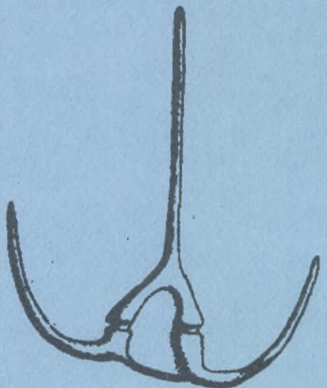
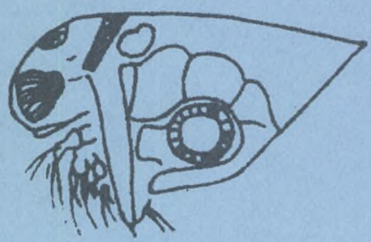
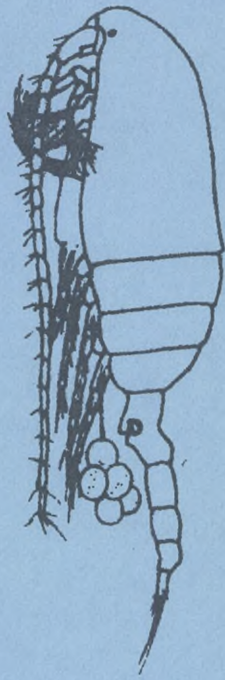
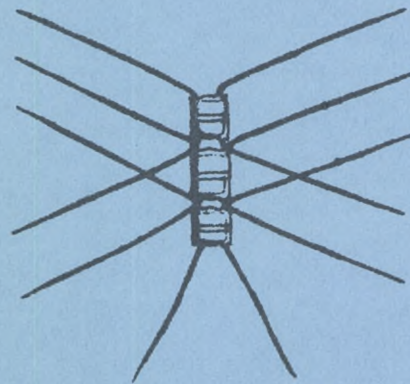
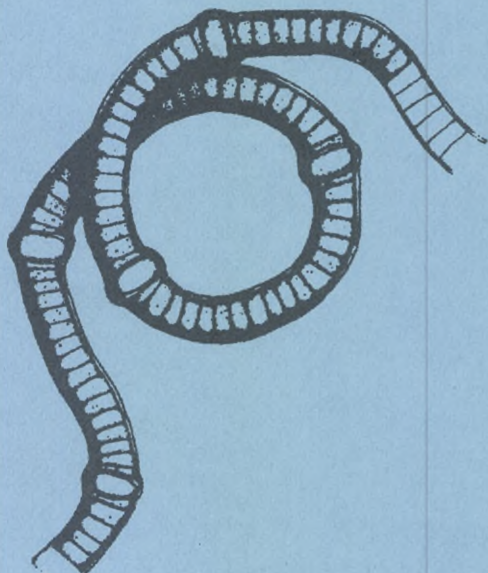
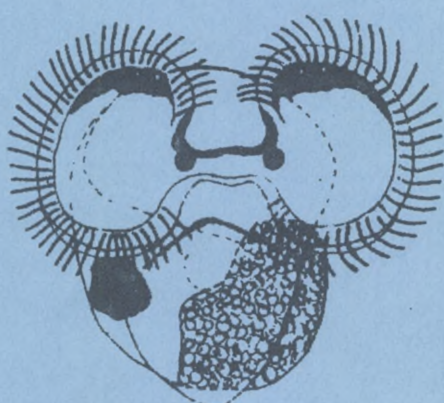

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INVESTIGATIONS ON PRIMARY PHYTOPLANKTON PRODUCTION IN THE BALTIC IN 1974

by

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ABSTRACT

Primary production, chlorophyll and phytoplankton studies were carried out at four offshore stations in the Baltic from the Hanö Bight in the south (N 55°40' E 15°20') to Sydostbrotten in the north (N 63°25' E 20°20'). The sampling was carried out at 42 occasions in 1974.

The winter in 1974 was comparatively mild and ice was found only in the Bothnian Sea. The summer in 1974 was windy and quite cold. The water temperature during summer was in the range 14-16°C. The salinity was almost homogeneous from surface down to 20 m depth and fluctuated at the various stations and seasons between 5-9 ‰.

The primary production was measured with the ^{14}C-technique in situ using 4-hours incubation time at 10 depths. The yearly primary production at the most southern station (station 1 in the Hanö Bight) was 121 gC m^{-2} $year^{-1}$, at station 2 east of Gotland 116 gC m^{-2} $year^{-1}$ and at station 4 in the Bothnian Sea the production was 70 gC m^{-2} $year^{-1}$. At station 3 in the Åland Sea no estimation of the yearly production has been done due to too few measurements. The production increased with about 15 % at the two southerly stations and was roughly the same at the northern station compared with 1973. As in 1973 the third quarter of the year was the most productive with about 50 % of the yearly production. The second quarter contributed as a mean with 35 %. The highest calculated daily production was 976 mgC m^{-2} d^{-1} in April at station 1. Looking at which depth the maximum primary production occurred, there was an obvious difference between cloudy and clear days. On a clear day the maximum production was found 2-3 m deeper compared with a cloudy day. The maximum production appeared mainly above the 5 m level and always above the 8 m level. Analysing data from measurements carried out in spring time, 1973-75, the spring bloom started when the water temperature exceeded 2.5°C. In the temperature range 2.5-3.0°C the Baltic water has density maximum and vertical spring convection occurs. This initiates the spring bloom.

The chlorophyll a values mainly ranged from 10-40 mg m^{-2} with slightly higher values in the north than in the south. As a mean the chlorophyll a values in 1974 were higher than in 1973.

The phytoplankton biomass values were also higher than in 1973. They were mainly in the magnitude 3-6 g m^{-2} (wwt), but there were also some values of about 14 g m^{-2}. The dominating phytoplankton species were the blue-green algae (*Aphanizomenon flos-aquae*, *Nodularia spumigena*), the diatoms (*Chaetoceros* spp., *Sceletonema costatum*, *Thalassiosira baltica*), the dinoflagellates (*Gonyaulax catenata*, *Gyrodinium spirale*) and the monads which were not identified to species.

INTRODUCTION

Since January 1973 the Institute of Marine Research in Lysekil, Sweden, has carried out a research program for primary production studies in the Baltic proper and the Bothnian Sea. The aim of this investigation which is still going on, is to find adequate values for the primary production in four different offshore areas of the Baltic. The measurements, which have been relatively continuous since the start, have been carried out at four stations 10-20 nautical miles off the coast (fig. 1). The results are therefore considered representative for real offshore conditions in the Baltic.

The authors want to thank the crews of the rescue cruisers GRÄNGESBERG, ÖSTERGARN, GUSTAV DALÉN, SIGURD GOLJE and the research vessel CLUPEA for their cooperative help during the many sampling occasions. We also want to thank Fk. Lars Edler, Fk. Nils Kautsky and Mrs Margaretha Frech for carrying out most of the measurements. The authors want to express many thanks to Mrs Rut Hobro, who has been responsible for the analyses of phytoplankton samples.

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METHODS AND MATERIAL

In this report only a summary of the methods and material used will be given. A more detailed description can be found in Ackefors & Lindahl (1975a).

Station net and measuring frequency

In table 1 the position of the stations and the number of measurements carried out at each station is listed.

Table 1. Station net and measuring frequency

Station No.	Position N	Position E	Distance from shore Nautical miles	Number of measurements 1973	1974	1975
1	55°40'	15°20'	20	18	15	14
2	57°25'	19°15'	10	10	9	16
3	59°50'	19°35'	15	9	7	-
3'	60°20'	18°50'	10	-	-	14
4	63°25'	20°20'	15	12	11	4

Data collected

In order to aquire a more detailed picture of the investigated areas, a number of other parameters have been included in the programme.

1. Water temperature, salinity and pH (only at station 1 and 2) is measured onboard the vessel.
2. Samples for determining the amount of chlorophyll and the phytoplankton biomass are collected from 15 m to surface.
3. A net sample for qualitative phytoplankton analysis is taken from 20 m to surface.
4. Mesozooplankton, and at station 1 micozooplankton, are collected from the whole vertical column since 1975.
5. Air temperature, cloudiness, wind direction and speed, state of sea and secchi-disc value are recorded on measuring occasions.
6. Irradiation is measured from a land based station close to each measuring area.

Irradiation

The irradiation is measured between 300-2500 nm by a Kipp & Zonen solarimeter type CM 6 connected to a Kipp & Zonen integrator type CC 1. A printer connected to the integrator gives the irradiation values every hour on a papertape.

When irradiation measurements are missing for one reason or another, values from the nearest irradiation station belonging to the Swedish Meteorological and Hydrological Institute (SMHI) are used. These stations are situated at Svalöv, Visby, Erken and Teg for station 1-4 respectively (cf. fig. 1).

Primary production

The primary production measurements are carried out <u>in situ</u> with the ^{14}C-technique in nearly all respects according to "A manual for phytoplankton primary production studies in the Baltic" proposed by Working Group 4 inside the Baltic Marine Biologists (1975). However, the methods had to be slightly modified due to practical reasons. Fixed incubation depths are used with a single light-bottle at each sampling depth. The depths are 0, 1, 2, 3, 4, 6, 8, 10, 15 and 20 m. Four dark-bottles are used at 0, 4, 10 and 20 m depth. The production below 20 m depth is negligible in the Baltic according to earlier measurements.

Four hours incubation time is used. The incubation is always carried out during the same period of the day (9 am - 3 pm). It is then possible to compare different measurements without any transformations. However, it is necessary to transform the four hour values (mgC m^{-2} h^{-1}) into daily production (mgC m^{-2} d^{-1}). The factor used for this transformation is called the lightfactor (LF). LF = $\frac{I_d}{I_m}$, where I_d is the irradiation during the day and I_m the irradiation during the measurement.

The ampouls and filters used (Sartorius, pore size 0.2 µ) are bought at the Carbon 14 Centralen in Copenhagen. The Central carries out the measurements of the radio-activity on the filters with a Geiger-Müller counting equipment.

Chlorophyll

The water-samples are taken with a hose (15 m long) as an integral sample. The SCOR/UNESCO method is used when storing the samples and measuring the amount of chlorophyll.

Phytoplankton biomass

The water-sample is taken as described above and is preserved in Keefe's solution. The phytoplankton is analysed according to the Utermöhl technique and the cellvolume for each species is calculated.

Phytoplankton flora

The samples are collected using a net with a mesh-size of 25 µ. Vertical hauls are taken down to 20 m depth. The samples are preserved in Keefe's solution.

RESULTS

On 42 occasions different parameters were investigated at four offshore stations: in the Hanö Bight, east of Gotland, in the Åland Sea and in the Sydostbrotten area between the Bothnian Sea and the Bothnian Bay (fig. 1). All stations are situated at least 10 nm off the coast. The distribution in time of the separate measurements is evident in fig. 2. The figure also shows the frequency of measurements carried out in 1973 and 1975. Because of unstable and windy weather conditions during 1974 the total number of measurements is less than the number originally planned.

Temperature, salinity and pH

The winter of 1974 was mild in comparison with a normal winter. Only at the most northern station there was ice at sea. The summer in 1974, however, was windy and quite cold. The isopleths at the various stations are reproduced in figure 3. Only at station 1 a water temperature above 18°C was found. That occurred in the end of August in the absolute surface layer of the water mass. The water temperature at the two southern stations were in the range 14-16°C in July and September, 16-18°C during August. The water at station 3 and 4 were colder. Neither of the stations reached 16°C. The warmest period was August-September when the temperature fluctuated between 14-16°C.

The heat content relative to 0°C below one square metre of the sea-surface down to 20 m has been calculated at all stations for all measurements (fig. 4). In general, the values for station 1 in the Hanö Bight are higher than the values for station 4 in the Bothnian Sea. In the beginning of the year the heat content is less than $50 \cdot 10^3$ Kcal m^{-2} down to 20 m at all stations. In April the heat content began to increase and the maximum occurred in late August. The main reason for calculating the heat content was to study the primary production during spring versus irradiation and water temperature (fig. 9).

On most occasions the salinity was homogeneous from surface to the 20 m level. There were, however, differences between the sampling occasions. The lowest and highest salinity found at station 1 was 6.4 ‰ and 9.1 ‰ respectively. A mean value of all measurements is 7.3 ‰. At station 1 the salinity was higher during the second half of the year. At station 2 the salinity fluctuated between 6.8 ‰ and 8.5 ‰ with a mean value of 7.6 ‰. This station had the highest salinity of all. In the Åland Sea the salinity was in the range 5.5-6.7 ‰ with a mean value of 6.0 ‰. At station 4 in the Sydostbrotten area no measurements of the salinity were performed in 1974. However, the mean salinity in the area was estimated to 4.8 ‰.

The pH was only measured at station 1 and 2 and the values fluctuated around 8.2 all the time.

Irradiation

In 1974 irradiation measurements were carried out at station 1, 2 and 4 i.e. at Hörvik, Herrvik and Norrbyskär. There have been some gaps in the registration of the irradiation, but this lack of data have been filled with data from the nearest SMHI solarimeter station. At station 3 all irradiation data origin from SMHI. The monthly, quarterly and yearly values as well as the yearly mean values of the irradiation on the four areas is evident in figure 5 and table 2.

The differences between the annual mean for the period 1958-69 and the 1974 values are +7, -1, +4 and -6 % for the different areas going from south to north. SMHI states that a yearly difference from the annual mean of at least ± 10 % is reasonable. From table 2 it can be calculated that in 1974 the contribution of the second quarter was about 50 % and of the third quarter 35 % of the total irradiation on all areas. Official statistics show that the second quarter always contributes with more than the third quarter to the yearly irradiation value.

Primary production

Station 1, Hanö Bight: 15 measurements were carried out in 1974 (table 5 and fig. 6). At the first measurement of the year in the beginning of January (74-01-03) a value of 30 mgC m^{-2} d^{-1} was found. In late February (74-02-26) the calculated daily production was found to be twice as high or 63 mgC m^{-2} d^{-1}. In the second half of March and in the beginning of April the primary production rapidly increased. By the turn of the month the production as a mean of four measurements was around 300 mgC m^{-2} d^{-1}. An unusually high peak value was found in the middle of April when the daily production was calculated to 976 mgC m^{-2} d^{-1} (74-04-19). This is the highest value found in the whole investigation so far. On this occasion the maximum production occurred at 4 m depth and was 109 mgC m^{-3} d^{-1}. In May the production dropped and the typical late spring minimum was observed. Around the middle of May (74-05-10) the production was 369 mgC m^{-2} d^{-1}. From the middle of June to the end of August five measurements were carried out with a mean production of 590 mgC m^{-2} d^{-1}. The lowest value of these five was 443 mgC m^{-2} d^{-1} (74-06-28) and the highest 700 mgC m^{-2} d^{-1} (74-08-08). Due to a period of very rough weather during the autumn only one measurement was carried out. The production found on this occasion (74-10-18) was 252 mgC m^{-2} d^{-1}. When calculating the quarterly and yearly production, the daily production in November was estimated to be 40 mgC m^{-2} d^{-1} and in December 30 mgC m^{-2} d^{-1}.

Station 2, east of Gotland: 9 measurements were carried out in 1974 (table 6 and fig. 6). At the first measurement in the middle of February a production of 23 mgC m^{-2} d^{-1} was found. Next measurement was not carried out until early April (74-04-08) and gave 251 mgC m^{-2} d^{-1}. The highest daily production found during the spring bloom was 587 mgC m^{-2} d^{-1} and occurred at the end of April (74-04-29). At this station a period of low production was observed in the middle of June (354 mgC m^{-2} d^{-1}, 74-06-18). In July, August and September three measurements were carried out with a mean production of 758 mgC m^{-2} d^{-1}. The peak value of 829 mgC m^{-2} d^{-1} during that period was observed in the middle of August (74-08-21). Only one measurement was done during the autumn (74-10-24) and the calculated daily production was 74 mgC m^{-2} d^{-1}. This last value of the year is rather uncertain due to very bad weather conditions during the measurement, which influenced the technical part of the measurement. When calculating the quarterly and yearly production, the daily production in November was estimated to 40 mgC m^{-2} d^{-1} and in January and December 30 mgC m^{-2} d^{-1}.

Station 3, Ålands Sea: Only 7 measurements were carried out in 1974 and of these only two during the most important period of the productive season (table 7 and fig. 6). The first measurement was carried out the first of March and the daily calculated production was 44 mgC m^{-2} d^{-1}. During April and May three measurements were carried out with a mean production of 310 mgC m^{-2} d^{-1}. No pronounced peak value was found and the highest value was 372 mgC m^{-2} d^{-1} (74-05-20). Unfortunately no values are available for June and July. In August two measurements were done with a mean value of 260 mgC m^{-2} d^{-1}. Only one more measurement was carried out during 1974 i.e. in November (74-11-07, 27 mgC m^{-2} d^{-1}). Due to too few measurements at station 3 no adequate value of the quarterly and yearly procuction for station 3 in 1974 can be calculated.

Station 4, Sydostbrotten area: 11 measurements were carried out in 1974 (table 8 and fig. 6). Due to fast ice until the middle of March, drifting ice until the middle of April and a failing research vessel, the first measurement was carried out as late as in the middle of May (74-05-21). On that occasion the daily calculated production was 408 mgC m^{-2} d^{-1}, which was the highest value during the spring. It is impossible to say whether this was the real peak value or if the primary production had been higher earlier in April or May. A close series of measurements in June showed a decreasing trend. The period of low production appeared in the middle of June (174 mgC m^{-2} d^{-1}, 74-06-18). In July, August and September four measurements were carried out. The mean production of the four measurements was 569 mgC m^{-2} d^{-1} with a peak value of 711 mgC m^{-2} d^{-1} in the end of July (74-07-24). The measurement carried out in the end of October (74-10-30) gave a daily production of 39 mgC m^{-2} d^{-1}. The last value of the year was only 5 mgC m^{-2} d^{-1} and was measured in the beginning of December (74-12-02).

The quarterly and yearly production has been calculated for the four areas (table 3). When no measurements have been carried out,each day of the winter months was considered to contribute to the production with about 30 mgC m^{-2} d^{-1}. The contribution from a winter month was thus calculated to be 0.9 gC m^{-2}.

Table 3. Quarterly and yearly primary production in gC m^{-2} at station 1-4 in 1974.

Station No.	I	II	III	IV	Total
1	8	50	54	9	121
2	6	37	64	9	116
3	7	-	-	-	-
4	0(ice)	17	47	6	70

As in 1973 the highest yearly production was found at the most southern station (station 1), i.e. the station in the Hanö Bight. The yearly production in 1974 at this station has been calculated to 121 gC m^{-2} $year^{-1}$. At station

2 east of Gotland the yearly production has been calculated to 116 gC m^{-2} $year^{-1}$. Due to too few measurements no yearly production value has been calculated for station 3 in the Åland Sea. The most northern station in the Sydostbrotten area had a yearly production of 70 gC m^{-2} $year^{-1}$ in 1974.

The most productive quarter was the third at all stations. The production in July-September was estimated to 45-67 % of the yearly production. The contribution of the second quarter was 27-41 %. The production figures from the second and third quarter was hence 86-91 % of the yearly production. The contribution to the yearly production from the months January-March and October-December was thus comparatively small.

Looking at which depth the maximum production occurred there was an obvious difference between cloudy and clear days. Especially in the summer time, when the altitude of the sun is high, the difference was pronounced. On a clear day the maximum production was found 2-3 m deeper compared with a cloudy day. This is due to photoinhibition in the top layer of the water column. This effect was also noticeable during spring and autumn. It was then less pronounced, probably due to the lower altitude of the sun. As a mean of all measurements carried out, there is a distinct trend how the maximum production depth changes during the year. If the depth of maximum production is plotted versus the time of the year, the curve obtained, has the same shape, as the curve obtained when plotting the altitude of the sun at noon versus time of the year. The maximum production appeared mainly above the 5 m level and always above the 8 m level.

The quarterly and yearly efficiency (= the production divided with irradiation) of the primary production in 1974 has been calculated. When transforming the assimilated carbon into calories, a value of 1 gC equals 8 Kcal has been used (Odum, 1971). In average 41 % of the measured irradiation has been found to contain the photosynthetic spectrum i.e. 400-700 nm (Gargas, pers.comm.). This value has been used in the efficiency calculations.

Table 4. The quarterly and yearly efficiency of the primary production at station 1-4 in 1974.

Station No.	I	II	III	IV	Annual mean
1	0.10	0.23	0.33	0.37	0.26
2	0.11	0.17	0.38	0.41	0.27
3	0.14	-	-	-	-
4	0(ice)	0.08	0.35	0.47	0.30

In table 4 it is obvious, that the plankton algae utilized the light better in the autumn than during spring.

Chlorophyll a

At all stations chlorophyll a measurements were performed according to the SCOR/UNESCO method. The filters were stored in a deep-freezer until they were analysed. The results are evident in tables 5-8 and in figure 7. The fluctuations of the chlorophyll a values expressed in mg m^{-2} showed similar fluctuations as the primary production, with a few exceptions.

At station 1 the chlorophyll a values were in average 13 mg m^{-2} during the first quarter. During April and May a value of 30 mg m^{-2} was found as a mean of five measurements. The rest of the year rather even values around 11 mg m^{-2} were recorded. At the last measurement of the year carried out in October, a value of 23 mg m^{-2} was found. East of Gotland no value from the winter months is available. In April and May 28 mg m^{-2} was found as a mean of three measurements. From June until September the average chlorophyll a content was 27 mg m^{-2}. The measurement at the end of October gave a value of 15 mg m^{-2}. At the Åland Sea station there was a big difference in the amount of chlorophyll a during spring. The first measurement in the beginning of March gave 10 mg m^{-2}, but a month later a conspicuous peak value of 70 mg m^{-2} was found. That is the highest value so far in the whole investigation. The two measurements in August were around 20 mg m^{-2}, and the last value in November was 18 mg m^{-2}. At station 4 the five measurements in May and June had a mean content of chlorophyll a of 24 mg m^{-2}. In the third quarter an average amount of 36 mg m^{-2} was recorded out of four measurements. The last available value of the year was 18 mg m^{-2}, measured in the end of October.

Phytoplankton

The biomass of the phytoplankton is reproduced in tables 5-8 and figure 8. Detailed information about the components of the phytoplankton biomass is reproduced in tables 9-12. At all stations phytoplankton biomass values in the magnitude of 3-6 g m^{-2} (wwt) were found. However, there were some divergences worth mentioning. In October in the Hanö Bight (station 1) a biomass of 19 g m^{-2} was observed. This is the highest amount of phytoplankton biomass so far in the whole investigation. During April the mean biomass value was 13 g m^{-2} and in May a value of 8 g m^{-2} was found at station 3 in the Åland Sea. In May and June the mean value of five measurements was 9 g m^{-2} with a peak value of 14 g m^{-2} in the Sydostbrotten area.

At station 1 the diatoms and the monads were dominant through out the whole year and made the largest contribution to the biomass (table 9). The blue-green algae were most frequent in June-August, and Aphanizomenon flos-aquae, which was the dominant species, was found in all samples. Among the diatoms an unidentified diatom species was frequent in February-March and later in April-May Chaetoceros spp. was dominating. The monads were not identified to species. They were abundant throughout the whole year, especially in June-October. The high biomass value in October (19 g m^{-2}) consisted to 99 % of monads.

The blue-green algae, the diatoms, the dinoflagellates and the monads dominated the phytoplankton flora at station 2, east of Gotland (table 10). The blue-green algae were most frequent in June-September and Aphanizomenon flos-aquae and Nodularia spumigena were the dominant species. The diatoms were frequent in February, April and October. Chaetoceros spp. and Sceletonema costatum were abundant in April and an unidentified diatom in February and October. The dinoflagellates were present during April-June and Gonyaulax catenata and Gyrodinium spirale were the most abundant species. The monads were frequent almost all the year.

In the Åland Sea at station 3 the blue-green algae, the diatoms and the dinoflagellates contributed most to the biomass, especially the diatoms were very frequent (table 11). The blue-green algae were abundant in August and November. Also in this area Aphanizomenon flos-aquae and Nodularia spumigena were the most abundant blue-green algae. The diatoms were mainly frequent during spring i.e. March-May. The most abundant species were Chaetoceros spp. and Thalassiosira baltica. The dinoflagellates were found in all samples and Gonyaulax catenata was the dominating species. Some monads were found in August.

At the most northern station, station 4, the blue-green algae, the diatoms and the monads were the most common algae (table 12). The blue-green algae were dominating from August and onwards. Aphanizomenon flos-aquae was found in all samples, but especially in August and September together with Nodularia spumigena. Chaetoceros spp. was the most abundant species among the diatoms, which were very frequent in May-June. Dinoflagellates were found in all samples, Gonyaulax catenata was especially abundant in May. Also the monads were found in all samples but they were most abundant in July-September.

DISCUSSION

In this discussion a comparison of hydrography, irradiation, primary production, chlorophyll a and phytoplankton biomass between 1973 and 1974 will be given. Unfortunately it has not been possible to measure the amount of nutrients simultaneously with the other parameters in this investigation due to practical reasons. Nutrient data would have been useful when drawing conclusions about primary production fluctuations.

Hydrography. The winters in 1973 and 1974 were mild compared with what is supposed to be a normal winter. However, the summers differed somewhat from each other. The water temperature was in the summer 1973 about 2°C warmer than in the summer 1974, except at station 4 where the temperature was about the same both years.

Irradiation. As a mean of the four areas and during both years, more irradiation reached the ground compared with the annual mean stated by SMHI. Especially in 1973 more irradiation than the average reached the ground. As a mean of both years the irradiation deviated from the yearly mean (1958-69) by +9, +4, +5 and -3 % for the different areas from south to north. In 1974 more irradiation reached the ground during the first half of the year compared with 1973. During the second half of the years it was the opposite situation as more irradiation was measured during this time in 1973 than in 1974.

Primary production. The yearly,primary production at the two southern stations was considerably higher in 1974 than in 1973 (table 13). The differences are about 15 %. At station 4 in the northern Bothnian Sea the production was at the same level both years. The amount assimilated carbon was considerably more during the period March-May in 1974 than in 1973 at station 1 and 2. However, at the two northern stations the situation was the opposite. The spring bloom was more pronounced 1973 and the amount assimilated carbon during that time was also more in 1973. The typical late spring or early summer minimum in primary production due to alack of nutrients, was more or less pronounced both years at all stations. During the most productive part of the year, the third quarter, the primary production was higher in 1974 than in 1973. This was especially obvious east of Gotland and in the Sydostbrotten area. Due to bad weather conditions during autumn both years, quite few measurements were carried out and no relaible comparisons can be made.

The phytoplankton biomass was higher in 1974 in comparison with the biomass values in 1973. This was particularly obvious at the two northern stations. The same trend was found for the chlorophyll a values, i.e. higher values at the two northern stations in 1974 than in 1973.

According to table 4 the plankton algae obviously utilized the light better in the autumn than in the spring 1974 as the efficiency was lower during spring than during autumn. This trend was also evident during 1973. The best way to explain this is probably to assume, that the irradiation has not been the limiting factor for primary production during spring. In order to find out which parameters that initiate the primary production in springtime a special study on the available data has been carried out. The mean temperature down to 20 m, the irradiation and the amount of assimilated carbon for all measurements carried out in 1973-75, when the mean temperature was lower than 4.5°C, has been plotted in a diagram (fig. 9). In this diagram it is obvious that the primary production will on most occasions not exceed values of 300 mgC m^{-2} d^{-1} if the mean temperature is below 2.5°C. On nearly all occasions the water temperature was almost homogeneous down to 20 m. Several measurements have been carried out during good light conditions for primary production when the mean water temperature was below 2.5°C. No high primary production rates were then found. If the 2.5°C limit was passed, high production rates were found even during quite bad light conditions. The low number of measurements carried out in light conditions below 150 mWh cm^{-2} d^{-1} is due to the fact that there are few days with low irradiance, when it is possible to carry out a measurement, as low irradiance and bad weather are closely connected. The fact that there are few measurements carried out, when the irradiation exceeded 400 mWh cm^{-2} d^{-1} and the mean water temperature was below 2.5°C, has its natural explanation. Days with irradiation exceeding 400 mWh cm^{-2} d^{-1} are rare until April, and in April the water temperature has mainly passed 2.5°C.

The water temperature must thus exceed 2.5°C in order to initiate the phytoplankton spring bloom. For physiological reasons the phytoplankton spring bloom can occur below 2.5°C (L. Edler, pers.comm.). However, there is a hydrographical solution to the problem. The temperature, when the Baltic waters have density maximum, is depending on the salinity. According to Dietrich & Kalle (1957) the density maximum appears in the temperature range 2.5-3.0°C (the shaded area in fig. 9), when the salinity fluctuates between 5-8 ‰, which are the salinities found in the surface waters at station 1-4 during spring. When the water has density maximum only a little wind force is needed in order to create a very effective vertical convection down to the halocline or to the bottom in shallow areas. When the water is mixed, nutrients will be brought up in the photosynthetic zone. It is possible, that species which hibernates at greater depth as well are brought up to the surface layers by this turn over process.

The conclusion is therefore, that the vertical convection in spring is necessary to initiate the spring bloom.

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Table 2. Irradiation in mWh cm^{-2} at station 1-4 in 1974.

	Station 1 (Hörvik)	Station 2 (Herrvik)	Station 3 (Erken)	Station 4 (Norrbyskär)
January	990	1186	961	390
February	3058	2447	2454	2059
March	9772	8764	7716	6602
April	14706	13680	13349	11861
May	17415	16640	19504	17555
June	17223	19246	18530	18432
July	15862	15445	13415	13188
August	13990	14547	14603	11136
September	7539	8646	7804	6514
October	3273	3261	2381	2111
November	1353	970	852	547
December	825	799	517	242
QUARTER				
I	13820	12397	11131	9051
II	49344	49566	51383	47848
III	37391	38638	35822	30838
IV	5451	5030	3750	2900
Total	106006	105631	102086	90637
AVERAGE	Svalöv	Visby	Stockholm	Teg
1958-69	99380	106428	97873	96610
DIFFERENCE				
1974	+7 %	-1 %	+4 %	-6 %

Table 5. Irradiation, measured production, calculated production, chlorophyll a and phytoplankton biomass at station 1, 1974.

Date	Irradiation $mWh\ cm^{-2}\ d^{-1}$	Measured production $mgC\ m^{-2}\ h^{-1}$	Calculated production $mgC\ m^{-2}\ d^{-1}$	Chlorophyll a $mg\ m^{-2}$	Phytoplankton biomass $g\ m^{-2}$ wwt
740103	9	5.7	30	13.2	0.1
740226	200	10.3	63	12.2	3.4
740321	152	24.3	239	11.0	6.5
740328	490	22.2	177	14.0	5.6
740403	488	37.2	305	27.5	1.5
740410	528	54.0	490	30.6	1.6
740419	436	116.2	976	34.3	2.8
740426	620	76.8	762	39.4	1.2
740510	721	39.1	369	17.5	5.2
740617	799	60.8	640	9.3	0.6
740628	474	48.1	443	13.0	2.7
740709	770	60.5	629	14.1	0.9
740808	675	72.9	700	7.6	4.0
740831	393	75.6	537	12.1	3.9
741018	189	37.6	252	23.0	19.1

Calculated yearly production: 121 gC m^{-2} $year^{-1}$

Table 6. Station 2, 1974

740213	171	3.7	23	-	0.1
740408	509	29.9	251	18.6	1.1
740429	637	64.1	587	36.3	2.7
740510	273	45.9	419	30.3	1.3
740618	559	28.5	354	19.6	0.8
740718	640	76.9	715	25.8	5.2
740821	602	93.1	829	32.7	4.6
740912	346	81.9	729	30.5	1.6
741024	23	10.1	74	15.4	1.2

Calculated yearly production: 116 gC m^{-2} $year^{-1}$

Table 7. Irradiation, measured production, calculated production, chlorophyll a and phytoplankton biomass at station 3, 1974.

Date	Irradiation $mWh\ cm^{-2}\ d^{-1}$	Measured production $mgC\ m^{-2}\ h^{-1}$	Calculated production $mgC\ m^{-2}\ d^{-1}$	Chlorophyll a $mg\ m^{-2}$	Phytoplankton biomass $g\ m^{-2}$ wwt
740301	236	6.3	44	9.6	1.4
740403	332	40.8	261	69.6	13.6
740429	397	37.2	298	31.3	13.0
740520	826	37.6	372	23.4	8.2
740811	432	29.5	218	21.0	2.3
740827	465	35.9	302	18.8	2.2
741107	15	5.4	27	17.9	0.5

Due to too few measurements no yearly production value has been calculated.

Table 8. Station 4, 1974

740521	732	31.1	408	36.6	13.1
740531	401	28.3	291	26.4	6.2
740613	759	21.5	228	17.7	14.1
740618	799	16.1	174	14.8	2.3
740624	762	30.5	322	24.2	8.2
740719	686	67.2	645	33.2	5.2
740724	720	67.7	711	33.9	1.1
740815	500	53.3	490	36.8	2.9
740914	339	52.8	428	38.9	2.9
741030	14	6.5	39	17.8	1.0
741202	4	0.9	5	-	0.7

Calculated yearly production: 70 $gC\ m^{-2}\ year^{-1}$

Table 9. The components of phytoplankton biomass expressed as percentage of the total. The total values are given as g m^{-2} (wwt). Station 1, 1974.

Date	Blue-green algae %	Diatoms %	Silico-flagellates %	Dino-flagellates %	Green algae %	Euglenids %	Monads %	Total g m^{-2} wwt
740103	19.5	68.6	0	0	0	1.9	10.0	0.1
740226	2.9	23.2	0	0	0	1.3	72.6	3.4
740321	0.6	94.1	0	0	0	0.6	4.7	6.5
740328	0.6	85.8	0.2	0	0.1	1.3	12.0	5.6
740403	4.1	30.5	0	0.1	0	5.8	59.5	1.5
740410	6.0	83.9	0	0	0	1.8	8.3	1.6
740419	0.9	90.4	2.6	0.3	0.1	1.3	4.4	2.8
740426	18.9	52.9	2.0	1.0	0.1	0.6	24.5	1.2
740510	3.0	34.2	1.2	0	0	0	61.6	5.2
740617	35.2	10.2	16.2	9.1	4.2	0.3	24.8	0.6
740628	25.7	4.1	8.2	0.4	0.6	0	61.0	2.7
740709	6.1	13.6	10.9	0.7	5.6	0.3	62.8	0.9
740808	7.4	41.0	0.3	0.5	2.0	0	48.8	4.0
740831	9.3	22.4	0.9	0.6	0	0	66.8	3.9
741018	0.6	0.3	0.1	0.1	0	0	98.9	19.1

Table 10. Station 2, 1974

740213	10.0	54.6	0	0	1.3	0	34.1	0.1
740408	0	1.1	3.2	47.5	0.1	22.3	25.7	1.1
740429	0.2	58.3	5.8	31.9	0	0	3.8	2.7
740510	8.6	19.7	4.5	61.0	0	0	6.2	1.3
740618	32.7	4.3	10.9	33.5	0	0	18.6	0.8
740718	62.5	10.5	4.1	5.6	0	0	17.2	5.2
740821	69.2	1.4	0.8	0.7	0	0	27.9	4.6
740912	35.5	12.1	1.5	1.1	0.1	0.6	49.1	1.6
741024	0.5	81.1	0	1.0	0	0.1	17.2	1.2

Table 11. The components of phytoplankton biomass expressed as percentage of the total. The total values are given as g m^{-2} (wwt). Station 3, 1974.

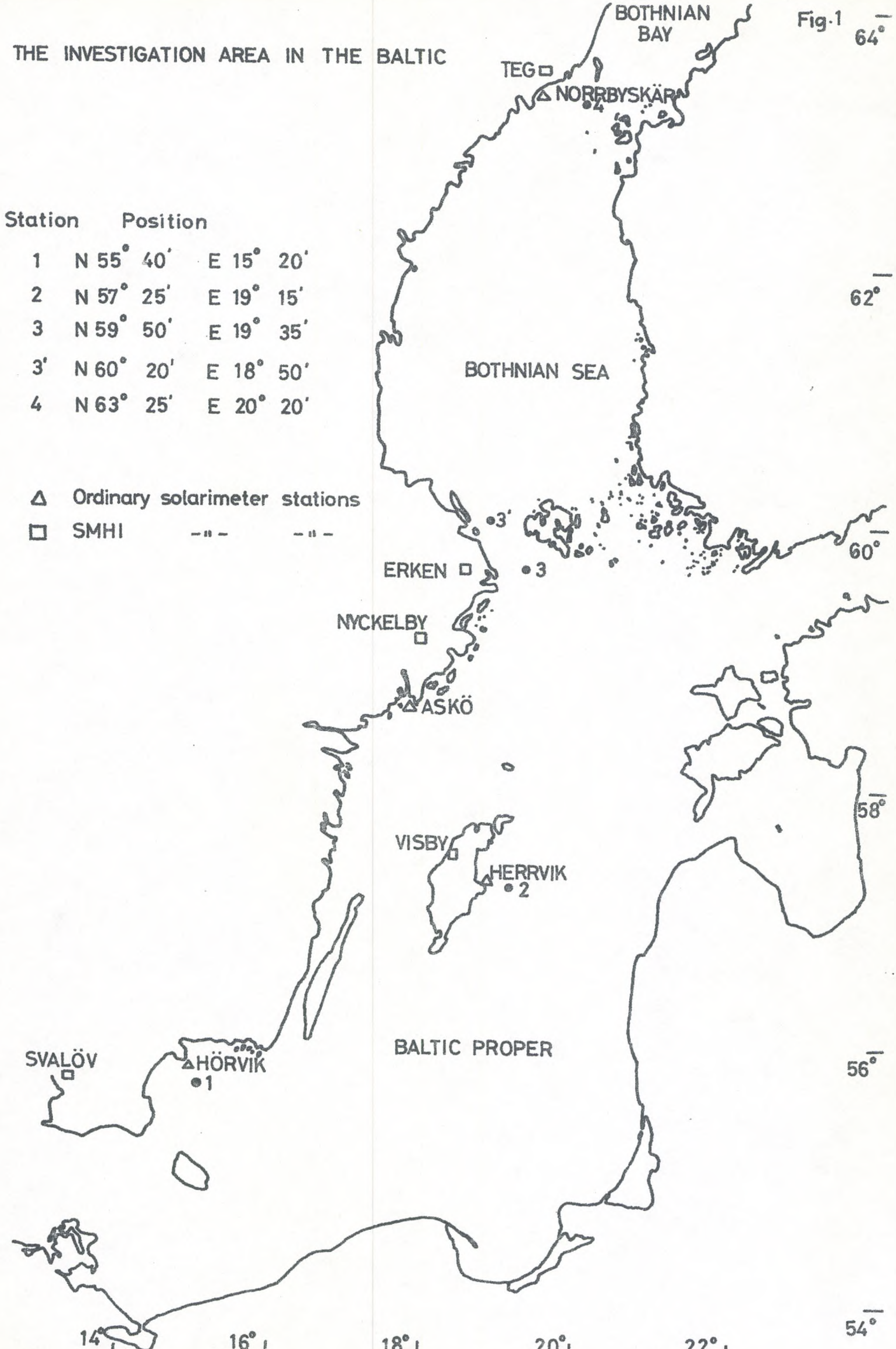
Date	Blue-green algae %	Diatoms %	Silico-flagellates %	Dino-flagellates %	Green algae %	Euglenids %	Monads %	Total g m^{-2} wwt
740301	2.5	69.7	0	26.2	0	0.2	1.4	1.4
740403	0.2	78.8	0.4	19.4	0	0	1.2	13.6
740429	0.1	47.9	1.7	48.4	0	0	1.9	13.0
740520	0	60.1	1.4	38.0	0	0	0.5	8.2
740811	71.0	0	6.4	3.5	0	0.1	19.0	2.3
740827	61.6	1.2	4.4	9.5	0.1	0	23.2	2.2
741107	60.5	27.5	2.3	9.3	0	0.3	0	0.5

Table 12. Station 4, 1974

Date	Blue-green algae %	Diatoms %	Silico-flagellates %	Dino-flagellates %	Green algae %	Euglenids %	Monads %	Total g m^{-2} wwt
740521	0.2	54.9	0.1	44.4	0.1	0	0.3	13.1
740531	1.4	73.8	1.4	18.1	1.7	0	3.6	6.2
740613	1.6	94.2	1.1	1.6	0.6	0	0.9	14.1
740618	15.9	48.5	4.2	14.6	14.9	0	1.8	2.3
740624	8.8	34.5	0	5.6	15.3	0	35.8	8.2
740719	7.4	1.5	2.3	3.0	0.2	0.1	85.5	5.2
740724	12.7	8.8	13.8	4.2	0.9	0	59.5	1.1
740815	35.4	0.5	1.7	0.6	0.1	0	61.7	2.9
740914	49.4	1.2	0.8	6.6	0.1	0	41.9	2.9
741030	66.9	13.3	0	1.2	0.1	0.3	18.2	1.0
741202	65.1	0	1.8	7.0	11.2	0	14.9	0.7

Table 13. Quarterly and yearly primary production in gC m^{-2} in the Baltic in 1973 and 1974.

	I		II		III		IV		Total	
	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974
Station 1	6	8	34	50	53	54	12	9	105	121
Station 2	4	6	25	37	50	64	12	9	91	116
Station 3	8	7	37	-	41	-	8	-	94	-
Station 4	3	~0 (ice)	29	17	36	47	4	6	71	70



THE INVESTIGATION AREA IN THE BALTIC

Fig. 2

MEASUREMENTS CARRIED OUT IN 1973, 1974 AND 1975

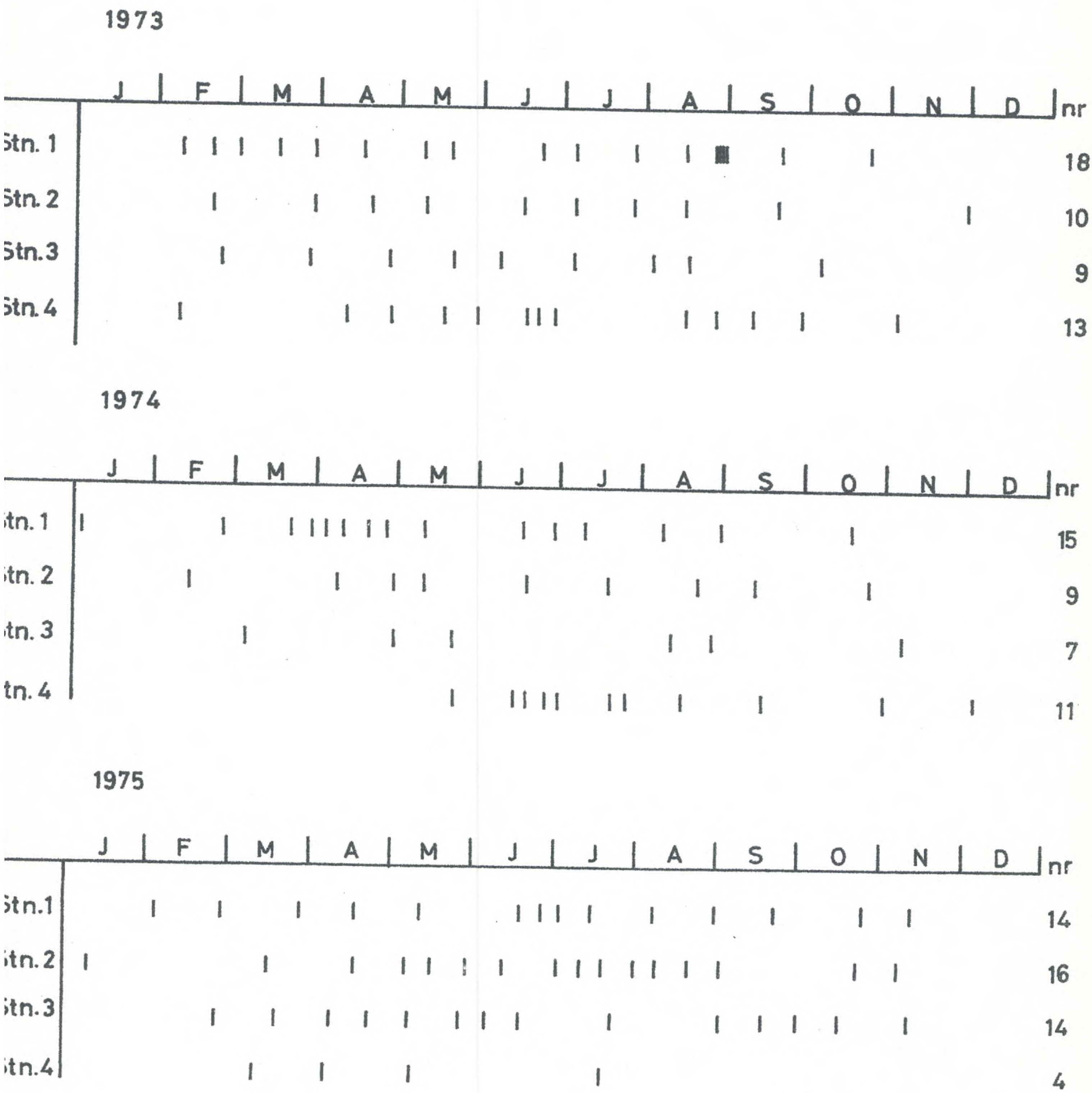


Fig. 3

TEMPERATURE (°C) 0-20M IN THE BALTIC
1974

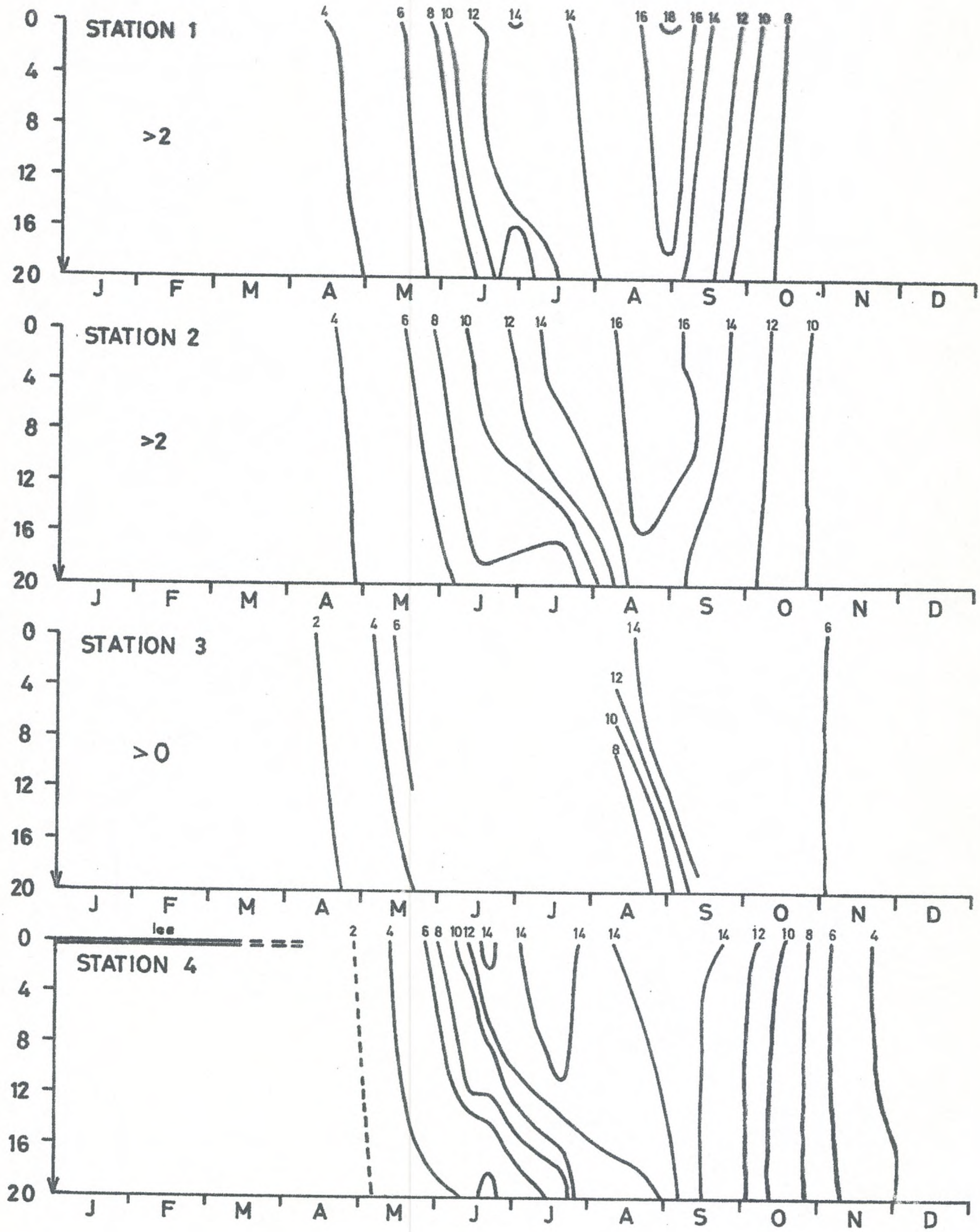
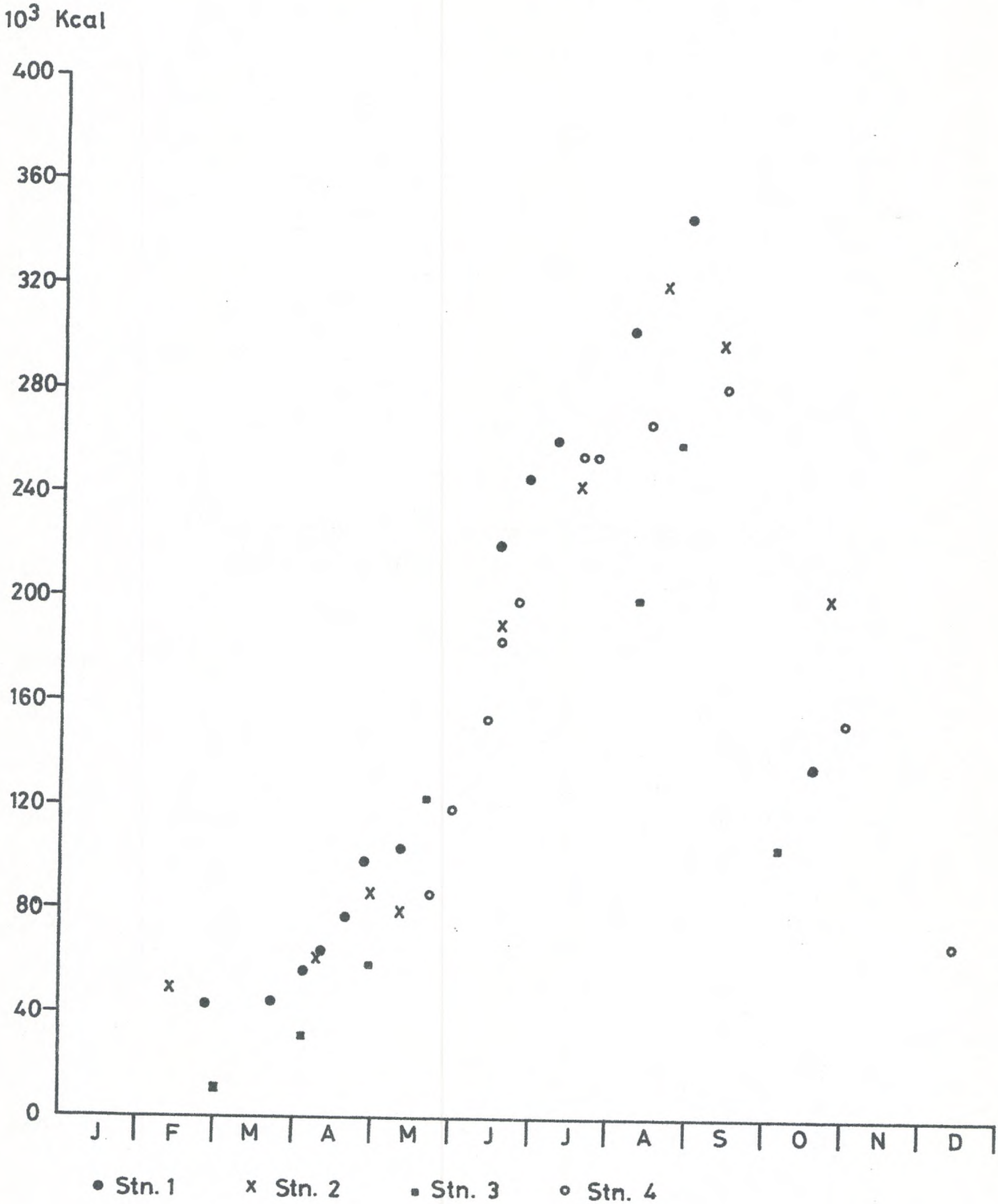


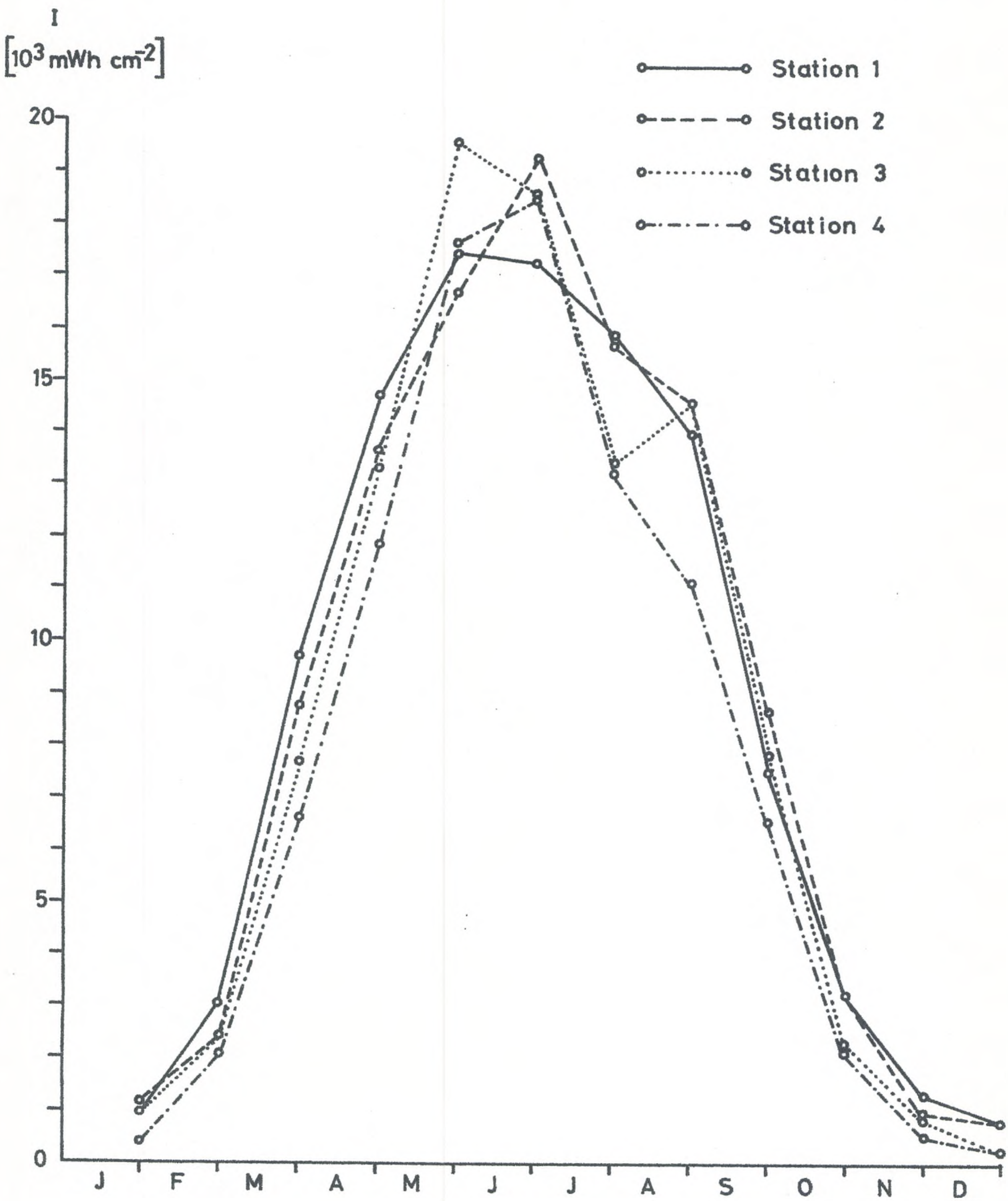
Fig.4

HEAT CONTENT RELATIVE TO 0°C BELOW 1 M² DOWN TO 20 M IN KCAL AT STATION 1-4 IN 1974



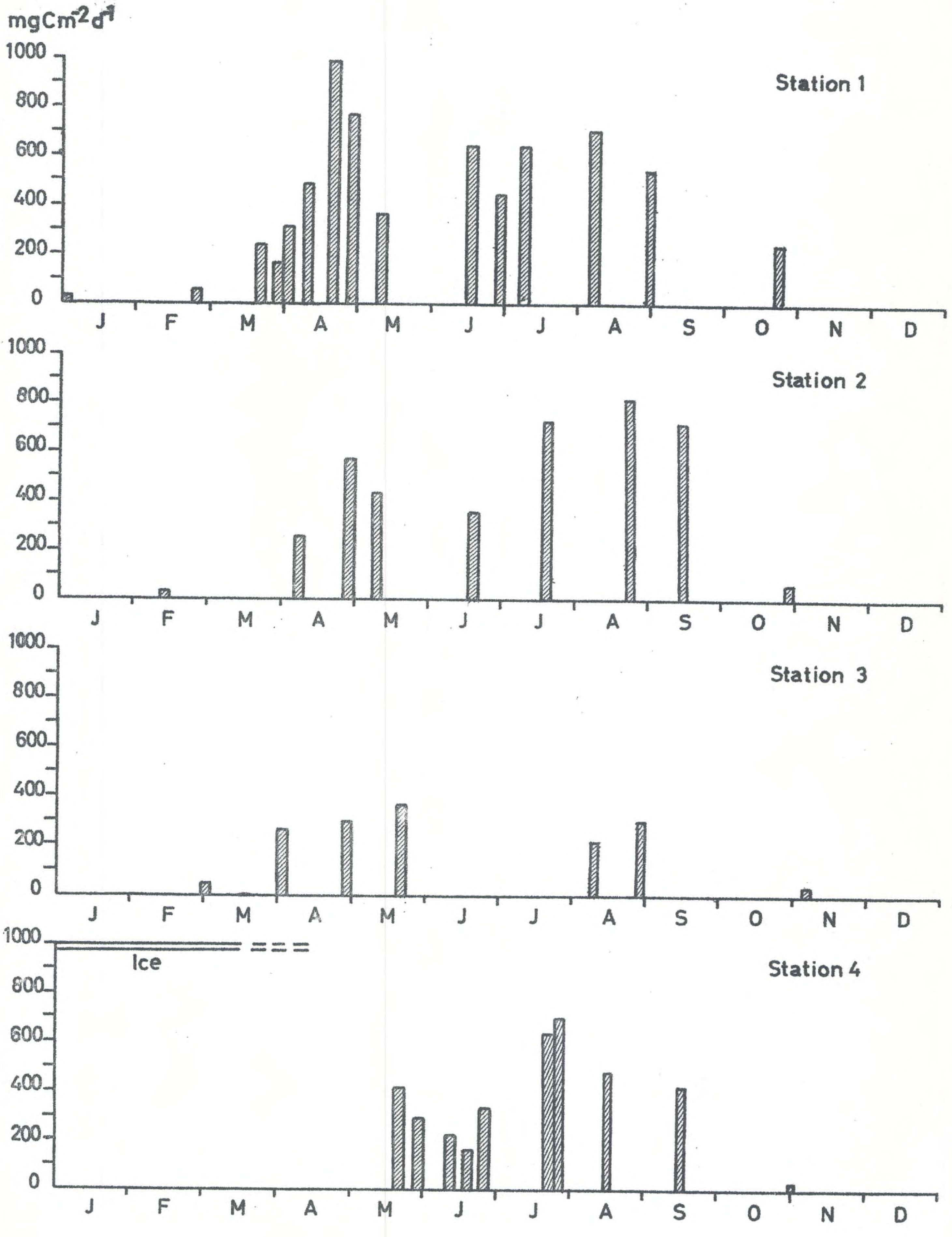
IRRADIATION ON THE BALTIC IN 1974

Fig. 5



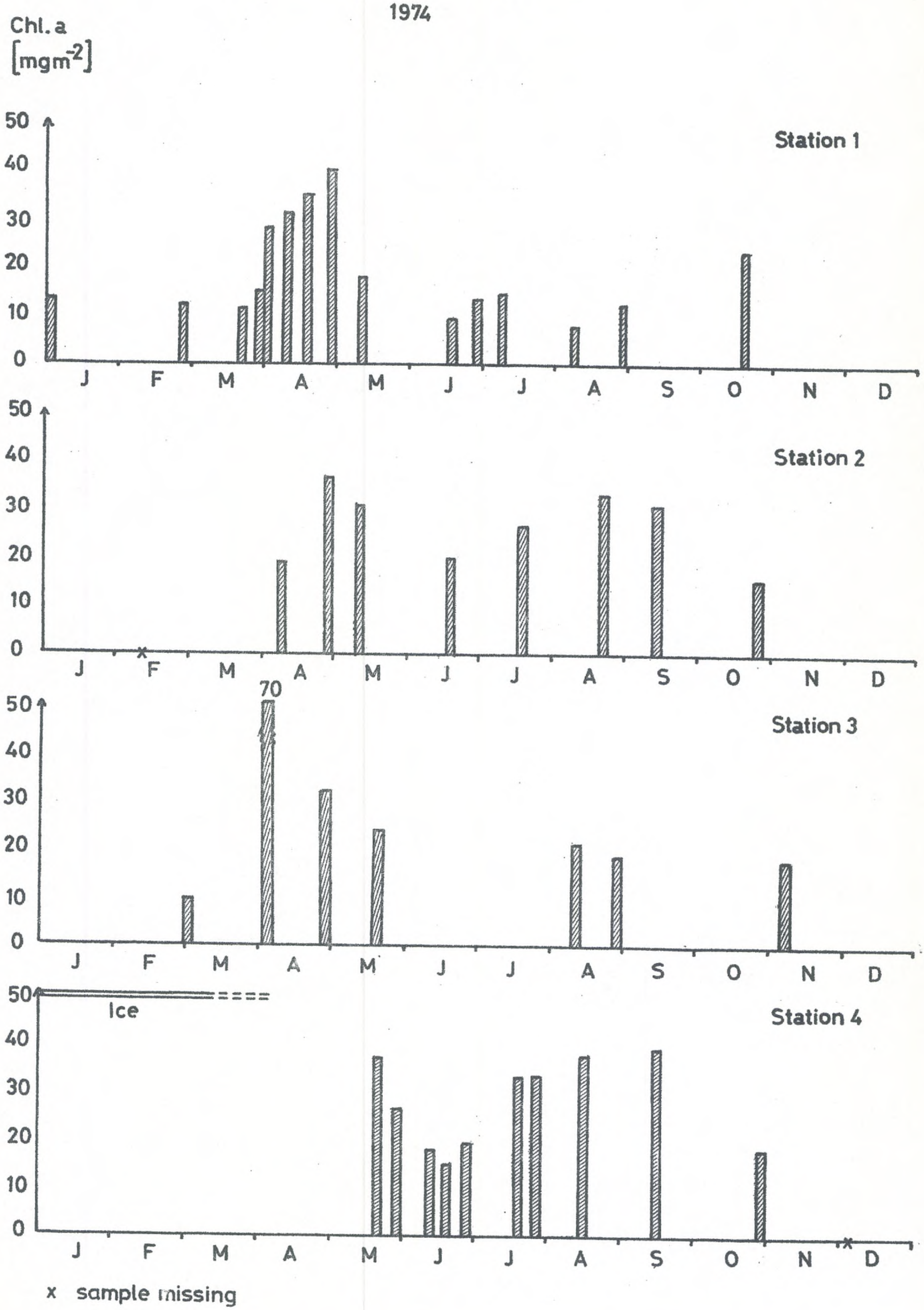
PRIMARY PRODUCTION 0-20M IN THE BALTIC

1974

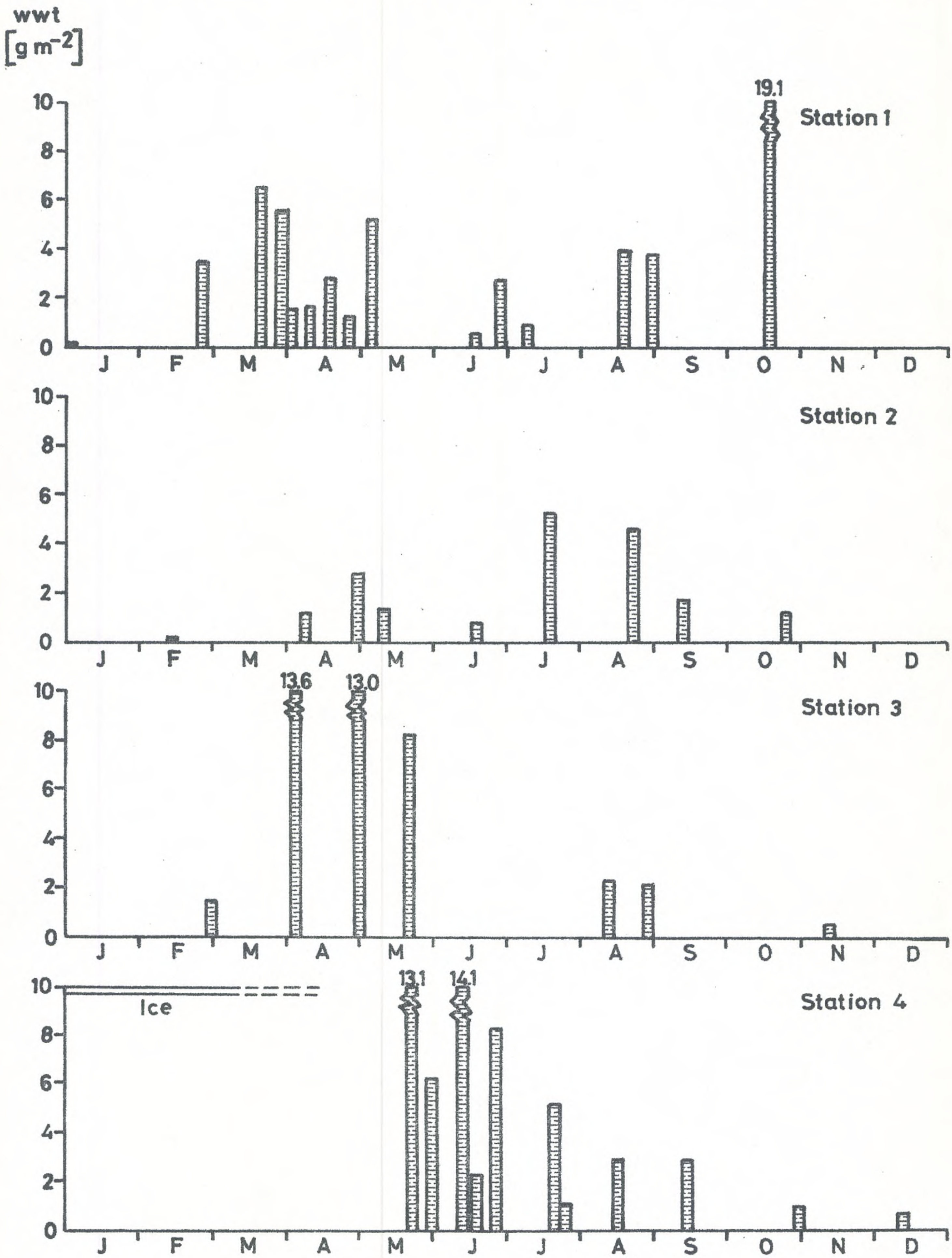


CHLOROPHYLL a 0-15M IN THE BALTIC Fig. 7

1974



PHYTOPLANKTON BIOMASS 0-15 M IN THE BALTIC 1974 Fig. 8



THE EFFECT OF MEAN TEMPERATURE 0-20 M ($\bar{T}$) AND IRRADIATION (I), ON PRIMARY PRODUCTION IN THE BALTIC DURING SPRING AT STATION 1-4 IN 1973-75

Fig. 9