Dana* in the same area and in the same month (July) in different years since 1950. It shows the number of Greenland Halibut larvae was only a little under normal on NORWESTLANT 3, as the average catch per 30-min haul for all the years shown in Fig. 48 was eight larvae.

The growth of the larvae in the Davis Strait from NORWESTLANT 2 to NORWESTLANT 3 is shown by the length measurement curves in Fig. 49. Most likely the distance between the peaks of the curves gives the best picture of the growth because there has presumably been a recruitment of younger larvae from deeper water in the time between NORWESTLANT 2 and 3, and at the same time there must have been some mortality of older larvae. Thus, the larvae in 1 month (from first half of June to first half of July) have grown from about 20 mm to about 27 mm.

The larvae taken south of Greenland on NORWESTLANT 3 measured 32 and 38 mm corresponding with the largest Davis Strait larvae, but the larvae from the East Greenland-Iceland area were much larger, from 38.5 to 57.0 mm (averaging 48 mm), which may indicate an earlier spawning in that area than in Davis Strait.

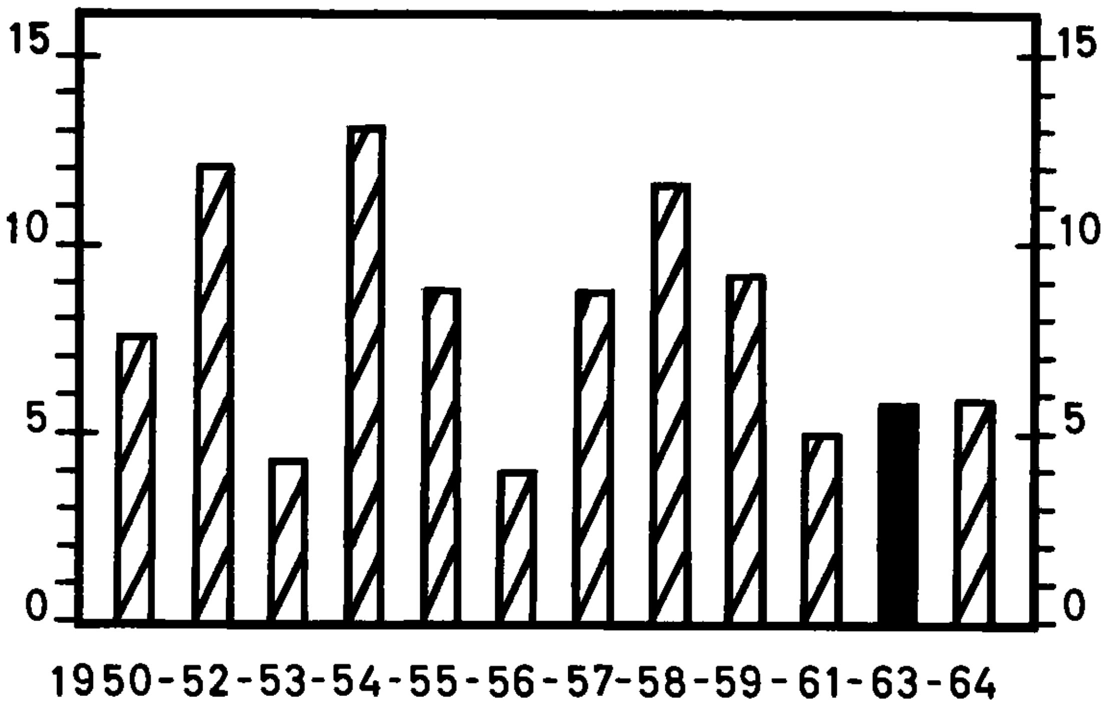

Fig. 48. Average numbers of Greenland Halibut larvae per 30-min-stramin-net haul in different years in the Davis Strait (ICNAF Divisions 1B-1E) in July. NORWESTLANT 3 shown as black column. The calculations are based on following numbers of stramin-net hauls: 1950 — 35; 1952 — 22; 1953 — 25; 1954 — 44; 1955 — 31; 1956 — 25; 1957 — 27; 1958 — 30; 1959 — 26; 1961 — 27; 1963 — 79; 1964 — 35.

HALIBUT, *Hippoglossus hippoglossus* (L.)

NORWESTLANT 1

Some eggs (total 11) were taken by *Thalassa* on six stations with stramin net in the area between East Greenland and Iceland on 15 and 16 April in numbers from one to five per 30-min haul. No larvae were taken.

NORWESTLANT 2

In the area between East Greenland and Iceland one larva was taken with IHSS on 19 May and one with Hensen net on 23 May by *Aegir*. Also, one larva was taken at Newfoundland (52°51'N, 49°00'W, not shown in chart) by *Sackville* on 12 May.

NORWESTLANT 3

In the Davis Strait single larvae were taken on three stramin-net stations by *Dana* from 10 to 14 July. Southwest of Greenland a few larvae were taken on three stramin-net stations by *Academician Knipovich* from 2 to 8 July in numbers of one to three per 30-min haul. Between East Greenland and Iceland one larva was taken in stramin net by *Ernest Holt* on 8 July.

Eggs

Eggs taken on NORWESTLANT 1 had a diam of 3 mm, which is in accordance with the description by Rollefsen (1934).

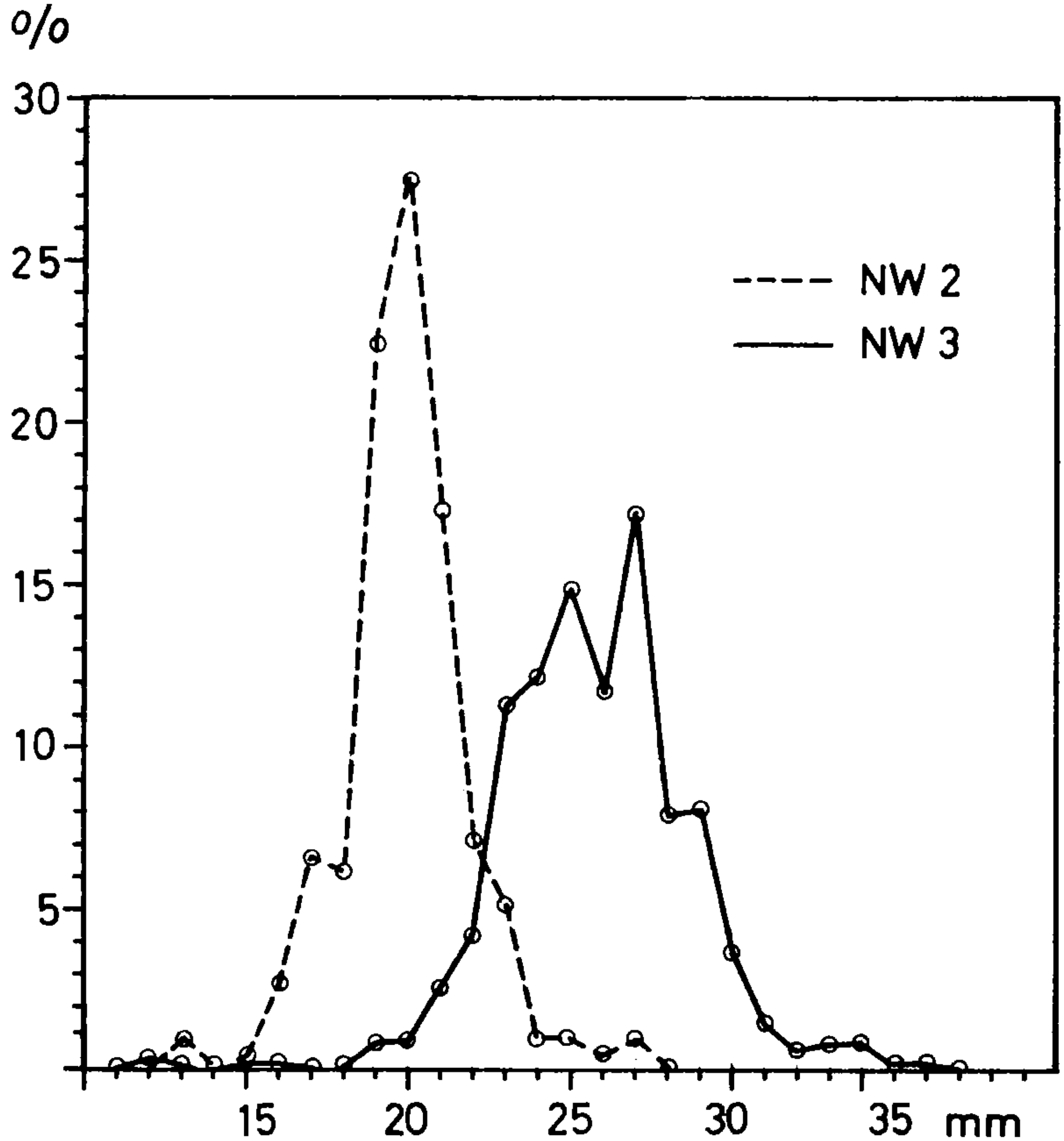

Fig. 49. Length distribution (in millimeters) of Greenland Halibut larvae from the Davis Strait. NORWESTLANT 2 — 27 May to 14 June. NORWESTLANT 3 — 30 June to 15 July.

Larvae

Descriptions with figures of larvae have been given by Rollefsen (*loc. cit.*), Schmidt (1904), and Tåning (1936). Both larvae from NORWESTLANT 2 were 12 mm and the larvae from NORWESTLANT 3 were from 26 to 35 mm. The distribution of larvae taken in the NORWESTLANT area has previously been described by Hansen (1959) and Tåning (1936, 1951). The larvae only occur scattered and few in numbers.

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Report on American Plaice Eggs and Larvae

By

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NORWESTLANT 1

Virtually no American plaice larvae were taken during NORWESTLANT 1. The bulk of the eggs was taken between about 62° and 66°N off the west coast of Greenland. Hensen-net samples were invariably small but some good catches were taken by the stramin net. At two stations occupied by the *G. O. Sars* the catch of eggs by stramin net exceeded 1,000 per haul. Off East Greenland, no eggs or larvae were taken by the *Ernest Holt* with any type of net. Of two positive stramin tows made by the *Thalassa* near Iceland, one contained 357 eggs. From the series of lines occupied by the *Academician Knipovich* and the *Topseda*, one small catch of two eggs was taken (Charts 251, 252, 257; Tables 93 and 94 in Part IV (Biological Data) of this publication).

NORWESTLANT 2

During NORWESTLANT 2 the *Aegir* took only small numbers of eggs and larvae near Iceland by Hensen net and Icelandic High Speed Sampler (IHSS). A small number of larvae were taken by IHSS and Hensen net off East Greenland at about 65°N. To the south over the grid of stations covered by the *Anton Dohrn*, no eggs or larvae were taken by any type of net. Off the west coast of Greenland the *Dana* took no larvae and only one egg by Hensen net. However, quantities of eggs, ranging up to 625, were generally present in the stramin tows. Larvae catches by stramin tow were smaller and less frequent than those of eggs. In the same area Hensen net catches by the *Baffin* included some small catches of eggs and larvae, while stramin tows produced fair egg catches - up to 105 - and small catches of larvae (Charts 253, 254, 258, 259, 262, 263; Tables 95, 96, and 97 in Part IV (Biological Data) of this publication).

NORWESTLANT 3

In the area between Iceland and Greenland, a large number of stations were occupied by the *Explorer* and *Ernest Holt* during NORWESTLANT 3. The stramin net took small catches of eggs and larvae. Lines occupied by the *Academician Knipovich* and sampled by IHSS, Hensen, and stramin nets produced no eggs or larvae.

On the line occupied by the *Dana* south of Cape Farewell one only larva was taken. Hensen catches by the *Dana* in the West Greenland area were very small and there were only three positive stations. Egg catches off West Greenland by stramin net were largest between about 62° and 64°N. The largest catch was 458 eggs. Catches of larvae were small in the southern area but were good at stations north of about 64°30'N. Apparently, some northward drift of larvae occurred between NORWESTLANT 2 and 3 (Charts 255, 256, 260, 261; Tables 98 and 99 in Part IV (Biological Data) of this publication).

The available information concerning the development of the eggs and the lengths of the larvae is not sufficient to determine with certainty the spawning times of the American plaice. Three larvae taken during NORWESTLANT 1 by France measured less than 4 mm. Length measurements by Canada, Iceland, and Denmark indicate that, although some larvae taken during NORWESTLANT 2 ranged up to 13 mm, most were under 7 mm. Larvae taken by Denmark during NORWESTLANT 3 ranged from 4 to 19 mm, most being greater than 11 mm. In NORWESTLANT 2, about 70% of the eggs examined by Canada were in stages 3 and 4 (Apstein's stages 12-19). Spawning occurred mainly in a wide area off West Greenland between about 62° and 66°N, with a smaller occurrence off Iceland. It was well under way in April and eggs were taken in good numbers until the end of July. By this time, however, the bulk of the larvae had reached a fair length.

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The stramin net appears to be the most efficient of the nets used for capturing American plaice eggs and larvae.

Report on Wolffish Larvae in West Greenland Waters

By

Paul Hansen[1]

SPECIES OF WOLFFISH IN GREENLAND WATERS

Three species of wolffish occur in Greenland waters: the spotted wolffish, *Anarhichas minor*; striped wolffish, *Anarhichas lupus*; and the blue wolffish, *Anarhichas latifrons*. The spotted and striped (especially the spotted) wolffish are of importance to the filleting industry, while the blue wolffish has no commercial value because of its watery meat. The spotted and the blue wolffish are by far the most common species in Greenland waters. The striped wolffish has a more southerly distribution (northern limit 73°N) than the two other species (northern limit 76°N). It has been a rare fish, but seems to have become more common off Greenland in recent years. It is much smaller than the two other wolffishes. The lengths of 174 *Anarhichas lupus* were 35-75 cm with a maximum at 50 cm. The lengths of 786 *Anarhichas minor* were 70-120 cm with a maximum at 100 cm. *Anarhichas latifrons* is about the same size as *Anarhichas minor* (Hansen, 1956).

Almost nothing is known concerning the propagation in Greenland waters of the three *Anarhichas* species. From other areas it is known that all three species deposit their eggs in lumps at considerable depths among stones on the bottom. Wolffish eggs with foetus are sometimes found in cod stomachs in Greenland waters.

IDENTIFICATION OF LARVAE

The larvae are hatched with a big yolk sac and when this is resorbed the larvae seek the surface. The identification of the larvae is difficult. Two different types occur in Greenland waters; one with big, dark spots, and another plain grey or brown. Numerical characters cannot be used for identification because the numbers of fin rays overlap between species (Andriyashev, 1954).

There is reason to believe that the spotted larvae belong to *Anarhichas minor*. In 1953 a spotted larvae was taken by *Dana* in Greenland waters. It was kept in the aquarium in Charlottenlund from August to January when it died. It grew to about 6-7 cm and at that size it became evident that it was *Anarhichas minor*.

Although it has been impossible to separate the two uniformly coloured species by meristric characters, there are reasons to believe that the vast majority of uniformly coloured larvae belong to the species *Anarhichas latifrons*. First, this species is much more numerous in Greenland waters than *Anarhichas lupus*, and it occurs at all depths from shallow waters down to several hundred meters, while *Anarhichas lupus* lives at rather moderate depths. Second, a comparison between larvae of *Anarhichas lupus* from Danish waters (where *Anarhichas lupus* is the only species) and the uniformly coloured larvae from Greenland showed that the Greenland specimens were a little different from the Danish ones.

In what follows the uniformly coloured larvae for practical reasons will be called *Anarhichas sp. l.*, to include *Anarhichas latifrons* and *Anarhichas lupus*.

DISTRIBUTION OF WOLFFISH LARVAE

NORWESTLANT 1

Thirteen wolffish larvae were captured, eight in Div. 1F and five in the area between 63°58'N - 65°49'N, and 28°24'W - 36°31'W, all of them were *Anarhichas sp. l.*

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NORWESTLANT 2

Of the 44 wolffish larvae captured (at 32 stations), 28 larvae belonged to *Anarhichas sp. l.*, 8 to *Anarhichas minor*, and 8 were lost. In the East Greenland area one larva of *Anarhichas sp. l.* was captured in each of three hauls with 2-m-stramin net east of Cape Farewell and four larvae were taken off Tingmiarmiut, Southeast Greenland.

NORWESTLANT 3

In 32 hauls with the 2-m-stramin net 51 wolffish larvae were captured. Thirty-five belonged to *Anarhichas sp. l.*, 16 were *Anarhichas minor*. In the East Greenland area three larvae were caught off Angmagssalik, and one east of Cape Farewell.

Charts 264 and 265 show the distribution of the catches of the larvae *Anarhichas minor* and *Anarhichas sp. l.*, respectively. Since the catches during NORWESTLANT 1-3 were small or negligible, they were combined for presentation.

Charts 266 and 267 show the distribution of the catches of *Anarhichas minor* and *Anarhichas sp. l.*, using the 2-m-stramin net in June and July of 1925, 1950, 1957, 1958, 1961, and 1963.

Chart 268 shows the distribution of all *Anarhichas* larvae off East Greenland.

The distributions of the larvae of *Anarhichas minor* and *Anarhichas sp. l.* are very similar. It appears that they are found in largest numbers along the slopes of the banks and over the open sea. According to many years' experience they are very rare in inshore waters, and they are never found in the fjords. It is remarkable that there is a concentration of larvae, especially of *Anarhichas minor*, off Sukkertoppen (about 65°20'N). Sukkertoppen is a town from where an important fishery on *Anarhichas minor* has been carried out in the winter months during several years. Another interesting fact is that there is a gap in the occurrence of wolffish larvae between 67° and 68°N. This applies to both *Anarhichas minor* and *Anarhichas sp. l.* The area where wolffish larvae have not been caught is Store Hellefiske Bank. It may be that the absence of wolffish larvae can be explained by the rather shallow water over this bank. North of the bank, from 68° to 69°30'N, wolffish larvae are found again. A single larva of *Anarhichas sp. l.* was caught at the entrance to Disko Bay.

SIZE OF WOLFFISH LARVAE

Lengthy measurements of 13 *Anarhichas sp. l.* larvae taken during NORWESTLANT 1 ranged from 17 to 30 mm. Eight *Anarhichas minor* larvae were measured on NORWESTLANT 2, and 16 on NORWESTLANT 3, with most of the larvae ranging from 25 to 43 mm, the three largest being 49, 43, and 41 mm. Twenty-eight larvae of *Anarhichas sp. l.* were captured during NORWESTLANT 2 and 35 during NORWESTLANT 3. Six very large specimens were taken during the catches; 53 mm (1), 54 mm (2), 57 mm (1), 60 mm (1), 65 mm (1). The majority of the larvae were between 20 and 30 mm on NORWESTLANT 2 and between 24 and 36 mm on NORWESTLANT 3. Average lengths of larvae on NORWESTLANT 2 and 3 were 28.5 and 31.3 mm respectively.

The lengths are in agreement with those found in 1925; the year (1925) for which we have the largest material of wolffish larvae separated in the same way as in 1963. Of the 137 *Anarhichas minor* captured, 33 were taken from 6 to 23 June and 104 from 1 to 14 July. The numbers of *Anarhichas sp. l.* taken during the same periods were 66 and 106. Two large specimens of *Anarhichas minor* measured 55 and 50 mm. The following table gives the limits of the length distribution and the mean lengths for the larvae of both species in two periods in 1925 .

Species:	6-23 June		1-14 July	
	Anarhichas minor	*Anarhichas sp. l.*	*Anarhichas minor*	*Anarhichas sp. l.*
Size limits	24-35 mm	21-30 mm	23-35 mm	20-34 mm
Mean lengths	27.8 mm	24.2 mm	27.7 mm	26.0 mm

The large specimens (50 mm or more) are so different in size and in appearance from the majority of the larvae that there is reason to believe that they belong to an older age-group, possibly the I-group.

DISCUSSION AND CONCLUSIONS

As appears from this report, very little is known about the larvae of the three wolffish species in Greenland waters. The same applies to the young age-groups which live on rocky bottoms where fishing gears cannot be used. Fishing experiments for *Anarhichas minor* carried out in Upernavik district in North Greenland and at different places in South Greenland have shown that individuals of small and medium sizes are common in catches in North Greenland while they seldom are caught in South Greenland.

This phenomenon can possibly be explained as follows. The adult *Anarhichas minor* live chiefly in the southern part of the West Greenland waters where it propagates. The larvae which seek the surface are carried by the current to northern Greenland waters where they go to the bottom and live until they grow to maturity and migrate to the southern spawning grounds (Hansen, 1957).

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The Feeding of Cod and Redfish Larvae

By

V. Bainbridge[1] and B. J. McKay[1,2]

INTRODUCTION

The main object of the NORWESTLANT Surveys was to study the effect of the environment on the planktonic stages of the cod, *Gadus morhua* L., and the redfish, *Sebastes* spp., in the seas around Greenland. Since the availability of suitable food has frequently been considered a key factor limiting the survival of fish larvae, information was required on the food and feeding habits of the young fish.

Some investigations have been previously carried out on the diet of the larvae of both species. Einarsson (1960) examined young *Sebastes* from two samples taken west of Iceland and noted that the staple food organisms were copepod eggs and *Spiratella* larvae. These observations were confirmed by Bainbridge (1965) using more extensive material collected during the Continuous Plankton Recorder Survey. Recently extruded redfish larvae (6-10 mm) from the Irminger Sea were feeding principally on *Calanus* eggs, the only other food item of any importance being *Spiratella* larvae.

The diet of cod larvae in the North Sea has been investigated by Goodchild (1925) and in the Gulf of Maine and Georges Bank areas by Marak (1960). In both regions copepod nauplii formed the main food of the smallest feeding larvae, and the copepodite stages of a variety of copepods, including *Calanus*, *Paracalanus*, *Pseudocalanus*, and *Temora* were identified in the larger larvae. The food of cod larvae was investigated in greater detail by Wiborg (1948) using material from the Lofoten area and other coastal waters off northern Norway. Young cod from 4 to 10 mm were mainly eating copepod nauplii, particularly those of *Calanus*, *Metridia*, and *Oithona*. Other organisms present in the guts included the eggs and copepodite stages of copepods, lamellibranch larvae, and *Evadne*.

The NORWESTLANT Surveys provide ideal material for a comparative study of the food of redfish and cod larvae over a vast area of the Northwest Atlantic and also allow a consideration of feeding in relation to the main environmental variables.

MATERIAL AND METHODS

The fish larvae were obtained from samples collected by a variety of methods, including oblique hauls from 50 to 0 m with 2-m-stramin nets, horizontal haults at 2 to 5 m, 15 to 18 m, and 25 to 30 m with Icelandic High Speed Samplers (IHSS) and vertical haults from 100 m to the surface with Hensen, Nansen, and Helgoland larva nets. Details of the techniques used in operating the various nets are described in the Guide Book to Surveys NORWESTLANT 1-3 and in the section on Zooplankton in this volume. The plankton was killed by the addition of 40% neutralized formalin and samples were subsequently preserved in 4% formalin buffered with hexamine. The cod and redfish larvae examined had already been sorted from the samples, counted and measured. Research vessels from eight countries participated in the surveys and we are grateful to the following people for their readiness to help by sending material.

J. Beaudouin	(*Thalassa*, NORWESTLANT 1)
E. Bratberg	(*G. O. Sars*, NORWESTLANT 1)
J. Corlett	(*Ernest Holt*, NORWESTLANT 1)
J. Magnússon	(*Aegir*, NORWESTLANT 2)
A. Kotthaus	(*Anton Dohrn*, NORWESTLANT 2)
E. Smidt	(*Dana*, NORWESTLANT 2 and 3)
R. Wells	(*Baffin* and *Sackville*, NORWESTLANT 2)

[1] Oceanographic Laboratory, Edinburgh, Scotland.
[2] Miss B. J. McKay now Mrs B. J. Philip.

Additional samples of larvae collected off West Greenland during *Dana* cruises of earlier years were made available by Dr E. Smidt.

Dr J. H. Fraser and Mr J. Corlett kindly allowed us to include their observations on the food of young fish collected during NORWESTLANT 3 from *Explorer* and *Ernest Holt*. Our thanks are also due to Dr G. A. Yarranton for advice with statistics.

The distributions of cod and redfish larvae during the three surveys have been described in the separate reports of Hansen and Magnússon (this volume). Figure 50 shows the distribution of the

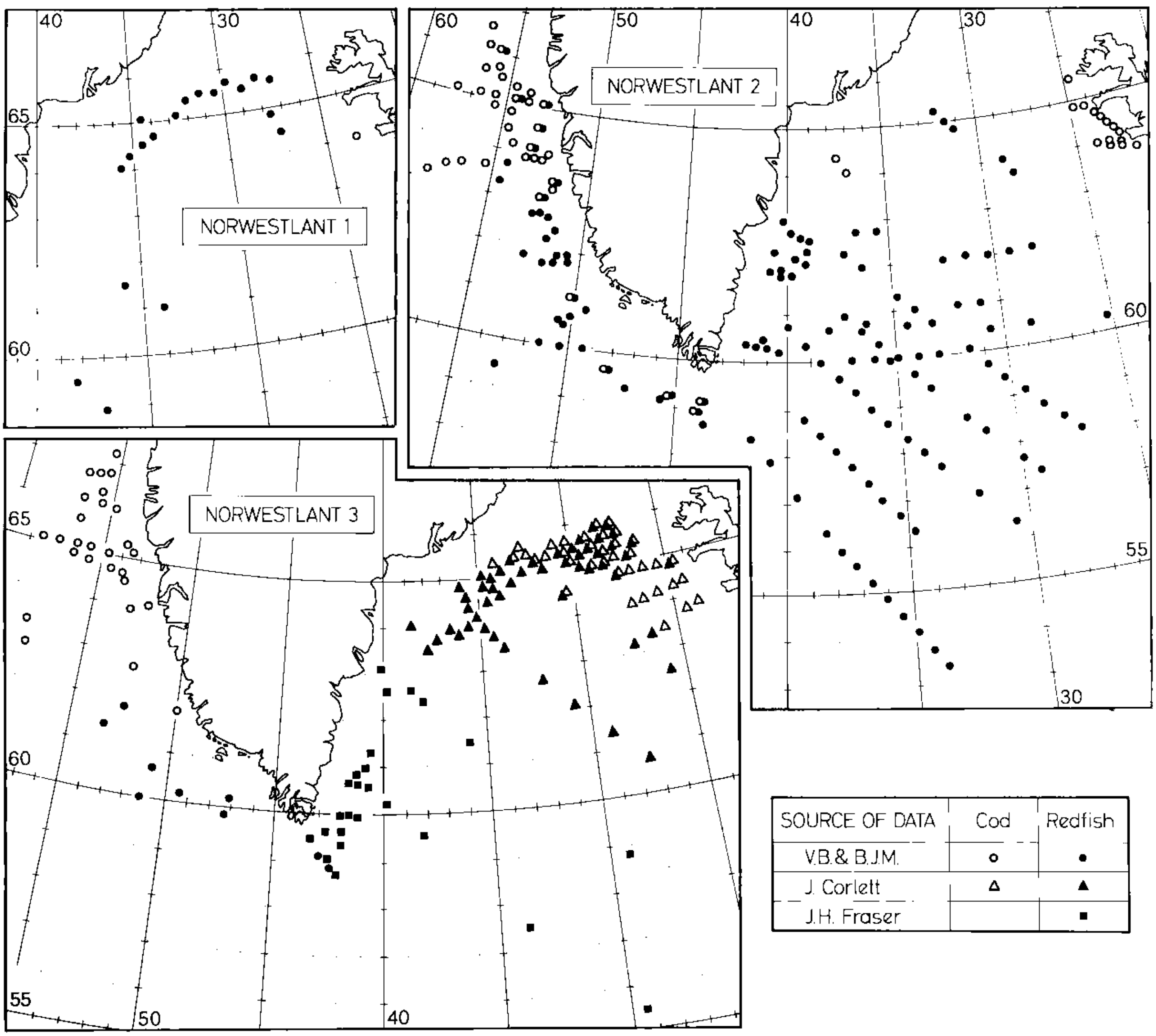

Fig. 50. The distribution of samples used for the analysis of the gut contents of fish larvae. Stations from which samples of cod larvae were examined are shown as open symbols and those from which samples of redfish larvae were examined as closed symbols.

samples used for the analysis of larval gut contents during each survey. These included the majority of the stations at which the young fish were present. From each sample all the larvae were examined if there were less than 10 of either species present, otherwise a subsample of at least 10 cod or redfish larvae was normally used. At some stations additional larger subsamples were examined. In the IHSS samples, larvae from the 15- to 18-m level were used when possible. Each larva was measured, then the whole of the gut was removed and slit open under a dissecting microscope with a pair of fine needles. The food remains were in an excellent state of preservation and clearly showed the various phases of digestion, from entire *Calanus* eggs to empty egg membranes and from perfect nauplii to exoskeleton "ghosts" (Fig. 51). In larvae up to about 15 mm in length there was only a little fragmentation of the food remains, so organisms present could be counted and identified. The basic data obtained has been tabulated in the Appendix with the young fish arranged in millimetre length-groups[3].

The numerical results were converted to biomass values and this has been done using the factors listed in Table 26. Biomass estimates so obtained represent the wet weight of food organisms, assuming no digestion, and not the true weight of the gut contents. Nevertheless, these biomass values allow rough assessment of the relative importance of each type of food and a comparison *inter se* of the intensity of feeding at different times and in different regions.

COMPARISONS OF THE RESULTS OBTAINED WITH DIFFERENT NETS

Although a standard method was adopted for the fixation of plankton samples, the question arises whether the various nets used, with different towing speeds, duration of hauling, and depth of sampling, influence the quantity of food remains found in the guts of the fish larvae. Some comparisons are therefore set out in the following discussion.

To investigate the results obtained for cod larvae from the Hensen net (hauled vertically from 100 m to 0 m at 1 m/3 sec) and the IHSS (hauled horizontally, depth 15-18 m at 8 knots), 10 larvae were examined from each of the two nets at three stations worked by *Aegir* during NORWESTLANT 2. Each larva was measured and the total biomass of the food remains estimated, the mean values being listed in Table 27a. An analysis of variance, using the raw data, indicated that the type of net did not affect the total gut contents, the contribution of nets and of net-station interactions to the total variance being quite insignificant (Table 27b).

A similar test was carried out on the gut contents of redfish larvae from the Helgoland larva net (hauled vertically from 100 m to 0 m at 1 m/3 sec) and the 2-m-stramin net (hauled obliquely from 50 m to 0 m at 1.5 knots). Biomass estimates of food remains could be obtained for only eight larvae from each of the two nets at two stations worked by *Anton Dohrn* during NORWESTLANT 2. Table 28a shows that the gut contents of larvae from the Helgoland net had about twice the biomass of the gut contents of larvae from the stramin net and the analysis of variance set out in Table 28b demonstrates that the differences between nets were significant.

The results of these two tests were contradictory but it was later realized that whereas the *Aegir* stations used were sampled during the day (the IHSS hauls being made immediately after the Hensen-net hauls) the only two *Anton Dohrn* stations with sufficient redfish larvae for net comparisons were worked at night. Moreover, the stramin-net hauls at these particular stations were made 0.5-2.0 hr after the Helgoland-net haul. The rapid decline in the amount of food in the guts of redfish larvae after sunset described in a subsequent section (Fig. 55) readily explains the discrepancy observed between the stramin and Helgoland nets.

The scarcity of redfish larvae in the Helgoland-net samples precluded further tests at individual stations but a comparison was possible by combining results for several stations. All available redfish larvae from the Helgoland-net samples of the *Anton Dohrn* cruise were measured, the gut contents analyzed and the results converted to biomass estimates. For each of these larvae, one of the same length was taken from the stramin-net sample at the same station and the biomass of the gut contents similarly estimated. In this way 34 pairs of larvae, from 7 to 13 mm, were obtained from 16 stations. Fortuitously, 17 pairs were from night stations and 17 from day stations. The biomass values were transformed by logarithms[4] to normalize distributions and the means for the two types of net were tested against each other using the t-test. The means for the Helgoland net (2.356, SD ± 0.881) and for the stramin net (2.372, SD ± 0.814) do not differ significantly.

From these tests it can be concluded that the gut contents of the preserved fish larvae were not appreciably influenced by the different types of net used during the survey. Data obtained from larvae taken with all the various nets have therefore been utilized in this investigation.

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[3] Measurements from n to n + 0.9 mm were classed as n where n is a whole number.

[4] $\log (n + 1)$ where n = weight in mg $\times 10^4$.

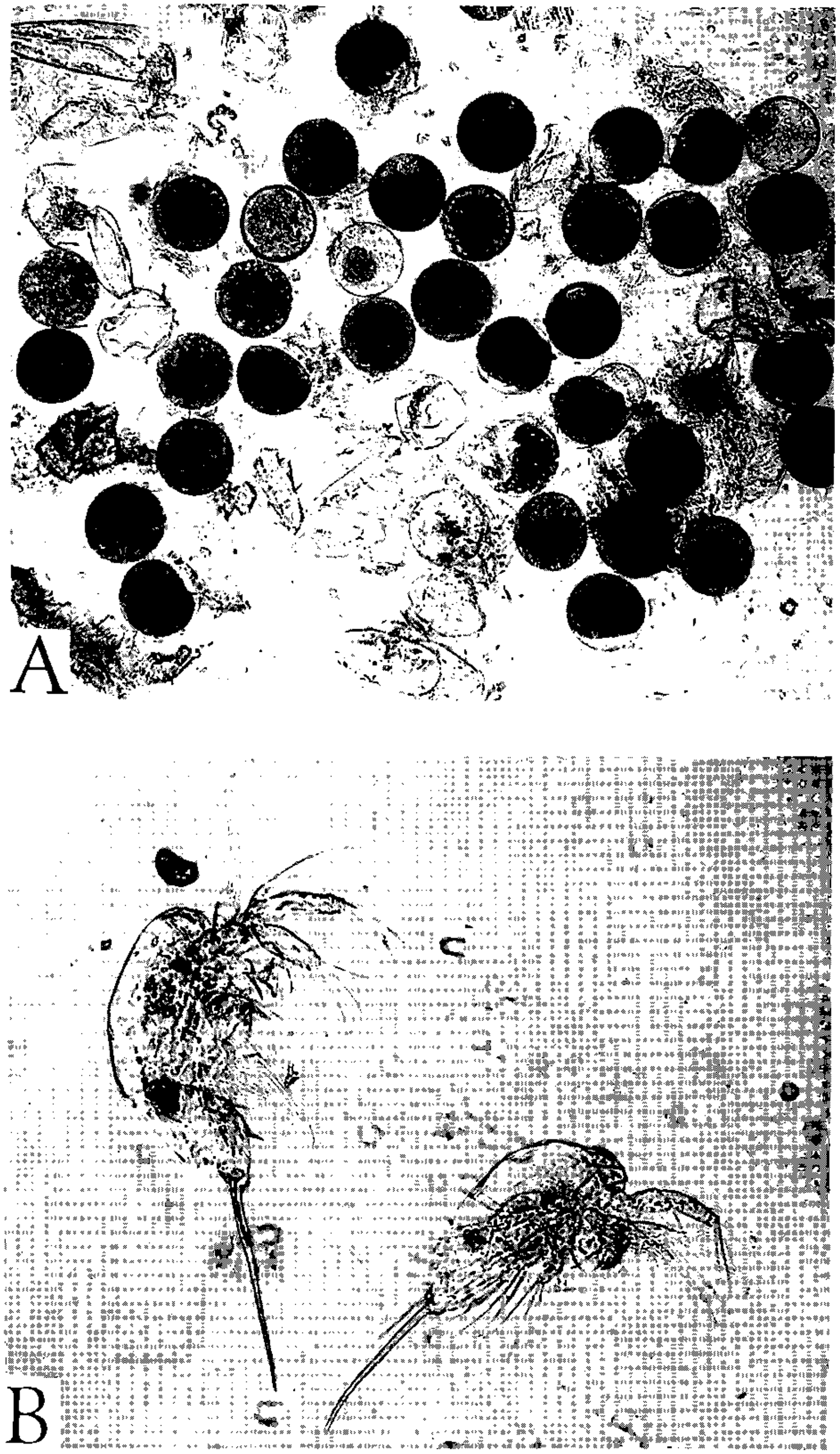

Fig. 51. The gut contents of fish larvae. A. Food remains from a redfish larva taken in the Irminger Sea during May consisting almost entirely of *Calanus* eggs in various states of digestion. B. Two *Temora* nauplii from a cod larva taken off Iceland during May. Although the soft parts of the nauplius are almost completely digested the exoskeleton remains intact.

TABLE 26. Estimated biomass values (wet or live weight) of organisms found in the guts of cod and redfish larvae. The calculated values have been obtained from the average dimensions of the organisms assuming a density of one, with the exception of *Calanus* eggs for which the density given by Salzen (1956) has been used.

Food item	Weight (mg)	Source
Calanus finmarchicus		
Eggs (c.135 μ diam)	0.0014	Calculated
Nauplii stages I-VI	0.010	Averages from Bogorov (1959)
Copepodites stages I and II	0.045	
Copepodites stages III and IV	0.28	
Copepodite V and Adults	1.24	
Pseudocalanus, Temora and *Centropages*		
Nauplii stages I-VI	0.005	Averages for *Pseudocalanus* from Bogorov (1959)
Copepodites stages I and II	0.022	
Copepodites stages III and IV	0.050	
Copepodite V and Adults	0.075	
Oithona		
Nauplii	0.001	Calculated
Copepodites and Adults	0.007	Bogorov (1959)
Oncaea borealis		
Crustacean Eggs (c. 60 μ diam)	0.0001	Calculated
Crustacean Eggs (c. 30 μ diam)	0.00001	
Evadne nordmanni	0.03	Calculated
Balanus nauplii	0.01	Bogorov (1959)
Euphausiacea		
Eggs (200-300 μ)	0.02	Bogorov (1959)
Nauplii	0.05	
Calyptopes	0.5	
Furcilias 2-3 mm	0.5	
Furcilias 3-4 mm	0.8	
Furcilias 4-5 mm	1.2	
Furcilias 6-7 mm	2.0	
Spiratella larvae (c. 125 μ diam)	0.001	Calculated
Lamellibranch larvae	0.001	
Radiolaria: *Phorticum*	0.001	Calculated
Tintinnoidea: *Tintinnopsis*	0.00004	Bogorov (1959)
Parundella	0.00007	Calculated
Ptychocylis	0.00004	Calculated
Parafavella	0.0002	Calculated

TABLE 27a. Comparison of the average values for the length and gut contents of cod larvae caught at the same stations by a Hensen net and an Icelandic High Speed Sampler (IHSS).

Aegir Station	B63/81	B63/82	B63/83
Station Time (GMT)	1102-1131	1628-1658	1758-1817
Larval Length (mm)			
Hensen	4.12	4.57	4.55
IHSS	4.23	4.69	4.52
Gut Contents (mg)			
Hensen	0.0112	0.0341	0.0350
IHSS	0.0177	0.0345	0.0354

TABLE 27b. Analysis of Variance of the gut contents of cod larvae (biomass values).

Factor	Sum of Squares	D.f.	Mean Square	Variance Ratio*
Nets	0.009045448	1	0.009045448	0.032
Stations	0.549555994	2	0.274777997	0.970
Interaction	0.012683596	2	0.006341798	0.022
Residual	15.291813223	54	0.283181714	
Total	15.863098261			

* None of the Variance Ratios are significant.

TABLE 28a. Comparison of the average values for the length and gut contents of redfish larvae caught at the same stations by a 2-m-stramin net and a Helgoland larva. net.

Anton Dohrn Station	AD/544	AD/545
Station Time (GMT)	0035-0125	0405-0645
Larval Length (mm)		
Stramin	8.43	8.81
Helgoland	8.46	8.56
Gut Contents (mg)		
Stramin	0.0375	0.0103
Helgoland	0.0659	0.0245

TABLE 28b. Analysis of Variance of the gut contents of redfish larvae (biomass values).

Factor	Sum of Squares	D.F.	Mean Square	Variance Ratio
Nets	0.004298963	1	0.004298963	4.913[a]
Stations	0.008400821	1	0.008400821	9.601[b]
Interaction	0.000645802	1	0.000645802	0.738
Residual	0.024500679	28	0.000875024	
Total	0.037846265			

[a] Significant $P < 0.05$.
[b] Significant $P < 0.01$.

PRESENTATION OF RESULTS

Inspection of the data suggested that the principal variables affecting the quantity and/or composition of the gut contents of fish larvae were:

a) the size of the larvae;
b) the time of day when caught;
c) the period (month) of sampling;
d) the region of sampling.

With regard to (a), an increase in the size of food organisms consumed with the growth of the larvae has been established for a number of clupeoids (Blaxter, 1965); three species of gadoids (Marak, 1960); cod (Wiborg, 1948); and plaice (Shelbourne, 1962). This predator-prey size relationship has been related both to an improvement of swimming ability and an increase in the gape of the jaws with development.

Diurnal fluctuations in the incidence of feeding (b) have been observed in a number of species. To select three examples, Bhattacharyya (1957) in a study of herring larvae and Ryland (1964) working with plaice and sand eel larvae, have shown that the intensity of feeding is related to the conditions of illumination with feeding virtually ceasing at night. In addition, experimental work by Blaxter (1965) has demonstrated the importance of vision in the capture of food organisms by herring larvae.

Finally, variables (c) and (d) may be presumed to be mainly due to differences in the availability of food. Little information is available on spatial and temporal variations in feeding other than the work of Shelbourne (1957) who showed that the feeding intensity and condition of plaice larvae are dependent on the abundance of *Oikopleura,* known to be their most preferred food.

In this paper, the NORWESTLANT data have been arranged to illustrate the general features of the diet of cod and redfish and to examine the effects of the main environmental variables on the intensity of feeding.

THE FOOD OF REDFISH LARVAE

General Composition of the Diet

The gut contents of redfish larvae are given in the Appendix (Tables 1-4) with the data, as numbers per fish for each length-group, arranged according to the month and region of sampling. NORWESTLANT 2 lasted for almost 7 weeks and has been divided into the parts completed during May and June.

The majority of redfish larvae were found over deep water and the species composition of the diet was relatively uniform over the whole sampled area. There were, however, considerable monthly variations in the developmental stages of the main food organisms. Figure 52 shows the composition of the gut contents in each month as average biomass values for individual length-groups. Food

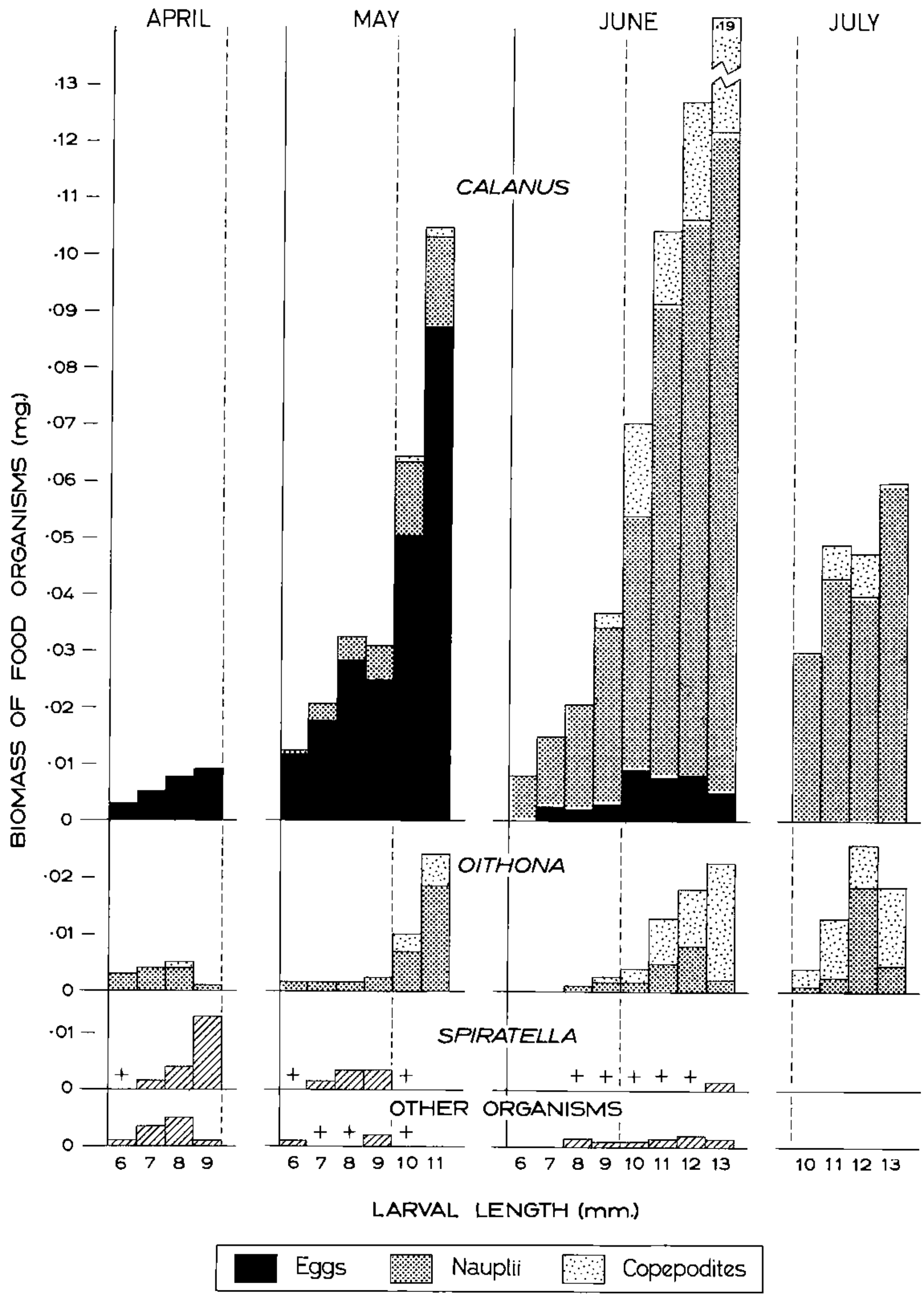

Fig. 52. The diet of redfish larvae from April to July (NORWESTLANT 1-3). The mean biomass of the various food organisms present in larvae of all length-groups from 6 to 13 mm, has been calculated for each month using data from the whole of the sampled area. Food items have been arranged in four groups, the histograms for the two main copepod species being further subdivided into eggs, nauplii, and copepodites.

organisms have been separated into four categories, two of which are copepod species and these have been further sub-divided into eggs, nauplii, and copepodites. The length range of redfish larvae considered (6-13 mm) includes virtually all those present during April and May, but only part of the population during June and July when many exceeded 13 mm.

Calanus finmarchicus was clearly the principal food organism, especially the eggs of this species from April to May and the nauplii during June and July when early copepodite stages were also well represented in the diet. Second in importance was another copepod, *Oithona similis*, mainly as nauplii from April to May and as copepodite stages during June and July. Larvae of *Spiratella retroversa*, with shells from 100 to 150 μ across, were eaten in appreciable quantities during April only. The eggs and nauplii of euphausiids and various stages of *Pseudocalanus minutus* constituted a minor element of the diet. Occasional large specimens of *Coscinodiscus* and *Peridinium* (ca 100 μ diam) were the only members of the phytoplankton found in the guts.

The data presented in Appendix Tables 2 and 4 show that *Calanus*, followed by *Oithona*, remained the main food species of the large larvae present in June and July which were not included in Fig. 52. Comparatively few specimens, 14-29 mm, from the Irminger Sea were examined personally, but the analyses made by Dr J. H. Fraser (Appendix Table 8) confirm the overwhelming importance of *Calanus*, especially copepodite stages, in the diet of these young redfish.

The monotonous diet of redfish larvae may be explained by the uniform composition of the oceanic zooplankton in the Northwest Atlantic with the marked predominance of *Calanus finmarchicus*. Monthly changes in the various stages present in the guts obviously follow the development of the spring generation of this species. The high proportion of *Calanus* eggs to nauplii in May, does however suggest that eggs may be the more vulnerable stage for capture (Bainbridge, 1965).

Predator-prey Size Relationship

Figure 52 shows that, in any 1 month, the total biomass of the gut contents and the developmental stages of the copepods eaten, depended on the size of the larvae. This is most clearly evident in Fig. 54a which gives the average biomass of the various stages of *Calanus* found in young redfish of each length-group during June. Nauplii constituted the main food of the smallest larvae, copepodites being absent in those shorter than 8 mm. The representation of copepodites increased with the growth of the larvae, so that these stages became the principal food of those from 14 to 16 mm.

TABLE 29. Average percentage composition by weight of food remains in redfish larvae at *Anton Dohrn* Station 608 (58°38'N, 35°31'W, 16 June 1963). Stramin-net sample. The food organisms are listed in ascending order of size.

Food Item	Larval length (mm)					
	9	10	11	12	13	14
Oithona nauplii	1.5	2.0	1.4	0.2	-	1.0
Calanus eggs	1.2	4.2	2.5	5.8	2.4	2.6
Oithona copepodites	4.3	2.3	4.8	0.4	4.4	6.3
Calanus nauplii	79.3	61.6	58.8	77.0	51.3	67.3
Euphausiid nauplii	-	-	8.8	-	-	-
Calanus copepodites	13.6	29.8	23.6	16.6	41.9	22.7
Number of larvae examined	4	6	7	5	5	3

The predator-prey size relationship (Fig. 52 and 54a) must partly be due to an improvement of feeding versatility with the growth of the larvae, but the trend was not sufficiently marked to be distinguished in individual samples which contained larvae of rather a narrow size range (Table 29). When the diet of larvae collected over a whole month is considered (Fig. 54a), a "serial effect" is involved. Most small larvae were caught during the early days of June and most larger larvae towards the end of the month. As the larvae grew larger so did the products of the spring spawning of *Calanu*. Since the Hensen-net samples showed that *Calanus* copepodites tended to increase in numbers through June, the grouping of all data during this month obviously gives a biased impression of the degree to which food organisms are selected by size. Coincidental changes in the plankton as the larvae grow are almost certainly the explanation of the decline in the numbers of *Calanus* eggs with increasing larval length shown in Fig. 54a. A sample taken at the beginning of August in the Irminger Sea, contained young *Sebastes* of 15-20 mm with over 100 *Calanus* eggs per gut as well as adult and late copepodite stages of the species. This suggests that a second spawning of *Calanus* takes place in the Irminger Sea during August and that young *Sebastes* of 15-20 mm can adapt a filter-feeding regime as well as capture large copepods. In this connection it is relevant that developing gill rakers were observed in larvae of 14-15 mm.

THE FOOD OF COD LARVAE

General Composition of the Diet

Cod larvae had a discontinuous distribution so the results for Icelandic coastal waters and for West Greenland waters will be considered separately. The food remains found in the young cod are listed in Appendix Tables 5-7 as average numbers per fish for each length-group.

In Icelandic waters cod larvae were taken at only a single station during April (NORWESTLANT 1). All specimens were newly hatched, from 3 to 4 mm, and with yolk sacs present. The only food remains consisted of a few *Calanus* eggs, tintinnids, and peridinians (Appendix Table 5).

By May (NORWESTLANT 2) cod larvae were abundant at stations over the Icelandic Shelf especially in Faxa Bay. The composition of the gut contents of these larvae, expressed as average biomass values for each length-group is illustrated in Fig. 53, the histograms referring to copepods being subdivided into eggs, nauplii, and copepodites. *Calanus finmarchicus* was the principal food organism, slightly exceeding *Temora longicornis* in abundance, the nauplii and copepodite stages of both copepods being well represented. Euphausiid nauplii and *Evadne normanni* also constituted important elements of the diet. Other food organisms included the nauplii and copepodites of *Centropages* spp. and *Oithona similis*, cirripede nauplii, and lamellibranch larvae. A few tintinnids, peridinians, and diatoms were found, mainly in yolk-sac larvae, but the quantities present would appear to contribute little of nutritive value. Phytoplankton has been previously found in the guts of cod larvae at the yolk-sac stage by Wiborg (1949).

Quantitative information is not available on the gut contents of cod larvae from the Icelandic region during July (NORWESTLANT 3) but observations made available by Mr J. Corlett and collated in Appendix Table 9, indicate that *Calanus* plays an increasingly important part in the diet of the larvae as they grow and tend to disperse from the spawning grounds.

Cod larvae were not found off West Greenland during April but adequate numbers were available during June and July to obtain information on the organisms eaten in this region. The data presented in Fig. 53 shows that, in marked contrast to those from Icelandic waters during NORWESTLANT 2, the cod larvae from West Greenland waters were feeding almost entirely on the nauplii and copepodites of *Calanus finmarchicus*. A few other organisms were found in the guts, such as the early stages of *Pseudocalanus minutus* and *Oithona similis*, but these were generally rare. There was little change in the species-composition of the diet during July but copepodite stages of *Calanus* became a more important item.

The differences observed in the diet of cod larvae from the two areas reflect the diversity of the neritic zooplankton off Iceland compared with the restricted species-composition of the zooplankton in West Greenland waters. *Temora* and *Evadne*, two of the common food organisms in Icelandic waters, were absent from all plankton samples taken off West Greenland.

In addition to the NORWESTLANT samples, a large number of cod larvae collected off West Greenland during July and August in the years 1950, 1957, 1958, and 1961 have been examined. Various stages of *Calanus* constituted over 95% by weight of the food of the larvae in all but one of the 18 samples. The only exception was a sample taken close to the coast at 66°50'N, 54°42'W, during July 1957 in which the cod larvae were found to contain almost equal proportions of the nauplii of *Calanus* and *Balanus crenatus*. It is noteworthy that the spawning of cod off Greenland in 1950 yielded a particularly good year-class and that cod larvae were abundant in both 1950 and 1957 (Hermann, *et al.*, 1965), yet there is no evidence that the species-composition of the diet during these 2 years differed appreciably from that in 1963.

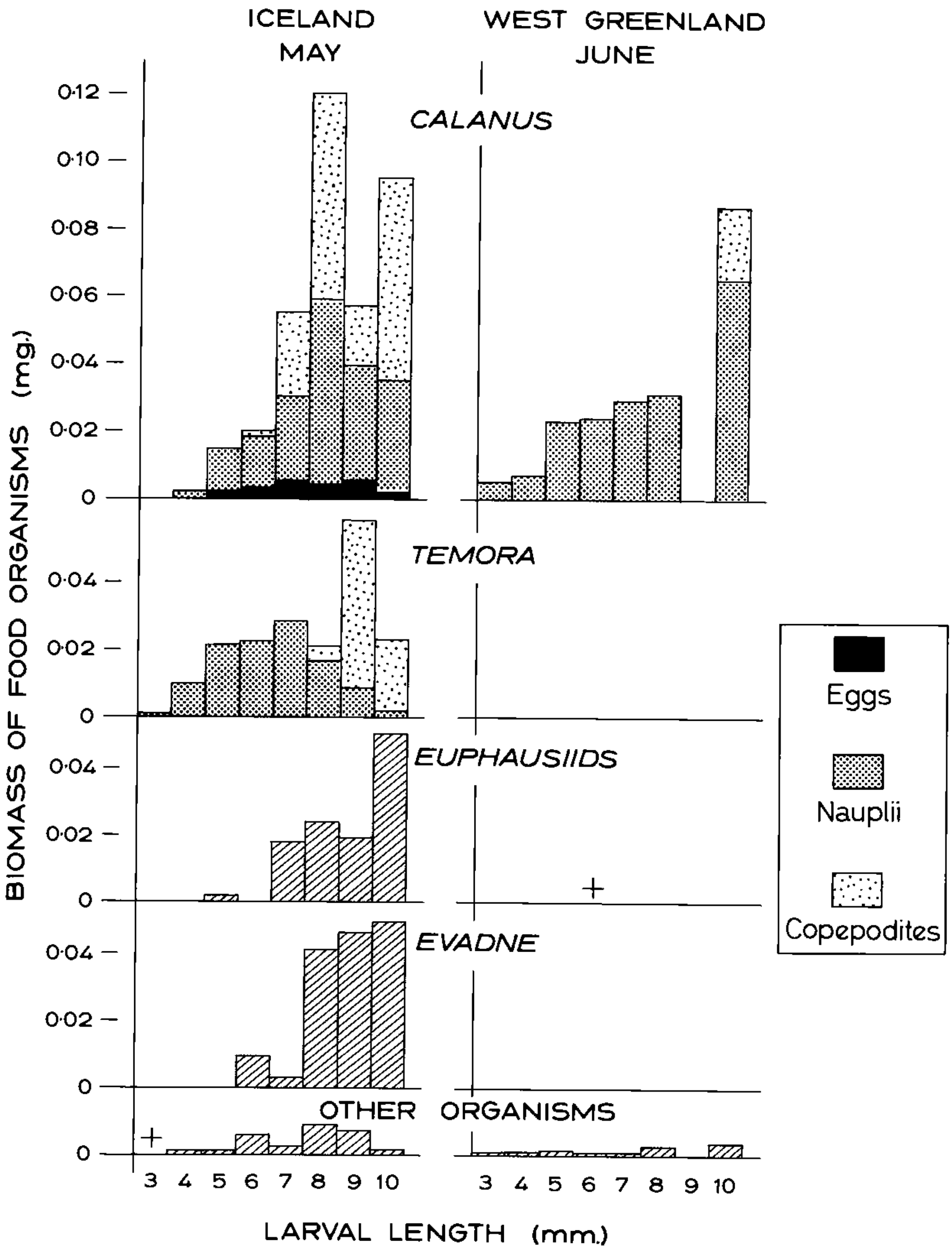

Fig. 53. The diet of cod larvae from the Faxa Bay area, Iceland, and in the Davis Strait off West Greenland during May and June (NORWESTLANT 2). The mean biomass of the various food organisms is shown for larvae of each length-group from 3 to 10 mm. Food items have been separated into five categories with the histograms for two main copepod species subdivided into eggs, nauplii, and copepodites. The euphausiids present were nauplius and early calyptopis stages.

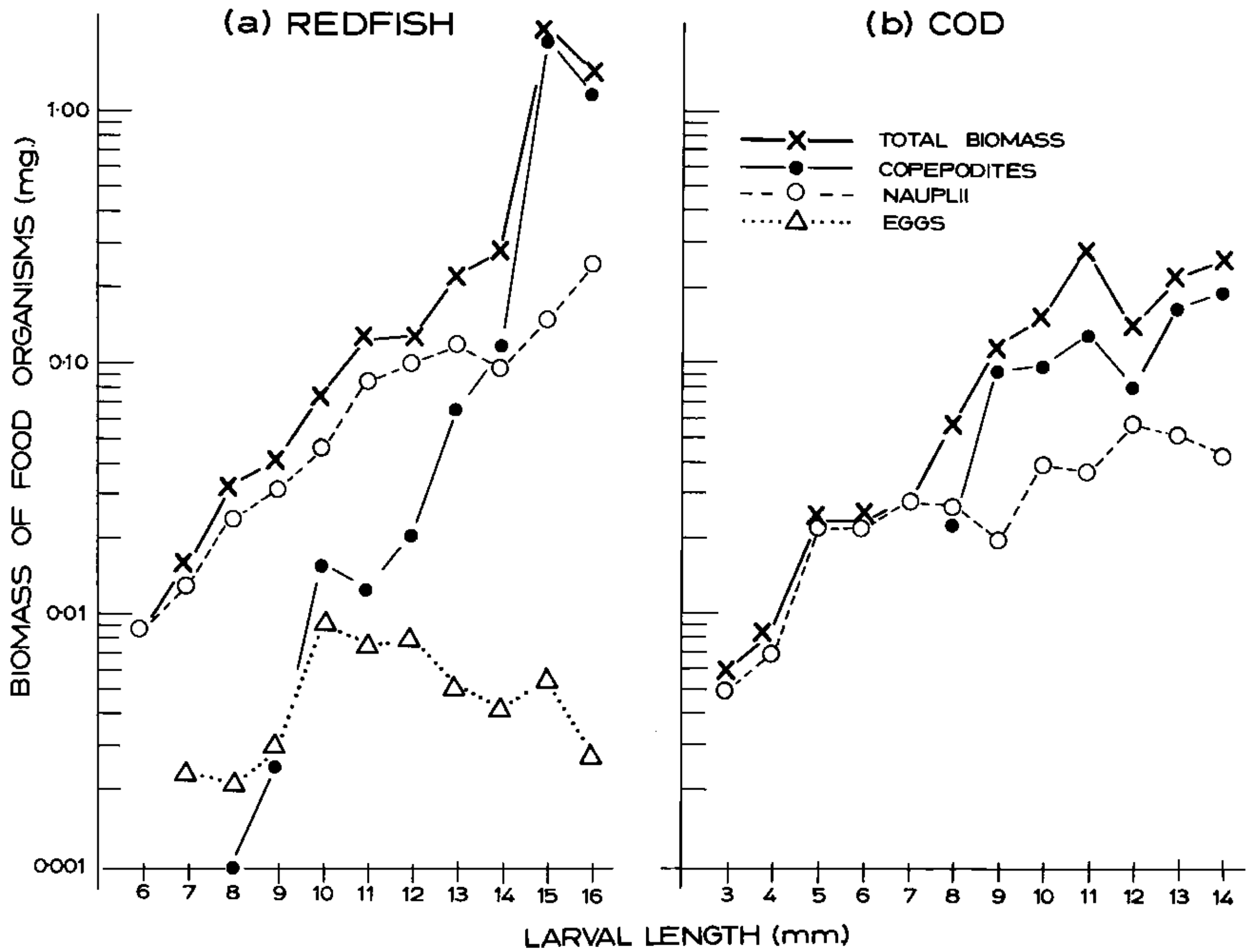

Fig. 54. Changes in the food eaten by redfish and cod larvae with increasing size. The mean biomass values of the various developmental stages of *Calanus* found in the guts has been calculated for each larval length-group using redfish data for the whole sampled area during June and cod data for West Greenland during June and July.

Predator-prey Size Relationship

Figure 54b gives the average biomass of eggs, nauplii, and copepodites of *Calanus* for each length-group of cod larvae taken off West Greenland in June and July. Considered together with Fig. 53, it can be seen that off both Iceland and West Greenland a diet which consisted predominantly of copepod nauplii in the smallest size-groups gradually gave way, as the larvae grew, to a diet which included increasing numbers of larger organisms such as copepodites. As in any 'time-series' this may be due partly to changes in the stage-composition of the main zooplankton species running parallel with the growth of the larvae. However, the relationship was also discernable in individual samples demonstrating that larger larvae tend to 'select' a higher proportion of bigger food organisms (Table 30).

Comparison with Redfish Larvae

The diet of cod larvae off West Greenland was similar to that of redfish larvae in that *Calanus* was by far the most important food organism. Figure 54 provides a comparison of the average biomass of the various developmental stages of *Calanus* found in the guts of the two species, from which it appears that cod larvae were eating a greater proportion of the older and larger stages of *Calanus*

TABLE 30. Average percentage composition by weight of food remains in cod larvae at *Aegir* Station 84 (64°23'N, 23°14'W, 18 May 1963). Icelandic High Speed Sampler. The food organisms are listed in ascending order of size.

Food Item	Larval length (mm)				
	4	5	6	7	8+
Oithona nauplii	-	0.6	+	0.8	-
Lamellibranch larvae	-	0.6	-	2.0	-
Calanus eggs	21.9	9.3	11.9	2.8	-
Temora nauplii	78.1	60.2	65.1	40.2	1.3
Calanus nauplii	-	29.2	22.8	8.5	2.8
Temora copepodites	-	-	-	-	20.0
Evadne	-	-	-	-	64.0
Calanus copepodites	-	-	-	46.1	12.0
Number of larvae examined	2	8	12	5	2

than redfish of equivalent length. For example, copepodites were the principal food of cod larvae of 9 mm but only exceeded nauplii as the main food items in redfish of 14 mm or more. The dietary differences between the two species may be partly attributable to differences of distribution, but the few samples available containing larvae of both species confirm that, length for length, cod larvae take food organisms of a larger average size than redfish larvae. Table 31 gives an example in which *Calanus* copepodites constituted over 80% of the gut contents of the cod larvae but were completely absent in redfish larvae of the same size-range. These results were rather surprising since redfish larvae were found to have substantially longer jaws than cod larvae of the same body length, the average length of the upper and lower jaws being 1.4-1.7 times that of cod larvae for specimens from 7 to 9 mm. However, it may not necessarily follow that the gape of the mouth is wider.

TABLE 31. Comparison of the food remains in redfish and cod larvae from a stramin-net sample (50-0 m) at *Dana* Station 10900 (62°12'N, 59°10'W, 19 July 1958). Mean biomass values (mg) for larvae in the length range 8-10 mm.

Food Item	Fish larvae	
	Redfish	Cod
Oithona nauplii	0.029	0.007
Oithona copepodites	0.034	0.041
Spiratella larvae	0.001	-
Calanus eggs	0.001	-
Calanus nauplii	0.012	0.009
Calanus copepodites	-	0.238
Number of fish larvae	20	8
Mean length of fish larvae (mm)	9.5	9.1

DIURNAL FEEDING ACTIVITY

Although nights are short during the early summer within the latitudes covered by the survey and include a high proportion of twilight, there was a distinct diurnal periodicity in the feeding activity of both cod and redfish larvae. In Figs. 55 and 56 the mean biomass of the gut contents of larvae at the stations worked during May and June (NORWESTLANT 2) have been averaged for 2- and 4-hourly intervals throughout the day, regardless of the region of sampling or the size of the larvae.

Figure 55 shows that the amount of food in the guts of redfish larvae gradually increased in the day and rapidly declined during the short night. Minimal quantities of food were present at about sunrise and maximal quantities just before sunset.

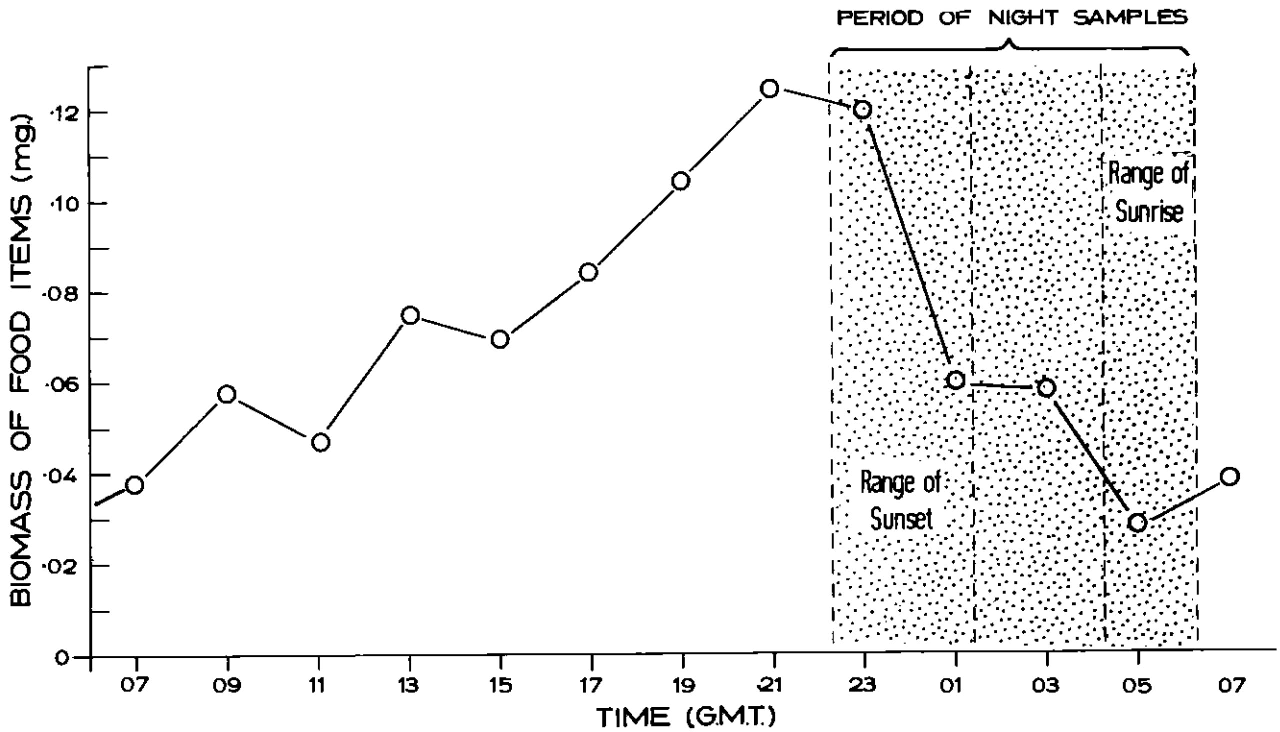

Fig. 55. Diurnal feeding periodicity of redfish larvae based on data from the whole sampled area during May and June (NORWESTLANT 2). The total biomass values for the gut contents of the larvae have been averaged for 2-hr intervals through 24 hr.

Cod larvae were not caught in sufficient numbers to obtain as detailed a picture of diurnal variations in feeding activity. They were also found in regions where the hours of darkness, including twilight, were generally limited to less than 6 hr. Figure 56 shows the smallest quantities of food were found in the guts of cod larvae during, or shortly after, the brief period of darkness.

In both redfish and cod larvae the highest proportions of completely digested nauplii, distinguished only as exoskeleton 'ghosts', occurred about sunrise. The ratio of *Calanus* eggs to empty egg membranes in redfish larvae was also lowest during the night and early morning (Fig. 56). These diurnal cycles in the condition of food remains confirm that, although the capture of food never ceases completely, the intensity of feeding is lowest during the hours of darkness.

GEOGRAPHICAL VARIATIONS OF FEEDING INTENSITY

The average biomass of food remains found in the fish larvae can be used as an index of the intensity of feeding. Attempts to establish regional differences in the feeding intensity of the larvae are complicated, however, by the variation due to the different length distributions and times of sampling. To obviate these difficulties all regional comparisons were made between larvae of equivalent length caught during a limited period of the day. Comparisons were mainly limited to NORWESTLANT 2 (May and June), when the highest numbers of both redfish and cod larvae were present and the majority of these were small specimens.

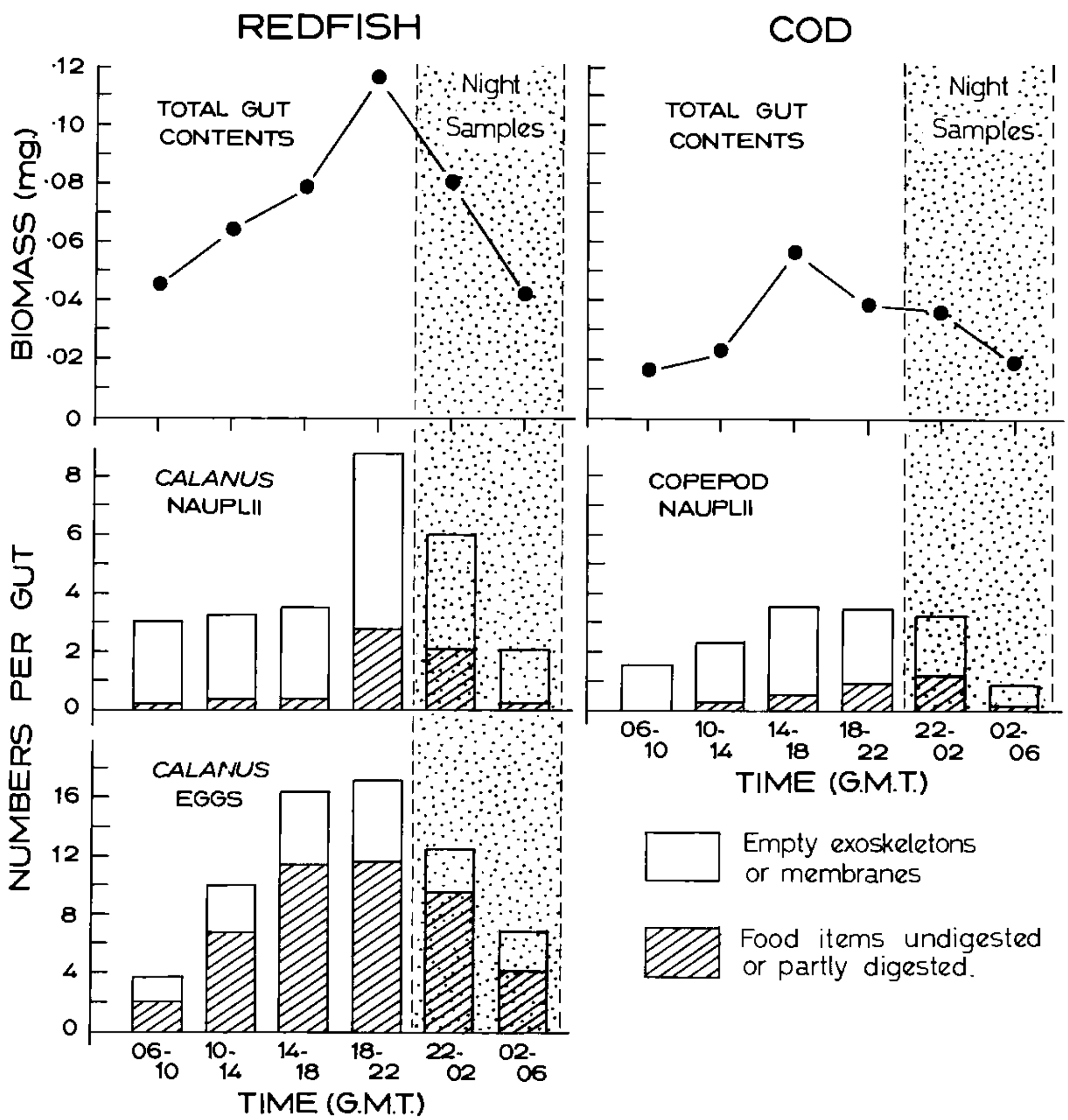

Fig. 56. Diurnal feeding periodicity of redfish and cod larvae based on data for the whole sampled area during May and June (NORWESTLANT 2). The mean biomass values (line graphs) and the average numbers of eggs and nauplii (histograms) are given for 4-hr intervals through 24 hr.

Redfish Larvae

Examination of the raw data suggested that it would be useful to consider the feeding of redfish larvae in the three broad regions shown in Fig. 57:

1) the Irminger Sea;
2) the waters off West Greenland in the Davis Strait;
3) the waters off East Greenland between Cape Mosting and Cape Bille, a region where the distribution of redfish larvae extended into the cold East Greenland Current (Fig. 50).

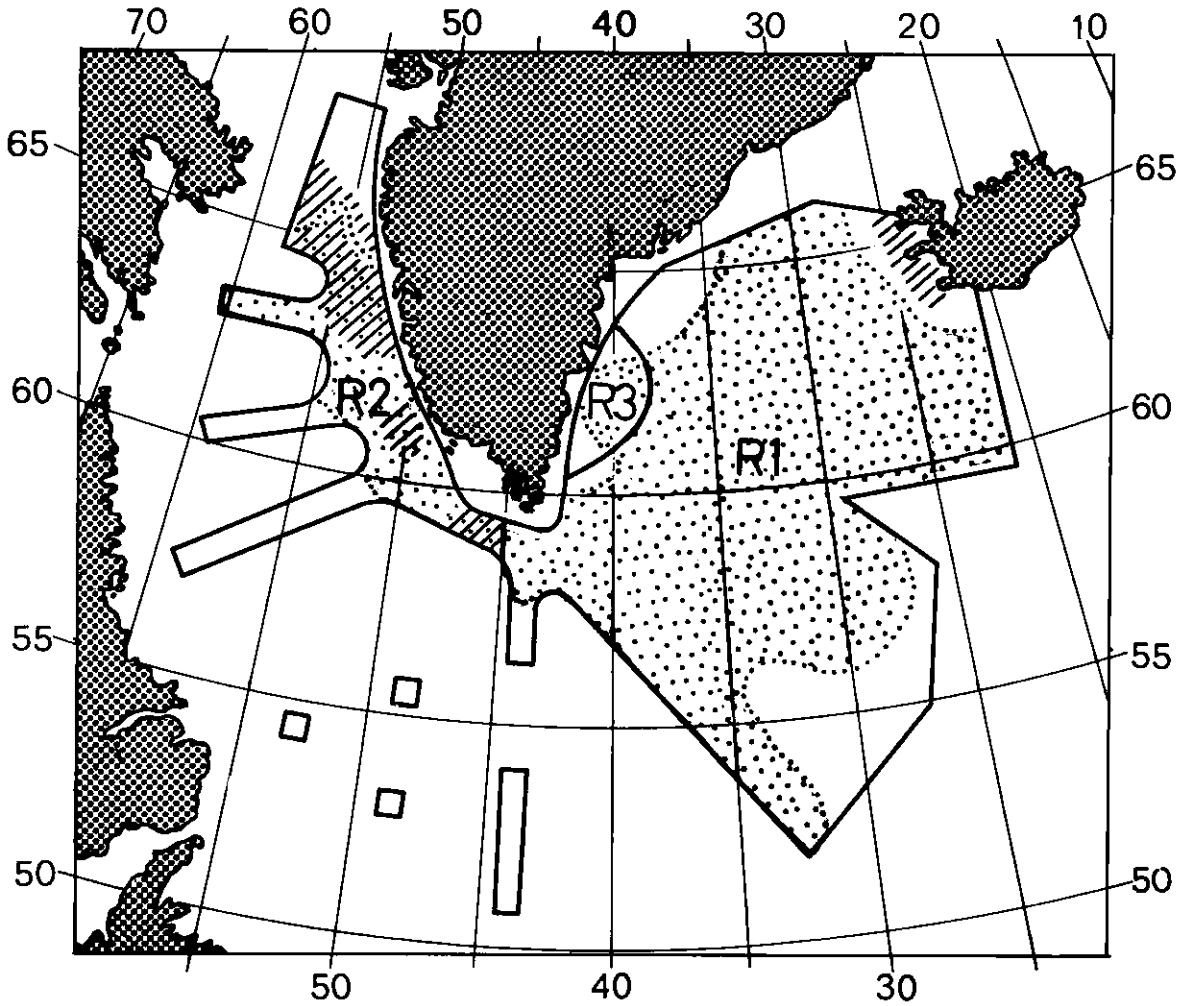

Fig. 57. Chart showing the area sampled for fish larvae during NORWESTLANT 2, with the three subdivisions used for the study of regional variations in the feeding of redfish larvae. Stippling indicates the approximate distribution of redfish larvae and hatching the distribution of cod larvae.

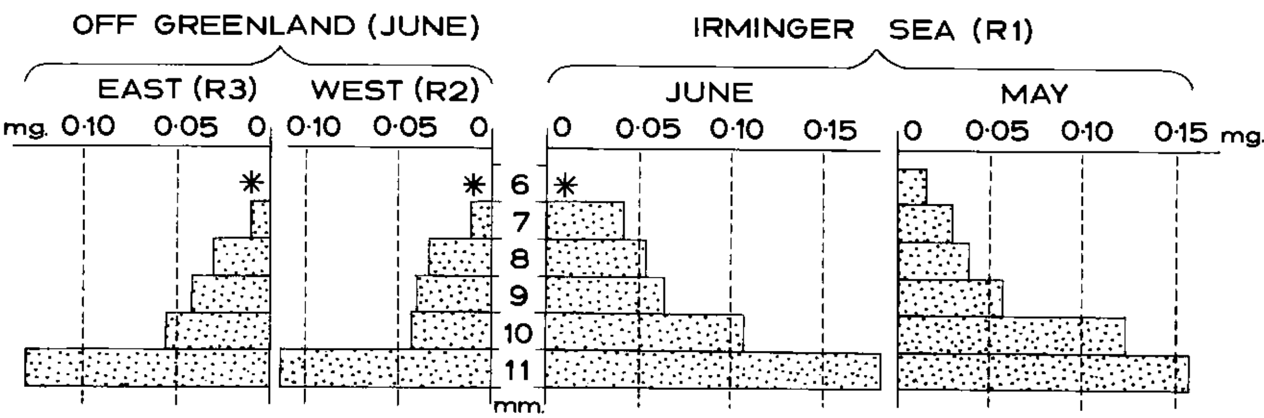

Fig. 58. Regional differences in the quantity of food present in the guts of redfish larvae during NORWESTLANT 2. Histograms represent the means for each length-group of those larvae caught between 0800-2400 hours, GMT. The three areas considered are delimited in Fig. 57. An asterisk indicates that no specimens were available in that category.

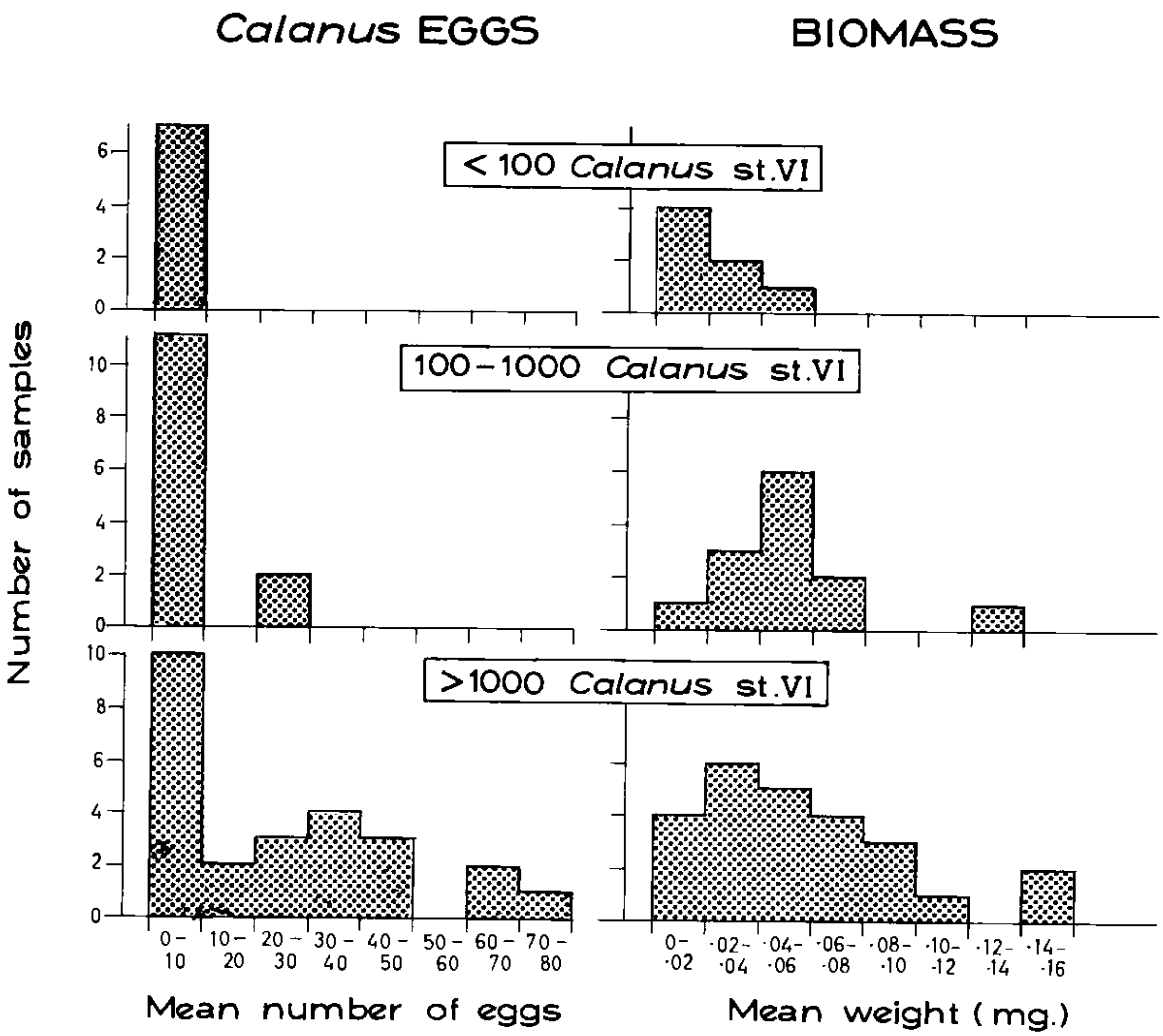

Fig. 59. Frequency distribution of day samples (0800-2400 hours, GMT) containing redfish larvae during NORWESTLANT 2 (May and June) in relation to the mean number of *Calanus* eggs per gut (left hand diagrams) and the mean biomass of the total food remains per fish (right hand diagrams). The means were calculated using larvae in the length-range 6 to 10 mm. Samples have been separated into three groups according to the numbers of *Calanus* stages VI per m^2 of sea surface as estimated from the vertical net samples.

Figure 58 shows the mean biomass values of the total gut contents of larvae from 6 to 11 mm for each region during NORWESTLANT 2. These values have been calculated using larvae caught between 0800 and 2400 hours, GMT, to exclude the period when little or no feeding occurs.

Results indicate that redfish larvae from the Irminger Sea during both May and June contained, on the average, more food than larvae of the same length from waters off East or West Greenland during June. These differences cannot be considered directly in relation to the availability of food since the main food items, *Calanus* eggs and nauplii, were not adequately sampled by any of the gear used during the survey. However, there does appear to be a sensible relationship with the distribution and abundance of the various stages of *Calanus* in the top 100 m of the sea as illustrated by the charts (192-231) in the section on Zooplankton by Bainbridge and Corlett. During NORWESTLANT 2 higher numbers of adult *Calanus* were present in the central Irminger Sea than in the coastal waters off West or East Greenland (Chart 207). Studies of the life history of *Calanus* described by Marshall and Orr (1955) and Ostvedt (1955) have shown that, in northern waters, the species overwinters at considerable depths mainly as copepodite stages IV or V, ascending to the surface layers during the spring. Moulting to stage VI occurs at this time, followed by spawning and the subsequent death of the spent females. It is reasonable therefore to presume that, regions with most adult *Calanus* near the surface during May and June, were also likely to have most eggs and early nauplii. The distribution of *Calanus* copepodites I-IV in the top 100 m showed rather the converse distribution to the adults with high numbers in the Davis Strait and near Fylkir Bank off the east coast of Greenland (Chart 205). Certainly in the northern part of the survey area off West Greenland it can be assumed that most of the products of the spring spawning had reached the copepodite stage by June and, in consequence, were not available as food for the earliest stages of redfish larvae.

Direct comparisons between the biomass of the food remains in redfish larvae and the numbers of adult *Calanus* at individual stations showed a considerable scatter of results despite standardization for the size of the larvae and the time of sampling. Figure 59 illustrates the closest relationship that could be ascertained. The average number of *Calanus* eggs in the guts and the average biomass of the gut contents at each station were calculated for larvae of 6-10 mm in length sampled between 0800 and 2400 hours, GMT, during NORWESTLANT 2. Figure 59 gives the frequency distribution of these means with the data separated into three groups according to the numbers of adult *Calanus* at each of the stations. There is a definite trend, the larvae at stations with high numbers of *Calanus* stage VI containing more *Calanus* eggs and altogether a greater amount of food than larvae at stations with low numbers of *Calanus* stage VI.

Cod Larvae

During NORWESTLANT 2 cod larvae were found in the Faxa Bay area, Iceland, and in the Davis Strait off West Greenland (Fig. 57). The average biomass of the total food remains in each larval length-group from 3 to 10 mm has been calculated for the two regions using larvae caught between 0800 to 2400 hours, GMT (Fig. 60). Young cod from Icelandic waters during the latter half of May generally contained about twice the amount of food present in those from West Greenland waters during early June. The only exception was the 3-mm length-group but off Iceland this consisted principally of yolk-sac larvae and consequently containing little if any food. Even when the results for West Greenland cod during July are considered, individual length-groups contained less food than the equivalents from Icelandic waters in May. Once again it is not possible to relate these differences to the availability of the food organisms since the early stages of copepods and other crustacea were inadequately sampled. However, it would appear from the Hensen-net samples that more food was available for the larvae off Iceland than off Greenland. During NORWESTLANT 2 the average displacement volumes of plankton at stations with cod larvae was 36 mℓ per m^2 of sea surface for Icelandic waters compared with 18 mℓ per m^2 of sea surface off West Greenland. Furthermore, copepoda and other small crustacea were almost twice as numerous in the Faxa Bay area as off West Greenland with the species-composition exhibiting greater diversity.

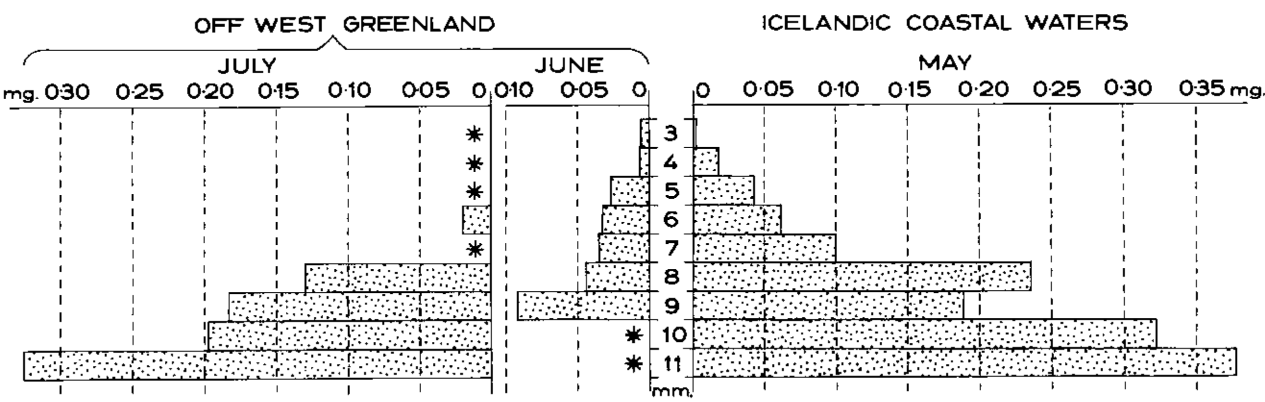

Fig. 60. Regional differences in the quantities of food present in the guts of cod larvae during May and June (NORWESTLANT 2). Histograms represent the means for each length-group of those larvae caught between 0800-2400 hours, GMT. The two regions compared are defined in Fig. 57. An asterisk indicates that no specimens were available in that category.

DISCUSSION

The Diet of the Larvae

Over most of the survey area the zooplankton was characterized by the overwhelming predominance of *Calanus finmarchicus* which, in these latitudes, has one major spawning period occurring in the spring (Bainbridge, 1965; Lie, 1965). Data presented in this paper have emphasized the almost complete dependence of cod and redfish larvae on the products of this spawning as a source of food in the seas around Greenland. The fortunes of the larvae must depend on the degree of synchronization of the commencement of active feeding with the timing of the spring spawning and the overall abundance of the early stages of *Calanus*. Marshall and Orr (1964) have demonstrated a close connection between egg production by *Calanus* and the supply of food, i.e., phytoplankton. Data collated for the report on Phytoplankton by Gillbricht (this volume, p. 73) show that there can be big annual variations of phytoplankton production in the seas around Greenland, while the Continuous Plankton Recorder Survey has revealed considerable differences in the seasonal timing and abundance of the various stages of *Calanus* from year to year (Glover and Robinson, this volume, p. 123).

If, as Hjort (1914) originally suggested, the year-class strength of such fish as the cod is determined during the larval stage, these considerations could conceivably provide an explanation for the sharp fluctuations of the year-class strength of Greenland cod relative to other stocks. In spawning areas such as Icelandic coastal waters, the North Sea, Gulf of Maine, and around the Lofoten Islands, where a greater variety of suitable food organisms are available and production is not so restricted seasonally, the timing of the hatching period of the fish will probably not be of such critical importance[5].

Hermann, *et al.* (1965) have shown a close relationship between variations in the year-class strength of West Greenland cod and the mean temperature of water (0-45 m) over Fyllas Bank in June, good year-classes being associated with warmer years. The limited time series available also showed a trend of increased numbers of cod larvae in those years with high June temperatures over Fyllas Bank. These temperature variations are a consequence of fluctuations in the relative strengths of the two current components which mix to form the West Greenland Current, i.e., the East Greenland Current from the North Polar Basin and the warm Irminger Current. Slight changes in temperature may have a direct effect on the mortality of the eggs and larvae of cod near the northern limit of its distribution as suggested by Hermann, *et al.* (1965). Alternatively, the relative strength of the two components forming the West Greenland Current may influence the timing and intensity of the spring spawning of *Calanus*, so affecting the food supply of cod larvae.

Finally, while the Greenland cod may be unusual in depending almost exclusively on *Calanus* as food for the larvae, this is normal for redfish over a vast area of the Northwest Atlantic. Larvae of *Sebastes* are exceptionally abundant in the Irminger Sea where they constitute about 90% of the total stock of young fish (Einarsson, 1960; Henderson, 1961). A number of adaptations may contribute to the success of redfish larvae in the area; for example, newly extruded redfish larvae are longer, more robust, and have distinctly larger eyes than have cod larvae when absorption of the yolk-sac is completed, suggesting obvious advantages for active feeding and escape from predators. The viviparous mode of reproduction may perhaps have survival value in ensuring that the larvae can make their appearance at a suitable time to utilize the rich but ephemeral source of food provided by the spring spawning of *Calanus*, as well as eliminating direct predation on the eggs.

Regional Variations of Feeding Intensity

The true significance of the geographical variations in the feeding of cod and redfish larvae during 1963 is obscured by the lack of information on their food requirements and rates of digestion. Shortage of food may affect the mortality rate of larvae directly or indirectly. Murphy (1961) has argued that if predation is held to be the main source of larval mortality, its effect can vary with the duration of the vulnerable planktonic stages as well as the density of predators. He pointed out that the time spent as a member of the plankton community depends on the growth rate which can be a function of food, temperature, or both.

Redfish larvae sampled during the survey afford an example of regional differences in the apparent growth rate; a compound effect of rate of extrusion, rate of mortality, and true growth. Magnússon (this volume, p.145) has described changes in the length-range and mean length of the

[5] Sysoeva and Degtereva (1965) have recently shown that various stages of *Calanus finmarchicus* generally constituted the main food of cod larvae in the southern Barents Sea. Other planktonic crustacea were, however, eaten more frequently than by the cod larvae taken off West Greenland during the NORWESTLANT Surveys. It is also relevant that the main spawning of the Arcto-Norwegian stock is in Westfjord, an area not included in their investigation.

larval population (fig. 43, this volume, p.154), and has shown that there was a more rapid increase in size east of Cape Farewell (i.e., mainly the Irminger Sea) than west of Cape Farewell (i.e., West Greenland waters). This is no doubt partly due to the temperature of the 0- to 50-m layer of the Irminger Sea being several degrees higher than that of West Greenland waters. Data presented in this paper offer a further explanation since redfish larvae caught in the Irminger Sea contained substantially more food than those taken off West Greenland.

Regional comparisons of the growth rate of cod larvae were difficult due to a number of factors, one of which was the difference of almost a month in the dates of sampling off Iceland and off West Greenland during NORWESTLANT 2. Hansen (this volume, p.127) notes that the average size of larvae off West Greenland increased from 5.6 mm during NORWESTLANT 2 to 10.0 mm during NORWESTLANT 3, about 1 month later. No valid estimate could be made of the growth of cod larvae off Iceland and in the Denmark Strait since the size of larvae in this area during NORWESTLANT 3 ranged from 10 to 43 mm with modes at about 19, 27, and 33 mm. Hansen has drawn attention to the enormous difference between the high numbers of eggs present in Greenland waters during NORWESTLANT 1 and the low numbers of larvae caught during NORWESTLANT 2, which suggests that there was a heavy mortality of eggs or early larvae between the two surveys. Since cod larvae taken off West Greenland were found to contain considerably less food than those in the Icelandic area, starvation of the early larvae could be a contributory cause — perhaps the major one.

Although these are isolated examples and the agreement obtained may well be fortuitous, the magnitude of the regional differences in the feeding intensity of cod and redfish larvae certainly supports the view that shortage of food was a major factor limiting their survival in the seas around Greenland during 1963. However, more information is obviously required on the physiology of the fish larvae before a satisfactory evaluation can be made of the parts played by temperature and food supply in limiting both growth and survival.

SUMMARY

A quantitative study has been made of the food remains present in cod and redfish larvae collected during the environmental survey of the seas around Greenland in 1963 (NORWESTLANT 1-3).

During April and May recently extruded redfish larvae in the Irminger Sea were feeding principally on *Calanus* eggs while older larvae taken during June and July over the Irminger Sea and in the Davis Strait were mainly eating the nauplii and copepodite stages of *Calanus*.

The diet of cod larvae from West Greenland waters during both June and July was also virtually restricted to the nauplii and copepodites of *Calanus*. In contrast, the diet of cod larvae from Icelandic waters, sampled during May, showed greater diversity and included the early stages of *Calanus*, *Temora*, *Evadne*, and euphausiids.

For both species of fish the average and maximum size of individual food items as well as the average quantity of the gut contents increased as the larvae grew. This was due to an improvement of feeding versatility as well as the parallel development of the young fish and of the products of the spring spawning of the zooplankton, in particular *Calanus*. Food organisms selected by cod larvae were generally larger than those found in redfish of equivalent length. Larvae of both species exhibited similar diurnal patterns of feeding, with the amount of food in the guts declining throughout the night to reach a minimum about sunrise.

There were distinct geographical variations in the feeding intensity of the two species. Redfish larvae from the Irminger Sea contained more food than those taken either in the Davis Strait off West Greenland or in the vicinity of the East Greenland coast. These differences could be related to the abundance and population structure of the principal food organism, *Calanus*. Cod larvae from Icelandic waters contained about twice the amount of food found in those caught off West Greenland, a difference which also seems to be correlated with the availability of food in the plankton.

The observations are discussed with reference to the apparently slower growth rate of redfish larvae off West Greenland compared with those in the Irminger Sea and the evidence for a heavy mortality of Greenland cod between the egg and early larval stage.

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APPENDIX TABLES

Tables 1-9 summarize the basic data on the food of cod and redfish larvae taken during the NORWESTLANT 1-3. Stations at which samples of fish larvae were examined are shown in Fig. 50 and the regions referred to are defined in Fig. 57. The average numbers of the various food organisms and estimates of the average biomass of the total gut contents are tabulated. A dash indicates the absence of a particular food item. Data are arranged by length-groups and are given as averages per fish larva. The biomass values of the food remains were obtained by conversion factors (Table 26) and are expressed as mg wet weight assuming no digestion. These have been calculated for larvae from all stations, for larvae from "day" stations only (i.e., those caught between 0800 and 2400 hours) and for larvae from "night" stations only (i.e., those caught between 2400 and 0800 hours). The groups miscellaneous nauplii(*) and miscellaneous copepodites (*) refer to all copepods other than those of the genera tabulated. *Pseudocalanus minutus* was the commonest species represented in these groups.

APPENDIX TABLE 1. Gut contents of redfish larvae from the Irminger Sea during April (NORWESTLANT 1) and May (NORWESTLANT 2) as mean numbers of food organisms per fish and mean biomass of total food remains per fish (mg). Data for April from samples collected by *Ernest Holt* and *Thalassa*. Data for May from samples collected by *Aegir*, *Anton Dohrn*, *Dana*, and *G. O. Sars*.

Month:	April				May							
Larval length (mm):	6	7	8	9	6	7	8	9	10	11	12	13
Diatoms and Peridinians	-	-	-	-	-	-	-	-	-	-	-	-
Tintinnids and Radiolarians	0.70	0.30	0.28	-	0.02	0.03	-	-	-	-	-	-
Spiratella larvae	0.30	1.40	3.80	12.80	0.60	1.55	3.58	3.58	0.03	-	-	-
Calanus eggs	2.20	3.80	5.70	6.70	8.40	12.63	20.46	17.88	36.10	62.40	18.00	70.00
Calanus nauplii	-	0.02	-	-	0.07	0.38	0.40	0.60	1.31	1.60	-	2.00
Calanus copepodite stage I and II	-	-	-	-	-	-	-	0.01	0.21	-	-	-
Calanus copepodite stage III and IV	-	-	-	-	-	-	-	-	-	-	-	-
Calanus copepodite stage V and VI	-	-	-	-	-	-	-	-	-	-	-	-
Oithona nauplii	3.20	4.00	4.00	2.20	1.70	1.75	1.76	2.36	7.10	18.40	-	32.00
Oithona copepodites	0.09	0.08	0.19	-	-	0.02	0.02	0.06	0.41	1.00	-	-
Small crustacean eggs	-	0.02	0.02	-	-	-	-	-	-	-	-	-
Miscellaneous copepod nauplii*	0.02	0.06	1.00	0.30	0.10	0.04	-	-	-	-	-	-
Miscellaneous copepod copepodites*	-	-	-	-	-	-	-	0.01	-	-	-	-
Euphausiid eggs	-	-	-	-	-	-	-	0.06	0.03	-	-	-
Euphausiid nauplii	-	-	-	-	-	0.01	-	-	-	-	-	-
Euphausiid calyptopes	-	-	-	-	-	-	-	-	-	-	-	-
Other groups	-	0.02	-	-	-	-	0.01	-	-	-	-	-
Number of larvae examined:	11	49	47	6	27	116	176	97	29	5	1	1
Biomass all stations	0.008	0.015	0.022	0.026	0.014	0.025	0.038	0.039	0.075	0.129	0.025	0.150
Biomass "day" stations	0.009	0.019	0.025	0.026	0.015	0.029	0.038	0.057	0.125	0.157	0.025	0.150
Biomass "night" stations	0.001	0.004	0.019		0.013	0.023	0.037	0.031	0.044	0.014		

APPENDIX TABLE 2. Gut contents of redfish larvae from the Irminger Sea during June (NORWESTLANT 2) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). Data from samples collected by *Anton Dohrn.*

	Larval length (mm)										
	7	8	9	10	11	12	13	14	15	16	17
Diatoms and Peridinians	-	-	-	-	-	-	-	-	-	-	-
Tintinnids and Radiolarians	-	-	-	-	-	-	-	-	-	-	-
Spiratella larvae	-	-	0.03	0.15	0.52	0.18	0.21	-	-	-	-
Calanus eggs	-	0.67	3.12	9.08	8.05	6.30	4.21	2.76	3.67	2.67	-
Calanus nauplii	2.50	3.72	3.68	5.88	10.86	10.48	12.45	9.90	14.78	25.33	6.00
Calanus copepodite stage I and II	-	-	0.06	0.45	0.16	0.36	1.24	1.67	3.89	2.33	-
Calanus copepodite stage III and IV	-	-	-	-	0.03	0.02	0.06	0.19	0.44	1.67	-
Calanus copepodite stage V and VI	-	-	-	-	-	-	-	-	-	-	-
Oithona nauplii	1.50	4.67	3.70	3.30	6.76	5.27	1.82	3.52	0.33	0.67	2.00
Oithona copepodites	-	0.17	0.26	0.38	1.13	1.50	3.15	3.43	3.67	4.67	-
Small crustacean eggs	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous copepod nauplii*	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous copepod copepodites*	-	-	0.03	0.04	-	0.04	-	-	-	-	-
Euphausiid eggs	-	-	-	-	-	-	-	0.10	-	-	-
Euphausiid nauplii	-	-	-	-	-	-	-	-	-	-	-
Euphausiid calyptopes	-	-	-	-	0.02	-	0.03	-	-	-	-
Other groups	-	-	-	-	-	-	0.06	-	-	-	-
Number of larvae examined:	4	6	34	60	63	56	33	21	9	3	1
Biomass all stations	0.026	0.041	0.051	0.099	0.160	0.152	0.227	0.279	0.477	0.863	0.062
Biomass "day" stations	0.041	0.055	0.055	0.108	0.181	0.160	0.296	0.332	0.616	1.262	
Biomass "night" stations	0.011	0.026	0.026	0.083	0.124	0.126	0.210	0.079	0.205	0.062	0.062

APPENDIX TABLE 3. Gut contents of redfish larvae caught off East and West Greenland during June (NORWESTLANT 2) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). Data from samples collected off East Greenland by *Anton Dohrn* and off West Greenland by *Dana*, *Baffin*, and *Sackville*.

Region:	East Greenland							West Greenland						
Larval length (mm):	6	7	8	9	10	11	13	6	7	8	9	10	11	14
Diatoms and Peridinians	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-
Tintinnids and Radiolarians	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-
Spiratella larvae	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-
Calanus eggs	-	-	0.46	2.48	4.20	4.50	1.00	-	2.33	2.02	1.03	0.33	0.50	-
Calanus nauplii	0.75	0.50	1.23	2.33	2.80	3.90	3.00	1.00	1.13	2.54	3.30	2.67	6.50	13.00
Calanus copepodite stage I and II	-	-	0.08	0.14	0.34	0.30	2.00	-	-	-	-	-	-	6.00
Calanus copepodite stage III and IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calanus copepodite stage V and VI	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oithona nauplii	-	-	0.15	0.48	0.26	0.10	-	-	0.47	0.22	0.33	-	-	-
Oithona copepodites	-	-	-	0.19	0.23	0.40	-	-	-	0.05	-	-	1.00	-
Small crustacean eggs	0.25	-	-	-	-	-	-	-	-	0.05	-	-	-	-
Miscellaneous copepod nauplii*	-	-	-	-	-	-	-	-	-	0.10	-	-	-	-
Miscellaneous copepod copepodites*	-	-	-	-	-	0.10	-	-	-	-	-	0.17	-	-
Euphausiid eggs	-	-	0.08	0.05	-	-	-	-	-	-	-	-	-	-
Euphausiid nauplii	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-
Euphausiid calyptopes	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-
Other groups	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of larvae examined	3	4	13	21	35	10	1	1	15	41	30	6	2	1
Biomass all stations	0.007	0.005	0.018	0.035	0.051	0.119	0.121	0.010	0.015	0.029	0.035	0.040	0.073	0.400
Biomass "day" stations	0.000	0.020	0.031	0.043	0.055	0.132	0.121	0.010	0.011	0.034	0.042	0.044	0.115	0.400
Biomass "night" stations	0.010	0.000	0.016	0.018	0.035	0.000			0.025	0.016	0.021	0.020	0.030	

APPENDIX TABLE 4. Gut contents of redfish larvae caught off West Greenland during July (NORWESTLANT 3) and in the Irminger Sea during July and August (NORWESTLANT 3) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). All data from samples collected by *Dana*.

Region:	West Greenland					Irminger Sea								
Larval length (mm):	9	10	11	12	13	14	16	17	18	19	20	21	22	29
Diatoms and Peridinians	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-
Tintinnids and Radiolarians	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spiratella larvae	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-
Calanus eggs	-	0.14	0.04	-	-	1.00	-	-	68.00	79.60	18.50	27.25	57.00	-
Calanus nauplii	0.50	3.00	4.37	4.00	6.00	-	23.00	7.00	5.67	2.00	4.00	12.00	9.00	-
Calanus copepodite stage I and II	-	-	0.12	0.17	-	-	-	1.00	-	-	-	0.50	-	-
Calanus copepodite stage III and IV	-	-	-	-	-	-	-	3.00	-	-	0.50	1.25	-	4.00
Calanus copepodite stage V and VI	-	-	-	-	-	-	-	1.00	-	-	1.50	2.00	-	6.00
Oithona nauplii	0.50	1.00	2.58	18.67	4.67	9.00	-	-	-	-	-	-	-	-
Oithona copepodites	-	0.29	1.50	1.17	2.00	-	6.00	2.00	8.33	5.00	-	9.75	30.00	-
Small crustacean eggs	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous copepod nauplii*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous copepod copepodites*	-	-	-	-	-	-	-	-	-	-	-	0.25	1.00	-
Euphausiid eggs	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiid nauplii	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiid calyptopes	-	-	-	-	-	-	-	-	0.33	-	-	0.25	1.00	-
Other groups	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of larvae examined:	2	7	26	6	3	1	1	1	3	1	2	4	1	1
Biomass all stations	0.005	0.032	0.062	0.075	0.079	0.010	0.272	2.209	0.375	0.156	2.086	3.688	0.596	8.560
Biomass "day" stations		0.032	0.072	0.075	0.079	0.010	0.272	2.209				5.682		8.560
Biomass "night" stations	0.005		0.002						0.375	0.156	2.086	0.456	0.596	

APPENDIX TABLE 5. Gut contents of cod larvae from Icelandic coastal waters during April (NORWESTLANT 1) and May (NORWESTLANT 2) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). Data for April from samples collected by *Thalassa*. Data for May from samples collected by *Aegir*.

Month:	April		May										
Larval length (mm):	3	4	3	4	5	6	7	8	9	10	11	12	13
Diatoms and Peridinians	-	+	+	+	+	+	-	-	-	-	-	-	-
Tintinnids	1.00	4.60	1.50	1.40	0.26	0.13	0.09	-	-	-	-	-	-
Calanus eggs	-	0.25	0.50	0.51	1.29	2.00	3.45	3.04	3.72	-	2.00	-	-
Calanus nauplii	-	-	-	0.17	1.26	1.48	2.55	5.48	3.39	6.00	0.67	-	-
Calanus copepodite stage I and II	-	-	-	-	-	0.04	0.55	-	0.06	0.33	0.33	-	1.00
Calanus copepodite stage III and IV	-	-	-	-	-	-	-	-	0.06	-	0.33	1.00	-
Small crustacean eggs	-	-	-	0.06	0.21	0.09	-	0.17	-	-	-	-	-
Temora nauplii	-	-	0.15	2.11	4.34	4.52	5.73	3.30	1.72	0.67	-	-	2.00
Temora copepodite stage I and II	-	-	-	-	-	-	-	-	0.06	-	-	-	-
Temora copepodite stage III and IV	-	-	-	-	-	-	-	0.09	0.89	-	0.33	11.00	-
Temora copepodite stage V and VI	-	-	-	-	-	-	-	-	0.06	-	0.33	-	-
Centropages nauplii	-	-	-	0.02	0.08	0.04	-	0.04	0.06	-	-	-	-
Centropages copepodites	-	-	-	-	-	0.04	-	-	0.06	-	-	-	-
Oithona nauplii	-	-	-	0.13	0.58	1.00	0.64	2.62	3.00	-	0.67	-	-
Oithona copepodites	-	-	-	0.02	-	-	-	-	0.11	0.33	-	-	-
Miscellaneous copepodites*	-	-	-	-	-	0.04	-	0.09	0.06	-	-	-	-
Euphausiid nauplii	-	-	-	-	0.05	-	0.36	0.48	0.39	1.67	0.33	-	-
Euphausiid calyptopes	-	-	-	-	-	-	-	-	-	0.33	-	-	-
Evadne	-	-	-	-	-	0.35	0.09	1.39	1.56	0.33	3.00	-	1.00
Cirripede nauplii	-	-	-	-	-	-	0.09	0.04	-	-	-	-	-
Lamellibranch larvae	-	-	0.15	0.30	0.65	0.04	1.09	0.09	0.06	-	0.33	-	-
Number of larvae examined:	1	8	13	47	38	23	11	23	18	3	3	1	1
Biomass all stations	0.000	0.001	0.002	0.014	0.040	0.058	0.107	0.217	0.191	0.339	0.266	0.830	0.115
Biomass "day" stations		0.001	0.003	0.020	0.044	0.062	0.107	0.236	0.192		0.045		
Biomass "night" stations	0.000		0.000	0.001	0.030	0.041		0.008	0.174	0.339	0.378	0.830	0.115

APPENDIX TABLE 6. Gut contents of cod larvae caught off West Greenland during June (NORWESTLANT 2) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). Data from samples collected by *Dana* and *Baffin*.

	Larval length (mm)						
	3	4	5	6	7	8	9
Calanus eggs	-	0.07	0.14	-	-	-	-
Calanus nauplii	0.50	0.73	2.31	2.40	2.89	3.11	6.50
Calanus copepodite stage I and II	-	-	-	-	-	-	0.50
Calanus copepodite stage III and IV	-	-	-	-	-	-	-
Oithona nauplii	1.00	0.07	-	0.06	0.07	0.11	1.50
Oithona copepodites	-	-	-	0.03	-	-	-
Miscellaneous nauplii*	-	0.07	0.29	0.03	-	-	0.50
Miscellaneous copepodites*	-	-	-	-	0.04	0.11	-
Euphausiid nauplii	-	-	-	0.03	-	-	-
Euphausiid calyptopes	-	-	-	-	-	-	-
Fish eggs	-	-	-	-	-	-	-
Number of larvae examined:	2	15	35	35	26	11	2
Biomass all samples	0.006	0.009	0.025	0.026	0.029	0.039	0.091
Biomass "day" samples	0.006	0.007	0.027	0.031	0.033	0.044	0.091
Biomass "night" samples		0.015	0.021	0.017	0.021	0.020	

APPENDIX TABLE 7. Gut contents of cod larvae caught off West Greenland during July (NORWESTLANT 3) as mean numbers of organisms per fish and mean biomass of total food remains per fish (mg). Data from samples collected by *Dana*.

	Larval length (mm)										
	4	5	6	7	8	9	10	11	12	13	14
Calanus eggs	-	-	-	-	-	-	-	-	-	-	-
Calanus nauplii	1.00	-	0.83	0.50	2.29	2.00	3.62	3.67	5.72	5.20	4.28
Calanus copepodite stage I and II	-	-	-	-	1.43	2.07	2.37	2.93	1.77	1.20	2.43
Calanus copepodite stage III and IV	-	-	-	-	-	-	-	0.20	-	0.40	0.28
Oithona nauplii	-	-	-	-	-	-	-	-	-	-	-
Oithona copepodites	-	-	-	-	-	-	-	0.07	0.11	0.20	-
Miscellaneous nauplii*	-	-	-	-	-	-	-	-	-	-	-
Miscellaneous copepodites*	-	-	-	-	-	0.13	0.37	0.13	0.11	-	0.14
Euphausiid nauplii	-	-	-	-	-	-	-	0.07	-	-	0.43
Euphausiid calyptopes	-	-	-	-	-	-	-	0.07	-	-	-
Fish eggs	-	-	-	-	-	-	-	-	-	-	-
Number of larvae examined:	1	1	6	2	7	15	16	15	18	5	7
Biomass all samples	0.010	0.000	0.008	0.005	0.087	0.119	0.161	0.284	0.143	0.219	0.260
Biomass "day" samples			0.020		0.130	0.183	0.197	0.325	0.107	0.115	0.554
Biomass "night" samples	0.010	0.000	0.006	0.005	0.030	0.020	0.056	0.184	0.215	0.245	0.050

APPENDIX TABLE 8. Gut contents of redfish larvae from the Irminger Sea off Southeast Greenland during July (NORWESTLANT 3, *Explorer*) as average numbers of food organisms per fish. Data supplied by Dr J. H. Fraser. The results were obtained by dissecting all larvae if less than 10 per sample or a sub-sample of about 15 larvae if larger numbers were present.

	Length range (mm) of larvae			
	<15	16-20	21-25	26+
Copepod eggs	1.73	2.67	0.35	1.50
Oithona nauplii	0.59	-	-	-
Calanus nauplii	0.24	0.57	-	-
Unidentified nauplii	0.17	0.85	0.57	0.33
Total nauplii	1.00	1.42	0.57	0.33
Oithona copepodite stage I-VI	0.59	0.45	-	0.33
Calanus copepodite stage I-VI	-	0.47	1.26	3.66
Temora copepodite stage I-VI	-	-	0.09	-
Euchaeta copepodite stage I-VI	-	-	0.04	-
Unidentified copepodite stage I-VI	0.29	2.00	0.86	0.50
Total adults and copepodites	0.88	2.92	2.25	4.49
Spiratella	0.02	0.15	-	-
Euphausiid furcilias	-	0.02	0.09	0.66
Decapod larvae	-	-	0.13	-
Number of young fish examined	41	40	23	6

APPENDIX TABLE 9. Gut contents of cod and redfish larvae in the northern part of the Irminger Sea during July (NORWESTLANT 3, *Ernest Holt*). Data supplied by Mr J. Corlett have been arranged to show the percentage of positive stations (i.e., stations with the species of fish larvae concerned) at which the various food items were observed in the guts.

Species	Redfish	Cod
Copepod eggs	2	-
Copepod nauplii	27	12
Calanus copepodite stage I-VI	44	55
Paracalanus copepodite stage I-VI	4	5
Temora copepodites stage I-VI	-	7
Oithona copepodites stage I-VI	14	12
Balanus nauplii	-	2
Euphausiid nauplii and calyptopes	6	5
Euphausiid furcilias	4	14
Amphipods	2	17
Spiratella	-	14
Oikopleura	2	-
Number of stations where fish larvae examined	52	42

Some Information on Adult Fishes Taken During NORWESTLANT 1-3, 1963

By

K. G. Konstantinov[1]

During NORWESTLANT 1-3, April-June 1963, adult fishes were collected along with eggs and larvae samples. They were caught by research fishing gear (pelagic trawl, mid-water Isaacs-Kidd trawl, plankton nets, etc.) and by commercial otter trawl. A brief description of the adult fishes, reported by some countries, follows.

ADULT FISH CAUGHT BY RESEARCH FISHING GEAR

Adult redfish were caught on four occasions by the pelagic trawl of the German Research Vessel *Anton Dohrn* during NORWESTLANT 2. Table 32 shows data presented by A. S. Kotthaus. Some specimens of bathypelagic fish as well as invertebrates (*Periphylla hyacinthina*, Schizopoda, Cephalopoda, Chaetognatha) were taken by the mid-water Isaacs-Kidd trawl (Station 583/63, 5 June, between 0155-0350 hours, at 62°31'N and 37°50'W, depth 2,250 m, hauling layer 400-500 m). All the specimens of bathypelagic fish sampled during the trip of the *Anton Dohrn* by the pelagic and mid-water Isaacs-Kidd (KMT) trawls will be treated and described by A. S. Kotthaus. On two occasions, adult fish were caught by a stramin net from the Soviet Research Vessel *Academician Knipovich* during NORWESTLANT 3 (Table 33).

ADULT FISH TAKEN BY BOTTOM-OTTER TRAWL

(a) from *Anton Dohrn*

Three hauls were made using bottom-otter trawl on board the German *Anton Dohrn* during NORWESTLANT 2 (Table 34). The first haul took 162 cod, *Gadus morhua*. The size composition is given in Table 35. Fifty-five cod were measured and gutted. Twenty-five were males (including 14 spent) and 30 were females (including 13 spent). In addition, five baskets (about 200 kg) of redfish, *Sebastes marinus* type *marinus*, were caught. One hundred and twelve of these were measured (Table 36). Five redfish, *Sebastes viviparus*, 5-10 cm in length, were taken. They were put alive into an aquarium. Four specimens of haddock, *Melanogrammus aeglefinus*, were 24, 26, 39, and 47 cm in length; one spotted catfish, *Anarhichas minor*, was 112 cm; one blue catfish, *Anarhichas latifrons*, was 104 cm; and 37 specimens of catfish, *Anarhichas lupus*, were from 19 to 69 cm. Furthermore, there were six American plaice, *Hippoglossoides platessoides*, from 27 to 40 cm; four specimens of halibut, *Hippoglossus hippoglossus*, of 50, 53, 56, and 65 cm; one argentine, *Argentina silus*, of 38 cm; and one Arctic cod, *Boreogadus saida*, of 25 cm.

The second haul took mainly redfish, *Sebastes marinus* type *mentella*. Some 1,000 specimens were measured (Table 37). Also captured were 110 argentine, *Argentina silus*, from 15 to 32 cm in length; 11 redfish, *Sebastes viviparus*, 17-25 cm; 39 black-spined dogfish, *Etmopterus spinax*, 13-42 cm; five ratfish, *Chimaera monstrosa*; 17 specimens of *Lepidion eques*, 9-44 cm; 23 trade ling, *Molva dipterygia*, 56-109 cm; 12 cusk, *Brosme brosme*, 49-66 cm; one specimen of greater forkbeard, *Phycis blennoides*, of 47 cm; one specimen of megrim, *Lepidorhombus whiff*, of 34 cm; and some 50 kg of the gadoid fish, *Micromesistius poutassou*.

The third haul took 13 redfish, *Sebastes marinus* type *marinus*, including nine males from 32 to 57 cm in length and four females from 26 to 66 cm; two redfish, *Sebastes viviparus*, of 16 and 20 cm; two cusk, *Brosme brosme*, of 33 and 53 cm; one American plaice, *Hippoglossoides platessoides*, of 32 cm; 39 gadoid fish, *Micromesistius poutassou*, 24-33 cm; and 19 argentine, *Argentina silus*, 30-37 cm.

[1] Polar Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, USSR.

(b) from *Ernest Holt* and *Explorer*

The English Research Vessel *Ernest Holt*, during NORWESTLANT 1, made one haul on 28 April with the otter trawl on the Fylkir Bank (62°27.5'N and 40°42'W) at 210-247 m. The haul lasted from 2010 to 2040 hours, but it failed because the headline was damaged and the net broken.

The catch consisted of 38 cod from 55 to 99 cm long, more than one third of them were spent; stomachs were mainly empty but some contained euphausiidae. In addition, there were 10 haddock from 34 to 81 cm; three of them of 50, 51, and 81 cm were mature males, all the others were immature. All stomachs contained ophiura. Furthermore, there were 11 redfish, *Sebastes marinus*, seven were males and four females. There were also six halibut from 52 to 63 cm in length.

During NORWESTLANT 3 near West Iceland three hauls were made at 165-201 m. Redfish predominated in the catches. Another English Research Vessel *Explorer* made a trawl haul near southeastern Greenland, but the net was damaged and the resulting catch consisted mainly of redfish and cod.

(c) from *Academician Knipovich*

The Soviet Research Vessel *Academician Knipovich*, during NORWESTLANT 1, made two hauls. The first haul began at 0835 hours on 10 April, at 57°30'N, 59°20'W. The depth was 240 m, and the bottom temperature was 2.17°C. The catch consisted of only five cod from 38 to 58 cm in length. Their stomachs were full of polychaetae, crabs, jellyfish, octopus, and small groundfish.

The second haul began at 0715 hours on 13 April and lasted 1 hr. It was made at 60°50'N, 48°43'W, at 125 m. The bottom temperature was about 0.8°C. Sixty-six cod from 47 to 70 cm in length were taken with some benthos in their stomachs. In addition, 199 redfish, *Sebastes marinus*, were taken, 52 were males from 27 to 43 cm and 147 were females from 29 to 50 cm. Eight spotted wolffish, *Anarhichas minor*, from 65 to 115 cm; 16 Atlantic wolffish, *Anarhichas lupus*, from 33 to 71 cm; and one blue catfish, *Anarhichas latifrons*, were also taken.

During NORWESTLANT 3, the *Academician Knipovich* made six hauls using the bottom-otter trawl. The positions and time of these hauls and the catches are given in Table 38.

SUMMARY

The main task of the NORWESTLANT program was the sampling of larvae and eggs, while the fishing of adult fish was of a casual character.

The otter-trawl hauls described above were made in the areas of regular and prolonged work by the research vessels. The catches made do not increase our knowledge of the habits of commercial groundfish in the ICNAF area. Of somewhat greater scientific interest is the fact that adult bottom fish were taken in pelagic fishing gear. For instance, the *Anton Dohrn* from 17 to 22 June 1963 took four redfish, *Sebastes mentella*, including three spent females (Table 32). They were taken in the open sea above depths of more than 2,000 m. These facts indirectly confirm our assumption of the existence of independent pelagic populations of redfish which spawn in the open ocean. Redfish were also taken by handlines by various research vessels and weather ships. The results of this program are described by Jones, this volume, p. 225.

The results of some studies of cod caught off Labrador are given by Postolaky, this volume, p. 139.

TABLE 32. Adult fish taken by pelagic trawl from the R/V *Anton Dohrn* in June 1963.

Station No.	Date	Time	Depth	Approx. depth of haul	Beginning of hauling N	Beginning of hauling W	End of hauling N	End of hauling W	Species	Size	Sex and maturity stage	Other fishes invertebrates
		(hr)	(m)	(m)						(cm)		
603/63	15 June	1800-1825	2,740	800	60°20'	39°20'	60°17'	39°11'	*Sebastes marinus* type *marinus*	38	Spent female	Bathypelagic fish, deepwater shrimp, *Periphylla hyacinthina*, Todarodes
611/63	17 June	0600-0850	2,100	800	57°51'	33°52'	57°48'	33°45'	*Sebastes marinus* type *mentella*	45	Spent female	Bathypelagic fish, deepwater shrimp, *Periphylla hyacinthina*
632/63	21 June	0000-0235	2,680 2,440	800	57°39'	37°10'	57°42'	37°15'	*Sebastes marinus* type *mentella*	40	Spent female	Bathypelagic fish, *Periphylla hyacinthina*, deepwater shrimp, Cephalopoda
641/63	22 June	2220-0035	2,520	800	59°18'	33°33'	59°13'	33°29'	*Sebastes marinus* type *mentella* (2)	43 45	Male, spent female	Bathypelagic fish, deepwater shrimp, Cephalopoda, *Periphylla hyacinthina*

TABLE 33. Adult fish taken by stramin net from the R/V *Academician Knipovich* in July 1963.

Station No.	Date	Time	Depth	Depth of haul	N	W	Species	Size
		(hr)	(m)	(m)				(mm)
791/137	13 July	2325-0050	2,036	105-0	59°17'	45°11'	*Mallotus villosus* (3)	63, 65, 75
806/152	17 July	0015-0135	3,650	105-0	55°40'	44°00'	*Stomias ferox*	135

TABLE 34. Data on the hauls made by the R/V *Anton Dohrn* in June 1963.

Station No.	Date	Time	Depth	N	W	Direction and strength of wind	Cloudiness
		(hr)	(m)				
567/63	3 June	0900-0930	240-270	62°32'	40°35'	Light wind	Clear
579/63	4 June	1150-1220	330	63°20'	39°21'	SW - 2	Clear
599/63	9 June	0825-0925	450	63°02'	24°00'	ESE - 4	Cloudy

TABLE 35. Size composition of cod obtained by the first haul of the R/V *Anton Dohrn.*

	Size in cm																												
	24 to 26	27 to 29	30 to 32	33 to 35	36 to 38	39 to 41	42 to 44	45 to 47	48 to 50	51 to 53	54 to 56	57 to 59	60 to 62	63 to 65	66 to 68	69 to 71	72 to 74	75 to 77	78 to 80	81 to 83	84 to 86	87 to 89	90 to 92	93 to 95	96 to 98	99 to 101	102 to 104	105 to 107	108 to 110
No. of specimens	2	2	1	2	3	4	5	3	1	5	4	1	4	5	4	8	14	18	5	13	13	11	14	4	8	3	4	-	1

TABLE 36. Size composition of 112 redfish, *Sebastes marinus* type *marinus*, obtained in the first haul of the R/V *Anton Dohrn.*

	Size in cm																														
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	Total
Males	-	-	-	-	-	-	-	-	1	2	2	5	7	7	1	2	7	3	2	2	1	2	-	-	-	1	-	2	-	-	1	48
Females	1	-	1	1	-	2	2	-	1	3	3	7	12	9	5	-	7	1	1	5	-	-	-	2	-	-	-	1	-	-	-	64
Total	1	-	1	1	-	2	2	-	2	5	5	12	19	16	6	2	14	4	3	7	1	2	-	2	-	1	-	3	-	-	1	112

TABLE 37. Size composition of 966 redfish, *Sebastes marinus* type *mentella*, obtained in the second haul of the R/V *Anton Dohrn.*

	Size in cm												
	38	39	40	41	42	43	44	45	46	47	48	49	Total
Males	8	17	8	25	50	67	117	42	17	-	-	-	351
Females	-	8	17	25	50	83	175	100	83	33	33	8	615
Total	8	25	25	50	100	150	292	142	100	33	33	8	966

TABLE 38. Results of trawl hauls made by the R/V *Academician Knipovich* in July 1963.

Date	Time	Depth	Beginning of haul		Cod			Other fishes taken
			N	W	Number	Length	Stomach contents	
	(hr)	(m)				(cm)		
4 July	2040–2100	108–110	60°51'	49°08'	30	49–90	Euphausiidae Ophiuroidea Holoturia	*Anarhichas minor* (3)
9 July	0800–0900	140	56°24'	59°19'	13	51–61	Themisto Amphipoda Ctenophora	–
9 July	1700–1740	160	55°39'	57°50'	12	44–66	Amphipoda Themisto Polychaeta	*Hippoglossoides platessoides* (1)
9 July	1835–1905	160	55°37'	57°45'	10	48–63	Amphipoda Themisto Ctenophora	*Hippoglossoides platessoides* (3)
10 July	0640–0745	200–205	55°27'	56°46'	336	40–70	Themisto Amphipoda	*Anarhichas lupus* (4) *Anarhichas latifrons* (2) *H. platessoides* (65) *Cyclopterus lumpus* (1)
19 July	1655–1815	175	59°39'	43°23'	12	47–80	Oikopleura Themisto	*Sebastes marinus* (1)

Angling for Redfish

By

D. H. Jones[1]

INTRODUCTION

Line-fishing trials for adult redfish have been carried out by weather ships at Ocean Weather Station *Alfa* (62°N, 33°W) from April 1962 to March 1965 on behalf of the Edinburgh Oceanographic Laboratory (Henderson and Jones, 1964). This paper deals only with the period of the NORWESTLANT Surveys (April-July 1963), but includes brief comments on the equivalent periods in 1962 and 1964.

All ships taking part in the surveys were asked to carry out a program of angling similar to that at Station *Alfa* and reports have been received from Danish, Icelandic, German, and British research vessels. In addition to 116 fish returned to Edinburgh by French and British weather ships, 60 fish were sent from the Danish research vessel *Dana*. The positions of fishing stations are given in Fig. 61 and the fishing program is summarized in Table 39. A total of 355 redfish, including those lost from the hook at the surface, were caught within the area bounded by 60° and 62°N lat and 32° and 40°W long; *Dana* also fished unsuccessfully between 25° and 32°W long.

The success of fishing was by no means constant. On some occasions fish were hauled in immediately a line was lowered and at these times catches were made at an average of approximately six fish per line per hour. On other occasions, under apparently similar conditions, fishing was very variable, long periods of unsuccessful fishing being relieved by occasional small catches.

GEAR, METHODS, AND DEPTH DISTRIBUTION

The standard equipment issued to the weather ships and *Explorer* consisted of a 6-ft- (2-m) fibreglass rod, a sea-reel, and 450 m of either a flax or braided nylon line marked at 50-m intervals. Three unbaited, triple-hooked mackerel spinners were generally used as lures or alternatively two of these were combined with a plastic shrimp or a 'Mepps' spoon. The weather ships used a standard method of fishing to 400 m, lowering and hauling in the line by 50-m stages and fishing for 5 min at each stage during both operations. Any subsequent fishing, either with the standard gear or by other lines, was concentrated on the successful depth.

The use of a rod and reel limited the weight which could be handled conveniently and a lead sinker of 200 g was used during calm conditions and was supplemented by a further 200 g during poor conditions. When the ship was drifting at 1 knot or more the maximum depth attained was assumed to be no more than 250 m.

Dana and *Aegir* both used reels fitted with nylon line which were mounted on the ship's rail. *Dana* used three reels at each station and each line was furnished with five to eight triple-hooked spoons ('jigs') and a weight of 3 kg. Bait, in the form of salt herring, was used once but without effect, although the Norwegian bait 'gummimak' (small rubber tubing) was generally used. *Aegir* used six cod-hooks per line with an artificial bait, three spinners and a weight of 1 kg.

On a number of occasions precise estimates of the depth of capture could not be made because of the impossibility of relating the ship's drift and the line angle to the depth achieved by the hooks. However, with this reservation in mind, it seems very probable that the largest catches at Station *Alfa* during June and July came from depths of roughly 100-150 m. All the fish taken by *Weather Adviser* at the end of June and in early July and most of those taken in June by *Weather Monitor* came from this depth range. It seems probable that during May, at Station *Alfa*, the fish were lying deeper as *France II*, fishing in calm conditions, caught fish easily from 200 to 300 m.

[1] Oceanographic Laboratory, Edinburgh, Scotland.

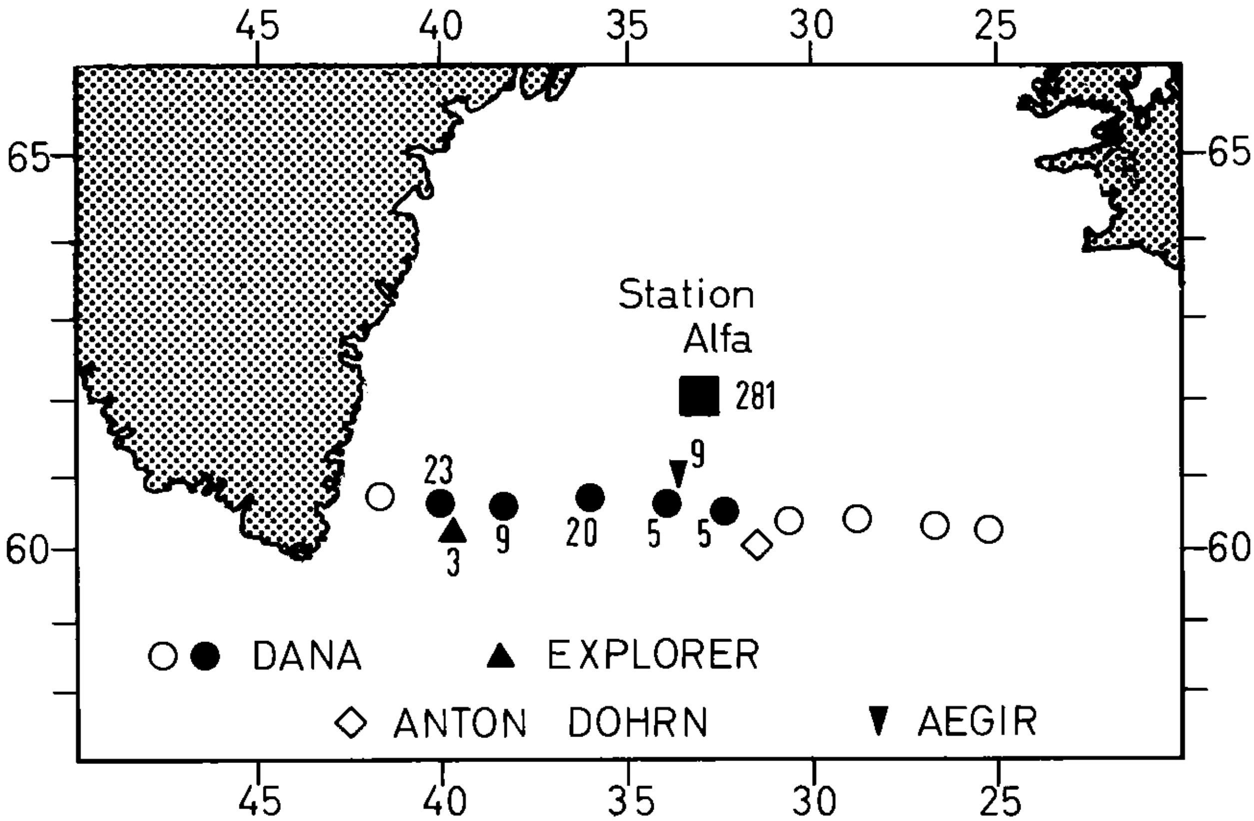

Fig. 61. Chart showing the position of angling stations and the numbers of fish caught at each station during NORWESTLANT 1-3.

TABLE 39. Ships taking part in the Angling Program (April-July 1963) and details of their catches. (The numbers of fish known to be lost at the surface are given in parentheses.)

Ships	Dates of fishing	Total hours fishing	Fish caught	Fish returned to Edinburgh
Station *Alfa*				
France I	21 April-9 May	9	0	0
France II	15-22 May	19	60	10
Weather Monitor	5-27 June	350	63 (18)	62
Weather Adviser	29 June-16 July	39	140	44
Total			281	116
NORWESTLANT Cruises				
Aegir (Iceland)	30 April-31 May	?	8 (1)	0
Dana (Denmark)	20-24 May	14	62	60
Explorer (UK)	4 July	?	3	0
Anton Dohrn (Fed. Rep. Germany)	6 June	?	0	0
Total			74	60

Dana, also during May, but further to the south and west (Fig. 61) took fish from a depth range of 90-180 m (mean 126 m), except at the most westerly station, where the range was 90-300 m (mean 187 m). Of the nine fish caught by *Aegir* in May, one was taken with 150 m and one with 500 m of line out, while 350 m of line were used to take the remaining seven fish. The three fish caught by *Explorer* in early June were all taken from approximately 100 m. Although only a few male fish were caught, their depth distribution showed no obvious difference from that of the females and occasionally males and females were caught on adjacent hooks. During the surveys the amount of night fishing was necessarily limited and it is difficult to make comparisons of depth distribution or ease of capture by day and night. However, there is no evidence from these trials that any marked upward vertical movement of redfish occurs during the night and the shallowest depth of capture (70-80 m) was recorded during daylight.

TABLE 40. Angling program April-July 1962 and May-July 1964, with details of the catches.

Ships	Dates of fishing	Total hours fishing	Fish caught	Fish returned to Edinburgh
Station *Alfa* 1962				
Weather Reporter	24 April-10 May	11	0	0
Weather Surveyor	18 May-7 June	17	5	4
Cumulus	10-20 June	30	65	13
Cirrus	7-21 July	51	32	6
Total		109	102	23
Station *Alfa* 1964				
France II	6-28 May	77	271	8
Weather Monitor	26 June-11 July	39	0	0
Total		116	271	8
1964				
Dana	2-5 July	7	83	-

Table 40 summarizes the fishing during April-July 1962 and May-July 1964. One of the outstanding catches during these periods was made by *France II* when, in seven days fishing between 14 and 28 May 1964, 271 redfish were taken from depths of 150-250 m. Of these, 89 were caught during one 10-hr spell and on four occasions echo-sounder traces were recorded at approximately the depth of capture. *Dana*, fishing to the west of Station *Alfa* in July 1964, caught 83 fish in 5 1/2 hr at three stations (Fig. 62) and tagged 48 of these with apparent success.

SHOALING, HORIZONTAL DISTRIBUTION, AND TEMPERATURE

Evidence collected during these trials indicates that in the three months following spawning (May-July), aggregations of redfish occurred at Station *Alfa* and in the area sampled by *Dana*. The occasional high rates of capture and the periodic complete failure of fishing suggest the occurrence of either distinct or loosely linked concentrations of fish.

It has not been possible to make a full examination of the relationship between the success of fishing and hydrography during the NORWESTLANT Surveys as sufficient data are not available, but the existence in the vicinity of Station *Alfa* of a boundary between Northwest Atlantic water and Labrador Sea water means (Anon., 1964) that the relatively rapid shifts of this boundary may cause marked, short-term changes in the physical environment of the area. These changes are likely to be reflected by changes in the fauna and could account for the success or failure of fishing either directly, by temperature, or indirectly by acting on the food supply. Dr Erik Smidt (personal communication) reported that redfish were caught by *Dana* in 1963 at all five stations where the temperature at 100 m lay between 4.5° and 6.3°C; but none were caught at any of the four stations with warmer water (7.27° to 8.01°C) or at the one station with cooler water (2.38°C).

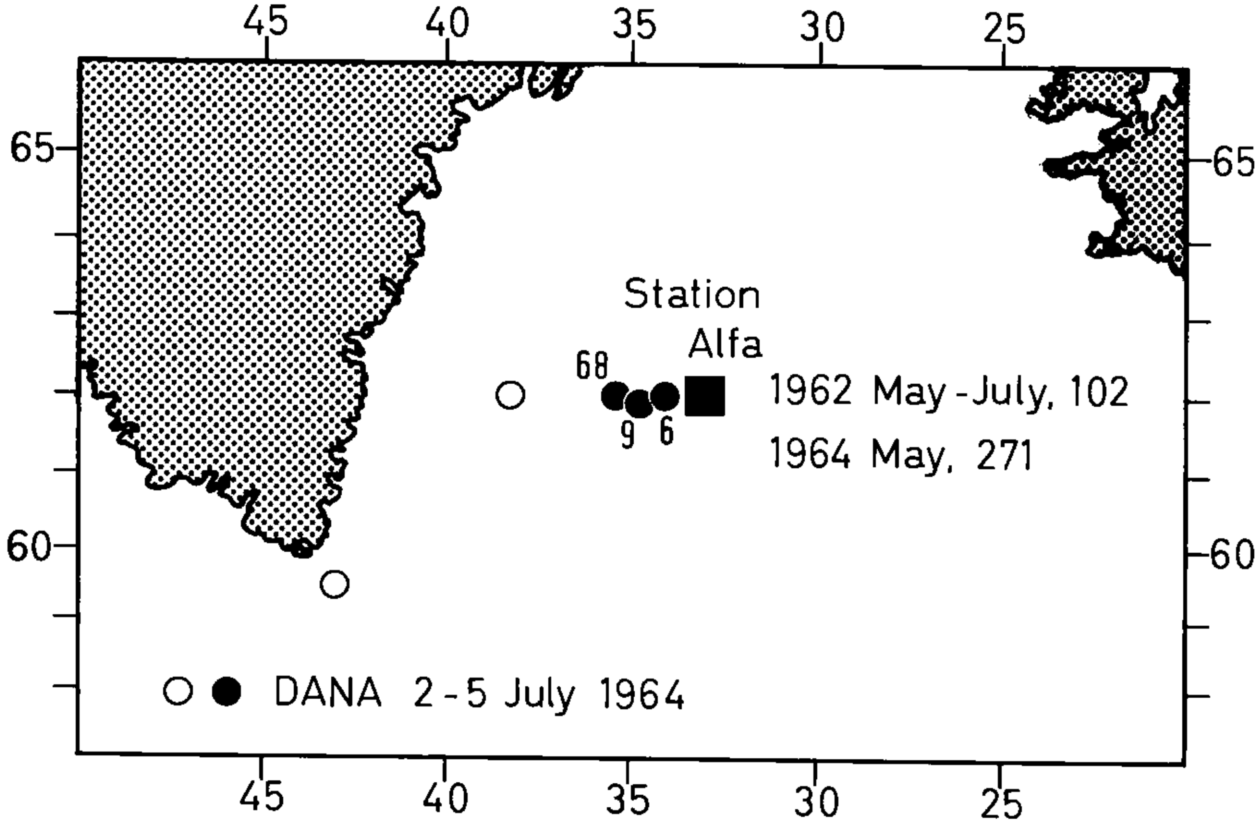

Fig. 62. Chart showing the numbers of fish caught at Station *Alfa* in May-July 1962 and in May 1964. Also shown are the fishing stations and catches of *Dana* in July 1964.

It is hoped that it will be possible to study success in fishing in relation to temperature by using all available records from Station *Alfa* during 1962-64 and NORWESTLANT 1963. Meanwhile, a preliminary inspection of available bathythermograph records taken by British weather ships in June and July 1963 suggests the possibility that a temperature of about 7°C may be critical, most of the successful fishing occurring in regions, or at times, when the water at 100 m was cooler than this.

IDENTIFICATION, MORPHOMETRIC, AND MERISTIC CHARACTERS

An examination of morphometric, meristic, and biological data showed no obvious differences between the 116 fish caught at Station *Alfa* and those (60) taken by *Dana* at stations up to 200 miles away. The evidence suggests, in fact, that all the fish are basically alike both in their conformation and in various aspects of their biology. There is at times quite a wide variation in some of the measurements within any size group, (*e.g.* orbit diameter or "schnabel" length) and such differences may occur between two fish caught on adjacent hooks.

All the fish caught by *Aegir* and *Explorer* were identified at sea as *Sebastes mentella* Travin as were all those returned to Edinburgh. In addition to the characteristically large eyes and the well-developed "schnabel" or beak on the lower jaw, two other criteria were applied, as suggested by Andriiashev (1954), to separate the *marinus* and *mentella* forms of *Sebastes*. These are: the relationship between horizontal orbit diameter (HOD) and head length (HL) and between horizontal orbit diameter and post-orbital length (POL). In this key the *mentella* form is distinguished by the orbit diameter being greater than 26% of the head length and greater than 60% of the post-orbital length. The mean figures for each of these measurements were respectively, 34.5% and 78.3% for the fish from Station *Alfa*, and 33.9% and 79.1% for fish from *Dana* (Table 41a and b). Because of a recently-corrected error in the translation of the Andriiashev key[2] the post-orbital length was

[2] In the translation from the Russian (by C. R. Robins, 1955) of the key to the identification of species of *Sebastes* (Guides to the fauna of Russia. Fishes of the northern seas of Russia, by A. P. Andriiashev), the term "zaglaznichnogo" has been translated as "inter-orbital". This should correctly be translated as "post-orbital". I am indebted to J. B. L. Matthews for retranslating the Andriiashev key and to K. G. Konstantinov for confirming the translation of "zaglaznichnogo".

measured for only 36 fish from Station *Alfa* and 10 from *Dana*. However, the range and mean figures for these few fish, when taken in conjunction with the other data, indicate that all the fish were in fact "good" *S. mentella*. Some specimens of the "intermediate" form of ***Sebastes*** have been recorded by Zakharov (1964) from the area covered by these trials, but none have been reported or found during the NORWESTLANT Surveys.

TABLE 41. Horizontal Orbit Diameter (HOD) as a percentage of: (a) Head length (HL); (b) Post-orbital length (POL).

(a)	(HOD/HL) × 100	Station *Alfa*		*Dana*	
	Range	No. of fish	Percent of fish	No. of fish	Percent of fish
	30.0-30.9	1	0.9	2	3.3
	31.0-31.9	10	8.6	4	6.7
	32.0-32.9	11	9.5	10	16.7
	33.0-33.9	26	22.4	15	25.0
	34.0-34.9	23	19.8	16	26.7
	35.0-35.9	22	19.0	7	11.9
	36.0-36.9	11	9.5	4	6.7
	37.0-37.9	8	6.9	1	1.7
	38.0-38.9	2	1.7	1	1.7
	39.0-39.9	1	0.9	0	-
	40.0-40.9	1	0.9	0	-
	Total	116		60	
	Mean	34.5%		33.9%	
	Range	30.2-40.7%		30.4-38.1%	

(b)	(HOD/POL) × 100	Station *Alfa*	*Dana*
	Range	No. of fish	No. of fish
	70.0-79.9	24	5
	80.0-89.9	12	5
	Total	36	10
	Mean	78.3%	79.1%
	Range	70.7-86.3%	72.7-87.2%

Kelly, *et al.*, (1961) suggested a series of measurements which they considered to be the most reliable aids to racial distinction in redfish and a selection of these measurements has been taken from all fish returned to the laboratory, both from Station *Alfa* and from *Dana*. All the measurements were taken from formalin-preserved material in which a shrinkage of 1-2 cm was found to occur in fish with a standard length of 29.0-37.0 cm. The means of nine body measurements and weights are given in Table 42 for each of 11 size-groups, together with the combined means and the overall range of the observations. Figure 63 shows the means of four of these measurements, head length, body depth, snout to ventral fin, and snout to anal fin, plotted separately against the standard length. The calculated regression lines indicate a sufficiently close agreement in the proportional growth of the two samples to suggest that they form part of the same stock.

TABLE 42. Redfish - Body Measurements, NORWESTLANT 1963 - Station *Alfa* (A) and *Dana* (D). The mean measurements are shown for each size category. The range of observations is shown at the right.

	Station:	Standard length (cm) 27	28	29	30	31	32	33	34	35	36	37	Combined Means	Range
No. of fish	A	0	0	7	17	28	25	14	19	3	2	1	31.92 cm	St. length
	D	1	1	3	3	12	16	9	7	6	1	1	32.23 cm	St. length
Weight (kg)	A	-	-	0.63	0.70	0.77	0.81	0.87	0.97	1.03	1.00	1.2	0.82	.6- 1.2
	D	0.50	0.50	0.58	0.67	0.76	0.82	0.91	0.89	0.97	1.10	1.2	0.82	.6- 1.2
Body depth (cm)	A	-	-	10.2	11.0	11.1	11.6	11.9	12.1	12.5	12.3	12.3	11.5	9.8-13.2
	D	9.0	9.6	10.0	10.5	11.0	11.3	11.7	11.7	11.9	13.3	12.6	11.3	9.0-13.3
Head length (cm)	A	-	-	10.4	11.0	11.2	11.6	12.0	12.1	12.2	12.3	12.7	11.5	9.9-12.7
	D	9.1	10.2	10.6	10.9	11.3	11.5	11.9	12.0	12.3	12.9	13.5	11.6	9.1-13.5
Snout to ventral fin (cm)	A	-	-	11.2	11.8	11.9	12.3	13.0	13.1	13.3	13.8	14.0	12.3	10.6-14.0
	D	11.2	11.5	12.5	12.2	12.5	12.7	13.8	13.9	13.8	14.5	14.4	13.1	11.2-15.6
Snout to anal fin (cm)	A	-	-	18.9	19.9	20.5	21.0	21.8	22.6	22.7	22.8	23.5	21.1	18.3-23.5
	D	19.0	18.7	19.1	20.1	20.9	21.4	22.3	22.7	24.1	23.7	24.3	21.7	18.7-24.7
Schnabel (mm)	A	-	-	11.4	12.5	12.8	13.1	13.4	14.1	15.0	13.5	14.0	13.0	11 -16
	D	10	10	11.0	11.3	12.4	13.1	13.8	13.7	13.5	15.0	14.0	12.6	10 -16
Orbit diam vertical (mm)	A	-	-	33.7	36.5	37.5	37.8	38.9	39.3	39.3	39.5	41.0	37.8	32 -42
	D	29	31	31.7	35.7	35.7	37.3	38.7	38.9	40.0	43.0	39.0	37.1	29 -44
Orbit diam horizontal (mm)	A	-	-	35.3	38.5	39.2	39.8	40.5	41.1	41.0	41.0	44.0	39.6	33 -45
	D	30	34	33.7	38.0	37.8	39.2	40.4	40.9	42.3	44.0	41.0	39.2	30 -45
Inter-orbital distance (mm)	A	-	-	21.1	21.4	22.3	23.0	23.2	24.8	25.0	26.0	26.0	22.9	18 -26
	D	20	20	22.0	20.0	22.2	22.8	23.2	23.4	23.3	26.0	26.0	22.7	18 -26
Orbit area (cm^2)	A	-	-	11.9	14.2	14.7	15.1	15.8	16.3	16.2	16.2	18.0	15.0	10.6-19.8
	D	8.7	10.5	10.7	13.6	13.5	14.6	15.7	15.9	17.0	18.9	18.0	14.7	8.7-19.8

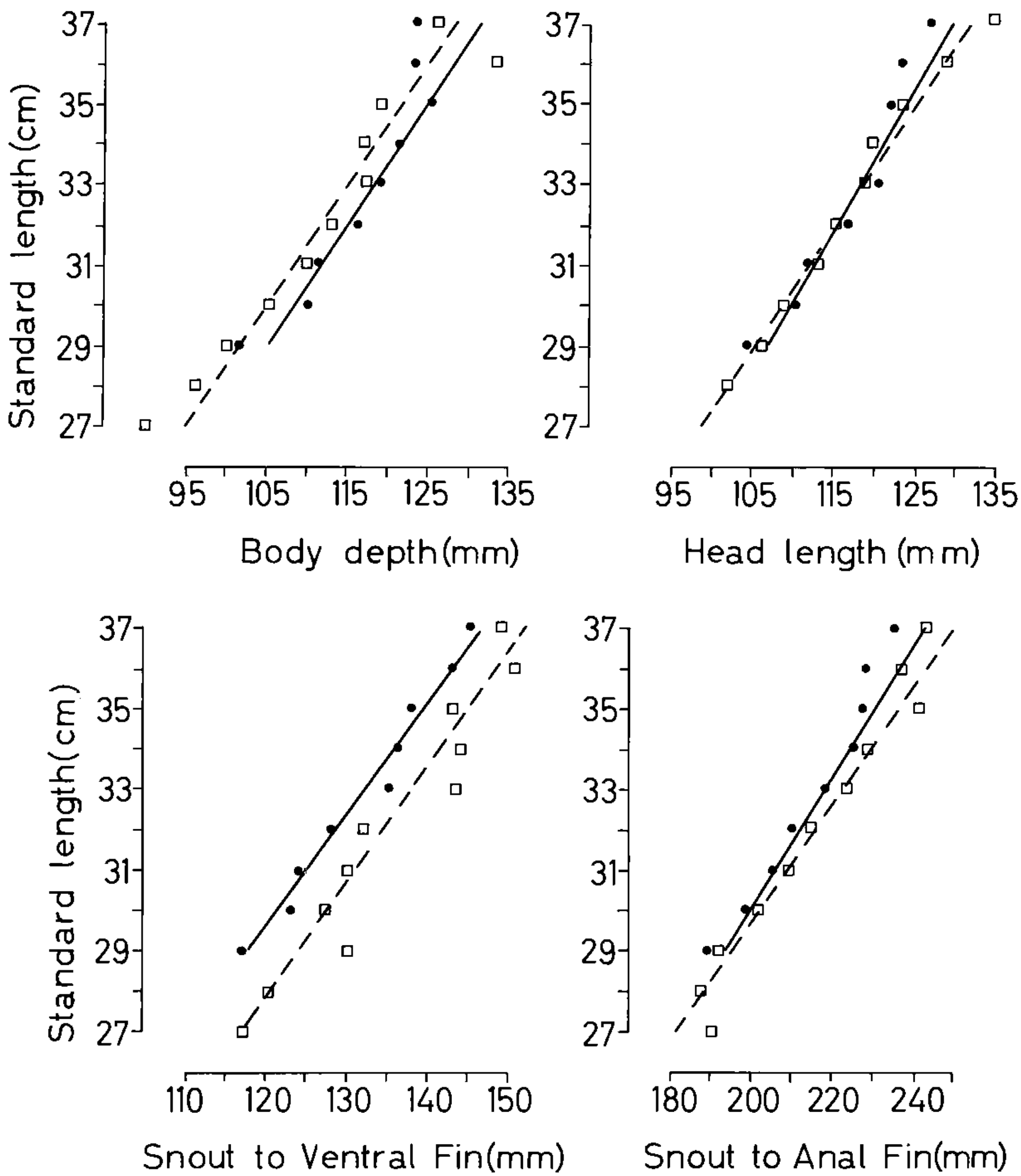

Fig. 63. Four body measurements plotted against the standard length, to demonstrate the similar proportional growth between fish caught by *Dana* (broken line) and fish caught at Station *Alfa* (solid line). Circles (Station *Alfa*) and squares (*Dana*) are mean measurements for each size group.

Two further features, the vertebral number and the number of pyloric caeca, appear to confirm this suggestion. Vertebral counts (including the urostylar element) have been made on 80 fish from Station *Alfa* and 50 from *Dana*, giving mean figures respectively of 31.15 and 31.18, the range in both cases being 30-32; 82.5% and 78%, respectively, had 31 vertebrae (Table 43). These results are similar to those found in populations from the Barents Sea and the east coast of North America. Travin (1951) gives a figure of 30.01 vertebrae (excluding the urostyle) for *S. mentella* in the Barents Sea, while Templeman and Pitt (1961) give a declining range from about 30.0 (or 31.0 including the urostyle) in the Labrador and West Greenland areas to 29.0 (30.0) in the Gulf of Maine. Yanulov (1962*a*), dealing with the latter region by ICNAF subareas, found an overall range of 28-33 and his highest mean figure for one subarea was 31.05 (including the urostyle). Counts of the number of pyloric caeca from 113 fish from Station *Alfa* and 60 fish from *Dana* provided similar mean figures. These were respectively 10.00 and 10.10; the overall range of numbers was 8-12 and 43.4% and 53.3% had 10 caeca. Yanulov (*loc. cit.*) gives one of the few available sets of data for this character; most of his counts were in the range 7-12. The highest mean figure for one subarea was 10.21.

TABLE 43. Numbers of vertebrae (a) and pyloric caeca (b).

(a)	No. of vertebrae 30	31	32	No. of fish	Mean no. of vertebrae
Station *Alfa*	1	49	13	63	31.15
Dana	1	39	10	50	31.18

(b)	No. of pyloric caeca 8	9	10	11	12	No. of fish	Mean no. of caeca
Station *Alfa*	5	27	49	26	6	113	10.00
Dana	1	11	32	13	3	60	10.10

Otoliths have been used to assess the age of only a few specimens and these figures are insufficient for an analysis of the age-composition of the samples. However, provisional figures for the minimum and maximum ages of the fish so far examined are 14 and approximately 50 years. As a preliminary study, observations are being made on the otoliths from a number of fish in each size group to assess the similarity in conformation and to determine the age/length relationships.

NOTES ON SOME BIOLOGICAL CHARACTERISTICS

Gonad Condition and Sex Ratio

All the female fish were mature and practically every one showed evidence of having spawned in the spring of 1963, either by the retention of some larvae within the ovary or oviduct, or by the presence of empty follicles. The male fish were also judged to be sexually mature, although in some specimens the testes were still small. The post-spawning recovery of the females was assessed by the Percentage Maturity Factor (gonad weight/body weight × 100, Sorokin 1961). When plotted against time (Fig. 64) these showed a recovery curve similar to that found by Sorokin in the Barents and Norwegian Seas. No spawning females were caught and microscopical examination of the ovaries failed to provide an accurate measure of the time that had elapsed since spawning. The developing eggs showed a relatively steady increase in size from May to July, but there was a considerable individual variation in any 1 week (Fig. 64). This may reflect a wide range of spawning times within the stock.

The sex ratios of the samples, both from Station *Alfa* and from *Dana*, are not typical of the stocks more commonly sampled from commercially fished areas. Sorokin (1961) states that in the Bear Island and Spitzbergen areas male and female *S. mentella* unite during the post-spawning migration to the summer feeding grounds. Zakharov (1964), reporting the results of two North Atlantic cruises, found a 1:1 ratio to exist in June over a wide area, both west and east of Greenland. However, during the NORWESTLANT Surveys the sex ratio at Station *Alfa* was 18:1, while the samples from *Dana* showed an overall ratio of 5:1. No males were found at the two most easterly stations and a ratio of approximately 4:1 was found at the other three stations. Two of the three fish taken by *Explorer* from the southwestern part of the sampled area were males.

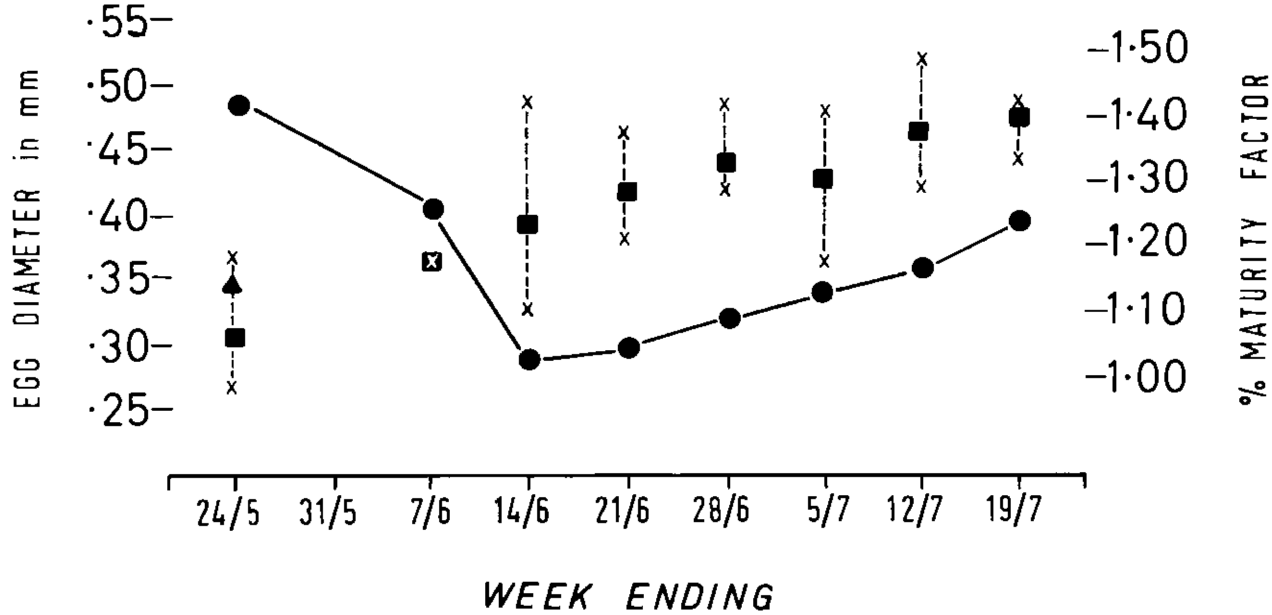

Fig. 64. Post-spawning recovery of the ovaries during May-July 1963, demonstrated by mean egg-size and % Maturity Factor.
Symbols:
□ = egg-size (mean of length + width) based on measurements of 100 eggs from each fish (1-7 fish per week: total of 48 fish).
x---x = range of observations in any one week.
O = mean % Maturity Factor based on 3-30 fish per week (total of 120 fish).

Larval Pigmentation

One object of the trials at Station *Alfa* was to examine larvae taken directly from ripe females in order to confirm the relationship between *marinus* and *mentella* adults and non-pigmented larvae (Henderson, 1964). This work was continued in 1963 and every ovary was examined for the presence of non-extruded larvae. Specimens (243) in good condition were examined for the presence or absence of the sub-caudal melanophores previously thought to be a satisfactory diagnostic feature for separating the two species. No sub-caudal melanophores were found in any larvae, confirming Henderson's findings from the non-extruded larvae of the 1962 fish and demonstrating further the fallibility of this character as a diagnostic feature for the larvae of all stocks of *S. mentella*.

Fecundity

In conjunction with long-term studies on the fecundity of redfish from Station *Alfa*, some estimates have been made from all the fish taken during NORWESTLANT Surveys which had developing eggs of a suitable size for counting.

The ovaries were weighed, sub-samples were removed with a cork borer and the weights of these were recorded. Samples were generally 2-3% of the weight of the pair of ovaries. All the developing eggs in the sub-samples were counted and, from these, an estimate was made of the number of potential eggs in both ovaries. Confirmatory counts on six whole ripe ovaries, made on the egg-counting machine at The Marine Laboratory, Aberdeen, showed a close agreement with the sub-sampling method.

The results are listed in Table 44 and, although some size-groups are poorly represented, the overall mean fecundity of 67,932 is similar to that estimated from the material taken from Station *Alfa* from 1962 to 1964 (59,426). The only available figure for the fecundity of other stocks of *S. mentella* is given by Corlett (1964). His data provide a mean of 14,975 eggs (range 2,500-31,800)

TABLE 44. Fecundity, grouped according to the standard lengths of the fish. Each count refers to one fish and mean figures for each length group are shown below.

Length in cm:	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0
Counts:	42,864	35,629	54,706	48,500	72,540	72,226	62,125	78,771	97,190
	32,483	65,820	72,777	65,805		77,124	145,637	73,971	
	38,880	43,639		49,999		93,130			
		63,762		67,366		90,759			
				69,669		109,410			
				40,315					
				69,455					
Mean fecundity:	38,076	52,213	63,742	58,587	72,540	88,530	104,183	76,371	97,190
Overall mean fecundity =				67,932					

for six fish from East Greenland. There are very few figures for the fecundity of *S. marinus*. Raitt (1964) found a range of 19,049-159,184 in 27 specimens from Iceland (lengths 36-49 cm) and 26,418-199,551 in 23 fish from Faroe (lengths 40-53 cm). Corlett (1964) gives a range of 21,000-207,000 in 18 fish from East Greenland (lengths 44-56 cm); two large specimens (lengths 70 and 73 cm) gave 308,000 and 187,000.

Food

The local distribution of the planktonic food supply of redfish may be one factor influencing the distribution of the fish, and, as the first stage in a study of this relationship, a detailed analysis has been made of the food of a representative sample of redfish caught during the NORWESTLANT Surveys.

The high proportion of stomachs which were everted (84%) made it necessary to carry out an analysis of the intestinal contents as well as the material retained in the buccal cavity and non-everted stomachs. At present, a quantitative analysis has been made of the food of 73 fish from Station *Alfa* and 15 from *Dana*, while a further 22 fish from *Dana* have been examined qualitatively. This work will be extended to include the full results of all Station *Alfa* trials, but for the present paper only qualitative and overall quantitative results will be given (Table 45), together with notes on the dominance of particular groups. A provisional list of the species identified among the food organisms is also included (Table 46).

In the samples from Station *Alfa* little difference was noted in the choice of food organisms between May and July and the changes that occurred were mainly variations in the relative proportions of the organisms. Also, there was no marked difference between the food of the fish from *Dana* in May and those from Station *Alfa* throughout the period of the surveys.

Euchaeta norvegica, hyperiids, euphausiids, and chaetognaths were found in about three-quarters of the gut contents; coelenterates and copepods, other than *Euchaeta*, occurred in approximately half. With the exception of *Euchaeta*, copepods were generally present in very small numbers and at Station *Alfa* consisted mainly of *Calanus finmarchicus* but at the *Dana* stations *Calanus hyperboreus* was more common.

Because of the effects of digestion certain soft-bodied organisms could not be identified in the intestinal contents, nor could they be counted with any certainty. Although *Clione limacina* was occasionally found in the stomach or buccal cavity, it was never observed in the intestine. *Tomopteris* was common in the plankton in June, but it was never found among the food remains. Coelenterate tissue identifiable as such by the nematocysts, was common and sometimes formed a high proportion of the gut contents but could rarely be identified. The numbers of cephalopods in the gut contents were generally low, but their importance in the redfish diet should not be underestimated; the size of specimens varied quite widely, but one redfish was found to have taken a *Gonatus fabricii* with a body length of about 12 cm.

TABLE 45. The occurrence of food organisms in the intestine, stomach, and buccal cavity of *Sebastes mentella* at Station *Alfa* (A) and *Dana* (D).

Food organisms		Percent of occurrence		No. of organisms per fish: Mean no. per occurrence		No. of organisms per fish: Maximum no. per occurrence	
		A	D	A	D	A	D
Euchaeta norvegica	Stage VI - ♀	94.5	86.8	44	47	279	189
	Stage V & IV - ♀	80.8	45.9	32	6	222	29
	Stage VI - ♂	8.2	5.4	2	2	4	2
	Stage V & IV - ♂	43.8	21.6	7	1	45	2
Total		95.9	89.2	74	47	282	96
Other Copepoda		47.9	59.5	3	11	38	78
Euphausiacea		67.1	75.1	6	5	55	16
Hyperiidea		86.3	78.4	34	7	352	30
Pteropoda Thecosomata		41.0	35.0	67	61	409	279
Pteropoda Gymnosomata		-	10.8	-	1	-	1
Cephalopoda		54.8	45.9	3	1	13	6
Chaetognatha		64.4	75.7	5	12	25	42
Pisces		10.9	5.4	1	1	3	1
Coelenterata		68.5	62.2	+	+	+	+
Ostracoda		1.4	2.7	1	1	1	1
Copepoda Caligoida		1.4	2.7	1	1	1	1
Polychaeta		-	5.4	-	+	-	+
No. of fish examined		73	37	73	15	73	15

No records of the food of truly pelagic redfish are available, although other workers (Boldowski, Barents Sea, 1944; Steele, Upper Laurentian Channel, 1957; Lambert, Gulf of St. Lawrence, 1960; Kashintsev, Newfoundland area, 1962) mention hyperiids, euphausiids and, at some seasons, fish, as the most important food organisms in the diet of commercially caught *Sebastes* spp. Both Scopelidae and young *Sebastes* have been found in the food of *S. mentella* during the NORWESTLANT Surveys but they are relatively unimportant either in frequency of occurrence or in quantity. Apart from this the main difference between the food of these oceanic redfish and those found over the Continental Shelf is the importance in the former of *Euchaeta norvegica* which was found to be the sole constituent of the diet in some specimens.

One of the fish taken by *Aegir* was reported to have retained food in the stomach. This consisted of amphipods, *Sagitta* sp. and *Thysanoessa* sp. No examination of food was reported from *Explorer*.

In general, all the intestines examined in the laboratory were quite well filled with food remains and frequently a variety of organisms was recorded in each fish. In many instances the more strongly chitinized forms had passed through the intestines with the exoskeleton relatively unaffected, hyperiids occasionally being identified easily in the rectum. The very few samples in which little or no food was found in the intestine were from fish which had been caught at night but until evidence is obtained concerning the rate of passage of food through the gut, the significance of this cannot be ascertained.

TABLE 46. Provisional list of organisms identified from the food of *Sebastes mentella* and graded as vc = very common, c = common, o = occasional, r = rare.

Organism	Grade	Organism	Grade
Copepoda Calanoida			
Euchaeta norvegica Boeck	vc	*Calanus hyperboreus* Krøyer	c
Calanus finmarchicus (Gunnerus)	c	*Heterorhabdus* sp.	r
Undeuchaeta plumosa (Lubbock)	r	*Arietellus setosus* Giesbrecht	r
Copepoda Caligoida			
Nesippus borealis (Steenstrup & Lutken)	r	*Sarcotretes scopeli* Jungersen	r
Euphausiacea			
Meganictyphanes norvegica (M. Sars)	c	*Thysanoessa longicaudata* (Krøyer)	vc
		Thysaneossa inermis (Krøyer)	r
Hyperiidea			
Parathemisto (Parathemisto) abyssorum (Boeck)	vc	*Hyperia* sp.	o
Parathemisto (Euthemisto) gaudichaudii (Guerin)	c	*Hyperoche* sp.	r
		Vibilia sp.	r
Chaetognatha			
Sagitta maxima Conant	vc	*Eukrohnia hamata* (Möbius)	o
Pteropoda Thecosomata		Pteropoda Gymnosomata	
Spiratella sp.	vc	*Clione limacina* (Phipps)	o
Cephalopoda			
Gonatus fabricii (Lichtenstein)	c		
Coelenterata			
Siphonophora - Physonectae, probably *Stephanomyia* and/or *Agalma*			o
Pisces			
Sebastes sp. and Scopelidae	o		

TABLE 47. The occurrence and degree of infestation of parasites and disease at Station *Alfa* (A) and *Dana* (D). The number of fish examined is given in parentheses.

Parasites and disease	% occurrence		Degree of infestation			
			Mean no.		Maximum no.	
	A	D	A	D	A	D
Active *Sphyrion lumpi*	12.1 (116)	10.0 (60)	3.7	1.86	12	5
Encysted heads	27.6 (116)	25.0 (60)	3.1	3.4	8	10
Total	32.7 (116)	30.0 (60)	-	-	-	-
Larval nematodes (body cavity)	94.8 (116)	90.0 (60)	6.24	7.24	46	32
Adult nematodes (intestine)	5.5 (73)	5.4 (37)	-	-	2	1
Mature cestodes (intestine)	1.7 (116)	1.7 (60)	-	-	1	2
Immature cestodes (intestine) (Plerocercoids & juveniles)	4.1 (73)	0 (37)	-	-	2	0
Tetrarhynchid larvae (Encysted in body cavity)	2.6 (116)	0 (60)	-	-	1	0
Digenetic trematodes	0 (73)	2.7 (37)	-	-	0	1
Ichthyosporidium hoferi	0 (116)	1.7 (60)	-	-	-	-

Parasites and Disease

Because of the developing use of parasites, diseases, and natural marks as "biological tags" to distinguish between races or stocks of fish, all specimens were examined for such indicators.

Sphyrion lumpi (Krøyer) was the only external parasite found on any fish and occurred on 12.1% of the fish from Station *Alfa* and on 10% of the fish from *Dana*. In addition, the presence of *Sphyrion* heads retained within the tissues was recorded and, including some cysts thought to have been caused by these, the overall total occurrence of this parasite was 32.7% for the fish from Station *Alfa* and 30.0% for the fish caught by *Dana* (Table 47). This similarity between the two samples was echoed by the positional distribution of the infestations (Fig. 65). The cloacal region was the favoured site for attachment, although early investations have occurred rather more frequently in the dorsal region. If one accepts Perlmutter's (1957) suggestion that cloacal or ventral attack by *Sphyrion* indicates a pelagic host and a dorsal site indicates a bottom-dwelling host, then perhaps an early life in shallower water should be postulated for these redfish.

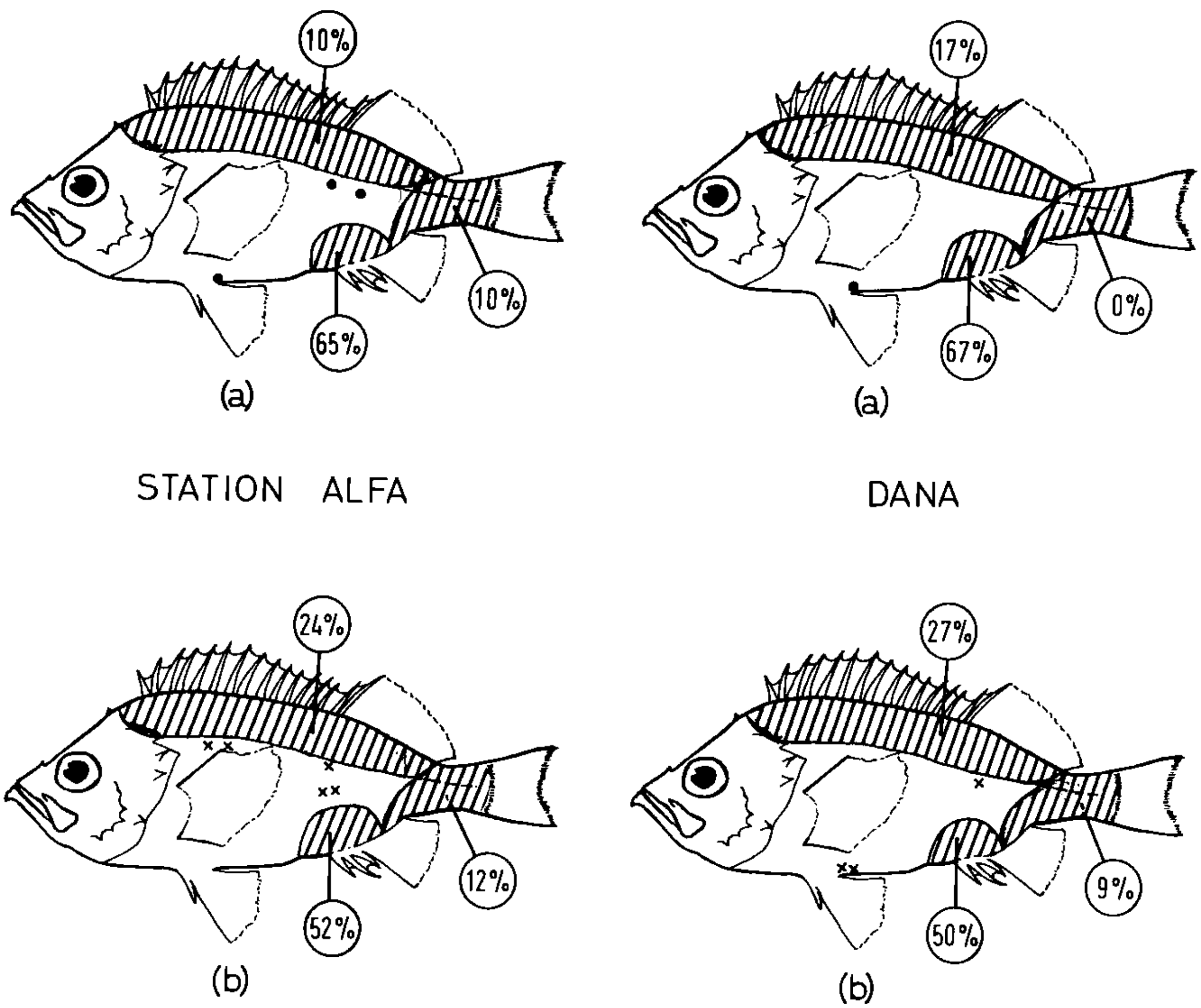

Fig. 65. The distribution of *Sphyrion lumpi* (Krøyer) on redfish from NORWESTLANT 1-3, May-July 1963. (a) Active parasites. (b) Heads remaining in the hosts' tissue. Encircled figures give the % of the total infestation in each body region. **Circles and crosses** indicate isolated specimens outside the main regions.

All the fish which were parasitized by *Sphyrion* were females, neither an active parasite nor an old head having been found in any of the 18 males taken during the NORWESTLANT Surveys. Investigations into the occurrence of *Sphyrion* on *Sebastes* by Templeman and Squires (1961) and by Kelly and Barker (1964) show that, in the Newfoundland area and the Gulf of Maine, the level of attack may be similar in both sexes. It is unlikely therefore that a physiological difference is the cause of the different level of parasitization in the oceanic redfish and variations in either life history or behaviour may be responsible.

An examination of 35 fresh and 141 preserved specimens showed no evidence of gill parasites and, while there is the possibility that these may have become detached during preservation, it is unlikely that their incidence can be anything but extremely low. The hearts of the majority of fish were examined, but also showed no evidence of parasitization.

Only one digenetic trematode was found and this occurred in the intestine of a fish caught at the most westerly successful *Dana* station. It has provisionally been identified as belonging to the family Allocreadiidae. Similarly, the parasite fungus, *Ichthyosporidium hoferi*, was only noted in one fish which had large numbers of the encysted spores in the kidneys and spleen.

The incidence of other parasites, larval nematodes in the body cavity, mature nematodes and larval and mature cestodes in the intestine, showed a striking similarity in the degree of infestation in both samples of fish (Table 47).

The full identification of some of the parasites has not yet been completed. The mature cestodes found in the fish, both from Station *Alfa* and from *Dana*, appear to be either *Bothriocephalus Angusticeps* or *B. nigropunctatus*, both of which have been identified from earlier samples, and the larval cestodes are *Phyllobothrium* sp. A species of *Raphidascaroides* has been noted amongst the nematodes of the intestine.

Black Colouration

It has been suggested that the areas of melanic deposits on the skin of redfish might be used as a biological tag, because records show that the incidence of such marks may vary from one region to another (Anon., 1957; Yanulov, 1962*b*). The condition that causes the development of such markings is not known. No pathogenic organism has been found in the tissue (Kabata, private communication) and although damage to the skin may be followed by the deposition of melanin, no such injury was found to be associated with the pigmented areas in any of the fish examined during the present survey. Approximately 50% of the fish bear some pigmented areas of a widely varying size and the most commonly affected part of the body is the flank, although localized patches are not uncommon on the fins or head.

In the hope that this feature can be used in future studies on the oceanic and other stocks of redfish, pictorial rerchods have been made to show the regions of the body that are affected and the areas that are involved. The latter have been graded according to an arbitrary scale and the results are summarized in Table 48.

TABLE 48. Black colouration of fish examined at Station *Alfa* and *Dana*.

	Station *Alfa*		*Dana*	
	No.	Total %	No.	Total %
Total no. with marks	58/116	50.0	24/60	40.0
No. marked both sides	9/58	15.5	8/24	33.3
No. marked one side only	49/58	84.5	15/24	62.5
No. marked on flanks	53/58	91.4	22/24	91.7
No. marked left flank only	20/49	40.8	7/16	43.8
No. marked right flank only	29/49	59.2	8/16	50.0
No. in grade 4[a]	4/58	6.9	2/24	8.3
No. in grade 3	7/58	12.1	7/24	29.2
No. in grade 2	17/58	29.3	5/24	20.8
No. in grade 1	29/58	50.0	8/24	33.3
No. in grade P	1/58	1.7	2/24	8.3

[a] Where both sides are marked the highest grade only is counted.

Arbitrary grades of colouration: P = a few small spots; 1 = one or two areas 5-10 mm diam; 2 = an unbroken area up to 25 mm in diam or discrete spots covering a larger area; 3 = an unbroken area up to 50 mm in diam or discrete spots covering a larger area; 4 = unbroken and/or discrete areas larger than the above.

SUMMARY AND CONCLUDING REMARKS

Research ships and weather ships caught 355 redfish by angling in the area bounded by 60° to 62°N lat and 32° to 40°W long between mid-May and mid-July 1963. Most of the fish were caught at depths between 100-150 m but there was considerable variation in fishing success. There is some evidence that the best catches were made in regions or at times when the temperature at 100 m was less than 7°C.

Detailed morphometric, meristic, and biological analyses were carried out on 176 fish which were returned to the laboratory. All were identified as *Sebastes mentella* Travin. Nearly all were females which had recently released their young.

There was a uniformity of conformation, gonad condition, fecundity, parasites, food, and natural marks which suggests that all the fish came from a single stock. There is insufficient information to permit a conclusive test of similarity or dissimilarity between the various stocks of *S. mentella* in the Atlantic and neighbouring seas. However, there are no obvious morphological distinctions between the oceanic stock and those of the shelf and slope waters. Few counts of fecundity have been made elsewhere; estimates on the oceanic fish gave on average 60,000 eggs. In common with other populations of *Sebastes*, the oceanic stock was infested with *Sphyrion lumpi*; about 30% of the fish were affected. Information about size, pyloric caeca, vertebrae, skin pigmentation, food, and internal parasites will be analyzed further.

Angling from weather ships during 3 years and from research vessels during the NORWESTLANT Surveys has served a useful purpose, therefore, in defining some of the characteristics of the oceanic population of *Sebastes mentella*. As a result of the angling from Station *Alfa*, Henderson and Jones (1964) have suggested that the stock is present throughout the year at this position. The samples have also shown that the young of these fish do not have sub-caudal melanophores and are identical with the larvae sampled by the Continuous Plankton Recorder over a very wide area of the North Atlantic and which were previously considered to be the young of *S. marinus* (Henderson, 1961, 1964).

However, in spite of these advances, it is clear that further investigation of this stock will require a more rigorous program of sampling and research than is possible by angling from weather ships. In particular, surveys are needed to:

1) Establish more precise morphological definitions of the redfish stocks both in the open ocean and the waters of the continental shelves;
2) Discover the overall extent of the pelagic population of *S. mentella* in the North Atlantic in terms of geographical and vertical distribution and abundance;
3) Investigate the possible existence of aggregations of the stock;
4) Investigate seasonal variations in the patterns of distribution and aggregation and the relation of these to environmental factors, including food, and the reproductive cycle;
5) Discover the distribution of the immature stages in the first 10 or 15 years of life;
6) Describe patterns of migration, if any, and discover whether there is any interchange between the stocks of the shelf and oceanic regions.

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Sightings of Marine Mammals

By

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INTRODUCTION

Sightings, mainly of Cetacea, were recorded from nine cruises of eight ships from 4 April to 8 August, 1963. The number of sightings and the estimated number of individual cetaceans included in these sightings are shown in Table 49. Some ships reported sightings *en route* to the survey area. These sightings are not included in Table 49 if they fall outside the NORWESTLANT area. Further they have not been included in the sightings plotted in Chart 269-271. Sightings not so included consist mainly of small cetaceans reported close to European coasts.

TABLE 49. Sightings of whales and dolphins in the NORWESTLANT area from April to August 1963.

Species	Number of sightings	Number of individuals estimated	Months when observed
Fin or Blue Whale, *Balaenoptera musculus* L., *B. physalus* L.	4	6-9	June-July
Humpback, *Megaptera nodosa* (Bonnaterre)	2	100	June-July
Minke, *Balaenoptera acutorostrata* Lacepede	6	15	June-July
Sperm, *Physeter catodon* L.	6	58-108	April-June
Bottlenose, *Hyperoodon rostratus* (Müller)	1	2	April
Killer, *Orcinus orca* L.	3	9-13	June-July
Pilot Whale, *Globicephala melaena* Traill	15	373-436	June-July
Common Dolphin, *Delphinus delphis* L.	6	hundreds	May-August
Unidentified whale of large or medium size	12	30	April-July
Unidentified whale of small size	4	15	May and July
Unidentified dolphin	2	200	April-May

Identifications are those given by observers and some of these identifications are tentative. Unidentified species presumably relate mainly to observations made at a distance or under conditions of poor visibility. They are grouped in three categories. Firstly, "unidentified whales of large or medium size" could include the larger species of rorqual, *Balaenoptera*; humpback, *Megaptera*; sperm, *Physeter*; and possibly even right, *Balaena*, whales. Secondly, "unidentified whales of small size" appear to include a variety of Odontocetes with possibly some minke whales, *Balaenoptera acutorostrata*. The third category, "unidentified dolphins", is discussed below at the end of the section on distribution of species.

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DISTRIBUTION OF SIGHTINGS IN SPACE

An area evidently very attractive to cetaceans in the spring of 1963 was bounded by coordinates 65° and 66°N lat, 28° and 32°W long (Chart 269-271). Sightings in this area included a large herd of sperm whales, *Physeter*, from April to June, as well as numerous scattered large whales in July, of which three were tentatively identified as humpbacks, *Megaptera*, and others as sei whales, *Balaenoptera borealis*. Several herds of pilot whales, *Globicephala*, and dolphins were also recorded in this area. There were no other notable concentrations of cetaceans, but sightings were frequent on the West Greenland banks.

DISTRIBUTION OF CETACEAN SPECIES

Of the rorquals (Chart 269), three out of four records assigned to blue, *Balaenoptera musculus*, or fin, *B. physalus*, whales come from the area of the West Greenland banks in June and July, and refer to two individuals and one small group. The fourth record is of a single animal far east of Newfoundland. Of unidentified large whales, apart from the concentration west of Iceland, there were two widely separated records from the Irminger Sea, one from south of Cape Farewell, and one on the West Greenland banks. From these sightings it does not seem as if the large rorquals were very numerous on the West Greenland banks in the early part of the summer of 1963.

Minke whales, *Balaenoptera acutorostrata*, were identified six times on the West Greenland banks. One group of 10 animals was seen in early June and five single animals in early July. The species enters colder waters than the large rorquals. On the Labrador coast, it tends to seek concentrations of capelin, *Mallotus villosus*, (Sergeant, 1963).

Of the two records attributed to humpback, *Megaptera*, three animals were seen west of Iceland in July, while a series of groups totalling about 100 animals was seen off the northeast coast of Newfoundland in June. Humpbacks are relatively tame and frequently approach ships stopped on station, unlike blue and fin whales which are indifferent to or avoid ships. Therefore, humpbacks are not easily missed, and even so few records may serve to indicate the relative abundance of the species in different parts of the North Atlantic. Humpbacks have been heavily hunted in the eastern North Atlantic (as far west as Iceland) in recent years and have here been considerably reduced in numbers. However, as a result of longer cessation of hunting, a few hundred exist in the western North Atlantic which summer in the general area of the Grand Banks (for sightings, see Slijper *et al.*, 1964, chart 4). It was presumably this herd or part of it which was met with off Northeast Newfoundland.

Of the larger Odontocetes (Chart 270), sperm whales, *Physeter*, were recorded early (April-June) at northern locations suggesting occurrence in quite cold water. Notable were groups totalling 50-100 in May close to the ice west of Iceland. Smaller numbers were reported off East and West Greenland. Two bottlenose, *Hyperoodon*, were seen off the southeast coast of Greenland in April. Three observations of killer whales, *Orcinus*, come from both east and west coasts of Greenland in June and July.

The reported distributions of the remaining two identified species are interesting (Chart 271). Pilot whales, *Globicephala*, doubtless the North Atlantic race of *G. melaena*, were recorded in the Irminger Sea and the Labrador Sea from late May to late July, as well as at more southerly locations in the North Atlantic Drift. The status of *G. melaena* as a species tolerant of cold-temperate waters (Brown, 1961) is thus confirmed, and the survey gives a useful picture of the northward limits of distribution and the dates of arrival of *G. melaena* in northern waters of its range. It is possible that a few reported pilot whales may have been bottlenose, *Hyperoodon*.

The common dolphin or saddleback porpoise, *Delphinus delphis*, was not identified in the areas of the survey proper but schools of this species were recorded commonly by ships underway in the warmer waters of the North Atlantic Drift. Some of these records are shown in Chart 271. There were in addition four records from the Celtic Sea and two from the northernmost North Sea. In the Newfoundland area this species rarely enters water colder than about 12°C (Sergeant, 1958).

Colder waters of the North Atlantic are inhabited by two species of *Lagenorhynchus*, the white-sided dolphin, *Lagenorhynchus acutus*, and the white-beaked dolphin, *L. albirostris*. There were two sightings of herds of unidentified dolphins, west of Iceland in April and May (Chart 271). The more southerly sighting refers to "a large school of dolphins estimated at 6-to 10-ft long and of a uniform grey-black colour". Possibly these referred to *L. albirostris*.

PINNIPEDS

Seals, evidently all or mostly harp seals, *Pagophilus groenlandicus* (Erxleben), were observed among loose pack ice along the edge of the heavy pack bordering the coast of southern Labrador at 52° to 54°N, 54°W, approximately on 25 May. There were no other observations of seals.

DISCUSSION

As shown in Chart 269, a concentration of whalebone whales was observed on *Anton Dohrn* Bank in the region 65° and 66°N lat, 28° and 32°W long during early July. Whether these whales were feeding on zooplankton is not definitely known but the *Ernest Holt* report on 9 July stated: "Some of the whales were observed in areas of heavy *Calanus* concentrations. The whales were not seen to roll sideways and when rolling or blowing not much of the back was visible. From these observations it may be that these were Sei Whales."

The Sei Whale, *Balaenoptera borealis*, is known to feed selectively on *Calanus* off the Norwegian coast (Hjort and Ruud, 1929).

As to the hydrography and productivity of the *Anton Dohrn* Bank, John Corlett wrote the author in a letter of 26 January 1965 as follows:

> "This area is one of complicated hydrography with generally cold East Greenland Current water on the shelf and Irminger Current water flowing along the edge of the shelf. Incursions of the warmer water on the shelf occur at various times and places. With this complex hydrographic pattern there is a complex pattern of plankton distribution. From our limited knowledge of the area, I would say that productivity is generally low in the cold water on the shelf, but often high in the area of mixing near the edge of the shelf."

Summarizing incompletely analyzed NORWESTLANT plankton data, John Corlett further writes:

> "In NORWESTLANT 2 in May the area between 64°30' and 66°N. and 25° and 31°W. was poor in zooplankton in the 0-100-metre layer, with generally less than 10 cc. displacement volume under a square metre from the Hensen net. This includes the area of the sightings by AEGIR on 20th May. But there was one isolated station near the ice edge about fifteen miles to the northeast with about 100 cc. under one square metre.
> "In July the same area had poor zooplankton on the shelf, with generally less than 10 cc., but with 15 to 25 cc. just off the edge of the shelf. There is one isolated station with about 60 cc. in 65°08'N., 31°30'W. which is where the ERNEST HOLT sightings of 9th July occurred."

Klumov (1961) reports feeding concentrations of whalebone whales around the Kurile Islands in waters where the average zooplankton biomass attained an average value of 500 mg/m^3 through the upper 100-m layer. This would be equivalent to 500×100 mg = 50 g/m^2 under 100 m, or dividing by a factor of 0.8 to convert to volume, 62.5 cc/m^2 under 100 m. With the very rough comparison possible between Klumov's and the present data, it can be seen that the biomass of plankton which attracted concentrations of whalebone whales was comparable in the *Anton Dohrn* Bank area with that at the Kuriles.

Sperm whales, pilot whales, and dolphins were also attracted to the *Anton Dohrn* Bank area but these species feed on organisms higher in the food chain — fish, squids, etc. Information on the nekton was also communicated by John Corlett, who wrote that in April 1962 the *Ernest Holt* caught cod that were feeding heavily on Myctophids and other small fish, and one trawl-haul with a fine-meshed codend cover captured many *Gadus poutassou*.

SUMMARY

Observations made from ships participating in NORWESTLANT 1-3 throw useful light on the distribution of Cetacea in cool waters of the North Atlantic, including the northward limits of certain warm-water species. Rather high concentrations of whalebone whales and others over *Anton Dohrn* Bank can be related to high productivity in the region of mixing overlying the Bank.

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Conclusion

By

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In the Introduction to this report Dr Lucas outlined the main aim of the NORWESTLANT Surveys. This was to establish the distribution, drift, and survival of cod eggs and larvae, and of redfish larvae, in relation to specific environmental factors, in the area around Greenland and south to northern Newfoundland.

A study of the sections of the report dealing with Cod Eggs and Larvae and with Redfish Larvae shows that the most striking feature of the NORWESTLANT Surveys was the small number of cod larvae caught during NORWESTLANT 2 and 3. In April, during NORWESTLANT 1, large quantities of eggs were taken around southern Greenland along both the east and west coasts, but in May and June the numbers caught were small. Further north, a fair amount of spawning went on between Iceland and Greenland and off East Greenland from May until July. However, the numbers of cod larvae taken from May to July were very low: they were mainly caught off West Greenland, and those taken in July were the further north. Comparison of the catch per tow with Danish data for 11 of the years in the period 1953-63 shows that only the years 1954 and 1956 produced smaller numbers.

A second feature of the surveys, as far as the cod is concerned, was the taking of eegs in large numbers off Labrador. The Labrador stock would seem to have its spawning here between 55° and 59°N lat from mid-March until the end of April. The eggs drift southwards in the Labrador Current towards northern Newfoundland where larvae were taken in May.

The analysis of the catches of redfish larvae shows that extrusion started in April and was particularly notable in the northernmost part of the Irminger Sea, and that during May extrusion was at its peak over nearly all of this area. It declined in June but surprisingly continued into July. Off West Greenland, however, extrusion was confined to the period from mid-May until mid-June. In the Irminger Sea the distribution of larvae was uneven, but it was in general agreement with the dynamic topography at 0 m, both there and off West Greenland. Thus, the larvae drifted from the central part of the Irminger Sea towards Iceland and then towards East Greenland and south to Cape Farewell. Off West Greenland they mixed with those extruded locally. Icelandic data show that the numbers of larvae caught per tow were lower than during surveys in 1961 and 1962, but they also demonstrate that in 1963 the larvae were deeper than in 1961, possibly due to the prevailing stormy weather. The Continuous Plankton Recorder data are somewhat at variance with the two net samples in that they indicate larger numbers of larvae in June and July than in April and May, a reversal of the usual trend. This may be because the sampling routes did not pass through the main centres of spawning activity in April and May, whereas the research vessels did. Again it may be because the stormy weather of April and May led to the larvae being deeper then. However, the general conclusion from the Recorder data is that 1963 was not a very good year for redfish larvae, but that it was probably not as bad as 1958.

The programme of angling for redfish at Ocean Weather Station *Alfa* and from research vessels yielded data about the fish that extruded the larvae. In May these fish were caught mainly at 200-300 m and in June and July at 100-150 m. There were notable periods of high rates of capture at *Alfa* and this phenomenon may be linked to the shifts observed in the front between different water masses in that area, there being some evidence to show that the best catches were made when the temperature at 100 m was less than 7°C. Uniformity of conformation, gonad condition, fecundity, parasites, food, and natural marks was found, suggesting that the fish came from a single stock of *Sebastes mentella* Travin.

It is tempting to look to the physical environment to provide clues to account for the low

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numbers of cod larvae taken and for the possibly reduced numbers of redfish larvae. A difficulty arises in that the base periods used in different sections of this report, in order to establish the norms of the various biological and physical parameters, are all different. It is impossible to establish a common base. The following comparison between various physical and biological phenomenon must therefore be treated with caution.

The summary of the meteorology during the period of the surveys shows that in April and May the frequencies of strong winds and gales at Ocean Weather Station *Alfa* were must above the normal for the period 1951-60, while at *Bravo* the frequency of strong winds only was above normal. Further south at *Charlie* both frequencies were below normal. The mean wind speed at *Alfa* was above normal in April, May, and July, and normal in June: at *Bravo* it was above normal in May and June and below normal in April; and at *Charlie* it was below normal in April-June. Thus, all but the most southerly part of the survey area seems to have had much stronger winds than usual over most of the period of NORWESTLANT 1-3 and particularly in the critical month of May.

Ice conditions, on the other hand, seem to have been normal or below normal along both the east and west coasts of Greenland throughout the survey period when compared with the norms for 1919-42. This may have been a response to the wind directions. The anomalous wind, from the mean for the period 1899-1939, was from between northwest and west over most of the period March-May, whilst no anomaly could be observed in June and July: winds from between northwest and west are in the right direction to help to keep the southern Greenland coasts free of ice.

In January and February the anomalous winds over the NORWESTLANT area were from between southeast and south. They would have the dynamic effect of bringing about the advection of more warm and saline water than usual into the area by means of the Irminger Current, and at the same time the thermal effect of reducing to below normal the heat loss from the sea to the air. The change in the direction of the anomalous winds in March-May to between northwest and west would reverse both these advective and thermal effects and bring about cooling. Added to this, the strong winds of April and May and the higher salinity of the water introduced earlier in the year, would bring about much greater vertical mixing of the water column than is normal. In June and July the winds were normal in direction and a little above normal in strength, bringing about only a slow recovery from the cooling effects of April and May. The anomalies of air and sea surface temperature at Ocean Weather Station *Alfa* from the decadal means 1951-60 show this train of events very well: those at *Bravo* do not, the subnormal air temperatures there in January-March being difficult to explain. The anomalies of sea surface temperature in ICES regions, A, B, and C from the means for 1876-1915 also indicate the sequence. Other lines of evidence tend to point the same way. The Norwegian investigations carried out in April off West Greenland since 1959 show that 1963 was a cold year as far as the surface layers are concerned and a year when the Irminger component was reduced in temperature. Danish investigations over the Fyllas Bank since 1937 indicate that during NORWESTLANT 2 the temperature of the 0-45-m layer was 0.4°C below normal, and in the Irminger Sea surface temperatures seem to have been 0.5° to 2°C below those of the only two comparable surveys, in 1955 and 1961 respectively. During NORWESTLANT 3 the mean temperature of the Irminger component at Cape Farewell was about 0.4°C above the normal found by the U.S. Coast Guard during their investigations since 1950, but the volume of the circulation seems to have been more than 50% below normal.

It must be noted that the transport of the Irminger Current system seems to have increased between NORWESTLANT 2 and 3 and decreased between NORWESTLANT 1 and 2, judging by the information presented in the section of this report dealing with Physical Oceanography. The decline in the circulation during NORWESTLANT 2 seems to have been in response to the shift between April and May in the mean monthly wind vectors for Ocean Weather Stations *Alfa* and *Bravo*. In April there was a big northeast vector assisting the current, but in May there was a fairly big west vector and this may have retarded it and caused its displacement to the south of Cape Farewell. The slow recovery of the circulation during NORWESTLANT 3 corresponds to the development of a weak northeast vector in June and July.

The physical data therefore points to the period April-July 1963 as being one with lower water temperatures and a more sluggish horizontal circulation than usual, but also as being more stormy and with a more vigorous vertical circulation. Hermann, Hansen, and Horsted (1965) have shown a close relationship between variations in the year-class strength of West Greenland cod and the mean 0-45-m water temperature over Fyllas Bank in June, good year-classes being associated with warmer years. This may be due to slight changes in temperature having a direct effect on the mortality of eggs and larvae of cod near the northern limit of its distribution. The colder conditions found during the NORWESTLANT Surveys suggests a poor year-class, and this is in line with the low numbers of cod larvae taken during the surveys.

In the section of this report dealing with Larval Feeding another hypothesis to account for variation in year-class strength is postulated. It is shown that there is an almost complete dependence by the cod and redfish larvae on the products of the spring spawning of *Calanus finmarchicus* as a source of food in the seas around Greenland. The fortunes of the larvae are thought to rest on the degree of synchronization of the start of active feeding with the timing of the spring spawning and the overall abundance of the early stages of *Calanus*. As support for this hypothesis there are the observations that the redfish larvae taken in the Irminger Sea contained more food and were bigger than those taken off both West and East Greenland, and that the cod larvae taken off West Greenland contained 50% less food than those in Icelandic waters. These differences in gut content all seem to be correlated with the abundance and population structure of the principal food organism, *Calanus*.

The close connection between egg production by *Calanus* and the supply of food, i.e. phytoplankton, is well-known. The section on Phytoplankton shows that the production cycle varied from region to region around the south of Greenland. Phytoplankton production was at a peak in the quadrant north and west of Cape Farewell during NORWESTLANT 1 while the cod spawning was occurring there: it then declined, particularly between NORWESTLANT 2 and 3. By contrast, in the quadrant north and east of Cape Farewell it increased steadily from NORWESTLANT 1 to 3. In the seas south of Cape Farewell production was at a peak during NORWESTLANT 2. This picture is in agreement with the data on stability, nutrient salts, turbidity, and chlorophyll A. For example, during NORWESTLANT 1 stability occurred off West Greenland only and it was brought about by north to northeast winds driving the low salinity coastal water westward over water of Irminger Current origin. Phytoplankton production was confined to this area, caused the high turbidity found there, and in its turn led to a reduction of the nutrient salt content and an increase in dissolved oxygen content in the surface layers. By contrast, off East Greenland stability did not become established until NORWESTLANT 2 and even then it was only marked in a narrow zone where the less dense water of the East Greenland Current overrode the Irminger Current, perhaps under the influence of the strong westerly winds which prevailed. In this zone phytoplankton production occurred, so that chlorophyll A was maximal, nutrient salt concentrations were reduced, and the dissolved oxygen content wss increased. In the deeper water further offshore the strong vertical mixing prevented any stratification of the surface layers until June and July when production became maximal and the nutrient salt and dissolved oxygen content of the surface layers responded accordingly. The Continuous Plankton Recorder results allow a comparison to be made of conditions in 1963 with those in other years from 1958 to 1964. Production off West Greenland was earlier than in 1962: elsewhere it was weaker than usual, but close to its normal timing.

The section on Zooplankton indicates that during NORWESTLANT 1 the overall volume of zooplankton in the upper 100 m over the survey area was low. It was highest off the edge of the shelf along the East and West Greenland coasts. Spawning of *Calanus* was about to begin in the Irminger and Labrador Seas in general, but over the East Greenland shelf between 62° and 63°N lat, near the south coast of Greenland, and along the edge of the West Greenland shelf north of 63°30'N lat it had just begun. By NORWESTLANT 2 the zooplankton volume was higher. *Calanus* copepodites I-IV had a converse distribution to the older stages: high numbers occurred in the Davis Strait and off West Greenland, suggesting that the main spring spawning had occurred there some weeks previously, but in the Irminger Sea there were few early copepodites and a persistence of adult *Calanus* from the overwintering generation, showing that spawning had been delayed. Off East Greenland the spring generation was a little more advanced. By NORWESTLANT 3 the young stages had developed more slowly in the Davis Strait than in the Labrador Sea and even more slowly off West Greenland. Similarly, in the Irminger Sea the population was more advanced in the south than in the north. Despite the delay in spawning in this area the population in the Irminger Sea was similar to that in the Davis Strait. This more rapid growth, like that in the Labrador Sea, could be an effect of temperature. It can be seen that spawning occurred earliest in the Davis Strait and West Greenland region where phytoplankton production was at a peak during NORWESTLANT 1. Elsewhere it was later and occurred when phytoplankton production was maximal during NORWESTLANT 2 or 3.

The results of the Continuous Plankton Recorder Survey suggests that the spawning in the northern Irminger Sea was 1 month later than usual. This could be due to a delay in the stabilization of the water column and hence in the onset of phytoplankton production. Thus, there is a clear sequence of events starting from the stormy weather of May and the cooler water conditions and leading through delays in stabilization, phytoplankton production, and *Calanus* spawning perhaps to redfish larvae extrusion: there is also evidence to suggest that both phytoplankton production and redfish larvae numbers were lower than usual in 1963.

For the cod larvae the picture is not so clear. The numerous eggs produced off West Greenland during NORWESTLANT 1 were in an area of peak phytoplankton production and *Calanus* spawning had begun. Conditions, except temperature, seemed to have been favourable. Did the lower than usual temperatures cause high mortality? Or did the current system in the Davis Strait take some of the larvae northwards to destruction and others westwards to Labrador as recruits to the Labrador and Newfoundland stocks? The eggs spawned off East Greenland in the Fylkir Bank area and the resulting larvae drifted in the East and West Greenland Currents and by mid-July would have been off Southwest Greenland in about 61°30'N lat judging by the travel of a drift bottle that was released in the spawning area during NORWESTLANT 1 and recovered 6 months later in Disko Bay. There is some evidence that during the critical period when these eggs and larvae were drifting around southern Greenland they were in lower temperatures than usual and that phytoplankton production was low and limited to a narrow zone along the edge of the shelf. The production of young stages of *Calanus* had begun, but it also appears to have been more limited in extent than off West Greenland. Also the current system was such that it took some of the larvae well to the south of Cape Farewell. We have no data from other years to test whether all or part of the above is normal or not. Further, the spacing between NORWESTLANT 1 and 2 was such that continuous monitoring of the eggs and larvae during the drift in order to measure mortality rates was not possible. Again, comparison with 1962 shows that the production cycle leading to the development of young stages of *Calanus* off West Greenland, where the larvae had to pass, was 1 month earlier in 1963, but we have no norm against which to set these events in 1962 or 1963.

It must be noted, however, that for various reasons the coverage of sampling stations around the southern tip of Greenland during NORWESTLANT 2 and 3 was not as close as had been planned. This was particularly the case along the stretch of coast running northwestwards from Cape Farewell. Moreover, R/V *Explorer* had to use a 1-m-stramin net instead of a 2-m net when working her stations along the east coast northwards from Cape Farewell during NORWESTLANT 3. It is therefore possible that the cod larvae, which originated from the spawnings over Fylkir Bank and further north along the East Greenland shelf, were not sampled properly during their drift around southern Greenland.

The catches of cod larvae were so low during NORWESTLANT 2 and 3 that it has been assumed up till now that the 1963 year-class would be poor. Sampling of the brood in 1966 and 1967 has indicated that this might not be the case. In Annex 1 to this concluding chapter Svend Aage Horsted supplies some notes on the strength of the 1963 cod year-class in Greenland waters. These show that it is better than previously thought and suggest that there may have been transport of a great proportion of it from East Greenland to Southwest Greenland by the East and West Greenland Currents.

This later finding about the strength of the 1963 year-class and its possible immigration into the Southwest Greenland area from East Greenland increases anxiety about the adequacy of the sampling grid around southern Greenland during NORWESTLANT 2 and 3. It should be noted, however, that as late as July, during NORWESTLANT 3, cod eggs and larvae were taken along the East Greenland coast north of 63°N lat and that larvae were found stretching across the Denmark Strait from Iceland to East Greenland. These eggs and larvae may have been the source of the 1963 year-class now being found off Southwest Greenland.

The NORWESTLANT Surveys produced a great deal of information other than that relevant to the cod and redfish larvae. A number of papers using data collected have already been published and these are listed in Annex 2. The various sections of this report contain a number of other findings.

The section on Bottom Topography contains a revised bathymetric chart based on soundings made during the NORWESTLANT Surveys and subsequently. Attention is paid in this section to the structure and morphology of the continental shelves and slopes. In particular, a trench was found at the bottom of the slope off Southwest Greenland. Soundings made in the Labrador Sea during the NORWESTLANT Surveys allowed the mid-ocean canyon there to be charted further. Taken together with the gravity and magnetic anomalies found, they do not show the mid-ocean ridge predicted by some authorities.

In the Meteorology section, not only are conditions in April-July 1963 and in the months prior to NORWESTLANT 1 compared with the average conditions, but the weather situations during successive periods of a few days are analyzed in detail over the whole period of the surveys. This material could be used for a deeper study of the effect of the atmospheric circulation on the physical oceanography of the NORWESTLANT area than has been possible in this report, particularly as the section on Physical Oceanography gives a detailed commentary on the development of the oceanographic situation from the beginning of April until August. This section also throws further light on the water masses of the northwestern Atlantic, which have been the subject of much study lately, and in particular, it demonstrates the development during the summer of a low salinity, central water mass to the south of Cape Farewell. This water mass moves far to the eastward on the northern side of the North Atlantic Current. For some years high current speeds have been thought to exist in the Greenland area following the study of dynamic topographic charts. During the NORWESTLANT Surveys current-measuring experiments with drift bottles, GEK and parachute drogues off East Greenland showed the actual currents to be much faster, of the order of 50-200 cm/sec. These experiments, and the detailed dynamic topographic charts obtained, also demonstrate the existence of complicated eddies along the boundary between the cold East Greenland Current and the warm Irminger Current. A mechanism whereby the strong frictional effects of this horizontal turbulence causes upwelling along the edge of the West Greenland shelf is described in the report.

Alongside the commentary on the development on the physical oceanographic situation, the section on Chemical Oceanography describes the changes in the phosphate, silicate, dissolved oxygen, ammonia, and organic carbon content of the 0- to 100-m layer during that part of the annual cycle which extends from the winter maximum to the summer minimum. The nutrient salt and oxygen content of the deeper layers are not examined in this report, although observations were made and are given in the data volumes. The commentaries on the physical and chemical situation provide the necessary physico-chemical background to the Phytoplankton and Zooplankton sections which, together with the sections on fish eggs and larvae, give a detailed account of the state of the plankton from April until July. Thus, in this report there is given for the first time a detailed account of the development during a particular year of the weather, the sea-ice, the physical and chemical hydrographic features, and the plankton in the northwestern part of the Atlantic Ocean from hydrographic winter until nearly midsummer. The bearing of this on the survival of cod and redfish larvae has already been discussed. In addition, new information about the distribution and abundance of the eggs and larvae of other fishes in the NORWESTLANT area, such as capelin, American plaice, halibut, Greenland halibut, and wolffish, is also given.

The adult fish sampled during the surveys are described in the section on Adult Fish and in the section on Marine Mammals an account of the distributions of the whales and seals sighted by participating vessels is given. There is some evidence to suggest that whalebone whales, sperm whales, pilot whales, and dolphins concentrate in an area of high zooplankton and nekton productivity in the vicinity of Anton Dohrn Bank off East Greenland.

Finally, I would like to express a few thoughts on the conduct of the surveys. From the outset the need for intercalibration of equipment and, where possible, for standardization was appreciated, and much attention was paid to this problem during the planning stages. Notes on the intercalibration of the physical and chemical methods used are given in the preamble to the volume containing the physical and chemical oceanographic data. It is apparent from these that the temperature and salinity observations made by the different participating ships contain small systematic differences, and the lesson to be learned is that even reversing thermometers and salinometers need to be calibrated before starting international cooperative investigations in the deep sea. Another lesson is to stick to well-tried chemical methods of nutrient salt determination, even though better methods may have been developed just before the investigations are due to begin. It takes a considerable length of time indeed for a new method to become adopted internationally and for all laboratories to become sufficiently well practised in it for international survey purposes.

The need to use standard plankton nets during an international expedition is well-known. In our case we faced a considerable difficulty. In making their important, long time series of cod larvae observations off West Greenland the Danish investigators had used a 2-m-stramin net. On the other hand, in making their shorter, but equally vital, series of redfish larvae surveys, the Icelandic scientists had used their Icelandic High Speed Sampler (IHSS). As these earlier studies of cod and redfish larvae were to be used as rules against which the relative level of larvae catches in 1963 could be assessed, we could not escape asking all participating vessels to use both the 2-m-stramin net and the IHSS, and so extending the amount of time which they would have to spend at each station. Unfortunately, the Icelandic R/V *Aegir* could not use the 2-m-stramin net, and arrangements had to be made for other vessels to calibrate this net against the IHSS during the course of the surveys. In the event, various circumstances prevented this from ever being properly achieved. As a result, there has been considerable difficulty in working-up the zooplankton data, including those on fish eggs and larvae.

A further lesson is the need for the coordinator of the surveys to test all vital new equipment before it is issued to ships for a survey. In our case, some countries had not used 2-m-stramin nets before and they undertook to purchase them from the supplier to those that had used them. Unfortunately, this supplier had changed his method of manufacture slightly and when the new nets were towed the rings tended to buckle. The scientists experienced in the use of the 2-m-stramin net had no need to purchase new supplies, and so were unable to detect in advance the small change which caused their colleagues in other countries so much trouble.

In planning the NORWESTLANT Surveys we decided to carry out three distinct surveys separated by as short a time interval as possible. This was because they were regarded as a reconnaissance of the basic physical and biological features of the area. To examine the mortality rate of the products of a spawning it is necessary for the ships to survey them very nearly continuously, but we felt that we did not know enough about these basic features to do this. For example, we were not certain exactly where and when the cod spawned. It was our hope that this more intensive type of survey could be carried out once our reconnaissance had been completed and reported upon.

The report, as it has turned out, has taken a lot longer to prepare than we intended. We decided that we would not aim to produce polished monographs such as normally come from an expedition, but that we would prepare a much more rough and ready report, and this we have done. The reason for the delay is that most of those responsible for the report have much other work to do. Judging from our experience, if for a future international cooperative investigation it is desired to produce a report of this kind within say 2 years, then it will be necessary to find a small team of reporters to work on the material collected to the exclusion of all else.

Before any further ICNAF cooperative work is carried out in the NORWESTLANT area, this report will be studied by its Research and Statistics Committee. The question will no doubt arise as to whether it is possible to carry out surveys which are much more sophisticated than those of the reconnoitering type which formed NORWESTLANT 1-3. The area is one with a bad weather record, and one where sea-ice forms not only a hazard but can also seal off parts of the area to be surveyed. Although modern research vessels are designed and equipped so as to reduce both the amount of time lost to bad weather and the hazards of ice, work in such an area is still a risk. The NORWESTLANT Surveys were carried out in a particularly stormy year, but one in which the sea-ice was not abnormal. It is hoped that this account of the results achieved will help others to assess the feasibility of carrying out further work in the area and, if they decide to do so, to plan it so as to obtain the most fruitful results.

Some Notes on the Estimated Strength of the 1963 Cod Year-Class in Greenland Waters

By

Svend Aage Horsted[1]

Predictions of the strength of the 1963 year-class have been given each year since 1963. The occurrence of the year-class as eggs and larvae is thoroughly dealt with by Hansen in this report and from the findings of the NORWESTLANT Surveys, everybody expected the year-class to be a rather poor one.

In 1964 research work on small cod was carried out in inshore waters of ICNAF Divs. 1D and 1F. Considerable numbers of the 1963 year-class (belonging now to age-group I) were found only in one sample taken with a hand seine in Div. 1F (Hansen, 1965). Still the year-class was regarded a poor one.

In the summer of 1965 only scarce quantities of small cod were observed along the West Greenland coast so that the year-classes 1962, 1963, and 1964 seemed to be relatively poor. An exception was the Godthåb Fjord (Div. 1D) where considerable quantities of small cod were observed (Smidt, 1966). Offshore the 1963 year-class occurred in German research catches taken with a trawl with covered codend in Divs. 1B and 1D. The highest figure was obtained on Fyllas Bank (Div. 1D) in December when close to 10% by numbers of the catch consisted of the 1963 year-class (Meyer, 1966). Still nobody regarded the 1963 year-class as more than a poor one.

In 1966 the Danish inshore investigations showed that cod belonging to the age-groups I and II were rare, while 3-year-old cod (the 1963 year-class) were found in rather large numbers especially in Divs. 1E and 1F (Hansen, 1967). Hansen (*loc. cit.*) predicts that in Divs. 1E and 1F small 4-year-old cod will be common in the 1967 catches, while Meyer (1967), judging from offshore research catches made in 1966 with a 60-mm-mesh size in the codend and from factory vessels' observations, says that the 1962 and 1963 year-classes are, at best, moderate and probably poor. The German catches showed that on Fyllas Bank (Div. 1D) the 1963 year-class was stronger than the 1962 year-class, while the opposite was the case off Cape Thorvaldsen (Div. 1F). Norwegian offshore research catches made in March-May with covered codend showed that the 1963 year-class to be promising and at any rate better than the 1962 year-class (Bratberg and Blindheim, 1967). Also, USSR catches in 1966 showed good occurrence of small cod belonging to the 1962 and 1963 year-classes (Konstatinov and Noskov, 1967).

Thus, in 1966 there was evidence that the 1963 year-class was better than previously thought. This change could probably be explained by supposing that a great proportion of the 1963 year-class had been transported by the current from East Greenland waters to Southwest Greenland as suggested by Hansen (*loc. cit.*).

Danish samples from 1967 give further evidence that the 1963 year-class will be of greater importance to the fishery than previously thought.

In 1967 the fastest growing individuals of the 1963 cod year-class have reached the size where they are big enough for filleting (42-43 cm total length in the Greenland factories). Analysis of the age composition of the landings, together with knowledge of the amount of discarded cod or cod used for fish meal, should therefore give us a preliminary idea of the strength of the 1963 year-class. Unfortunately, the Danish research programme was rather limited in 1967 due to the building of a new research vessel, and the samples of commercial landings taken by Greenland fishermen were not supplied with information on discards. The judgment of the strength of the 1963 year-class must therefore be taken with some reservation.

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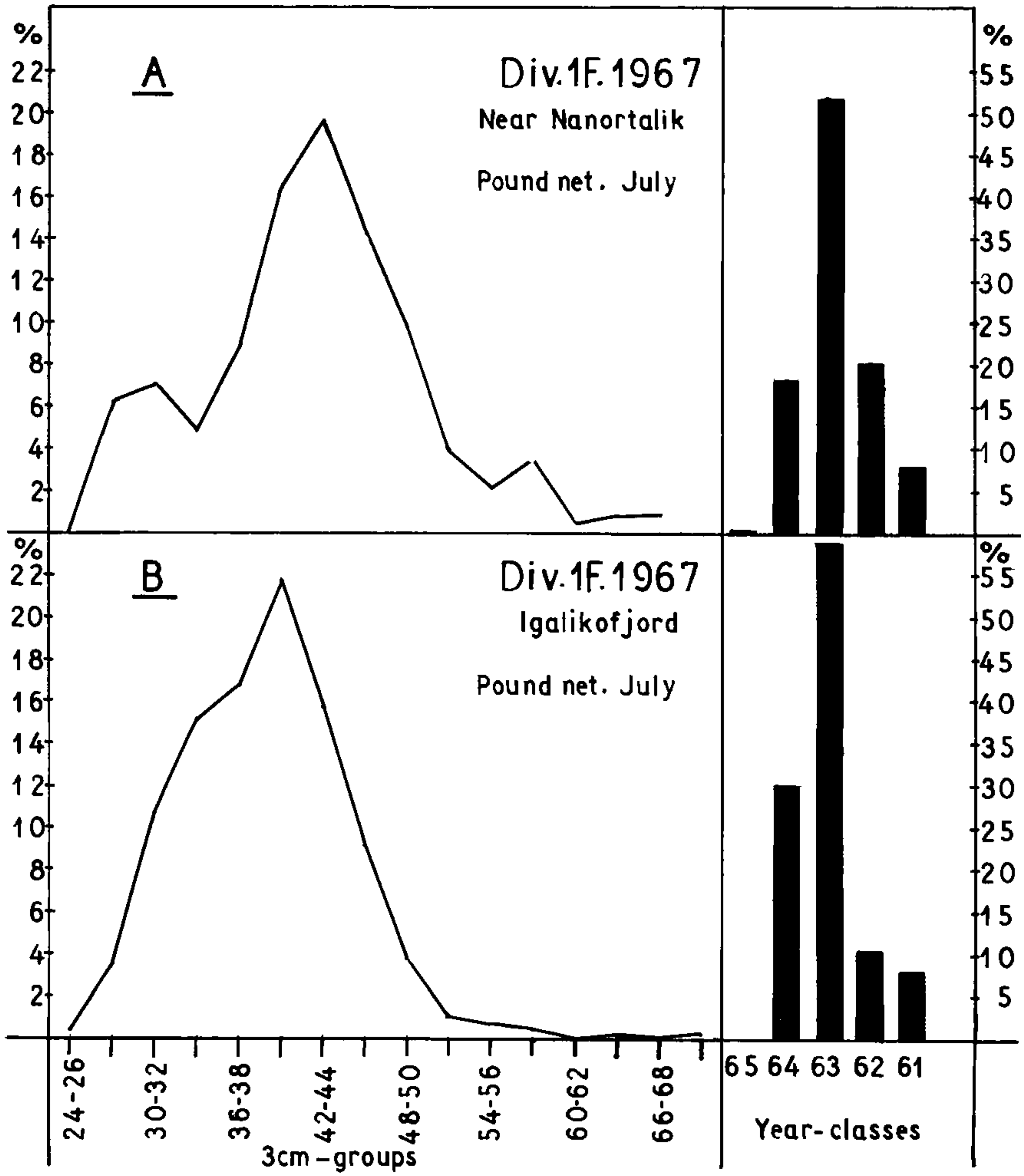

Fig. 66. Cod. Length and age. Div. 1F, July 1967. A — 225 fish sampled at random for length and age include two not shown in figure, one 76-cm long, 7 years old, and one 90-cm long, 9 years old. B — 991 fish as stratified sample, all measured, 180 aged.

Figure 66 (A and B) shows the age and length distribution of some nominal catches caught in pound nets in the inshore waters of Div. 1F. A great proportion of the catch must be discarded or used for fish meal. This proportion is 44% (sample A) and 68% (sample B) by numbers. The 1963 year-class is by far the most dominating (52% and 59% by numbers in A and B respectively). The mesh size in the bag of the pound net was 24 mm (A) and 28 mm (B) bar length (less than 48 and 56 mm stretched mesh), so that, supposing a likely selection factor of 3.3 and a selection range of 10 cm , all cod larger than 24 cm would be retained and hence fully represented in the samples. But it is necessary to take into account that in July small cod seems to have a greater tendency than big cod to school in shallow water where the pound nets are set. Occurrence (recruitment) and probably also catchability may therefore differ between year-classes represented in the samples of Fig. 66.

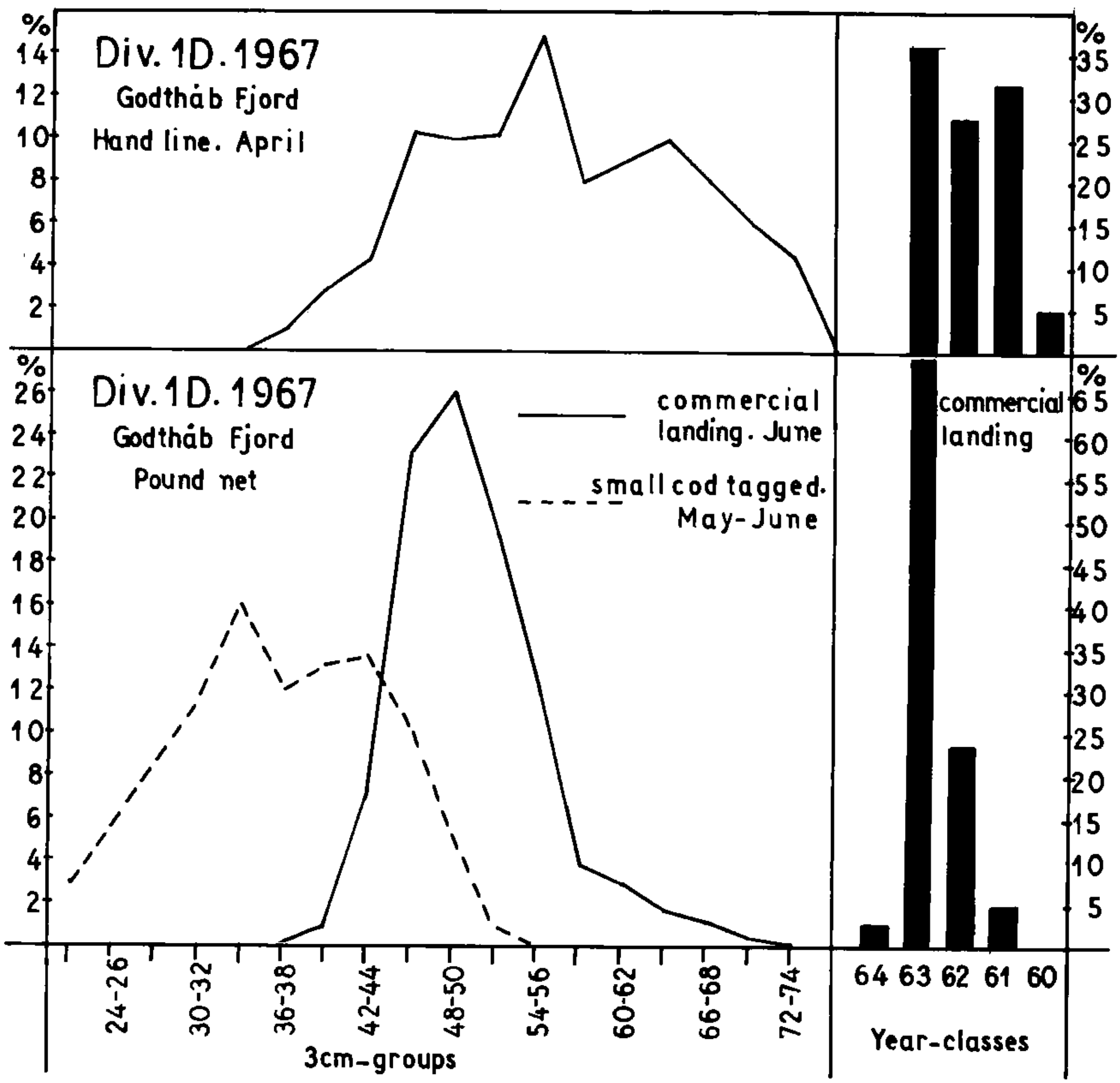

Fig. 67. Cod. Length and age. Div. 1D, 1967. The handline sample consists of 203 specimens (1 day's nominal catch). The commercial landing was sampled after discards. Total landing 7,530 tons gutted weight, approximately 3 tons discarded. The sample was taken as a stratified sample, 892 cod measured, 142 of these aged. Length distribution of small cod (844 specimens) tagged from pound net catches is shown by hatched line, but the sample is not representative of the nominal catch.

Judging roughly from these samples one would, however, say that the 1963 year-class is better than the 1964 year-class and also better than the 1962 year-class, even when taking a total mortality of Z up to 0.85 for the latter into account. Correcting for a total mortality of Z = 0.85 the relation between the year-classes 1963/1962/1961 is 1.0/0.9/0.8 (sample A) and 1.0/0.4/0.07 (sample B).

Figure 67 shows the length and age composition of some samples from the Godthåb Fjord (Div. 1D). The sample taken by handline is a research sample where all specimens have been aged. In this sample the 1963 year-class again is the major one, but also year-classes 1962 and 1961 are well represented, and taking a probable total mortality of Z = 0.85 into account, we find that the 1961 year-class is the strongest of the three year-classes mentioned, the relation between the three year-classes 1963/1962/1961 then being 1.0/1.8/4.8. It is, however, a question whether the 1963 year-class is fully recruited on the ground, the fishing depth being 80-100 m, and there is also likely to be a difference in catchability, the smallest fish possibly not being caught by handline to the same extent as the medium-sized fish.

The sample from the commercial landings of pound-net-caught cod was taken after cod had been discarded. The total landings were 7,530 tons, gutted weight, with approximately 3 tons being discarded. It is thus likely that the 1963 year-class has been strongly represented in the actual nominal catch. Tagging of small cod discarded from pound nets has been done in the Godthåb Fjord. The length distribution of the small cod (844) tagged is given by the hatched diagram in Fig. 67, and, although the tagged cod cannot be taken as a representative sample, they nevertheless confirm the assumption that 4-year-old cod (the 1963 year-class) have contributed very much to the nominal catch. The 1964 year-class must also have been well represented.

Samples have also been collected from a Faroese trawler in Div. 1E and from commercial landings in most Greenland ports. But all these samples were taken after cod had been discarded, and, as no precise information exists on the amount of discards, these samples cannot be used to judge the strength of the 1963 year-class.

It must be emphasized that all figures given in this paper are relative figures. The strength of the 1963 year-class in terms of the number of recruits (Horsted, 1967) cannot be given before the year-class has contributed to the landings for some years. At the present stage it is, therefore, impossible to say more about the 1963 year-class than to call it a year-class of medium strength or possibly of strength a little above medium. A good proportion of the 1963 year-class now occurring at West Greenland may originate from schools spawning off Southeast Greenland.

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