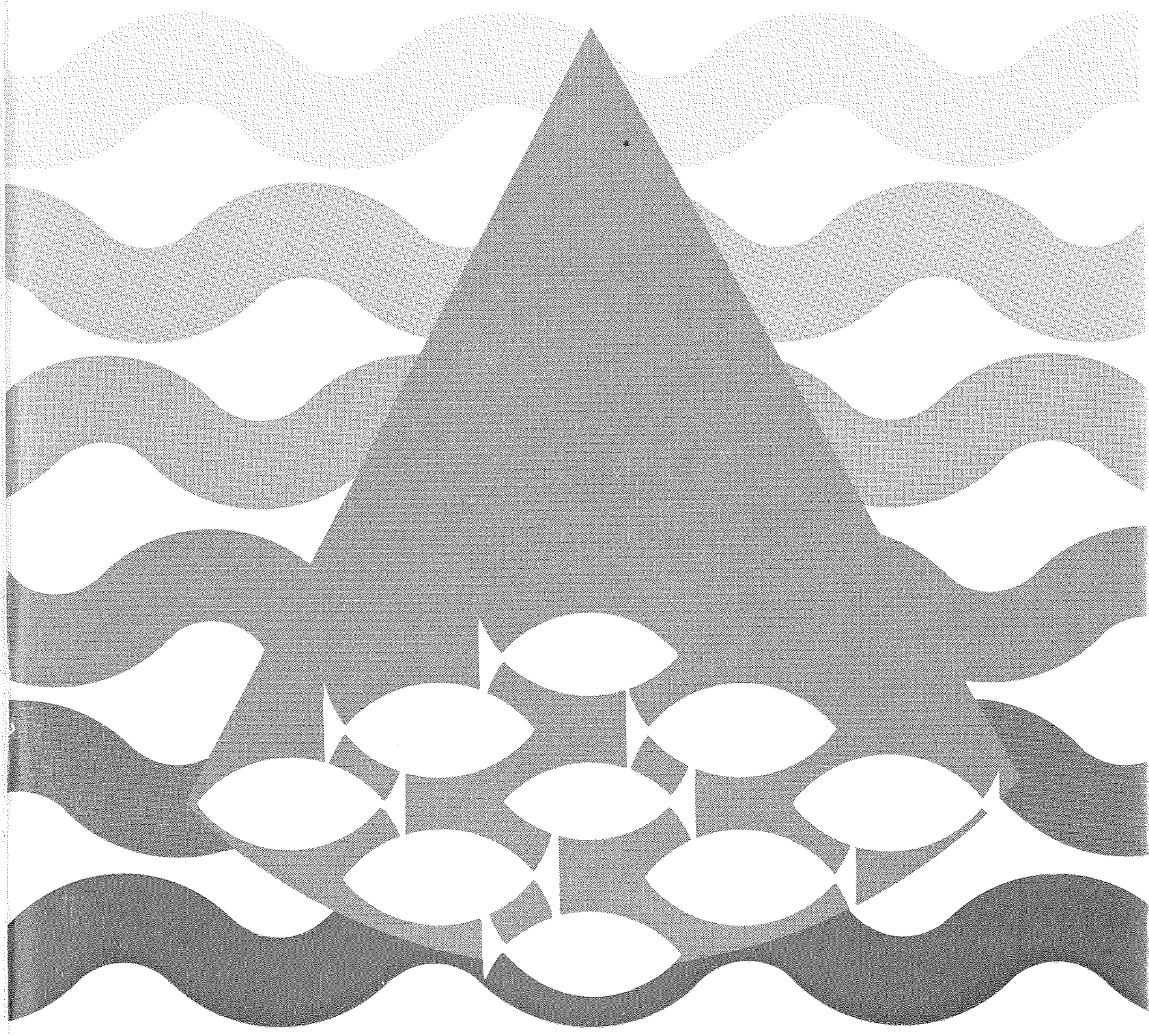
FISKERIDIREKTORATETS SKRIFTER

SERIE HAVUNDERSØKELSER

VOL. 16, NO. 12



DIRECTORATE OF FISHERIES, BERGEN, NORWAY
1978

FiskDir. Skr. Ser. HavUnders., 16: 457—464.

THEORETICAL ESTIMATION OF THE MEAN ECHO INTENSITY – FISH NUMBER DENSITY RELATION FOR ENCAGED SAITHE IN THE DORSAL ASPECT

By

KENNETH G. FOOTE

Department of Applied Mathematics, University of Bergen.

ABSTRACT

FOOTE, K.G. 1978. Theoretical estimation of the mean echo intensity — fish number density relation for encaged saithe in the dorsal aspect. *FiskDir.Skr.Ser.HavUnders., 16* : 457—464.

The formulation of an earlier theoretical study on the scattering of sound by encaged aggregations of fish (FOOTE 1978) is applied to the problem of the scattering of sound by an encaged aggregation of saithe when ensonified dorsally. The relationship of the mean time-integrated echo intensity $\bar{\varepsilon}$ and fish number density ν is computed for narrow-band pulsed sinusoidal signals of center frequency 38 kHz and 120 kHz for the same constant geometric and corresponding physical quantities as in the earlier study, but with use of the pertinent dorsal aspect target strength data in place of ventral aspect data. The computed $\bar{\varepsilon}$-ν relationships are compared with the corresponding ventral aspect results as obtained experimentally by RØTTINGEN (1976) and modelled theoretically in FOOTE (1978).

INTRODUCTION

In a recent paper (FOOTE 1978) some experimental results on the scattering of ultrasonic sound by encaged aggregations of fish were analyzed. The subject of the analysis, the empirical results of RØTTINGEN (1976), was expressed in the form of relationships of the normalized, mean time-integrated echo intensity $\bar{\varepsilon}$ to fish number density ν. These relationships had been obtained for a range of conditions of ensonification by a pulsed sinusoidal signal for two different kinds of fish, *Pollachius virens* (L.) or saithe, and *Sprattus sprattus* (L.) or sprat. The insensitivity in the forms of the empirical $\bar{\varepsilon}$-ν relationship to both the pulse duration and center frequency of the ensonifying signal for each species of fish was explained qualitatively by purely geometric considerations. A theory was then constructed and applied to the case of the saithe, for which more pertinent scattering data were available than for the case of the sprat.

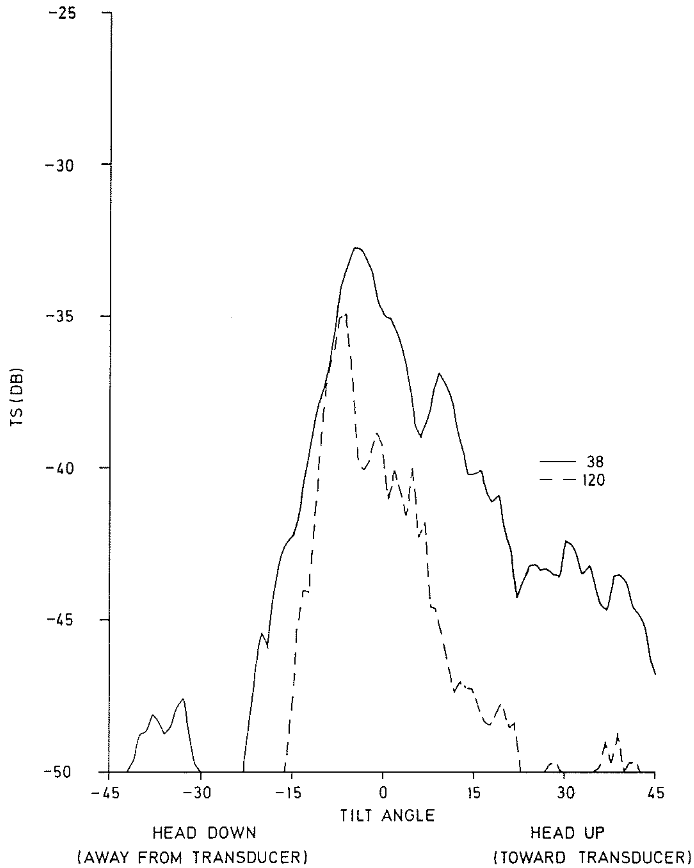


Fig. 1. Dorsal aspect target strength of saithe of mean length 35.1 $\pm$ 0.6 cm at 38 kHz when averaged with respect to 16 specimens, and at 120 kHz when averaged with respect to 17 specimens.

The fish in Røttingen's experiments were ensonfied ventrally in each case, as the transducers were located in a fixed position below the net cage. The corresponding ventral aspect target strength data were used in the quantitative analysis. Because of interest in at-sea applications of this work in fisheries research, where fish are generally ensonified dorsally, an evaluation of the theoretical $\bar{\varepsilon}$-ν relationship for saithe in the dorsal aspect is presented here for the same conditions of ensonification that obtained during the experiments.

METHOD

The evaluation of the theoretical expression for acoustic scattering by an aggregation of fish, as developed and applied in Foote (1978) to the particular circumstances of Røttingen's experiment, proceeds similarly to

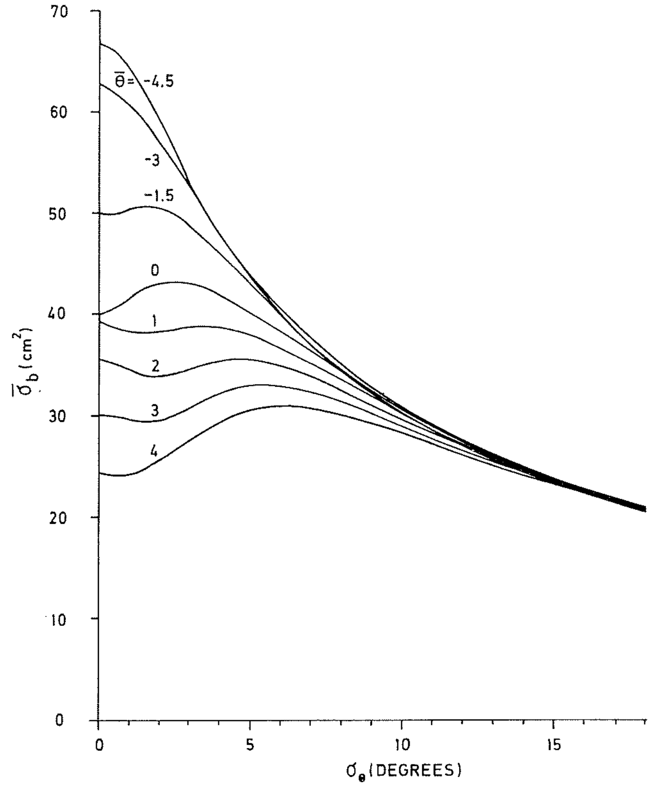


Fig. 2. Mean backscattering cross section $\bar{\sigma}_b$ of saithe in dorsal aspect at 38 kHz as a function of the spread σ_θ in tilt angle distribution with mean tilt angle $\bar{\theta}$ as a parameter.

that of the quoted study. The only difference is that the pertinent dorsal aspect target strength data are used in place of the ventral aspect target strength data.

The new dorsal aspect target strength data for saithe of mean length 35.1 ± 0.6 cm are shown in Fig. 1. The corresponding ensemble-averaged backscattering cross sections are presented in Fig. 2 and 3 for the respective cases of 38 kHz and 120 kHz. These latter quantities were computed with respect to the identical parameters of the orientation distribution of the earlier study.

RESULTS

The results of the evaluation of the model are shown in Fig. 4 and 5 for the respective cases of 38 kHz and 120 kHz signals. In both figures the same geometric conditions that obtained in Foote (1977) apply. In particular, it was assumed that the mean tilt angle θ of the orientation

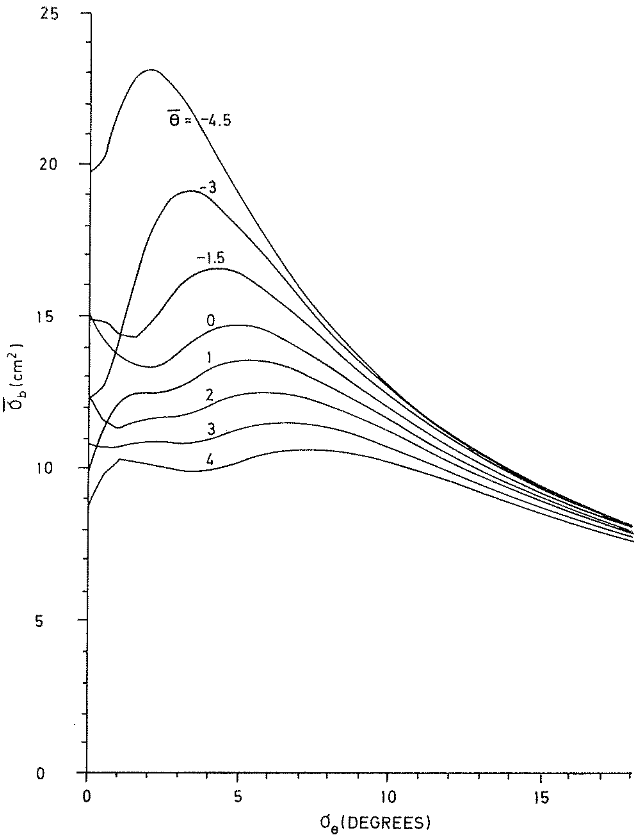


Fig. 3. Mean backscattering cross section $\bar{\sigma}_b$ of saithe in dorsal aspect at 120 kHz as a function of the spread σ_θ in tilt angle distribution with mean tilt angle $\bar{\theta}$ as a parameter.

distribution was 0 degrees and that the mean spread σ_θ in tilt angle distribution has the following form:

$$\sigma_\theta = [\sigma^2_{\theta,1,0} \exp(-2v/v_{cr}) + 4.2]^{1/2}$$

where $\sigma_{\theta,1,0}$, which is the free-space spread in tilt angle distribution, is 18 degrees, and ν_{cr}, or critical fish number density, is either 100 or 125 fish/m³. The same extinction cross sections that were used earlier were used here; namely, $\sigma_{e,o} = 60$ cm² for the 38 kHz signal and $\sigma_{e,o} = 100$ cm² for the 120 kHz signal.

DISCUSSION

The predicted normalized $\bar{\varepsilon}$-ν relationships for saithe in the dorsal aspect, cf. Fig. 4 and 5, are rather different from the corresponding relationships for the ventral aspect as observed by RØTTINGEN (1976) and

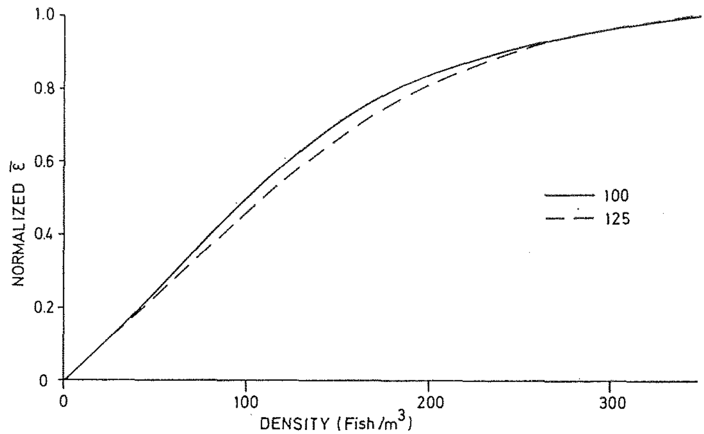


Fig. 4. Theoretical normalized mean time-integrated echo intensity $\overline{\varepsilon}$ as a function of density ν for saithe (in the dorsal aspect) at 38 kHz for the following model parameters: $\overline{\theta}$ = 0 degrees; $\sigma_{e,o}$ = 60 cm²; $\sigma_{\theta,1,0}$ = 18 degrees; ν_{cr} = 100 and 125 fish/m³.

reproduced theoretically by FOOTE (1977). The source of these differences in the case that the corresponding ventral and dorsal aspect extinction cross sections are identical and all geometric quantities remain unchanged, according to theory, lies entirely in differences in the tilt angle dependences of corresponding ventral and dorsal aspect target strength data, thence to differences in the ν-dependences of the corresponding ensemble-averaged backscattering cross sections. These differences are illustrated in Fig. 6 and 7, which show the dependence of $\overline{\sigma}_b$ on the spread σ_θ in tilt angle distribution for a mean inclination of 0 degrees

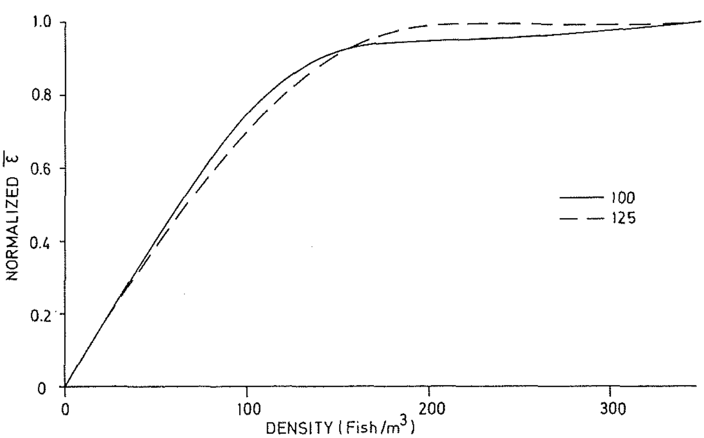


Fig. 5. Theoretical normalized mean time-integrated echo intensity $\overline{\varepsilon}$ as a function of density ν for saithe (in the dorsal aspect) at 120 kHz for the following model parameters: $\overline{\theta}$ = 0 degrees; $\sigma_{e,o}$ = 100 cm²; $\sigma_{\theta,1,0}$ = 18 degrees; ν_{cr} = 100 and 125 fish/m³.

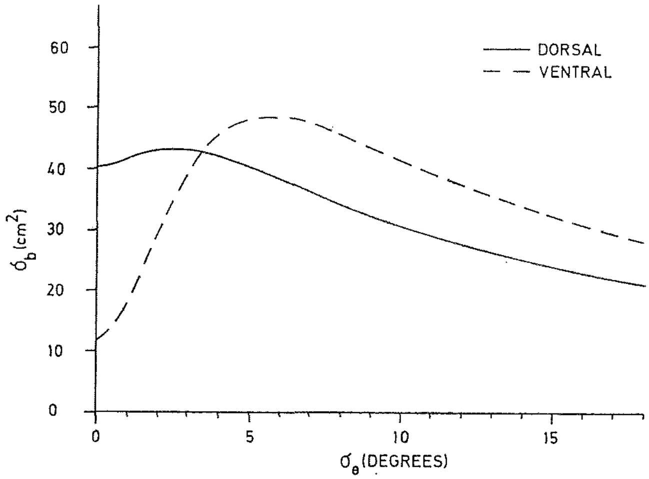


Fig. 6. Mean backscattering cross sections of saithe in dorsal and ventral aspects at 38 kHz as a function of the spread σ_θ in tilt angle distribution for mean tilt angle of 0 degreses.

for signals with respective center frequencies of 38 kHz and 120 kHz. The dorsal aspect curves shown here were extracted from Fig. 2 and 3, while the ventral aspect curves were taken from Fig. 5 and 6 of FOOTE (1978).

In the case of the 38 kHz signal the difference in behaviour of $\bar{\sigma}_b$ for σ_θ less than 5.5 degrees, cf. Fig. 6, is significant. For these values of σ_θ, which correspond to values of ν greater than about 125 fish/m^3, $\bar{\sigma}_b$ decreases with decreasing σ_θ or, equivalently, with increasing ν for the ventral aspect, while remaining nearly constant for the dorsal aspect. The corresponding $\bar{\varepsilon}$-ν relationships show a definite peaking for ν approximately equal to 160 fish/m^3 in the ventral aspect, and a steady monotonic increase to the maximum computed density, 350 fish/m^3, in the dorsal aspect.

The dependences of $\bar{\sigma}_b$ on σ_θ for the case of a 120 kHz signal are very similar at all values of σ_θ in excess of about 2 degrees. Because the irreducible perspectival contribution to σ_θ exceeds 2 degrees for the particular conditions of Røttingen's experiment, the dependences of $\bar{\sigma}_b$ on ν over the entire range of values of ν can be considered similar for both aspects. Thus the $\bar{\varepsilon}$-ν relationships, after appropriate normalization, are seen to be nearly identical at 120 kHz.

An assumption which has been applied consistently in the computations of this paper is that the dorsal and ventral aspect extinction cross sections are identical. Thus the dorsal aspect extinction cross section has been equated to 60 cm^2 and 100 cm^2 for the respective cases of 38 kHz and 120 kHz signals. It is noted that there is no a priori reason why the dorsal

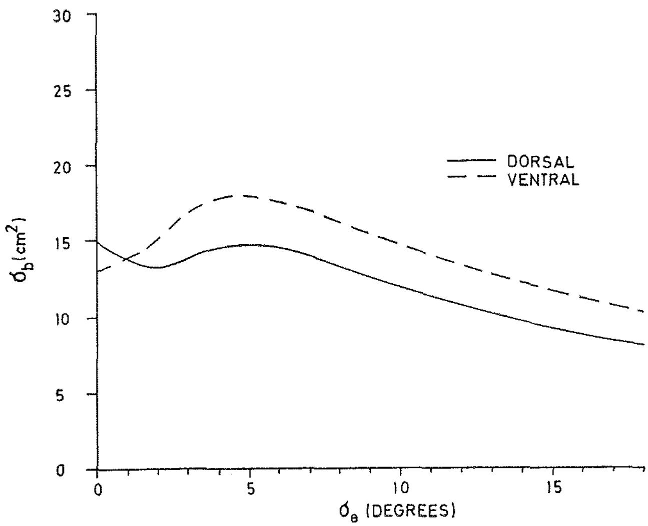


Fig. 7. Means backscattering cross sections of saithe in dorsal and ventral aspects at 120 kHz as a function of the spread σ_θ in tilt angle distribution for mean tilt angle of 0 degreses.

and ventral aspect cross sections should be equal, except in the limit of sufficiently high frequencies. In this limit the pheomenon of scattering is said to become geometric, and the total scattering cross section, thence extinction cross section in the case that absorption within the fish is negligible, is equal to twice the net projected area of the fish. Thus the total scattering cross sections of the fish in ventral and dorsal aspects, and, presumably, the ventral and dorsal aspect extinction cross sections, would be equal.

With respect to the specimens of saithe and signal frequencies of Røttingen's experiment it was found that the characteristic scattering size-to-wavelength ratio was generally much greater than unity, i.e., that the ensonifying frequencies were high. However, the high frequency asymptotic limit evidently did not obtain, for the extinction cross section was observed to depend on frequency. In this case, in which scattering is non-geometric, or frequency dependent, the dorsal and ventral aspect extinction cross sections, like their backscattering cross sections, may be different. The effect of a change in the extinction cross section on the normalized $\bar{\varepsilon}$-ν relationships of Fig. 4 and 5 will be similar to that shown in Fig. 10 of Foote (1977) by virtue of the mathematical equivalence of the quantitative descrtptions of ventral and dorsal aspect scattering.

ACKNOWLEDGEMENT

I. Røttingen, Institute of Marine Research, Bergen, is thanked for providing previously unpublished dorsal aspect target strength data for saithe, and O. Olsen, Department of Physics, University of Bergen, for his help in analyzing them. The financial support of the Royal Norwegian Council for Scientific and Industrial Research is acknowledged.

REFERENCES

FOOTE, K.G. 1978. Analysis of empirical observations on the scattering of sound by encaged aggregations of fish. *FiskDir.Skr.Ser.Havunders.*, *16*: 423–456.

RØTTINGEN, I. 1976. On the relation between echo intensity and fish density. *FiskDir.Skr.Ser.HavUnders.*, *16*: 301–314.

Received 20 June 1977
Printed 7 June 1978

FiskDir. Skr. Ser. HavUnders., 16: 465–487.

VARIATIONS IN ZOOPLANKTON VOLUMES AT THE PERMANENT OCEANOGRAPHIC STATIONS ALONG THE NORWEGIAN COAST AND AT WEATHERSHIP STATION M(IKE) IN THE NORWEGIAN SEA DURING THE YEARS 1949–1972

BY

KRISTIAN FREDRIK WIBORG
Institute of Marine Research, Bergen

ABSTRACT

WIBORG, K.F. 1978. Variations in zooplankton volumes at the permanent oceanographic stations along the Norwegian coast and at weathership station M(ike) in the Norwegian Sea during the years 1949–1972. *FiskDir. Skr. Ser. HavUnders., 16*:465–487.

During the years 1949–1972 zooplankton was sampled in vertical hauls at permanent oceanographic stations along the coast of Norway and at the weathership station «M» in the Norwegian Sea. During 1949–1962 (station M: –1965) Nansen net «8/72» was used, later the Juday net, J.36. The Juday net was found to catch more plankton in relation to the opening of the net.

During May–August average plankton volumes were larger off northwestern Norway than farther south.

Deviations from the long term averages in plankton volumes were compared with observations from adjacent areas of the North Sea, Norwegian Sea and Barents Sea. Some similarities were found, but local variations seem to be the major cause of observed differences.

No clear relationship was established between zooplankton biomass and sea temperature.

Rich year classes of cod seem to be born more frequently in years when zooplankton biomass is above average, while medium and poor year classes are possibly more frequent in years with lower abundance of plankton, but the data are not sufficient for a conclusion.

No correlation was found between abundance of plankton and of cod larvae.

INTRODUCTION

Since 1949 the composition and quantities of zooplankton along the coast of Norway and in the Norwegian Sea have been described in a number of reports (LIE 1961, 1966, 1968, WIBORG 1954, 1955, 1958, 1960 a and b, 1976). This paper deals with variations in zooplankton volumes at the permanent oceanographic stations and at station M during the years 1949—1972.

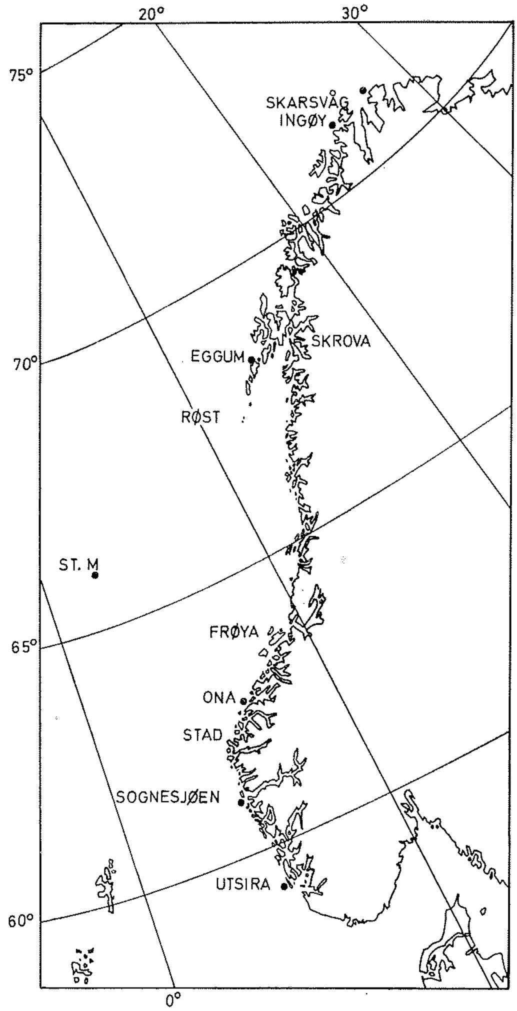


Fig. 1. Permanent zooplankton stations 1949—1972.

MATERIALS AND METHODS

Zooplankton has been sampled in vertical hauls from the bottom to 0 m and from 50 to 0 m at permanent oceanographic stations along the coast of Norway (Fig. 1) at intervals from one week to one month since 1949. At weathership station M in the Norwegian Sea (lat. 66°00′ N, long. 02°00′ E) samples have been taken weekly from 100 to 0 m and during some years also from 25 to 0 m. Here, a 600—100 m haul was also taken once a month and since September 1959, once a week.

During 1949—1965 a Nansen net (opening diameter 70 cm, mesh size approx. 180 μ, Dufour bolting silk No. 8) was used, to be replaced by the Juday net, (diameter 36 cm, mesh size 180 μ, Nytex nylon gauze). The net was not changed simultaneously at all stations and was shifted last at station M.

Plankton volumes were measured after removal of large organisms such as salps and medusae, until 1970 by draining (WIBORG 1954) and later by displacement (ROBERTSON 1970). A comparison indicated slightly higher figures for draining, and a correction factor of 0.75 was calculated and used for the earlier figures from draining.

According to BOGOROV (1959) the Juday net catches up to twice as many organisms per 1 m^3 as the Nansen net. In the present investigation the displacement volumes in relation to the net opening were also larger in the Juday net hauls. TRANTER and SMITH (1968) assumed that the tropical Juday net, which is a scaled up version of the ordinary Juday net, might have an initial efficiency of more than 100% because of its non-porous reduction cone, and that the probability of clogging could be high in tows longer than 50 m in water rich in plankton. In order to test the effect of the reduction cone a Juday net similar to those used in the present investigation was equipped with a Tsurumi-Seiki flowmeter placed halfway between the sentre and the rim (ANON. 1968 p. 156) and suspended from a bar, one end of which extended well outside the rim of the net. Another flowmeter was fastened at this end. The unit was twice towed round a circular tank for a distance of approximately 180 m at a speed of 1.0 m/sec. and 0.8 m/sec. The reading of the flowmeter indicated a filtration of 83.2% of the water offered. Vertical hauls were taken in September 1977 in the sea near Bergen at a speed of 0.5 m/sec. In five 20-0 m hauls the percentages of filtration were, 73.8, 88.3, 88.3, 88.3, and 90.2; average 85.8%. In four 200-0 hauls, 62.8, 67.0, 68.7, 71.0, average 67.4%. In two 300-0 hauls, 65.1, 67.7, average 66.4%. Thus it is evident that the initial filtration of the Juday net is below 100% and that the percentage of filtration may decrease further with increasing length of the haul if plankton is abundant. No flowmeter tests are available for the Nansen net.

In the present investigation no correction factor has been used for filtration. Accordingly, volumes of plankton per unit of sea surface are minimum figures.

RESULTS

AVERAGE MONTHLY ZOOPLANKTON VOLUMES DURING 1949—1972

The monthly average plankton volumes during 1949—1972 are shown in Fig. 2 and Table I, p. 484. The Juday net figures are generally higher, and are considered to give a more reliable picture of the plankton quantities.

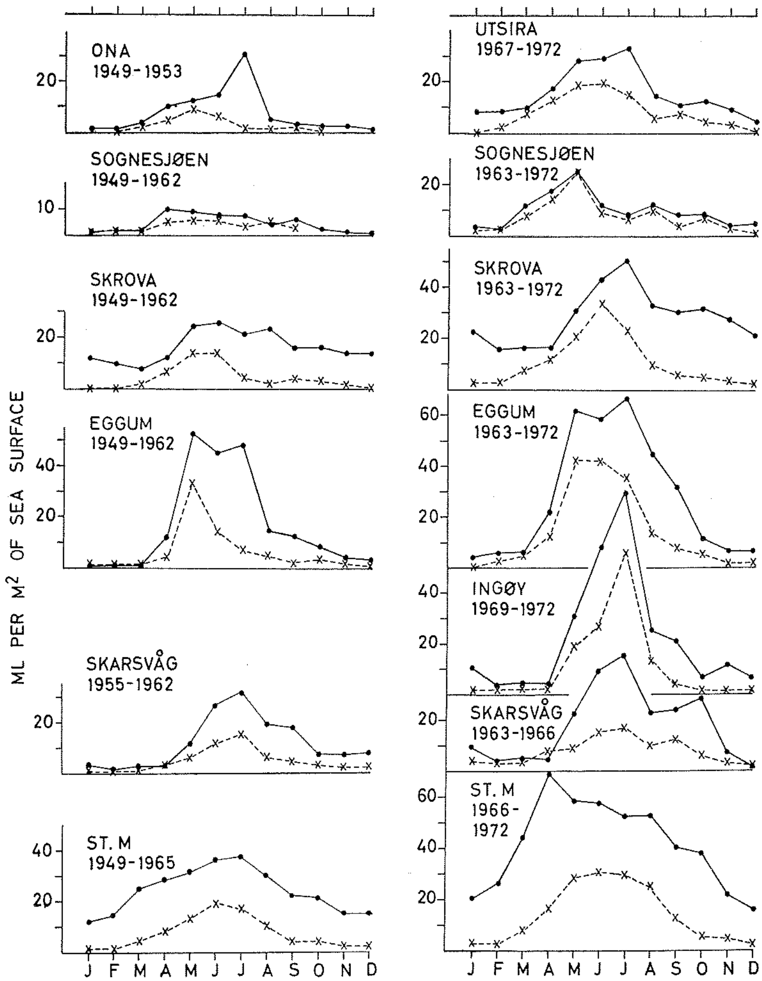


Fig. 2. Average annual variations in displacement volumes of zooplankton at permanent stations along the coast of Norway and at station M 1949—1972. Left) Nansen net hauls, right) Juday net hauls. Monthly mean figures per m² of sea surface. Dashed) 50-0 m, solid) bottom to 0 m (station M 100-0 m and 600-0 m).

Utsira

Sampling started in 1965 though samples were not regular until 1967. The spring increase starts at the end of March with maximum volumes occurring in June—July. These were of about 30 ml/m² in the total hauls and 20 ml/m² in the upper 50 m. Small increases have been observed in September—October.

Sognesjøen

Plankton volumes were small when compared to those of the other stations. The bottom is at 300 m, but hauls were only taken from 200 m, and some plankton may not have been sampled due to it staying below this depth, especially from autumn to spring. The spring increase starts in March—April though during 1949—1962 the average volume did not change very much from April to July. There was a second increase in August—September.

During 1963—1972 the peak in May was more pronounced with a maximum of 25 ml/m².

Ona

Complete data are only available from 1949 to 1953. The spring increase started in March—April, the main maximum in the upper 50 m occurring in May and in the total water column, in July.

Skrova

The spring increase started in April—May. During 1949—1962 the plankton of the upper 50 m was most abundant from May to June and in the total hauls from May to August. A second peak was indicated in September—October. During 1963—1972 the total volume had a main peak of 50 ml/m² in July while the 50-0 volume was at a maximum of 34

Table 1. Average biomass of zooplankton from 0 to 50 m in the eastern Norwegian sea (Norwegian Current) in June 1958 (mg/m³). From GRUZOV and PAVSHTIKS (1961), TIMOKHINA (1963, 1972).

Section	1958	1959	1960	1961	1962	1965	1966	1967	1968	1969	1970
71°10′ N	1183	831	1464	1240	1154	960	1480	—	1220	1870	1223
69°20′ »	1736	1100	1160	1230	1528	1180	1684	1820	1480	1444	830
67°30′ »	—	—	1256	735	818	2040	3000	2080	2500	1370	1014
65°45′ »	—	—	—	—	1346	2320	1840	1040	1620	574	1600
63°00′ »	—	1070	920	552	1204	1200	1340	840	846	1407	1134
60°04′ »	—	1406	940	—	636	1240	—	—	1432	1056	822

ml/m² in June. During winter the plankton was relatively abundant, 15—22 ml/m², probably an accumulation effect due to the topography of the Vest fjord.

Eggum

The variations have been characterized by small volumes during late autumn and winter and distinct peaks in May—July. Volumes have been larger than at Skrova, maxima in 1963 were 60—67 ml/m² for the total hauls and 42 ml/m² in the upper 50 m.

Skarsvåg—Ingøy

The spring increase starts in April—May, the main maximum occurring in July and a second peak in September. In 1963—1966 the average maximum volumes were 37—45 ml/m². After three years without plankton sampling at the Skarsvåg station, it was replaced by Ingøy in 1969 with complete sampling from July 1969 to August 1972. The high peak in July (Fig. 2) was caused by one sample of 165 ml/m² in July 1970.

Station M

The spring increase starts in February—March. For the 1949—1965 period the peak for the 100-0 m hauls reached in May, for 600-0 m in July, and during 1966—1972 the maxima for both intervals were reached in April. Plankton was relatively abundant in the upper 100 m until July and in the upper 600 m until October.

AVERAGE ZOOPLANKTON VOLUMES DURING MAY—AUGUST

Averages have been worked out per month for the period May—August when the plankton generally is most abundant (Fig. 3).

The larger figures calculated for the Juday net hauls are immediately apparent, but the ranging in biomass at the stations is more or less the same, viz. Eggum, station M, Skrova, Skarsvåg and Sognesjøen. During the period 1949—1962 Ona ranged before Sognesjøen as did Utsira during 1963—1972.

The 50-0 m volumes were about half the total volume or below, except at Sognesjøen where the deeper layers may have been sampled insufficiently. At station M the 100-0 m volumes where of nearly the same size as the 50-0 m volume at Eggum.

It is assumed that the 1963—1972 figures give a relatively correct picture of the average quantities of plankton during May—August at Eggum and station M, *i.e.* 50—60 ml/m², at Skrova and Skarsvåg 30—40 ml/m², at Sognesjøen and at Utsira 15—25 ml/m².

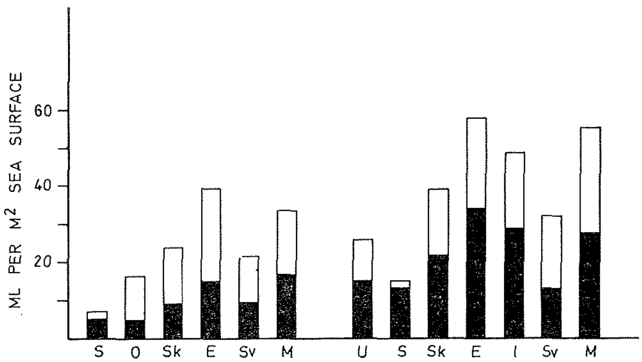


Fig. 3. Average monthly zooplankton volumes during May—August. Left) Sognesjøen (S), Skrova (Sk) and Eggum (E) 1949—1962, Ona (O) 1949—1954 Skarsvåg (Sv) 1955—1962, station M 1949—1965. Right) Utsira (U) 1967—1972, Sognesjøen, Skrova and Eggum 1963—1972, Ingøy (I) 1969—1972, Skarsvåg 1963—1966, station M 1966—1972. Total column) bottom to surface, black column) 50-0 (station M 600-0 m and 100-0 m).

DEVIATIONS FROM THE MEAN MONTHLY AVERAGES DURING THE YEARS 1949—1972

Fig. 4—10 show deviations from the mean plankton volumes for each month and for the period April—August during the years 1949—1972 (Table I). In some years data are incomplete, lacking for one to several months or even years. For this reason the period April—June has been used for station M instead of April—August. The figures have therefore to be considered with reservation.

The deviations in a particular year are seldom similar at two or more stations. During 1950 positive deviations occurred in June at Eggum and station M, and in August at Ona, Skrova, Eggum and station M. In

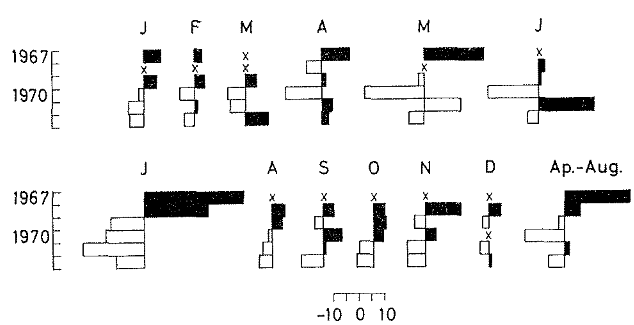


Fig. 4. Utsira. Deviations from the mean zooplankton volumes for each month of the year and of the period April—August 1967—1972. x) No observations.

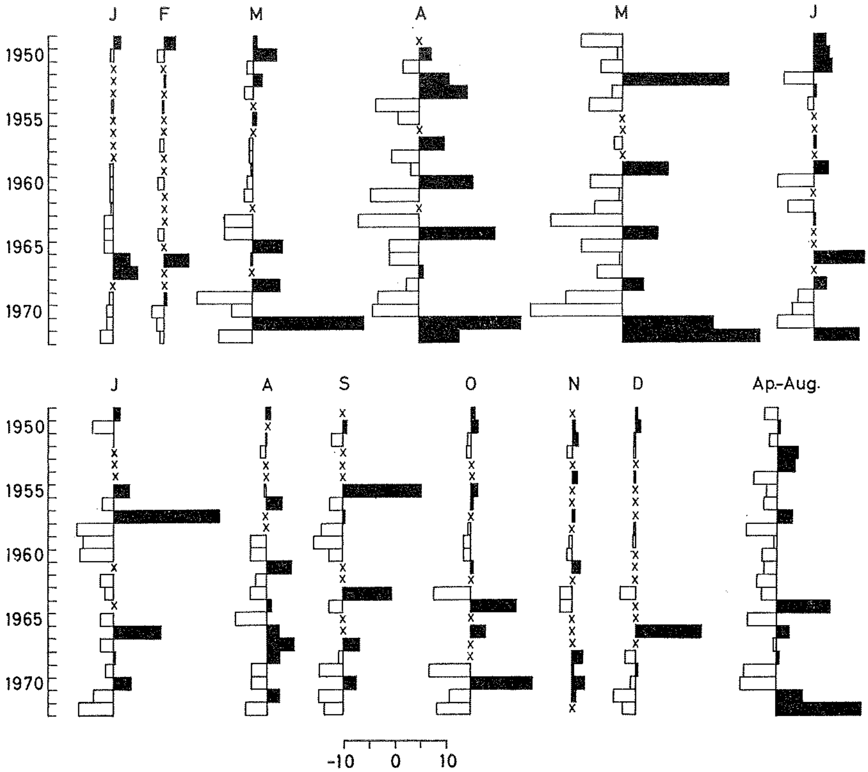


Fig. 5. Sognesjøen. Deviations from the mean zooplankton volumes for each month of the year and of the period April-August during 1949–1972. x) No observations.

1965 there were positive deviations in June, July and August at Skarsvåg and station M. In 1966 deviations were common in June at Sognesjøen, Skrova and Eggum, and in July at Sognesjøen and Skrova.

DISCUSSION

COMPARISON OF ZOOPLANKTON IN ADJACENT AREAS

During April 1962 and April—May 1963 zooplankton was very abundant on the coastal banks off Stad—Frøya on the west coast of Norway (Wiborg 1976), but scarce at the permanent station at Sognesjøen. At Eggum the biomass was below average during April—May 1962, but above average in May 1963. During April—May 1964 zooplankton was abundant over all coastal banks between Stad and Røst (Wiborg 1976) and at Sognesjøen and Eggum.

Longhurst *et al.* (1972) reported on annual fluctuations in abundance of various plankton organisms west of the British Isles and in the North

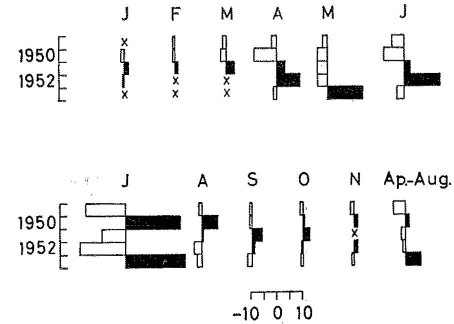


Fig. 6. Ona. Deviations from the mean zooplankton volumes for each month of the year and of the period April—August 1949—1953. x) No observations.

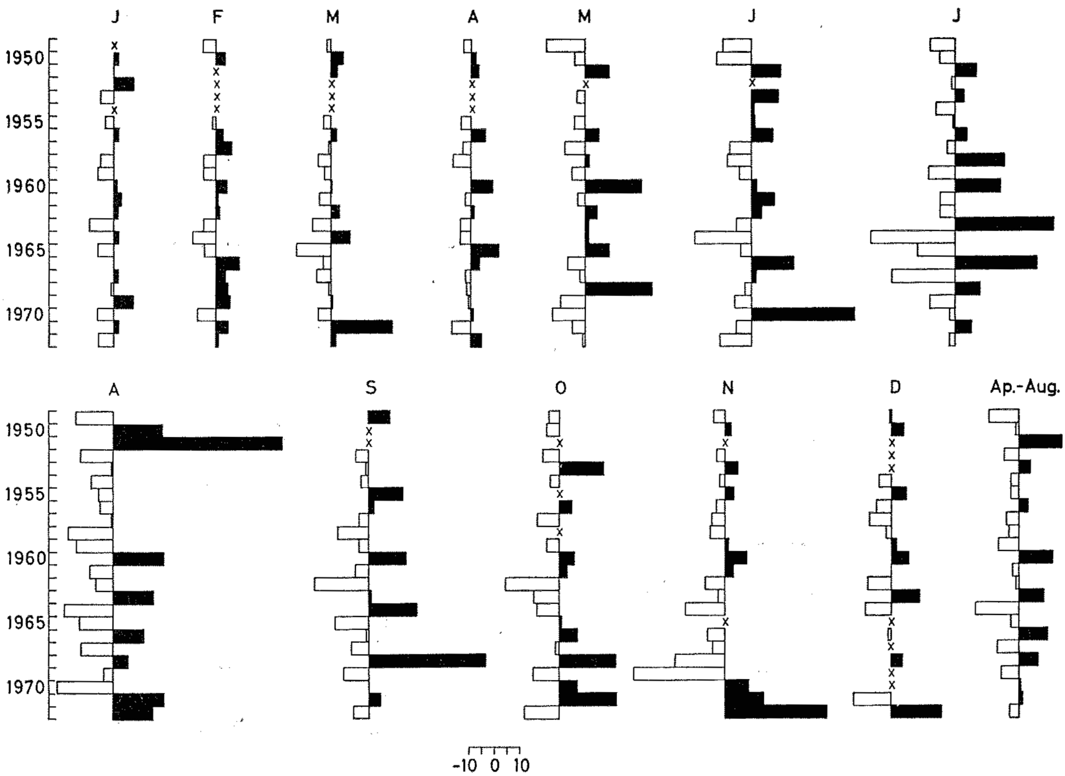


Fig. 7. Skrova. Deviations from the mean zooplankton volumes for each month of the year and of the period April—August 1949—1972. x) No observations.

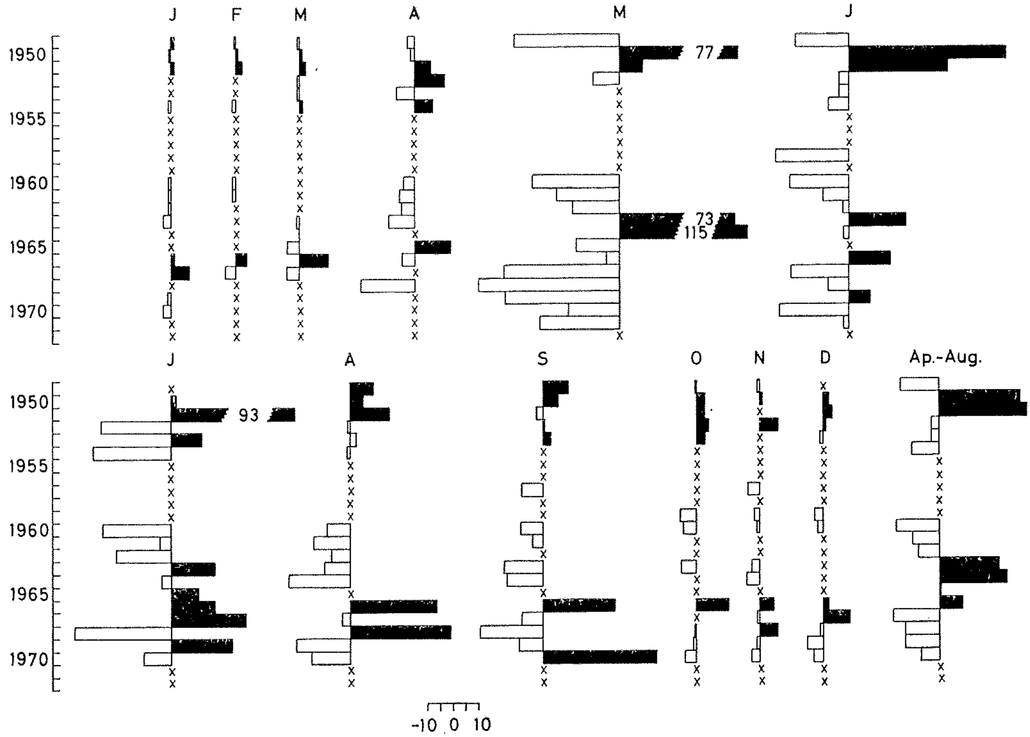


Fig. 8. Eggum. Deviations from the mean zooplankton volumes for each month of the year and of the period April—August 1949—1972. x) No observations.

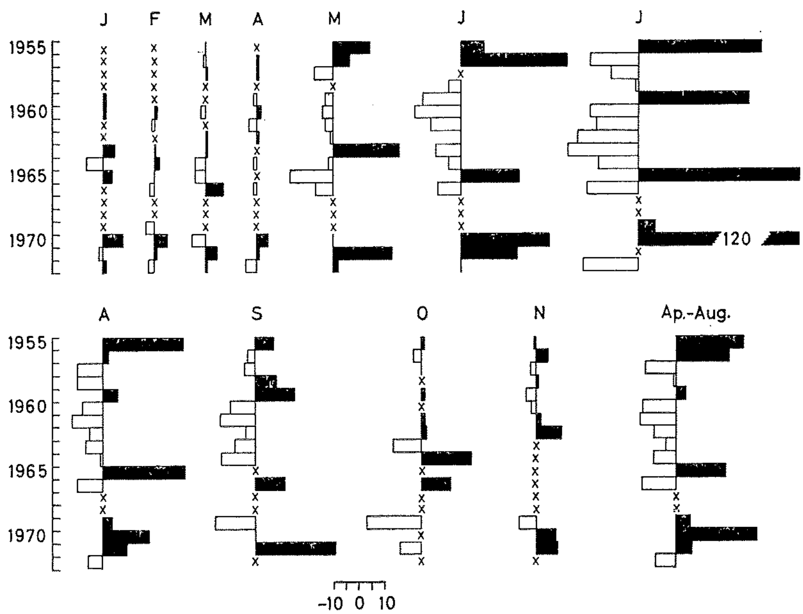


Fig. 9. Skarsvåg and Ingøy. Deviations from the mean zooplankton volumes for each month of the year and of the period April—August 1949—1972. x) No observations.

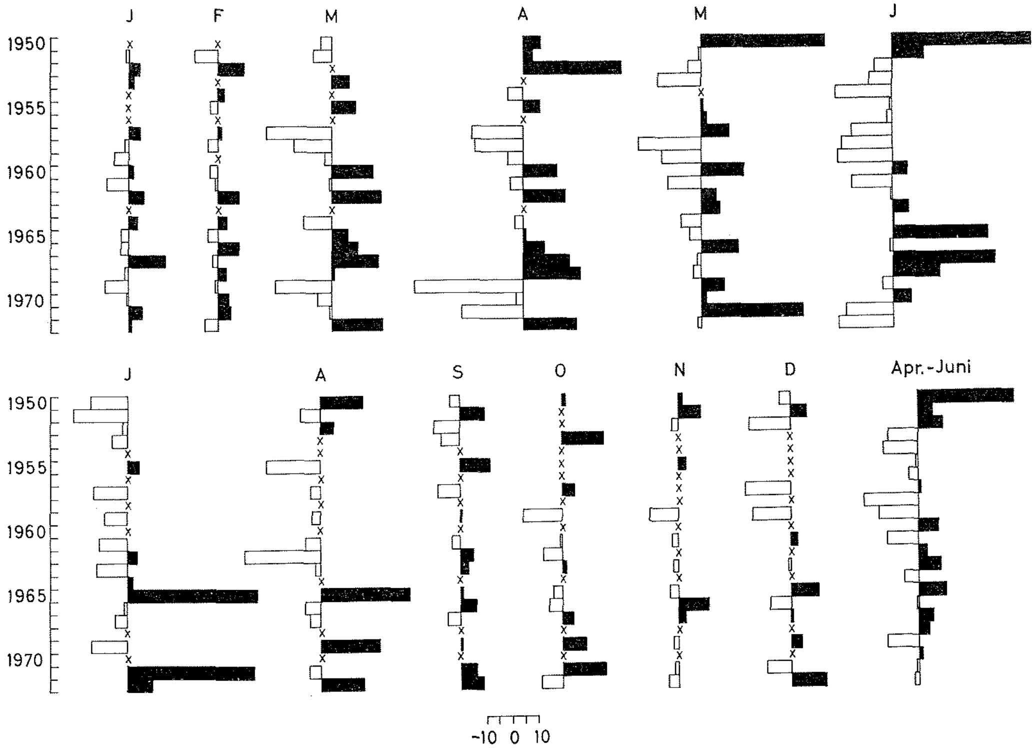


Fig. 10. Station M. Deviations from the mean zooplankton volumes for each month of the year and of the period April—June 1949—1972. x) No observations.

Sea during the years 1949—1970. In the North Sea the number of *Calanus* sp. fluctuated in very much the same way as in the figures for April—August at Sognesjøen, with peaks in 1952 and 1964 and large reductions in 1958, 1962 and 1965 (Fig. 11).

The biomass and composition of the zooplankton in the Norwegian Sea have been studied for a number of years by Soviet scientists. Most of the samples were collected in June in the eastern part of the area in sections along the parallels between 60°N and 74°N. Biomass was calculated as mg/m^3 of zooplankton in 50-0 m. Data from GRUZOV and PAVSHTIKS (1961), and TIMOKHINA (1963, 1972) are compiled in Table 1. The two northern sections may be compared with Skarsvåg and Ingøy, the median ones with Skrova and Eggum and the two southern sections with Sognesjøen. There does not seem to be any common trend in the variations of abundance among the sections, neither do they correspond with any of the coastal stations in their variations.

TIMOKHINA (1968) calculated the average annual biomass of *Calanus*

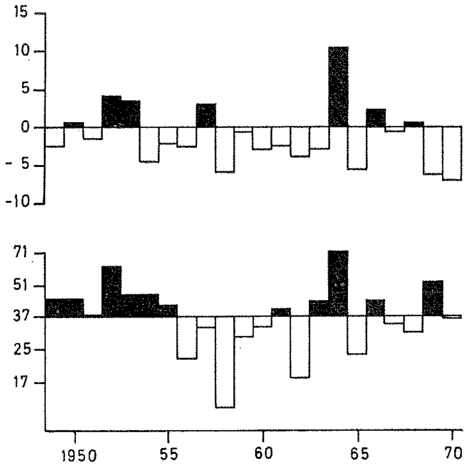


Fig. 11. Deviations from the mean monthly zooplankton volumes for the period April —August at Sognesjøen 1949—1970 compared with variations in relative abundance of *Calanus* sp. in the same years, redrawn from LONGHURST *et al.* (1972).

finmarchicus in coastal waters off western and northern Norway during 1959—1963. The figures were as follows (tons per km^2): 1959, 19.5; 1960, 14.4; 1961, 2.8; 1962, 12.4; 1963, 22.0.

A zooplankton biomass above average was recorded at station M and Skrova during April—August 1960 and at station M, Skrova and Eggum during the same period in 1963. At Skarsvåg the biomass was above average in 1959, but below during 1960—1963.

CORLETT (1965) studied zooplankton in the western Barents Sea during the summers of 1949—1959. The biomass was relatively high in 1949, 1950, 1954 and 1957—1959, but low in other years (see Table 4, p. 00). Similarities to the Eggum and Skarsvåg results thus occurred in 1950, 1952, 1953, 1958 and 1959.

During the years 1951—1958 ZELIKMAN and KAMSHILOV (1960) observed a small biomass in the southern Barents Sea in 1952, maxima in 1951 and 1954, and also high figures in 1955—1957. At Eggum and Skarsvåg the April—August figures were similar in 1951, 1952, 1955 and 1956.

ANTIPOVA, DEGTYAREVA and TIMOKHINA (1974) observed peaks in abundance of zooplankton biomass in the southern Barents Sea in May 1950, 1959, 1960, 1961 and 1967, and in July 1950, 1953, 1962 and 1964.

Zooplankton thus seems to have been commonly very abundant both off the northwestern coast of Norway and in the western, or southern, or in both areas of the Barents Sea during the spring and summer months of 1950, 1951, 1955, 1956 and also in July 1953. A biomass below average was common in 1952.

ZOOPLANKTON AND SEA TEMPERATURE

ZELIKMAN and KAMSHILOV (1960) did not find any clear relationship between the abundance of zooplankton and sea temperature.

ANTIPOVA, DEGTYAREVA and TIMOKHINA (1974) observed a positive correlation between the temperature of the sea in April and May and the biomass of zooplankton along the Kola section in the southern Barents Sea. They concluded that the warming of the upper water layers stimulated the growth of phytoplankton which in turn influenced the development of the zooplankton. Furthermore, the heat content of the upper water layers might also stimulate the development of the gonads of *Calanus finmarchicus*. For June, July and September there was no positive correlation, probably because *Calanus* then descended to deeper layers to hibernate.

MIDTTUN (1969, 1975) studied the annual variations in the sea temperature at the permanent oceanographic stations along the Norwegian coast during 1945—1965 and also surface temperatures at other coastal stations during 1936—1970. At Eggum maxima in temperatures were observed in 1950, 1961, and 1964 while surface maxima occurred in 1967 and 1970. Plankton biomass above average was observed in 1950 and 1964, but also in 1963 and 1966 when the temperature was low. Near Skarsvåg there were temperature maxima in 1959—1961 and minor peaks in 1964, 1967 and 1969—1970. Zooplankton biomass was slightly above average in 1959 and 1970 whereas the other peaks coincided with low sea temperatures.

The simultaneous occurrence of high sea temperatures and above average plankton biomass seems therefore to be rather accidental. It should, however, be noted that in 1950 there was a more general abundance of plankton at several localities, both at station M, Eggum, and partly at Ona and Skrova.

ZOOPLANKTON BIOMASS, ABUNDANCE OF COD LARVAE OFF THE NORTH-WESTERN COAST OF NORWAY, AND THE SIZE OF THE YEAR CLASSES OF ARCTO-NORWEGIAN COD

Deviations from the mean of the zooplankton biomass at Skrova, Eggum and Skarsvåg during April—August are compared in Table 2 with the relative abundance of cod larvae during May—July 1949—1972 and with the strength of the same year classes of cod at an age of 2 + years. Data on cod larvae have been taken from BARANENKOVA (1974), DRAGESUND and HOGNESTAD (1967), HOGNESTAD (1969 a, b, and c, 1971, 1972, 1973), SMESTAD and ØYESTAD (1974) WIBORG (1957, 1960) and on year classes of cod from PONOMARENKO (1976) and ANON. (1976).

Table 2. Occurrence of cod larvae off northern Norway, number of cod of 2+years/hour of trawling in the Barents Sea, and abundance of zooplankton at Skrova (S), Eggum (E) and Skarsvåg-Ingøy (Sk) during April—August 1949—1972. +) at or above average, ÷) below average, ×) no observation. R-rich, M-medium, P-poor. See text, p. 477-478

Year	Cod larvae		Cod, 2 + years No./hr of trawling	Zooplankton abundance		
	Apr.—June	June—July		S	E	Sk
1949	+	×	24 M	÷	÷	×
1950	÷	×	75 R	+	+	×
1951	÷	×	6 P	+	+	×
1952	+	×	3 P	÷	÷	×
1953	÷	×	9 P	+	÷	×
1954	+	×	6 M	÷	÷	×
1955	+	×	9 P	÷	×	+
1956	+	×	14 M	+	×	+
1957	÷	×	13 M	÷	×	÷
1958	+	×	19 M	÷	×	+
1959	+	÷	10 M	÷	×	+
1960	÷	÷	13 M	+	÷	÷
1961	÷	+	2 P	÷	÷	÷
1962	+	+	6 M	+	÷	÷
1963	÷	+	76 R	+	+	÷
1964	÷	÷	46 R	÷	+	÷
1965	÷	÷	1 P	÷	÷	+
1966	÷	÷	1 P	+	+	÷
1967	÷	÷	1 P	÷	÷	×
1968	÷	÷	5 P	+	÷	×
1969	÷	÷	9 P	÷	÷	+
1970	+	+	79 R	+	÷	+
1971	+	×	32 R	+	÷	+
1972	+	×	35 R	÷	×	+

The abundance of cod larvae has been classified very roughly as high (+) or low (—). Year classes of cod with 30—79 specimens per hour of trawling are characterized as rich, those with 10—29 per hour as medium and those below 10 per hour as poor. The year classes of 1954 and 1962 have been adjusted to medium according to ANON. (1976).

The figures do not lend themselves to detailed statistical analysis, but in order to get a rough idea of the relationships, the data have been arranged as shown in Tables 3—6.

Rich year classes of cod seem to be born more frequently in years when zooplankton biomass is above average while medium and poor year classes are possibly more frequent in years with low abundance of plankton, but as data are lacking for a number of years, the conclusion is uncertain.

Table 3. Number of instances where zooplankton biomass was at or above average (+) or below average (÷) at Skrova, Eggum and Skarsvåg-Ingøy during April-August and year classes of cod aged 2 + years in the Barents Sea for the years 1949—1972. ×) no observation. Data from Table 2.

Cod Year-class	Zooplankton										
	Skrova		Eggum			Skarsvåg-Ingøy			Total		
	+	÷	+	÷	×	+	÷	×	+	÷	×
Rich	4	2	3	2	1	3	2	1	10	6	2
Medium	3	6	0	5	4	4	3	2	7	14	6
Poor	4	5	2	6	1	2	2	5	8	13	6

Corlett (1965) found a high positive correlation between the summer biomass of zooplankton in the western Barents Sea and the relative strength of the corresponding year classes of cod. His data have been used in Table 4 together with the figures from Eggum and Skarsvåg for the same period. Only 6 of the 11 observations of zooplankton above or below average correspond with the figures of relative strength of the cod year classes. This may indicate that the size of the year classes is partly determined after the cod fry have left the coastal areas of northern Norway.

Sysoeva (1973) studied the feeding and survival of the Barents Sea cod larvae. She concluded that the number of cod larvae in June—July did not depend on the number of eggs and larvae in April—May, but was determined by the survival from April—May to June—July. This sur-

Table 4. Year-classes of cod and zooplankton biomass in the western Barents Sea during summer (CORLETT 1965), and at Eggum-Skarsvåg in 1949—1959. Data and symbols as in Table 2.

Year	Year-class cod	Zooplankton mg/m^3	Zooplankton Eggum-Skarsvåg
1949	M	47	÷
1950	R	54	+
1951	P	15	+
1952	P	22	÷
1953	P	26	÷
1954	M	46	÷
1955	P	24	+
1956	M	29	+
1957	M	34	÷
1958	M	45	+
1959	M	35	+

Table 5. Number of cases where abundance of zooplankton was above (+) or below (÷) average, and abundance of cod larvae above (+) og below (÷) average in April–June and June–July at Skrova, Eggum and Skarsvåg. ×) no observation. Data from Table 2.

Cod larvae	Skrova		Eggum			Skarsvåg			Total		
April–June	+	÷	+	÷	×	+	÷	×	+	÷	×
+	4	7	0	6	5	7	1	3	11	14	8
÷	7	6	5	7	1	2	6	5	14	19	6
June–July											
+	3	1	1	3	0	1	3	0	5	7	0
÷	3	5	2	5	1	3	3	2	8	13	3

vival was determined by the feeding conditions and by the condition of the larvae. The feeding conditions were influenced by the number of nauplii of *Calanus finmarchicus* in May, but this dependency was not expressed very clearly. In June—July she found a negative correlation between the biomass of plankton and survival and number of cod larvae, therefore she concluded that the plankton had been consumed by the cod larvae.

The relationship between cod larvae and plankton biomass at Skrova, Eggum and Skarsvåg—Ingøy in 1949—1972 is shown in Table 5. As observations on zooplankton are missing for a number of years no conclusions may be drawn with certainty. As mentioned by Sysoeva (1973) eggs and larvae of copepods (*Calanus finmarchicus*) which are important as food for cod larvae, may be abundant in April—May, even if the biomass of zooplankton is small. It may therefore be concluded that it is the *quality* and *particle size* rather than the quantity of zooplankton which is the critical factor for the survival of the cod larvae.

The relationship between the size of the year classes and the abundance of cod larvae is shown in Table 6. For the poor year classes a positive correlation seems to exist with a low abundance of cod larvae both in

Table 6. Number of cases with high (+) or low (—) abundance of cod larvae along the coast of northern Norway in April–June and June–July and the same year-classes 2 + years old. Data from Table 2.

Year-class	Abundance of cod larvae			
	April–June		June–July	
	+	—	+	—
Rich	3	3	2	1
Medium	6	2	1	2
Poor	2	8	1	5

April—June and June—July, for the rich and medium year classes combined, a positive correlation in April—June. The observations are, however, too few to be reliable. WIBORG (1957) found no correlation between abundance of cod eggs and larvae in the Lofoten area and the size of the corresponding year classes.

CONCLUSION

It may be concluded that plankton observations from single stations close to the Norwegian coast mainly reflect the local conditions. When plankton hauls are taken at long time intervals, occasional patchiness may obscure the variations. This is especially felt for the quantitative observations.

Continuous observations during a series of years may nevertheless yield valuable information on the general trends in the development and quantity of the plankton, especially when combined with information from other sources on physical, chemical and biological parameters.

ACKNOWLEDGEMENTS

I am very grateful to the observers at the permanent oceanographic stations and to the officers and crew on board the Norwegian weather ships «Polarfront I» and «Polarfront II» for the collection of zooplankton.

The working up of the zooplankton samples and technical treatment of the data have largely been carried out by Signe Johannessen and Karsten Hansen, and I am also grateful to them for typing and drawings. Herman Bjørke has been a very valuable consultant for the possible statistical treatment. Claudia Hamilton has kindly revised the English text.

REFERENCES

ANON. (ed.) 1968. *Zooplankton sampling.* Monographs on oceanographic methodology 2. UNESCO, Paris.

ANON. 1976. Report of the north-east arctic fisheries. Working Group Charlottenlund 22—26 March 1976. *Coun.Meet. int.Coun.Explor.Sea, 1976* (F:10): 1—13. [Mimeo].

ANTIPOVA, T.V., DEGTYAREVA, A.A. and TIMOKHINA, A.F. 1974. Longterm variations in the biomass of plankton and benthos in the Barents Sea. *Mater.Ryb.Issled. Sever.Bass., 21*:81—87. (In Russian).

BARANENKOVA, A.S. 1974. Long-term fluctuations in the abundance of fish eggs and larvae in the Barents Sea. *Mater.Ryb. Issled.Sever.Bass., 21*: 93—100. (In Russian.)

BOGOROV, V.G. 1959. On the standardization of marine plankton investigations. *Int. Rev.Ges.Hydrobiol.Hydrogr., 44(4)*: 621—642.

CORLETT, J. 1965. Winds, currents, plankton and the year-class strength of cod in the western Barents Sea. *Int. Commn NW Atlant.Fish.Spec.Publ.No.6*: 373—378.

DEGTERYOVA, A.A. 1970. On studying the relationship between plankton, temperature and distribution of cod demersal yearlings by method of correlation analysis. *Mater.Ryb.Issled.Sever.Bass.*, *14*: 69—77. (In Russian).

DRAGESUND, O. og HOGNESTAD, P.T. 1967. Forekomst av egg og yngel av fisk i vest- og nord-norske kyst- og bankfarvann våren 1966. *Fiskets Gang*, *53*: 419—422.

FRASER, J. 1968. The history of plankton sampling. P. 11—18 in ANON. ed. *Zooplankton sampling. Monographs on oceanic methodology 2.* UNESCO, Paris.

GRUZOV, L.N. and PAVSHTIKS, E.A. 1961. Soviet plankton investigations in the Norwegian Sea in 1959. *Annls biol. Copenh.*, *16*: 69—71.

HOGNESTAD, P.T. 1969 a. Forekomst av egg og yngel av fisk i nordnorske kyst- og bankfarvann i mai og juni 1967. *Fiskets Gang*, *55*: 10—12.

— 1969 b. Forekomster av fiskelarver i nordnorske kyst- og bankfarvann våren 1968. *Fiskets Gang*, *55*: 58—61.

— 1969 c. Forekomst av fiskelarver i nordnorske kyst- og bankfarvann våren 1969. *Fiskets Gang*, *55*: 739—743.

— 1972. Registrering av fiskelarver i nordnorske kyst- og bankfarvann med F/F «Asterias» våren 1971. *Fiskets Gang*, *58*: 312—316.

— 1973. Registrering av fiskelarver i nordnorske kyst- og bankfarvann våren 1972. *Fiskets Gang*, *59*: 313—317.

LIE, U. 1961. Zooplankton in relation to herring in the Norwegian Sea, June 1959. *FiskDir.Skr.Ser.HavUnders.*, *13*(1): 5—14.

— 1965. Quantities of zooplankton and propagation of *Calanus finmarchicus* at permanent stations on the Norwegian coast and at Spitsbergen 1959—1962. *FiskDir.Skr.Ser.HavUnders.*, *13* (8): 5—19.

— 1966. Variations in the quantity of zooplankton and the propagation of *Calanus finmarchicus* at station «M» in the Norwegian Sea, 1959—1966. *FiskDir.Ser.Ser. HavUnders.*, *14*: 121—128.

— 1968. Dyreplankton fra faste stasjoner langs Norskekysten i årene 1963—1965. *Fiskets Gang*, *40*: 736—740.

LONGHURST, A., COLEBROOK, M., GULLAND, J., Le BRASSEUR, R., LORENZEN, C. and SMITH P. 1972 The instability of ocean populations. *New Scient.*, *1 June* 1972: 500—502.

MIDTTUN, L. 1969. Variability in temperature and salinity at some localities off the coast of Norway. *Progr.Oceanogr.*, 5: 41—54.

— 1975. Observasjonsserier av overflatetemperatur og saltholdighet i norske kystfarvann 1936—1970. Observations series on surface temperatures and salinity in Norwegian coastal waters 1936—1970. *Fisken og Havet Ser. B*, *1975* (5): 1—50.

PONOMARENKO, V.P. 1976. Procedure of forecasting the trawl fishery production in the Barents Sea. *Trudy polyar.nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr.*, *37*: 158—169.

ROBERTSON, A.A. 1970. An improved apparatus for determining plankton volume. *Fish Bull.Un.S.Afr.*, *6*: 23—26.

SMEDSTAD, O.M. and ØYESTAD, V. 1974. Preliminary report of investigations of cod-eggs and larvae in the Lofoten area in the years 1968—1972. *Coun. Meet. int. Coun. Explor. Sea*, *1974* (F: 37) 1—19. [Mimeo].

SYSOEVA, T.K. 1973. Feeding and survival of larvae of the Barents sea cod. *Trudy polyar. nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr.*, *33*: 82—103. (In Russian.)

TIMOKHINA, A.F. 1963. Some peculiarities of plankton development in the Norwegian Sea in 1962. *Coun.Meet.Int.Coun.Explor.Sea*, *1963* (63): 1—3. [Mimeo.]

TIMOKHINA, A.F. 1968. Production of mass-species of zooplankton in the Norwegian Sea. *Trudy polyar.nauchno-issled.Inst.morsk.ryb.Khoz.*, *23*: 173–192. (In Russian).

— 1972. Peculiarities in the development of plankton in the Norwegian Sea in spring and summer 1970. *Annls biol.Copenh.*, *27*: 211–214.

TRANTER, D.J. and SMITH, P.E. 1968. Filtration performance. P. 27–56 in ANON. ed. *Zooplankton sampling. Monographs on oceanic methodology 2.* UNESCO, Paris.

WIBORG, K.F. 1954. Investigations on zooplankton in coastal and offshore waters of western and northwestern Norway. *FiskDir.Skr.Ser.HavUnders.*, *9*(1): 1–246.

— 1955. Zooplankton in relation to hydrography in the Norwegian Sea. *FiskDir. Skr.Ser.HavUnders.*, *12*(1): 1–17.

— 1957. Factors influencing the size of the year classes in the Arcto-Norwegian tribe of cod. *FiskDir.Skr.Ser.HavUnders.*, *11*(8): 1–24.

— 1958. Quantitative variations of the zooplankton in Norwegian coastal and offshore waters during the years 1949–56. *FiskDir.Skr.Ser.HavUnders.*, *21*(1): 1–17.

— 1960 a. Investigations in Norwegian waters and in the Norwegian Sea during 1957–1958. *FiskDir.Skr.Ser.HavUnders.*, *12*(6): 1–19.

— 1960 b. Investigations on eggs and larvae of commercial fishes in Norwegian coastal and offshore waters in 1957–58. *FiskDir.Skr.Ser.HavUnders.*, *12*(7): 1–27.

— 1976. Quantitative distribution of zooplankton in the coast and bank areas of western and northwestern Norway during March-June 1959–1966. *FiskDir.Skr. Ser.HavUnders.*, *16*: 259–277.

ZELIKMAN, E.A. and KAMSHILOV, M.M. 1960. Mnogoletnyaya dinamika biomassy planktona yushnoi chasti Barentseva Morya i factory ee opredelyayushcie. Long-term variations in the biomass of plankton in the southern Barents Sea and the biomass of plankton in the southern Barents Sea and the determining factors. *Trudy Murm.morsk.biol.Inst.*, *2*(6): 68–113. (In Russian).

Received 13 October 1977
Printed 7 June 1978

Table I. Plankton displacement volumes per m² of sea surface at the permanent oceanographical stations along the coast of Norway and at St. M in the Norwegian Sea during the years 1949—1972. Mean of the monthly averages and mean of the months April—August of the different years. x̄) mean, s) standard deviation, n) number of years. As the period April—August during some years is incomplete, the corresponding *n* may be larger than n̄ of the individual months, see text, p 468.

	J	F	M	A	M	J	J	A	S	O	N	D	April—August
						Utsira 200-0 m (1976—1972)							
x̄	8.1	7.8	10.0	17.6	28.1	29.4	33.2	14.8	11.3	12.4	8.7	4.0	26.3
s	5.90	3.98	7.70	8.56	18.45	15.59	25.47	4.52	6.01	7.26	8.79	3.17	13.77
n	5	5	4	6	5	5	6	5	5	5	5	5	6
						Utsira 50-0 m (1967—1972)							
x̄	3.2	2.9	8.3	12.9	18.5	20.3	15.0	5.8	7.6	5.4	3.4	1.5	17.0,
s	2.14	1.25	6.43	7.16	16.65	12.70	12.21	1.80	8.40	4.50	4.27	0.97	7.39
n	5	5	4	6	6	5	6	5	5	5	5	5	5
						Sognesjøen 200-0 m (1949—1962)							
x̄	1.2	2.2	2.2	10.3	8.5	7.9	7.4	3.9	6.1	2.4	1.7	1.1	7.7
s	0.67	1.51	1.78	6.96	8.35	3.89	8.12	2.83	6.64	1.12	0.95	0.51	2.93
n	6	6	11	11	10	10	10	9	8	10	8	7	13
						Sognesjøen 200-0 m (1963—1972)							
x̄	3.5	3.0	12.0	17.8	26.1	12.3	8.8	12.0	8.5	8.7	4.1	5.1	17.4
s	2.71	2.75	10.22	10.78	14.20	6.46	5.24	3.85	4.94	8.25	2.00	5.90	7.64
n	9	6	9	10	10	7	9	10	8	7	6	7	10
						Sognesjøen 50-0 m 1949—1962)							
x̄	0.4	0.4	2.3	6.2	5.4	7.3	3.6	3.5	4.1	1.6	0.8	0.4	5.1
s	0.34	0.37	1.3	3.58	5.48	3.90	1.58	3.55	7.67	1.33	0.95	0.31	1.45
n	9	6	9	10	10	10	8	7	8	9	8	8	11

					Sognesjøen 50-0 m (1963—1972)								
x̄	2.8	3.3	8.2	14.4	26.6	9.0	7.4	10.5	4.5	7.5	4.2	2.0	14.5
s	0.65	2.40	3.61	15.30	15.79	8.24	4.42	6.86	2.21	12.98	2.50	1.14	5.91
n	9	6	8	10	10	6	9	10	7	7	8	9	10
					Ona 200-0 m (1949—1953)								
x̄	1.5	1.5	3.8	12.3	12.2	15.7	31.3	5.2	2.7	2.8	2.6	1.7	15.3
s	1.07	0.35	2.53	6.37	7.37	8.54	20.17	3.42	1.76	1.04	1.39	1.63	4.10
n	3	3	3	5	5	3	5	5	5	5	4	2	5
					Ona 50-0 m (1949—1953)								
x̄	—	1.0	2.3	5.3	8.6	7.0	1.9	0.8	2.1	1.1	3.0	1.1	4.7
s		0	0	3.51	8.80	4.60	2.02	0.29	1.93	0.64	0	0	3.36
n		1	1	4	4	3	3	3	3	2	1	1	4
					Skrova 300-0 m (1949—1962)								
x̄	12.0	9.7	7.9	12.3	24.5	25.7	22.1	23.7	16.0	16.2	13.6	13.9	21.8
s	4.23	3.82	3.25	4.35	8.87	8.35	9.52	19.75	7.71	7.48	4.53	4.54	7.65
n	12	11	11	11	13	13	14	14	14	12	11	13	14
					Skrova 300-0 m (1963—1972)								
x̄	22.9	15.8	17.4	17.2	30.8	43.1	50.4	33.0	32.4	36.4	28.6	23.3	34.9
s	6.71	6.04	9.75	4.78	11.00	17.38	22.83	15.61	17.26	15.21	18.01	13.07	18.35
n	10	10	10	10	10	10	10	10	10	10	9	6	10
					Eggum 200-0 m (1949—1962)								
x̄	1.7	1.4	1.52	8.9	52.5	41.7	47.9	15.3	9.8	8.9	4.9	3.8	32.0
s	1.17	1.17	1.06	6.74	40.37	28.12	40.62	9.04	6.66	4.07	3.86	2.33	19.24
n	8	6	6	9	7	10	8	9	8	7	6	6	9
					Eggum 200-0 m (1963—1972)								
x̄	5.3	6.6	6.9	22.0	61.8	58.8	67.0	44.9	32.1	7.0	6.8	7.4	54.1
s	4.10	5.09	7.66	12.49	56.44	25.02	22.17	25.67	25.37	9.97	4.41	5.98	16.74
n	5	2	4	3	9	8	8	7	7	6	7	5	8

	J	F	M	A	M	J	J	A	S	O	N	D	April — August
Eggum 50-0 m (1949—1962)													
x̄	0.6	0.6	0.9	3.1	33.5	14.0	6.8	4.9	2.3	3.1	1.6	0.8	11.9
s	0.6	0.76	0.94	2.63	41.30	11.43	8.68	4.76	1.55	2.40	1.91	0.76	9.38
n	7	6	5	7	7	10	9	7	9	7	5	6	9
Eggum 50-0 m (1963—1970)													
x̄	2.3	3.0	5.6	12.5	42.6	42.7	35.8	13.9	16.0	11.9	2.3	3.2	30.8
s	1.27	0	2.40	6.45	39.79	26.32	18.29	7.39	21.50	16.10	1.94	2.14	13.61
n	3	2	3	4	8	7	8	8	8	8	7	4	8
Skarsvåg 260-0 m (1955—1962)													
x̄	2.9	2.1	2.7	3.1	11.5	26.6	31.3	19.0	18.1	7.5	6.7	8.0	19.5
s	0	1.00	1.37	1.46	6.99	20.61	28.79	13.95	9.65	1.98	4.18	4.19	13.14
n	2	3	4	6	7	7	8	8	8	6	8	4	8
Skarsvåg 260-0 m (1963—1966)													
x̄	8.6	4.0	5.4	4.5	22.5	39.5	45.5	22.5	24.0	28.0	7.5	1.8	30.7
s	5.89	2.11	4.82	2.12	19.08	15.86	42.00	19.36	13.08	15.10	2.12	0	16.10
n	3	3	4	2	4	4	4	4	3	3	2	1	5
Skarsvåg 50-0 m (1955—1962)													
x̄	0.5	10.0	10.0	2.4	5.7	11.1	14.9	6.2	3.9	2.7	2.0	2.2	9.6
s	0	0	0	0.78	3.79	7.11	12.83	3.76	2.45	2.15	1.41	1.42	6.0
n	2	1	1	2	5	6	8	8	5	5	2	4	8
Skarsvåg 50-0 m (1963—1966)													
x̄	4.0	3.0	3.0	7.5	9.0	14.7	16.5	9.8	11.7	5.6	3.0	3.0	12.1
s	1.73	0	0	6.36	4.24	5.29	7.14	2.87	10.92	2.42	0	0	2.66
n	3	4	4	2	4	4	4	4	4	3	1	1	4

Ingøy 50-0 m (1969—1972)

x̄	1.9	1.8	1.6	2.4	18.7	26.7	56.3	13.6	5.4	2.4	2.0	2.4	23.1
s	1.85	1.11	1.13	1.60	10.13	10.50	37.88	7.27	3.29	2.26	2.26	1.13	9.67
n	3	3	2	3	3	4	3	4	4	2	2	2	4

Ingøy 300-0 m (1969—1972)

x̄	10.4	4.0	4.8	5.3	30.9	50.7	80.2	26.2	22.2	7.6	12.5	8.0	39.2
s	4.45	3.70	5.66	3.33	12.76	17.39	75.18	10.58	21.00	9.62	8.17	3.39	16.80
n	3	4	2	3	3	3	3	4	4	2	3	2	4

St. M 100-0 m (1950—1965)

x̄	0.6	0.7	4.0	8.2	12.6	19.0	16.6	10.2	4.3	3.7	2.1	1.2	13.3
s	0.46	0.40	2.10	5.33	4.71	13.46	6.91	6.25	2.44	2.22	1.35	1.15	6.31
n	13	14	13	14	15	15	12	10	11	9	9	9	16

St. M 100-0 m (1966—1972)

x̄	2.5	2.0	7.5	15.8	28.0	30.2	29.1	23.8	12.2	5.0	3.6	18.0	27.1
s	3.06	0.98	8.18	8.49	20.44	19.53	19.78	15.65	11.10	3.50	3.94	0.93	5.99
n	7	7	9	9	9	9	5	5	5	5	5	5	7

St. M 600-0 m (1950—1965)

x̄	11.9	13.9	24.8	28.1	30.9	35.9	37.0	30.3	21.8	21.2	14.6	14.9	31.5
s	4.60	5.65	11.75	13.23	17.83	20.62	25.76	13.07	7.20	9.45	4.15	10.81	13.79
n	11	11	12	14	15	16	12	10	11	8	8	8	16

St. M 600-0 m (1966—1972)

x̄	20.0	26.1	43.6	69.2	58.4	57.7	52.4	52.9	40.3	38.1	22.2	15.3	61.8
s	7.87	7.47	16.57	24.76	24.51	23.15	30.94	15.67	13.37	15.42	6.81	9.41	6.77
n	7	7	7	7	7	7	7	5	5	5	5	5	7

FiskDir. Skr. Ser. HavUnders., 16: 489–505.

PHYTOPLANKTON OBSERVATIONS IN OFFSHORE NORWEGIAN COASTAL WATERS BETWEEN 62°N AND 69°N

I. Variation in time of the spring diatom maximum 1968—71

By

TRYGVE BRAARUD and INGRID NYGAARD
Department of Marine Biology and Limnology, University of Oslo

ABSTRACT

BRAARUD, T. and NYGAARD, I. 1978. Phytoplankton observations in offshore Norwegian coastal waters between 62° N and 69° N. I. Variation in time of the spring diatom maximum 1968–71. *FiskDir. Skr. Ser. HavUnders., 16:* 489–505.

An attempt was made to trace yearly fluctuations in the timing of the spring diatom maximum along the Norwegian west coast, 62° N–69° N. Quantitative data on the diatom population at 281 stations with 0 m samples and 120 stations with additional samples from the 10, 20 and 30 m levels, collected in March–April during the four years 1968–71, were used. A delay of about three weeks from the southern to the northern part of the area, as previously observed, was again established. The years 1970 and 1971 were years with an early maximum while 1969 was a definitely late year within the whole area. The time variation in 1968–71 recorded in the Trøndelag and Helgeland subareas, showed trends different from those of the neighbour areas. The phytoplankton data were not adequate for a detailed analysis of the factors responsible for the timing of the maximum each year in the respective parts of the investigated area.

PREFACE

A study of the plankton in offshore coastal waters along the Norwegian coast from Møre to Vesterålen was adopted as part of the Norwegian contribution to the International Biological Programme (IBP), section Marine Productivity (PM). The plankton work formed an integrated part of a marine biological survey, "The recruitment mechanism for herring and cod", undertaken by the Institute of Marine Research, Fisheries Directorate, Bergen, in March—April 1968—71.

The present report on the phytoplankton material deals with the variation in time of the spring diatom maximum of the near-coastal and intermediate coastal waters off Møre, Trøndelag, Helgeland and Vestfjorden—Vesterålen in 1968—71.

Cand. real. Ingrid Nygaard carried out the microscopical examination by means of the Utermöhl technique (UTERMÖHL 1931) of the water samples from 400 stations. The financial support through IBP sources was, however, inadequate for her continued engagement at the project until the results could be presented for publication. The senior author is, therefore, mainly responsible for the editing of the report.

In subsequent reports, accounts will be given of the seasonal and regional occurrence of the more important diatom species and of groups playing a subordinate role in the phytoplankton during March—April.

INTRODUCTION

In Norwegian coastal waters the spring diatom maximum is the most spectacular event in the annual phytoplankton cycle as indicated by popular designations as "bloom" or "outburst". Within a period of few weeks a huge production of organic matter takes place, doubtless being of major importance for the secondary producers and the subsequent links in the production chain. Success of the reproduction of these later stages may depend upon a satisfactory coordination in time of spawning and availability of food for the fish larvae. In this connection variation in time of the season of high productivity by phytoplankton in spring may play a role.

With this reasoning in mind, a program for the study of phytoplankton in water samples collected during a survey organized by the Institute of Marine Research, Fisheries Directorate, Bergen, was set up. The purpose was to bring out information on variation from year to year and from one part of the area of investigation to the other in the time of the diatom maximum.

SUBAREAS AND WATERMASSES

For the present purpose, the area of investigation was divided in four subareas (fig 1):

Møre — from 62° N to 63° 30° N
Trøndelag — from 63° 30° N to 65° N
Helgeland — from 65° N to 67° N
Vestfjorden—Vesterålen — from 67° N to 69° N

The topography and hydrography of the offshore coastal areas which the survey covers, are so diverse that the environmental situation for phytoplankton and zooplankton, even within one of the subareas, exhibits a rather broad range. In order to obtain a meaningful basis for

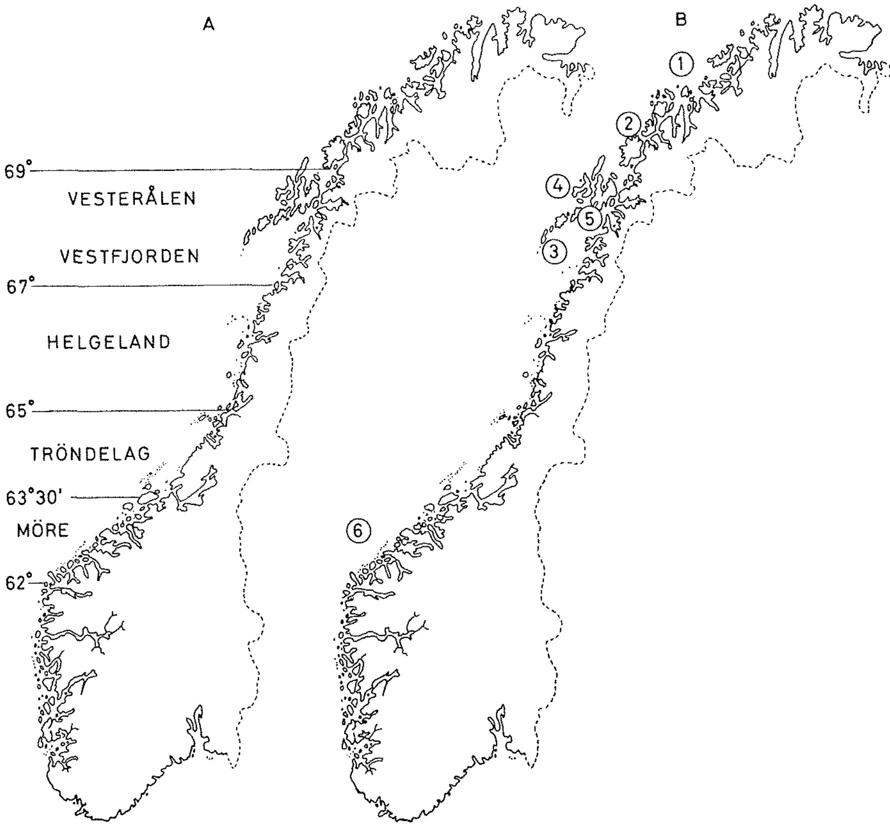


Fig. 1. A. The investigated area for the phytoplankton survey 1968—71 of the Norwegian IBP—PM project.
B. Number in circles: Reference to previous quantitative phytoplankton studies in spring in Norwegian offshore coastal waters north of 62° N. 1) Lopphavet, HEIMDAL 1974. 2) Malangen, GAARDER 1938. 3) Lofoten, FØYN 1929; GRAN 1930. 4) Vesterålen, GRAN 1930; BRAARUD *et al.* 1958. 5) Vestfjorden, NORDLI 1949; BRAARUD *et al.* 1958. 6) Møre, GRAN 1929, 1930; BRAARUD and KLEM 1931.

comparison of the time sequence of the spring diatom development along the coast, a division of the watermasses encountered in a section from a fjord area out to the atlantic drift has been adopted for the upper 50 m. In addition to the old distinction between coastal and atlantic water based on salinities (HELLAND-HANSEN and NANSEN 1909), the term "semi-atlantic waters" for stratified waters with coastal water overlying Atlantic water within the upper 0—50 m layer is introduced. This situation may be expected to involve a certain admixture of atlantic water to the overlying water within the euphotic zone. Trophic conditions for phytoplankton growth may in the semi-atlantic waters differ essentially

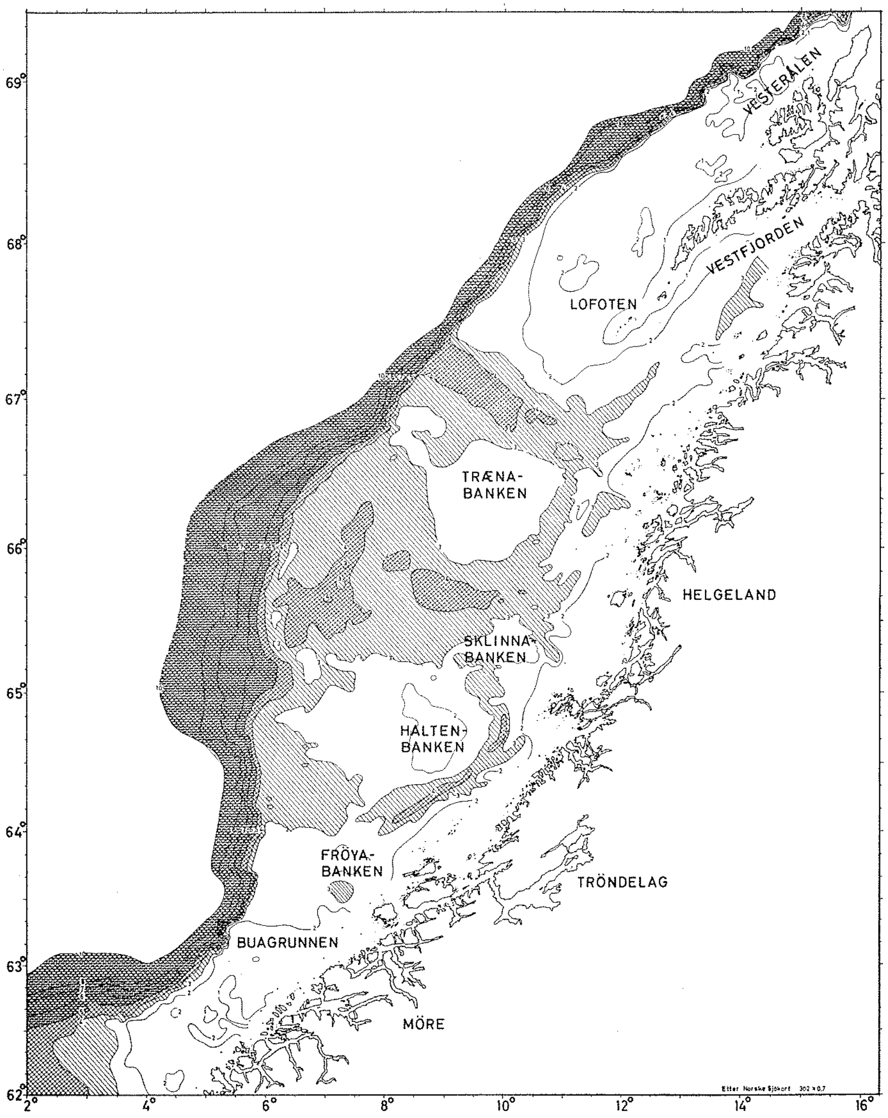


Fig. 2. Bathymetric map of the investigated area. Depths in hectometer. The figure represents an extension of Fig. 1 in NAKKEN and LJØEN (1969) and was supplied by LJØEN.

from those in the coastal waters, and the same may pertain to other environmental conditions as well. In Fig. 3 a diagram is shown, indicating the five categories of watermasses encountered in the section. While the border lines between the atlantic and semi-atlantic waters and between the latter category and the intermediate coastal waters are based upon

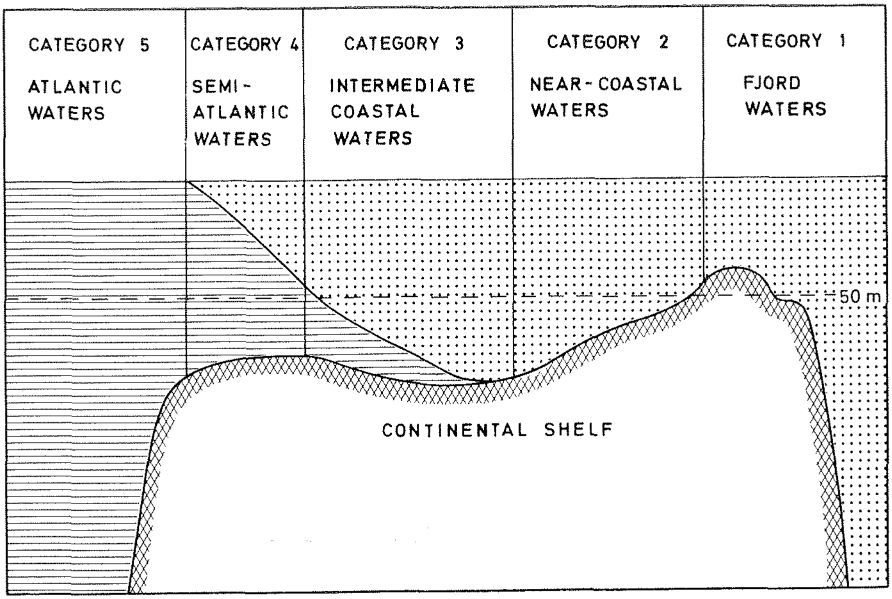


Fig. 3. A hydro-topographical division of the watermasses 0–50 m on the Norwegian west coast. Salinities within the 0–50 m layer: Category 1, 2 and 3) lower than 35‰, category 4) lower than 35 ‰ in the uppermost strata, higher than 35‰ beneath, category 5) higher than 35‰, even at the surface. ≡ >35‰, ⁚⁚ <35‰

hydrographical criteria, the topographical delineation of the intermediate coastal and the near-coastal waters is more arbitrary. The extention of the various categories differs with locality and season, and may show yearly variation within any of the subareas investigated.

QUANTITATIVE PHYTOPLANKTON DATA 1968–71

At most of the stations surface samples only were examined while in some cases samples from the 10, 20 and 30 m levels were also studied. In Table 1 the number of stations of the two categories are given for the four subareas and for each year. Only 2 ml samples were examined, using the Utermöhl technique. Original tables for each station as well as excerpt tables for the various cruises are deposited at the University of Oslo, Department of Marine Biology and Limnology. Hydrographical data are available from the Norwegian Oceanographic Data Centre, Bergen.

The situation in semi-atlantic and atlantic waters will be considered in a subsequent report.

Table 1. Stations for which quantitative phytoplankton data were obtained. Italized figures indicate numbers of stations with data for more than the 0 m sample. Otherwise only the 0 m sample has been examined. The number of stations of each category as well as their total number are given for each subarea and each year.

Year	Area				Sum for each year
	Møre	Trøndelag	Helgeland	Vestfjorden —Vesterålen	
1968........	56 + *5*	20 + *7*	11 + *3*	26 + *11*	113 + *26*
1969........	16 + *5*	7 + *5*	17 + *3*	29 + *8*	69 + *21*
1970........	14 + *9*	21 + *17*	7 + *15*	15 + *13*	57 + *54*
1971........	6 + *2*	21 + *2*	3	12 + *15*	42 + *19*
	92 + *21*	69 + *31*	38 + *21*	82 + *47*	281 + *120*
Sum for each subarea.	113	100	59	129	Total 401

METHOD FOR ESTIMATING THE TIME OF THE SPRING DIATOM MAXIMUM

In handling the observational data, which are scattered in time as well as geographically, it was found neccessary to refer the situation at each station to a common scale, indicating various stages of the spring diatom increase. It is obvious that the adoption of such a procedure for the whole area of investigation requires that it is not based upon too strict a gradation. Conditions in the Møre area in the south and in the Vestfjorden—Vesterålen area in the north are so different hydrographically (Braarud, Gaarder and Nordli 1958) that it might have been preferable to treat them separately. However, the inclusion of the two subareas in the middle of the coastal region investigated, makes it infeasible to draw any rational division line between a southern and a northern situation. We shall, therefore, deal with each of the four subareas shown in Fig. 1.

The following stages of the spring diatom increase were distinguished:

Stage 0 — No sign of any increase of the diatom population after the winter minimum.
— I — A definite increase is noticeable.
— II — The diatom population has reached about 50/ml.
— III — The diatom population has increased further, apparently approaching maximum.
— IV — The population has reached 1 000/ml or more.
— V — Post-maximum situations are given this designation, regardless of the size of the diatom population.

This coarse scale is subjective, and other criteria than the numerical size of the diatom population have been employed as well. A sample with a diatom population of 100/ml might either be referred to stage III or to V. The additional criteria which then have been considered are: 1) The composition of the diatom community, 2) the occurrence of resting stages and, in some cases, the general composition of the other components of the phytoplankton.

When the composition of the diatom population is used, our knowledge from previous investigations of the spring diatom increase has been employed, such as the early appearance of *Chaetoceros socialis* and *C. furcellatus*. The percentage of resting spores in these species is also taken as an indicative detail.

During the collation of the phytoplankton data from this survey, observations were made on the relative abundance of the artificial group "monads and unidentified flagellates" (MF) at various stages of the diatom spring growth. In the south a definite increase took place after the diatom maximum had passed. A detailed discussion of the quantitative distribution pattern of this group relative to the diatom population is planned to be published separately. For the Møre area in 1968, when the observational material was relatively adequate, a condensed table is presented (Table 2). It indicates that post-maximum stages are apt to have acquired much larger populations of MF than those occurring in pre-maximum stages with similar diatom abundance or when the diatom maximum is reached. In the northernmost area, the picture is not as consistent in this respect, possibly because density stratification at this time of the year is far less pronounced in the northern than in the southern area (BRAARUD *et al.* 1958).

Table 2. Changes in the component "Monads and unidentified flagellates" (MF) during the phytoplankton development in the offshore coastal waters after the winter minimum. Examples from the Møre area in 1968. Populations as cells/ml. For definition of development stages 0—V, see p. 494.

Stages	0	I	II	III	IV	V
Cruise 2a						
7—12 March						
Number of stations	9	—	—	—	—	—
Diatoms, cells/ml	<8					
MF, cells/ml						
Range........	3—23					
Mean.........	10					

Tabie 2 cont.

Stages	0	I	II	III	IV	V
Cruise 2b						
25–27 March						
Number of stations	—	—	3	2	7	—
Diatoms, cells/ml	—	—	<250	<800	2300–5800	—
MF, cells/ml						
Range			7–14	1–22	1–21	—
Mean			10	11	9	
Cruise 3a						
7–8 April						
Number of stations	2	3	1	5	4	5
Diatoms, cells/ml	<7	130	530	1400–1700	2600–3200	150–1100
MF, cells/ml						
Range	6–16	0–8	5	8–36	4–11	9–40
Mean	11	3		18	7	21
Cruise 3b						
18–23 April						
Number of stations	—	—	—	—	1	29
Diatoms, cells/ml					3800	<1–557
MF, cells/ml						
Range					11	78–3300
Mean						734
Cruise 4						
17–29 April						
Number of stations	—	—	—	—	2	23
Diatoms, cells/ml					1000–2500	2–481
MF, cells/ml						
Range					9–39	21–1735
Mean					24	574

Stage V is even less well-defined than the earlier stages. In some cases the decline of the population after the diatom maximum may be very rapid, as shown by the observations by Gran (1927) in Fig. 4. However, dependent upon the hydrographic situation and the grazing intensity, a slower decrease may occur. This may particularly be expected in the northern coastal area where wind-generated turbulence is apt to be especially effective in supplying nutrients from deeper layers to the euphotic zone due to the small density gradients encountered there at the season in question (Heimdal 1974).

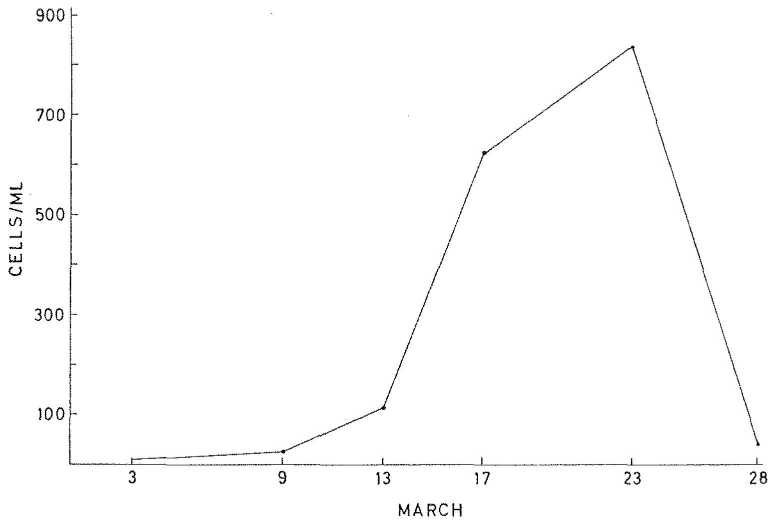


Fig. 4. Changes in the diatom population (1—2 m) at Kårtveit, south of Bergen, 3—28 March 1922. Records from GRAN (1927).

The size of the MF populations recorded may to some extent be influenced by the amount of larger forms in the sample. When diatoms are very abundant, the accuracy of the counting of the very small forms of MF is apt to be considerably reduced. For this reason the records of MF populations for stages III and IV may be too small. This inaccuracy would, however, hardly invalidate the use of the present criterion for distinguishing between stage V and stages I and II in cases when the diatom population of the former is of a similar, fairly modest size as in I and II.

VARIATION IN TIME OF THE SPRING DIATOM MAXIMUM 1968—71

The present survey can only give fragmentary information on variation in the time schedule of the spring diatom increase within the coastal area 62°—69° N. Irregularities in the cruise program of the co-operative project, curtailment of the microscopical work for financial reasons and the preselection of samples for the phytoplankton studies have made the observations less suited for a description of the time schedule in the four subareas in each of the four years of investigation.

In Table 1 the number of stations for which phytoplankton data were obtained, is given for the various years and subareas. A further documentation of the observational material on which the estimation of the time of the diatom maximum has been based, is given in Table 3 for the Møre, Trøndelag and Helgeland subareas and in Table 4 for Vestfjorden—Vesterålen. For each of the subareas the tables give information on which stages have been observed in each week and, for each stage, the number of stations at which it was represented is noted in parenthesis.

Fig. 5 gives a diagrammatic summary of the results. It should be accepted with due reserve since in many cases the observations are too scanty for a more accurate estimate. This is especially the case for Helgeland.

A comparison between the results for the Møre and Vestfjorden—Vesterålen subareas shows that in all years a delay in the north of 3—4

Table 3. Subareas Møre, Trøndelag and Helgeland. Summary for each year of recordings of she stages 0-V (see p. 494) observed in March-April and the first week of May. For each stage, the number of stations at which it was observed in the week and year in question is given in parenthesis.

Month	March				April				May
Week	1	2	3	4	1	2	3	4	1
	MØRE								
1968 Cruise 2a, 2b, 3a, 3b, 4.		0 (7)		III (1) IV (7)	II (1) III (2) IV (3) V (6)		V (13)		
1969 Cruise 6a, 6b, 6d					II (4) III (2) IV (2)		V (6)		
1970 Cruise 8a, 8b, 8c, 9a, 9b . . .					V (3)	V (11)	V (5)	V (4)	
1971 Cruise 10		0 (4)			V (4)				
	TRØNDELAG								
1968 Cruise 2a, 3a, 3b, 4		0 (1)			III (2)		V (3)	V (13)	V (1)

Table 3 cont.

Month Week	March 1	 2	 3	 4	April 1	 2	 3	 4	May 1
1969 Cruise 6a, 6c, 6e					II (5)		V (2)		V (1)
1970 Cruise (8a, 8b) 9a, 9b					V (5)	V (8)		V (10)	
1971 Cruise 10	0 (15)				V (9)				
1968 Cruise 3a, 3b, 4	HELGELAND				0 (1) I (2)		V (5)	V (3)	
1969 Cruise 6b, 6c, 6d, 6e						0 (1) I (1)	II (6)	V (3)	V (5)
1970 Cruise 8a, 8b, 9a, 9b					0 (2) I (2) II (1)	0 (2) I (1) II (2)		V (4)	
1971 Cruise 10				0 (2)	0 (2)				

weeks was registered. This is in accordance with previous investigations in these areas (see p. 491). An earlier spring maximum in Vestfjorden than in near-coastal waters off Vesterålen, which was indicated in 1968—71, has also been observed before. The early stages of the diatom increase in these areas were, however, rather synchronous.

The two subareas between Møre and Vestfjorden do not seem to show any consistent agreement with the trend of the yearly variation of any of their neighbour areas during the four year period. For Møre and Trøndelag, there was in 1968 and 1969 a considerable time difference

Table 4. Vestfjorden—Vesterålen. The various stages of the spring diatom development late March to early May, 1968—1971. Scale 0—V, see p. 494. For each reference to stage the number of stations is given in parenthesis. See also legend to Table 3.

		Vestfjorden, outer and central						Offshore						
Month		March	April				May		March	April				May
Week		4	1	2	3	4	1		4	1	2	3	4	1
1968 Cruise 1a, 1b	Central	I—II (4)				V (5)		Near the coast	II (1)				V (8)	
	Outer	I—II (4)				IV (5)		Farther offshore	I (8)				IV (3)	
1969 Cruise 5a, 5b	Central			0 (1) I (2) II (2)		V (8)		Near the coast			I (2)		V (5)	
	Outer			I—II (7)			V (3)	Farther offshore			0 (5)		V (2)	
1970 Cruise 7a, 7b	Near land			IV (1)				Near the coast			II—III (6)		V (3)	
	Outer			II (3)			V (5)	Farther offshore			0—I (3)		V (3)	
1971 Cruise 11a, 11b	Central		II (5)				V (3)	Near the coast		0—II (2)				IV—V (2)
	Outer		II (3)				IV—V (1)	Farther offshore		0 (4)				IV—V (5)

while in the «early years» 1970 and 1971 the maxima appeared to be synchronous. With regard to the time variation from year to year, the situation in the four subareas cannot be expected to have the same trend considering the large geographical distance which they cover. However, an earlier maximum in Vestfjorden in 1970 and 1971 than in the other years is in accordance with what was observed in Møre and Trøndelag.

COMPARISON WITH RESULTS FROM PREVIOUS SURVEYS

For the Vestfjorden—Vesterålen area observations are available for a number of years. On the basis of these, we have tried to give a characterization of the various years by reference to the scale which has been

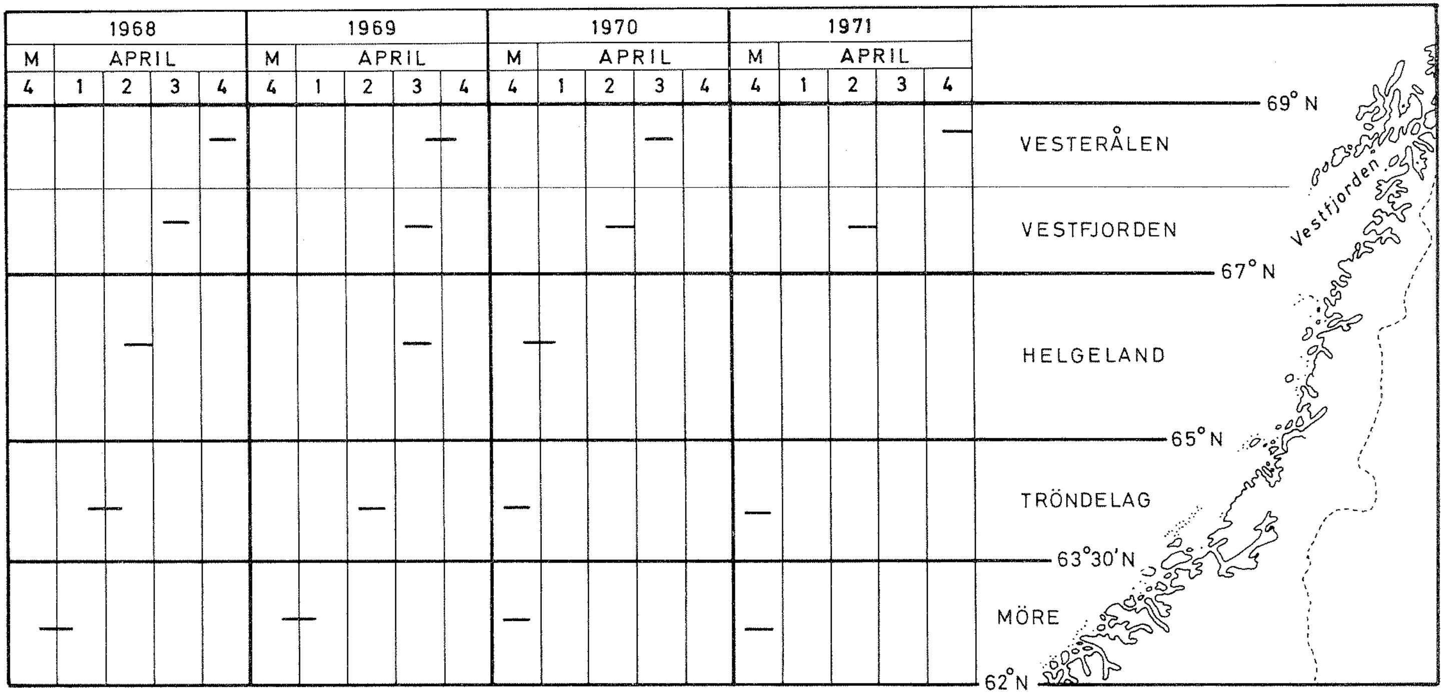


Fig. 5. Estimated cccurrence of the spring diatom maximum in four subareas of the Norwegian coast between 62° N and 69° N in 1968, 1969, 1970 and 1971. The diagram is based upon observations in the near-coastal waters, and the time is indicated by weeks, from the fourth week of March to the fourth week of April. For data and methods, see the text.

Table 5. For the period 3rd week of March to 2nd week of May, available quantitative phytoplankton data have been used for a characterization of the spring diatom development with the use of a 0—V scale (see p. 494) and reference to the nearest week. The origin of the data is given in the text. The Malangen locality is not strictly offshore, but at the mouth of a fjord system, while the station on the shelf off Ullsfjord is comparable to the near-coastal stations in Vesterålen.

A	Vestfjorden								Offshore on the shelf							
Month	March		April				May		March		April				May	
Week	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
1922		0	I—II	II		II										
1923	0	0	0—II	II	II—III	V						I—IV				
1924	0	0	I	I—II						0		I				
1925								V								
1926		0—I	I	I	II	V		V		0	I	III		V		V
1927						V								V		
1929	0	0	0	I	0—II	V				0				IV		
1945		II		III		V					I			V		
1946	I									I		II		V		
1949[1]												IV				

B	Malangen 1930—31								The shelf off Ullsfjord (U 3) 1963—64							
	I				IV	V	V			0	I			I		

[1]) Observation from a single station by NORDLI (1949).

used for 1968—71, defined on p.494. The results are presented in Table 5 A, based on observations in 1922—27 by FØYN (1929), in 1929 by GRAN (1930) and in 1945—46 by BRAARUD *et al.* (1958). As a supplement, corresponding information is given in Table 5 B for Malangen and the shelf outside Ullsfjord, based on the observations by GAARDER (1938) and HEIMDAL (1974).

The following conclusions may be suggested with regard to the timing of the spring diatom development in the different years as indicated by these surveys.

In Vestfjorden — A very late maximum in 1922.
A remarkably late start of the increase in 1929.

Offshore — Somewhat early development in 1923, 1926, 1949. Late maximum in 1929.

Malangen — The situation in 1930—31 was comparable to what had been recorded in some years in Vestfjorden, perhaps with a slightly earlier maximum.

Off Ullsfjord — 1962—63, 1964. Maximum even later than in Vesterålen.

The general impression gained from these observations is that in the Vestfjorden—Vesterålen area and still further north, considerable variation may be expected from one year to another as to the time when diatom growth starts after the winter minimum and the further increase towards maximum. Ordinarily the increase appears to start in the first week of April, and the maximum may, with few exceptions, be observed in the third to fourth week of April. However, deviations from this time schedule seem well documented in the publications mentioned above.

From the other subareas the only observations which may be used for comparison with the results from the present survey, are those by GRAN (1929, 1930) from Møre.

On the basis of his quantitative investigations in 1926 and 1927 and older qualitative phytoplankton data, GRAN (1929, p. 49) stated: "We found the maximum number in the Skagerrak from February—March, off Bergen during the later half of March, at Romsdalen at the end of March and during the early half of April, and at the Lofoten Islands during the first half of April." Observations from 1929 in the same section from Romsdalsfjorden to Storegga (GRAN 1930) indicated that maximum had been reached in the last week of March at the stations nearest land, in agreement with his general statement quoted above.

A combination of the results from the older surveys with those from the 1968—71 survey seems to justify the following broad conclusions.

1. There is a delay of about three weeks in the occurrence of the spring diatom maximum when going from Møre (62° N) to Vestfjorden — Vesterålen (69° N). This is in accordance with the general statement by GRAN (1929) quoted above as well as with observations in 1945—46 by BRAARUD *et al.* (1958) at Eggum and Skrova in the north and Sognesjøen and Utsira in the south.
2. In the Møre subarea, the years 1970 and 1971 had earlier maxima than 1968 and 1969 which showed a delay also compared with GRAN's observations in 1929.
3. Also for the other subareas there was in 1970 a relatively early maximum, as in the Møre area, while in 1969 the maximum was relatively late in all subareas. North of Møre the variation in the time schedule in 1968 and 1971 did not show any common trend for the three subareas.
4. In the Vestfjorden—Vesterålen subarea there is generally an earlier maximum in Vestfjorden than in Vesterålen, in accordance with observations in previous surveys.

CONCLUDING REMARKS

From quantitative phytoplankton data for Eggum and Skrova in the Vestfjorden—Vesterålen area and Sognesjøen and Utsira in the southern part of the Norwegian west coast, BRAARUD *et al.* (1958) documented a delay in 1946 of about three weeks in the spring diatom development in the north compared with the south. In their summary (p. 41) they commented on the background for this delay: "Factors of general nature: the different light supply due to geographical position and the delayed vernal stabilization at the northern stations, conditioned by a smaller fresh-water supply, were pointed out as main factors causing the delay in spring phytoplankton growth in the north. Extensive winter mixing, inducing a more pronounced dilution of the winter population in the north, may also result in smaller phytoplankton stocks in early spring".

The observations from the present survey demonstrate that within the coastal area from 62° N to 69° N yearly fluctuations in the timing of the spring diatom maximum occur. They are well within the time range indicated by the general statements of GRAN (1929) and BRAARUD *et al.* (1958). In actual situations, however, the variation from year to year may be large enough to be taken into consideration in the search of causes for unsuccessful reproduction in commercial fishes. The present phytoplankton material is, unfortunately, inadequate for an analysis of the background for the yearly variations observed in the four year period 1968—71. For this purpose a concentrated study of the situation within a much smaller area would have been preferable. The hydrography of the offshore coastal waters is so complex that a very dense station net is needed for an adequate analysis of the environmental situation for diatom growth.

In a subsequent report, the variations in the composition of the diatom vegetation within the area of investigation will be discussed, also in view of the hydrographical heterogeneity of the Norwegian coastal waters (BRAARUD and NYGAARD, in prep.).

ACKNOWLEDGEMENTS

The Norwegian committee on the International Biological Program (IBP) organized the program on Marine Productivity. The present contribution deals with one aspect of its project 1, which was a part of a project, "The recruitment mechanism for herring and cod", which was planned and operated by the scientific and technical staff of the Institute of Marine Research, Fisheries Directorate, Bergen. This institute provided the water samples for the phytoplankton studies as well as hydrographical and biological data from the cruises and the bathymetric chart in Fig. 2. We are greatly indepted to all who in this way have facilitated the present study.

REFERENCES

BRAARUD, T. and KLEM, A. 1931. Hydrographical and chemical investigations in the coastal waters off Møre and in the Romsdalsfjord. *Hvalråd.Skr. 1*: 1–88.

BRAARUD, T., GAARDER, K. R. and NORDLI, O. 1958. Seasonal changes in the phytoplankton at various points off the Norwegian west coast. *FiskDir. Skr. Ser.Hav-Unders., 12* (3): 1–77.

FØYN, B. R. 1929. Investigation of the phytoplankton at Lofoten, March–April, 1922–1927. *Skr. norske Vidensk-Akad. Mat.-naturv. Kl., 1929* (10): 1–71.

GRAN, H. H. 1927. The production of plankton in the coastal waters off Bergen March–April 1922. *FiskDir. Skr. Ser.Hav.Unders., 3* (8): 1–74.

– 1929. Investigation of the production of plankton outside the Romsdalsfjord 1926–1927. *Rapp. P.-v. Réun. Cons.perm. int. Explor. Mer, 56*: 1–112.

– 1930. The spring growth of the plankton at Møre 1928–29 and at Lofoten in 1929 in relation to its limiting factors. *Skr.norske Vidensk-Akad. Mat.-naturv. Kl., 1930* (5): 1–49.

GAARDER, K. R. 1938. Phytoplankton studies from the Tromsø district 1930–31. *Tromsø Mus.Årsh., 11, 55 (1932)* (1): 1–159.

HEIMDAL, B. R. 1974. Composition and abundance of phytoplankton in the Ullsfjord area, North Norway. *Astarte, 7*: 17–42.

HELLAND-HANSEN, B. and NANSEN, F. 1909. The Norwegian Sea: Its physical oceanography based upon the Norwegian researches 1900–1904. *FiskDir. Skr. Ser. HavUnders., 2 (Part 1)* (2): 1–390.

LJØEN, R. and NAKKEN, O. 1969. On the hydrography of the shelf waters off Møre and Helgeland. *FiskDir. Skr. Ser. HavUnders., 15*: 285–294.

NORDLI, O. 1949. Fytoplanktonundersøkelser i Lofoten 1945–1946 og 1948. (Phytoplankton investigations in Lofoten 1945–1946 and 1948.) Thesis in botany, Univ. Oslo, 1949/II. [Manuscript].

UTERMÖHL, H. 1931. Neue Wege in der quantitativen Erfassung des Planktons. (Mit besonderer Berücksichtigung des Ultraplanktons.) *Verh. int. Verein.theor. angew. Limnol., 5*: 567–596.

Received 5 March 1977.
Printed 7 June 1978