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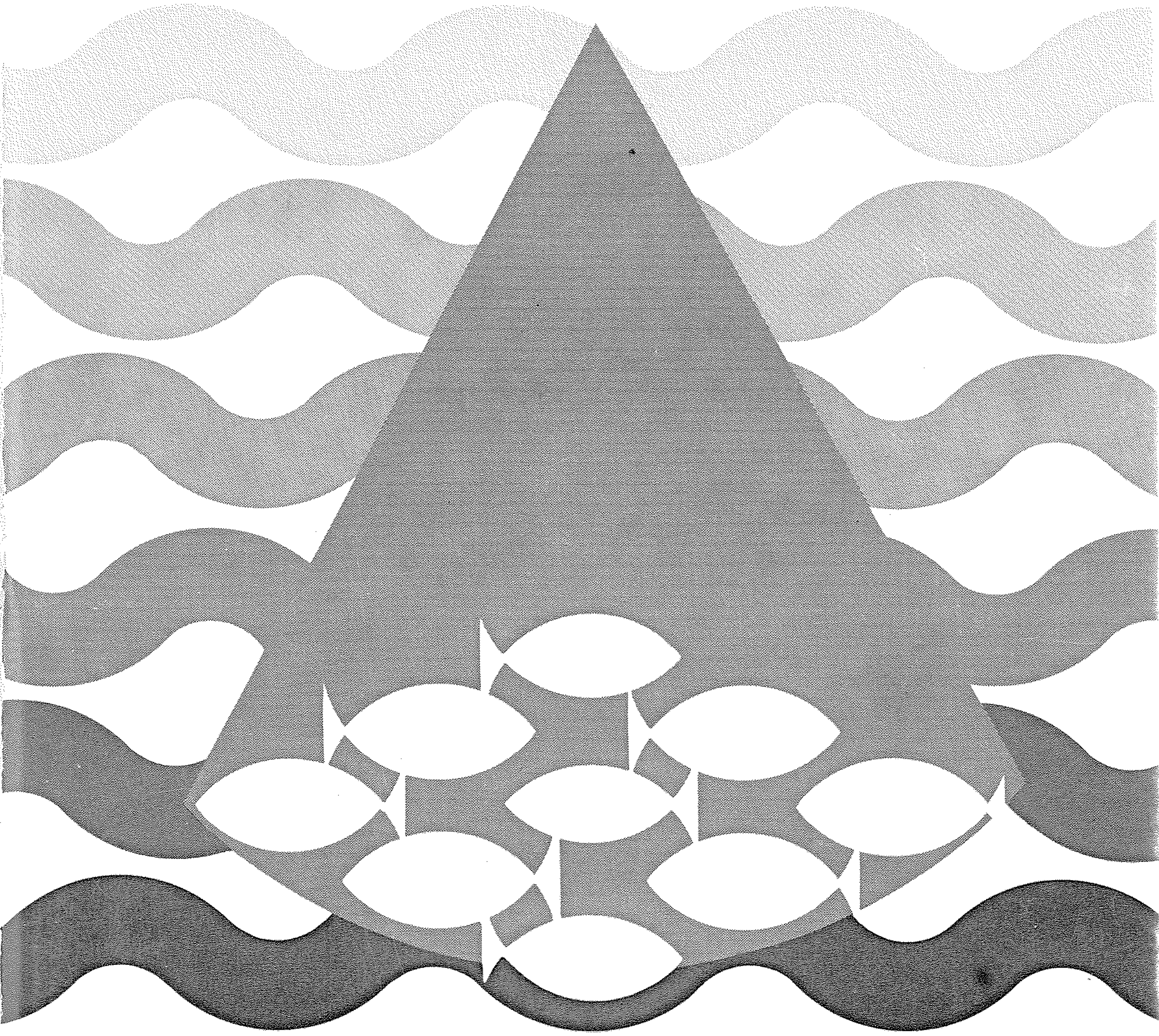

DIRECTORATE OF FISHERIES, BERGEN, NORWAY
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OCCURRENCE OF SHELL DISEASE IN LOBSTERS, *HOMARUS GAMMARUS* (*L.*), IN THE SOUTHERN PART OF OSLOFJORD, NORWAY

BY

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ABSTRACT

ROALD, S.O., AURSJØ, J. and HÅSTEIN, T. 1981. Occurence of shell disease in lobsters, *Homarus gammarus*, (L.), in the southern part of Oslofjord, Norway. *Fisk.Dir. Skr. Ser. HavUnders., 17*: 153—160.

Shell disease in a natural lobster population in Norway is described. The external signs were characterized by necrotic lesions of the exoskeleton, especially on the large chelae. Chitin-degrading bacteria were cultured from the necrotiv erosions.

INTRODUCTION

Exoskeleton lesions have frequently been observed on many different marine crustaceans, particularly on commercially, important neretic species such as the American lobster, *Homarus americanus* (HESS 1937; ROSEN 1970; YOUNG and PEARCE 1975), the European lobster, *Homarus vulgaris* (FISHER 1977), the blue crab, *Callinectes sapidus* (ROSEN 1967; KRANTZ, COLWELL and LOVELACE 1969; COOK and LOFTON 1973), the king crab, *Paralithodes camtschatica* (BRIGHT, DURHAM and KNUDSEN 1960), the tanner crab, *Chionoecetes tanneri* (BAROSS, TESTER and MORITA 1978), and various penaeid shrimps, *Penaeus spp.* (COOK and LOFTON 1973). I n Norway this disease seems to be very frequent among the common edible crab, *Cancer pagurus*.

The gross signs of shell disease are similar in all species. The exoskeleton is pitted and marred with necrotic lesions, and although the disease is not immediately fatal, death may occur. SAWYER and TAYLOR (1949) reported that shell disease may also cause erosion of lobster gills, resulting in impaired gas exchange. The disease has been found to be contagious, especially when the lobsters are held in mass confinement. Lobsters may overcome minor cases of shell disease by molting (MCLEESE 1965).

Most investigations have been carried out on adult lobsters, although larvae and post-larvae are also susceptible (FISHER, ROSEMARK, and NILSON 1976).

It is generally believed that chitin-digesting bacteria are the principal causative organisms of shell disease. Chitin-digesting *Vibrio spp.* (frequently called *Beneckea spp.)* have been successfully isolated from all marine crustacean exoskeleton lesions (Hess 1937; Rosen 1967, 1970; Cook and Lofton 1973, Young and Pearce 1975; Malloy 1978). It is not precisely known what sequence of events leads to shell erosion; however, many investigators report that mechanical damage to the shell is the chief prerequisite to lesion formation (Rosen 1970). High incidences of necrotic lesions have also been observed in lobsters and rock crabs collected in or near dumping grounds of sewage sludge (Young and Pearce 1975).

This paper reports the incidence of shell disease among adult European lobsters sampled over a four month period in 1979 in the area of the three small islands of Bolærne in the southern part of Norway.

In this work, believed to be first reported incidence of shell disease in a natural lobster population in Norway, the results of microscopic and microbiologial examinations of exoskeleton lesions are described.

MATERIAL AND METHODS

From August to November 1979 European lobsters *(Homarus gammarus (L.))* were collected by help of monofilament nets along the nearshore waters of the islands of Bolærne in he southern part of Oslofjord, Norway (Fig. 1). This area was selected as the area of study because our first cases of shell disease were received from this region. During the period 1959—1975 large quantities of sewage sludge were disposed two nautical miles north of these islands.

The lobsters were obtained alive and kept for a short time in wooden tanks three feet by six feet in seawater, before they were brought to the laboratory for examination.

Normal and diseased tissues were prepared for microscopic examination by fixation in 10% buffered formalin, decalified in 5 % nitric acid solution, embedded in paraffin, sectioned and stained with hemtoxylin and eosin (H & E).

Swabs of typical exoskeleton lesions were streaked on chitin agar (Needham 1978) which was incubated aerobically at 22°C for two weeks. Chitin utilization was indicated by clearing of the opaque medium around the colonies (Lear 1963).

The salt requirement of isolates capable of utilizing chitin was determined on nutrient agar (Difco) with and without 3% NaCl. Other test wedia were made with 3% NaCl.

Cell shape and motility were determined on trypticase soy broth

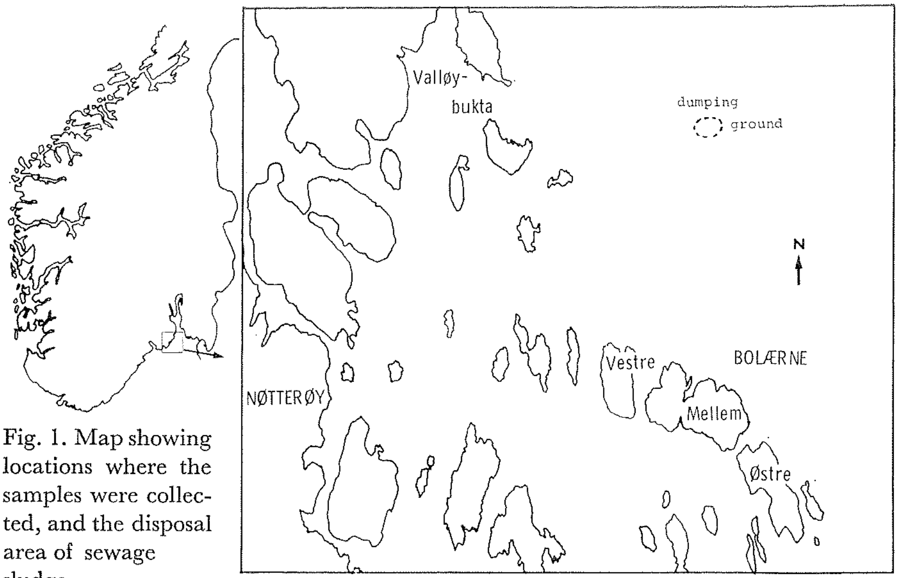

Fig. 1. Map showing locations where the samples were collected, and the disposal area of sewage sludge.

(Difco) cultures by phase contrast microscopy. Gram stains were performed on 24 hr trypticase soy agar (BBL) cultures. The type of flagellation was determined by electron microscopy of negatively stained preparations from 24 hr nutrient agar cultures.

The catalase and oxidase activity (Sandvik 1972) was examined on nutrient agar.

Hemolytic activity was tested on blood agar containing 5% defibrinated goat blood.

For detecting indole production, chitinolytic isolates were grown on a broth containing 0.5% peptone, 0.1% yeast extract, 0.01% ferric phosphate and supplemented with 1% tryptone. For detection of nitrate reduction, this broth was used with 0.2% KNO_3 (Malloy 1978).

Starch hydrolysis, gelantinase activity and casein hydrolysis were determined on nutrient agar containing 0.2% filter-sterilized starch, 3% gelatin or 30% skim milk, respectively (Malloy 1978).

The medium of Hugh and Leifson (1953) was used to test the ability of the isolates to utilize glucose, sucrose and lactose.

Antibiotic sensitivity was tested on freshly-seeded trypticase soy agar plates with the following antibiotic discs: 10 I.U. Penicillin,* 100 μg Streptomycin,* 80 μg Tetracycline,* 100 μg Novobiocin,* and 0.1% vibriostat 0/129 (2,4 diamino — 6,7 di-isopropylpteridine).

An electrophoretic casein precipitation test (CPI-test) was performed

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as described by SANDVIK (1967), in order to reveal any relationship between extracellular proteinases of the isolates and those produced by *Vibrio anguillarum.*

Isolates capable of utilizing chitin were classified at the generic level with the schemees of SHEWAN *et al.* (1960), SKINNER and SHEWAN (1977), BAUMANN, HOBBS and HODGKISS (1971), and BERGEY'S MANUAL (1974).

RESULTS

From August to November 1979, 67 adult lobsters were examined. Four female and four male lobsters (12%) were affected and showed visible lesions on some part of the shell. Affected animals showed no clinical symptoms of disease, such as weakness or abnormal movements.

The external signs were characterized by medium to advanced necrotic lesions in the exoskeleton. In the early stages, the lesions appeared macroscopically as few to numerous punctiform dark brown to black crater-like erosions, especially on the ventral side of the large chelae (Fig. 2 a). These early stages were also present on the dorsal side of the large chelae and on the carapace and only one lobster showed typical small erosions scattered over the dorsal carapace. In later stages the marks joined to form large irregular areas with a deep necrotic center. Large necrotic erosions were especially found on the ventral side of the large chelae, where lesions up to 5 centimetres in diameter were seen (Fig. 2 b). All lesions were limited to the normal shell surface by darkly colored lines surrounding the necrotic areas. In these dry necroses, normal broken off material could be recognized.

Historically it could be seen that in the diseased areas all calcified layers of integument were attacked, and in severely eroded areas the calcified shell was completely dissolved. Penetration of the innermost layer of the shell (noncalcified endocuticle) was not observed, this dense tissue of the integument appearing to form a barrier to the diseased shell. The underlying muscle tissue was not attacked. In none of the affected animals were the gill or gill membranes injured. Microscopical examination of smears from the necrotic areas showed the presence of numerous motile and non-motile Gram negative rods.

Twelve chitinolytic isolates were obtained from different necrotic lesions. All isolates were relatively large, straight, Gram negative rods with polar flagella. On agar surface they grew with smooth, opaque, round, low convex, slightly cream coloured colonies, They all required NaCl supplement for growth. Concerning growth rate and biochemical properties there were some differences between the isolates. The general classification schemes divide the isolates into three groups: *Vibrio* spp.,

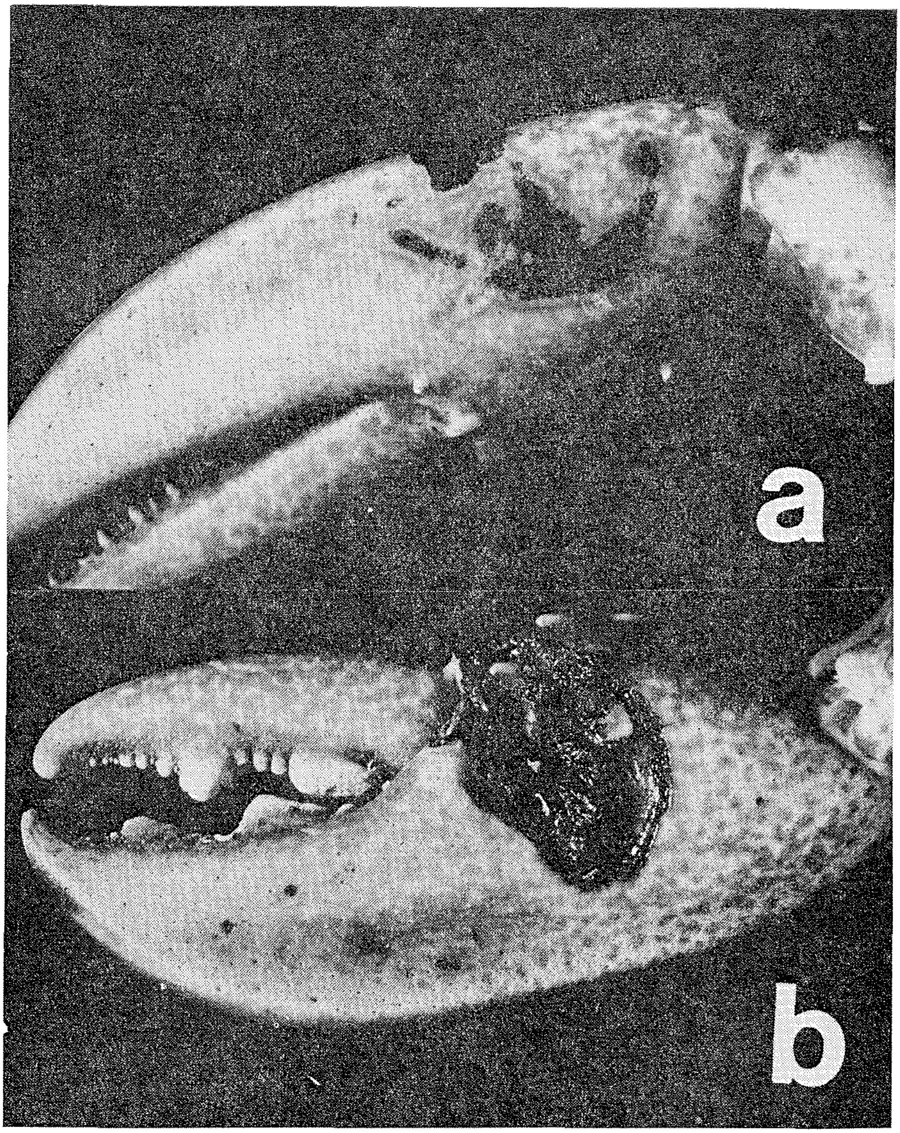

Fig. 2. Early stages (a) and later stages (b) of the shell disease on the ventral side of the large chelae.

Aeromonas-like bacteria, and *Pseudomonas*-like bacteria (Table 1). Two of the isolates (isolate nr. 1 and nr. 6) classified as *Vibrio* spp. gave positive CPI-reactions, showing an enzymo-serological relationship with *V. anguillarum*. In the other ten isolates the enzyme production was so weak that the test could not be performed.

In addition to the chitinoclasts, a varity of psychrophilic nonchitin digesters were isolated from lesions sampled. Fungi were not found.

Table 1. Properties of the chitinolytic isolates.

	Vibrio spp.						*Aeromonas*-like bacteria				*Pseudomonas*-like bacteria	
Isolate number	1	2	3	4	5	6	7	8	9	10	11	12
Gram reaction	—	—	—	—	—	—	—	—	—	—	—	—
Motility	+	+	+	+	+	+	+	+	+	+	+	+
Polar flagella	+	+	+	+	+	+	+	+	+	+	+	+
Salt requirement	+	+	+	+	+	+	+	+	+	+	+	+
Catalase test	+	+	+	+	+	+	+	+	+	+	+	—
Oxidase test	+	+	+	+	+	+	+	+	+	+	+	+
Hemolysis	+	+	+	+	—	+	+	+	—	—	—	—
Indole production	+	+	+	+	+	+	—	—	—	—	+	—
Nitrate reduction	+	+	+	+	+	+	+	+	+	—	+	+
Scarch hydrolysis	+	+	+	+	+	+	+	+	+	+	—	+
Gelatin hydrolysis	+	+	+	+	+	+	+	+	+	+	+	—
Casein hydrolysis	+	+	+	+	+	+	+	+	+	+	+	—
Ability to utilize Carbohydrates												
Glucose	F	F	F	F	F	F	F	F	F	F	0	0
Sucrose	+	+	—	—	+	—	+	+	+	+	—	—
Lactose	+	+	+	+	+	—	—	—	—	+	—	—
Antibiotic sensitivity												
Penicillin	+	+	+	+	+	+	+	—	+	+	—	—
Streptomycin	+	+	+	+	+	+	+	+	+	+	+	+
Tetracycline	+	+	+	+	+	+	+	+	+	+	+	+
Novobiocin	+	+	+	+	+	+	+	+	+	—	+	+
Vibriostat o/129	+	+	+	+	+	+	—	—	—	—	+	+

\+ = positive reaction
— = negative reaction
F = fermentative metabolism
0 = oxidative metabolism

DISCUSSION

The gross signs and microscopic findings of the shell erosions in the study corresponded well with documented descriptions of shell disease in lobster (HESS 1937; ROSEN 1970; YOUNG and PEARCE 1975; MALLOY 1978). In our material the highest incidence of necrotic erosions was found on the large chelae, whereas the prevalence of disease found by other workers (HESS 1937; MALLOY 1978) seemed to be located especially on the carapace.

Eight of the 67 (12%) adult lobsters were attacked by shell disease.

Lobster shell disease appears to be quite rare in natural environments (HESS 1937). TAYLOR (1948) found 0.06⁰/₀ incidence of the diseace in a survey of Canadian lobster producing-centers. Compared to these observations, the frequency of the shell disease in the Bolærne area seems to be high. Relatively high incidences of shell disease have been reported from lobsters and rock crabs collected in or near dumping grounds of sewage sludge (YOUNG and PEARCE 1975). In the actual area the influence of pollution has not been documented, however only two nautical miles north of Bolærne large amounts of sewage sludge have been dumped from 1959—1975, and a connection between these disposals and the occurence of the disease cannot be excluded.

Twelve isolates of chitinolytic bacteria were collected for further examination from different necrotic erosions. Six of the isolates were found to belong to the genus *Vibrio,* four resembled *Aeromonas,* while two isolates fitted in the genus *Pseudomonas,* except that one of them showed negative catalase reaction ,and they were both sensitive to vibriostat. According to MALLOY (1978) vibriostate sensitivity does not exclude the diagnosis of *Pseudomonas.* In the taxonomic designations we have paid little attention to the origin of bacteria, or to their morphology.

There is considerable agreement among various investigators that the primary cause of shell disease is chitinoclastic bacteria which occur abundantly in the environment (HESS 1937; SAWYER and TAYLOR 1949; ROSEN 1967; BRIGHT 1960). MALLOY (1978) isolated chitin-degrading spescies of bacteria in the genera *Pseudomonas, Vibrio* and *Beneckea* from the lesions of lobsters with shell disease. He was able to reproduce the shell disease in experimental lobsters with a spescies of the genus *Vibrio (Beneckea)* when the integument had been damaged prior to inoculation. Until now no attempts to infect healthy lobsters with our isolates have been undertaken.

Further studies concerning development of the disease, mortalityrate and contagiousness of lobster shell disease in Norwegian waters are recommended.

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ON THE VARIABILITY OF ATLANTIC INFLUENCE IN THE NORWEGIAN AND BARENTS SEAS

By

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ABSTRACT

BLINDHEIM, J and LOENG, H. 1981. On the variability of Atlantic influence in the Norwegian and Barents Seas. *FiskDir. Skr. Ser. HavUnders., 17*: 161—189.

Variability in Atlantic influence in the regime of the Norwegian Atlantic current and its branches in the Barents Sea are studied by establishing time series of mean temperature and salinity values in four hydrographic sections. A section Svinøy-NW was worked in December from 1951 to 1968 and in January from 1952 to 1973. In the Barents Sea three sections have been worked in August—October, one between Fugløya and Bjørnøya since 1964, one northward from Vardø along 31°13'E since 1953 and one northward from the Sem Islands along 37°20'E since 1956.

Mean values of temperature and salinity have been established for parts of the sections in the depth intervals 0—50, 50—100 and 100—200 m. Three-year running means have been prepared to reduce the effect of year-to-year fluctuations. The three-year running means of the time series showed the same long-term trends in all three depth intervals. Similar features were found in all the sections.

The most outstanding feature in the time series is a decrease in both temperature and salinity during the period 1972—79. This trend agrees with observations made in the Rockall Channel, the open northeast Atlantic and Norwegian Sea. However, the longterm trends indicate a time lag of about three years between the Rockall Channel and the Barents Sea sections.

INTRODUCTION

The Norwegian Atlantic Current transports Atlantic water along the Norwegian continental shelf. The current enters the Norwegian Sea mainly through the Faroe-Shetland Channel. Before it reaches the Norwegian continental shelf between 62 and 63°N, a branch diverts into the North Sea along the western and southern slope of the Norwegian Channel. However, the bulk of the Atlantic water flows northwards off the shelf edge. Off the coast of Troms the current splits in two branches, one continuing northwards along the continental slope as the West Spitsbergen Current, and the other diverting into the Barents Sea as the Nordkapp Current.

The Atlantic water is isolated from the coast by the Norwegian Coastal Current which is a continuation of the Baltic Current. The freshwater surplus in the Baltic is an important source of the Baltic Current. This freshwater mixes with North Sea and Atlantic water to form the Norwegian Coastal Current. Along the Norwegian coast there is further supply of freshwater by runoff, but in spite of this there is a northward salinity increase due to mixing with Atlantic water. The light coastal water spread out in a wedge form above the heavier Atlantic water. The seaward extent of this wedge of coastal water varies seasonally and has its minimum in winter.

Between Iceland and Jan Mayen the East Icelandic Current enters the Norwegian Sea. Its relatively cold, low-salinity waters are of Arctic origin and characterize the area from northeast of Iceland towards the Faroes. At sub-surface depths, water from this current spreads towards the Norwegian continental slope, intruding between the Atlantic water and the Norwegian Sea Deep water.

Observations in the Barents Sea have revealed a marked decrease in temperature and salinity in the Atlantic water during the years after 1974. The reason for this decrease may be either local fluctuations or advective changes in the Atlantic inflow to the Norwegian and Barents Seas.

A recent cooling trend in the North Atlantic has been dealt with by several authors. RODEWALD, (1972) studying sea surface temperatures on North Atlantic Ocean weather stations, states that falling temperatures were significant for the decade 1961—1970. ELLETT (1978) presents a time series of sea surface observations in the Rockall Channel, showing a steady decrease after 1970 in long-term trends of temperature and salinity. ALEKSEJEV and PENIN (1973) describe anomalies in temperature and salinity during the period 1952—1972 based on hydrographic stations worked in June in the Greenland and Norwegian Seas, and they connect the anomalies with varying Atlantic inflow. Fluctuations in the East Icelandic Current have been described by MALMBERG (1969, 1976 and 1978) while DICKSON, LAMB, MALMBERG and COLEBROOK (1975) link these fluctuations with the atmospheric pressure distribution during the same period. MIDTTUN (1969) studied trends at fixed oceanographic stations and compared these trends with fluctuations in the Kola section.

In an attempt to throw some light on such fluctuations in the regime of Norwegian Atlantic Current, time series of hydrographic sections in the Norwegian and Barents Seas are studied in the present paper.

MATERIALS AND METHODS

Some of the sections worked in the Norwegian and Barents Seas by research vessels from the Institute of Marine Research, Bergen, have been repeated in the same season over several years. In the present paper, time series of observations from four sections have been utilized for the study of year-to-year and long-term trends. These sections are Svinøy-NW, Fugløya—Bjørnøya (Bear Island), Vardø-N and Sem Islands-N, the locations of which are shown in Fig. 1.

The data collected before 1970 are from Nansen casts with observations at standard depths to maximum 500 m. In the period 1970—1974 some sections were worked with a Bissett Berman salinity-temperature-depth observation system. After 1975 most observations have been taken with a Neil Brown CTD system.

The section Svinøy-NW was worked in December from 1951 through 1968 and in January from 1952 through 1973. As a general rule the section was laid along the line between 62°22'N, 05°12'E and 64°40'N,

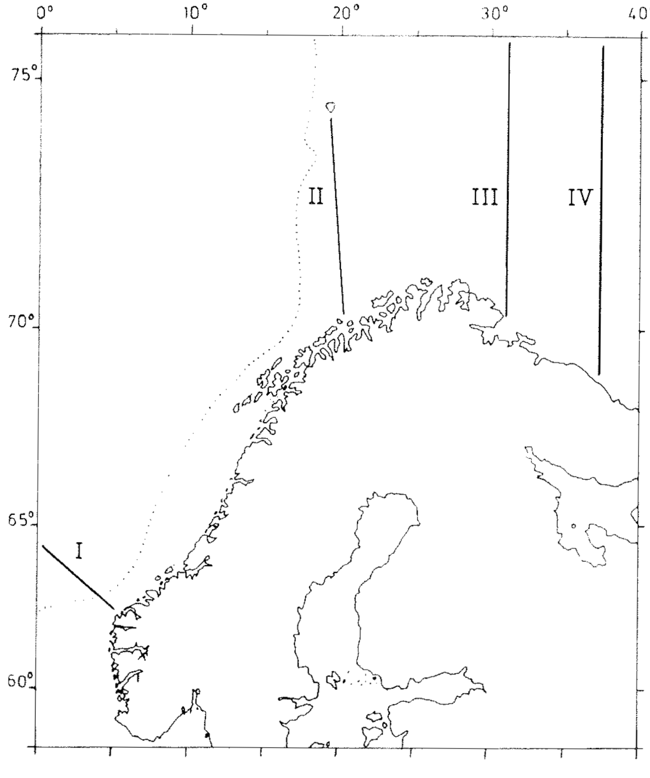

Fig. 1. Location of the sections. I: Svinøy-NW, II: Fugløya-Bjørnøya (Bear Island), III: Vardø-N, IV: Sem Islands-N.

00°00'E. The distance between stations was 10 nautical miles to beyond the shelf break and 20 nautical miles further seaward, but the stations were not always worked at fixed positions.

In the Barents Sea sections have been worked in various seasons, but regular observations obtained within the same month over some years are available mainly in August—September. The data series considered here range from 1953 to 1979.

The section between Fugløya and Bjørnøya has been operated along the line 70°40'N, 20°00'E—74°15'N, 19°10'E. Since 1964 the section has been worked in late August or early September.

The Vardø-N section has been worked along 31°13'E, between 70°30'N and 76°30'N with 30 nautical miles between stations. From 1953 to 1960 the section was worked in early October. In the period 1961—1965 it was worked at dates varying from late August to late September, while from 1966 on it has been worked around 1 September.

The Sem Islands-N section has been worked along the meridian 37°20'E from 69°05'N to 76°30'N with a distance of 30 nautical miles between stations. The section was worked in October from 1956 to 1960 and since then in late August — early September. In 1962 this section was not worked, and from 1972 only temperature observations are available.

In these three sections the stations have normally been worked at fixed positions. In a few cases, when stations were taken at other positions along the track of the section, values of temperature and salinity at the fixed positions have been obtained by linear interpolation between the neighbouring stations. For the period 1966—1977 means of temperature and salinity were worked out at the standard depths in the fixed positions and mean sections have been prepared for the period. Standard deviations have been calculated for the same points. Means of σ_t were calculated from the mean values of temperature and salinity.

The positions of the stations in the Svinøy-NW section varied in some cases too much from year to year to warrant the preparation of a mean section here.

To study temperature and salinity fluctuations from year to year, mean values have been prepared in depth intervals at the different stations in all four sections. Means were computed for the depth intervals 0—50, 50—100 and 100—200. On the various stations, temperature averages ($\bar{t}_m$) for the depth intervals have been calculated from observations at standard depths by:

$$\bar{t}_m = \frac{1}{z_N - z_0} \sum_{n=0}^{N-1} \frac{t_{n+1} + t_n}{2} (z_{n+1} - z_n) \qquad (1)$$

where t_n is the temperature at the standard depth z_n, and z_O and z_N are the upper and lower depths in the layer respectively. From these mean values for single stations (m), averages were prepared over the part, L, of the section with most outstanding Atlantic characteristics. Also these averages ($\bar{t}$) were prepared for the same three depth intervals based on the means ($\bar{t}_m$) on the stations within L, weighted in accordance with the distance between neighbouring stations:

$$\bar{t} = \frac{1}{L} \sum_{m=1}^{M} t_m \, l_m \tag{2}$$

Here, l_m is the distance represented by each station included in the average, normally half the distance to neighbouring stations. M is the total number of stations.

In the time series these means were smoothed as three-year running averages, where the current year has twice the weight of the year before and the year after:

$$\bar{t}_n = \frac{1}{4} (t_{n-1} + 2t_n + t_{n+1}) \tag{3}$$

The salinity observations have been treated in the same way.

Fig. 2 shows means of temperature and salinity along the sections in the depth layers 0—50, 50—100 and 100—200 m (Eq. 1). The graphs for the Svinøy-NW section are based on data from January averaged over the period 1952—1969. The mean curves along the sections in the Barents Sea were averaged over the period 1966—1977. The parts of the sections showing most outstanding Atlantic characteristics in Fig. 2 were chosen for the study of time fluctuations in Atlantic influence. Averages of temperature and salinity were prepared for these parts in accordance with Eqs. 1 and 2.

The averages along the Svinøy-NW section show more Atlantic dominance at stations IV, V and VI than at stations III and VII. The part of the section covered by stations IV—VI, between 62°57'N, 04°41'E and 64°10'N, 02°21'E, was therefore chosen for the study of time fluctuations.

In the Fugløya—Bjørnøya section there was a clear salinity maximum in the middle of the section, while the temperature decreased from south to north. The part of the section between 71°30'N and 73°30'N was selected to represent the area of Atlantic inflow into the Barents Sea.

In the Vardø-N section (Fig. 2) a splitting of the Atlantic water is indicated and there were two maxima in salinity. The southern maximum, falling between 72°15'N and 74°15'N, was chosen for the study of time fluctuations.

In the Sem Island-N section the means along the section show two

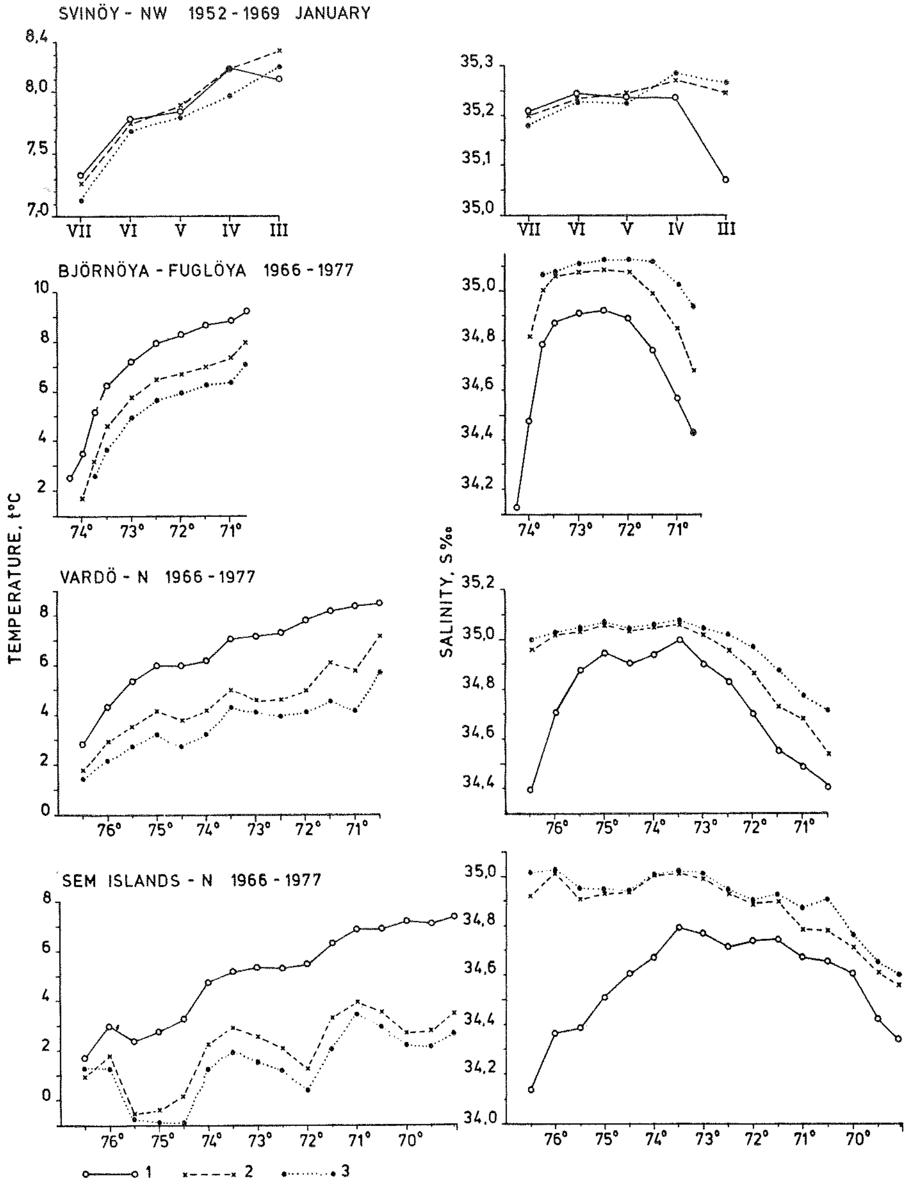

Fig. 2. Mean values of temperature and salinity in the depth layers 0–50 (1), 50–100 (2) and 100–200 m (3) along the Svinøy–NW, Fugløya–Bjørnøya, Vardø-N and Sem Islands-N sections.

separate zones with Atlantic characteristics. As in the Vardø-N section, the southern zone, between 72°45'N and 74°15'N, was chosen for analysis.

The mean sections and standard deviation sections described below support the choice of the section parts selected here.

MEAN CONDITIONS

THE SVINØY-NW SECTION

Since the positions of the stations in this section in some cases were considered insufficiently fixed to warrant the preparation of a mean section, the sections from January 1966 and 1971 have been selected to

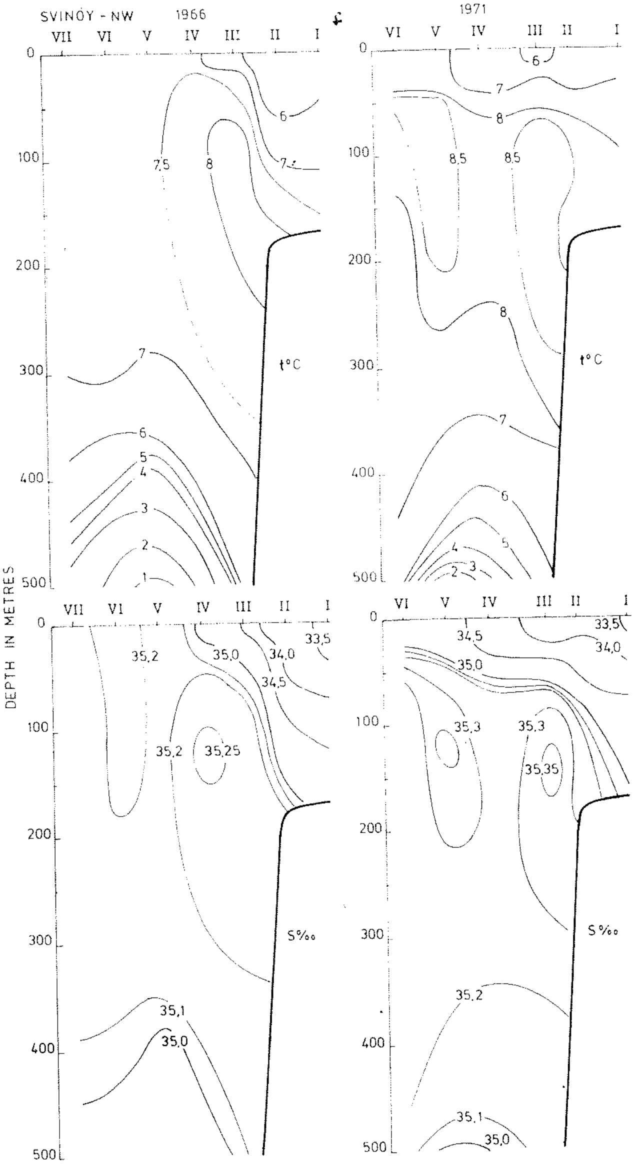

Fig. 3. Temperature and salinity in the Svinøy-NW section in January 1966 and 1971.

illustrate the hydrographic structure. These sections are shown in Fig. 3; they are also chosen to demonstrate sections with varying Atlantic dominance.

The section from 1966 exemplifies a year with moderate Atlantic influences, while the section from 1971 shows stronger Atlantic characteristics. In both sections the main core of Atlantic water was situated off the shelf edge, while there was a secondary core further offshore. Such a splitting of the Atlantic water in two cells was frequently observed in the sections.

The section from 1966 shows salinities up to 35.25⁰/₀₀ and temperatures about 8°C in the main Atlantic core. In the secondary core of Atlantic water salinities were just above 35.20⁰/₀₀.

In 1971 salinities in excess of 35.35⁰/₀₀ were observed in both cores of Atlantic water, and the associated temperatures were close to 9°C. The lower limit of the Atlantic water, as indicated by the 35.0 isohaline, was situated about 100 m deeper in 1971 than in 1966 (Fig. 3).

In 1971 coastal water extended further offshore than in 1966, and salinities were below 35⁰/₀₀ in the upper layer in the whole length of the section, to about 200 km offshore.

The averages along the Jaunary section in Fig. 2 show more Atlantic dominance at stations IV, V and VI than at stations III and VII. At stations III and VII there were also greater standard deviations in the annual means than at the other stations. At station III this was due to varying influence of coastal water, while the greater fluctuations at station VII were due to varying admixture of water from the East Icelandic Current.

THE BARENTS SEA SECTIONS

A T-S diagram based on the mean temperature and salinity values at standard depths in the Fugløya—Bjørnøya section is shown in Fig. 4, and four main water masses may be identified from their T-S relations.

Following Helland-Hansen and Nansen (1909), Atlantic water is defined by a salinity higher than 35⁰/₀₀. During the period 1966—1979 the mean salinity and temperature in the core of the Atlantic water were 35.13⁰/₀₀ and 6.2°C respectively.

The water mass with a salinity of about 35.05⁰/₀₀ and temperatures about 1.5°C is bottom water which is formed in the Barents Sea.

The waters with temperatures below about 4°C and low salinities are mixed Artic water observed in the northern part of the section.

The Norwegian coastal water is also characterized by low salinities, but its temperatures are mainly above 6°C.

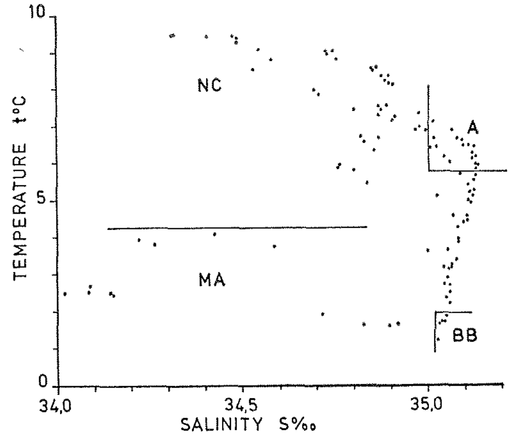

Fig. 4. TS diagram for the Fugløya–Bjørnøya section based on mean values for the period 1966–77. NC: Norwegian coastal water, A: Atlantic waters in the core of the inflow, MA: Mixed Arctic water, BB: Barents Sea bottom water.

Eastward in the Barents Sea the characteristics of these water masses change. This is demonstrated in Fig. 5 which shows a T-S diagram based on the mean temperature and salinity values applied in the time series for the 100—200 m layer in the three sections.

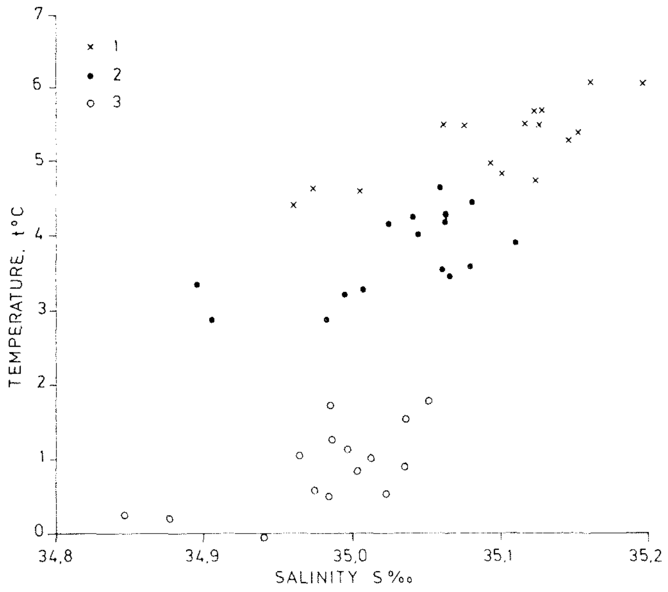

Fig. 5. TS plot based on mean values of temperature and salinity in the 1) Fugløya–Bjørnøya, 2) Vardø-N and 3) Sem Islands-N sections.

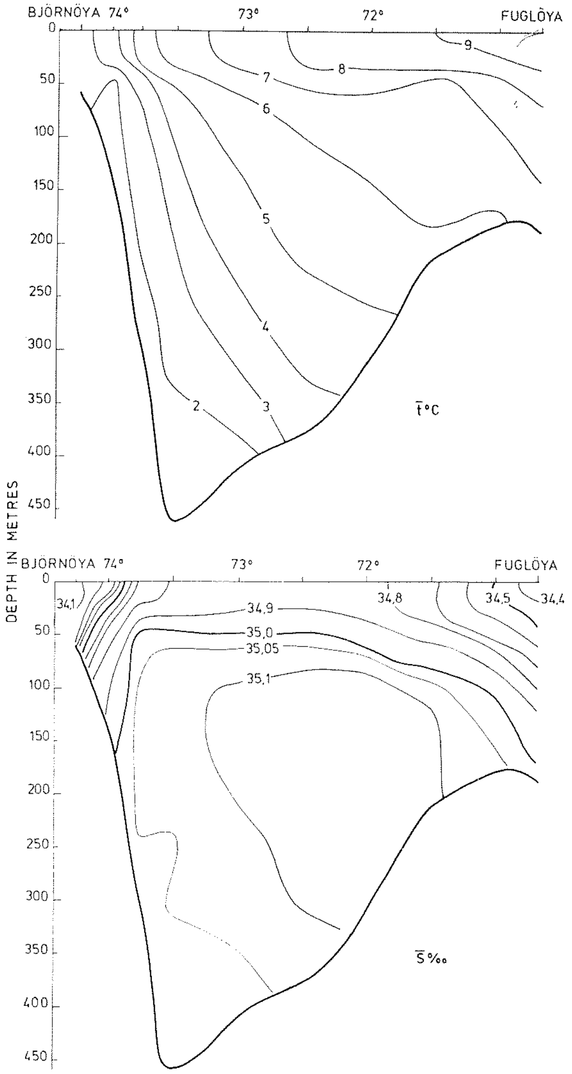

Fig. 6. Mean values of temperature, salinity and σ_t in the Fugløya-Bjørnøya section.

Generally the T-S relation indicates a mixing between relatively warm and saline water to the west and cold water of lower salinity to the east (Fig. 5). Although there was considerable spread in the three sections from year to year, they fall into clear groups in the diagram. This was mainly due to differences in temperature, while there was a considerable overlap in salinity. In the Fugløya—Bjørnøya section the temperature ranged between 4.4 and 6.2°C and the salinity between 34.96 and 35.20⁰/oo. The temperature distribution in the Vardø-N section overlapped slightly with that of the Fugløya—Bjørnøya section, ranging

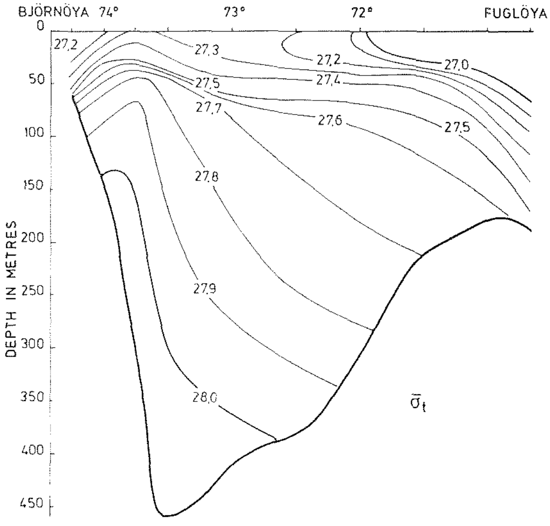

Fig. 6.

from 2.8 to 4.7°C. In the Sem Islands-N section the temperatures were generally below 1.8°C and the salinities between 34.84 and 35.05⁰/₀₀.

The mean sections based on the Fugløya—Bjørnøya, Vardø-N and Sem Islands-N sections are shown in Figs. 6, 7 and 8 respectively. At the entrance to the Barents Sea, in the Fugløya—Bjørnøya section, the Atlantic inflow was concentrated over the southern slope of the Bjørnøya channel were there was a wide core identified by mean salinities above 35.10⁰/₀₀. Salinity above 35⁰/₀₀ was found almost in the whole channel below 50 m depth (Fig. 6).

In the Vardø-N section (Fig. 7) the highest mean salinity values were between 35.05 and 35.10⁰/₀₀, indicating a decrease of 0.05⁰/₀₀ from the Fugløya—Bjørnøya section. The shape of the core of Atlantic water with salinities above 35.05⁰/₀₀ indicated that a split took place over the Central Bank.

Further east, in the Sem Islands-N section, the Atlantic water was completely split in two separate cores. One was centered in the intermediate layer south of the Central Bank, while the other was observed between 75 m and the bottom north of the bank, flowing eastwards in the deeper area between the Central Bank and the Great Bank. The mean salinity in both cores was only slightly above 35.00⁰/₀₀.

The southern part of the sections was characterized by waters of relatively low salinity and high temperature, mainly coastal water and a mixture of coastal and Atlantic waters. The lateral extent of these waters increased eastwards in the Barents Sea. In the Sem Islands-N section the majority of the heat transport through the section seemed to be carried by mixed waters of salinity below 35⁰/₀₀ (Fig. 8).

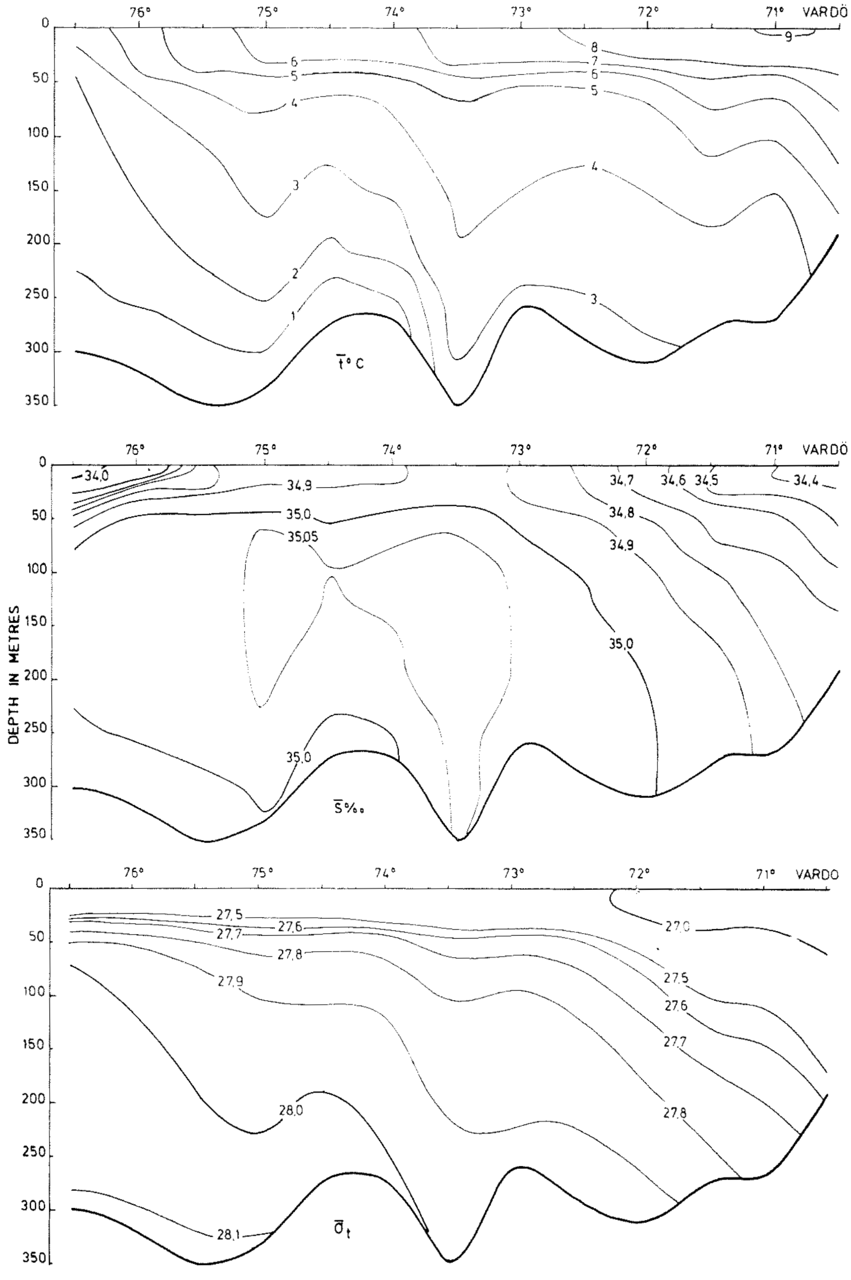

Fig. 7. Mean values of temperature, salinity and σ_t in the Vardø-N section.

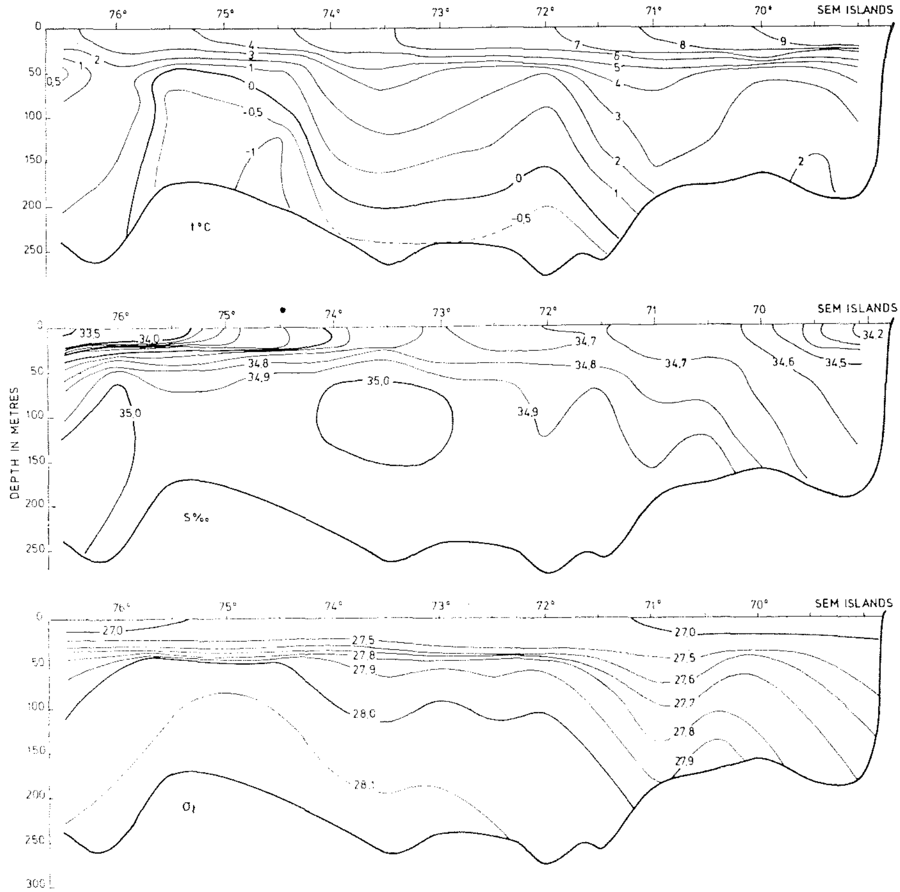

Fig. 8. Mean values of temperature, salinity and σ_t in the Sem Islands-N section.

North of 73°30'N the Fugløya—Bjørnøya section is characterized by the Bjørnøya Current which transports cold, low-salinity Arctic water towards west and southwest from the northern Barents sea. In the vicinity of Bjørnøya the Atlantic and Arctic waters meet and form a well defined Polar Front. South of Bjørnøya the position of the Polar Front may vary as much as 30 nautical miles from year to year (FOSTER, JOHANNESEN and ISOPPO 1974). The front may therefore be considerably more abrupt than indicated by the horizontal gradients in the mean section (Fig. 6).

In the northern part of the Vardø section (Fig. 7) there was a marked decrease in the surface layer salinity. This decrease was due to melting of ice and not to the influence of Artic water, such as in the Fugløya—Bjørnøya section. The transition layer between the melt water and the Atlantic water below was sharp. Consequently there was little exchange

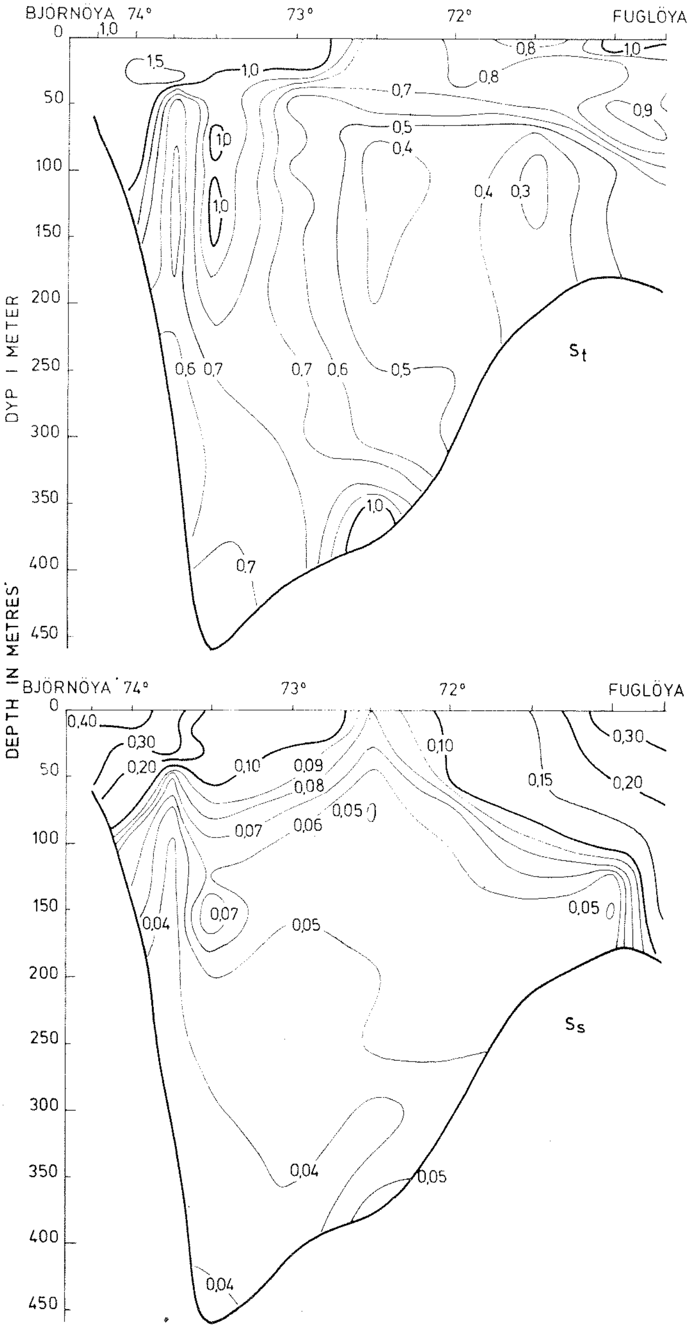

Fig. 9. Standard deviations of temperature and salinity in the Fugløya-Bjørnøya section.

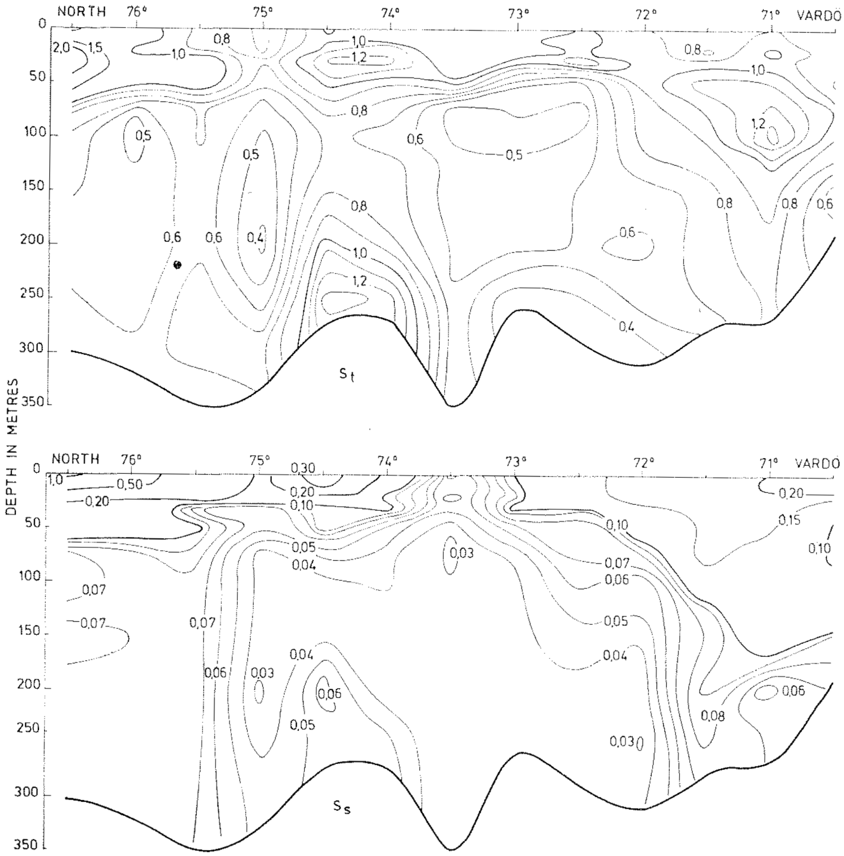

Fig. 10. Standard deviation of temperature and salinity in the Vardø-N section.

of properties between these water masses. How far south the melt water was observed varied considerably from year to year in accordance with the ice extension in spring. This effect of ice melting was more clearly demonstrated in the Sem Islands-N section (Fig. 8). The salinity was usually lower than 34.00⁰/₀₀ in the upper 20 m north of 75°30'N, and there was a sharp transition layer between the melt water and the Atlantic water.

The standard deviation sections (Figs. 9, 10 and 11) of temperature and salinity yield some information with regard to what parts of the sections were least influenced by year-to-year fluctuations. Standard deviations were generally low in the Atlantic water, and in the Fugløya—Bjørnøya and Vardø-N sections the lowest values were found in the core of the Atlantic inflow, indicating the least year-to-year variations in this water mass. In the Sem Islands-N section, where standard

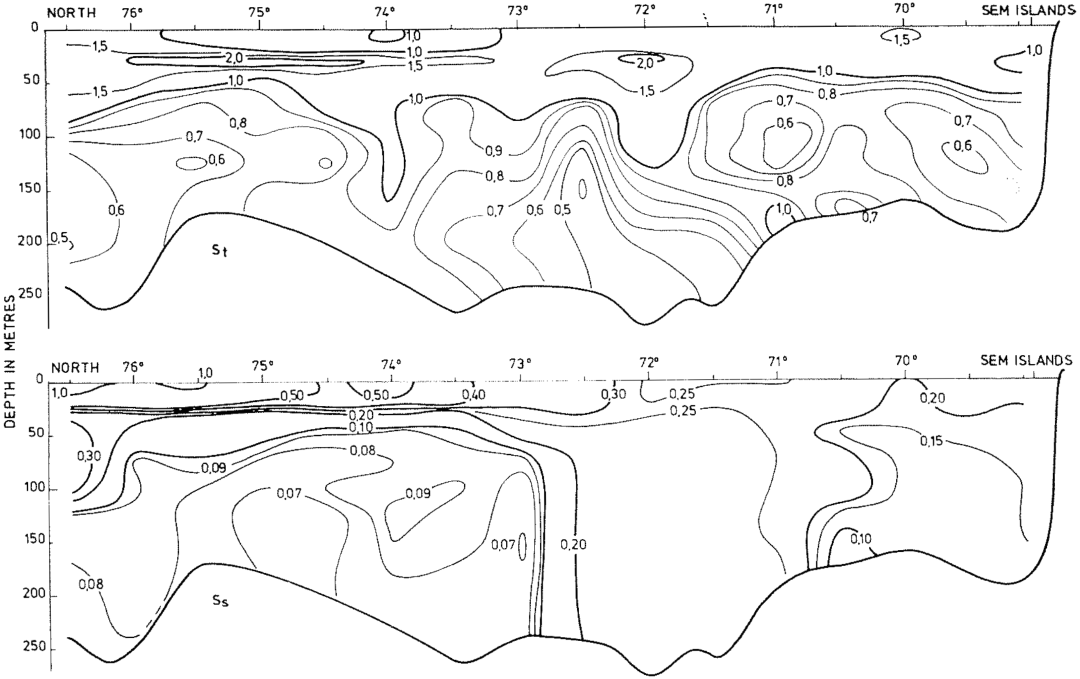

Fig. 11. Standard deviation of temperature and salinity in the Sem Islands-N section.

deviations were generally higher, the core of Atlantic water could not be identified by cells of minimum standard deviation.

The highest values of standard deviation were found in the northern parts of the sections, in the polar front area and in the area of melt water. High standard deviations were also found in the coastal water masses.

In the Sem Islands-N section the standard deviations in both temperature and salinity were much higher than in the other sections, particularly in the upper 50 m. In general, it suggests larger variations in the eastern Barents Sea than in the western part.

TIME FLUCTUATIONS

The time scale of variations in temperature and salinity in waters carried by the Norwegian Atlantic Current and its branches in the Barents Sea covers a wide range. SÆLEN (1959) and KVINGE, LEE and SÆTRE (1968) have studied the short-term fluctuations in some detail. In transport computations based on geostrophically computed currents they found considerable fluctuations over time periods of a couple of days. Similarly, the thermohaline structure often changed quickly due to wave formations on the isolines probably connected with vortices and meandering in the current. Therefore, such short-term fluctuations can obviously be imposed on the long-term trends in the sections dealt with here.

SVINØY-NW

Time series of temperature and salinity obtained from the sections worked in January are plotted in Fig. 12. Mean values in the depth layers 0—50, 50—100 and 100—200 m are shown. It appears from the figure that the long-term as well as the year-to-year fluctuations showed similar trends in all three depth layers. The most conspicuous deviations were observed in the 0—50 m layer.

The more long-term trends of temperature and salinity, as indicated by the three-year running means, show an increase from the beginning of the period towards a maximum around 1960. After this there was a decrease to a minimum in the mid-sixties. Toward the end of the period there was again a rise.

Mean values of temperature and salinity, averaged over time, and standard deviations for the values in the time series are presented in Table 1. Also corresponding means for December are entered. The means were averaged over the period 1951—1968 for December and from 1952—1969 for January. The lowest temperatures in December were observed between 0—50 m, while in January the lowest temperatures were found in the 100—200 m layer. Maximum temperatures were observed in December in the 50—100 m layer. In January, maximum temperatures were found in the homogeneous layer between 0—100 m. Irregularities between depth layers in year-to-year fluctuations were more pronounced in the December series than in January.

The lowest salinities were observed in the upper layer in both months, while the highest values were found in the 100—200 m layer in December and in the 50—100 m layer in January. The differences between the layers decreased from Desember to January, indicating a mixing of the water masses.

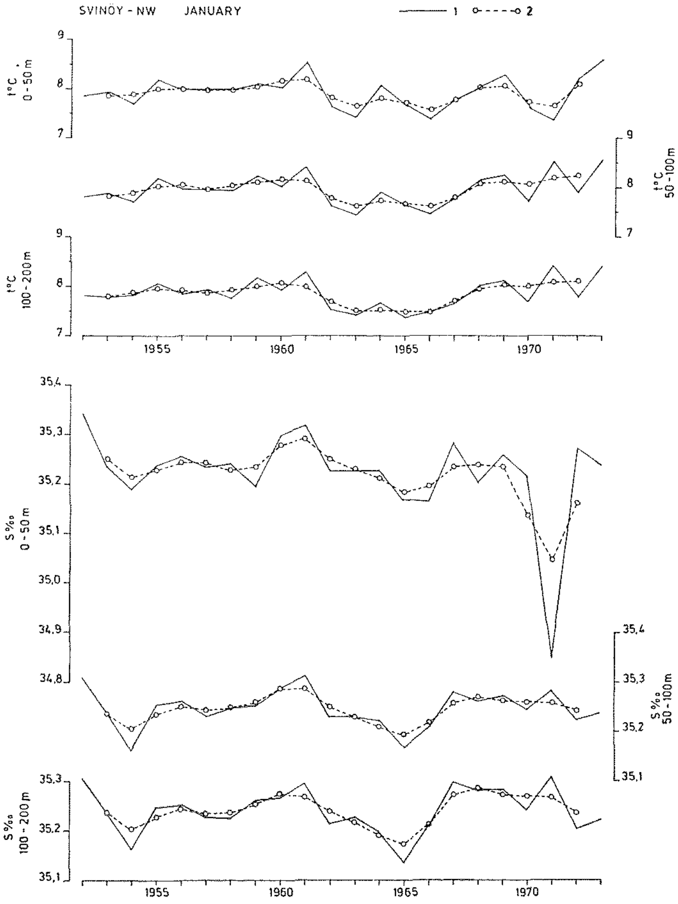

Fig. 12. Time series of temperature and salinity in the Svinøy-NW section for January 1952–1973. 1) Annual means, 2) Three-yearrunning means.

Table 1. Mean temperature ($\bar{t}$ °C) and salinity ($\bar{s}$ ‰) in the different depth layers in the section Svinøy–NW in December and January and corresponding standard deviations (s_t, s_s)

Depth Layer	December				Januar			
	$\bar{t}$	s_t	$\bar{s}$	s_s	$\bar{t}$	s_t	$\bar{s}$	s_s
0– 50 m	8.38	0.41	35.142	0.145	7.91	0.29	35.239	0.048
50–100 m	8.50	0.32	35.209	0.066	7.91	0.27	35.245	0.041
100–200 m	8.45	0.25	35.254	0.034	7.81	0.27	35.241	0.046

THE BARENTS SEA SECTIONS

Time series with three-year running means for the selected part of the Fugløya—Bjørnøya section are plotted in Fig. 13. When comparing the year-to-year curves for temperature with the curves for the three-year running means, the fluctuations between successive years were in some cases greater than the more long-term variations over the whole period. This was most pronounced in the period from 1966 to 1970. Considerable year-to-year variations in salinity were observed, but their amplitudes were less than those of the long-term trends. The figure shows that the year-to-year variations decreased with depth while the long-term trends, lasting for several years, had about the same amplitude in all three depth layers.

In the Fugløya—Bjørnøya section the smoothed curves indicate a period with high temperatures and salinities from 1969 to 1973. The maximum in temperature was observed in 1972 with three-year means of 8.08 and 5.52°C in the upper and lower depth-layer respectively. During the last six years the mean temperatures show a decreasing trend and the minimum for the whole period was observed in 1979, except in the 0—50 m layer.

The curves for the salinities have a similar trend to that of the temperature curves. The three-year means in salinity were fairly constant from 1969 to 1973. After 1973 the three-year means decreased towards a minimum at the end of the period. There was, however, a difference between the temperature and salinity trends. The maximum in the three-year means for salinity was observed in 1969 in all depth layers, three years before the maximum in temperature.

In the sections Vardø-N and Sem Islands-N, a longer time period was covered. Time series for the Atlantic influence in these sections are plotted in Figs. 14 and 15. The figures indicate that the main features in trends, observed in the section Fugløya—Bjørnøya, were repeated in these

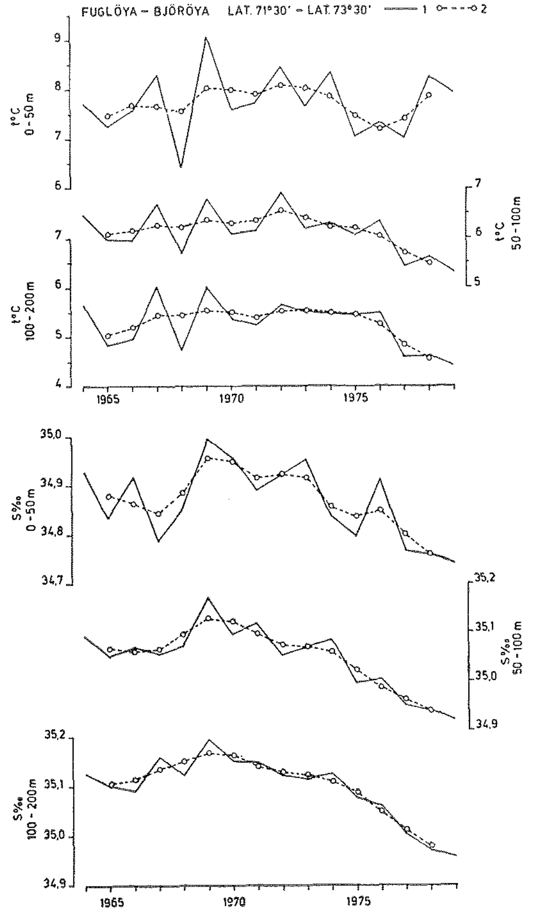

Fig. 13. Time series of temperature and salinity in the Fugløya–Bjørnøya section, 1964–1979. 1) Annual means, 2) Three-year-running means.

sections. Also the three year time lag between maximum salinity and temperature around 1970 is clearly seen in the Vardø-N section (Fig. 14) while it is difficult to see the same in the Sem-Islands section (Fig. 15).

The observations previous to 1964 in the section Vardø-N indicate a maximum of Atlantic influence around 1960. This was observed in all three depth layers and was more pronounced with regard to salinity than temperature. In the section Sem Islands- N this maximum was less pronounced, but temperatures and salinities were generally at a high level compared with the rest of the period.

Table 2 gives mean values of temperature and salinity over the period 1966—1979 for the three depth intervals with corresponding standard

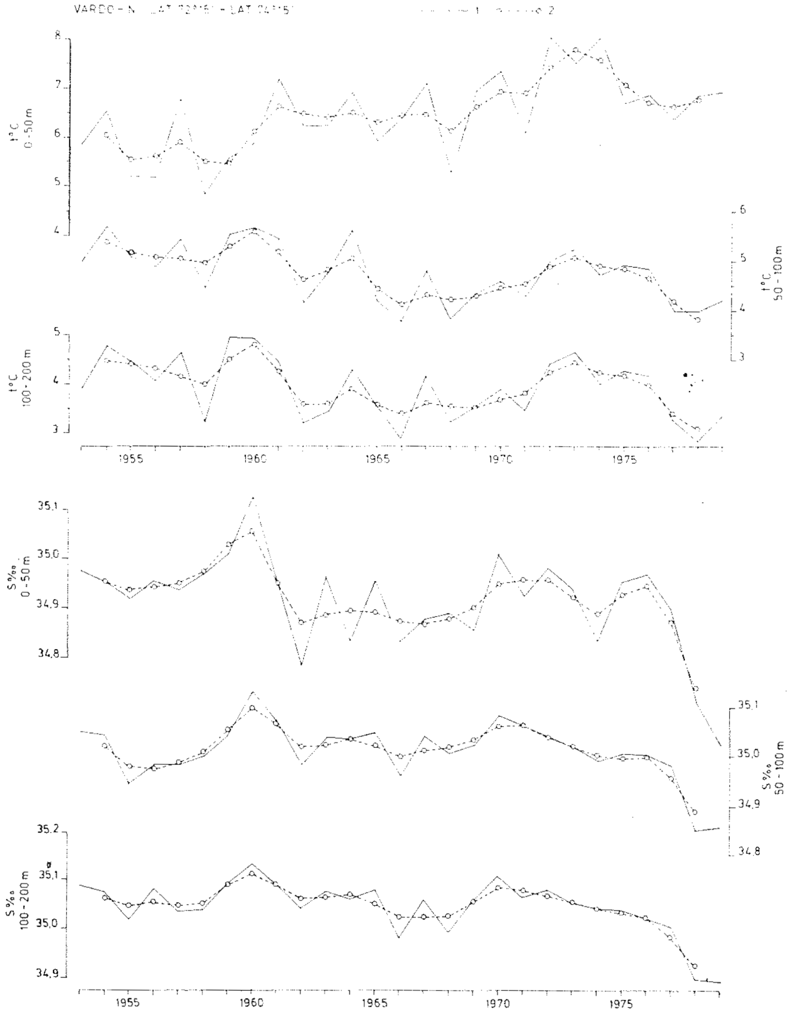

Fig. 14. Time series of temperature and salinity in the Vardø-N section, 1953–1979. 1) Annual means, 2) Three-year-running means.

deviations for the sections Fugløya—Bjørnøya, Vardø-N and Sem Islands-N.

The standard deviations in both temperature and salinity increased from west to east in the upper layer, indicating greatest variability in this layer in the eastern Barents Sea. In the deepest layer the variation in the standard deviations between the sections was small.

The temperature differences between the different layers generally increased a little eastwards. Between the 50—100 and 100—200 m

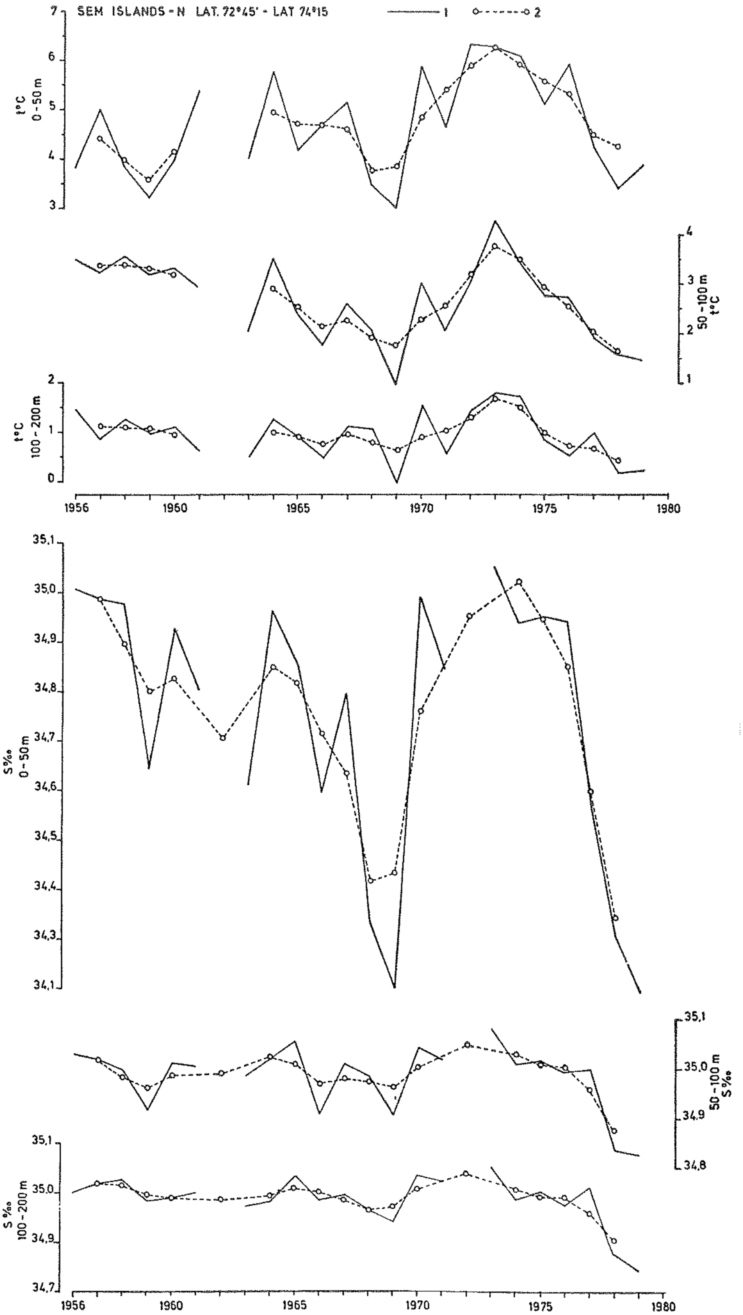

Fig. 15. Time series of temperature and salinity in the Sem Islands-N section, 1956–1979. 1) Annual means, 2) Three-year-running means.

Table 2. Mean temperature ($\bar{t}$ °C) and salinity ($\bar{s}$ $^0/_{00}$) with corresponding standard deviations (s_t, s_s) in the sections Fugløya–Bjørnøya, Vardø-N and Sem Islands-N.

Depth layer	Fugløya–Bjørnøya		Vardø-N		Sem Islands-N	
	$\bar{t}$	s_t	$\bar{t}$	s_t	$\bar{t}$	s_t
0– 50 m	7.73	0.65	6.84	0.73	4.89	1.10
50–100 m	6.12	0.47	4.52	0.54	2.47	0.87
100–200 m	5.25	0.51	3.76	0.55	0.92	0.55
	$\bar{S}$	s_S	$\bar{S}$	s_S	$\bar{S}$	s_S
0– 50 m	34.867	0.079	34.881	0.101	34.703	0.309
50–100 m	35.046	0.068	35.001	0.065	34.982	0.077
100–200 m	35.096	0.067	35.029	0.060	34.980	0.057

layers the temperature difference was nearly the same in the Fugløya—Bjørnøya and Vardø-N sections, while it was greater in the Sem Islands-N section. As opposed to temperature, the difference in salinity between the two deepest layers decreased from west to east, from 0.050$^0/_{00}$ in the Fugløya—Bjørnøya section to almost no difference in the Sem Islands-N section.

CURRENT CONDITIONS

It might be postulated that fluctuations in temperature and salinity are proportional to fluctuations in volume transport of Atlantic water into the Barents Sea, i.e. that low values in temperature and salinity correspond to low intensity of the inflow.

The Fugløya—Bjørnøya section is the most suitable section for study of this volume transport. However, only a few current measurements have been carried out in this area, and measurements covering the same period from year to year are not available.

One way of getting an estimate of the current and therewith the volume transport, is to calculate the current dynamically in the Fugløya—Bjørnøya section by using Helland-Hansen's formula (Mohn 1887, Helland-Hansen 1905). This formula is only valid under stationary conditions, a requirement which was certainly not fulfilled in detail in this case. Former knowledge from the area (Ljøen 1962, Dickson, Midttun and Mukhin 1970), however, indicates that the main features of the system were stationary and that the current was roughly described by this method.

The 400 db surface was chosen as a reference level. When the reference depth was greater than the depht to the bottom, the method described by Helland-Hansen (1934) was used.

According to previous current measurements in this area (Blindheim and LOENG 1978, HELLE 1979, LOENG 1979), the velocities at 400 m depth can be high, typically 5—15 cm/sec, and there may be considerable velocities near the bottom. The measurements also showed considerable time variations with respect to speed and direction.

Under such conditions the computed current would vary with the current at the reference surface. Comparison between obtained transports over the years will therefore not necessarily represent fluctuations in Atlantic inflow. Thereby the dynamic computations give only a rough picture of the velocity field.

The computations gave, roughly, the same picture from year to year. Therefore, only the mean velocities in the section are presented in Fig. 16. One characteristic feature was the strong horizontal gradient in north. This gradient zone coincided with the mixing zone between the Atlantic and Arctic waters .There was an outflow of Arctic water from the Barents Sea along the northern slope, and the strongest east-going current occurred near the surface just south of this outflow region. The current measurements done in this area (BLINDHEIM and LOENG 1978, HELLE 1979, LOENG 1979) seemed to confirm this picture. These measurements, however, show that the west-going current may have been somewhat

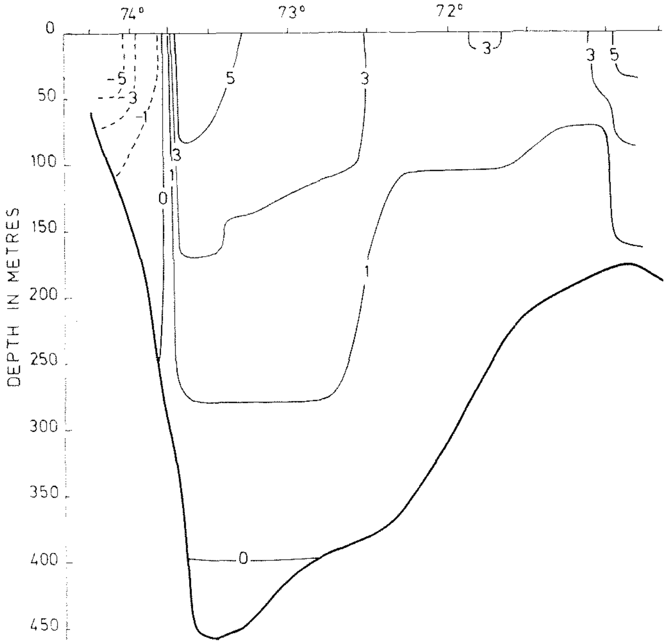

Fig. 16. Mean velocities (cm/s) computed by Helland-Hansen's formula in the Fugløya–Bjørnøya section, 1966–1977. —— : Current towards east. – – –: Current towards west.

wider and much deeper than shown in Fig. 16. The current measurements indicate that the westward current existed down to the bottom along the northern slope.

Rather high velocities were also calculated in the southern part of the section, in the coastal water. However, the velocities were much lower than found by the above mentioned current measurements.

In some years the horizontal velocity gradient in the northern part was much stronger than shown in Fig. 16. Another feature which may be seen from dynamic computations is west-going currents between branches of the east-going current. This may either be due to vortices or counter currents, or the conditions at the reference surface. Similar features were also found by KUDLO (1961) and LJØEN (1962).

DISCUSSION

The present data set consists of sections repeated in the same season from year to year. Therefore the influence of seasonal fluctuations has to a considerable extent been avoided. As mentioned above, short-term fluctuations may be quite significant in the area of the Svinøy-NW section (SÆLEN 1959). The time series indicate that year-to-year variations are considerable, also in the Barents Sea. The information offered by sections repeated only once a year has serious limitations with regard to the time scale of short-term fluctuations. Variations obtained by comparing consecutive sections are here called year-to-year fluctuations, but their time scale may have been much shorter than a year. However, care has been taken to study the variations in parts of the sections where year-to-year fluctuations seemed least significant. In the sections Fugløya—Bjørnøya and Vardø-N the cores with maximum salinity in the mean sections (Figs. 6 and 7) coincided with low standard deviations in temperature and salinity during the observation period (Figs. 9 and 10). The same indication was given by the standard deviations of the mean curves of temperature and salinity along the sections in the depth layers 0—50, 50—100 and 100—200 m (Fig. 2). In the Svinøy-NW section no mean section is available, so the part of the section for which time series were prepared was chosen on the basis of the standard deviations of these means.

In the Sem Islands-N section the standard deviations were generally higher than in the other sections, and the cores with highest salinity were not characterized by low standard deviations. In this section the choice of the part of the section for study of time variations was therefore not supported by the standard deviation section (Fig. 11). A reduction of year-to-year variations by choice of area was therefore not obtained here.

The mean values of temperature and salinity in the Svinøy-NW section given in Table 1 show more homogeneous conditions in January than in December. In January the salinity was almost homogeneous in all three depth layers, while temperature was homogeneous in the two upper layers. The reason for this was vertical mixing due to seasonal thermo-haline convection. This convection may go deeper than 200 m, and colder, less saline water mixes from below. The intensity of the convection may, however, vary from year to year. As a result of this, there was an increase in the standard deviation in the 100—200 m layer from December to January. In the 0—50 and 50—100 m layer, however, the standard deviations decreased from December to January. This indicates that the convection had a smoothing effect on year-to-year and small-scale fluctuations. The time series from January should consequently give a better indication of the long-term trends than the series from December.

In the Barents Sea the year-to-year fluctuations decreased with depth and were greatest above the transition layer, i.e. in the 0—50 m layer. The standard deviations in this layer were considerably higher than in the two deeper layers (Table 2) and show that the relatively shallow upper layer was rather sensitive to atmospheric influence. The eastward increase in year-to-year fluctuations was due to the effect of varying ice conditions.

The annual means in the sections comprise portions of the sections great enough to have a smoothing effect on variations of small-scale spatial extent. In spite of this averaging, there were still considerable year-to-year variations in the time series. Comparison of the sections in the Barents Sea shows that the year-to-year fluctuations varied from section to section, indicating that these fluctuations were, to a great extent, local phenomena.

When the curves were smoothed by three-year running means, the more long-term trends could be more clearly seen. These trends were recognized in all sections from Svinøy-NW to the Sem Islands-N section, and their time scale was over several years. A rising trend from low temperatures in the mid 1960's to a maximum in the period 1970—1973 was observed in all sections. Observations in the Rockall Channel presented by ELLETT (1978) and at Ocean Weather Station M (GAMMELSRØD and HOLM, manuscript) show a similar trend. Decreasing temperatures and salinities in the 1970's were also observed in the Barents Sea as well as in the Rockall Channel and at Ocean Weather Station M.

ALEKSEYEV and PENIN (1973) describe temperature and salinity anomalies in the Norwegian and Greenland Seas. Also in their study the mid 1960's are characterized by negative anomalies though positive anomalies were observed around 1960.

The long-term fluctuations therefore show similar trends in the Rockall Channel as in wide areas of the Norwegian and Barents Seas, indicating that they were relatively large-scale phenomena. These trends were most likely connected with fluctuations in the Atlantic Current.

Another common feature of the observations in the Rockall Channel (ELLETT 1978) and those in the Barents Sea was the time lag between maximum salinity and temperature around 1970, while during the maximum period around 1960 no such time lag was observed.

The indications of a time lag between the trends observed in the Rockall Channel and the sections in the Barents Sea, support the assumption that the long-term trends were advective phenomena. COLEBROOK and TAYLOR (1979) draw similar conclusions from studies of sea surface temperatures in the open North Atlantic. Due to the rather local year-to-year fluctuations it is difficult to establish the time scale of this lag, but it appears that the time lag between the Rockall Channel and the Fugløya—Bjørnøya and Vardø-N sections is two-three years. This time lag is in fairly good agreement with the conclusions drawn by HELLAND-HANSEN and NANSEN (1909) who indicate a time lag of two years between the Svinøy area and the Kola section (along 33°30'E) in the Barents Sea.

The current computations made in the Fugløya—Bjørnøya section only give information on broad features of the current pattern. Current measurements have shown that the current directions are governed by the bottom topography. In the area of main Atlantic inflow through the section, measurements have shown an average current direction towards southeast (BLINDHEIM and LOENG 1978, HELLE 1979, LOENG 1979). This current direction is not normal to the section, and geostrophic computations will only give a component of the current. The computed velocities will consequently be lower than the real velocities in the flow direction.

The current measurements have also shown considerable speeds close to the bottom. In the deepest part of the Bjørnøya Channel there was transport towards the west, out of the Barents Sea, of cold, heavy, Barents Sea bottom water. In the mean density section (Fig. 6) this watermass was indicated by σ_t-values close to 28.1. The various sections showed fluctuations also in the volume of this water mass. Hence, the current conditions on the reference level at 400 m depth were not stationary and would give rise to fluctuations in the current computations. Therefore, any correlation between geostrophically-computed currents in the Fugløya—Bjørnøya section and Atlantic inflow, as indicated by Atlantic characteristics, cannot be expected.

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