A SEASONAL STUDY OF PHYTOPLANKTON IN THE PHOTIC AND APHOTIC ZONES OF THE FIRTH OF CLYDE

by

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Fig. 1. 1. A map of the Clyde Sea area.

This diagram is taken from S. M. Marshall and A. P. Orr's first major paper on Clyde Sea plankton, published in 1927. It is placed here as a Frontispiece in grateful recognition of their contributions to the study of Clyde Sea plankton, carried out over some 40 years.

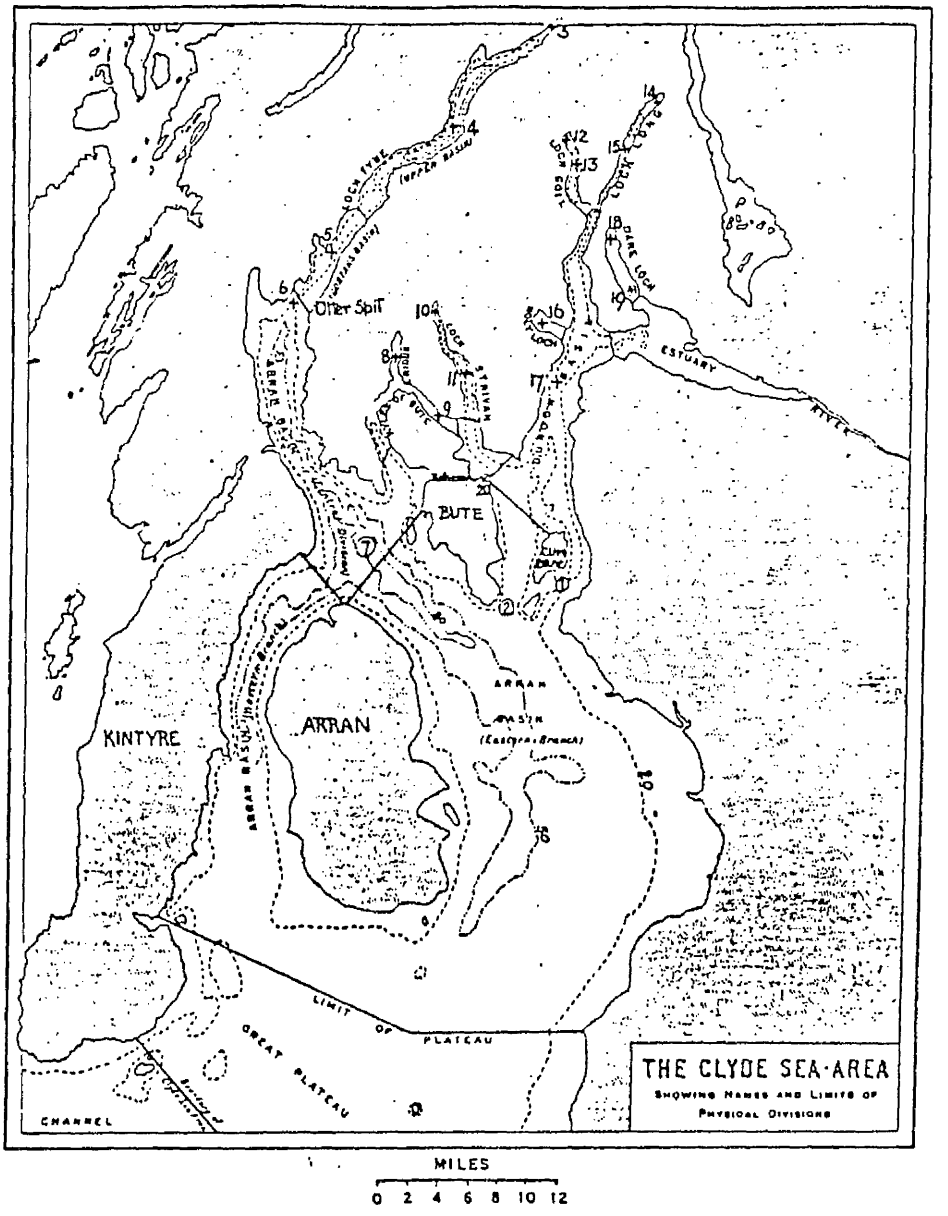

FIG. 1.—Depth contours are shown for ---- 20 fm., —·—· 50 fm., ... 80 fm. Stations worked are shown by crosses and numbers.

	Depth in fm.		Depth in fm.
No. 1. Keppel	—	No. 11. Clapochlar	40
No. 2. Garroch Head	60	No. 12. Loch Goil Head	27
No. 3. Cuill	15	No. 13. Stuckbeg	40
No. 4. Strachur	75	No. 14. Arrochar	10
No. 5. Gortans	30	No. 15. Thornbank	35
No. 6. Otter	30	No. 16. Holy Loch	10
No. 7. Inchmarnock	88	No. 17. Gantock	55
No. 8. Loch Ridun	10	No. 18. Gareloch Head	10
No. 9. Strone Cotes	20	No. 19. Clynder	23
No. 10. Loch Strivan Head	12	No. 20. Meteorological Station.	

DEDICATION

I wish to dedicate this thesis to

my father and mother

my wife and my childrens

for their sacrifice and unending encouragement

Declaration

I hereby declare that this thesis is composed of work carried out by myself unless otherwise cited or acknowledged and that the thesis is of my own composition. The research was carried out within April 1984 to April 1987. This dissertation has not been previously presented for any other degree in whole or part.

Signed

Salim M. Al - Harbi

Date : 4.12.89

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SUMMARY

The seasonal variations of the phytoplankton in the photic and aphotic zones in the Fairlie Channel, Firth of Clyde, during the period April 1984 to April 1987 were determined by measuring the changes in chlorophyll *a* and phaeopigments, nutrient concentrations, total biomass in terms of cell numbers, total particulate matter, oxidizable organic carbon and carbon fixation rates. The phytoplankton composition was also determined in terms of the species present and the balance of planktonic and benthic species present in the suspended populations in both the photic and aphotic zones, as well as the pigment assay by chromatographic analysis. The presence of attached (benthic and epiphytic) diatoms in the suspended algal biomass could, on occasions, be correlated with preceding wind data.

Fortnightly samples were collected from two stations in the middle of Fairlie Channel. The seasonal patterns of phytoplankton, nutrients and productivity for the photic zone in this Channel were similar to those obtained in the past studies. The general seasonal variations for this zone in the present study for cell numbers and carbon fixation followed the chlorophyll *a* changes with high values of these parameters during the peak periods of phytoplankton quantities in the spring, on some occasions in summer and autumn, whilst in the winter months these gave the very low measurements.

Similar general trends of chlorophyll *a*, total cell numbers and carbon fixation rates were obtained in the aphotic zone throughout 1984-1987 with lower levels than that in the photic zone, although occasionally comparable high values were obtained during spring, summer and autumn, so reflecting the links between increases of the photic phytoplankton biomass and aphotic populations.

The phytoplankton composition was always dominated by *Skeletonema costatum* in the spring outburst period constituting 92-98% of total biomass during 1985-1987 in the photic and aphotic zones, with a similar phytoplankton population in both zones. Nutrient levels were generally higher in the aphotic zone, indicating its likely role as a nutrient reservoir.

The samples incubated in the laboratory for carbon fixation measurements during 1986 have given some indication of potential activity of phytoplankton in the natural environments. These studies have revealed the viability of the aphotic zone phytoplankton populations, with a retained capability of photosynthetic activity once returned to the lighted regions, although the stress effects of a prolonged residence in the dark regions would counteract this potential activity.

1. INTRODUCTION

The Clyde Sea area (Fig. 1.1) was first described in detail by Mill (1889). It is situated in south west Scotland and lies between latitudes 55^{o} 5' to 56^{o} 17' N and longitudes 4^{o} 30' to 5^{o} 40' W with a surface area of 1140 sq. miles (2942.24 km^2). This region communicates with the north eastern Atlantic through a narrow channel lying between Tor Point (Northern Ireland) and the Mull of Kintyre. Through this gap (some 10 miles wide), termed the Kintyre Passage, at the entrance to the North Channel of the Irish Sea, all the exchange of water takes place between the Atlantic and both the Clyde Sea Area and The North Channel. This basin (Clyde Sea area) is bounded by the long and narrow peninsula of Kintyre to the west, which separates it from the Atlantic. The Ayrshire coast forms the eastern boundary of the basin. The Irish Sea connects with the Clyde Sea area from the south through the narrowest part of the North Channel between Galloway and the Irish coast. To the north of a line between the Mull of Kintyre and Corswel Point lies the Clye Sea area. Across the mouth of this area lies the Great Plateau which has an average depth of 24 fathoms (43.89 m). Northwards lies Arran Island with the Arran Basin to the east with an average depth of 34 fathoms (62 m). Inchmarnock, Bute and the Cumbrae Islands divides this region into a number of narrow sounds, continued to the north as a series of sea lochs or deep fjords. At the extreme north western limit the deep inlet of Loch Fyne stretches into Argyll, with the deepest water in the Clyde Sea area of 107 fathoms (195.7 m). This region of islands and sea lochs is referred to as the Firth of Clyde. The Firth is joined in the east by the shallow estuary of the River Clyde, the only important river entering the area.

The Clyde Sea area has been studied extensively since 1889 . In the earlier years attention was focussed on the principal climatic conditions and hydrographical data and the plankton. Mill (1889), Barnes (1955), Hinton (1974) and Hannah (1979) investigated the climatology and hydrography of the area. The trends of temperature are typical of the north temperate zone and the rainfall is typical of a wet oceanic climate (Barnes, 1955). Mill (1901) demonstrated the warm oceanic water influence on

the annual sea temperatures in the Clyde Sea area. Between 1886 and 1888 the mean air temperature was 8.3 ^{o}C while the mean temperature of the upper 5 fathoms (9.15 m) was 9.4 ^{o}C. Both Mill (1901) and Barnes (1955) found the highest sea temperatures in August while the coldest were recorded in February . A delay of a month between water and air temperature maxima occurred in summer. Barnes (1955) stated an annual minimum monthly mean air temperature in February (4.3 ^{o}C) and the maximum of 14.1 ^{o}C in July, a month before that of the sea temperature for which the highest was recorded in August of 13.72 ^{o}C and the minimum of 6.69 ^{o}C in February. He reported also that the variation in mean monthly temperatures from year to year is small, rarely deviating from the 5 year mean by more than 1^{o}C and generally only by 0.5 ^{o}C. The principal climatic conditions and sea temperatures for 1976-1977 were similar for 1972-1973 (Boney, 1986). The minimum and maximum sea temperatures in 1976 were obtained in March (6.4 ^{o}C) and July (14.8 ^{o}C), while during 1977 the lowest sea temperature was in February (5.9 ^{o}C) and the highest was in August (14.2 ^{o}C). The sea surface temperature followed closely the change in maximum and minmum recorded air temperatures with more extreme temperatures recorded in 1976-1977 than in 1949-53. The maximum air temperatures were recorded in August and July whilst the minima were in March and January during 1976 and 1977.

Mill (1901) investigated the thermal conditions throughout the Clyde area and found the North Channel remained isothermal throughout the year whereas no distinct thermal stratification occurred in the Arran Basin which remained completely mixed (probably due to tidal mixing) even at the period of maximum surface temperature (August). A constant gradient of temperature from 12.2 at surface to 8.3 ^{o}C at 110 m was evident. Barnes (1955) suggested that a well developed thermocline in the outer Firth occurred during summer which agreed with that stated in the annual report for 1972 by the Clyde River Purification Board and that observed by Hinton (1974) and Hannah (1979). Boney (1986) reviewing the hydrographical data for the latter two programmes showed that the water column was well mixed for the most of the year with short periods of thermal stratification in summer. The establishment of

stratification was between 20-26 June 1973, whilst during July 1973 the stratification became more stable and the thermocline extended from 10 m to 15 m with a temperature gradient of about 3 ^{o}C (Hinton, 1974). The appearance of slight stratification in July and August during 1976 and late June and August during 1977 was demonstrated by Hannah (1979).

Barnes (1955) reviewed the wind speed and direction. The wind speed mean is relatively constant throughout the year. The most windy month was October being slightly higher than the calmest month (June). The most frequent winds are always from the south west except for March and May. A high proportion of winds blew from the north east quadrant in these two months. Winds of highest velocity blew from the south west. The high winds were obtained in the late autumn and winter with mean monthly values ranging from 16-17 knots. The data in Hinton (1974) also showed the high speeds were in autumn and winter ranging from 12-25 knots. The analysis of winds data made by Hannah (1979) did not follow the pattern of winds described by Barnes (1955). The winds blew from the southwest quadrant for only 18-19% of the time in the months considered, while during March and May the wind was from the east for 2% of the time in 1976 and 18% in 1977.

Barnes (1955) suggested that the period with most sunshine was in summer, a view which agreed with that obtained by Hinton (1974) and Hannah (1979), although the most sunshine hours were in July 1973 (Hinton 1974) and in August and May with June during 1976 and 1977 respectively (Hannah, 1979).

Barnes (1955) reported that the rainfall in the west of Scotland, being in annual amounts of 45 inches (1143 mm) was less than the normal for Scotland and only slightly higher than the average rainfall in Britain. Generally the wettest month was December with 5.42 inches (137.6mm), and May the driest with only 1.82 inches (46.2 mm). Mill (1891) found December and January the wettest months and the driest months being May and June. He reported that the average annual rainfall for the 20

years (1866- 1885) in the Clyde Sea area was 43 inches. Barnes and Goodley (1958) showed that the land rainfall was higher than that at sea with annual rainfall averaging 55.24 inches (1403mm), supplying 1.162×10^{10} cubic metres, and the islands have rainfall of 47.86 inches (1215.8 mm) supplying 0.07×10^{10} cubic metres, whereas the sea and loch surface receive 42.47 inches (1085.6 mm) supplying 0.387×10^{10} cubic metres per annum. two cubic miles are the net addition of water directly entering the Firth of Clyde after the annual loss by evaporation has been taken into account (14 inches) equalling 8.4% of the volume. They also stated the much mixing of this fresh water and the greater mass of the annual exchange water preserved the salt balance in the Firth of Clyde. The wettest months during 1976 and 1977 were in January (142.39 mm) and in September (158.4 mm) while August (12.7 mm) and May (48.4 mm) were the driest months (Hannah, 1979). The total rainfall amounts during the two years were 952.4 mm and 1147.6 mm respectively.

The salinity of the Clyde Sea area was studied by Mill (1889) at the surface and the bottom of the sea from different places. The highest mean salinity was found in the North Channel (34.2°/oo) falling to around 33°/oo at the Cumbraes and lower in the Gareloch (31.36°/oo, the nearest to the River Clyde). Hinton (1974) mentioned that the salinity of surface water within narrow channels could be lowered by dilution following spells of wet weather or even heavy rain. This dilution was not found at any depth. The mean (surface) salinity of the outer Firth was from 32 to 33°/oo according to Barnes (1955). The latter author and Mill (1889) showed the clear reduction in surface (and bottom) salinities in the Clyde Sea area during winter months reaching a minimum of 31.26°/oo (at Millport) in January. A maximum of 32.98°/oo was recorded by Barnes in June while Mill found a surface maximum between July and September. Both authors correlated these changes with the pattern of seasonal rainfall changes. Mill (1889) stated that changes in rainfall take two months to produce their full effect on salinity, while Barnes (1955) showed a delay of one month. Mill (1889) attributed the small difference in vertical distribution of salinities to mixing processes. Barnes (1955) mentioned that the distinctive winter minimum of salinity is clearly related to the seasonal pattern of

rainfall and influence of winds on movement of water masses, whilst the short term fluctuations may be related to the state of the tide at the time of sampling (Barnes and Goodley, 1958). Hinton (1974) stated that a similar distinctive winter salinity minimum (January) was related to similar influence of rainfall and winds. He mentioned also that the salinity in August 1972 fluctuated between 32.5 and 33°/oo rising to a maximum of 33.3°/oo in October coinciding with the very high (20 Knots) south westerly winds in August which evidently introduced high salinity water into the lower Firth, and extremely low rainfall throughout August, September and the first half of October. Hannah (1979) reviewed the fluctuation of the surface salinity values were between a minimum of 31.2°/oo (8 April) and maximum of 33.3°/oo (15 September) in 1976 whilst in 1977 the minimum and maximum values were 30.2 (November) and 33°/oo (8 September). The reduction in salinity values due to fresh water run-off was normally only observed down to a maximum depth of 10 m in the Fairlie Channel.

The Firth of Clyde has a small tidal range with weak tidal currents. Circulation patterns indicate a partially mixed system with a residence time of 9 months (Heath, 1974).

The chemical conditions of the sea in the Clyde Sea area were studied by Mill (1889) for the first time, but limited to the study of sulphates and carbonates. These natural chemicals achieve a higher proportion in waters of lowered salinity. For the first annual survey Marshall & Orr (1927) described the seasonal changes in dissolved phosphate, pH and the percentage saturation of oxygen in Loch Striven. They showed the occurrence of a phosphate peak (0.75 μg at.P.l^{-1}) at the surface in November which fell to unmeasurable levels in May and September. During the spring phytoplankton increase the phosphate content of the water fell from 0.68 to 0.22 μg at. P. l^{-1} at the surface, while small changes were evident in the deep waters. The regeneration of phosphate in deep water was shown to occur during late summer and autumn. Oxygen saturation reached its highest values of more than 135% at the surface in April and August while at the bottom a minimum of 30% was recorded during autumn. The pH

varied within fairly close limits and never exceeded 8.45 or fell below 7.75, with the lowest values in the winter. Johnston *et al* (1974) studied (for April 1970) the nitrate enrichment of the Firth region close to the Irvine Bay. The addition to this area may be up to 15 tons per day. The values of nitrate were found on occasions in this area to exceed 30 μg at. $N.l^{-1}$. The lowest nitrate values were found along the eastern coastline of Kintyre (5-9 μg at. $N.l^{-1}$), while in the upper Firth levels were markedly higher to the west of Cumbraes (12-14) than the east (10.5 - 12 μg at. $N.l^{-1}$). Steele *et al* (1973) showed that the daily input of soluble nitrogen compounds into the upper eustary is up to 30 tons per day. According to the C.R.P.B. annual report (1972) the major portion of this addition is ammonia which reaches up to 4 mg $N.l^{-1}$. In the inner Firth and around the Cumbraes little evidence of pollution was found. Boney (1986) stated that the autumn and winter buildup of all nutrients is evident in the two programmes carried out by Hinton (1974) and Hannah (1979). In both programmes the quantities were similar down to 10 m. In 1972-73 there were declines in all three nutrients (dissolved silica, nitrate N. and phosphate P.) during late March and early April. In this time dissolved silica, nitrate N. and phosphate P. levels reduced from the high winter values of 14.0 to 0.5 μg at $Si.l^{-1}$, 23.7-4.0 μg at. $N.l^{-1}$ and 1.5-0.25 μg at. $P.l^{-1}$. In 1976 and 1977 this decline was most evident in April when the dissolved silica declined rapidly from the high winter months values of 6.9 to 3.14 μg $at.l^{-1}$ in 1976 and 13.1-0.42 μg at. Si. l^{-1} in 1977, whilst nitrate N. and phosphate P. fell from 17.9 to 4.75 μg at. $N.l^{-1}$ and 1.78-0.8 μg at. P. l^{-1} in 1976 with another drop in both nutrients in 1977 from 13.3 to 4.5 μg at. $N.l^{-1}$ and the decrease in phosphate P. during the spring increase of 1977 was not pronounced, dropping from 0.97 to 0.51 μg at. P. l^{-1}. Variable levels were obtained in the summer months leading to the winter maxima.

The chlorophyll *a* measurements in the Clyde Sea showed maxima in early April, middle of May and in early September (1968) with a maximum abundance of 1.2 mg m^{-3} in May according to Butler *et al* (1970). Hinton (1974) executed the first survey which combined three different methods of assessing the phytoplankton standing crop, direct enumeration, chlorophyll *a* estimation and total particle volume with annual

cycles of dissolved silica, nitrate and nitrite and phosphate in the Firth of Clyde. He found with Hannah (1979) that the spring outburst varied from late March to the middle of or late in April with the highest value for chlorophyll *a* (10.0 mg m^{-3}) recorded in the Clyde Sea area since the first measurements for chlorophyll *a* in 1968 (Butler *et.al*, 1970). The autumnal phytoplankton increase was recorded during September (Hinton, 1974 ; Hannah, 1979), whilst the lowest values were recorded during the winter period with unsuitable conditions for phytoplankton activity. Hannah (1979) measured the phaeopigment levels during the autumn period of 1977 and the spring of 1978 and found that phaeopigments made up a substantial part of the plant pigment content of the water. She measured that the chlorophyll *a* and phaeopigments levels from 0-10 m depth and found that the phaeopigments were often twice as high as the chlorophyll *a*, with the highest in April 1978 (5.05 mg phaeopigments. m^{-3}). Wood *et al.* (1973) found that the levels of chlorophyll *a* and carbon fixation in the depth samples (10-50 m) from Loch Etive were lower than those obtained in the top 10 m of water column with similarity in the general trends for both the chlorophyll *a* and carbon fixation in the surface layer (0-10 m) and deep layer (10-50) mainly in the spring and summer peaks.

A three day survey in the Firth of Clyde during April 1970 measuring carbon fixation by the phytoplankton was carried out by Johnston *et al* (1974). They found the rate of carbon fixation was 1 mg C. m^{-3}. h^{-1}. This level of fixation was obtained by Hannah (1979) just before and immediately after the decline of the spring increase which occurred in April 1976 and 1977 in the Firth of Clyde. The maximum fixation levels of 66.6 and 55.7 mg C. m^{-3} h^{-1} were observed in July 1976 and September 1977 respectively, based on measurements made in the field.

The seasonal changes in the phytoplankton of the Clyde Sea was first investigated by Murray (1897) as part of a general survey for Scotland (Boney, 1986). In a later brief summary (Murray & Blackman, 1901) thirty five diatom species were listed. Qualitative evidence of seasonal changes was also given, especially the

extraordinary abundance of the diatoms (dominated by *Skeletonema costatum*) in March and April follwed by a rapid decline. Large numbers of dinoflagellates (*Ceratium* and *Protoperidinium* spp.) were seen in the summer. Small algal cells (probably simple members of the Chlorophyceae) were fairly often seen. These early observations were followed by extensive surveys on phytoplankton seasonality, quantitatively and qualitatively for the Clyde Sea since 1924. In that year Marshall carried out the first seasonal survey of phytoplankton by analysing the gut contents of the copepod *Calanus* from the Firth of Clyde (inner Firth off Great Cumbrae island). The *Calanus* gut contents were dominated by *Skeletonema costatum* in the spring with small numbers of *Thalassiosira* spp., reflecting their relative quantities in the phytoplankton population. The last species replaced *Skeletonema* in May and June, with small quantities of *Fragilaria* and *Navicula* spp. followed by large numbers of *Chaetoceros* and *Rhizosolenia*, together with dinoflagellates (*Protoperidinium* and *Ceratium* spp.) in the summer. *Skeletonema* and *Thalassiosira* became the main food in autumn. The latter diatom continued in small numbers during the winter with *Biddulphia* and *Coscinodiscus* spp. A series of classic studies by Marshall & Orr (1927, 1928 and 1930) on the seasonal changes of phytoplankton biomass was concentrated in Loch Striven in the Cowal Peninsula to the north with considerable attention on the outburst of diatoms during the spring and the succession of the phytoplankton. In most years *Skeletonema costatum* completely dominated the population in the spring phytoplankton biomass. The greatest abundance of diatoms over the years varied from late March to late early April, with usually a 10 days interval between the first noticeable appearance of the principal diatoms and the maximum numbers attained. These maxima ranged between 3.5 to $6x10^6$ cells. l^{-1} off Great Cumbrae and from 16 to $30x10^6$ cells.l^{-1} in Loch Striven. Again *Thalassiosira* replaced *Skeletonema* at the end of May, while during the summer *Chaetoceros*, *Nitzschia seriata* and *Leptocylindrus danicus* were common. The latter organism (*L. danicus*) completely dominated the population in the surface sample, while at 20 m only *Nitzschia* was observed. At 10 m a mixture was present. A small peak of *Rhizosolenia* came at the start of October with a subsequent peak of *Skeletonema* at the begining of November. Marshall *et al* (1934) drew attention to the

abundance of flagellates along with the spring diatoms in Loch Striven 1932-33. Similar observiations were repeated for the 1960 spring and summer sequences (Marshall & Orr, 1962). Boney (1986) mentioned that the annual descriptions of the spring sequence were mainly based on tow -netted samples from 1944-1959. The dominance of *Skeletonema* repeatedly described by Pyefinch (1948, 1949) and Barnes (1956). This pattern of events was changed in 1951 when the spring growth consisted mainly of *Coscinodiscus* and *Chaetoceros* spp., with *Skeletonema* appearing in mid-May (Marshall & Orr, 1952; Barnes, 1956). After protracted cold weather and easterly winds in 1958 the early spring growth was *Coscinodiscus* dominated with a later (mid-April) pulse of *Skeletonema* followed by *Chaetoceros* and *Thalassiosira* in May (Edwards, 1959). *Thalssiosira* dominated the spring outburst in 1969 (Butler *et al*, 1970). This dominance was attributed to a low sea temperature (5 ^{O}C) during March, which favoured *Thalassiosira*. The summer floras were characterised by dinoflagellates (*Protoperidinium*, *Ceratium* and *Dinophysis* spp.) along with *Chaetoceros* spp., *Rhizosolenia* spp. *Leptocylindrus danicus* Cleve, *Eucampia zoodiacus* Ehrenb. and *Nitzschia* spp. (Marshall & Boney, 1974) with *Skeletonema* and *Thalassiosira* being again more numerous in the autumn. From 1972 onwards attention was focussed on these seasonal fluctuations in the diatom populations in the inner Firth, and on the contributions made by the nanophytoplankton component to primary productivity (Hinton, 1974; Hannah, 1979 and Hannah & Boney, 1983). In 1976 and 1977 (Hannah, 1979) the sequence of changes in net phytoplankton followed those described for 1972-73 by Hinton (1974). The seasonal changes for the net phytoplankton from the Fairlie Channel observed by Hinton (1974) during 1972-73 showed dinoflagellates (mainly *Protoperidinium* spp.) to be numerous in the summer and autumn of 1972 along with *Chaetoceros* spp., the silicoflagellate *Distephanus speculum* and the diatoms *Leptocylindrus danicus*, *Nitzschia seriata* and *Eucampia zoodiacus* and the small loricate chrysophyte *Kephyrion ovum*. A sparse winter flora included a 'seed' population of *Skeletonema costatum* and *Thalassiosira* spp. The peak of the spring abundance of population in 1973 occured in late March and late April followed by a gradual decline in numbers through May. The phytoplankton population in the spring

was dominated by *Skeletonema costatum* and *Thalassiosira* (mainly *T. nordenskioldii*) with smallar numbers of *Nitzschia seriata* and *Cylindrotheca closterium.* During June 1973 *Chaetoceros* spp. became co-dominant with the declining *Thalassiosira* population. *Kephyrion ovum* was once more present in large numbers, and with the onset of summer the colonies of *Chaetoceros* tended to predominate, with smaller numbers of *Eucapia zoodiacus* and *Protoperidinium* spp. A small pulse of the coccolithophorid *Emilian huxleyi* was recorded in July.

It has become axiomatic that the biomass and productivity of phytoplankton is higher in the photic zone, according to the sufficient intensity of light, than in the aphotic zone. Each water mass of both these two zones has its own characteristic species, composition succession and productivity. Hentschel (1928) was the first to report the ocurrence of pigmented phytoplankton in the aphotic zone of the deep ocean. There have been a number of reports on the abundance of algal cells in this zone with implications that they may be viable (Wood, 1956; Bernard & Lecal, 1960; Bernard, 1953; Kimball *et al.*, 1963; Kimor & Wood, 1975; Silver & Bruland, 1981; Platt *et al.*, 1983), and they possibly subsist heterotrophically. All these authors and Fournier (1966, 1970, 1971); Hamilton *et al.* (1968) reported the presence of micro-organisms in the samples from the aphotic zone of oceans containing chlorophyll and even from deep sea sediments (Malone *et al.*, 1973). Terazaki *et.al.*(1978) found that chlorophyll *a* was dominant in both the photic and aphotic zone, and he also found that chlorophylls and carotenoids in the aphotic zone were present at the concentration on the thin layer chromatograms as high as 10% of the surface whilst a significant amount of phaeophytin *a* was found in the particles suspended in the aphotic zone. This pigment is often present in the deep sea (Lorenzen, 1965; Saijo, 1969). Subba Rao & Sameoto (1988) suggested that cells collected from the aphotic zone of tropical sea contained photosynthetic pigments such as chlorophyll *a*. Cole *et al.* (1985) found that phaeopigments were present in most samples collected from deep waters of the Panama Basin and small amounts of chlorophyll *a* obtained in some, while all the samples contained carotenoid pigments.

Cole *et al.* (1985) reported that the relatively high rates of flux of pigment to deep water are probably the result of both the high surface productivity and the rapid rate of sedimentation. The flux of algal pigments and organic carbon varied seasonally in the aphotic zone with minimum values in June-July and maximum flux of chlorophyll and phaeopigments to deep water occurred during the spring algal bloom (February- March) and this was also associated with a large flux of organic carbon. Bernard & Lecal (1960) and Subba Rao & Sameoto (1988) reported a general increase in the abundance of aphotic zone phytoplankton in the Mediterranean, Indian, tropical Atlantic and tropical Pacific Oceans depending on an increase in the biomass in the photic zone, suggesting a vertical flux of surface production.

The population composition of phytoplankton present in the aphotic zone consisted of a wide variety of algae. The aphotic population reported from depth more than 1,000 m were micro- organisms ranging between 1-5 μm, often coccolithophores, (Hentschel, 1928; Bernard & Lecal, 1960; Kimor & Wood, 1975). The abundance of this population was $7x10^6$ cells. l^{-1} in the Mediterranean (Bernard, 1963; 1967) while in the North Atlantic Fournier (1966; 1970; 1971) recognized procaryotic cells (1-15 μm) in concentrations up to $22x10^4.l^{-1}$. Hamilton *et al* (1968) reported pigmented cells (1-4 μm) up to $8x10^4$cells. l^{-1}. The picoplankton (<1 μm) concentration in the 1,000 m samples was $7.16x10^6$ cells. l^{-1} (Li *et al.*, 1983). The large phytoplankton cells w hich were obtained in this zone from tropical region of the Pacific Ocean consisted mainly of diatoms, dinoflagellates and silicoflagellates (Subba Rao & Sameoto, 1988). Urrere & Knauer (1981) stated that the abundance of larger phytoplankton (diatoms and dinoflagellates) constitute important food items in the aphotic waters. 48 species of diatoms and 14 dinoflagellates based on 127 net hauls taken in the 500-3,000 m of south west Indian Ocean were recorded (Nel, 1968) and 20 diatoms, 14 dinoflagellates and 1 silicoflagellate were found in the aphotic zone (200-1,000) of the tropical Pacific Ocean (Subba Roa & Sameoto, 1988).

A similar net phytoplankton composition in the deep sea was observed between the oceans. The genera and species common in the aphotic zone from the Indian Ocean and the tropical Pacific Ocean were *Chaetoceros peruvianum*, *Fragilaria* sp., *Nitzschia* sp. *Planktoniella sol*, *Rhizosolenia robusta*, *R. setigera*, *R. styliformis*, *Thalasssionema nitzschioides*, *Thalassiothrix* sp., *Amphisolenia* sp., *Asteromphalus* sp., *Nitzschia seriata*, *Ceratium* sp. and *Prorocentrum micans* (Nel, 1968; Bernard & Lecal, 1960 and Subba Rao & Sameoto, 1988). In the Mediterranean Sea (Kimor & Wood, 1975), in the Pacific Ocean off Japan (Ohwada, 1960) and off Costa Rica (Subba Rao & Sameoto, 1988) *Coscinodiscus* was also commonly found. This latter species with *Thalassiothrix* and *Gymondinium* were common between Coral and Tasman Sea, in the southwest Pacific Ocean (Kimball *et al.*, 1963).

Subba Rao & Sameoto (1988) compared the species composition in the photic zone (0-200 m) with that in the aphotic zone (200- 1,000 m) from the Pacific Ocean off Costa Rica and suggested that the algal cells from the aphotic zone probably originated from the photic populations, although not all species present in the photic layer extended to the aphotic waters.

Platt *et al.* (1983) for the eastern tropical Pacific and Vincent (1978) for Lake Tahoe found that the aphotic phytoplankton were able to photosynthesize immediately on exposure to light. They also demonstrated the photosynthesis-light curves for the 1000 m sample and for the 10 m sample, which were quite similar in both shape and amplitude. The photosynthetic recovery of a phytoplankton culture after 25 days of darkness occurred when it was exposed to the light (Yentsch, 1965).

The possible mechanisms by which these viable cells pass to the aphotic zone have been discussed by many workers. Platt *et al.* (1983) stated that the transporting of phytoplankton cells to the aphotic zone was rapid. A major proportion of the downward transport of biological material in the ocean is in the form of aggregates of cells rather than individuals (Platt *et al.*, 1983). Culver (1989) stated that estimates of

carbon flux at stations in the open ocean and marginal ice zone of the Greenland Sea with a vertically mixed photic zone indicated that approximately 30% of the daily primary production sinks from the photic zone in the form of small particulates. This sinking of phytoplankton cells through the water column contributes to the vertical transfer of organic matter from the photic zone to deep sea, either by the cells sinking rapidly to the various aphotic zone depths, or being transported as viable cells within faecal pellets of herbivores (Schrader, 1971; Smayda, 1971; Bishop *et al.*,1977; Silver and Bruland, 1981; Bruland and Silver, 1981; Deuser *et al.*, 1981; Dunber & Berger, 1981; Sasaki & Nishizawa, 1981; Urrer & Knauer, 1981 and Subba Rao & Sameoto, 1988). This transportation of cells may then be seeding the aphotic zone with metabolically competent phytoplankton, partcularly if the faecal pellets disintegrate at great depth (Silver & Alldredge, 1981; Silver & Bruland, 1981), as it is known that some of the phytoplankton cells after passing through the guts of zooplankton may still retain their photosynthetic activity (Porter, 1976). The cells of phytoplankton might be also carried down by other large biogenic particles when they have been impacted or otherwise, sinking at higher Stokes' velocities than individual phytoplankton cells (Honjo, 1980; Lal, 1980; Fellows *et al.*, 1981; Silver & Alldredge, 1981). Sinking of phytoplankton whether by negative buoyancy or turbulence is also relevant. The environmental variation in nutrients, temperature and irradiance, all of which affect production, may also influence bouyancy and ultimately vertical flux. The species succession and abundance can be influenced with altering the vertical position of cells in the water column with respect to light and nutrient (Riley *et al.*, 1949; Hutchinson, 1967; Smayda, 1971; Malone, 1971; Huntsman & Barber, 1977). There is much evidence for the survival of phytoplankton when carried down into the aphotic zone.

The aim of the present work is to investigate the algal community in the aphotic zone and to determine the viability of this community, a feature not so well known for the Firth of Clyde, particularly in the Fairlie Channel. Comparisons were to be made with the photic zone populations in this region, in addition to the role of the

suspended algae as bio-indicators of water conditions and environmental changes. This study of the seasonal and annual variations of phytoplankton in the photic and aphotic zones in the Fairlie Channel was also planned to complement previous studies of phytoplankton in the Firth of Clyde, which have indicated a high productivity on many occasions during spring and summer in the upper 10 m of the sea, and with very low carbon fixation rates on occasions, barely measurable at 10 m depth in the winter months.

The photic (euphotic) zone is the illuminated zone where the available light (= PAR. the photosynthetically available radiation) is enough to support the photosynthesis of the phytoplankton in the water column, and where the production of organic material by photosynthesis exceeds breakdown of organic material by respiration. This photic zone extends to a depth where the decrease in PAR due to attenuation reaches critical limits. This compensation depth is taken as the lower limit of the photic zone. This depth is variable depending on the nature of the habitat and organisms. Latitude, season and time of day all influence the depth of the euphotic zone, as well as the amounts of suspended matter, water colour, cloud cover and sea turbulence, and it is impossible to define the depth of this zone in absolute units. For some purposes (eg. mathematical modelling) it is taken to be the depth at which there is 1% of the subsurface light intensity. This PAR input is influenced by the sun's position in the sky. The deepest parts of the photic zone are illuminated only when the sun is directly overhead with maximum penetration of light. When the sun is lower in the sky, more of the radiant energy is absorbed by the air, and more of the incident radiation reaching the water surface is reflected. The photic zone depth varies also seasonally - during winter months in temperate waters the compensation depth lies very close to the surface, while in summer the photic zone is deeper due to the sun's position and the higher input of radiant energy. During periods of phytoplankton abundance the phenomenon of selfshading can influence the depth of penetration by PAR. A daily radiant energy budget in tropical waters through the year is similar to that of temperate

summer except in the rainy season. The averages of photic zone depth were some 30 m in costal waters and 150 m in the open ocean in tropical regions. For temperate seas the compensation depths are about 10 m in turbid inshore waters. Since the photic zone depth is defined by reference to PAR and photosynthetic activity, the aphotic zone for the purpose of this thesis is regarded as all the water below the depth at which there is insufficient PAR to support photosynthesis by phytoplankton.

The photic zone for phytoplankton measured by the photosynthetic activity is about 10 m in the Firth of Clyde (Boney, 1989), whilst Hannah (1979) found that on occasions during autumn and winter, assimilation at 10 m in the Fairlie Channel was zero or just above, this depth being approximately at the compensation point at this time. Hence, in the present work, sampling depths of 20 and 40 m were regarded as being representative of the aphotic zone for the phytoplankton.

2. THE STUDY AREA AND SAMPLING PROGRAMME

2.1. DESCRIPTION OF STATIONS AND DEPTHS

This study has been carried out in Fairlie Channel which lies to the east side of Great Cumbrae Island and separates it from the mainland. The location of this island is at latitude 55^{o} 57' N and longitude 4^{o} 46' W, west of Scotland. The sea area near the Marine Biological Station at Millport, situated at the south east corner of Great Cumbrae, was selected since it was convenient for using the marine station's facilities. The research vessels Aplysia and Aoro, were kindly made available for sampling. Two stations were chosen from this area (3 and 6) as shown in Fig. 2.1 due to the depths required. These depths were 3 m (as representative of the lighted photic zone) and 20 m with 40 m depths which are in the aphotic zone for the phytoplankton.

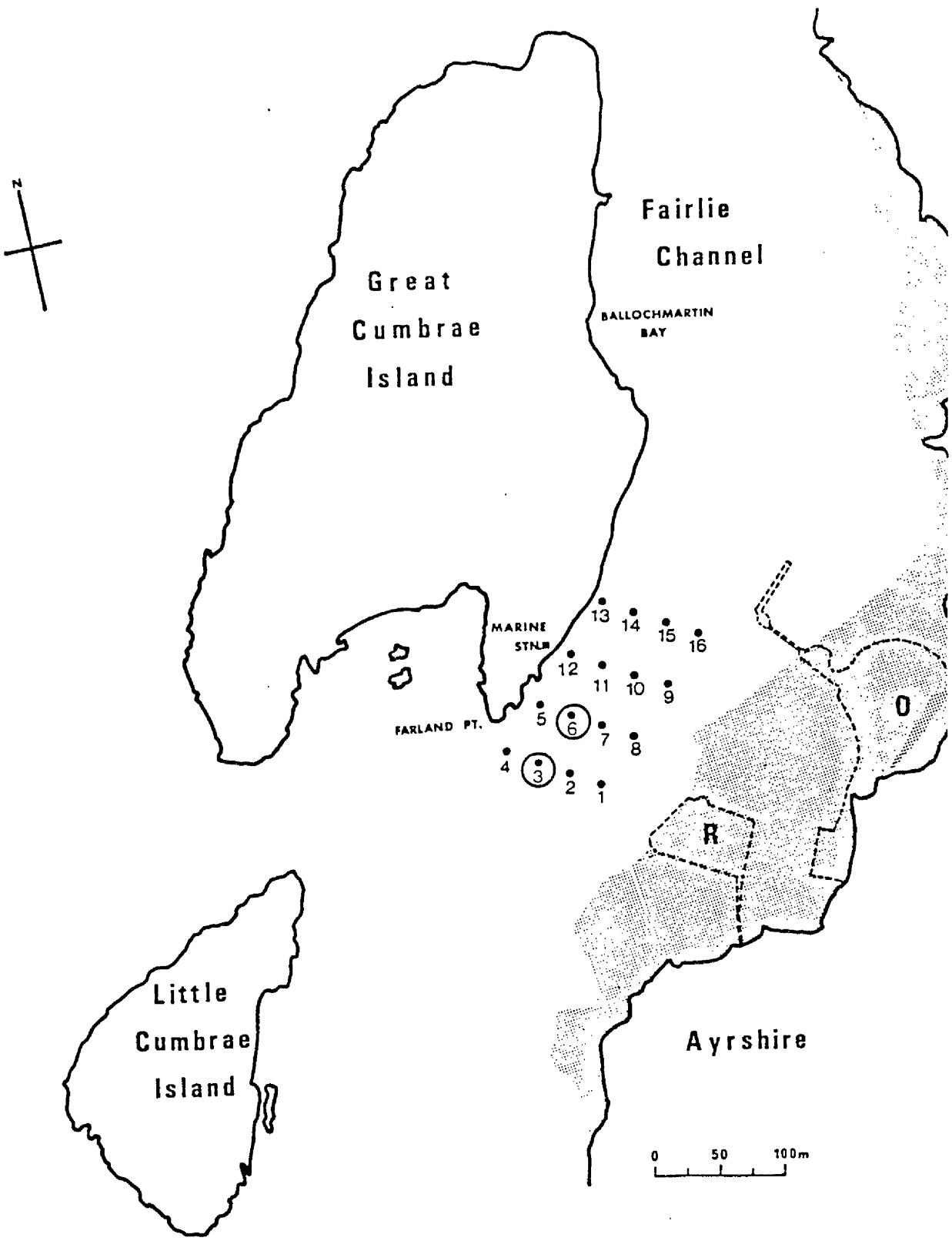
2.2. SAMPLING PROGRAMME

Samples of sea water were collected fortnightly (occasionally once a month when the vessel or transportation were not available). During the spring season through March and April the sampling became weekly from both stations.From 11th April 1984 twenty and forty metre samples were taken regularly. Sampling at 3 m depth was commenced from 8th May 1985 till the end of sampling programme (March 1987). One station (no. 6) was sampled in April 1987.

2.3. PROGRAMME OF STUDIES

The sea water samples were used for various analyses :-

Fig. 2. 1. A map of the Fairlie Channel showing the position of the smpling stations (3 and 6).
These two stations formed part of the grid survey by Hannah (1979).


N
Fairlie
Channel
Great
Cumbrae
Island
BALLOCHMARTIN
BAY
MARINE
STN.
FARLAND PT.
13
14
15
16
12
11
10
9
5
6
7
8
4
3
2
1
O
R
Little
Cumbrae
Island
Ayrshire
0
50
100m

a : NUTRIENT DETERMINATIONS

These were carried out fortnightly from 11th April 1984 to 2nd of April 1986. Thereafter for the eight months the measurements were made monthly.

b : STANDING CROP

The evaluation of chlorophyll *a* and phaeopigment levels applied over all the investigation period, whilst the enumeration of phytoplankton cells was carried out from January 1985 to the end of this work.

c : PRIMARY PRODUCTIVITY MEASUREMENTS (^{14}C)

This was mainly carried out from 19 March 1986 till the end of the study in the laboratory by incubation of the samples in the growth room. Measurements *in situ* were made over six weeks starting from 18 March 1987.

d : CHROMATOGRAPHIC ANALYSIS

Photosynthetic pigments were analyed from the begining to the end of this project.

e : TOTAL OXIDIZABLE ORGANIC MATTER DETERMINATION

Measurements were made from 26th of March 1986 to 25th of March 1987.

f : DETERMINATION OF PARTICULATE OXIDIZABLE CARBON (Wet Oxidation With Dicromate)

As in (e).

3. MATERIALS AND METHODS

3.1. SAMPLE COLLECTION

Sea water samples were collected from both stations by means of a 5 litre Van Dorn-type sampler (Hydrobios, West Germany) and transferred to 5 litre plastic containers after straining the water through a 212 nylon mesh to remove the zooplankton. Samples for total organic matter determinations were drained from the sampler direct into 1 litre containers.

3.2. METEOROLOGICAL DATA

Measurements of maximum and minimum air temperatures, sea surface temperature, rainfall amounts and total cloud were obtained from the Marine Biological Station, Millport. Wind speeds and directions were provided by the Ardrossan station, while the sunshine hours per day records (sunshine levels) were obtained from Rothesay meteorological station.These two stations are the nearest coastal stations known to measure these parameters. Ardrossan and Rothesay lie at latitude 55:0^{o} N and 55:50^{o} N and longitude 4:0^{o} W and 05:04^{o} W respectively.

3.3. DETERMINATION OF SALINITY AND TEMPERATURE

The temperature and salinity of sea water samples were recorded in the field at the time of sampling by Salinity Temperature Bridge (M.C.5 Electronic Swichgear licensed by the National Institute of Oceanography). These determinations accompanied the start of productivity measurements.

Fig. 3. 1. The sea water sampler used and the 5 litre plastic container.

3.4. DETERMINATION OF pH

Sea water subsamples were kept in polyethylene containers with tight fitting screw caps at low temperature in a dark room until just before the pH measurement (Strickland & Parsons, 1972). After warming up to room temperature. 100 ml samples were then placed in wide mouth polyethylene bottles with screw caps to determine the pH using a How pH meter Model 6030. The electrode was previously standarized by commercially available pH buffer tablets having pH values of 4 and 7. The electrode was then cleaned and dried from the buffer solution by distilled water and a tissue before immersion in the samples. After 5 minutes equilibration the pH was then read directly.

3.5. DETERMINATION OF TOTAL ALKALINITY AND CARBON DIOXIDE

To measure the total alkalinity, sea water samples (100 ml) was mixed with 25 ml of exactly 0.0100 N hydrochloric acid as outlined in Strickland & Parsons (1972). This total alkalinity (T. Alk.) could be obtained from this

$$\text{T. Alk.} = 2.5 - 1250 \times a_h/f$$

Whilst the total carbon dioxide (T. Co_2) content of sea water could be calculated by the following expressions :-

$$\text{Carbonate Alk.} = \text{T. Alk.} - A \qquad (\text{milliequivalents } l^{-1})$$

$$\text{T. } CO_2 = \text{Carbonate Alk.} \times 12 \times F_t \qquad (\text{mg } ^{12}C \text{ available } l^{-1})$$

where :-

A, Ft, a_h and f are all factors (taken from Tables in Strickland and Parsons, 1972) which are dependent on temperature, salinity and pH.

3.6. DETERMINATION OF NUTRIENTS

Within 2 hours of completion of collection and on returning to the laboratory (in Glasgow) subsamples of sea water were immediately filtered through two types of filters depending on the kind of analysis, through Whatman 5.5 cm GF/C glass microfibre filters for phosphate, nitrate and nitrite determinations, whilst the samples for silicate determination were filtered through Whatman No. 1 filter papers. The filtered sea water samples were then immediately frozen for storage until the analysis, which was usually within a week of collection.

The analyses were carried out in plastic containers. All extinctions of samples (in duplicate), standards (in triplicate) and blanks (in duplicate) were read by a Unicam SP 600 Spectrophotometer using 4 cm cuvettes for all these various determinations.

a : DETERMINATION OF ORTHOPHOSPHATE PHOSPHORUS

All methods for determination of phosphate in sea water are colorimetric and depend on the formation of highly coloured blue compound after the reduction of a phosphomolybdate complex.

The procedure applied in this present study was based on the Murphy & Riley method (1962) which is an easy and rapid analysis as described by Strickland & Parsons (1972).

The required reagents are as follows :-

1. AMMONIUM MOLYBDATE SOLUTION

15 g of Analytical Reagent grade ammonium paramolybdate $(NH_4)_6 Mo_7O_{24}.4H_2O$ were dissolved in 500 ml of distilled water and stored in covered plastic bottle with double layers of aluminium foil to protect from direct sunlight.

2. SULPHURIC ACID SOLUTION

140 ml AR of concentrated sulphuric acid (sp gr 1.82) were added with care to 900 ml of distilled water in glass measuring cylinder kept cool with running tap water.

3. ASCORBIC ACID SOLUTION

27 g. of good quality ascorbic acid were dissolved in 500 ml of distilled water. This solution was stored in a plastic bottle and frozen in a freezer and then melted for use, and then refrozen.

4. POTASSIUM ANTIMONYL - TARTRATE SOLUTION

0.34 g of good quality potassium antimonyl - tartrate was dissolved in 250 ml of distilled water and stored in a glass bottle.

5. MIXED REAGENT

25 ml of ammonium molybdate, 125 ml sulphuric acid, 50 ml ascorbic acid and 25 ml potassium antimonyl - tartrate solutions were mixed togather for immediate use.

To complete the procedure 100 ml sea water samples were warmed to room temperature (15 - 30 ^{0}C) and then mixed with 10 ml of composite reagent to react. The

acidity was necessary to allow the conversion of phosphate in the presence of a large excess of silicate (Murphy and Riley, 1958). The usual reductants for the reduction process are either stannous chloride, which suffers from rapid oxidation in air and the final colour development is very temperature and salinity dependent (Martin 1972), or ascorbic acid which suffers from none of these disadvantages and is now used in 90% of marine analyses (Burton, 1973).

Ascorbic acid was used in the preesnt investigation as a reductant, whilst the antimony salt is added to reduce the time of colour formation (Murphy and Riley, 1962). The procedure was calibrated using a phosphate standard, consisting of 5.0 ml of the dilute anhydrous potassium dihydrogen phosphate ($KH_2 PO_4$) solution equivalent to 3.0 µg - at. P. l^{-1}, made up to 100 ml with distilled water. These standard solutions and two blanks of distilled water were also allowed to react with mixed reagent.The final colour reaches the maximum extinction in about 5 minutes and stays constant for many hours. The final colour development of samples and standards against reagent blank after 5 minutes and within the first hour were measured with a spectrophotometer at 885 nm using a red filter.

The calibration factor (F) was calculated from the following expression

$$F = \frac{3}{E_s - E_b}$$

Where E_s was the mean extinction of three standards and E_b was the mean extinction of blanks.

This factor is fairly constant, around 12 for a 4 cm cell. The phosphate concentrations in µg at P l^{-1} were calculated from this expression

$$\mu g \text{ at. P. } l^{-1} = \text{Corrected extinction} \times F$$

b : DETERMINATION OF DISSOLVED SILICA

The method of dissolved silica determination in sea water relies on the reaction of orthosilicic acid with molybdate producing a silicomolybdate complex which is then usually reduced to a hetero-poly blue comblex. Lund (1965) considers that the orthosilicate which is estimated by the standard method is available to diatoms while the more highly polymerized forms are not. This view is supported by Strickland and Parsons (1972) who state that " the reactive silicate" measured by this method probably gives a meaningful measure of the amount of silicon available to growing plant cells.

The method employed in this investigation is a modification of the method of Mullin and Riley (1955) as described by Strickland and Parsons (1972).

To perform this analysis special reagents were prepared as follows

1. AMMONIUM PARAMOLYBDATE SOLUTION

4 g good quality ammonium paramolybdate were dissolved in 300 ml of distilled water and mixed with 12 ml of concentrated hydrochloric acid and the volume made up to 500 ml with water. This solution was stored in a plastic container.

2. METOL - SULPHITE SOLUTION

6 g of anhydrous sodium sulphite $Na_2 SO_3$ were dissolved in 500 ml of distilled water and 10 g of metol (p-methylaminophenol sulphate) were then added. The mixture was then filtered through No. 1 Whatman filter paper after dissolving the metol.This solution was stored in a tightly stoppered glass bottle and renewed once a month.

3. OXALIC ACID SOLUTION

50 g of good quality oxalic acid dihydrate $(COOH)_2.2H_2O$ were added to 500 ml of distilled water. This saturated solution was stored in a glass container.

4. SULPHURIC ACID SOLUTION

250 ml of concentrated sulphuric acid were added with care to 250 ml of distilled water in a glass measuring cylinder kept cool with tap water and the volume was made to 500 ml with water and stored in a glass bottle.

5. REDUCING REAGENT

A mixture was prepared for immediate use containing 100 ml of metol - sulphite, 60 ml oxalic acid and 60 ml 50% sulphuric acid (care was taken while the sulphuric acid was added). The volume was made to 300 ml with distilled water.

The analysis involves the reaction of water samples (25 ml) with 10 ml of acidified ammonium molybdate solution for 10 minutes at room temperature to allow the silicate and molybdate to combine. After that reducing solution was added and mixed rapidly to complete the volume of 50ml. The oxalic acid is added to the reducing reagent to decompose any phospho or arseno - molybdate formed along with the silicomolybdate.

The metol reductant is more stable than stannous chloride and the blue colour produced by this reagent is stable (Strickland and Parsons, 1972).

Each analysis was calibrated with a standard solution of sodium silicofluoride, Na_2SiF_6, which was prepared by dissolving 0.96 g of fine dried sodium silicofluoride in one litre of distilled water, and then stored in a plastic container avoiding any storage in glassware because the solution picks up silica rapidly. The analyses were carried out

in polyethylene containers.

2 ml of this standard solution was diluted to 100 ml with synthetic sea water (prepared as in Strickland and Parsons, 1972) to give the final concentration of 4 ug at Si l^{-1}. This diluted solution was prepared for immediate use. Three and two 25 ml samples of standard solution and blanks of distilled water in order were treated as the samples through the experimental procedure. The extinctions were measured after 2 hours using a spectrophotometer with a red filter at 810 nm.

c : DETERMINATION OF NITRATE

The colorometric method used in this present investigation relied on that of Wood , Armstrong & Richards (1967), as described by Strickland & Parsons (1972). The nitrate in sea water is reduced almost quantitatively to nitrite when a sample is run through a column containing cadmium filings loosely coated with metallic copper.

The nitrite thus produced was determined by diazotizing with sulphanilamide and coupling with N-(1-naphthyl)- ethylenediamine to form a highly coloured azo dye. The reducing cadmium column (Fig. 3.3) needed for this determination was prepared by joining three pieces of glass tubing end to end. A tube of 10 cm length and 5 mm inside diameter was joined to a 30 cm length and 10 mm inside diameter of tubing, containing cadmium filings,. This tube was joined in turn to a 35 cm tube which was 2 mm in diameter. The last tube was bent just below this join into a U-shape so that it ran parallel to the 10 mm diameter tubing and then its end was bent over to form an inverted U-siphon.

To prepare this column a stick of cadmium was filed off and the fraction which sifted through a 2 mm screen but was retained by a 0.5 mm screen was taken for use in the column. 60 g of cadmium filings were stirred with 500 ml of 2% w/v copper sulphate pentahydrate, $CuSO_4.5H_2O$, until the blue colour had left the solution and the

semicolloidal copper particles began to enter the supernatant liquid. A small plug of glass wool was then placed at the bottom of the column which was then filled with supernatant liquor from the preparation of the cadmium-copper above.

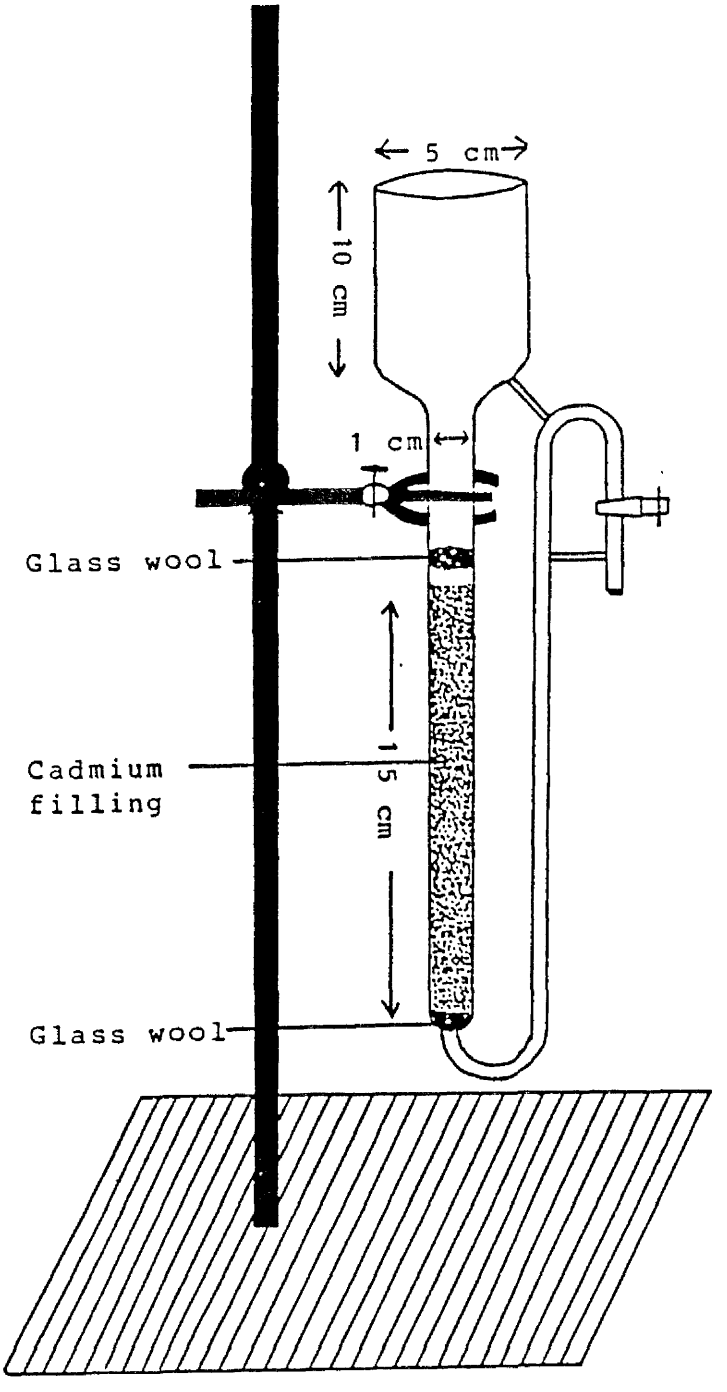
A sufficient amount of the cadmium-copper mixture was poured in to produce a column of 25 - 30 cm in length; tapping the column firmly was necessary to settle the filings well. The reduction column was then washed thoroughly with dilute ammonium chloride solution. The flow rate was fixed so that 100 ml of the solution took between 8 to 12 minutes to flow completely through the column which was controlled by loosening or packing the glass wool at the bottom of the column, followed by placing a small plug of glass wool on the top to prevent the cadmium filings being washed into the top chamber when solutions were added.

Dilute ammonium chloride solution covered the reductor column when not in use. When efficiency of reduction was suspect, usually after passing about 100 samples through the column, (Anber, 1984) the column was repacked by emptying its contents into a beaker, and the filings washed vigorously twice with 500 ml of 5% v/v hydrochloric acid solution. The acid was decanted and the metal was finally washed with 300 - 500 ml of distilled water until the wash was no longar acid (pH > 5). The liquid was decanted and the metal was left as dry as possible and retreated with the copper sulphate solution as described above.

The special reagents needed in this method to determine nitrate N were :

1. CONCENTRATED AMMONIUM CHLORIDE SOLUTION

125 g of good quality of ammonium chloride (NH_4 Cl) were dissolved in 500 ml of distilled water and stored in a glass bottle. The dilute ammonium chloride solution were prepared by diluting 25 ml of concentrated ammonium chloride solution to 1000 ml with distilled water and stored in a glass bottle.


5 cm
10 cm
1 cm
Glass wool
Cadmium filling
15 cm
Glass wool

2. SULPHANILAMIDE SOLUTION

5 g of sulphanilamide was dissolved in a mixture of concentrated hydrochloric acid (sp.gr. 1.18) and about 300 ml of distilled water. The volume was made up to 500 ml with water and stored in a glass container and renewed every 3 months.

3. N-(1-NAPHTHYL)-ETHYLENEDIAMINE DIHYDROCHLORIDE SOLUTION ($C_{10}H_7$, $NH.CH_2.CH_2.NH_2.2HCl$)

0.5 g of dihydrochloride was dissolved in 500 ml of distilled water. This solution was stored in a dark bottle and renewed every month.

To complete the procedure 100 ml aliquot samples were placed in plastic bottles and then 2 ml of concentrated ammonium chloride were added to each sample and mixed for a slight acidification of the sample which greatly slows the deactivation process caused by continual use of the column.

About 5 ml portion of sample was poured into the column to wash it and ensure that the liquid in the top part of the column has the composition of the sample. The remainder of the sample was then added and a graduated cylinder was placed under the discharge tap. 15 ml of the sample was allowed to pass through the column and was used for rinsing the cylinder. The next 25 ml of passed sample was collected to rinse the plastic bottle. The passage of all 40 ml has been found necessary to flush the column completely from the previous sample (Strickland and Parsons, 1972). Then a further 50 ml of the reduced sample was collected and transferred to the analysis bottle.
The sample was thereafter treated as a nitrite sample. For a full description see Nitrite Determination (p. 32).

In the case of high concentration of nitrate solutions, dilutions were made depending on the concentration once, twice or three times and then the readings were multiplied

by 2 or 4 or 8 as required.

The sample determination were accompanied by nitrate standards which were prepared by dissolving 1.02 gm of good quality potassium nitrate, KNO_3, in one litre of distilled water. 1 ml of this solution was equivalent to 10 μg at. N. 1.0 ml of this solution was diluted to 500 ml with synthetic sea water (prepared as outlined in Strickland and Parsons 1972) in a volumetric flask for immediate use. The concentration of this diluted solution was 20 μg at $N.l^{-1}$. Three 110 ml water and the reagent blanks were carried through the complete procedure. The blanks were passed through the reducing column before the samples and the standards while the column were previously flushed with at least 50 ml of dilute ammonium chloride solution just before use.

The concentrations of nitrate-nitrogen were calculated, after subtracting from the reagent blank extinctions, from this expression

$$\mu g \text{ at } N.\ l^{-1} = \text{corrected extinction} - 0.95\ C$$

where C was the concentration of nitrite present in the sample.

d : DETERMINATION OF NITRITE

All nitrite determinations in natural waters are based on a diazotization process. The nitrite ions react with an aromatic amine ($R\text{-}NH_2$) under acid conditions to form a diazo compound which couples with a second aromatic amine ($Ar\text{-}NH_2$) to form a red azo dye (Martin & Goff, 1972).

To estimate the nitrite concentrations, 50 ml of sea water samples were poured into plastic bottles, rinsed previously with the sample. One ml of sulphanilamide was added to each sample using an automatic pipette. After 5 minutes 1 ml of naphthy- ethylene diamine solution was mixed immediately.

The standard solution used in this method was 0.345 gm of anhydrous analytical reagent quality sodium nitrite, $NaNO_2$, which was dried at 110 ^{o}C for one hour. This reagent was dissolved in one litre of distilled water ; stored in a dark bottle with 1 ml of chloroform as preservative and renewed after two months. 1.0 ml of this solution contained 5 µg at. N. was diluted to 100 ml with distilled water and immediately used. 2ml of this dilute solution was made up to 50 ml volume with distilled water to calibrate the analysis.The standards and reagent blanks were carried through the analysis procedure. The extinction of samples and standards were measured against the reagent blanks at 543 nm wavelength. For the too concentrated samples, the same dilution procedure as with nitrate was followed.

The calibration factor was calculated from the this expression

$$F = \frac{2}{E_s - E_b}$$

Where E_s and E_b were the mean extinction of standards and blanks respectively.

The value for F was very close to 2.0.

So the concentration of nitrite-nitrogen in µg at. $N.l^{-1}$ was calculated by multiplying (F) by corrected extinction.

3.7. ESTIMATION OF STANDING CROP

a: ESTIMATION OF CHLOROPHYLL *a* AND PHAEOPIGMENTS

The procedure used in this investigation was based on the method described in Strickland and Parsons (1972) with minor changes in the concentration of the acetone and the period of chlorophyll extraction. This procedure was using for measuring the total quantity of chlorophyll *a* and phaeophytin specrophotometrically.

Sea water samples, brought back to laboratory within 2 hours of collection, were immediately vigorously shaken in the polythene containers and filtred (4-6 litre) under reduced pressure onto a 5.5 cm Whatman GF/C glass fibre filter (0.45 μ pore size) with 1 ml of magnesium carbonate ($MgCO_3$) suspension in the last 200 ml of the sample to prevent any decomposition of phytoplankton chlorophyll to give phaeophytin pigments. The filters were then drained under suction before removing and trimming away the unstained excess of the filters. They were thereafter folded, covered with aluminium foil and stored in a deep freezer at -20 ^{o}C for a few days but not more than one week.

The filters containing the golden-brown film of phytoplankton were ground in a homogenizer mortar with 4.5 ml of 100% acetone, as recommended by SCOR-UNESCO (1966), as also mentioned in Jeffrey (1974). After the first extraction in 100% acetone, the glass fibre pulp was then quantitatively transferred into a 15 ml covered centrifuge tube covered with aluminium foil for light protection, followed by rinsing the mortar with 5 ml 90% acetone and preceded by adding 0.5 ml of distilled water to bring the concentration of the acetone to 90%. The pigments were allowed to be extracted for 1-2 hours at room temperature. The contents were centrifuged for 5 minutes at 5300 r.p.m. to remove debris and fibres then the clear supernatant was decanted into 1 cm cuvettes. Extinction values were read against a blank of 90% acetone at 665 and 750 nm. For phaeopigments measurement two drops of 50% HCL were added to each sample, mixed, and after 5 minutes to allow the complete

breakdown of the chlorophyll *a*, the extinctions were remeasured again at the same wavelengths.

The equations used to calculate chlorophyll *a* and the phaeopigment levels are given in Strickland and Parsons (1972) which based on the original proposed by Lorenzen (1967).

$$\text{Chlorophyll } a \text{ (mg m}^{-3}) = \frac{26.7[(665_o - 750_o) - (665_a - 750_a)]xv}{V \times l}$$

$$\text{Phaeopigments (mg m}^{-3}) = \frac{26.7[1.7(665_a - 750_a) - (665_o - 750_o)]x\ v}{V \times l}$$

where :-

665_0 and 750_0 = The extinctions at 665 nm and 750 nm before acidification.

665_a and 750_a = After acidification.

v = The volume of acetone for extraction.

V = The volume of sea water filtered in litres.

l = The path length of the cuvette (1 cm).

b : ENUMERATION OF PHYTOPLANKTON CELLS

The enumeration of phytoplankton is one method of estimating the standing crop, based on counting the individual cell numbers.

The technique applied in this present study was a modification of membrane filtering procedure of Fournier (1981) as in Phytoplankton Manual (Sournia, 1981).

This technique consisted of the following steps:-

1. FIXATION AND PRESERVATION

Sea water samples were shaken throughly and 500 ml samples were then placed in a graduated measuring cylinders. These samples were fixed in an acid Lugol's solution, consisting of 100 g potassium iodide (KI) dissolved in one litre of distilled water, plus 50 g iodine (crystalline) dissolved in the same solution and 100 ml of glacial acetic acid added. The amount of Lugol's iodine was added to the sample for preservation was 2.5 ml (0.4 - 0.8 ml per 200 ml sample (Willen, 1976).

This fixing and preserving agent is one of the most used fixatives for phytoplankton. The advantages of this solution are that, a large number of flagellates retain their flagella, and other phytoplankton cells fix reasonably well and become brownish yellow and easy to observe during the counting procedure (Throndsen, 1981).

2. SEDIMENTATION

The method used to concentrate the phytoplankton carried out in this project was to allow the samples sedimented by Lugol's solution to settle down on the base of the glass graduated cylinder for 7 -10 days and then remove the upper 400 ml by gentle suction using a 25 ml pipette. In the last year of the study, the supernatant was

siphoned off instead of pipetted.

3. FILTRATION

A suitable amount of sediment samples were filtered, after inverting the samples containers many times for mixing, on HA Millipore filters (25 mm diameter) with 0.45 μm pore size, whilst gentle vacuum was applied during the filtration procedure. The filtered amount of samples depends on the density of phytoplankton population and high suspended matter in the water which made the filtration, enumeration and identification very difficult. However, at the end of the filtration all Millipore filters were removed from the filtration unit and placed, filtration surface up, on microscope slides inscribed with relevant identifying information at one end by diamond pen. All slides with their contents were put in Pyrex glass petri dishes and then in an oven at 25 - 30 ^{O}C overnight to dry.

4. MOUNTING

The dried filters so obtained were trimmed with scissors to remove the unstained membrane. They were replaced again on to a drop of Microoil immersion oil, for clearing, centred on the slides. Two drops were then added onto the surface of filters, followed by a square cover slip on the filters and finally mounts were sealed with clear nail varnish. The slides which were prepared in this way showed no signs of deterioration after two or more years.

5. IDENTIFICATION AND ENUMERATION

The phytoplankton cells were identified as genera and as many distinct species as possible and counted by scoring 30 random fields using a Leitz- Ortholux microscope with a high power (x 40) objective.

To calculate the number of algae per litre the following equation was used.

$$\text{Number of algae } l^{-1} = \frac{\text{Area of Filter } (mm^2) / \text{x total counts in 30 fields}}{\text{Total area of 30 fields } (mm^2) / \text{x Sample volume in (l)}}$$

3.8. CARBON FIXATION MEASUREMENTS BY ^{14}C UPTAKE

The ^{14}C technique used in this study for estimating the primary productivity of the phytoplankton involved illuminating samples with a fixed light intensity and a known time both under laboratory conditions, and *in situ* on some occasions, after adding a known amount of radioactive sodium (^{14}C) bicarbonate. The uptake rate of ^{14}C during photosynthesis was measured to assess the carbon fixation.

The procedures used are here as described in Strickland and Parsons, (1972) with addition of reagents as follows :-

1. SODIUM (^{14}C) BICARBONATE AQUEOUS SOLUTION

This solution was obtained from the RadioChemical Centre, Amersham, in 1 ml quantities of 50 $\mu Ci\ ml^{-1}$ in sterile vials. These were diluted to 1 μ Ci ml^{-1} immediately with diluted sodium chloride solution before inoculation.

2. DILUTED SODIUM CHLORIDE SOLUTION

The preparation of this solution was taken from Strickland and Parsons (1972) by making the solution consisting of 5% w/v Analar sodium chloride and distilled water. Then 0.3 g of anhydrous sodium carbonate ($Na_2\ CO_3$) and 0.2 g of sodium hydroxide (NaOH) were added to each litre of this solution.

3. TRITON SCINTILLANT

5 g of PPO(2, 5, diphenyloxazolyl), was mixed with 0.3 g dimethyl-popop-1, 4-Di-[2-(4-methyl-5-phenyloxazolyl)]-benzene and 200 ml Triton in a dry measuring cylinder. The volume was made up to one litre with toluene.

PROCEDURE :-

1. PREPARATION OF SAMPLES AND INOCULATION

a) IN THE LABORATORY

Subsamples of sea water from the collection in the field were filled in one litre polyethylene bottles and placed inside a black polythene container.

On returning to the laboratory (about 1 hour), two light (glass bottles with ground glass stoppers) and one dark (similar, covered with double layer of black tape) bottles all of actual volume 129.8 ml were filled with sea water sample from each depth. Samples were then inoculated rapidly with 1 ml of 1 μCi ml^{-1} concentration of sodium [^{14}C] bicarbonate solution using a disposable syringe, and mixed.

b) *IN SITU* MEASUREMENTS

Bottles with ground plastic stoppers were filled with water samples and kept in light-tight wooden box till completion of the inoculation by which was adding 1.0 ml of working ^{14}C solution. Then bottles were well stoppered and mixed. For more accuracy dark bottles were wrapped with aluminium foil.

2. INCUBATION

Samples prepared in the laboratory were immediately incubated in growth room under fluorescent strip lights at 13 - 15 ^{o}C for 4 - 6 hours in 1.3 W m^{-2} light irradiance. Dark bottles were additionally covered with black nylon.

For *in situ* measurements, sampling bottles were fixed in perspex holders designed to hold three bottles in a horizontal position to allow maximum exposure of the bottles to

the available light at each depth. The holders' design was as recommended by Schindler and Holmgren (1971) with slight addition by surrounding the holder with a metal ring to hold the bottles firmly. These holders were threaded on two ropes (Fig. 3.3)

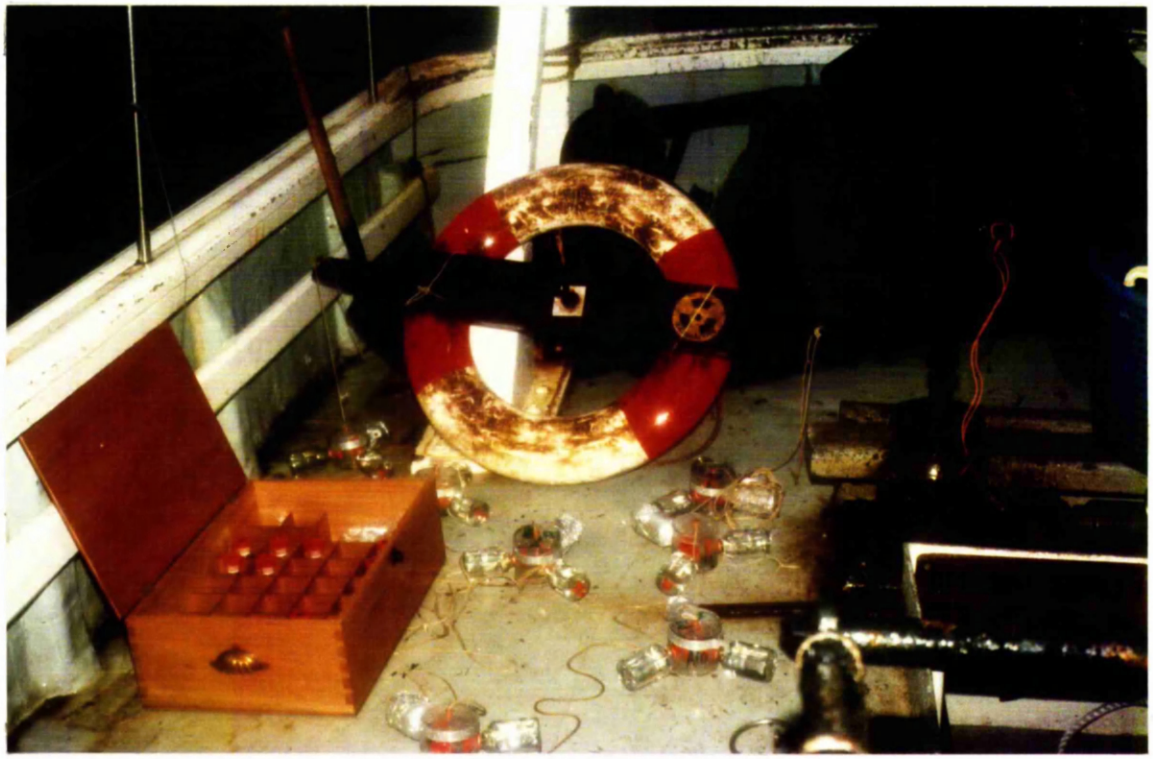
A float consisting of a lifebuoy with wooden spar strapped across it was moored near the pier (Keppel Pier) of the Biological Station where 10 m depth was available to suspend the samples. The two ropes with the holders and their contents were attached to either end of the spar, away from the possible shading effect of the buoy. These samples were incubated at their original sampling depths except 40 m samples which were suspended at surface ; 1 m ; 5 m and 10 m depths for four hours under natural light and temperature conditions.

4. FILTRATION

After incubation of the samples both in the laboratory and *in situ* the bottles were placed in a dark box to prevent any further fixation and 2 ml of formaldehyde solution were added using a disposable syringe to stop any further photosynthetic activity.

All light and dark sample bottles were shaken and their contents were filtered on to 50 mm Millipore HA filters (0.45 μm pore size) under slight vacuum. After removal of the contents of each bottle it was rinsed with 10 ml of sea water previously filtered (through Millipore HA filters) and then finally the filtration unit and filter washed with filtered sea water. Every washing was sucked through the filter till it was dry. Clean forceps was used to transfer the filters to scintillation vials containing 10 ml of scintillant. The scintillation vials were then left at room temperature for 16 hours.

Fig. 3. 3. The perspex bottle holders used in the *in situ* carbon fixation experiments.



5. COUNTING

The vials with contents were transferred into the liquid scintillation counter (LKB Wallac model 1211 minibeta) to measure the radioactivity which was expressed as counts per minute (cpm).

The photosynthetic production in mg C m^{-3} h^{-1} was calculated using the following equation:-

$$P = \frac{{}^{14}C \text{ uptake} \times {}^{12}C \text{ availability} \times 128.8 \times 1.06}{{}^{14}C \text{ added} \times E \times V \times T}$$

where :-

^{14}C uptake = mean light - dark bottles values.

^{12}C avail. = total CO_2 (mg C available) in water (see 3.5) $(mg\ C\ m^{-3})$

128.8 = Volume of incubation bottles (ml).

1.06 = Isotope correction factor.

E = Scintillation counting efficiency.(the efficiency was determined as in Hannah, 1974).

V = Volume of filtered incubation samples (ml).

T = Incubation time (in hours).

3.9. QUALITATIVE DETERMINATION OF PHOTOSYNTHETIC PIGMENTS Using thin-layer chromatography

The chromatographic procedure using thin layer (T.L.C.) separates the major photosynthetic pigments of green algae, diatoms, dinoflgellates and chrysomonads in addition to the degradation products of parent chlorophylls (Jeffrey, 1968). Different chlorophylls can also be identified.

The chromatographic technique used in this study was based on the method applied by Jeffrey (1974) with modification of some points in the original procedure.

One dimensional chromatography was used with 50% redistilled ethyl acetate in light petroleum (60 - 80 ^{o}C) as solvent. These substituted solvents were found to be more suitable, due to the problem of the low concentrations of chloroplast pigments, especially in summer and winter, and in the samples from deep water even if the volumes of filtered sea water were increased to 7 litre for each sample in the deep water collections. Therefore to overcome this problem the samples were assembled together in every season corresponding to the sampling programme in each month :

SPRING

Samples collected in March, April and May.

SUMMER

Samples collected in June, July and August.

AUTUMN

Samples collected in September, October and November.

WINTER

Samples collected in December, January and February.

1. FILTRATION

Sea water samples were filtered (3 - 7 litre) onto a 5.5 cm Whatman GF/C glass fibre filters (0.45 μm pore size) under reduced pressure. one ml of magnesium carbonate suspension was added to the last 200 ml of the sample. The filters were then drained and stored at -20 ^{O}C until the analysis was carried out.

2. EXTRACTION

The same extraction technique was followed here as in the chlorophyll analysis (3.7.1).The volume of acetone used for this extraction was 10 - 16 ml according to the number of filters (2 - 7 filters).

The acetone pigment extract volume after centrifugation was between 6 - 11 ml.

3. CONCENTRATION

Immediately after extraction, the extracts were prepared for chromatography by adding twice the volume of redistilled diethyl ether preceded by 10 volumes of cold 10% sodium chloride (NaCl) solution. The separatory funnel with the mixture was inverted gently several times. The mixture was then allowed to stand for a few minutes, during which time the pigments migrated to diethyl ether on the top of mixture and the acetone and sodium chloride solution was drained from the bottom.

The remaining ether layer containing pigments was transferred in test tube and then concentrated to a small volume under a stream of oxygen-free nitrogen. This volume of concentrated pigments was transferred to a glass tube and centrifuged to remove any remaining water.

4. SEPARATION

Concentrated pigments were spotted on silica gel thin layer plates which were transferred to a tank lined with filter paper previously prepared by placing the solvents of 50% ethyl acetate in light petroleum to separate the pigments by one dimensional chromatography. All plates after completion of development of separation were dried for a few minutes and then wrapped with aluminium foil and kept in deep freezer till identification of pigments was carried out.

5. IDENTIFICATION

The sequences of pigment colours obtained on the silica gel plates were identified by comparison with those obtained in research reports of other workers. The procedures of all the steps above were carried out in subdued light.

3.10. DETERMINATION OF TOTAL ORGANIC MATTER

The technique applied in this investigation relies on the determination of the mass of particulate organic matter by estimating the loss in weight of the total organic matter after ignition of samples. The amount of organic matter can be regarded directly or indirectly as an energy source (Riley and Chester, 1971). The procedure used was taken from Teixeira and Kutner, (1962). The sea water samples (1 litre) were immediately fixed with 2 ml of 40% formaldehyde solution after collection in the field. Filtration was carried out for all samples onto 4.5 cm Whatman GF/C glass fibre filters (0.45 μm pore size) which were previously freed from volatile material by placing them on separate portions of aluminum foil for each sample in a muffle furnace (Electric Carbolite, Furnace model No.5.67.1455) at a temperature of 400 ^{o}C for 30 minutes.

After filtering, filters with their contents were dried in an oven at 80 ^{o}C for 4 hours followed by weighing the filters to determine the total particulate matter (TPM) in mg m^{-3} for each sample.

Filters were then ignited in the muffle furnace again at 500 ^{o}C for one hour. After cooling the weights of filters with contents were measured. The particulate organic matter (POM) was calculated from this expression

$$\text{POM (mg m}^{-3}) = \text{TPM} - \text{weight after ignition}$$

3.11. DETERMINATION OF PARTICULATE OXIDIZABLE CARBON

[Wet Oxidation with Dicromate]

The procedure of particulate oxidizable carbon measurement used was based on that of Johnson (1949), modified by Strickland and Parsons (1972).

The method involves the wet oxidation of carbon by acid dichromate prepared with other reagents as mentioned below.

1. SULPHURIC ACID - DICHROMATE OXIDANT

4.84 g of potassium dichromate $K_2Cr_2O_7$ was dissolved in 20 ml of distilled water. This solution was added with care a little at a time to about 500 ml of concentrated analytical quality sulphuric acid in a water cooled one litre volumetric flask . The volume was made up to one litre with more concentrated acid.The solution was stored in a glass-stoppered bottle protected from the dust.

2. PHOSPHORIC ACID

A solution of 70% grade of phosphoric acid.

3. SODIUM SULPHATE SOLUTION

45 g of good quality anhydrous sodium sulphate (Na_2 So_4) was dissolved in one litre of distilled water and stored in a glass bottle.

The procedure was as follows

1. IGNITION

The 4.5 cm Whatman GF/C glass fibre filters (0.45 um pore size) were individually placed on aluminium foil in a muffle furnace at 450 ^{o}C for 30 minutes to be freed from any oxidizable material. They were then wrapped with the foil and stored in an oven at 110 ^{o}C.

2. FILTRATION

Sea water samples were filtered through a 212 nylon mesh in the field to remove zooplankton (Riley and Chester, 1971). These samples were then passed through ignited glass fibre filters fitted into Millipore filtration equipment using reduced pressure not exceeding one fourth of an atmosphere to avoid drawing any material through the filters. At the end of filtration 2 ml of sodium sulphate solution were added and immediately suction repeated till the filters were dried. This process was repeated again to avoid any error caused by chlorides reacting with the dichromate.

3. HEATING

Clean forceps was used to remove the filters and lay each one flat on the bottom of a clean 30 ml Pyrex beakers.1 ml of phosphoric acid (to volatilize most of chloride as hydrogen chloride) and 1 ml of distilled water were pipetted on to the flattened filters and mixed thoroughly. The beakers were then covered with aluminium foil and placed in the oven protected from any dust to heat the contents to 110 ^{o}C. After 30 minutes 10 ml of sulphuric acid dichromate oxidant and 4 ml of distilled water were added using graduated pipettes to the beakers with their contents and these were then returned to the heater for a further 60 minutes.

Two blanks and three standards were treated by the sample procedure mentioned in the above previous paragraph and the rest procedures below, but 4 ml of glucose solution

were added to these three standards instead of the distilled water which was added to the samples and blanks.

4. CENTRIFUGATION

The heated solutions were transferred to 100 ml stoppered graduated cylinders after cooling and made up to 50 ml with distilled water. After a few minutes suitable volumes (when the solutions settled down) were decanted into centrifuge tubes and centrifuged at 3000 rpm for 10 minutes.

5. CALIBRATION

The extinction determination processes were calibrated by a standard glucose solution which was prepared by dissolving 7.5g of pure glucose and a few crystals of mercuric chloride, $HgCl_2$, in 100 ml of distilled water in a volumetric flask. 1 ml of this solution was diluted to 100 ml with distilled water in a volumetric flask for immediate use. 1 ml of this solution was equivlent to 300 µg of carbon.

6. DETERMINATION OF EXTINCTIONS AND CALCULATION

The blank extinctions were measured against distilled water followed by determination of the samples and standards.

Extinctions were determined using a Unicam SP 600 Specrophotometer in a 1.0 cm cuvette at 440 nm with a blue filter.

Factor F value was around 279.1 which was calculated from this expression:-

$$F = \frac{120}{E_c}$$

where E_c was the mean corrected extinction of the standards.

The measured extinctions of samples were corrected by multiplied them by 1.1 and then the particulate carbon in mg C m^{-3} was calculated from the expression:-

$$\text{mg C m}^{-3} = \frac{E \times F \times v}{V}$$

where :-

E = the corrected readings of samples.

F = factor.

v = the volume of oxidant used (in ml, usually 10 ml).

V = the volume of filtered sea water (in litres).

4. THE PHYSICO - CHEMICAL DATA

4.1. INTRODUCTION

Previous studies on the phytoplankton in the Firth of Clyde have been principally concerned with the photic zone. This emphasis is understandably linked with the productive role of the phytoplankton in lighted zone of the water. Data on phytoplankton below the photic zone for the Firth is sparse, and there has never been a seasonal study concentrating on this aspect. The results obtained in the present work fall into two sections.

The first year's data (May 1984 to April 1985) are largely exploratory, in setting out to determine what factors were measurable in the aphotic regions. The second sets of data (May 1985 to April 1987) were investigated from a comparative point of view, with both the aphotic and photic zones studied.

4.2. HYDROGRAPHICAL DATA

The hyrographical data were obtained during the period 19 March 1986 to 25 March 1987. The temperature measurements showed that thermal stratification occured for a short period during July 1986 when the water column was stable (the wind speeds were below 12 knots), and the differences in the sea temperature for station 3 and 6 between the surface water and deep water was at about 5.0 ^{o}C (Table 4.1). The annual patterns of surface temperature changes were similar to those obtained by Hinton (1974) and Hannah (1979).

Table 4.1

Measurements of sea water temperatures (^{o}C) during the period March 1986 to March 1987 For 3 m, 20 m and 40 m depths at stations 3 and 6 on sampling date.

Date	Station 3			Station 6		
	3 m	20 m	40 m	3 m	20 m	40 m
10.3.86	5.5	5.2	5.1	5.6	5.2	5.1
19.3.86	6.0	5.8	5.4	5.8	5.6	5.4
26.3.86	6.2	5.9	5.8	5.6	5.6	5.6
02.4.86	6.2	6.0	5.8	6.2	5.8	5.6
09.4.86	6.0	6.0	6.0	6.0	6.0	6.0
23.4.86	6.5	6.1	6.0	6.5	6.1	6.0
07.5.86	8.0	7.6	6.4	7.6	7.2	6.4
21.5.86	8.8	8.4	7.4	8.8	8.6	7.4
18.6.86	11.4	8.2	7.4	11.5	8.4	7.6
02.7.86	14.4	10.2	9.2	14.2	10.2	9.0
16.7.86	13.6	12.5	9.4	13.6	12.5	9.4
30.7.86	12.6	11.2	10.0	12.4	10.6	9.8
27.8.86	10.5	10.6	10.6	10.5	10.6	10.6
10.9.86	11.2	11.1	11.0	11.2	11.2	11.0
24.9.86	11.6	11.4	11.7	11.2	11.3	11.4
06.10.86	12.0	11.8	11.4	12.4	11.8	11.4
27.10.86	9.5	9.7	9.8	9.4	9.5	9.5
06.12.86	7.6	-	8.8	-	-	-
22. 1.87	5.8	6.0	6.2	5.8	6.0	6.2
18. 2.87	6.4	6.4	6.3	6.2	6.4	6.4
04. 3.87	5.7	5.8	5.5	6.4	6.0	7.0
18. 3.87	6.0	6.0	6.0	5.8	6.0	4.8
25. 3.87	6.0	6.0	6.0	6.0	6.0	6.0

The surface salinity at both stations (3 and 6), given in Appendix III, fluctuated between a minimum of 27.4°/oo (29 October 1986) and maximum of 34.5°/oo (10 March 1986), whilst the salinity in the deep water recorded the minimum and maximum of 27.7°/oo and 35.0°/oo respectively on the same dates.

4.3. WIND DATA AND SUNSHINE HOURS

These extensive data are given in Appendices I and II. Their interpretations will be reserved for the comparative discussion in Chapter 8.

4.4. NUTRIENTS

a. Dissolved Silica

Dissolved silica levels in the surface waters in previous studies (see summaries in Introduction) varied between analytical zero during spring and early summer and maxima of 14 μg. at. Si l^{-1} during winter . Figs. 4.1 to 4.4 display the seasonal changes in dissolved silica levels from April 1984 to April 1986 showing the low levels at 20 m and 40 m at both stations in the end of the spring of 1984 (23 May 1984) reaching analytical zero at 20 m depths in the two stations on 6 June 1984 and on 5 June 1985 for station 3. The levels of dissolved silica for these two depths at the two stations (3 and 6) rarely fell below 10 μg. at. Si l^{-1} during the most months of autumn and winter 1985, reaching about 23 μg. at. Si l^{-1} in very early spring (1985) at station 3 and 6 . When compared with data from 3 m in 1985-6 (Figs. 4.3 and 4.4) at no time did the depth samples reach analytical zero, as with the 3 m depth samples in May and June 1985, whilst the winter levels in the 3 m, 20 m and 40 m samples were quite close quantitatively during winter months 1985-6. Generally the depth samples were higher in silica than those at the surface.

Fig. 4. 1. Seasonal changes in dissolved silica levels (μg at $Si.l^{-1}$) for 20 m and 40 m samples from station 3 during the period April 1984 to March 1985.

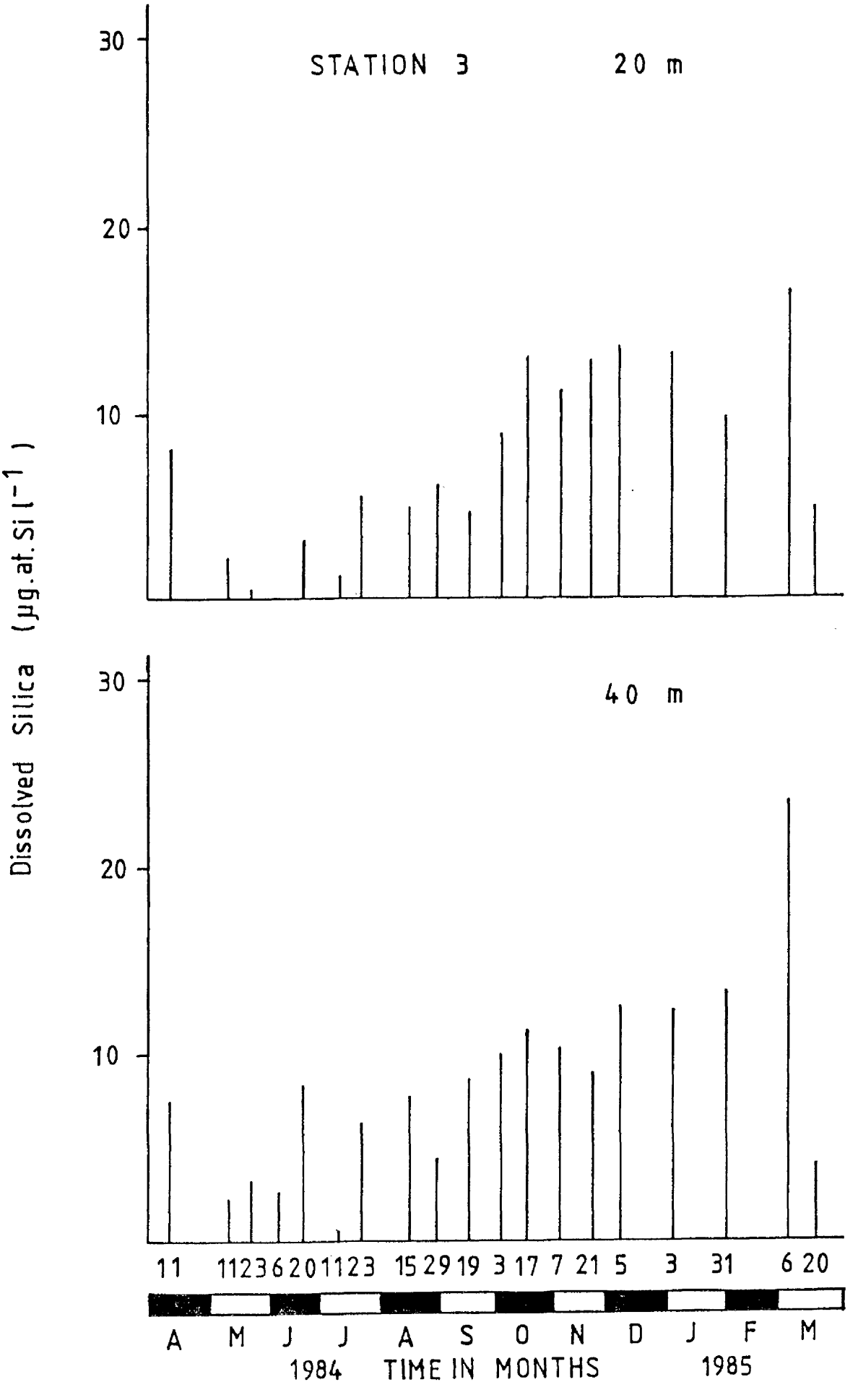

STATION 3
20 m
40 m
30
20
10
Dissolved Silica (µg.at.Si l⁻¹)
11 11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984 TIME IN MONTHS 1985

Fig. 4. 2. Seasonal changes in dissolved silica levels (μg at $Si.l^{-1}$) for 20 and 40 m samples from station 6 during the period April 1984 to March 1985.

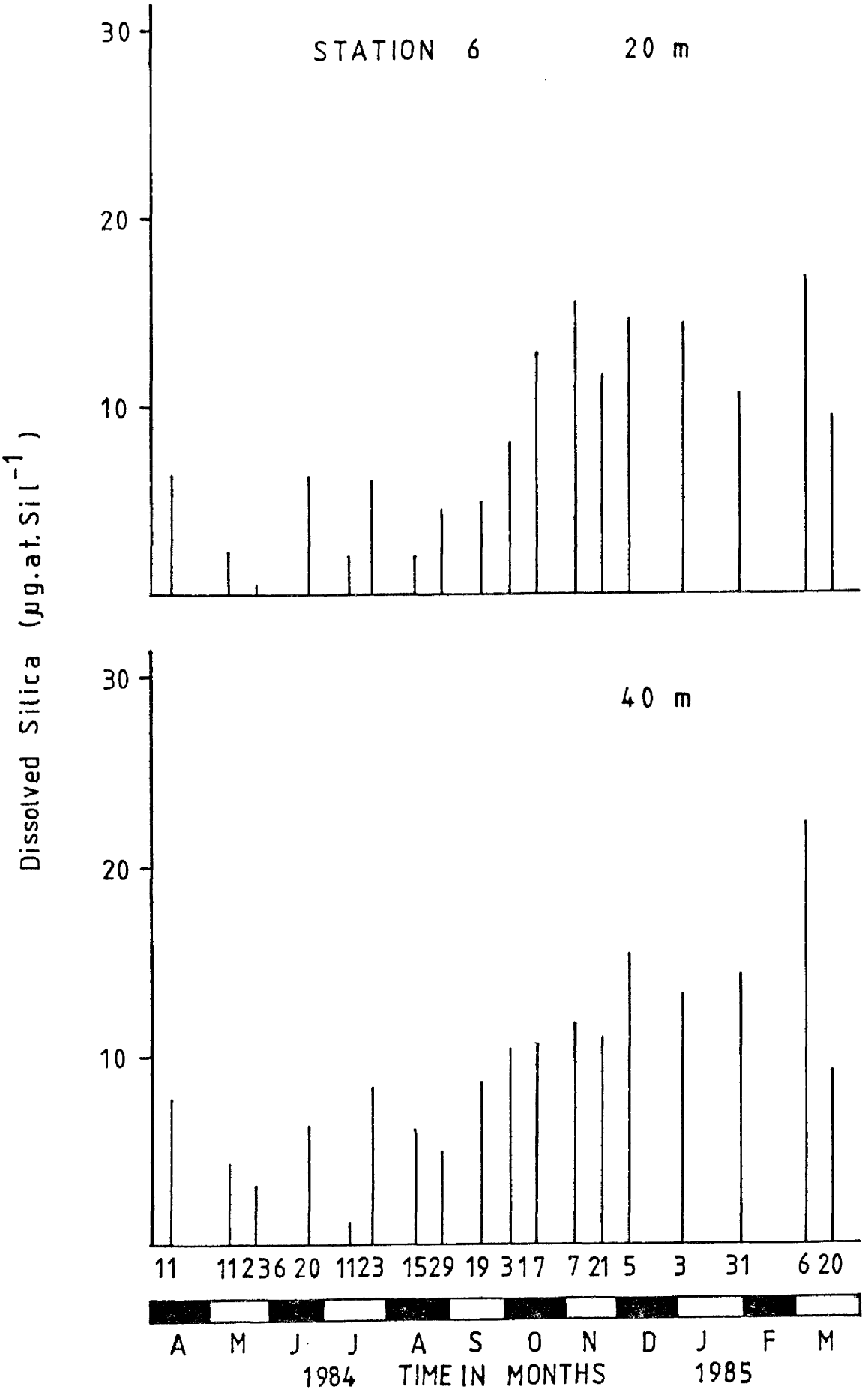

STATION 6
20 m
40 m
30
20
10
Dissolved Silica (µg.at.Si l^{-1})
11 11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984 TIME IN MONTHS 1985

Fig. 4. 3. Seasonal changes in dissolved silica values (μg at $Si.l^{-1}$) in 3 m, 20 m and 40 m samples at station 3 during the period April 1985 to April 1986.

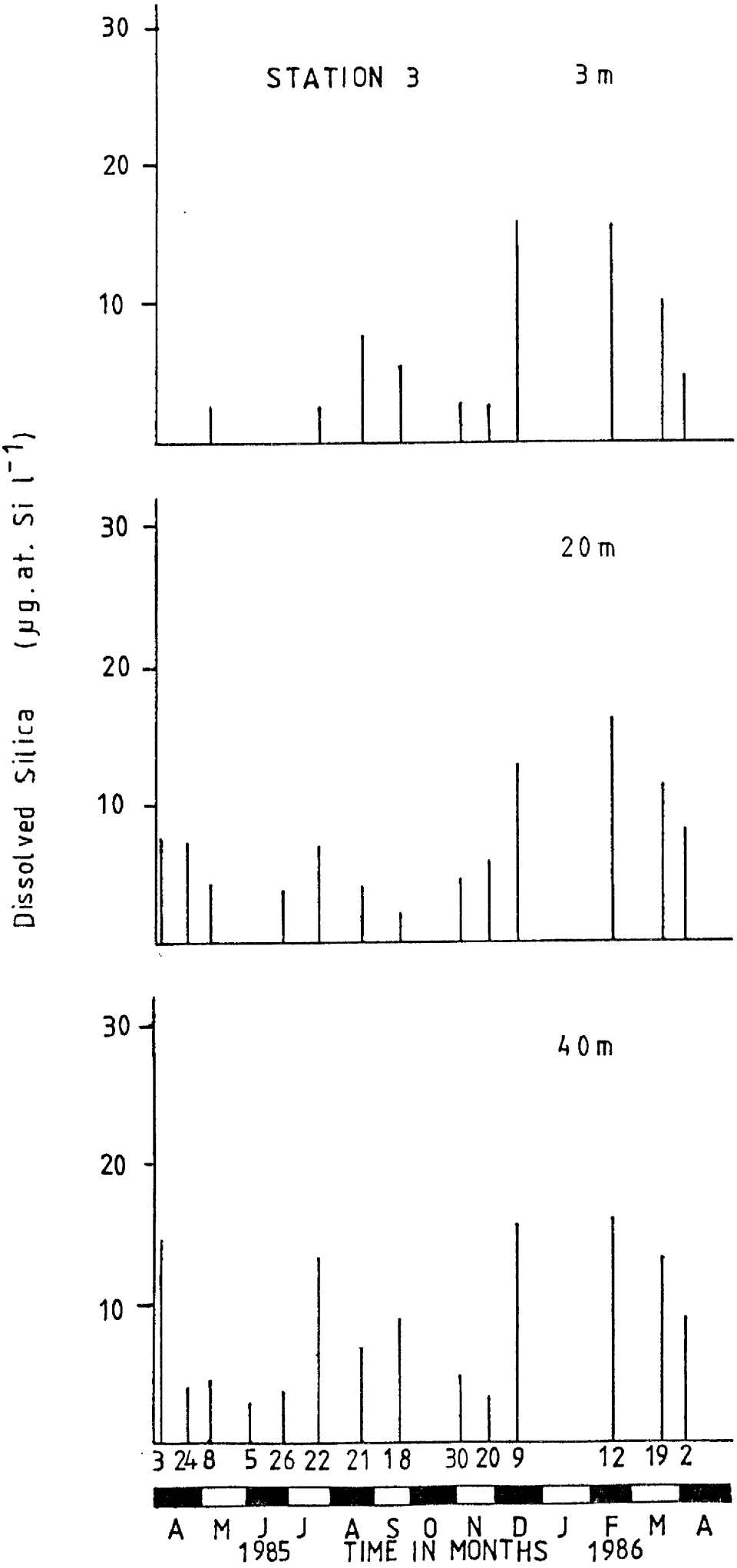
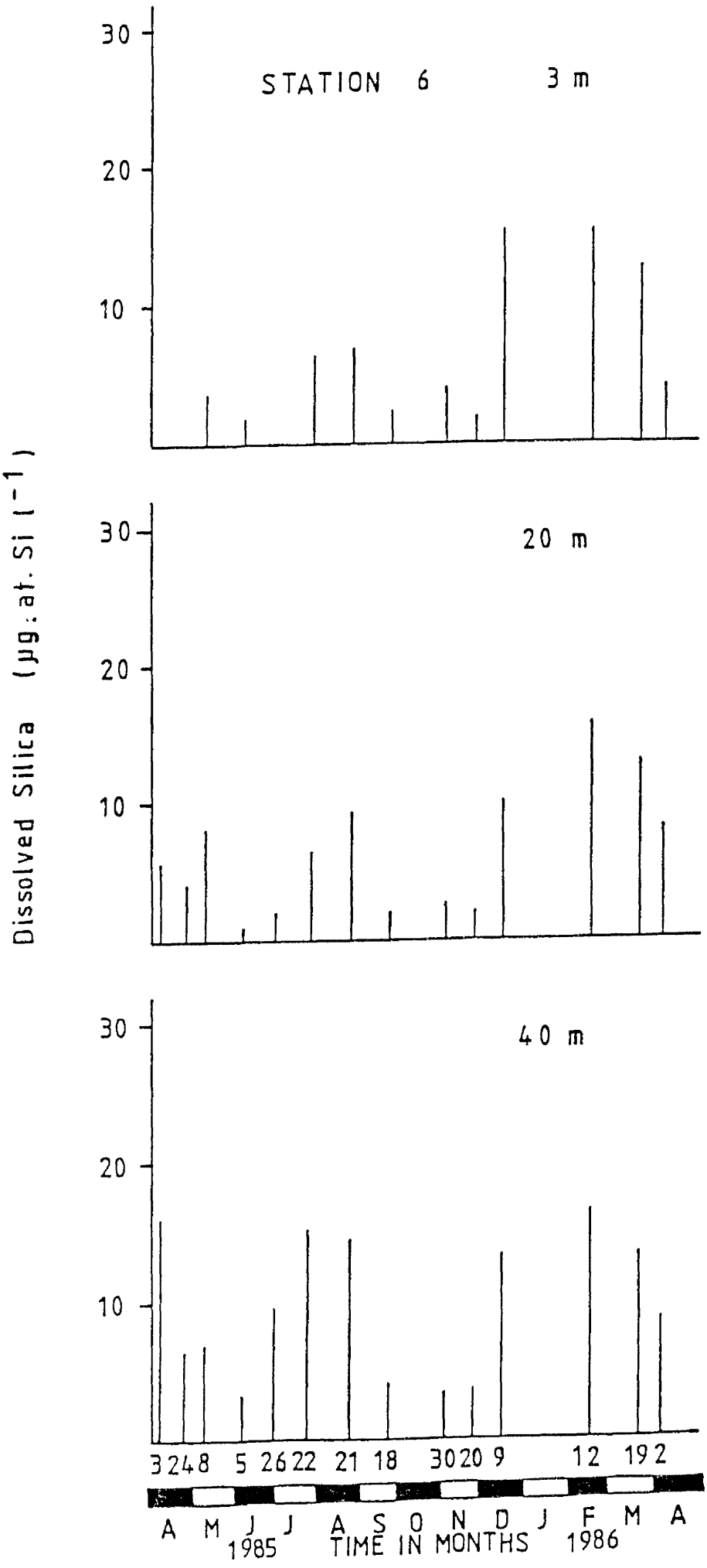

STATION 3
3 m
20 m
40 m
30
20
10
Dissolved Silica (µg.at. Si l⁻¹)
3 24 8 5 26 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985 TIME IN MONTHS 1986

Fig. 4. 4. Seasonal changes in dissolved silica values (μg at $Si.l^{-1}$) during the period April 1985 to April 1986 in 3 m,20 m and 40 m samples fom station 6.


STATION 6
3 m
20 m
40 m
30
20
10
Dissolved Silica (µg.at.Si l⁻¹)
3 2 4 8 5 26 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985
TIME IN MONTHS
1986

b. Nitrate N + Nitrite N

Previous records have shown that the nitrate N levels of the surface waters varied between winter maxima up to 20 µg at nitrate Nl^{-1} and summer levels approaching analytical zero, with the build up to the winter maxima proceeding through late autumn. For the depth samples in 1984-5 (Fig. 4.5 and 4.6) , for the most part the nitrate + nitrite N levels fluctuated within narrow limits (about 2.5 - 7.5 µg. at. N l^{-1}) for station 3 and 3.5-12.5 µg. at. N l^{-1} at station 6). Very low N levels were recorded on 19 September 1984. When comparative measurements were made with 3 m samples in 1985-6 (Fig 4.7 and 4.8), it was generally noted that much wider fluctuation, with some approaching analytical zero , were observed at 3 m than at the depth samples at both stations.

c. Phosphate Phosphorus

Previous studies have shown that for the surface waters (1-3 m depth) the phosphate P levels shows wide seasonal fluctuations, with winter maxima of about 1.5 µg. at. P l^{-1} and minima (spring and summer) of about 0.25 µg. at. P l^{-1} (Hinton, 1974, Hannah,1979).

Some measurements carried out in surface waters collected from near to stations 3 and 6 showed winter maxima similar to those obtained by Hinton (1974) and Hannah (1979).(Personal communication from A. Ben Omran). Between these extremes there can be wide fluctuations - even on a daily basis (Hinton 1974). Hence fortnightly or longer sampling can be taken as indications of general trends.

The data for depth samples at station 3 and 6 in 1984-5 (Figs. 4.9 and 4.10) show that phosphate P levels never fell as low as the surface minima observed over a number of years, and at times (winter) the levels attained maxima (up to 4.7 µg. at. P l^{-1}) not

previously recorded in the surface waters. Comparative measurements made for 3 m, 20 m and 40 m at station 3 and 6 from May 1985 to April 1986 (Figs. 4.11 and 4.12), showed fluctuations, with the maximum value of 1.8 µg. at. l^{-1} in the surface samples on 12 February 1986. The meassurements at this time in the depth samples were 1.3 µg. at. l^{-1} at 20 m and 40 m at station 3, whilst at station 6 the quantities of 2.94 and 1.1 µg at l^{-1} were measured at 20 m and 40 m respectively.

Fig. 4. 5. Seasonal changes in combined nitrate and nitrite values (μg at $N.l^{-1}$) for 20 m and 40 m samples from station 3 during April 1984 to March 1985.

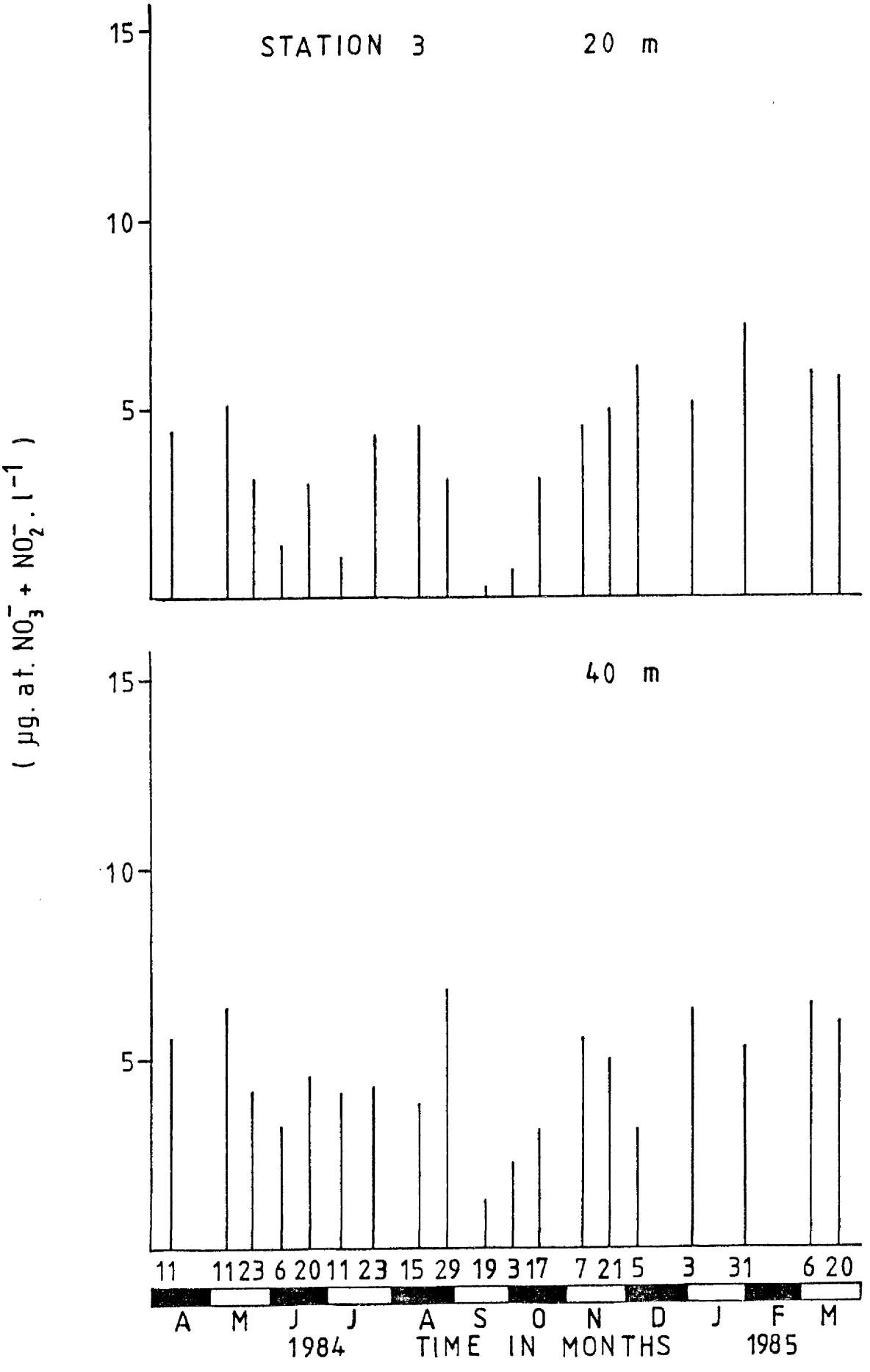

STATION 3
20 m
40 m
15
10
5
(µg. at. NO_3^- + NO_2^-. l^{-1})
11 11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984
TIME IN MONTHS
1985

Fig. 4. 6. Seasonal changes in the values of the combined nitrate and nitrite (μg. at. N l^{-1}) for 20 m and 40 m samples from station 6 through April 1984 to March 1985.

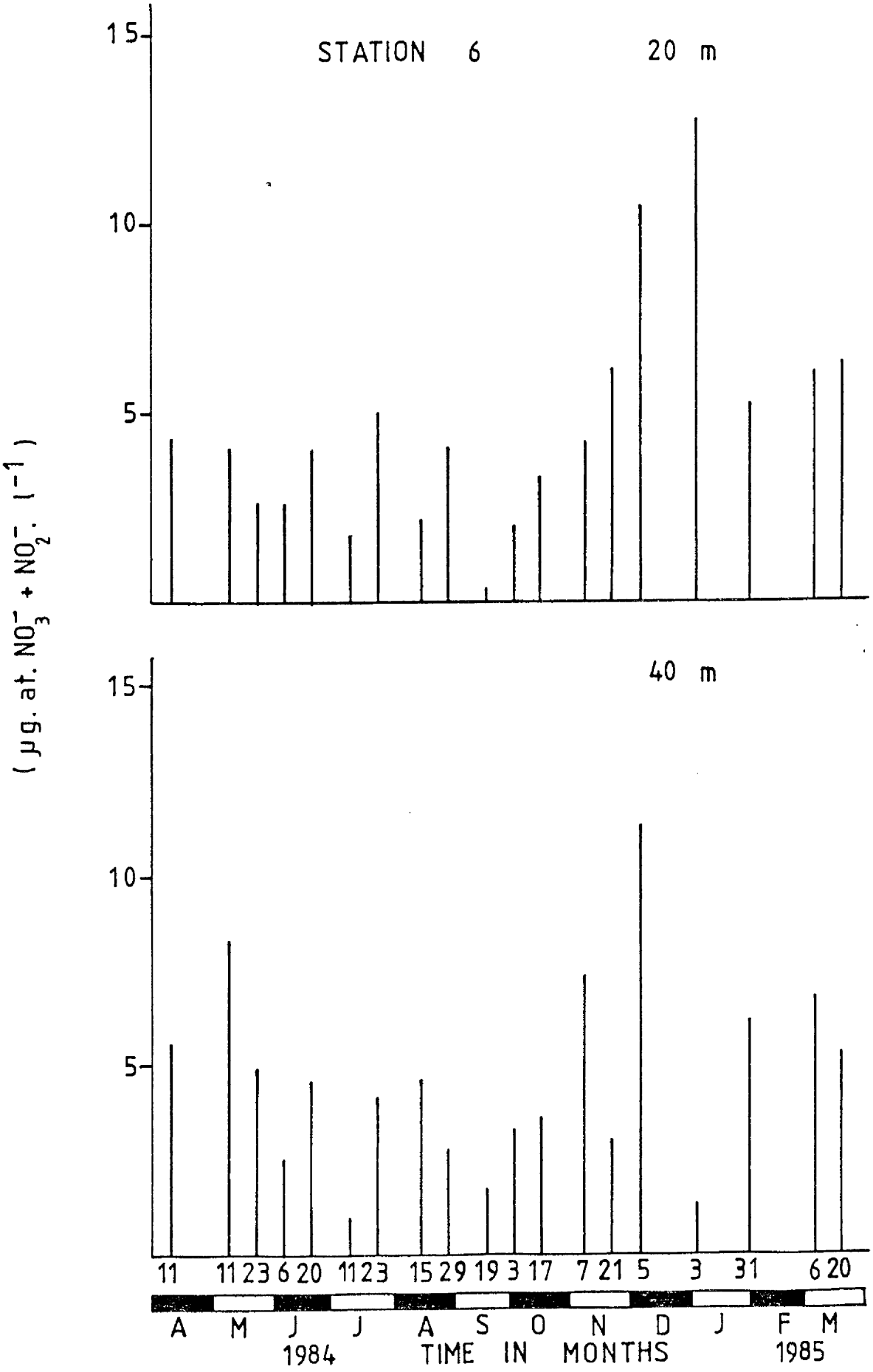

STATION 6
20 m
40 m
15
10
5
(µg. at. NO_3^- + NO_2^-. l^{-1})
11 11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984
TIME IN MONTHS
1985

Fig. 4. 7. Seasonal changes in the values of the combined nitrate and nitrite (μg. at. N l^{-1}) in the 3 m, 20 m and 40 m samples at station 3 during April 1985 to April 1986.

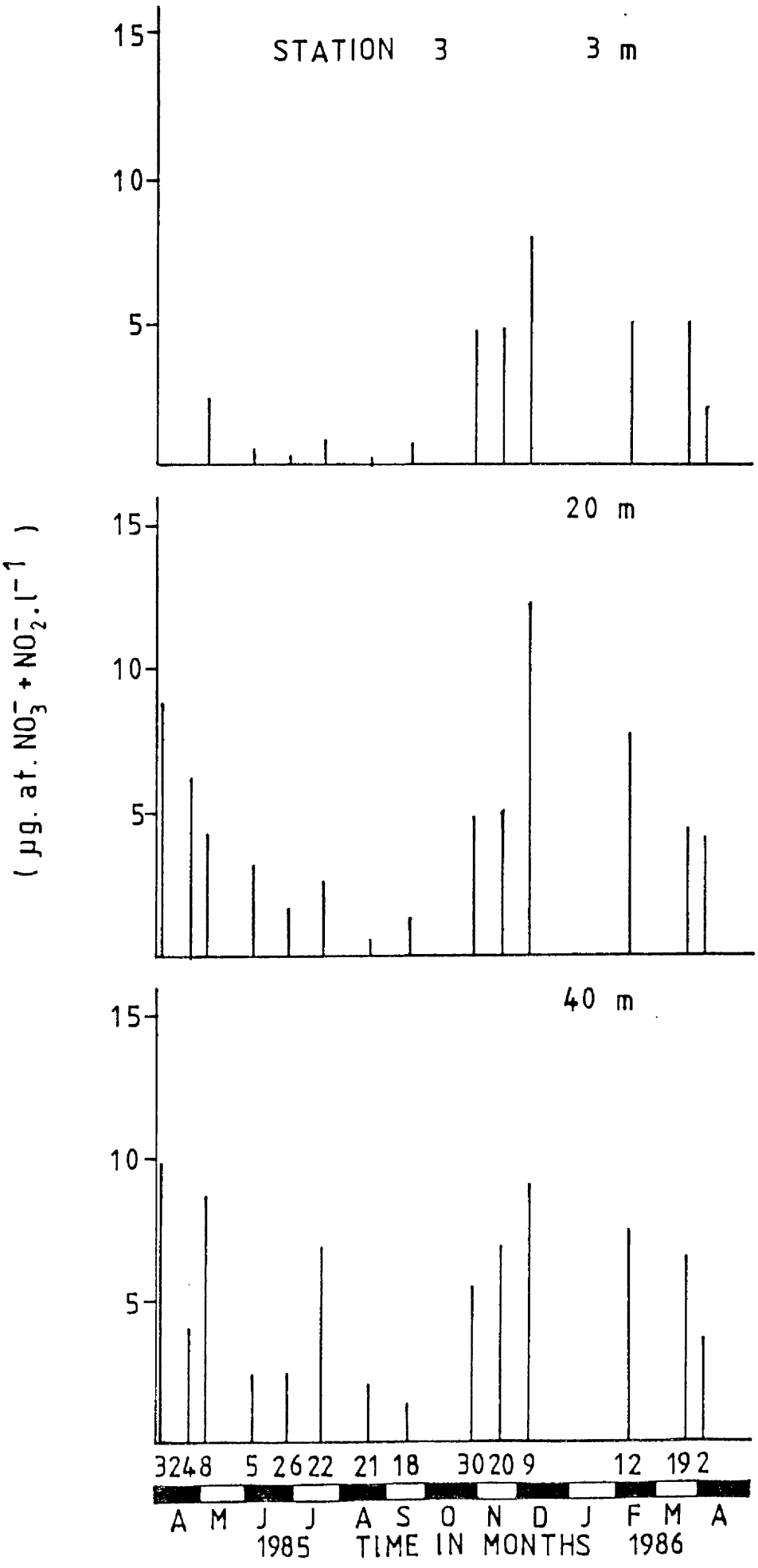

STATION 3
3 m
20 m
40 m
15
10
5
(µg. at. $NO_3^- + NO_2^-.l^{-1}$)
3 2 4 8 5 2 6 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985 TIME IN MONTHS 1986

Fig. 4. 8. Seasonal changes in the values of the combined nitrate and nitrite (μg. at. N l^{-1}) in the 3 m, 20 m and 40 m samples from station 6 during April 1985 to April 1986.

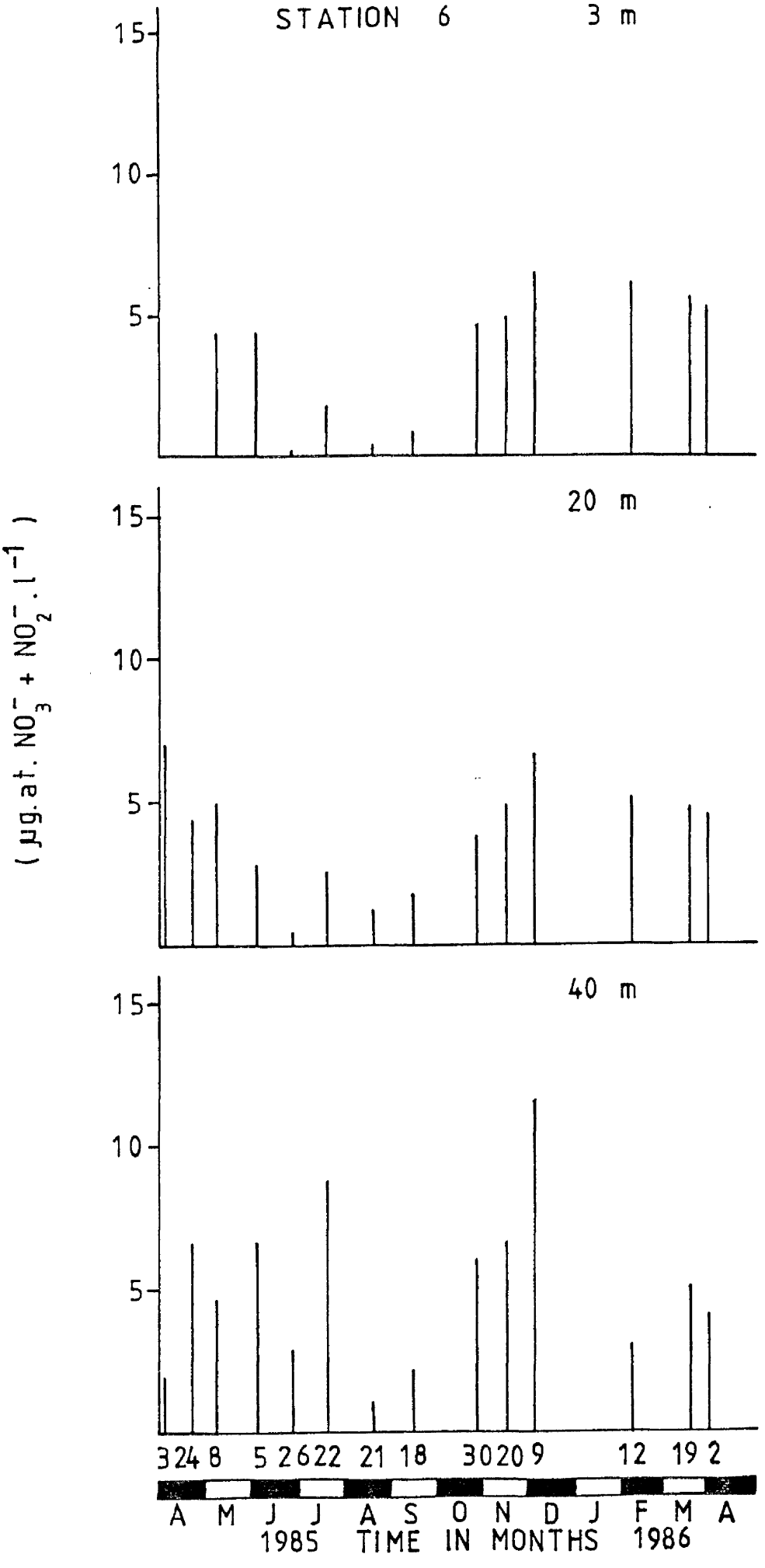

STATION 6
3 m
20 m
40 m
15
10
5
(µg.at. NO_3^- + NO_2^- . l^{-1})
3 2 4 8 5 2 6 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985 TIME IN MONTHS 1986

Fig. 4. 9. Seasonal changes in the phosphate P. (μg at $P.l^{-1}$) levels for 20 m and 40 m samples from station 3 during April 1984 to March 1985.

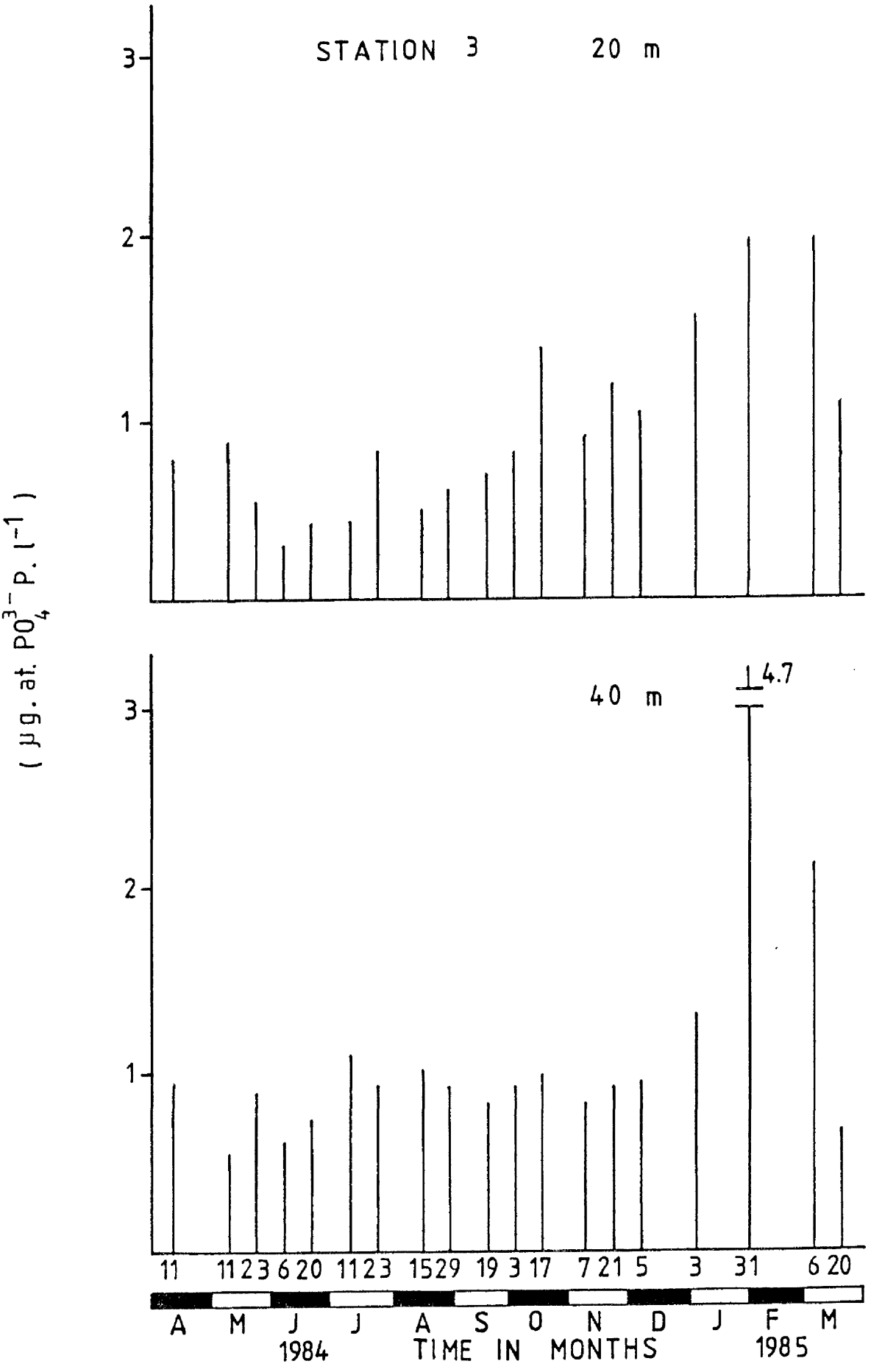

STATION 3
20 m
40 m
4.7
3
2
1
(µg. at. PO_4^{3-} P. l^{-1})
11 11 2 3 6 20 11 2 3 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984
TIME IN MONTHS
1985

Fig. 4. 10. Seasonal changes in the phosphate P. (μg at $P.l^{-1}$) levels for 20 m and 40 m samples from station 6 during April 1984 to March 1985.

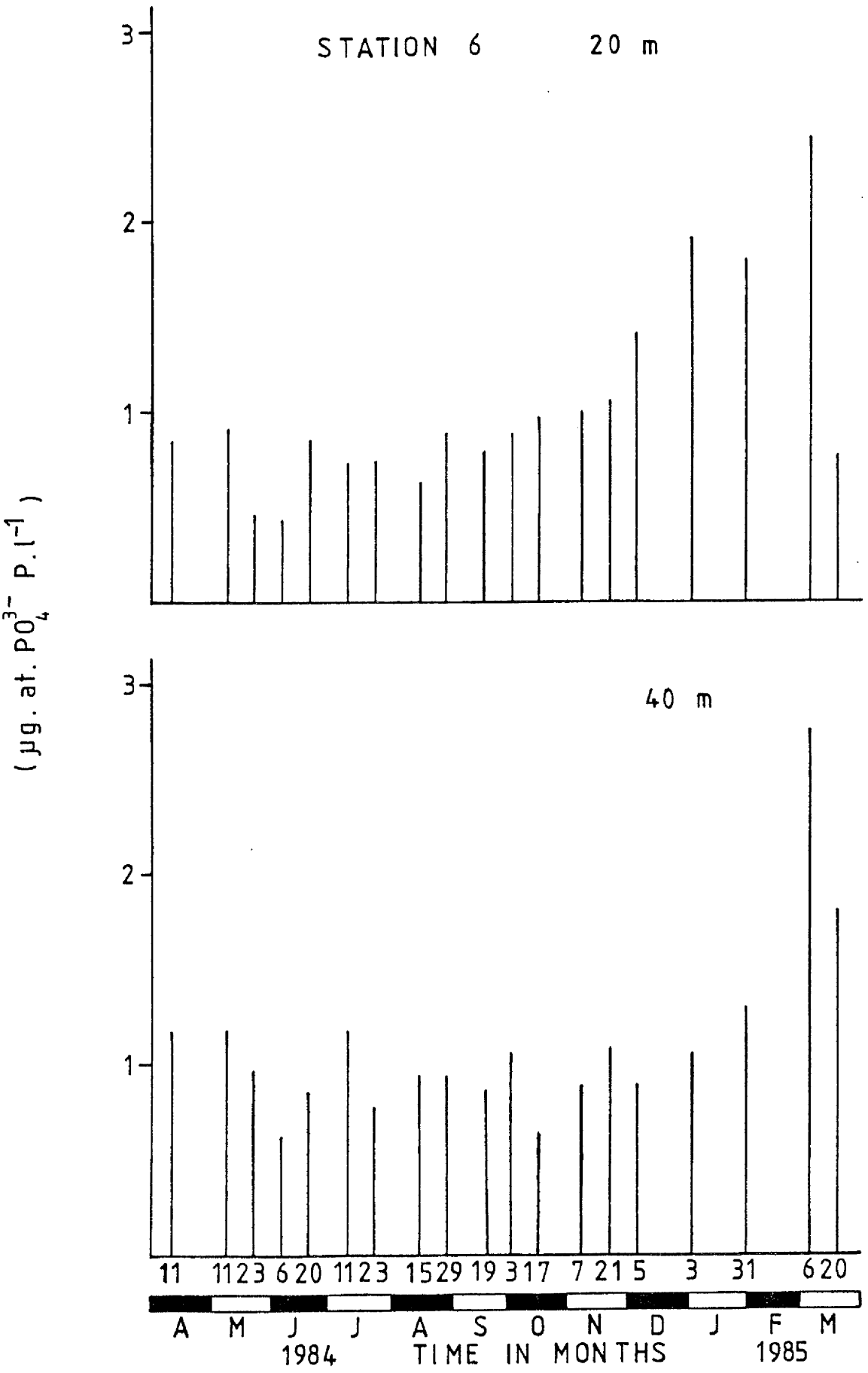

STATION 6
20 m
40 m
3
2
1
(µg. at. PO_4^{3-} P. l^{-1})
11 11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20
A M J J A S O N D J F M
1984
TIME IN MONTHS
1985

Fig. 4. 11. Seasonal changes in the phosphate P. (μg at $P.l^{-1}$) levels for the 3 m, 20 m and 40 m samples fromstation 3 during April 1985 to April 1986.

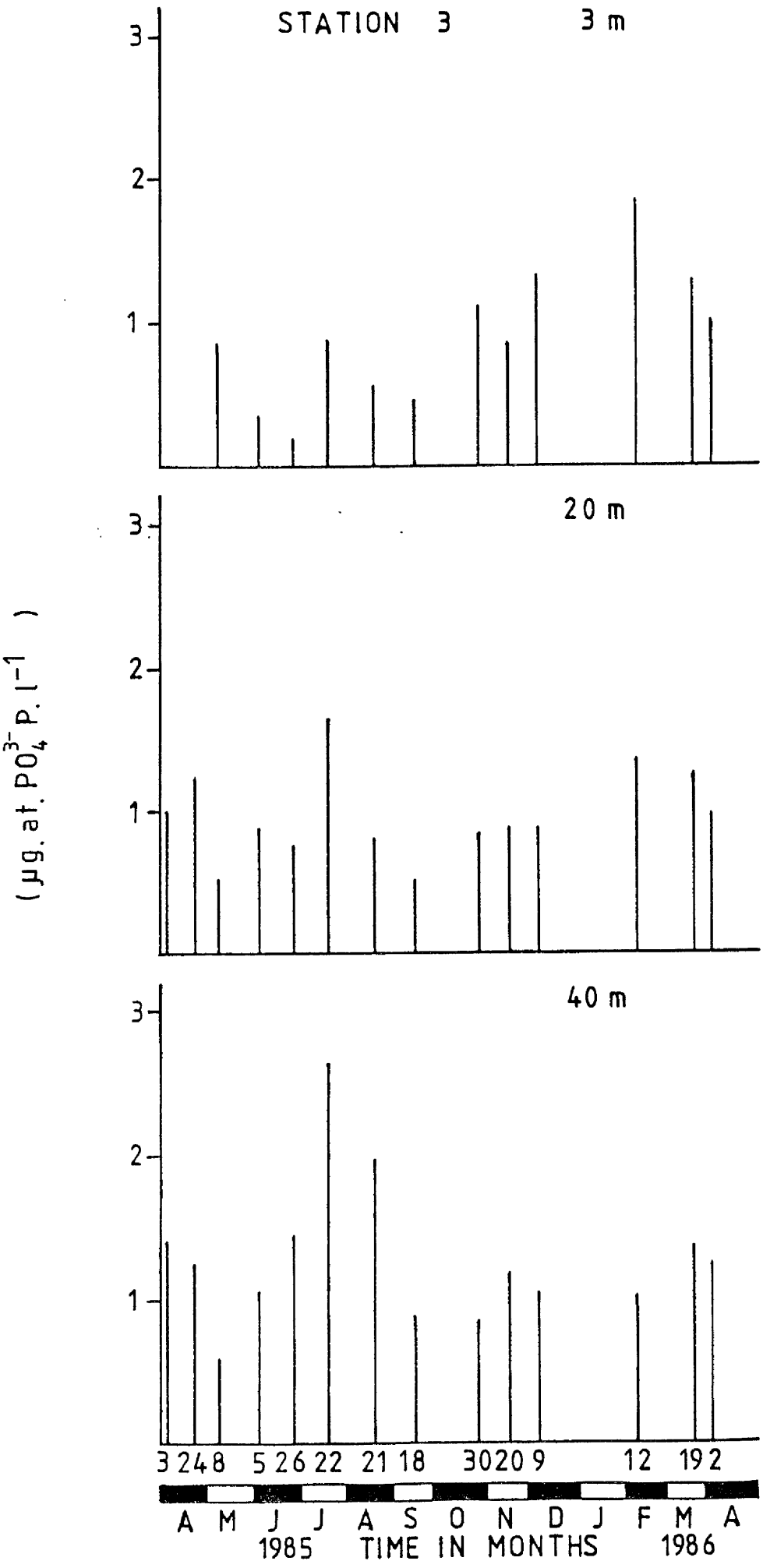
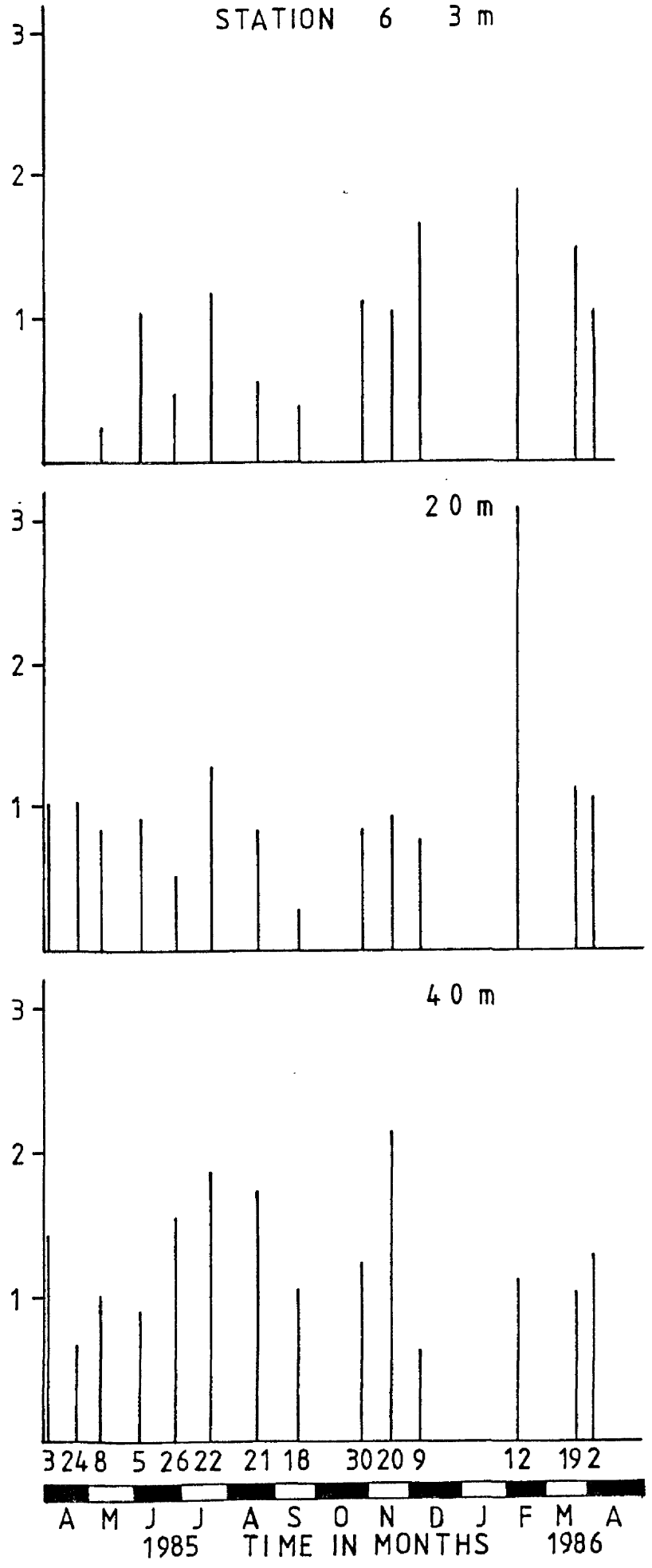

STATION 3
3 m
20 m
40 m
3
2
1
(µg. at. PO_4^{3-} P. l^{-1})
3 24 8 5 26 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985 TIME IN MONTHS 1986

Fig. 4. 12. Seasonal changes in the phosphate P. (μg at $P.l^{-1}$) levels for 3 m, 20 m and 40 m samples from station 6 during April 1985 to April 1986.


STATION 6 3 m
20 m
40 m
(µg. at. PO_4^{3-} P. l^{-1})
3
2
1
3 2 4 8 5 26 22 21 18 30 20 9 12 19 2
A M J J A S O N D J F M A
1985 TIME IN MONTHS 1986

5.1. THE STANDING CROP OF SUSPENDED ALGAE : CHLOROPHYLL *a* AND PHAEOPIGMENTS

Measurements of chlorophyll *a* content of natural waters is a useful guide to the suspended phytoplankton biomass. The accompanying measurements of phaeopigment levels are necessary to establish the active component of the chlorophyll assay.

In 1984-5 the chlorophyll and phaeopigment levels were examined in order to establish whether measurable quantities of each were obtainable with depth samples through the seasons. Data are summarised in Figs. 5.1 and 5.2.

The results show that measurable quantities of chlorophyll *a* were found at the two stations at 20 m and 40 m depths during spring, summer and autumn, whilst in the winter months the quantities were very low, often approaching analytical zero. Chlorophyll *a* quantities at 20m depth were variable and generally higher than at 40 m. The ranges for 20 m at both station (3 and 6) were in order from analytical zero to 9.1 and 10.2 mg chlorophyll *a* m^{-3}, whilst for 40m depth the ranges at station 3 and 6 were from analytical zero to 3.0 and 2.8 mg chlorophyll *a* m^{-3} respectively. Phaeopigment levels tended to be high at both depths in spring, low in summer and autumn, and, whilst of low values, often higher in the winter months than the chlorophyll levels.

The high levels of chlorophyll *a* during March 1985 at 20 m depth coincided with a measurement at 3 m of 13.3 mg m^{-3}, probably indicating the period of the spring outburst. Phaeopigment levels were also high. The chlorophyll (and phaeopigment) levels at 40 m depth were of a lower value at both stations. Hence, measurable quantities of chlorophyll *a* were obtainable in 1984-5 from the deep water except during the winter months.

Fig. 5. 1. Chlorophyll *a* and phaeopigments mesurements for the 20 m and 40 m samples from station 3 during May 1984 to April 1985.

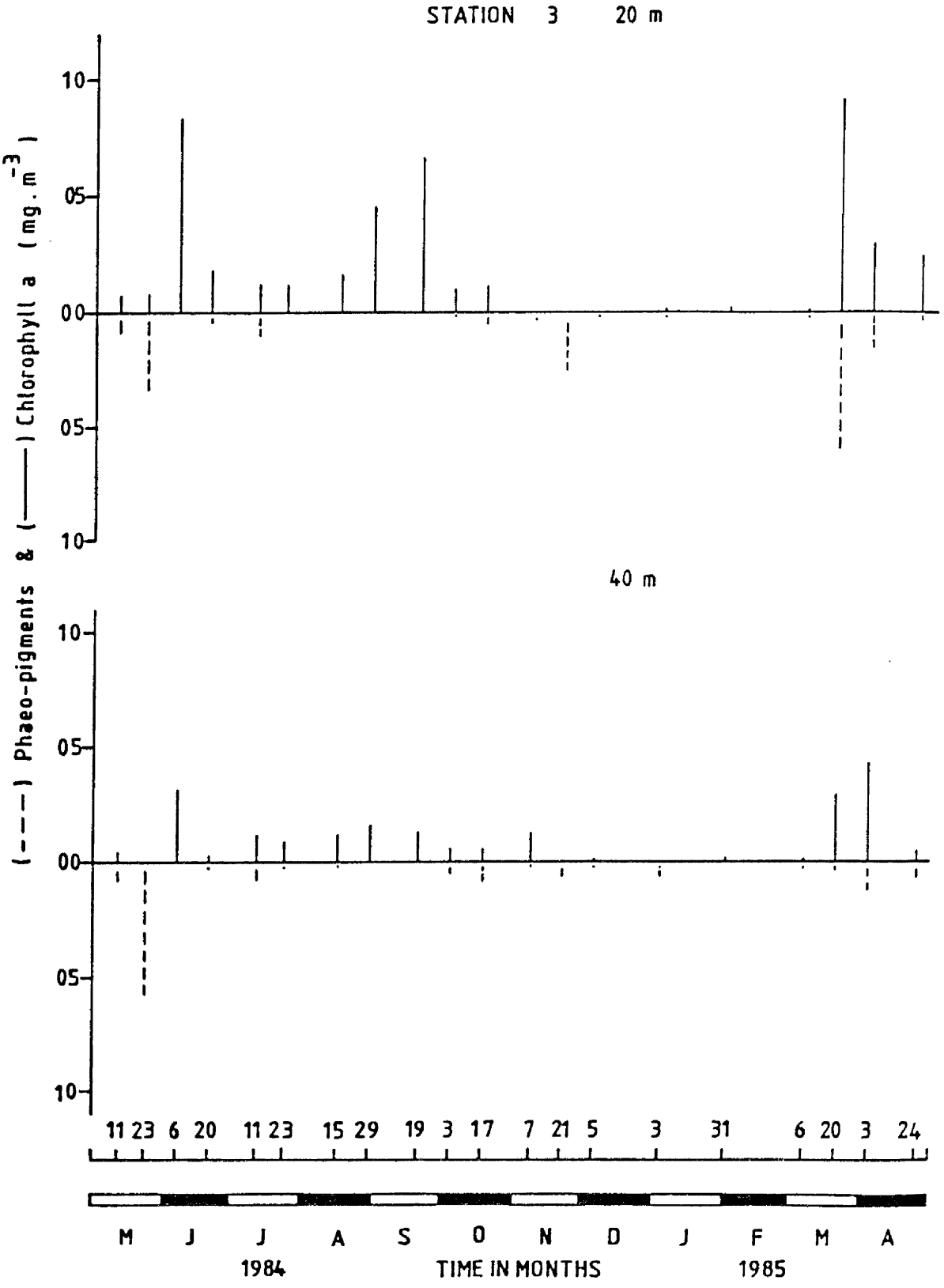
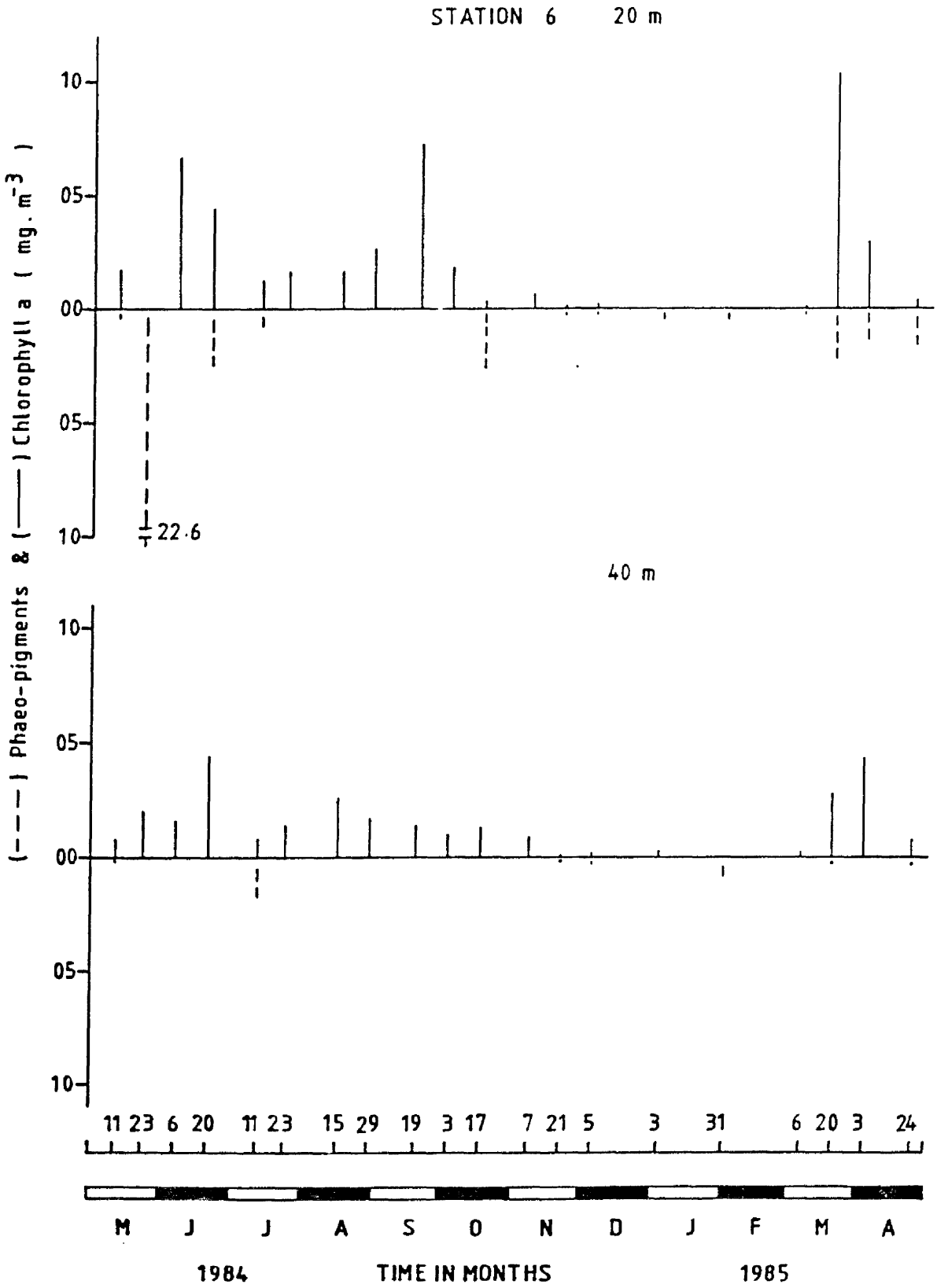

STATION 3 20 m
10
05
00
05
10
40 m
10
05
00
05
10
(---) Phaeo-pigments & (——) Chlorophyll a (mg.m^{-3})
11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20 3 24
M J J A S O N D J F M A
1984
TIME IN MONTHS
1985

Fig. 5. 2. Chlorophyll *a* and phaeopigments measurements in the 20 m and 40 m samples at station 6 during May 1984 to April 1985.


STATION 6 20 m
10
05
00
05
10
22·6
40 m
10
05
00
05
10
(——) Chlorophyll a (mg.m^{-3})
(– – –) Phaeo-pigments &
11 23 6 20 11 23 15 29 19 3 17 7 21 5 3 31 6 20 3 24
M J J A S O N D J F M A
1984
TIME IN MONTHS
1985

A comparative study of chlorophyll *a* and phaeophigment levels in the photic and aphotic zones was therefore carried out from May 1985 to April 1987 (Figs 5.3 to 5.6)

During May (Table 5.1) chlorophyll *a* measurements were obtained on 8 May at 3 m, 20 m and 40 m higher than phaeopigment levels with decline of both pigment amounts with the depth at both stations except with 3 m sample from station 6 where analytical zero for the degradation product was found.

On 22nd May the phaeopigment measurement was close to the chlorophyll *a* at station 3 for the 3 m sample. These values were greater than at 20 m, and 40 m , where the phaeopigments at 20 m were quantitatively equal to that in the 40 m sample, whilst the chlorophyll *a* level was lower than the phaeopigment value at 40 m. At this time the available chlorophyll contents at station 6 were high at the depths of 3 m and 20 m, whilst at 40 m the phaeopigment levels were higher than the chlorophyll amount and higher than the phaeopigment content in the 20 m sample.

Fig. 5. 3. Measurements of chlorophyll *a* and phaeopigment in the 3 m, 20 m and 40 m samples at station 3 during May 1985 to April 1986.

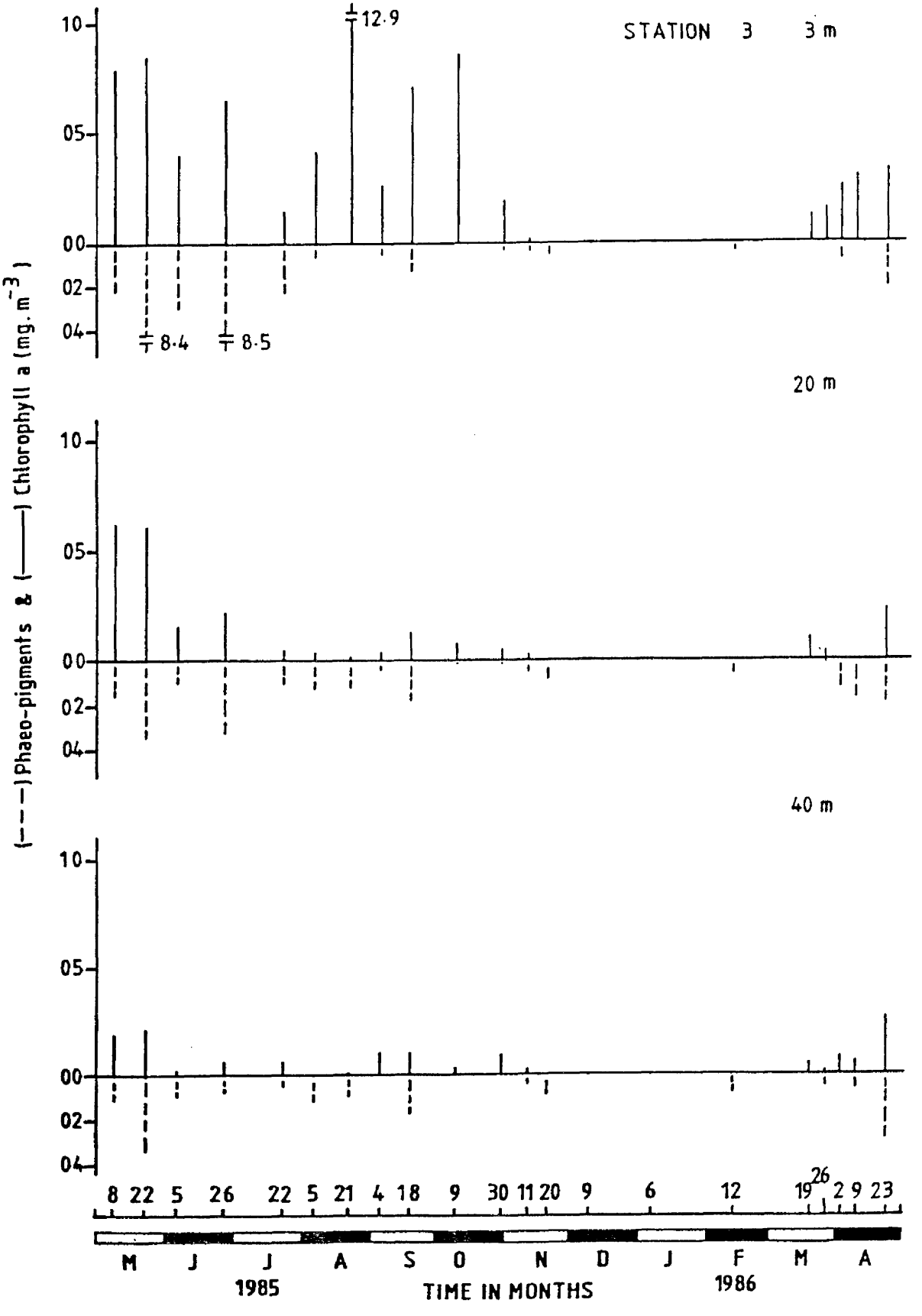

STATION 3 3 m
20 m
40 m
12·9
8·4
8·5
10
05
00
02
04
(- - -) Phaeo-pigments & (——) Chlorophyll a (mg.m⁻³)
8 22 5 26 22 5 21 4 18 9 30 11 20 9 6 12 19 26 2 9 23
M J J A S O N D J F M A
1985
1986
TIME IN MONTHS

Fig. 5. 4. Measurements of chlorophyll *a* and phaeopigments in the 3 m, 20 m, 40 m samples at station 6 during May 1985 to April 1986.

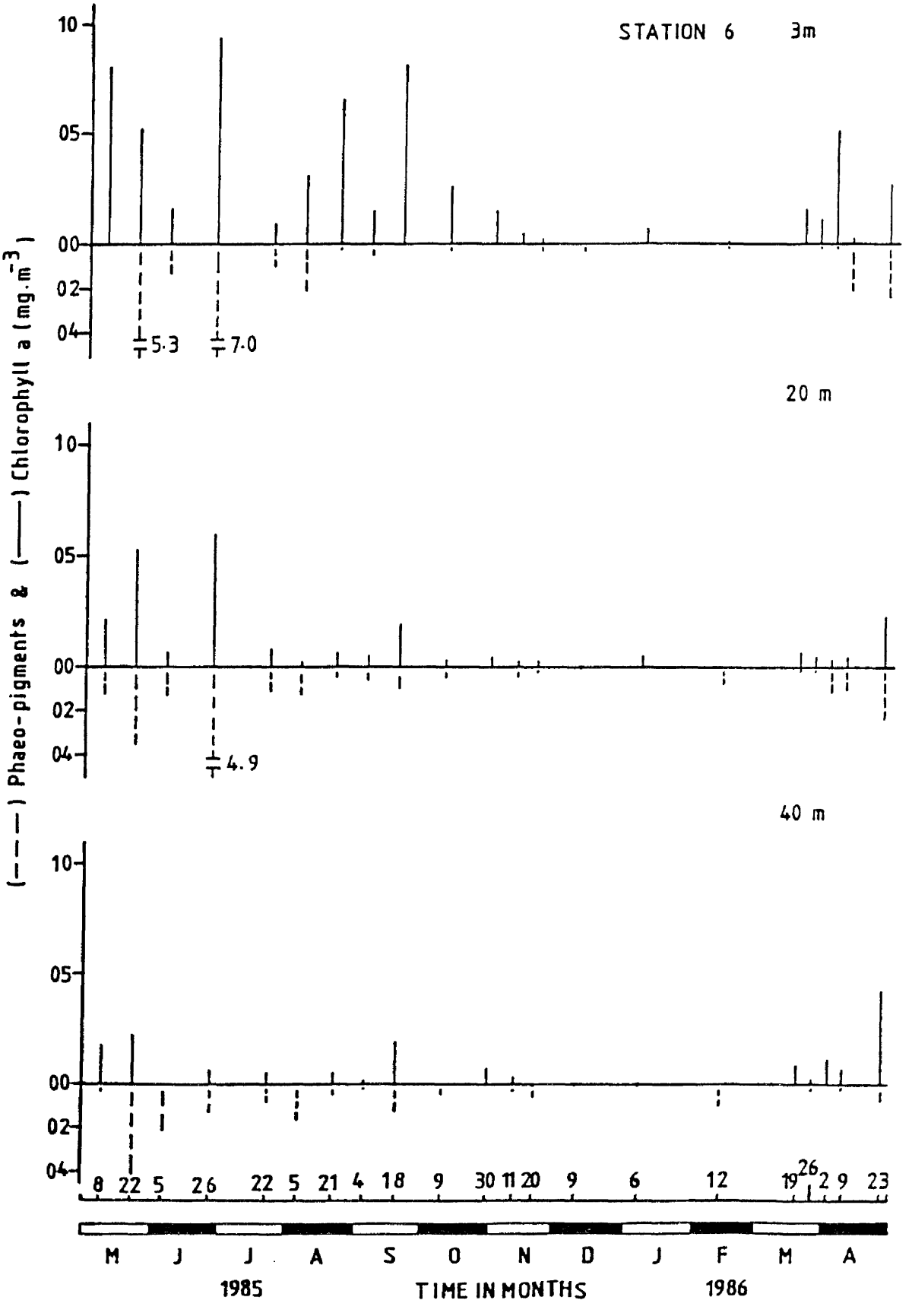

STATION 6 3m
20 m
40 m
10
05
00
02
04
±5.3
±7.0
±4.9
(——) Chlorophyll a (mg.m⁻³)
(— — —) Phaeo-pigments &
8 22 5 26 22 5 21 4 18 9 30 11 20 9 6 12 19 26 2 9 23
M J J A S O N D J F M A
1985
TIME IN MONTHS
1986

Fig. 5. 5. Measurements of chlorophyll *a* and phaeopigments in the 3 m, 20 m and 40 m samples at station 3 during May 1986 to March 1987.

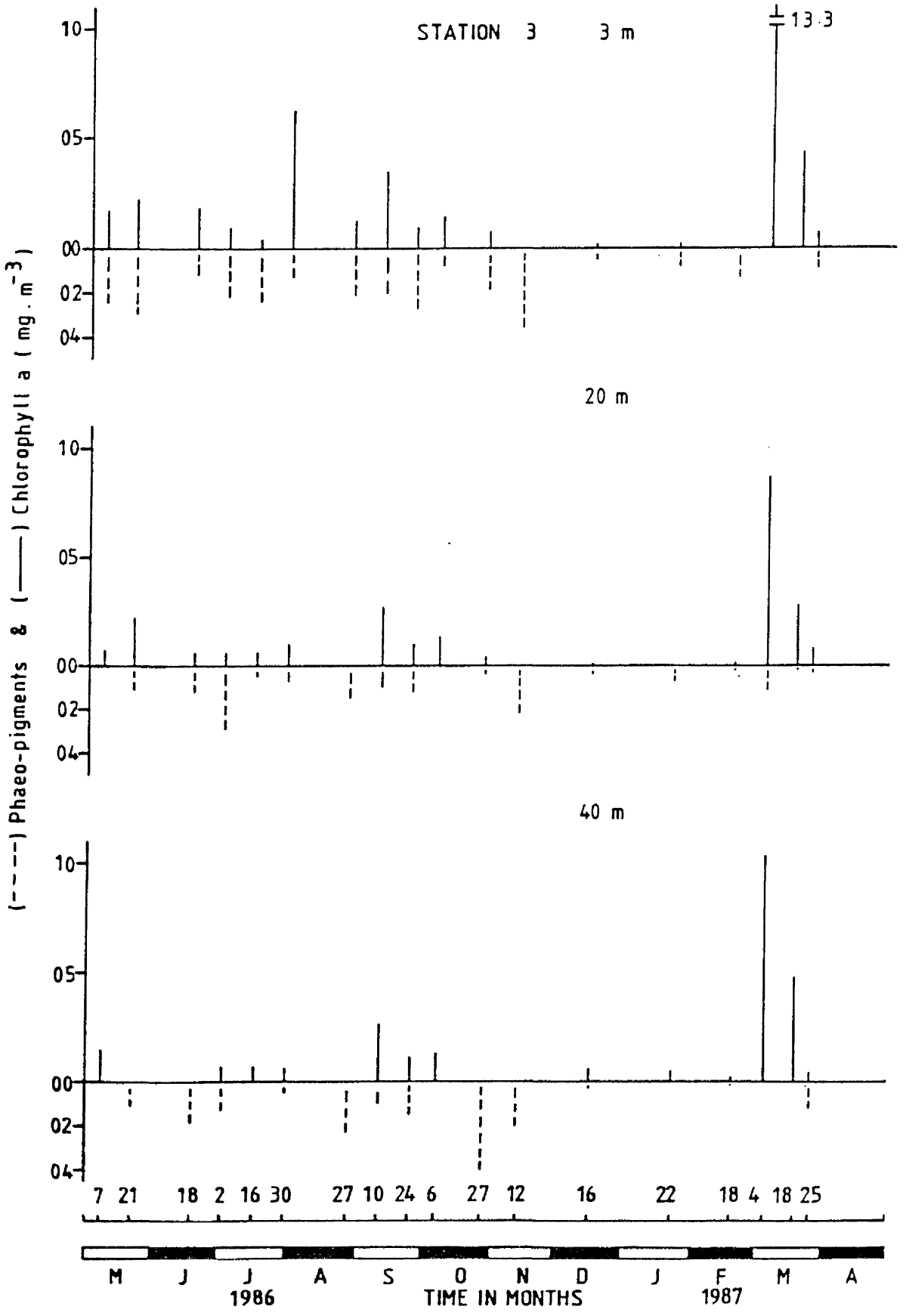

STATION 3 3 m
13·3
20 m
40 m
10
05
00
02
04
(- - - -) Phaeo-pigments & (——) Chlorophyll a (mg . m⁻³)
7 21 18 2 16 30 27 10 24 6 27 12 16 22 18 4 18 25
M J J A S O N D J F M A
1986
TIME IN MONTHS
1987

Fig. 5. 6. Measurements of chlorophyll *a* and phaeopigments in the 3 m, 20 m and 40 m samples at station 6 during May 1986 to March 1987.

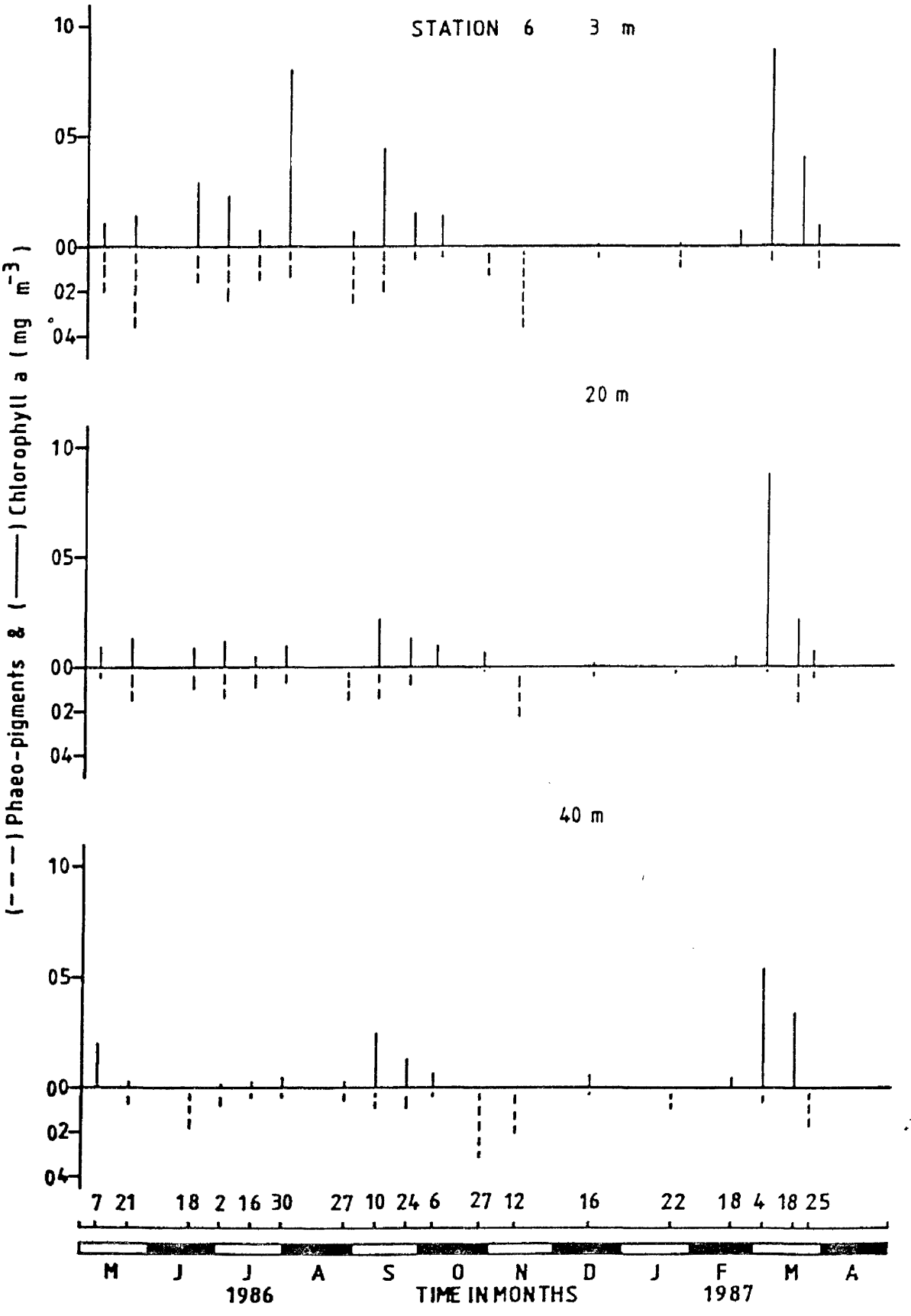

STATION 6 3 m
20 m
40 m
10
05
00
02
04
(- - - -) Phaeo-pigments & (——) Chlorophyll a (mg m^{-3})
7 21 18 2 16 30 27 10 24 6 27 12 16 22 18 4 18 25
M J J A S O N D J F M A
1986
TIME IN MONTHS
1987

Table 5.1

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for May 1985

0a = analytical zero

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
8.5.	3 m	7.9	2.2	8.0	0 a
	20 m	6.2	1.5	2.1	1.2
	40 m	2.0	1.0	1.8	0.3
22.5.	3 m	8.3	8.4	5.7	5.3
	20 m	6.1	3.4	5.3	3.5
	40 m	2.1	3.4	2.2	4.1

Sharp decreases of the pigments at all depths at the two stations were observed in summer (Table 5. 2) starting on 5 June with more chlorophyll at 3m and reductions with depth. The samples at 40 m contained more of the inactive pigment on most occasions with very low chlorophyll *a* measurements, ranging between 0.7 mg m^{-3} and analytical zero over summer months. The quantities of chlorophyll *a* and phaeopigments increased suddenly at 3 m and 20 m for stations 3 and 6 on 26 June with maxima of 9.3 mg m^{-3} for chlorophyll *a* at 3 m sample at station 6 and 8.5 mg m^{-3} for phaeopigments at 3 m at station 3 which higher than chlorophyll *a* level. Low levels of chlorophyll *a* and the degradation pigment were observed on July 22nd at all depths at the two stations with higher phaeopigment levels than chlorophyll *a* amounts at all depths except for 40 m sample from station 3 . High levels of chlorophyll *a* were measured at 3 m at both stations on 5 August. The values decreased at 20 m depth and were depleted at 40 m, whilst the phaeopigment quantities increased in the depth samples. On 21 August the amounts of chlorophyll *a* found at 3 m were high with much lower values in deeper water associated with increases in phaeopigments at all depths, being higher or equal to chlorophyll *a*.

Autumnal chlorophyll *a* and phaeopigmment measurements are shown in Table 5.3 starting from 4 September when chlorophyll *a* measurements were still high at 3 m (although lower than that in August) compared with phaeopigment concentrations, then with variable levels of chlorophyll *a* against its breakdown products during the rest of the autumn samples. Autumnal increases in chlorophyll *a* and phaeopigment quantities were observed at all depths at both stations on September 18, with the exception of the phaeopigment level in the 3 m sample from station 6. Lower levels of chlorophyll *a* in depth samples at station 3 were associated with high levels of phaeopigment, whilst the chlorophyll *a* amounts at 20 m and 40 m depths from station 6 were higher. Another, greater peak occurred at 3 m at station 3 and was also high in the 3 m sample from station 6 accompanied by very low phaeopigment levels in 3 m samples from the two stations on 9 October.

Table 5. 2

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for summer 1985

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
5.6.	3 m	4.0	3.0	1.6	1.3
	20 m	1.6	0.9	0.6	1.3
	40 m	0.2	0.9	0 a	2.1
26.6.	3 m	6.5	8.5	9.3	7.0
	20 m	2.2	3.2	6.0	4.9
	40 m	0.7	0.7	0.6	1.3
22.7.	3 m	1.4	2.3	0.9	1.1
	20 m	0.5	1.0	0.8	1.1
	40 m	0.7	0.4	0.5	0.8
5.8.	3 m	4.1	0.7	3.1	2.1
	20 m	0.4	1.2	0.2	1.3
	40 m	0 a	1.2	0 a	1.6
21.8.	3 m	12.9	0 a	6.5	0.1
	20 m	0.1	1.2	0.5	0.5
	40 m	0.1	0.9	0.5	0.5

Table 5.3

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for autumn 1985

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
4.9.	3 m	2.6	0.6	1.5	0.5
	20 m	0.4	0.4	0.5	0.1
	40 m	1.1	0 a	0.1	0.6
18.9.	3 m	7.0	1.3	8.1	0 a
	20 m	1.3	1.8	1.9	1.0
	40 m	1.1	1.7	1.9	1.2
9.10.	3 m	8.5	0 a	2.6	0.3
	20 m	0.8	0.1	0.3	0.5
	40 m	0.4	0 a	0 a	0.5
30.10.	3 m	1.8	0.4	1.5	0 a
	20 m	0.5	0.1	0.4	0 a
	40 m	1.0	0 a	1.2	0 a
11.11.	3 m	0.2	0.4	0.5	0 a
	20 m	0.3	0.5	0.3	0.5
	40 m	0.2	0.3	0.2	0.2
20.11.	3 m	0 a	0.6	0.2	0.3
	20 m	0 a	0.8	0.3	0.1
	40 m	0 a	0.8	0 a	0.6

The levels of chlorophyll *a* and phaeopigment fell sharply in the other depth samples at station 3 and 6 on 9 October. Low levels of the chlorophyll *a* and of phaeopigment were observed at all depths on 30 October with generally higher values for chlorophyll *a* at all depths in the two stations except for the 20 m sample at station 6. Noticeably the phaeopigment levels were at analytical zero at station 6. On 11 November all measurements were again low, with higher phaeopigment levels at most depths. measurements of phaeopigment obtained on 20 November were still higher than chlorophyll *a* amounts, at all depths except the 20 m sample from station 6.

The chlorophyll *a* and phaeopigment measurements for winter 1985-6 are tabulated in Table 5.4. During the winter months at the two stations there were no measurable quantities of either chlorophyll *a* or phaeopigment except on some occasions as on 9 December at 3 m at station 6 for phaeopigment (0.3 mg m^{-3}) and on 6 January 1986 for chlorophyll *a* at 3 m and 20 m (0.7 and 0.5 mg m^{-3}), whilst on 12 February phaeopigment appeared suddenly at all depths at station 3 and 6 with the maximum at 40 m samples and minimum at 3 m depths. A very low chlorophyll *a* measurement of 0.1 mg m^{-3} was obtained at 3 m at station 6.

Table 5. 4

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for winter 1985-1986

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
9.12.	3 m	0 a	0 a	0 a	0.3
	20 m	0 a	0 a	0 a	0 a
	40 m	0 a	0 a	0 a	0 a
6.1.	3 m	0 a	0 a	0.7	0 a
	20 m	0 a	0 a	0.5	0 a
	40 m	0 a	0 a	0 a	0 a
12.2.	3 m	0 a	0.5	0.1	0.2
	20 m	0 a	0.6	0 a	0.8
	40 m	0 a	0.7	0 a	1.0

The spring increases of 1986 are displayed in Table 5. 5, showing the gradual increases of chlorophyll *a* at 3 m at station 3 through March and April, being higher at 3 m than at greater depths. On almost all occasions the chlorophyll *a* levels were lower in the 40 m samples except with the value obtained on 23 April of 4.2 mg m^{-3} at 40 m at station 6. Chlorophyll *a* concentrations rose from 19 March with absence of phaeopigment content at this time except for a small amount (0.1 mg m^{-3}) measured at 20 m for station 6. Very low values of phaeopigment were obtained on 26 March in 3 m samples for stations 3 and 6, whilst at 20 m and 40 m there were low values of chlorophyll *a*, lower than the phaeopigment levels at both depths. The chlorophyll quantities increased at 3 m and 40 m on 2nd April with a maximum of 5.1 mg m^{-3} at 3 m at station 6, with a value of analytical zero or very low amount for the two 20 m samples. The phaeopigment content recorded was highest at 20 m, whilst at 40 m it was not measurable. On 9 April no measurable phaeopigment occurred at 3 m at station 3 with a high value of chlorophyll *a* , whilst at station 6 the chlorophyll *a* level at 3 m was very low . Levels of chlorophyll *a* and phaeopigment at 20 m and 40 m were similar in pattern to that found in the 2 April measurements, with higher values for phaeopigment at 20 m and for chlorophyll *a* at 40 m. Increases of chlorophyll *a* and phaeopigment quantities were obtained at all depths at station 3 and 6 on 23 April. At this time the amounts of chlorophyll *a* were higher than phaeopigment at station 3 from 3 m and 20 m samples and were also higher at depths of 3 m and 40 m from station 6. The highest values were recorded at 3 m for chlorophyll *a* (3.2mg m^{-3}) and at 40 m for phaeopigment (2.8 mg m^{-3}) at station 3, and at 40 m for chlorophyll *a* (4.2 mg m^{-3}) and at 3 m and 20 m for phaeopigment (2.4 mg m^{-3}) at station 6. The quantities of chlorophyll *a* and phaeopigment were of similar order at corresponding depths in the two stations on 7 May , with no detectable measurements of phaeopigment at 20 m and 40 m for station 3 and at 40 m for station 6. On 21 May the chlorophyll *a* levels increased at 3 m and 20 m at both stations, and similar increases in the phaeopigment were measured at all depths. Generally values of phaeopigment were higher than chlorophyll *a* in samples from 3 m and 40 m from both stations and at 20 m depth at station 6.

Table 5.5

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for spring 1986

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
19.3.	3 m	1.1	0 a	1.6	0 a
	20 m	1.0	0 a	0.6	0.1
	40 m	0.6	0 a	0.8	0 a
26.3.	3 m	1.4	0 a	1.1	0.1
	20 m	0.4	0.1	0.4	0.1
	40 m	0.2	0.4	0.2	0.3
2.4.	3 m	2.4	0.9	5.1	0.1
	20 m	0 a	1.2	0.3	1.2
	40 m	0.9	0 a	1.1	0 a
9.4.	3 m	2.9	0 a	0.2	2.1
	20 m	0 a	1.7	0.4	1.1
	40 m	0.7	0.5	0.6	0.3
23.4.	3 m	3.2	2.1	2.7	2.4
	20 m	2.3	1.9	2.2	2.4
	40 m	2.7	2.8	4.2	0.8
7.5.	3 m	1.7	2.4	1.1	2.0
	20 m	0.7	0 a	0.9	0.5
	40 m	1.5	0 a	2.0	0 a
21.5.	3 m	2.2	2.9	1.4	3.6
	20 m	2.2	1.1	1.3	1.5
	40 m	0 a	1.1	0.3	0.7

The measurements obtained in summer 1986 are tabulated in Table 5. 6. Generally quantities of chlorophyll *a* decreased gradually starting from 18 June till 16 July associated with steadily increasing phaeopigment concentrations.This was followed by increases in chlorophyll *a* levels at all depths at the two stations and in phaeopigment at 20 m and 40 m at station 3 on 30 July , whilst phaeophigment values showed a continuing reduction at station 6. The chlorophyll *a* values at 3 m were usually higher than at greater depths throughout the summer period except at station 3 on 16 July. Most of the time the phaeopigment levels exceeded chlorophyll *a* values at all depths except for 3 m sample at the two stations on 18 June and at all depths at station 3 and 6 on 30 July 1986. The chlorophyll *a* levels were in general low and lower in the depth samples, reaching analytical zero on 27 August, while the measurements at 3 m never reached analytical zero.

Table 5.7 show the 1986 autumnal measurements of chlorophyll a and phaeophigment. The Table shows an autumnal peak of chlorophyll *a* which was observed on 10 September at all depths at the two stations. The chlorophyll *a* levels were higher than phaeopigment measurements, which decreased with depth. On 24 September a fall in the chlorophyll *a* measurements was observed at all depths. These measurements increased with depth at station 3, and were lower than the phaeopigment levels. The chlorophyll *a* and phaeopigment levels decreased with depth with lower phaeopigment values at all depths at station 6. Chlorophyll *a* showed slight increases in levels at station 3, but decreases at station 6 on 6 October, and the levels also decreased with the depth, coinciding with very low phaeopigment levels. On 27 October phaeopigment showed increases in values at all depths with the highest (3.1 mg m^{-3}) at 40 m at station 6, exceeding the chlorophyll *a* values, except station 6, 20 m which fell sharply reaching analytical zero at 40 m and 3 m at stations 3 and 6 respectively. This active pigment was not measurable at any depth on 12 November at station 6 (samples from station 3 were not available), whilst phaeopigment was detected at 3 m, 20 m and 40 m at station 6 with the highest at 3 m and lowest at 40 m.

Table 5.6

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for summer 1986

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
18.6.	3 m	1.8	1.2	2.9	1.6
	20 m	0.6	1.2	0.9	1.0
	40 m	0 a	1.8	0 a	1.8
2.7.	3 m	0.9	2.2	2.3	2.4
	20 m	0.6	2.9	1.2	1.4
	40 m	0.7	1.3	0.2	0.8
16.7.	3 m	0.4	2.4	0.8	1.5
	20 m	0.6	0.5	0.5	0.9
	40 m	0.7	0 a	0.3	0.4
30.7.	3 m	6.2	1.3	7.9	1.3
	20 m	1.0	0.7	1.0	0.7
	40 m	0.6	0.5	0.5	0.4
27.8.	3 m	1.2	2.1	0.7	2.5
	20 m	0 a	1.5	0 a	1.5
	40 m	0 a	2.3	0.3	0.6

Table 5.7

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for autumn 1986

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
10.9.	3 m	3.4	2.1	4.3	2.0
	20 m	2.7	1.0	2.2	1.4
	40 m	2.6	1.0	2.5	0.9
24.9.	3 m	0.9	2.7	1.5	0.6
	20 m	1.0	1.2	1.3	0.8
	40 m	1.1	1.5	1.3	0.9
6.10.	3 m	1.4	0.8	1.4	0.5
	20 m	1.3	0 a	1.0	0 a
	40 m	1.3	0 a	0.7	0.4
27.10.	3 m	0.7	1.9	0 a	1.8
	20 m	0.4	0.4	0.7	0.1
	40 m	0 a	0.4	0.4	3.1
12.11.	3 m	-	-	0 a	3.7
	20 m	-	-	0 a	2.0
	40 m	-	-	0 a	2.0

Very low winter measurements in 1986-7 (Table 5.8) of chlorophyll *a* and its breakdown products were obtained in December 1986 (samples from station 6 with the 20 m sample from station 3 could not be collected through failure of the sampler), January and February 1987. Some of these quantities were close to the limits of accurate measurements , and indicate the poor condition of the phytoplankton at this time. The phaeopigment levels were higher than the chlorophyll *a* at 3 m and 20 m at the two stations during this period, being highest at 3 m. Chlorophyll *a* levels exceeded phaeopigment values in 40 m sample on 16 December , on 22 January at station 3 only and on 18 February at both stations, and were higher than at the other depths (3 m and 20 m). The phaeopigment concentrations were low at station 6 on 18 February 1987, whilst measurable quantities of chlorophyll *a* were found, the highest being reached at 3 m although the chlorophyll *a* at 3 m at station 3 was absent with barely detectable measurements at 20 m and 40 m.

The values of chlorophyll *a* and phaeopigment during March 1987, are summarized in Table 5.9, showing that a spring outburst of phytoplankton in 1987 was early observed at all depths. On 4 March there were marked increases in chlorophyll *a* levels reaching maxima of 13.3 mg m^{-3}, 8.7 mg m^{-3} and 10.3 mg m^{-3} at 40 m, these values being associated with low quantities of phaeopigmment at all depths, being analytical zero at 3 m and 40 m from station 3, and a similar pattern at station 6 with a decrease of chlorophyll *a* with depth and high levels of phaeopigment at 3 m and 40 m. The chlorophyll *a* levels were reduced at all depths from both stations on 18 March with the lower levels from the 20 m samples at the two stations. Undetectable concentrations of phaeopigment were observed at 3 m and 40 m samples from station 3 and 6. On 25 March the chlorophyll *a* values had further decreased at both stations giving the lowest value at 40 m depth, whilst the phaeopigment increased at all depths except at 20 m depth for station 6. The highest amounts were obtained in the 40 m samples.

Table 5.8

Chlorophyll *a* and phaeopigmment (mg m^{-3}) measurements for winter 1986-7

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
6.12.	3 m	0.2	0.6	-	-
	20 m	-	-	-	-
	40 m	0.6	0.3	-	-
22.1.	3 m	0.2	0.8	0.1	0.9
	20 m	0 a	0.7	0 a	0.3
	40 m	0.5	0 a	0 a	0.9
18.2.	3 m	0 a	1.3	0.7	0 a
	20 m	0.1	0.2	0.5	0 a
	40 m	0.2	0.1	0.5	0 a

Table 5.9

Chlorophyll *a* and phaeopigment (mg m^{-3}) measurements for March 1987

		station 3		station 6	
Date	Depth	Chl.*a*	phaeopigment	chl.*a*	phaeopigment
4.3.	3 m	13.3	0 a	8.8	0.7
	20 m	8.7	1.1	8.4	0.2
	40 m	10.3	0 a	5.4	0.6
18.3.	3 m	4.3	0 a	4.0	0 a
	20 m	2.8	0.1	2.1	1.6
	40 m	4.7	0 a	3.4	0 a
25.3.	3 m	0.7	0.9	0.9	1.0
	20 m	0.8	0.3	0.7	0.5
	40 m	0.4	1.2	0 a	1.7

5.2 QUALITATIVE STUDY OF PHOTOSYNTHETIC PIGMENTS USING THIN - LAYER CHROMATOGRAPHY

The study of natural mixed algal populations and their definitive pigments distribution and concentration in the particulate matter should include the chlorophyll degradation products which may at times constitute a significant fraction of the the total green pigments in sea water below in the aphotic zone, or in samples from areas where there has been heavy grazing by zooplankton. These degraded forms of inactive chlorophyll (such as phaeophytin and phaeophorbide) absorb light strongly at the wavelengths of maximum absorption of chlorophylls, causing an interference with the specrophotometeric determination of chlorophylls (Strickland and Parsons, 1972). Thin layer chromatography offers a means of obtaining indications of both the algal types and biological processes in the water column (Jeffrey, 1980).

Pigment analysis for this purpose started from the begining of summer 1984 for 20 m and 40 m samples from stations 3 and 6, with the addition of 3 m samples from the two stations from 8 May 1985 until the end of March 1987 for station 3 and until the end of April 1987 for station 6.

Photosynthetic pigments and the degradation products of parent chlorophylls were chromatographed with 50% redistilled ethyl acetate in light petroleum (60 -80 ^{o}C) on silica gel thin-layer plates in one dimension chromatography. One dimension chromatograms are less time consuming and any oxidation of the pigments caused by the drying chromatograms between the development in two dimentions is avoided.

The initial identification of pigments was based on comparison of chromatograms with those described in research reports of other workers, with the characteristic colours of definitive pigments and their locations being noted as described in Jeffery (1974).

The major pigments obtained from phytoplankton samples from the two stations are tabulated in Table 5.10.

Table 5.10

number	definitive pigments	colours	type of organisms or biological process
1	phaeophytin *a*	grey	feeding activity of zooplankton
2	carotene	orange	all algae
3	chlorophyll *a*	blue green	all algae
4	fucoxanthin	orange	diatoms
5	neofucoxanthin	orange	diatoms
6	chlorophyllide *a*	blue green	chlorophyllase activity in senescent diatoms (or it can be filtration artifact)
7	chlorophyll *b*	olive green	green algae
8	phaeophorbide *a*	grey	feeding activity of zooplankton
9	chlorophyll *c*	light green	diatoms and dinoflagellates

R_f values were not applied because of their variability. Variation in R_f values can be caused by differences in the amount of pigment extract spotted onto chromatograms, variations in the thickness of the adsorbent, and will also be affected by the presence of water in the ether and/ or the running solvent (Gowen, 1981).

Summer 1984 (Fig. 5.7)

The pigment extracts developed on the chromatograms for 20 m and 40 m samples for stations 3 and 6 gave phaeophytin *a*, carotene and chlorophyll *c* at both depths at the two stations, although the location of chlorophyll *c* at 20 m at station 3 was very close to the original spot. Phaeophorbide *a* was noted on the chromatograms of the 20 m and 40 m samples at station 6. Chlorophyll *a* was not detected, except for 20 m from station 3.

Autumn 1984 (Fig. 5.8)

The presence of phaeophytin *a* in 20 m samples at the two stations and at 40 m at station 3 was observed with carotene at both depths at stations 3 and 6. Pigments probably from diatoms and dinoflagellates (chlorophylls *a* and *c*) were found in 20 m and 40 m samples respectively.

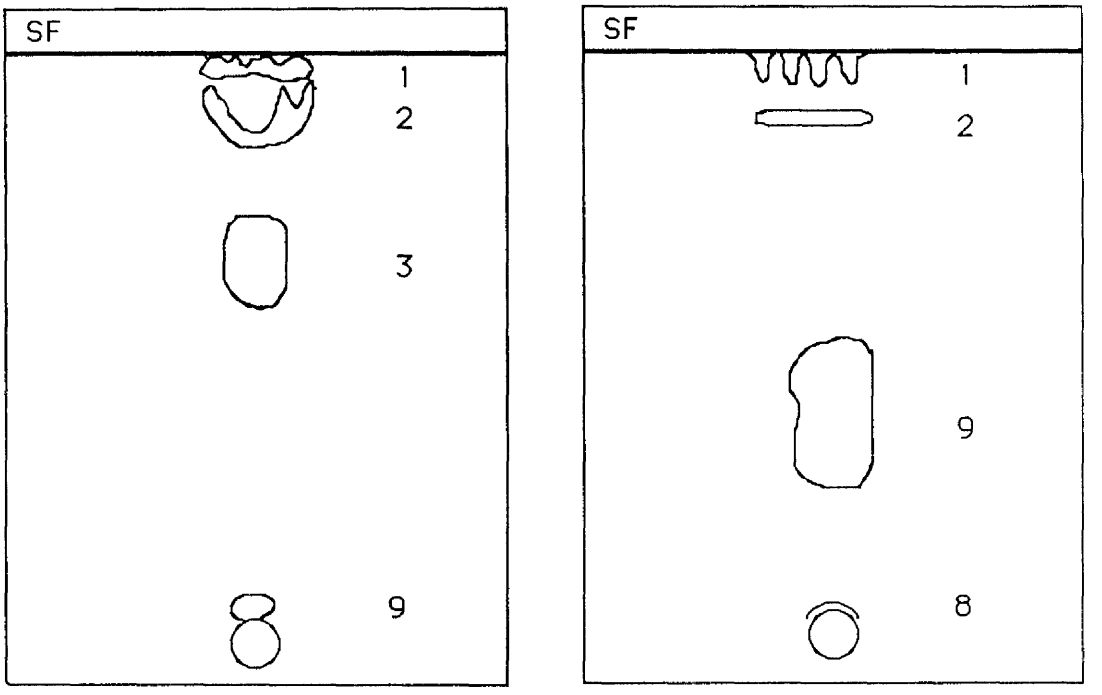
Winter 1984-5 (Fig. 5.9)

Carotene pigment was only detected in the winter samples for 20 m and 40 m from station 3 only with phaeophytin *a*, in addition to phaeophorbide *a* at 40 m.

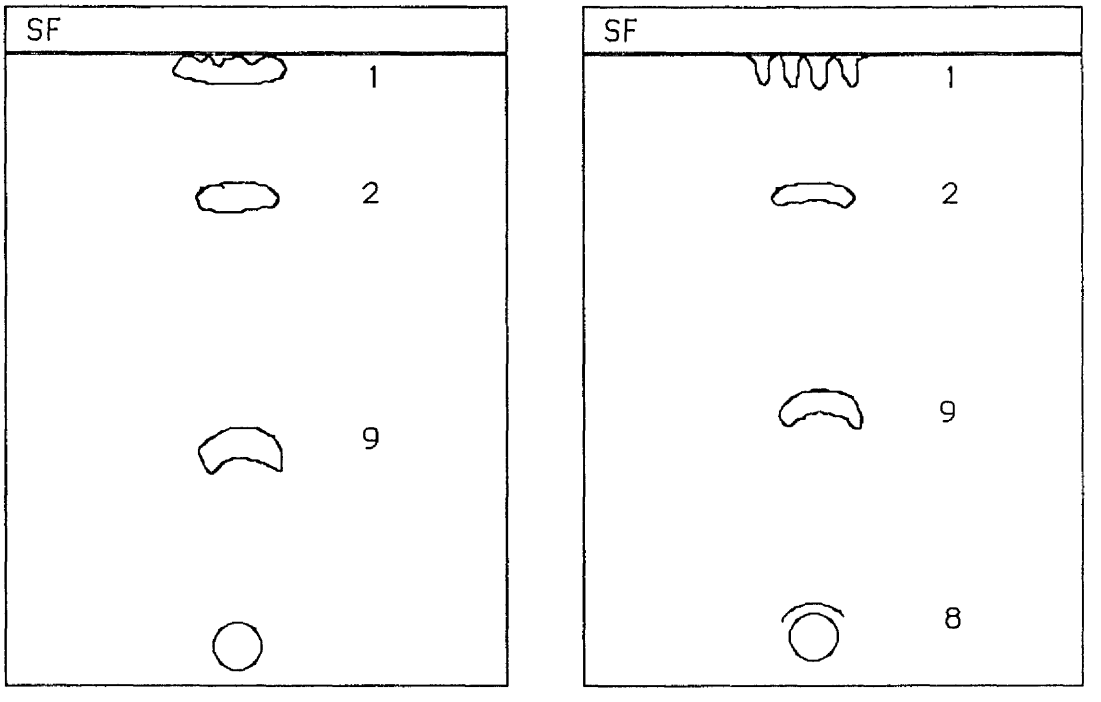
Spring 1985 (Fig. 5.10)

Chlorophylls *a* and *c*, fucoxanthin and carotene (diatom pigments) were obtained in depth samples for both stations and in the 3 m sample for station 6. The chlorophyll breakdown products phaeophytin *a* and phaeophorbide *a* occurred at all depths for the two stations, whilst chlorophyllide *a* was detected at 3 m at station 6. Chlorophyll *b* the definitive pigment for green algae, was found at all depths except for 3 m samples at

Fig. 5.7 Chromatograms of samples in Summer 1984.

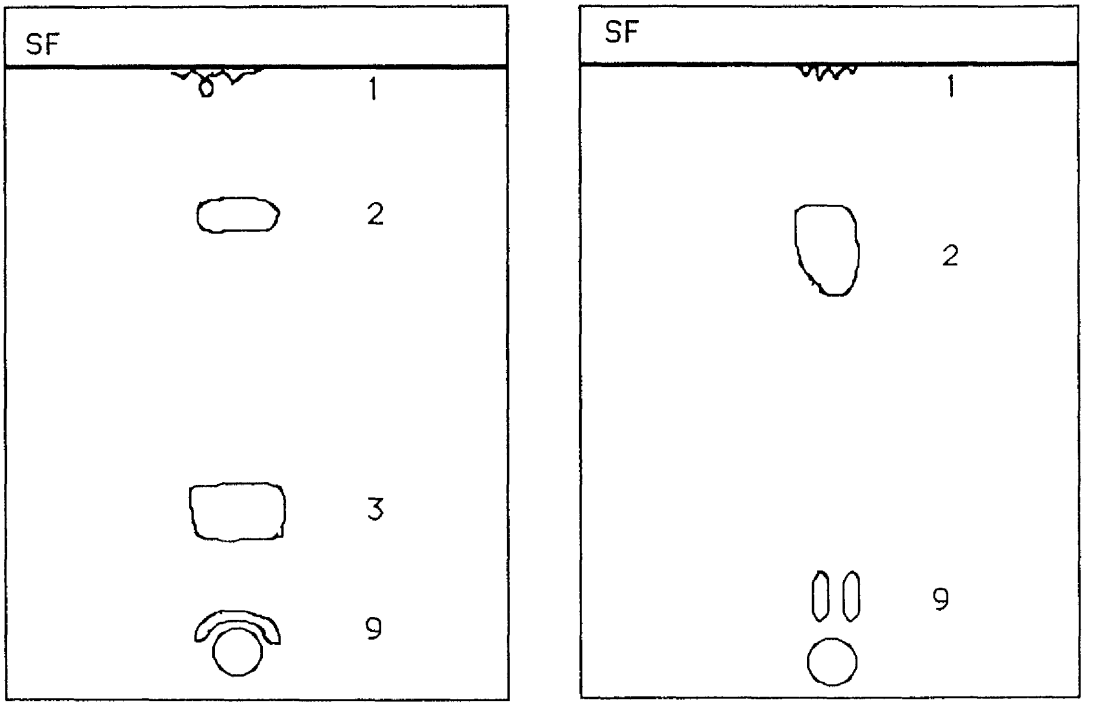


Station 3 20 m 40 m

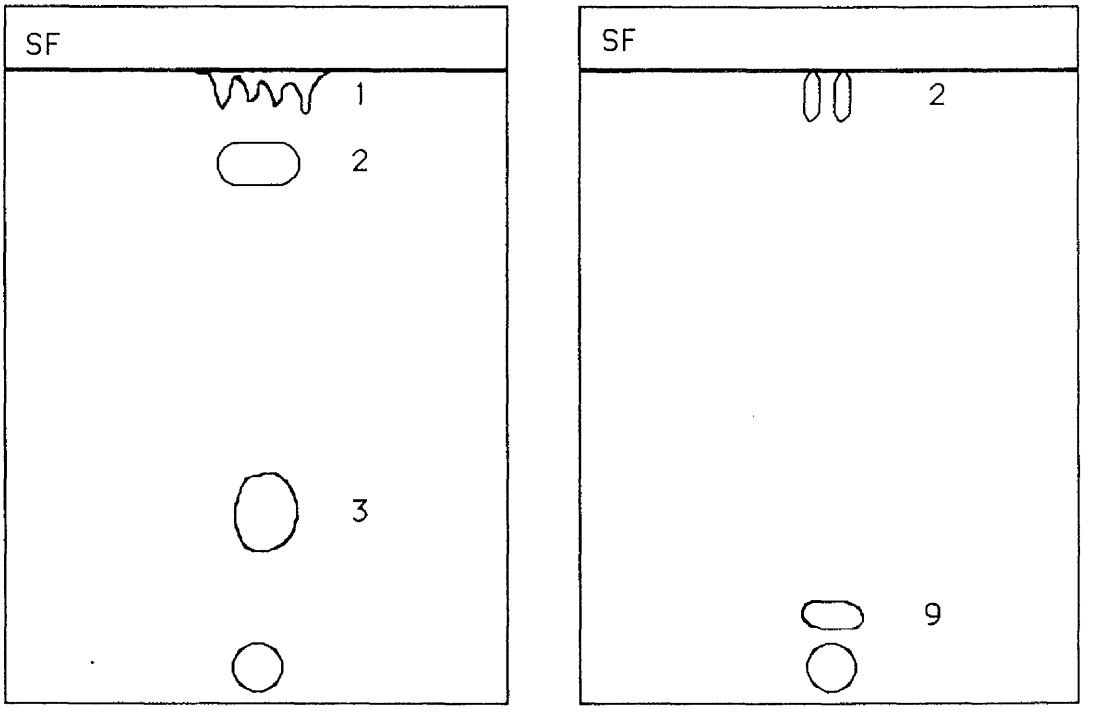


Station 6 20 m 40 m

Fig. 5.8. Chromatograms of samples in Autumn 1984

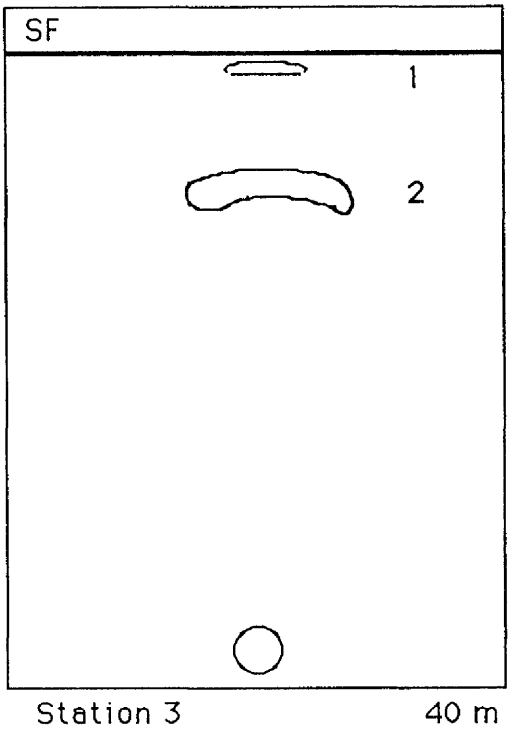


Station 3 20 m 40 m

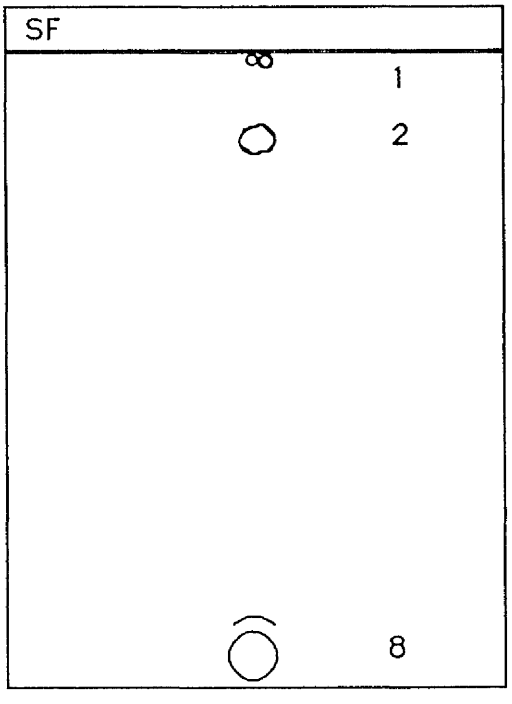


Station 6 20 m 40 m

Fig. 5.9 . Chromatograms of samples in Winter 1984-5

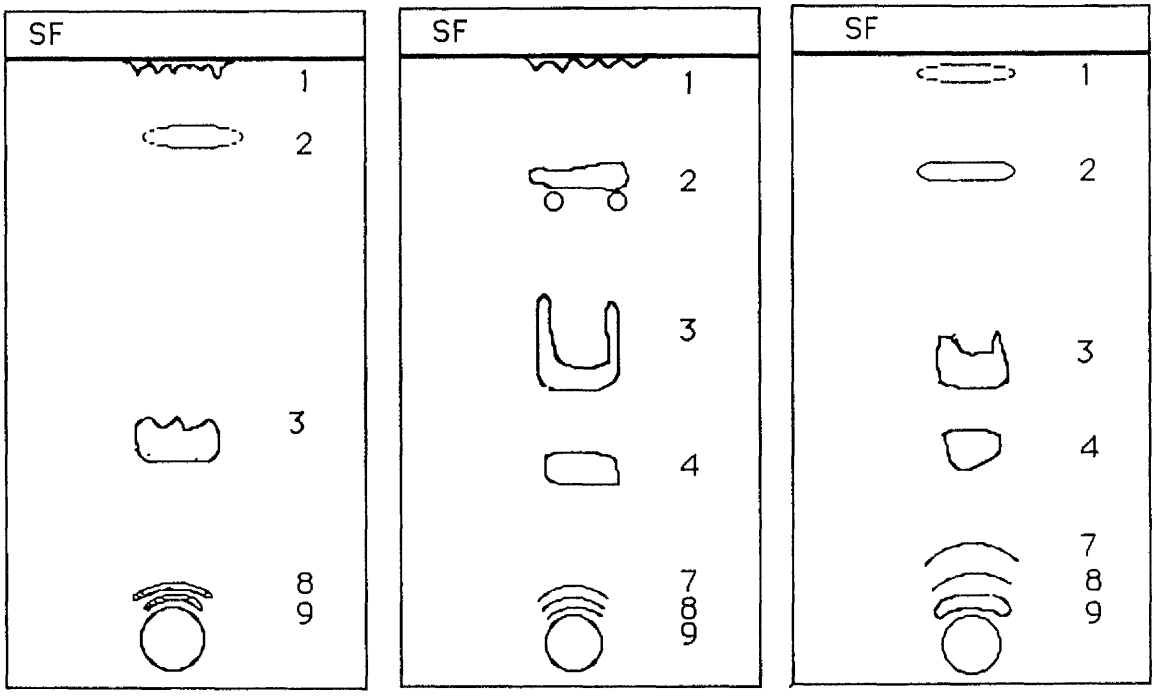


Station 3 40 m

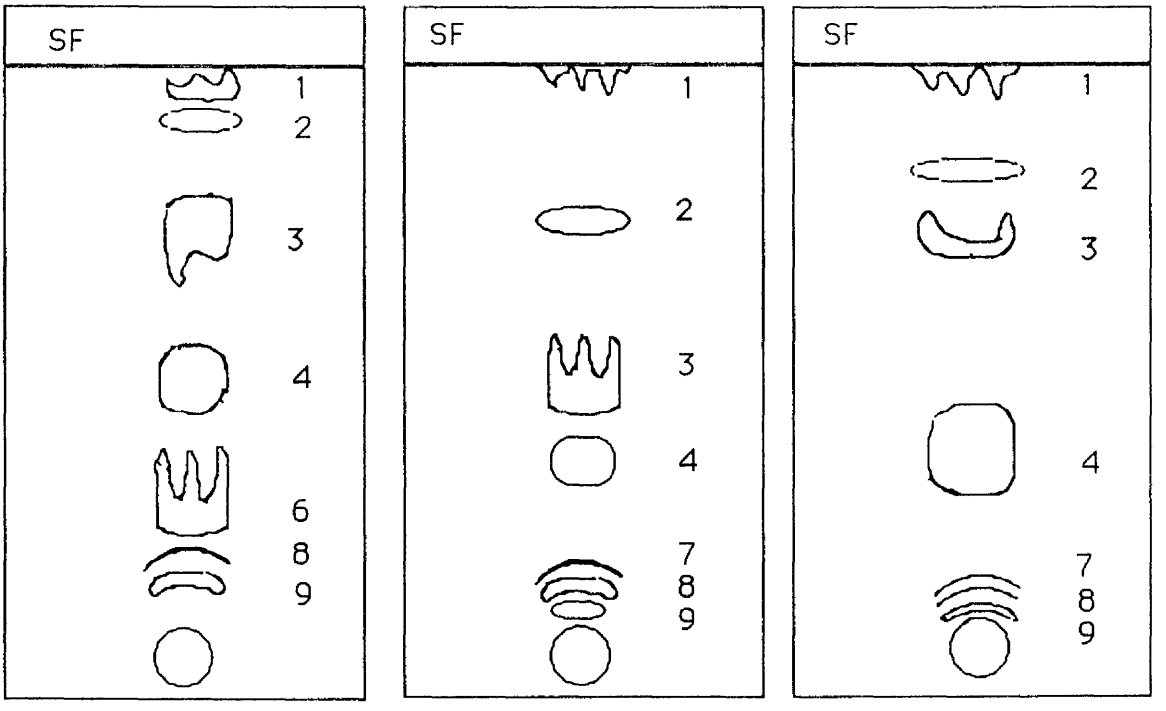


Station 6 40 m

Fig. 5.10 Chromatograms of samples in Spring 1985



Station 3 3 m 20 m 40 m



Station 6 3 m 20 m 40 m

definitive pigment for green algae, was found at all depths except for 3 m samples at both stations.

Summer 1985 (Fig. 5.11)

A similar pattern to that in the spring was observed again in the summer, indicating the presence of diatoms and dinoflagellates. Chlorophyllide *a* was detected at 20 m depth at station 6 instead of its presence in the 3 m sample (spring 1985), whilst the green algal pigment (chlorophyll *b*) was not detected in any of the samples from both stations.

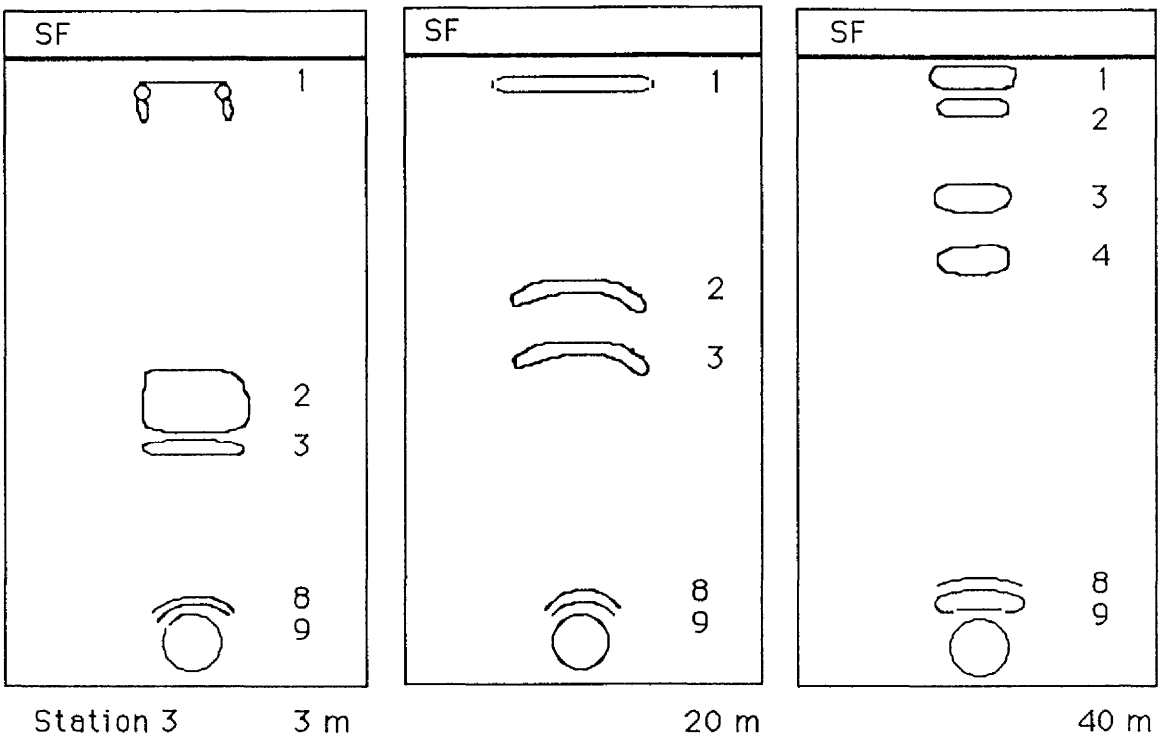
Autumn 1985 (Fig. 5.12)

Carotene and phaeophytin *a* were obtained in all samples for stations 3 and 6, whilst chlorophyll *a* was detected only on the chromatogram for 3 m at station 3 and in all samples for station 6. Phaeophorbide *a* occurred in the depth samples at both stations, in addition to the 3 m sample at station 6. Chlorophyll *c* was observed on the chromatograms for the 20 m depths at stations 3 and 6 and in the 3 m sample from station 6.

Winter 1985-6 (Fig. 5.13)

Pigments were barely detected on the chromatograms during winter except for the 3 m sample from station 6, where carotene and a degradation pigment (phaeophorbide *a*) were noticed in a small zone.

Fig. 5.11 Chromatograms of samples in Summer 1985



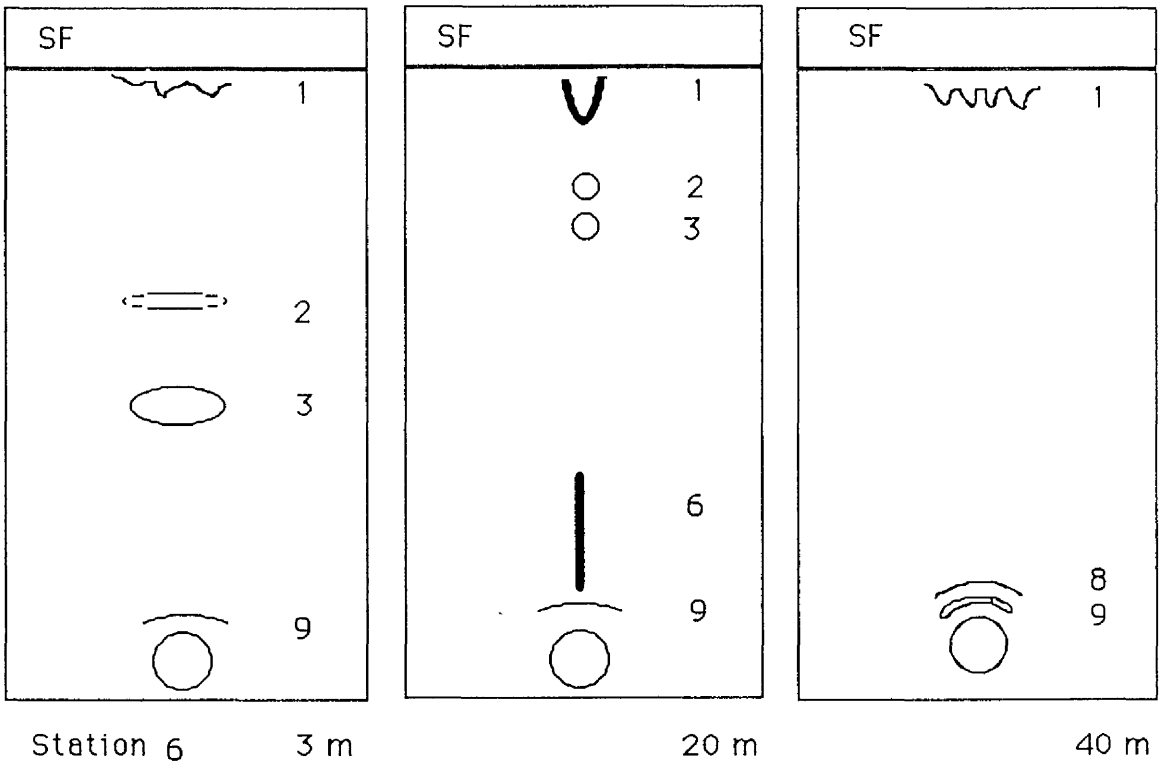
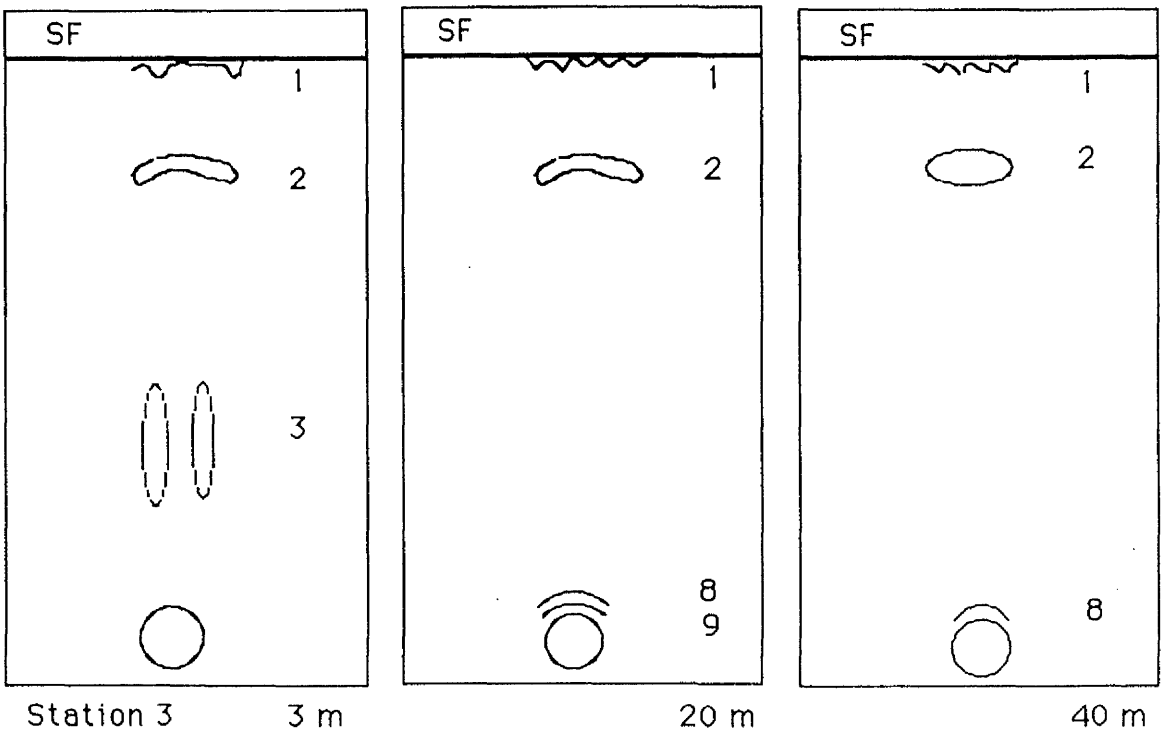


Fig. 5.12 Chromatograms of samples in Autumn 1985



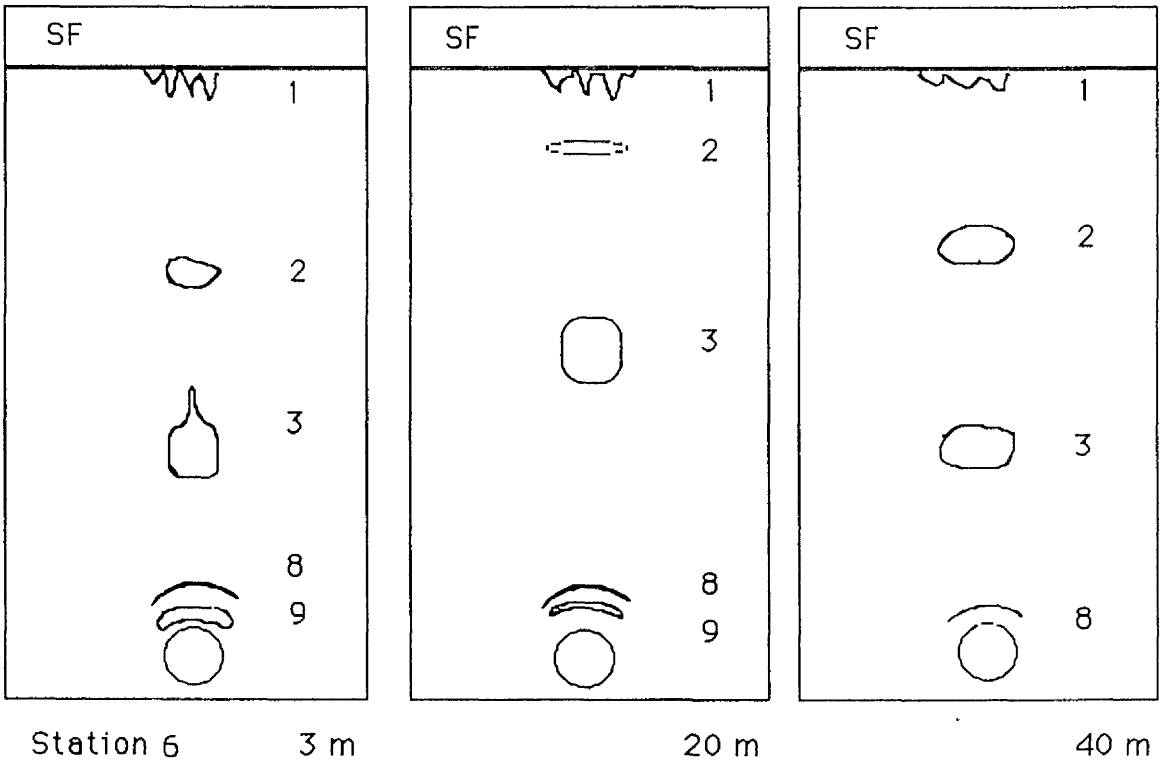
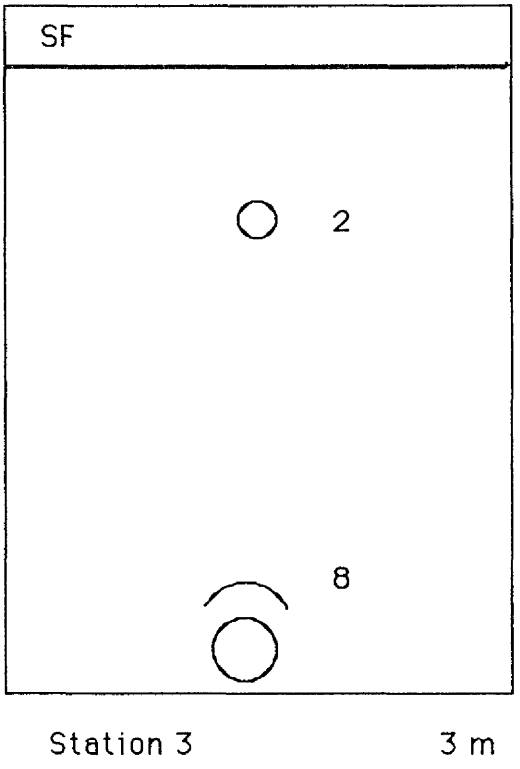


Fig. 5.13 Chromatogram of a sample in Winter 1985-6



Spring 1986 (Fig. 5.14)

Carotenoids were present in all samples from station 3 and in the 3 m and 20 m samples for station 6. No pigments developed on the chromatogram for the 40 m sample of station 6 (this may have been due to the very weak extract obtained or to a manipulative error on the initial spotting). Chlorophyll *a* occurred in surface samples at the two stations and at 20 m at station 3. Phaeophorbide *a* and chlorophyll *c* were in all samples. Fucoxanthin and neofucoxanthin (diatom pigments) were found at 3 m and 20 m depths at station 3 and at 3 m at station 6 for the first pigment.

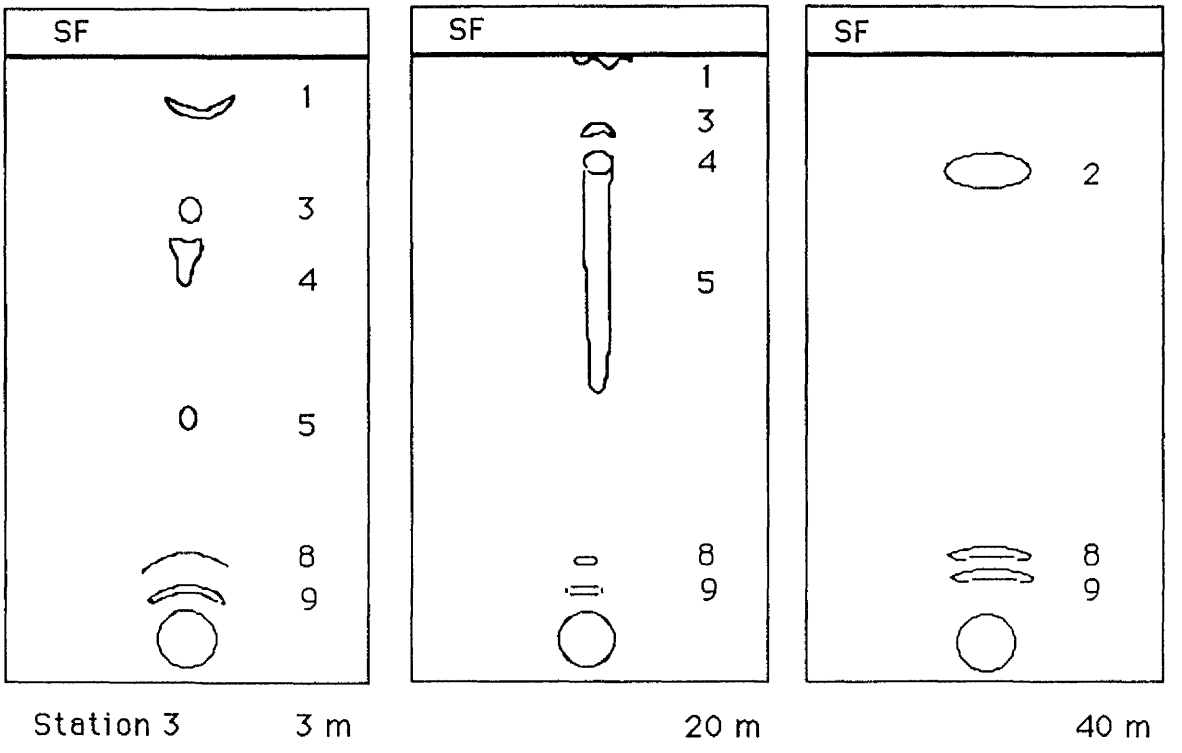
Summer 1986 (Fig. 5.15)

The chromatograms obtained from stations 3 and 6 for 3 m, 20 m and 40 m during summer showed chlorophyll *a* which in the surface water samples at both stations and in all depth samples except for the 20 m sample at station 6, whilst carotene was not detected in the surface samples. Fucoxanthin was detected on the chromatograms of all samples from stations 3 and 6 with degradation pigments (phaeophytin *a* and phaeophorbide *a*), whilst a large zone of chlorophyllide *a* was obtained from the surface water samples and at 20 m depth at the two stations. Chlorophyll *c* appeared on the chromatograms of all samples at station 6 and 20 m and 40 m depths at station 3.

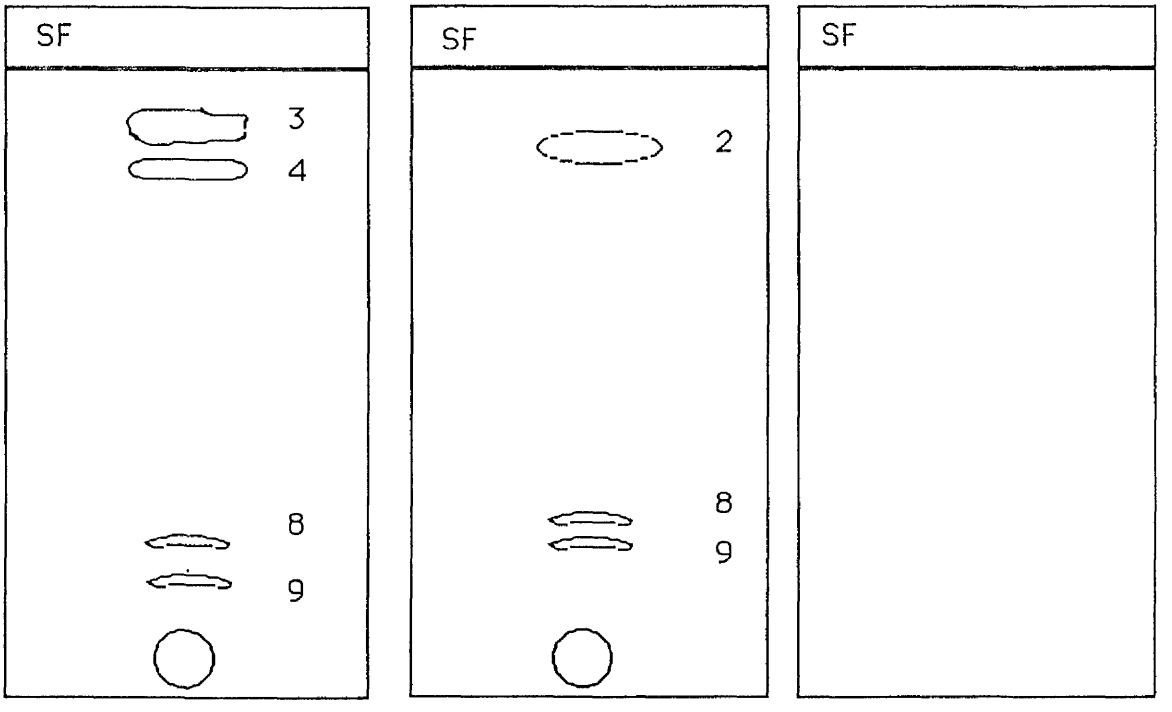
Autumn 1986 (Fig. 5.16)

Chlorophylls *a* and *c* and fucoxathin were detected in surface water samples with the chlorophyll breakdown products phaeophytin *a* , phaeophorbide *a* and chlorophyllide *a*. This latter degraded pigment was found in the depth samples at station 6 associated with carotene and chlorophyll *c* at both stations, whilst phaeophytin *a* and phaeophorbide *a* were presented in the 20 m sample from station 6 with phaeophorbide *a* at 40 m at station 3.

Fig. 5.14 Chromatograms of samples in Spring 1986



Station 3 3 m 20 m 40 m



Station 6 3 m 20 m 40 m

Fig. 5.15. Chromatograms of samples in Summer 1986

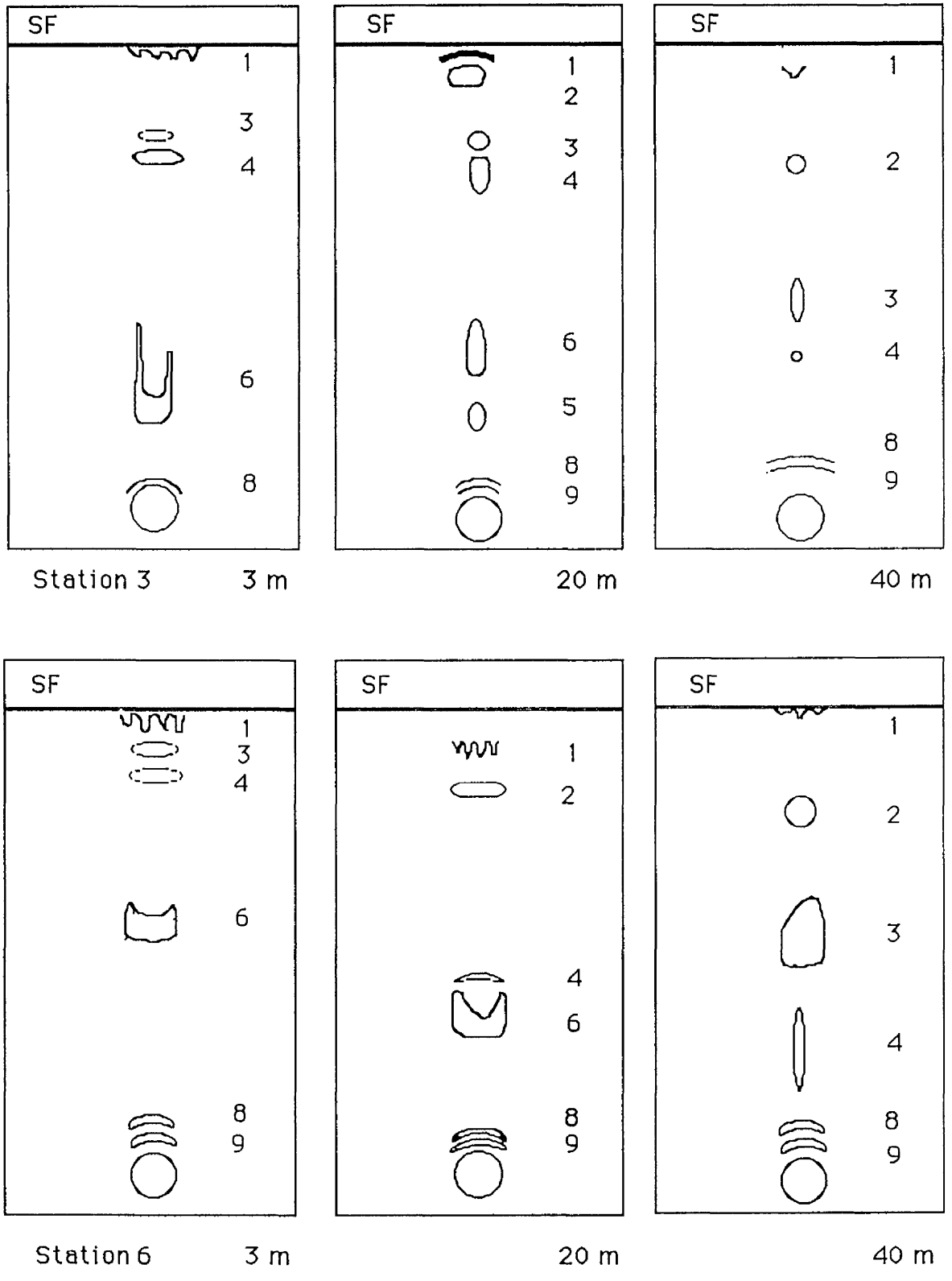
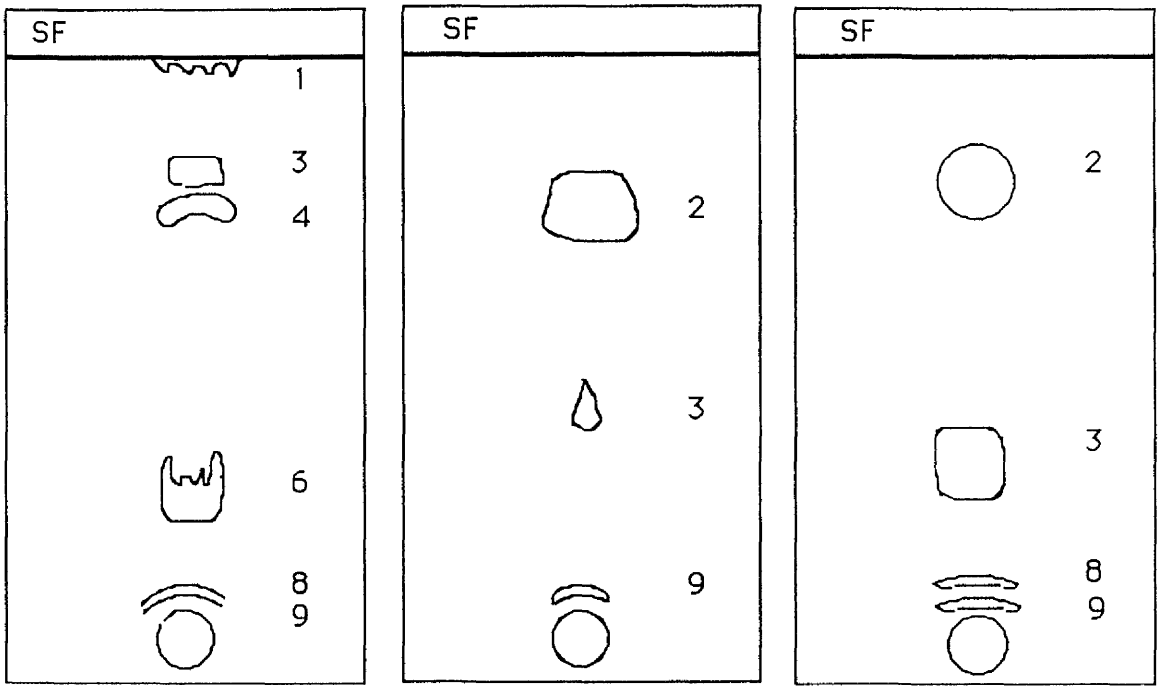
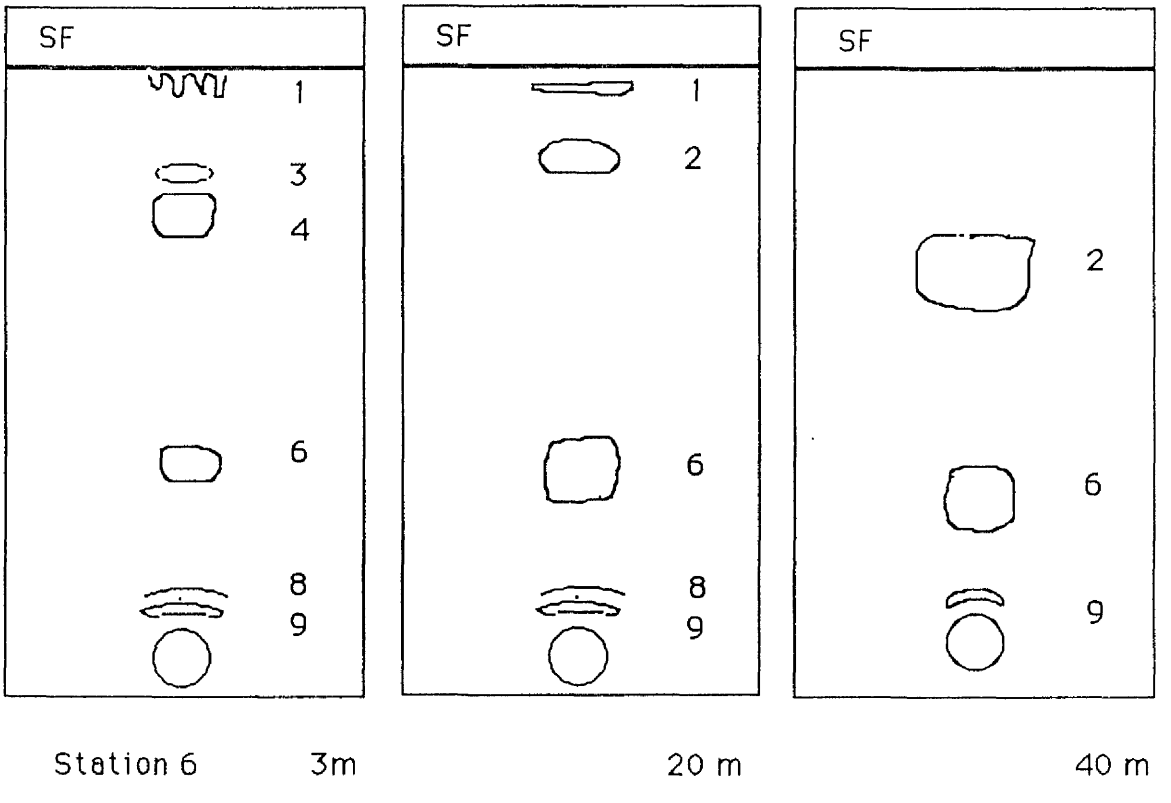


Fig. 5.16. Chromatograms of samples in Autumn 1986





Winter 1986-7

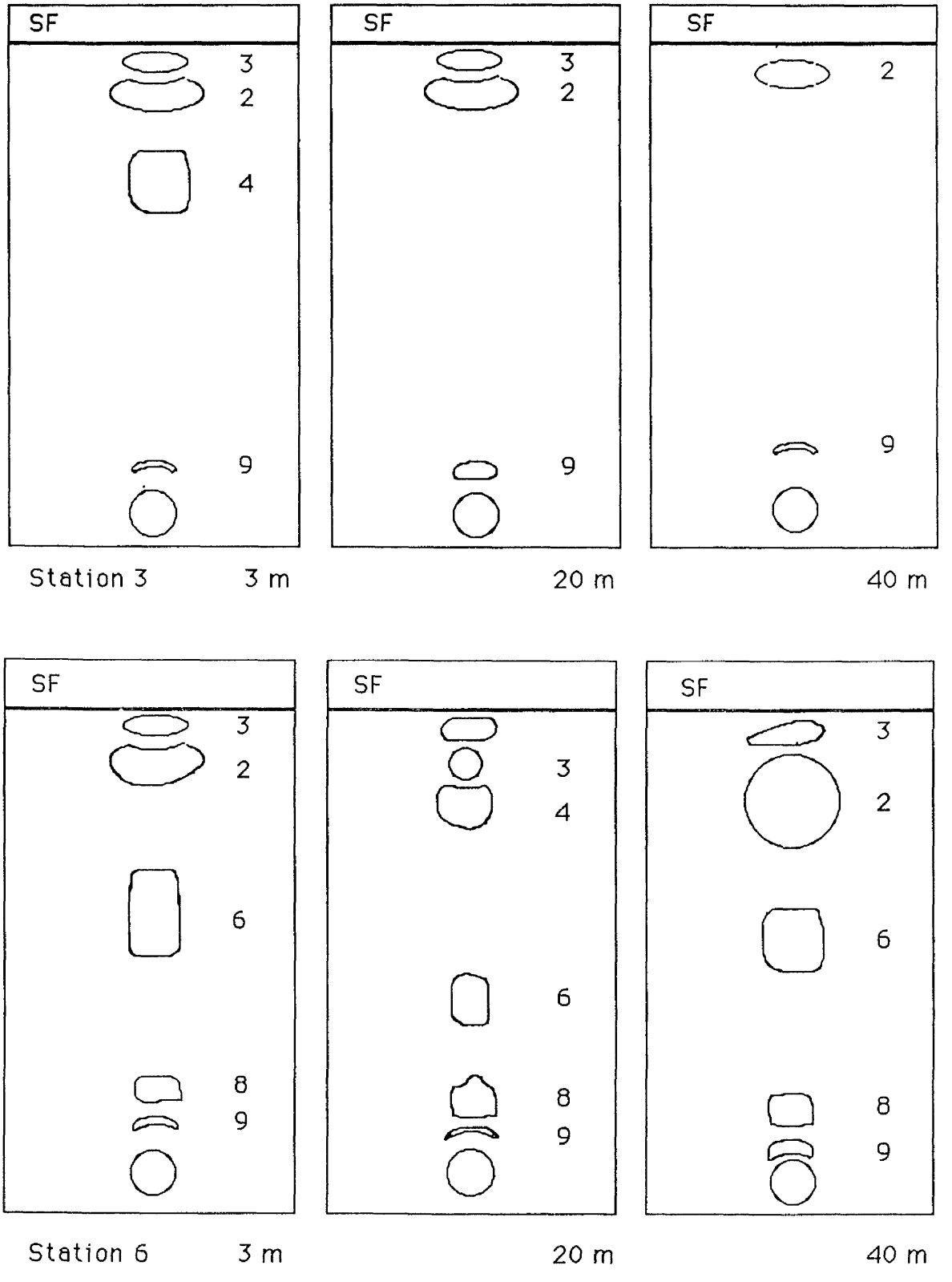
Pigments were not detected in samples from either station .

Spring 1987 (Fig. 5.17)

Chlorophyll *c* was found in all samples from the two stations. Chlorophyll *a* was obtained at 3 m and 20 m from station 3 and in all samples from station 6. Chlorophyllide *a* and phaeophorbide *a* occurred in the 3 m, 20 m and 40 m samples from station 6. Large zones of carotene were obtained for all samples at both stations, whilst fucoxanthin was found in the 3 m (station 3) and 20 m samples (station 6).

The preliminary observations made from March 1984 to April 1985 indicated that measurable quantities of chlorophyll *a* and of phaeopigments (the latter sometimes very high) could be determined in the deep water samples. Compared with the 3 m samples, the deeper water samples in early May 1985 showed that the phaeopigments formed higher proportions of the total pigments, whilst later in the month the phaeopigment quantities were relatively high in all the depth samples, perhaps indicating the final phase following the spring outburst, with faecal pellets from the grazing action by zooplankton. For most of the summer of 1985, at all depths, any noticable pulses in chlorophyll *a* were accompanied by high levels of phaeopigment, the latter showing up mainly as phaeophytin *a* and phaeophorbide *a* on the chromatograms. Again this may be a further indication of continued grazing action, and since the quantities were significantly higher at 3 m, accompanied by some thermal stratification. The autumnal samples in 1985 showed at first a higher chlorophyll *a* balance in the surface waters compared with the deeper samples, suggesting the second important seasonal pulse.

Fig. 5.17 Chromatograms of samples in March 1987



The phaeopigment component again appeared as phaeophytin *a* and phaeophorbide *a* on the chromatograms. Later in the autumn, and in the winter , of 1985-86 the quantities of chlorophyll *a* and phaeopigment fall to undetectable levels, on occasion, and the only detectable chromatographic separation was obtained with surface samples.

Spring 1986 showed the build up of chlorophyll *a* in the surface samples followed by the increase in quantities of phaeopigment in late spring (again possibly due to the impact of grazing activity by zooplankton). Again phaeophytin *a* and phaeophorbide *a* were the principle breakdown products detected on the chromatograms. The summer of 1986 was not an exact replica of 1985, but there were similar trends - any surface 'pulsing' of chlorophyll *a* accompanied by a rise in phaeophytin, whilst in the deeper water quantities remained low, with phaeopigments tending to be the more prominent . In autumn 1986 there were some indications of the surface increase in chlorophyll *a*, for the most part with the smaller quantities of phaeopigment, as in the previous year, with reduced quantities in the deeper water. Late autumn samples led into the winter period of low chlorophyll *a* and phaeopigments, the latter usually exceeding the former at all depths.

The sequence of biomass changes (as chlorophyll *a*) in the surface waters for 1985-87 follow the general trends previously described for the Firth of Clyde. Of interest are the observations that, in the deeper waters, recurring and similar trends of relative abundance the active chlorophyll *a* and its breakdown products are to be observed over the seasons. Whilst the chromatographic summaries of pigment types were not always clear out, the most prominent components of the phaeopigments were regularly observed.

Measurement of chlorophyll *a* and phaeopigment gives only one dimension of biomass changes, although a valuable one. Cell numbers and species composition are also very important measures of phytoplankton populations, and the results of these measurements will be next described.

6. THE STANDING CROP OF SUSPENDED ALGAE: CELL NUMBERS AND COMPOSITON

6.1. Cell Numbers

The data in Figs. 6.1 - 6.5 show the seasonal variations of populations of phytoplankton in Fairlie Channel over 1985, 1986 and part of 1987 (January until the end of March 1987 for station 3 and until the end of April 1987 for station 6) in which the cell numbers are shown on a logarithmic scale.

The total cell numbers in the 3 m samples at stations 3 and 6 were not determined from January to 8 May 1985. At this initial stage of the research project attention was focussed on the potential offered by the routine enumeration of the suspended algae in the deep water samples.

Table 6.1 shows the total cell numbers during January, March and April 1985 for 20 m and 40 m for both stations. These depth samples reflected the typically low winter populations of phytoplankton on 3 January at station 3 and 6 at 20 m and 40 m with the larger numbers at 20 m than at 40 m. The marked increases in numbers were observed on 20 March 1985 indicating the spring outburst of phytoplankton, with a dramatic change from the sparse population during winter (less than 4.7×10^4 cells l^{-1}) to exceed 3 million cells l^{-1} at 20 m and one million cells l^{-1} at 40 m. Total cell numbers had decreased rapidly at both stations at 20 m on 3 April whilst at 40 m the cell numbers were higher than the total biomass at both 20 m depths. Further sharp reductions were measured on 24 April at both stations, and with all depth samples. The population biomass was higher at 20 m than 40 m depths.

Fig. 6. 1. Seasonal variations of phytoplankton cell numbers in the 3 m sample during the period 8 May to December 1985 and in 20 m and 40 m samples at station 3 during the period January to December 1985 (Cell numbers shown on a logarithmic scale).

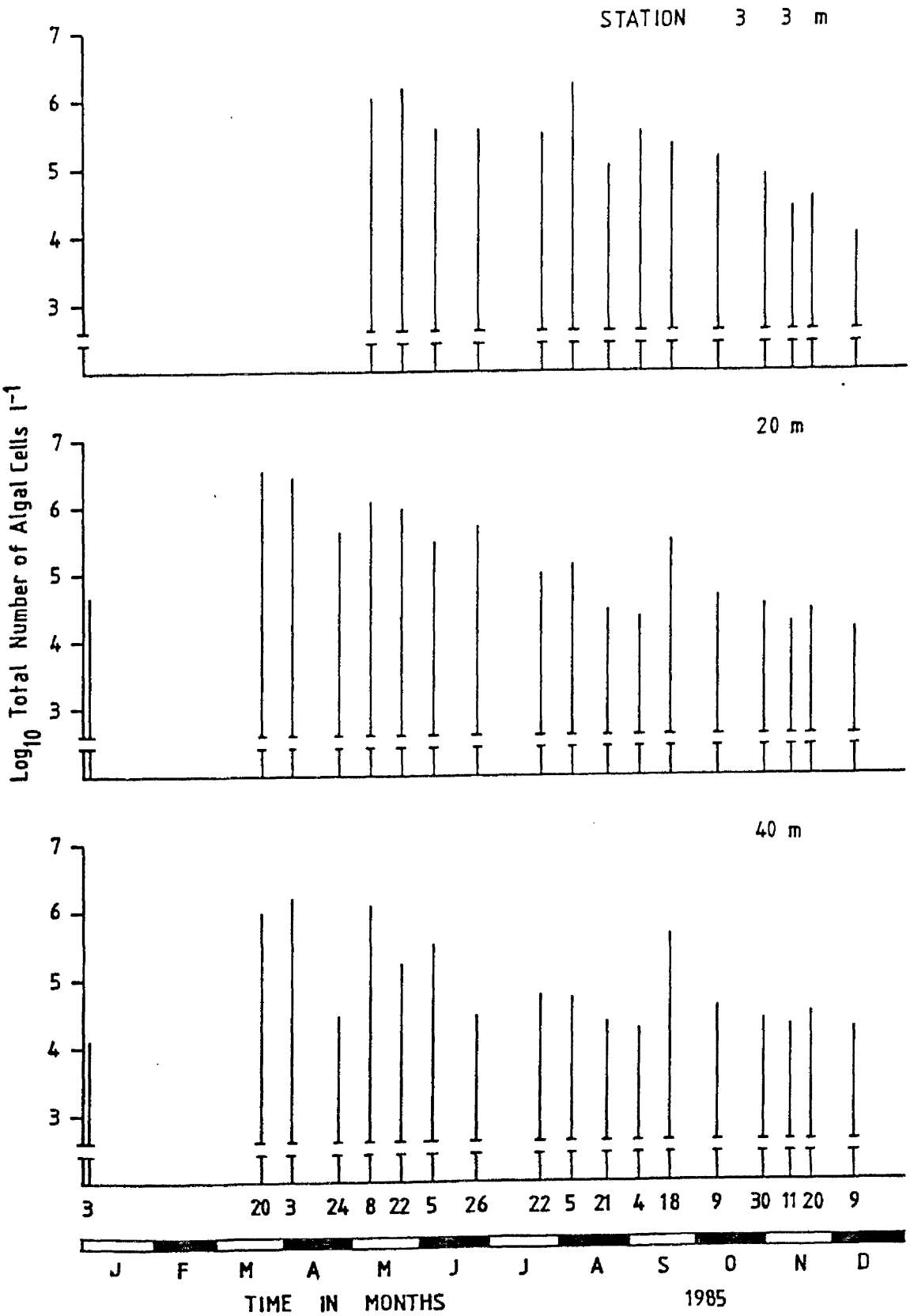

STATION 3 3 m
20 m
40 m
Log10 Total Number of Algal Cells l-1
7
6
5
4
3
3 20 3 24 8 22 5 26 22 5 21 4 18 9 30 11 20 9
J F M A M J J A S O N D
TIME IN MONTHS
1985

Fig. 6. 2. Seasonal variations of phytoplankton cell numbers in the 3 m sample during the period May to December 1985 and in 20 m and 40 m samples at station 6 throughout January to December 1985 (Cell numbers shown on a logarithmic scale).

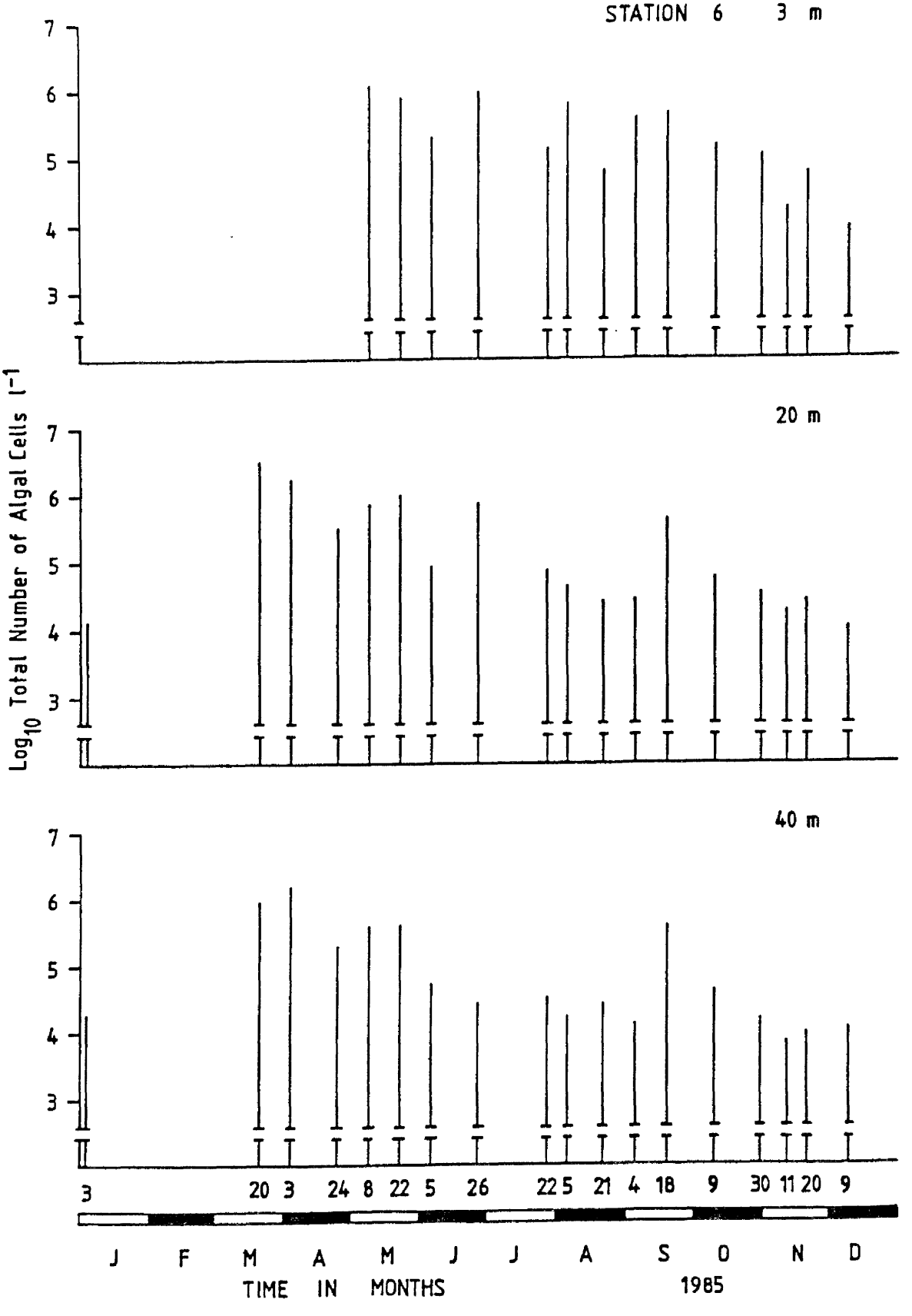

STATION 6 3 m
20 m
40 m
Log10 Total Number of Algal Cells l-1
7
6
5
4
3
3 20 3 24 8 22 5 26 22 5 21 4 18 9 30 11 20 9
J F M A M J J A S O N D
TIME IN MONTHS
1985

Fig. 6. 3. Seasonal variations of phytoplankton cell numbers in the 3 m, 20 m and 40 m samples at station 3 during the period January to December 1986 (Cell numbers shown on a logarithmic scale).

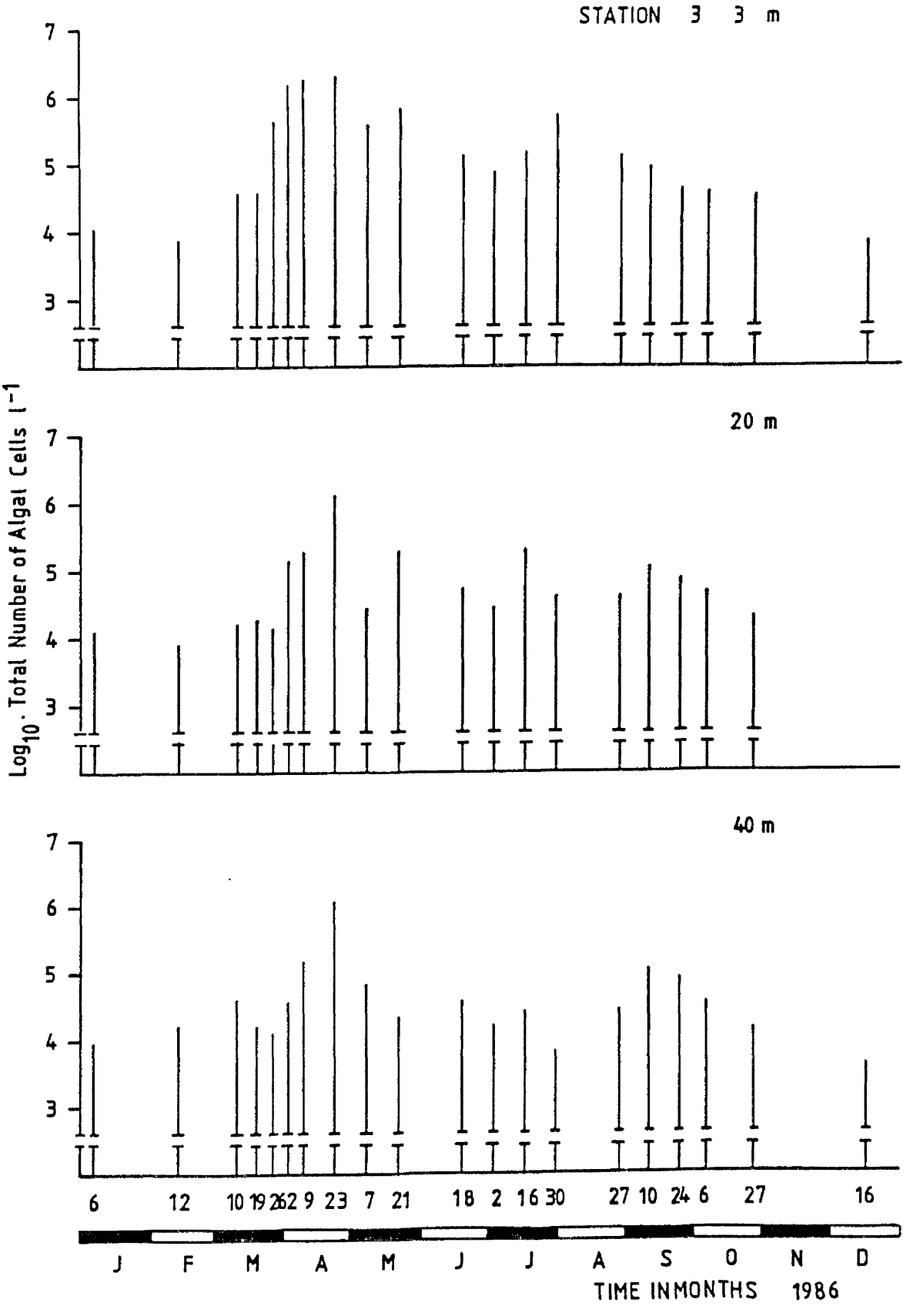

STATION 3 3 m
20 m
40 m
Log_{10}. Total Number of Algal Cells l^{-1}
7
6
5
4
3
6 12 10 19 26 2 9 23 7 21 18 2 16 30 27 10 24 6 27 16
J F M A M J J A S O N D
TIME IN MONTHS 1986

Fig. 6. 4. Seasonal variations of phytoplankton cell numbers in the 3 m, 20 m and 40 m samples at station 6 during the period January to December 1986 (cell numbers shown on a logarithmic scale).

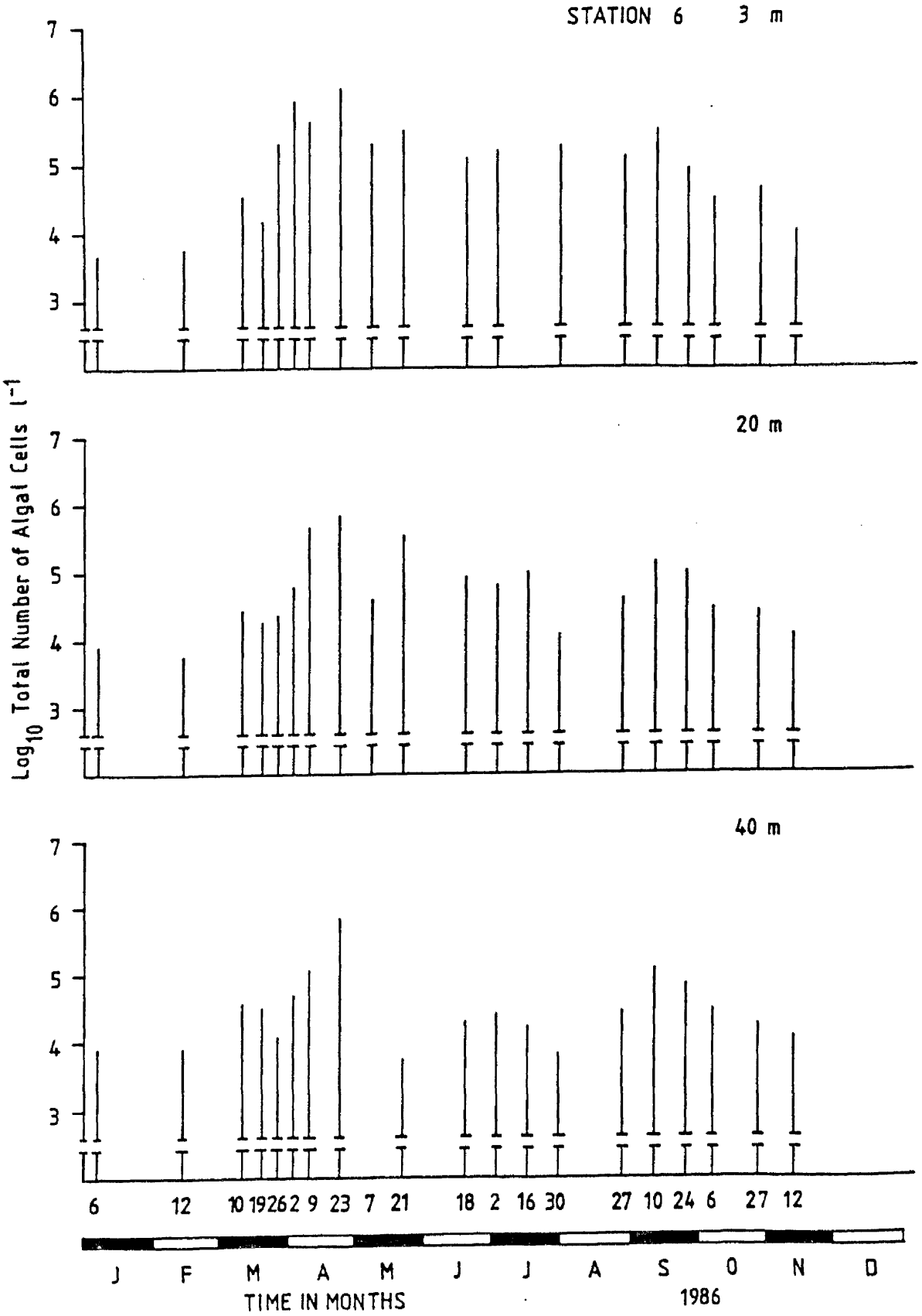

STATION 6 3 m
20 m
40 m
Log10 Total Number of Algal Cells l-1
7
6
5
4
3
6 12 10 19 26 2 9 23 7 21 18 2 16 30 27 10 24 6 27 12
J F M A M J J A S O N D
TIME IN MONTHS
1986

Fig. 6. 5. Seasonal variations of the phytoplankton cell numbers for 3 m, 20 m and 40 m samples from stations 3 and 6 during the period January to March for statin 3 and to April 1987 for station 6 (Cell numbers shown on a logarithmic scale.

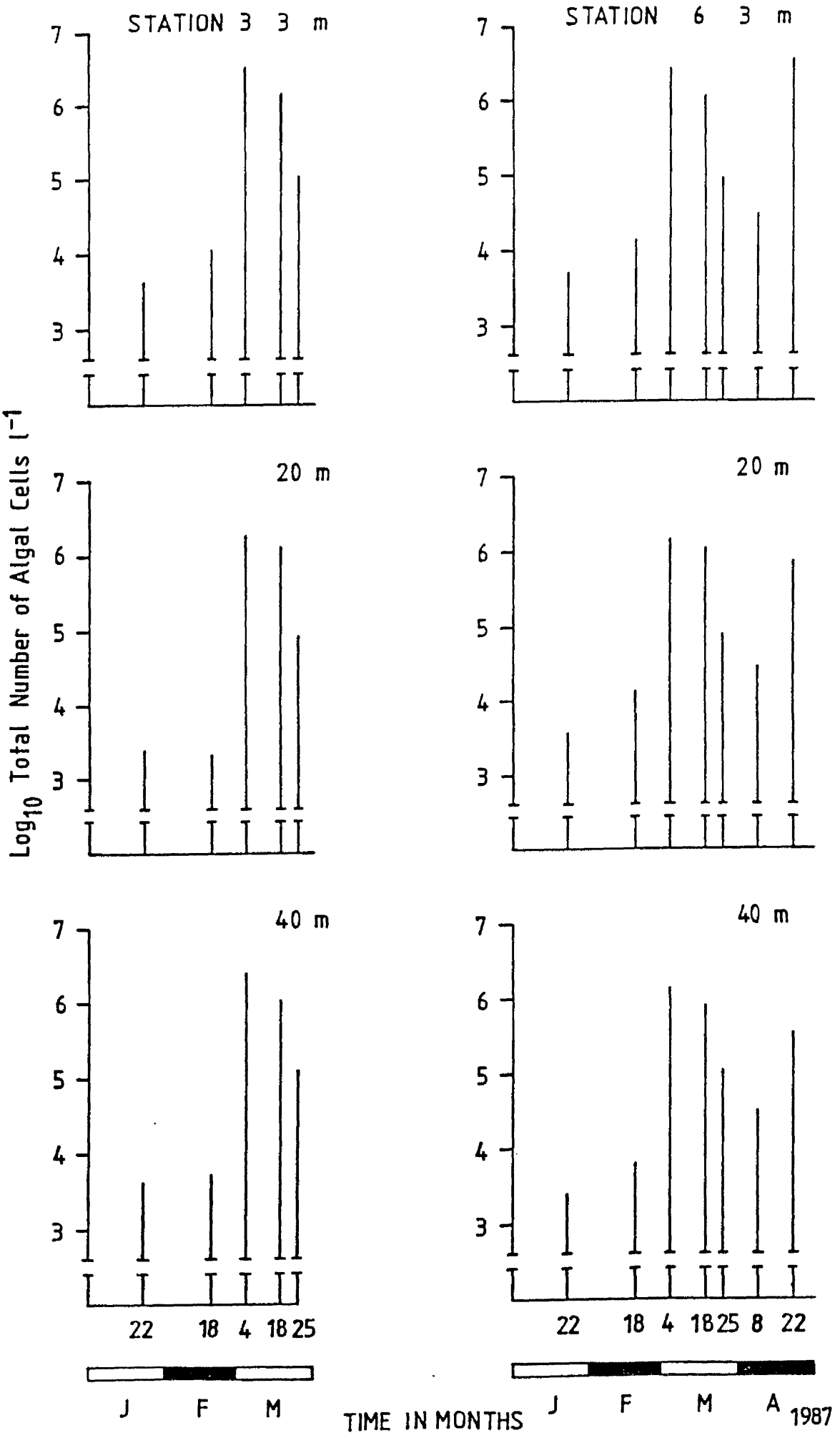

STATION 3 3 m
STATION 6 3 m
20 m
20 m
40 m
40 m
Log10 Total Number of Algal Cells l-1
7
6
5
4
3
22 18 4 18 25
22 18 4 18 25 8 22
J F M
J F M A 1987
TIME IN MONTHS

Table 6.1

Total cell numbers of phytoplankton for January, March and April 1985.

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
03.01.	20 m	4.68×10^4	1.57×10^4
	40 m	1.35×10^4	1.47×10^4
20.03.	20 m	3.43×10^6	3.36×10^6
	40 m	1.06×10^6	9.64×10^5
03.04.	20 m	1.11×10^6	1.75×10^6
	40 m	1.70×10^6	2.32×10^6
24.4.	20 m	4.51×10^5	3.22×10^5
	40 m	2.77×10^4	2.11×10^4

Increases in the numbers of phytoplankton cells were observed on May 8 at all depths at the two stations making a second pulse in spring period. A comparative study of the 3 m samples with depth samples (Table 6. 3) showed the large quantities of phytoplankton populations in the surface waters. Total numbers at this time showed a gradual declined with depth at both stations. Increases in total cell numbers were once more obtained on 22nd May at 3 m for station 3 with 20 m and 40 m for station 6, whilst the numbers in the other depths declined.

Table 6.2

Total cell numbers of phytoplankton for May 1985

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
08.05.	3 m	$1.28x10^6$	$1.25x10^6$
	20 m	$1.25x10^6$	$7.60x10^5$
	40 m	$8.42x10^5$	$4.06x10^5$
22.05.	3 m	$1.54x10^6$	$8.96x10^5$
	20 m	$9.35x10^5$	$8.90x10^5$
	40 m	$1.78x10^5$	$4.90x10^5$

The plant cell numbers for the summer months of 1985 are summarized in Table 6.3, which displays the generally lower populations over the summer period compared with previous spring increases. Surface water samples contained larger numbers of cells than the depth samples throughout this period except on one occasion (26 June) when $5.40x10^5$ cells l^{-1} were measured at 20 m at station 3. The low numbers of 5 June was followed by increases in the total phytoplankton biomasses at 3 m and 20 m depths for stations 3 and 6 on 26 June whilst the total cells in 40 m samples remmained low. On 22 July the phytoplankton numbers declined slightly at both stations at 3 m and 20 m, except with 40 m depths where the quantities increased, but remaining less than in the overlying water. On 5 August the total cells increased sharply, exceeding one million cells.l^{-1} at 3 m at station 3, whilst the increase at station 6 at this depth was not as much . In the 20 m samples for the two stations the numbers fluctuated with a small reduction at 40 m. By 21 August the total numbers had decreased at all depths except for 40 m at station 6.

Autumnal increases of cells for 3 m samples in the two stations were observed on 4 September whilst the quantities in the depth samples (20 m and 40 m) were low and less than in August. The population peak was recorded on 18 September at all depths at station 3 and 6 with maxima of $4.9x10^5$ cells.l^{-1} at 3 m at station 6 and $4.97x10^5$ cells.l^{-1} at 40 m at station 3. The total number of cells increased with the depth at station 3, whilst a normal pattern was found at station 6 (decline with the depth) with similar quantities at 3 m, 20 m and 40 m. After the autumnal peak the phytoplankton cell numbers declined gradually during October these decreases in numbers continuing for all depths in the November samples.

Table 6.5 displays the low winter cell numbers in December 1985 and January and February 1986. The total biomass decreased gradually to reach the lowest measures on February 12 . The cell numbers in depth samples were higher than at 3 m depth throughout the winter with the highest in 40 m samples in the two stations except on 6 January at 20 m at station 6 where the total numbers were higher than at 40 m.

Table 6.3

Total cell numbers of phytoplankton for summer of 1985

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
05.06.	3 m	3.89×10^5	2.01×10^5
	20 m	3.01×10^5	8.87×10^4
	40 m	3.47×10^4	5.70×10^4
26.06.	3 m	4.00×10^5	9.58×10^5
	20 m	5.40×10^5	7.90×10^5
	40 m	2.98×10^4	2.92×10^4
22.07.	3 m	3.20×10^5	1.37×10^5
	20 m	1.09×10^5	7.45×10^4
	40 m	6.05×10^4	3.47×10^4
05.08.	3 m	1.82×10^6	6.81×10^5
	20 m	1.38×10^5	4.40×10^4
	40 m	5.76×10^4	1.85×10^4
21.08.	3 m	1.19×10^5	6.71×10^4
	20 m	2.99×10^4	2.64×10^4
	40 m	2.48×10^4	2.54×10^4

Table 6.4

Total cell numbers of phytoplankton for autumn 1985

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
04.09.	3 m	3.04×10^5	4.32×10^5
	20 m	2.36×10^4	2.83×10^4
	40 m	1.97×10^4	1.39×10^4
18.09.	3 m	3.17×10^5	4.90×10^5
	20 m	3.31×10^5	4.36×10^5
	40 m	4.97×10^5	4.18×10^5
09.10.	3 m	1.39×10^5	1.68×10^5
	20 m	4.73×10^4	6.04×10^4
	40 m	4.13×10^4	4.55×10^4
30.10.	3 m	7.89×10^4	1.20×10^5
	20 m	3.52×10^4	3.53×10^4
	40 m	2.15×10^4	1.71×10^4
11.11.	3 m	2.71×10^4	1.88×10^4
	20 m	1.99×10^4	1.91×10^4
	40 m	2.08×10^4	1.66×10^4
20.11.	3 m	3.58×10^4	6.60×10^4
	20 m	3.11×10^4	2.71×10^4
	40 m	3.18×10^4	1.12×10^4

Table 6.5

Total cell numbers of phytoplankton for winter of 1985-6

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
09.12.	3 m	1.00×10^4	9.39×10^3
	20 m	1.57×10^4	1.11×10^4
	40 m	1.98×10^4	1.23×10^4
06.01.	3 m	1.10×10^4	4.69×10^3
	20 m	1.35×10^4	8.45×10^3
	40 m	9.70×10^3	8.45×10^3
12.2.	3 m	7.40×10^3	6.26×10^3
	20 m	7.94×10^3	6.10×10^3
	40 m	1.58×10^4	7.98×10^3

The total cell numbers at all depths increased during the spring months of 1986 (Table 6. 6), shown in the samples collected from 10 March at all depths at station 3 and 6, with larger numbers in the surface samples at the two stations and with reduced numbers at the two depths. On March 19 the cell numbers were lower in all samples except for 40 m at station 6. On 26 March the cell numbers in 3 m samples for the two stations again increased, while the depth samples appeared lower cell numbers except for 20 m depth at station 6. This was followed by gradual increases at all depths, exeeding one million cells.l^{-1} at 3 m depth at station 3 on 2nd April with smaller number at 3 m at station 6 on 9 April. The spring peak for this sampling program was obtained on 23 April at all depths at both stations, with numbers exceeding one million cells.l^{-1} at all depths from station 3 and 3 m at station 6. This peak was lower than the spring measured peak in 1985. Within two weeks the numbers declined sharply on 7 May at all depths. On 21st May the total numbers in 3 m and 20 m remained relatively high at both stations, similar in pattern to May 1985.

The quantities of total biomass obtained during summer 1986 are summarized in Table 6.7. Sharp reductions occurred on 18 June at 3 m and 20 m at both stations, whilst the numbers in the 40 m samples increased at the two stations. Continuing decreases were observed on 2nd July at all depths except with 40 m depth for station 6. On 16 July the total numbers of phytoplankton increased at 3 m, 20 m and 40 m at station 3 and at 20 m at station 6 with decrease in 40 m sample, (the phytoplankton population data for the 3 m sample was not available). On 30 July the cell totals continued to increase in the surface water samples whilst the number of cells in the depth samples from the two stations were lower. On 27 August the 3 m samples at station 3 and 6 contained large numbers of cells but lower than on 30 July with increases in the total numbers in the depth samples but still smaller than those in the surface water. The plant cell numbers for 3 m depths for the stations throughout the summer were always of a higher level than in deeper water.

Table 6.6

Total cell numbers of phytoplankton for spring of 1986

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
10.3.	3 m	7.93×10^4	3.51×10^4
	20 m	3.58×10^4	2.75×10^4
	40 m	4.14×10^4	3.95×10^4
19.3.	3 m	3.80×10^4	1.57×10^4
	20 m	1.95×10^4	1.68×10^4
	40 m	1.68×10^4	3.21×10^4
26.3.	3 m	4.05×10^5	2.36×10^5
	20 m	1.36×10^4	2.41×10^4
	40 m	1.34×10^4	1.17×10^4
02.4.	3 m	1.54×10^6	8.68×10^5
	20 m	1.36×10^5	6.10×10^4
	40 m	3.80×10^4	5.35×10^4
09.4.	3 m	1.77×10^6	4.32×10^5
	20 m	3.95×10^5	4.87×10^5
	40 m	1.48×10^5	1.25×10^5
23.4.	3 m	1.84×10^6	1.29×10^6
	20 m	1.25×10^6	7.31×10^5
	40 m	1.23×10^6	7.24×10^5
07.5.	3 m	3.79×10^5	2.38×10^5
	20 m	2.77×10^4	4.14×10^4
	40 m	6.79×10^4	–
21.5.	3 m	6.41×10^5	3.29×10^5
	20 m	1.97×10^5	2.14×10^5
	40 m	2.29×10^4	5.95×10^3

Table 6.7

Total cell numbers of phytoplankton for summer of 1986

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
18.6.	3 m	$1.35x10^5$	$1.35x10^5$
	20 m	$5.48x10^4$	$8.70x10^4$
	40 m	$4.09x10^4$	$2.03x10^4$
02.7.	3 m	$7.89x10^4$	$1.62x10^5$
	20 m	$2.71x10^4$	$6.59x10^4$
	40 m	$1.64x10^4$	$2.65x10^4$
16.7.	3 m	$1.47x10^5$	-
	20 m	$2.12x10^5$	$1.03x10^5$
	40 m	$2.63x10^4$	$1.66x10^4$
30.7.	3 m	$5.19x10^5$	$1.90x10^5$
	20 m	$2.15x10^4$	$1.19x10^4$
	40 m	$6.42x10^3$	$6.34x10^3$
27.8.	3 m	$1.38x10^5$	$1.89x10^5$
	20 m	$4.11x10^4$	$4.10x10^4$
	40 m	$2.70x10^4$	$2.85x10^4$

Table 6.8 shows the cell numbers for the autumn of 1986. The numbers recorded at all depths was on 10 September decreasing with depth except at 40 m at station 3 where the numbers were higher than at 20 m. After this autumnal peak in the sampling programme the quantities of phytoplankton population declined gradually during the remaining months at all depths at both stations. (On 12 November the samples from station 3 were not collected because of the breakdown of the sampler).

Phytoplankton population size for winter of 1986-7 are tabulated in Table 6.9, being started from 12 December 1986 and 22 January and 18 February 1987. Irregularities in the sampling programme were mainly due to restrictions on boat time, brought about by inclement weather, and failure of the sampler. The available samples from 3 m and 40 m showed the typically low winter quantities , with reduced numbers recorded on 22 January, whilst the numbers on 18 February increased at all depths except for 20 m for station 3.

Table 6.10 shows the early spring increases of total biomass as measured on 4 March with over 3 million cells.l^{-1} at 3 m at station 3 and 2 million cells.l^{-1} in depth samples (at 40 m at station 3), similar high number at all depths were recorded for station 6. The total cell numbers thereafter decreased gradually at both stations The general pattern showed high cell numbers still present on 18 March and on 25 March the larger numbers appeared in the 40 m depth samples. The lowest cell numbers were recorded on 8 April for station 6 for all depths with a slight increase in cell numbers in 40 m sample. On 22 April the plant cell numbers increased highly at all depths exceeding 3 million cells.l^{-1} at 3 m, higher than that recorded on 4 March.

Table 6.8
Total cell numbers of phytoplankton for autumn of 1986

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
10.09.	3 m	1.90×10^5	3.35×10^5
	20 m	1.08×10^5	1.45×10^5
	40 m	2.51×10^5	1.22×10^5
24.09.	3 m	4.20×10^4	8.64×10^4
	20 m	7.80×10^4	1.01×10^5
	40 m	7.99×10^4	6.92×10^4
06.10.	3 m	3.85×10^4	3.41×10^4
	20 m	4.82×10^4	2.96×10^4
	40 m	3.49×10^4	2.97×10^4
27.10.	3 m	3.42×10^4	4.33×10^4
	20 m	2.04×10^4	2.65×10^4
	40 m	1.44×10^4	1.74×10^4
12.11.	3 m	-	1.02×10^4
	20 m	-	1.19×10^4
	40 m	-	1.25×10^4

Table 6.9

Total cell numbers of phytoplankton for winter of 1986-7

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
16.12.	3 m	$6.83x10^3$	-
	20 m	-	-
	40 m	$4.70x10^3$	-
22.1.	3 m	$4.47x10^3$	$5.35x10^3$
	20 m	$2.66x10^3$	$3.81x10^3$
	40 m	$4.64x10^3$	$2.70x10^3$
18.2.	3 m	$1.25x10^4$	$1.46x10^4$
	20 m	$2.19x10^3$	$1.46x10^4$
	40 m	$5.63x10^3$	$6.57x10^3$

Table 6.10

Total cell numbers of phytoplankton for spring of 1987

		Station 3	Station 6
Date	Depth	total cells l^{-1}	
04.3.	3 m	$3.24x10^6$	$2.66x10^6$
	20 m	$1.90x10^6$	$1.56x10^6$
	40 m	$2.61x10^5$	$1.47x10^6$
18.3.	3 m	$1.39x10^6$	$1.14x10^6$
	20 m	$1.27x10^6$	$1.11x10^6$
	40 m	$1.10x10^6$	$8.47x10^5$
25.3.	3 m	$1.15x10^5$	$9.29x10^4$
	20 m	$9.04x10^4$	$8.36x10^4$
	40 m	$1.28x10^5$	$1.10x10^5$
08.4.	3 m	-	$3.13x10^4$
	20 m	-	$3.01x10^4$
	40 m	-	$3.17x10^4$
22.4	3 m	-	$3.66x10^6$
	20 m	-	$7.75x10^5$
	40 m	-	$3.41x10^5$

From numerical point view throughout the seasons the surface waters tend to possess the larger populations of phytoplankton in spring, most of the summer and in the autumn. In winter, the season of reduced cell numbers, the numerical differences between the surface and deeper waters are less obvious. This last observation is consistent with the view that more complete mixing of the water column will have taken place. The more striking feature of these data, however is the way in which the populations in the deeper water though smaller quantitatively, follow the general patterns of change in spring, summer, autumn as shown in the surface waters. Hence it was thought important to examine in detail the composition of the populations from the three depths, in order determine whether there were similarities in the genera and species present.

6.2. Phytoplankton Composition

The study of species composition of phytoplankton populations at stations 3 and 6 for samples collected from 3 m, 20 m and 40 m depths commenced in January 1985 and continued up to the end of March 1987 for station 3, and until the end of April 1987 for station 6. The samples from 3 m were started on 8 May 1985. Tables 6.11 to 6.28 display the annual variations of the contributions of the phytoplankton species to the biomass during January 1985 to December 1985, whilst contributions of the planktonic and benthic and epiphytic cells to the suspended algae are presented in Figs. 6.6 and 6.7 with the proportions of diatoms, dinoflagellates, green flagellates and silicoflagellates shown in Figs. 6.8 and 6.9.

January 1985 (Table 6.11)

On 3 January 1985, when the cell numbers were small, the range of species represented was similar at the two depths (20 m and 40 m) at stations 3 and 6, although showing clear evidence of patchy distribution. Whilst the population at 20 m from station 3 was dominated by *Diatoma elongata*, this species made small contributions to the biomass in the other samples. The green flagellates were more numerous in the samples from 40 m at station 3, and at both depths at station 6. In general, the composition of the biomass in these 3 samples were similar, and quite distinct from that of 20 m at station 3. The planktonic species dominated the biomass in each sample.

March 1985 (Table 6.12)

On 20 March *Skeletonema costatum* contributed in considerable numbers in all samples collected from both stations with similarity at these two stations.

Fig. 6. 6. The contributions of planktonic and benthic algal cells (in percentages) to the total biomass for 3 m, 20 m and 40 m samples from station 3 during the period May for the 3 m sample and January for the 20 m and 40 m samples to December 1985.

Planktonic species

Benthic and epiphytic species

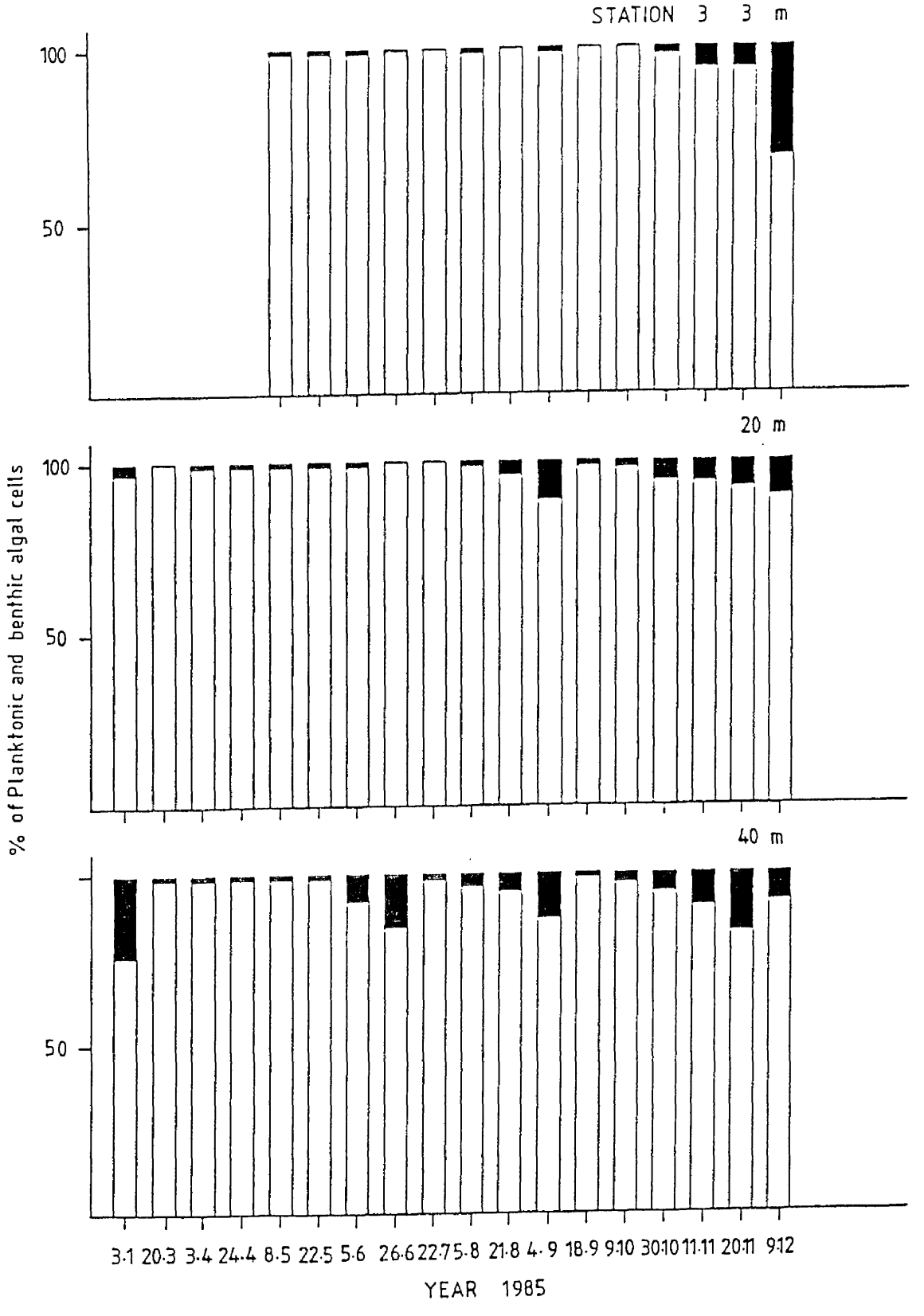

STATION 3 3 m
100
50
20 m
100
50
40 m
50
% of Planktonic and benthic algal cells
3·1 20·3 3·4 24·4 8·5 22·5 5·6 26·6 22·7 5·8 21·8 4·9 18·9 9·10 30·10 11·11 20·11 9·12
YEAR 1985

Fig. 6. 7. The contributions of planktonic and benthic algal cells (in percentages) to the total biomass for 3 m, 20 m and 40 m at station 6 during the period May 1985 for the 3 m samples and January 1985 for the 20 m and 40 m samples to December 1985.

Planktonic species

Benthic and epiphytic species

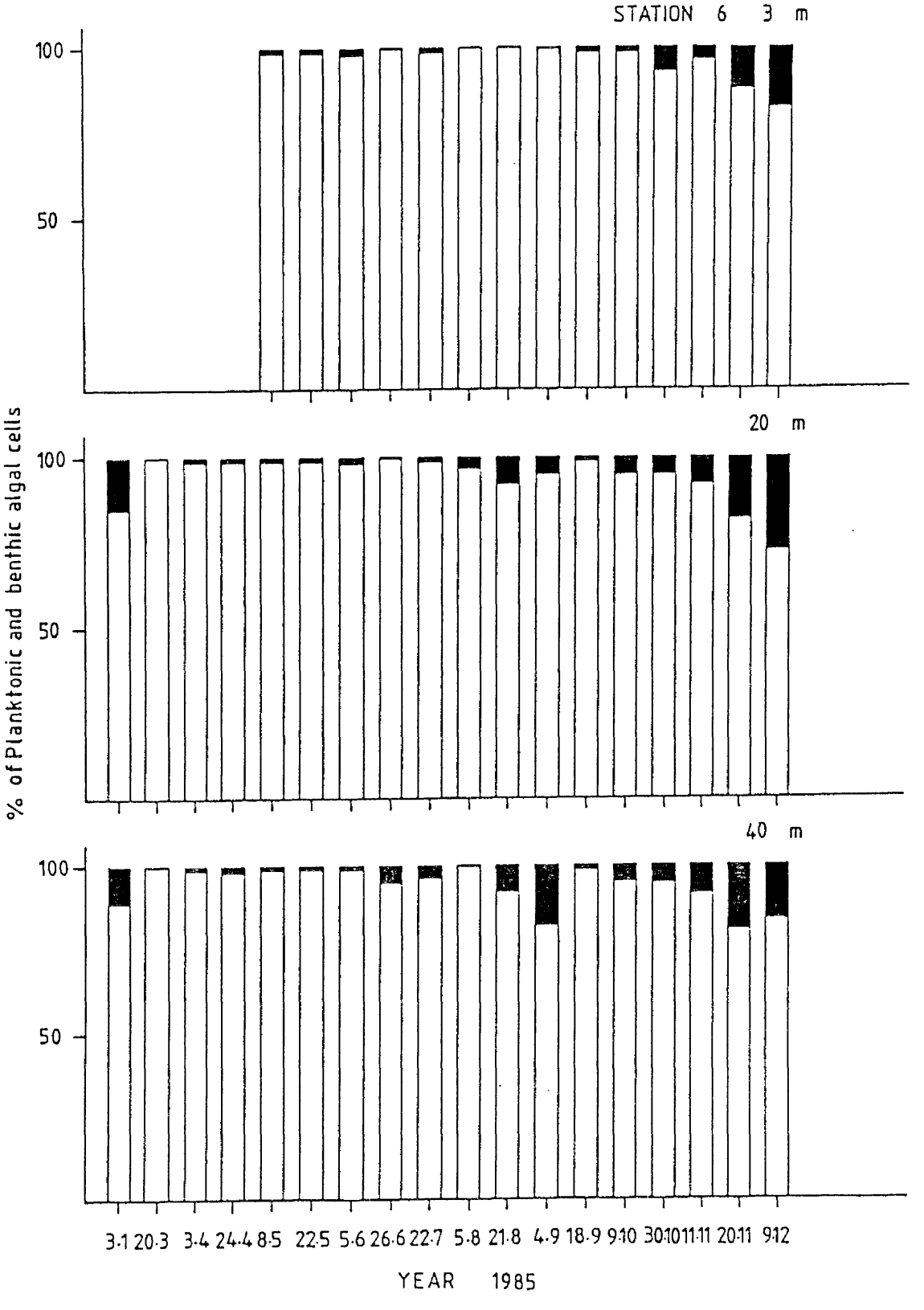

STATION 6 3 m
100
50
20 m
100
50
40 m
100
50
% of Planktonic and benthic algal cells
3·1 20·3 3·4 24·4 8·5 22·5 5·6 26·6 22·7 5·8 21·8 4·9 18·9 9·10 30·10 11·11 20·11 9·12
YEAR 1985

Fig. 6. 8. The contributions of diatoms, dinoflagellates, green flagellates and silicoflagellates (in percentages) to the total biomass for 3 m, 20 m and 40 m samples at station 3 during the period May 1985 for the 3 m sample and January 1985 for the 20 m and 40 m samples to December 1985.

Diatoms

Dinoflagellates

Green flagellates

Silicoflagellates

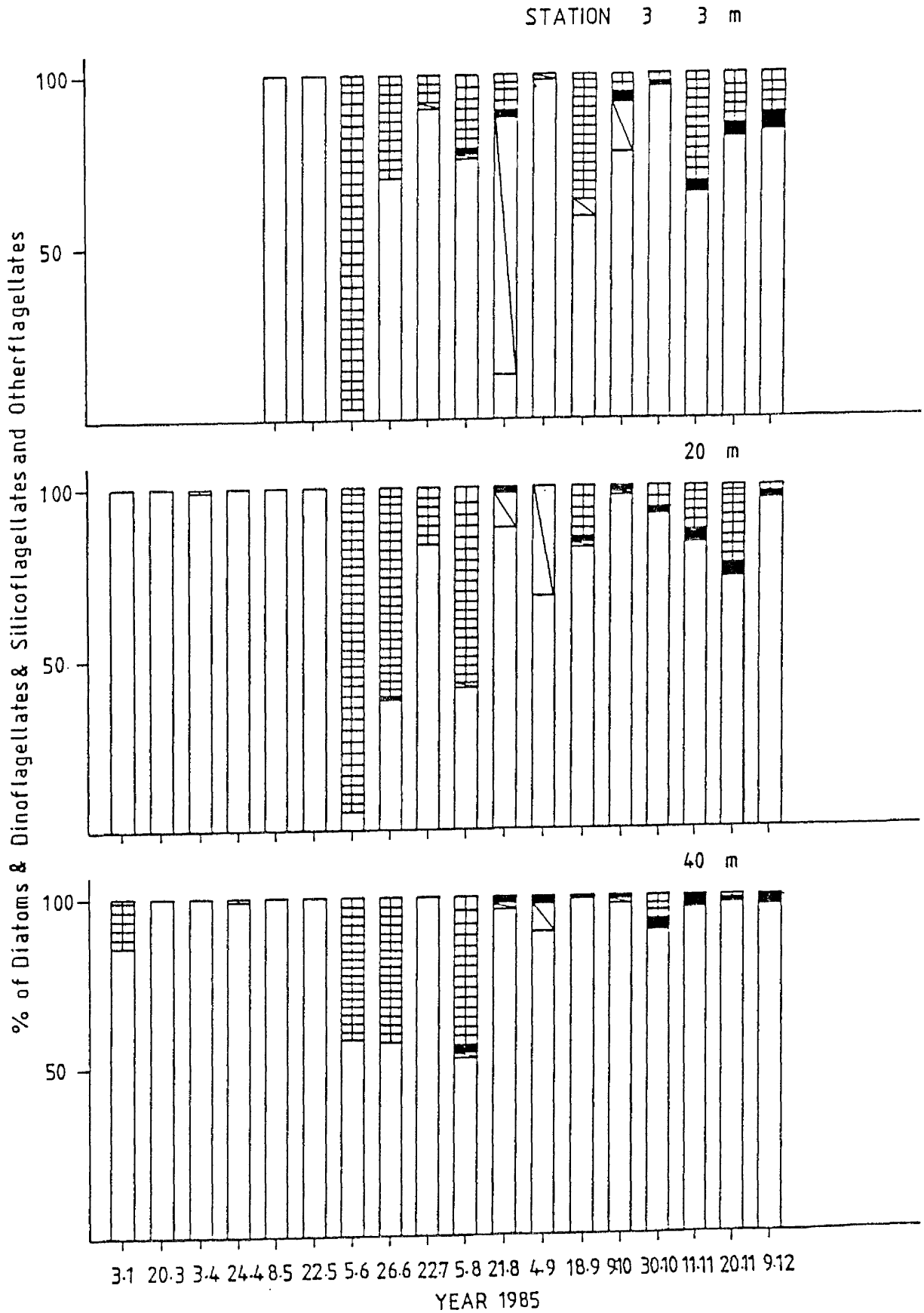

STATION 3 3 m
100
50
20 m
100
50
40 m
100
50
% of Diatoms & Dinoflagellates & Silicoflagellates and Other flagellates
3·1 20·3 3·4 24·4 8·5 22·5 5·6 26·6 22·7 5·8 21·8 4·9 18·9 9·10 30·10 11·11 20·11 9·12
YEAR 1985

Fig. 6. 9. The contributions of diatoms, dinoflagellates, green flagellates and silicoflagellates (in percentages) to the total biomass for the 3 m, 20 m and 40 m samples at station 6 during the period May 1985 for the 3 m sample and January 1985 for the 20 m and 40 m samples to December 1985.


Diatoms


Dinoflagellates


Green flagellates


Silicoflagellates

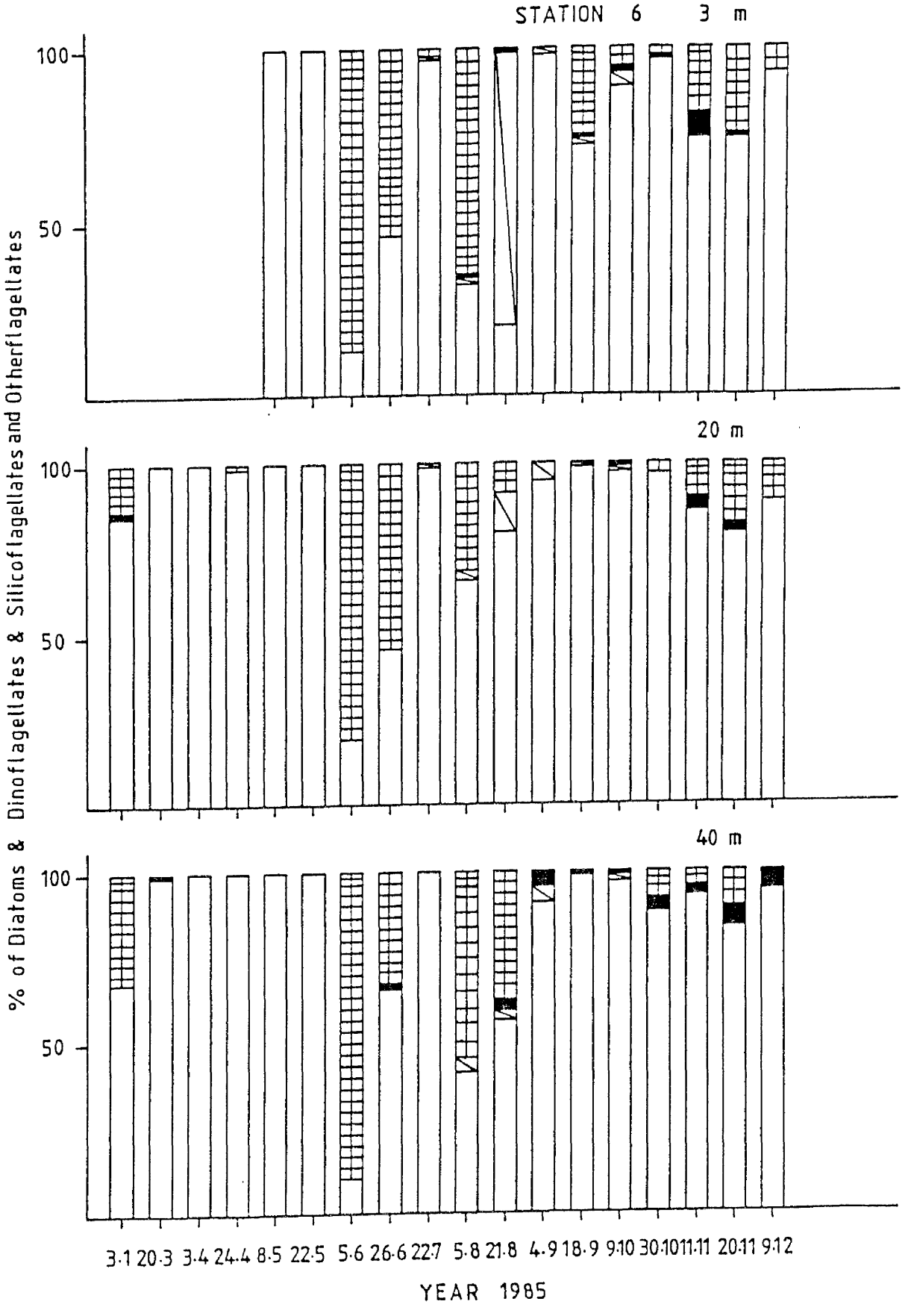

STATION 6
3 m
20 m
40 m
100
50
% of Diatoms & Dinoflagellates & Silicoflagellates and Otherflagellates
3·1 20·3 3·4 24·4 8·5 22·5 5·6 26·6 22·7 5·8 21·8 4·9 18·9 9·10 30·10 11·11 20·11 9·12
YEAR 1985

Table 6.11

% composition of suspended algae on 3 January 1985

		station 3		station 6	
		20 m	40 m	20 m	40 m
Cell numbers ($x10^4$) per liter		4.68	1.35	1.57	1.47
Green flagellates		1.0	15.0	12.0	35.2
Biddulphia sp.		0.3	-	-	-
Coscinodiscus spp.		0.7	7.0	8.0	4.3
Diatoma elongata		88.0	9.3	18.0	19.0
Diploneis sp.	*	-	1.3	-	-
Grammatophora marina	*	-	-	2.0	-
Leptocylindrus danicus		-	-	3.0	3.1
Melosira sp.		-	15.1	-	-
Navicula spp.	*	3.0	18.6	9.0	7.4
Nitzschia closterium		-	1.1	1.0	16.0
N. seriata		1.0	1.2	5.0	4.3
Pinnularia spp.	*	-	4.7	2.0	2.3
Pleurosigma sp.	*	-	-	2.0	-
Skeletonema costatum		0.7	-	-	-
Synedra ulna	*	-	-	3.0	-
Thalassiosira spp.		5.3	26.7	33.0	8.5
Dictyocha speculum (Silicoflagellate)		-	-	2.0	-
% of Green flagellates		1.0	15.0	12.0	35.2
% of Diatoms		99.0	85.0	86.0	64.8
% of Planktonic species		97.0	75.4	82.0	90.3
% of Benthic species	(*)	3.0	24.6	18.0	9.7

Table 6.12

% composition of suspended algae on 20 March 1985

		station 3		station 6	
		20 m	40 m	20 m	40 m
Cell numbers ($x10^5$)		34.3	10.6	33.6	96.4
Biddulphia spp		-	0.13	0.08	-
Coscinodiscus spp.		0.11	0.01	0.08	0.04
Chaetoceros spp.		-	-	0.01	0.12
Diatoma elongata		0.03	0.1	0.01	0.03
Leptocylindrus danicus		-	0.03	0.02	0.11
Melosira sp.		-	0.13	-	-
Navicula sp.	*	-	0.6	-	-
Nitzschia closterium		-	0.1	-	-
Pinnularia sp.	*	-	0.4	-	-
Skeletonema costatum		98.06	96.4	98.6	94.8
Thalassiosira spp.		1.3	2.1	1.2	3.9
Dictyocha speculum (Silicoflagellate)		-	-	-	1.0
% of Diatoms		100	100	100	99
% of Planktonic species		100	99	100	100
% of Benthic and Epiphytic species	(*)	-	1	-	-

The populatios in 40 m samples from station 3 consisted of more diverse diatoms, especially those benthic. Whilst the other samples were quite similar in composition . *Thalassiosira* spp. were more numerous at 40 m depth at the two stations. The phytoplankton biomass in all of the samples was predominantly of planktonic species.

April 1985 (Tables 6.13 and 6.14)

On 3 April the dominancy of *Skeletonema costatum* continued with the highest numbers in 40 m samples from both stations. The species composition was similar at both depths with small variations at 40 m. The benthic and epiphytic species made small contributions to the total biomass at both depths, with a continuing predominance of the planktonic species.

Similar species were observed on 24 April at both depths from the two stations, with the disappearance of *Biddulphia* spp. from deeper water and *Coscinodiscus* spp. and *Chaetoceros* spp. from stations 3 and 6.

May 1985 (Tables 6.15 and 6.16)

Thalassiosira spp. replaced *Skeletonema costatum* as the dominant representatives on 8 May, although the latter species made up a sizeable part of the biomass. The remaining species were present in small numbers.

On 22 May *Thalassiosira* spp. tended to predominate at all depths at the two stations with small numbers of *Skeletonema costatum*.

Table 6.13

% composition of suspended algae on 3 April 1985

		station 3		station 6	
		20 m	40 m	20 m	40 m
Cell numbers ($x10^5$)		11.1	17.0	17.5	23.2
Green flagellates		1.0	-	-	-
Amphiprora surirelloide	*	-	-	0.02	-
Amphora spp.	*	0.02	-	0.02	0.01
Biddulphia spp.		0.02	-	0.01	-
Coscinodiscus spp.		0.15	0.06	0.06	0.07
Chaetoceros spp.		0.10	0.01	0.26	-
Diatoma elongata		0.10	0.11	-	0.06
Fragilaria spp.	*	0.02	-	0.23	0.01
Leptocylindrus danicus		-	-	-	0.01
Melosira spp.		0.41	-	-	0.12
Navicula spp.	*	0.61	0.81	0.70	0.95
Nitzschia closterium		0.12	0.06	0.15	0.04
N. seriata		-	-	0.02	-
Pinnularia spp.	*	0.35	0.01	0.01	0.01
Pleurosigma spp.	*	-	0.12	-	0.02
Rhabdonema arcuatum	*	-	0.02	0.02	-
Rhizosolenia sp.		-	-	-	0.01
Skeletonema costatum		94.0	96.7	95.9	97.10
Thalassiosira spp.		3.1	2.1	2.6	1.5
% of Green flagellates		1	-	-	-
% of Diatoms		99	100	100	100
% of Planktonic species		99	99	99	99
% of Benthic and Epiphytic species	(*)	1	1	1	1

Table 6.14

% composition of suspended algae on 24 April 1985

		station 3		station 6	
		20 m	40 m	20 m	40 m
Cell numbers ($x10^4$)		45.1	2.77	32.2	2.11
Green flagellates		-	1.0	1.0	-
Amphiprora surirelloide	*	-	0.07	-	-
Amphora spp.	*	-	0.20	0.07	-
Chaetoceros sp.		0.10	-	-	-
Cocconeis clandestira	*	-	-	-	0.1
Coscinodiscus sp.		-	0.2	-	-
Diatoma elongata		0.25	-	0.40	0.1
Fragilaria sp.	*	-	0.2	-	-
Grammatophora marina	*	-	0.26	-	-
Leptocylindrus danicus		0.05	-	-	0.1
Navicula spp.	*	1.0	0.3	0.66	1.9
Nitzschia closterium		-	0.9	0.56	0.5
Skeletonema costatum		93.2	94.7	94.54	94.0
Surirella smithii	*	-	0.17	-	-
Thalassiosira spp.		5.4	3.0	3.5	3.3
Thalassiothrix frauendii	*	-	-	0.27	-
% of Green flagellates		-	1.0	1.0	-
% of Diatoms		100	99.0	99.0	100
% of Planktonic species		99	99.0	99.0	98
% of Benthic and Epiphytic species	(*)	1.0	1.2	1.0	2

Table 6.15

% composition of suspended algae on 8 May 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		128	125	84.3	125	76.0	40.6
Diatoma elongata		-	0.04	-	0.08	0.15	-
Fragilaria spp.	*	0.5	0.40	0.31	0.20	0.40	0.5
Leptocylindrus danicus		-	-	-	0.12	0.45	0.9
Navicula spp.	*	0.5	0.70	0.69	0.80	0.60	0.5
Nitzschia closterium		0.2	0.16	0.30	-	-	0.1
Skeletonema costatum		32.2	37.4	11.8	41.1	40.3	41.6
Thalassiosira spp.		66.6	61.3	86.9	57.7	58.1	56.4
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		99	99	99	99	99	99
% of Benthic and Epiphytic species	(*)	1	1	1.1	1	1	1

Table 6.16
% composition of suspended algae on 22 May 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		154	93.5	17.8	89.6	89.0	49.0
Chaetoceros spp.		-	0.3	0.2	-	0.1	0.4
Diatoma elongata		1.7	0.34	0.2	-	-	0.4
Fragilaria spp.	*	0.6	0.6	0.5	0.5	-	0.5
Leptocylindrus danicus		1.05	-	-	-	-	-
Navicula spp.	*	0.4	0.4	0.5	0.5	1.0	0.5
Nitzschia closterium		0.05	0.06	-	-	-	0.2
N. seriata		-	-	-	-	0.2	-
Skeletonema costatum		1.4	5.3	12.4	1.0	5.4	7.9
Thalassiosira spp.		94.8	93.0	86.2	98.0	93.3	90.1
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		99	99	99	99	99	99
% of Benthic and Epiphytic species	(*)	1	1	1	1	1	1

June 1985 (Tables 6.17 and 6.18)

The predominance of green flagellates was found in the samples collected on 5 June from 3 m, 20 m and 40 m from stations 3 and 6, within two weeks of the domination by *Thalassiosira* spp. with the maximum contributions at 3 m at station 3 and at 40 m at station 6. *Skeletonema costatum* and *Thalassiosira* spp. made large contributions to the total in the 40 m samples from station 3.

On 26 June the dominance of the green flagellates was accompanied by pulses of *Leptocylindrus danicus*. This species was dominant at 3 m at station 3 and made a significant contribution at 3 m at station 6. Benthic species made noticeable contributions to the biomass in 40 m samples at both stations.

July 1985 (Table 6.19)

Leptocylindrus danicus remained the dominant species in phytoplankton populations on 22 July, being most numerous in surface water samples, whilst *Nitzschia seriata* was next in quantity at all depths (Table 6.19). As the water became warmer during summer, the dinoflagellates became more numerous as seen in the appearence of *Ceratium tripos*, *C. arcticum* and *Dinophysis acuta* at 3 m depths at both stations.

August 1985 (Tables 6.20 and 6.21)

Green flagellates reappeared again in all samples on 5 August, making with *Leptocylindrus danicus* the major biomass contributions at 20 m and 40 m at station 3, and dominating the species from 3 m and 40 m at station 6. Dinoflagellate species contributed this time to the standing crop at all depths at both stations, although in small numbers.

Table 6.17

% composition of suspended algae on 5 June 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		38.8	30.1	3.47	20.0	8.87	5.70
Green flagellates		97.0	94.7	49.0	88.0	81.0	90.3
Coscinodiscus sp.		-	0.1	-	-	-	-
Diatoma elongata		-	0.2	0.5	-	-	-
Fragilaria sp.	*	-	0.2	-	-	-	-
Grammatophora marina	*	-	0.5	0.9	-	1.8	0.3
Leptocylindrus danicus		-	-	-	-	2.8	-
Navicula spp.	*	0.4	0.3	8.1	1.7	1.8	0.8
Nitzschia closterium		0.2	0.1	-	-	1.3	-
N. seriata		0.1	-	-	-	1.0	-
Pinnularia sp.	*	-	-	-	0.3	-	-
Skeletonema costatum		0.3	1.0	14.0	4.6	5.1	3.1
Thalassiosira spp.		2.0	2.9	27.5	5.4	5.1	5.5
% of Green flagellates		97.0	94.7	49.0	88.0	81.0	90.3
% of Diatoms		3.0	5.3	51.0	12.0	19.0	9.7
% of Planktonic species		99.6	99	91	98	96.4	98.9
% of Benthic and Epiphytic species	(*)	0.4	1.0	9.0	2.0	3.6	1.1

Table 6.18
% composition of suspended algae on 26 June 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		40.0	54.0	2.98	95.8	79.0	2.92
Green flagellates		30.0	62.0	42.6	54.0	54.3	34.0
Biddulphia spp.		-	-	-	-	-	3.4
Diatoma elongata		-	-	1.6	-	-	0.7
Fragilaria sp.	*	-	-	3.8	-	-	-
Leptocylindrus danicus		62.5	34.3	10.9	45.5	44.7	6.8
Melosira spp.		0.2	-	-	0.3	-	-
Navicula spp.	*	-	-	8.2	-	0.2	4.1
Nitzschia closterium		3.2	-	-	-	-	0.7
N. seriata		-	-	-	-	-	0.7
Pinnularia sp.	*	-	-	2.3	-	-	-
Rhizosolenia alata		1.6	-	-	-	-	-
Skeletonema costatum		-	1.0	15.8	-	0.5	26.0
Thalassiosira spp.		2.5	1.7	14.8	0.2	0.5	22.6
Dictyocha speculum		-	1.0	-	-	-	1.0
% of Green flagellates		30.0	62.0	42.6	54.0	54.3	34.0
% of Diatoms		70.0	37.0	57.4	46.0	45.7	65.0
% of Planktonic species		100	100	85.7	100	99.8	95.9
% of Benthic and Epiphytic species	(*)	-	-	14.3	-	0.2	4.1

Table 6.19
% composition of suspended algae on 22 July 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		32.0	10.9	6.05	13.7	7.45	3.47
Green flagellates		6.0	16.8	-	1.4	-	-
Amphora sp.	*	-	-	0.3	-	-	-
Ceratium arcticum		0.9	-	-	0.2	-	-
Ceratium tripos		1.1	-	-	0.3	-	-
Chaetoceros sp.		-	-	-	2.8	-	-
Diatoma elongata		0.3	-	-	-	-	-
Dinophysis acuta		-	-	-	0.9	0.7	-
Leptocylindrus danicus		82.3	54.7	72.6	70.1	69.3	63.0
Melosira spp.		-	1.8	-	-	-	6.3
Navicula spp.	*	-	-	1.8	0.5	0.7	4.1
Nitzschia closterium		0.8	-	-	1.1	0.7	-
N. seriata		8.1	25.3	16.0	20.6	24.4	22.5
Rhizosolenia spp.		-	0.6	0.7	0.5	-	-
Skeletonema costatum		-	-	2.8	1.4	1.7	-
Thalassiosira spp.		0.5	0.8	5.8	-	2.5	4.1
Dictyocha speculum		-	-	-	0.2	-	-
% of Dinoflagellates		2.0	-	-	1.4	0.7	-
% of Green flagellates		6.0	16.8	-	1.4	-	-
% of Diatoms		92.0	83.2	100	97.0	99.3	100
% of Planktonic species		100	100	97.9	99.5	99.3	95.9
% of Benthic and Epiphytic species	(*)	-	-	2.1	0.5	0.7	4.1

Table 6.20

% composition of suspended algae on 5 August 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		182	13.8	5.76	68.1	4.40	1.85
Green flagellates		23.0	58.4	45.1	65.0	31.3	55.1
Ceratium arcticum		0.1	-	-	1.7	2.0	1.7
Ceratium tripos		0.9	0.5	-	-	-	0.9
Chaetoceros spp.		0.3	1.1	1.4	0.1	-	-
Diatoma elongata		-	-	-	-	-	4.2
Dinophysis acuta		-	0.3	0.9	-	0.8	-
Leptocylindrus danicus		72.4	33.0	37.1	30.3	56.2	19.5
Navicula spp.	*	1.0	0.8	4.2	-	2.7	-
Nitzschia closterium		0.02	0.2	-	0.1	-	2.5
N. seriata		0.15	-	-	-	-	3.4
Rhizosolenia spp.		0.13	0.3	-	-	-	-
Skeletonema costatum		-	-	3.3	-	-	-
Thalassiosira spp.		1.0	5.4	6.1	1.8	7.0	12.7
Dictyocha speculum		1.0	-	1.9	1.0	-	-
% of Dinoflagellates		1.0	0.8	0.9	1.7	2.8	2.6
% of Green flagellates		23.0	58.4	45.1	65.0	31.3	55.1
% of Diatoms		74.0	40.0	52.1	32.3	65.9	42.3
% of Planktonic species		99.0	99.2	95.8	100	97.3	100
% of Benthic and Epiphytic species	(*)	1.0	0.8	4.2	-	2.7	-

On 21 August the phytoplankton biomass was dominated by the dinoflagellates in the 3 m samples at both stations, (especially *Ceratium tripos*) and by *Thalassiosira* spp. in the depth samples at the two stations. *Skeletonema costatum* and green flagellates made high contributions to the cell numbers in 40 m samples at stations 3 and 6 respectively. *Navicula* spp constituted the main component of the benthic species in the depth samples.

September 1985 (Tables 6.22 and 6.23)

A similar composition of species was observed on 4 September at both stations at all depths with *Skeletonema costatum* representing more than 90% of cell numbers in 3 m samples, whilst *Thalassiosira* spp. dominated the populations in the depth samples at the two stations. At this time *Ceratium tripos* tended to remain numerous in the depth samples, with maxima at 20 m depths at both stations.

On 18 September (probably at about the autumnal peak of cell numbers) the majority of the total biomass consisted of green flagellates, *Skeletonema costatum* and *Thalassiosira* spp., with small contributions from the remaining species. The predominance of *Skeletonema* was evident at all depths at both stations with maxima at 40 m at stations 3 and 6, whilst the green flagellates made numerous contributions to the total cell numbers at 3 m depths at the two stations and at 20 m at station 3.

October 1985 (Tables 6.24 and 6.25)

Thalassiosira spp. now replaced *Skeletonema* as the most numerous organism, although high numbers of *Skeletonema* was observed in the depth samples on 9 October . The silicoflagellate *Dictyocha speculum* occurred at all depths. Dinoflagellates disappeared completely on 30 October, whilst green flagellates and *Navicula* spp. were found at all

Table 6.21

% composition of suspended algae on 21 August 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		11.9	2.99	2.48	6.71	2.64	2.54
Green flagellates		11.7	-	-	-	8.9	38.0
Amphora sp.	*	-	-	-	-	-	0.5
Caloneis sp.	*	-	-	-	-	-	1.1
Ceratium candelabrum		4.7	-	-	7.6	-	-
Ceratium extensum		4.7	1.1	-	-	0.6	-
Ceratium fusus		5.6	1.6	-	9.5	1.8	2.7
Ceratium setaceum		5.6	-	-	1.8	-	-
Ceratium tripos		51.1	5.2	-	61.1	8.3	-
Chaetoceros spp.		-	2.1	-	-	3.0	-
Diatoma elongata		2.6	1.6	-	-	-	-
Dinophysis acuta		-	1.1	-	-	-	-
Fragilaria sp	*	-	-	3.4	-	-	-
Leptocylindrcus danicus		2.1	7.3	-	1.4	20.1	1.1
Melosira sp.		-	-	-	-	2.4	-
Navicula spp.	*	-	3.1	5.0	-	7.1	5.3
Peridinium spp.		4.2	1.1	1.7	1.4	-	-
Pinnularia sp.	*	-	-	-	-	-	1.1
Rhizosolenia sp.		-	-	2.5	-	-	-
Skeletonema costatum		-	11.5	25.2	-	6.5	-
Thalassiosira spp.		5.4	62.7	60.5	15.8	41.3	47.0
Dictyocha speculum		2.3	1.6	1.7	1.4	-	3.2
% of Dinoflagellates		75.9	10.1	1.7	81.4	10.7	2.7
% of Green flagellates		11.7	-	-	-	8.9	38.0
% of Diatoms		10.1	88.3	96.6	17.2	80.4	56.1
% of Planktonic species		100.0	96.9	91.6	100.0	92.9	92.0
% of Benthic and Epiphytic species	(*)	-	3.1	8.4	-	7.1	8.0

Table 6.22

% composition of suspended algae on 4 September 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		30.4	2.36	1.97	43.2	2.83	1.39
Green flagellates		-	-	-	0.3	-	-
Ceratium arcticum		-	-	-	0.1	-	-
Ceratium candelabrum		0.3	-	-	0.1	-	-
Ceratium extensum		-	-	-	0.1	-	-
Ceratium fusus		0.3	2.0	-	-	-	-
Ceratium tripos		1.4	23.2	7.9	0.7	5.0	4.5
Chaetoceros sp.		-	-	-	-	1.1	-
Diatoma elongata		-	-	3.2	-	2.2	5.6
Dinophysis acuta		-	2.7	-	-	-	-
Fragilaria sp.	*	-	-	-	-	1.7	-
Leptocylindrus danicus		-	9.3	4.0	-	-	-
Navicula spp.	*	0.5	9.9	7.9	0.2	5.0	9.0
Nitzschia closterium		0.2	-	-	-	-	-
Pinnularia spp.	*	-	-	3.2	-	-	5.6
Skeletonema costatum		91.3	15.2	4.0	93.2	19.3	5.6
Synedra ulna	*	-	-	-	-	-	3.4
Thalassiosira spp.		5.7	37.7	66.6	5.0	65.7	61.8
Dictyocha speculum		0.3	-	3.2	0.3	-	4.5
% of Dinoflagellates		2.0	27.9	7.9	1.0	5.0	4.5
% of Green flagellates		-	-	-	0.3	-	-
% of Diatoms		97.7	72.1	88.9	98.4	95.0	91.0
% of Planktonic species		99.5	90.1	88.9	99.8	93.3	82.0
% of Benthic and Epiphytic species	(*)	0.5	9.9	11.1	0.2	6.7	18.0

Table 6.23

% composition of suspended algae on 18 September 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^5$)		3.17	3.31	4.97	4.90	4.36	4.18
Green flagellates		38.2	15.9	-	25.3	-	-
Ceratium candelabrum		1.5	0.3	-	0.8	0.2	-
Ceratium fusus		0.3	0.1	-	-	-	-
Ceratium tripos		0.7	0.2	-	0.2	0.2	-
Diatoma elongata		-	0.3	-	-	-	-
Dinophysis acuta		-	-	-	0.1	0.3	-
Eunotia repens	*	-	-	0.5	-	-	-
Fragilaria spp.	*	-	0.1	-	0.4	0.3	-
Leptocylindrus danicus		0.3	-	-	0.4	0.3	-
Navicula spp.	*	-	0.5	0.2	0.3	0.3	0.5
Nitzschia closterium		-	-	-	-	0.1	-
Skeletonema costatum		43.2	57.3	85.6	55.5	83.0	81.2
Thalassiosira spp.		15.8	24.2	12.9	16.3	15.0	17.6
Dictyocha speculum		-	1.1	0.8	0.7	0.3	0.7
% of Dinoflagellates		2.5	0.6	-	1.1	0.7	-
% of Green flagellates		38.2	15.9	-	25.3	-	-
% of Diatoms		59.3	82.4	99.2	72.90	99.0	99.4
% of Planktonic species		100	99.4	99.3	99.3	99.4	99.5
% of Benthic and Epiphytic species	(*)	-	0.6	0.7	0.7	0.6	0.5

Table 6.24
% composition of suspended algae on 9 October 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		13.9	4.73	4.13	16.8	6.04	4.55
Green flagellates		6.8	-	-	5.5	-	-
Ceratium candelabrum		11.7	1.0	-	3.4	-	0.7
Ceratium fusus		1.8	-	-	-	-	-
Ceratium tripos		0.4	-	1.2	0.4	0.5	1.0
Diatoma elongata		-	-	-	0.2	-	-
Fragilaria sp.	*	-	-	-	-	-	1.7
Leptocylindrus danicus		-	-	-	0.6	-	-
Navicula spp.	*	-	1.0	1.7	-	4.5	3.1
Skeletonema costatum		3.0	19.8	43.7	2.8	29.3	44.3
Thalassiosira spp.		74.1	77.5	51.7	85.4	64.4	47.8
Dictyocha speculum		2.2	0.7	1.7	1.7	1.3	1.4
% of Dinoflagellates		13.9	1.0	1.2	3.8	0.5	1.7
% of Green flagellates		6.8	-	-	5.5	-	-
% of Diatoms		77.1	98.3	97.1	89.0	98.2	96.9
% of Planktonic species		100	99.0	98.3	100	95.5	95.2
% of Benthic and Epiphytic species	(*)	-	1.0	1.7	-	4.5	4.8

Table 6.25

% composition of suspended algae on 30 October 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		7.89	3.52	2.15	12.0	3.53	1.71
Green flagellates		2.2	4.1	6.8	1.6	3.2	8.3
Diatoma elongata		0.6	2.7	-	0.8	-	-
Fragilaria spp.	*	0.6	3.2	-	5.9	1.1	1.8
Leptocylindrus danicus		-	2.5	3.4	-	3.8	2.8
Navicula spp.	*	1.6	3.3	5.1	0.6	4.3	2.8
Nitzschia seriata		-	-	-	0.3	-	-
Skeletonema costatum		1.2	4.3	5.9	6.9	3.8	7.3
Thalassiosira spp.		92.8	79.2	75.4	82.8	83.8	73.3
Dictyocha speculum		1.0	0.7	3.4	1.1	-	3.7
% of Green flagellates		2.2	4.1	6.8	1.6	3.2	8.3
% of Diatoms		96.8	95.2	89.8	97.3	96.8	88.0
% of Planktonic species		97.8	96.8	94.9	93.5	94.6	95.4
% of Benthic and Epiphytic species	(*)	2.2	6.5	5.1	6.5	5.4	4.6

depths, this time with the dominance of *Thalassiosira.*

November 1985 (Tables 6.26 and 6.27)

The same species component was recorded on 11 November, with *Thalassiosira* spp. remaining dominant at all depths, with larger numbers in depth samples at both stations.

On 20 November three organisms were present in considerable numbers with *Skeletonema costatum* the most numerous in 3 m samples and 20 m sample at station 3, although this species was scarce in the preceeding week. *Thalassiosira* spp. dominated the population at 40 m depths at station 3 and 6. *Nitzschia frigida* was found at 20 m and 40 m depths at station 6.

December 1985 (Table 6.28)

The winter period was characterized by a reduction in day lengths and hours of sunlight, low temperatures and strong winds. These effects on the population were clearly shown on 9 December when low phytoplankton cell numbers were obtained. The standing crop composition was mainly of *Thalassiosira* spp.. *Navicula* made high contributions to the total at 3 m at the two stations and at 20 m at station 6 and *Coscinodiscus* spp. appeared usually in winter and the rest of the species made thier contributions to the biomass as seen in Table 6.28.

Table 6.26

% composition of suspended algae on 11 November 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		2.71	1.99	2.08	1.88	1.91	1.66
Green flagellates		32.8	13.4	-	18.6	9.8	3.8
Biddulphia sp.		-	-	-	1.6	-	-
Diatoma elongata		1.8	-	2.3	4.0	-	-
Fragilaria spp.	*	-	1.6	5.3	-	-	1.9
Leptocylindrus danicus		4.1	2.4	-	3.2	-	-
Navicula spp.	*	5.9	6.3	4.8	2.4	7.4	5.7
Rhisosolenia sp.		-	-	-	-	-	0.9
Skeletonema costatum		7.0	10.2	7.9	-	-	-
Thalassoisira spp.		46.1	62.2	75.7	62.9	78.7	84.9
Dictyocha speculum		2.3	3.9	4.0	7.3	4.1	2.8
% of Green flagellates		32.8	13.4	-	18.6	9.8	3.8
% of Diatoms		64.9	82.7	96.0	74.1	86.1	93.4
% of Planktonic species		94.1	92.1	89.9	97.6	92.6	92.4
% of Benthic and Epiphytic species	(*)	5.9	7.9	10.1	2.4	7.4	7.6

Table 6.27

% composition of suspended algae on 20 November 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		3.58	3.11	3.18	6.60	2.71	1.12
Green flagellates		14.7	22.1	1.0	24.6	18.5	11.1
Biddulphia spp.		-	-	-	0.5	-	-
Diatoma elongata		0.9	1.0	-	1.2	3.5	5.6
Fragilaria spp.	*	2.2	5.5	4.4	1.9	6.9	8.3
Grammatophora marina	*	-	-	1.0	-	-	-
Green algae		-	-	19.7	-	-	-
Gyrosigma hippocampus	*	-	-	-	-	1.2	-
Leptocylindrus danicus		2.2	3.5	1.0	1.7	1.7	-
Melosira sp.		4.0	-	-	-	-	-
Navicula spp.	*	6.1	4.5	3.9	11.1	9.8	9.7
Nitzschia frigida		-	-	-	-	18.5	2.8
Rhabdonema sp.	*	-	-	11.8	-	-	-
Skeletonema costatum		37.2	30.2	-	39.3	16.8	-
Thalassiosira spp.		29.2	29.7	56.2	19.2	20.2	56.9
Dictyocha speculum		3.5	3.5	1.0	0.5	2.9	5.6
% of Green flagellates		14.7	22.1	1.0	24.6	18.5	11.1
% of Diatoms		81.7	74.4	98.0	74.9	78.6	83.3
% of Planktonic species		91.7	90.0	78.9	87.0	82.1	82.0
% of Benthic and Epiphytic species	(*)	8.3	10.0	21.1	13.0	17.9	18.0

Table 6.28

% composition of suspended algae on 9 December 1985

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		1.00	1.57	1.98	0.94	1.11	1.23
Green flagellates		12.3	2.0	-	6.7	11.3	-
Amphora spp.	*	-	-	1.8	-	-	10.2
Biddulphia sp.		-	-	2.5	-	-	-
Coscinodiscus spp.		9.4	7.0	7.7	8.3	14.1	8.2
Diatoma elongata		3.2	-	1.8	-	2.8	10.2
Diploneis spp.	*	4.7	2.0	-	-	-	-
Fragilaria spp.	*	6.4	2.0	1.8	-	-	-
Gyrosigma sp.	*	-	-	1.8	-	-	-
Melosira sp.		-	8.0	-	-	-	-
Navicula spp.	*	20.3	6.0	2.8	16.7	19.7	4.1
Pinnularia spp.	*	-	-	-	-	7.0	-
Skeletonema costatum		7.8	15.0	-	-	-	-
Thalassiosira spp.		28.1	56.0	77.2	68.9	45.1	61.2
Dictyocha speculum		7.8	2.0	2.6	-	-	6.1
% of Green flagellates		12.3	2.0	-	6.7	11.3	-
% of Diatoms		79.9	96.0	97.7	93.3	88.7	93.9
% of Planktonic species		68.6	90.0	91.8	83.3	73.3	85.7
% of Benthic and Epiphytic species	(*)	31.4	10.0	8.2	16.7	26.7	14.3

The phytoplankton composition throughout the months of 1986 and until April 1987 is displayed in Tables 6.29-6.56 showing the distributions of the species and their contributions to the total biomass at the different depths of the two stations, whilst planktonic and benthic algal cells (Figs. 6.10-6.12) with diatoms, dinoflagellates, green flagellates and silicoflagellates are presented in Figs. 6.13-6.15.

January 1986 (Table 6.29)

The population composition found during December 1985 occurred again on 6 January, with a prediominancy of green flagellates at 3 m at station 3 and at station 6, whilst *Thalassiosira* spp. were dominant at 40 m at both stations and *Skeletonema costatum* at 3 m at station 6. The high contributions of benthic (mainly of *Navicula* spp.) algae were obtained at 40 m at station 3 and at 3 m at station 6.

February 1986 (Table 6.30)

The dominance of *Coscinodiscus* spp. occurred on 12 February at 3 m, 20 m and 40 m depths at station 3 and at 40 m depth at station 6. Equal quantities of cell numbers of *Coscinodiscus* spp., *Navicula* spp. and *Thalassiosira* spp. were found with a considerable contribution of *Skeletonema costatum* at 3 m at station 6. *Synedra ulna* contributed more to the total biomass at 20 m at station 6 so increasing the proportion of benthic species in the total cell numbers.

Fig. 6. 10. The contributions of planktonic and benthic algal cells to the total biomass (in percentages) for 3 m, 20 m and 40 m from station 3 during the period January to December 1986.

Planktonic species

Benthic and epiphytic species

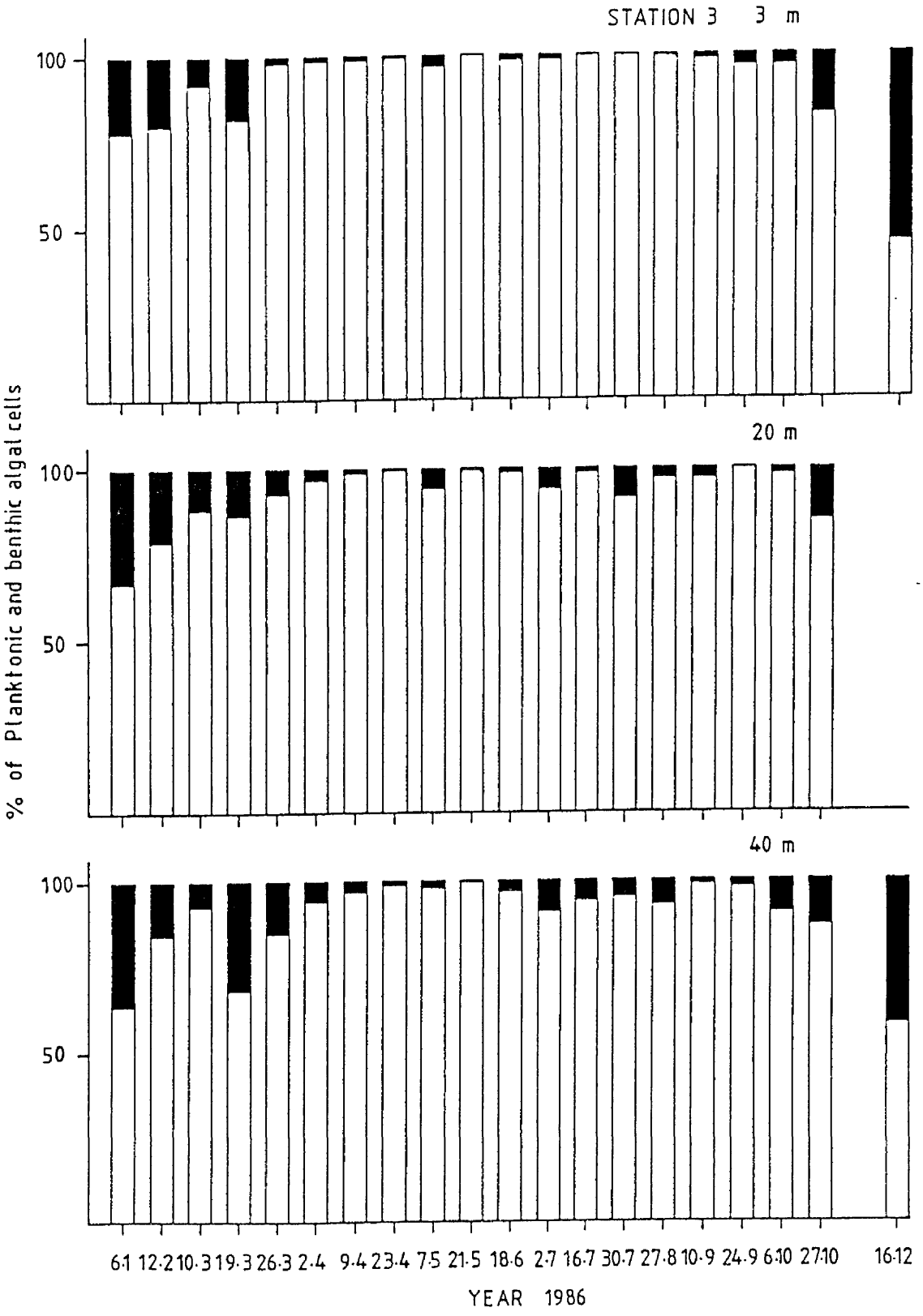

STATION 3 3 m
100
50
20 m
100
50
40 m
100
50
% of Planktonic and benthic algal cells
6·1 12·2 10·3 19·3 26·3 2·4 9·4 23·4 7·5 21·5 18·6 2·7 16·7 30·7 27·8 10·9 24·9 6·10 27·10 16·12
YEAR 1986

Fig. 6. 11. The contributions of planktonic and benthic algal cells in the (percentage) in the 3 m, 20 m and 40 m samples at station 6 during the period January to December 1986.

Planktonic species

Benthic and epiphytic species

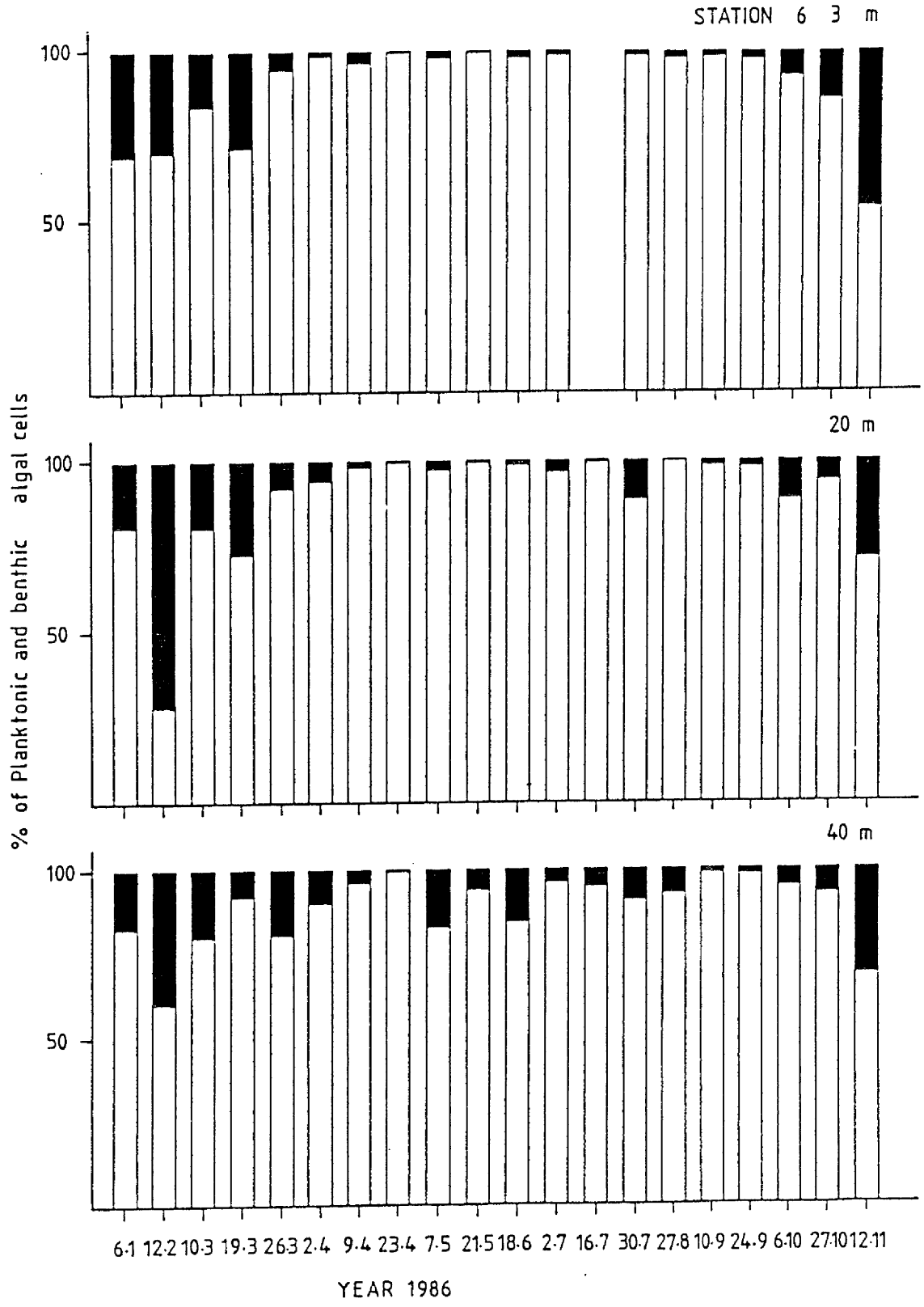

STATION 6 3 m
100
50
20 m
100
50
40 m
100
50
% of Planktonic and benthic algal cells
6·1 12·2 10·3 19·3 26·3 2·4 9·4 23·4 7·5 21·5 18·6 2·7 16·7 30·7 27·8 10·9 24·9 6·10 27·10 12·11
YEAR 1986

Fig. 6. 12. The contributions of planktonic and benthic cells to the total biomass (in percentages) in the 3 m, 20 m and 40 m samples at stations 3 and 6 during the period January to the end of March 1987 for station 3 and to the end of April 1987 for station 6.

Planktonic species

Benthic and epiphytic spcies

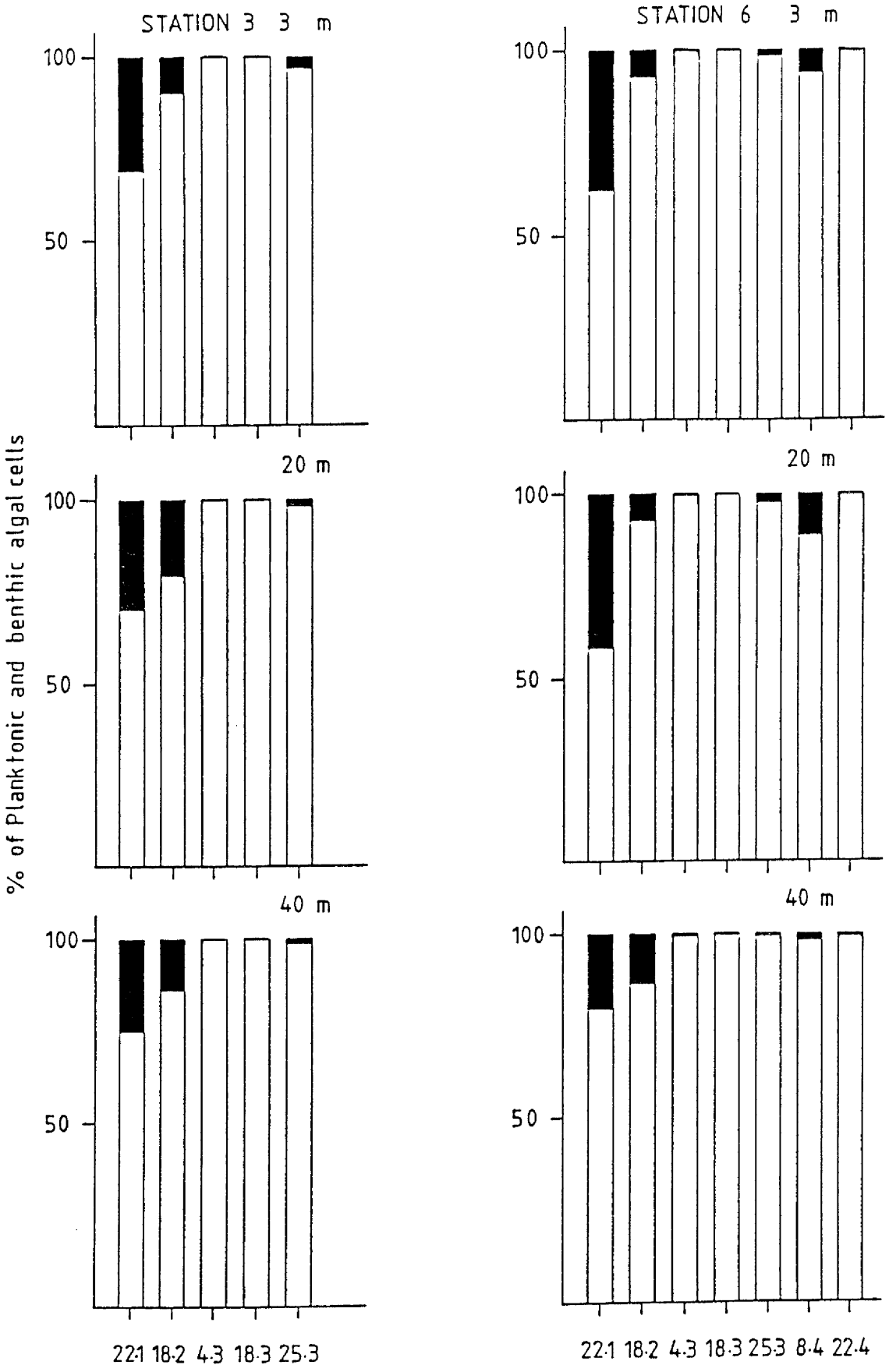

STATION 3 3 m
STATION 6 3 m
20 m
20 m
40 m
40 m
100
50
% of Planktonic and benthic algal cells
22·1 18·2 4·3 18·3 25·3
22·1 18·2 4·3 18·3 25·3 8·4 22·4
YEAR 1987

Fig. 6. 13. The contributions of diatoms, dinoflagellates, silicoflagellates and green flagellates (in percentages) to the total biomass for 3 m, 20 m and 40 m at station 3 through the period January to December 1986.

Diatoms

Dinoflagellates

Green flagellates

Silicoflagellates

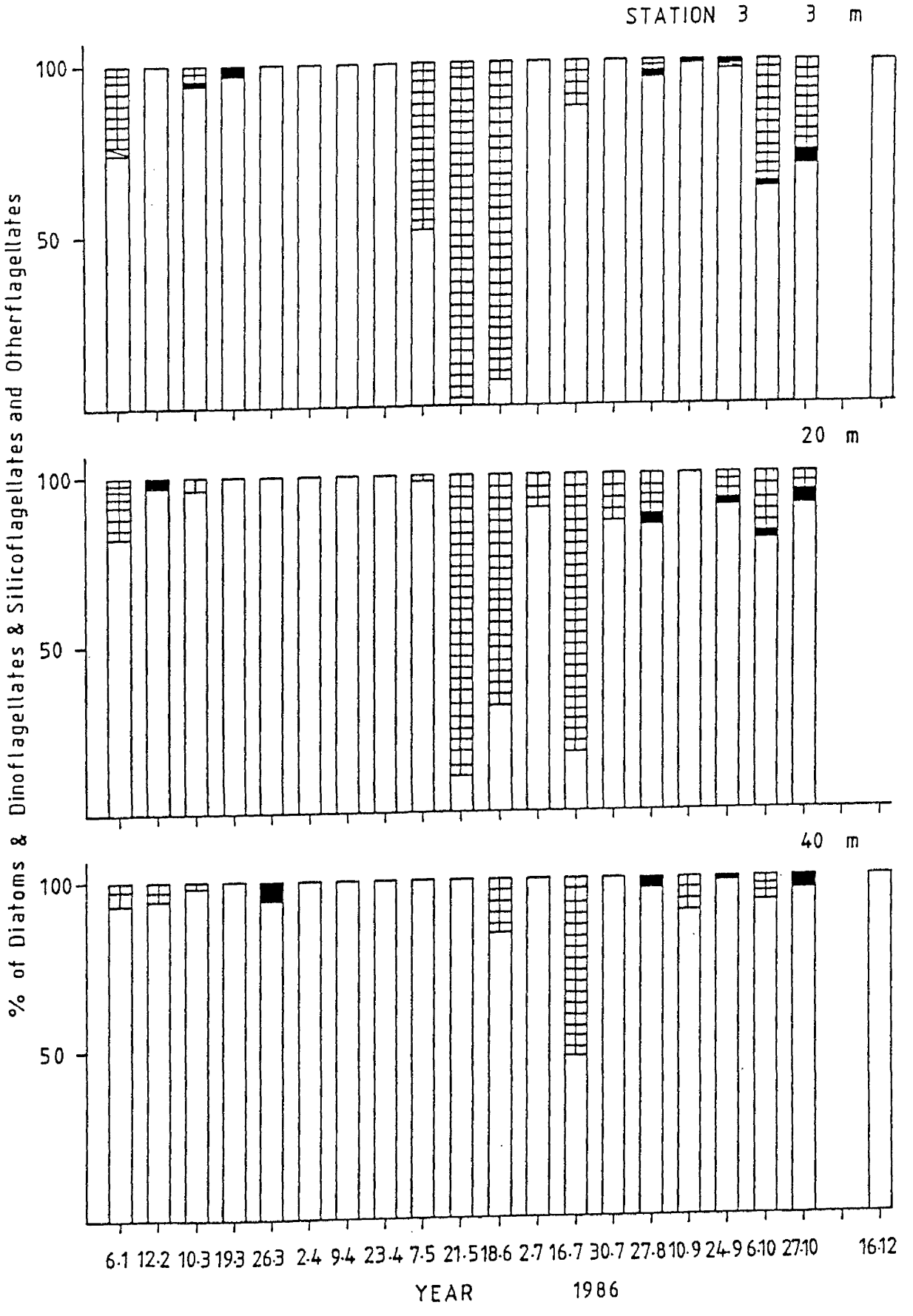
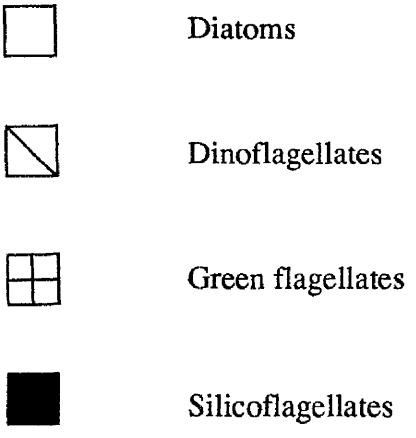

STATION 3 3 m
100
50
20 m
100
50
40 m
100
50
% of Diatoms & Dinoflagellates & Silicoflagellates and Otherflagellates
6·1 12·2 10·3 19·3 26·3 2·4 9·4 23·4 7·5 21·5 18·6 2·7 16·7 30·7 27·8 10·9 24·9 6·10 27·10 16·12
YEAR 1986

Fig. 6. 14. The contributions of diatoms, dinoflagellates, green flagellates and silicoflagellates contributions in the percentages to the total biomass for 3 m, 20 m and 40 m from station 6 through January to December 1986.



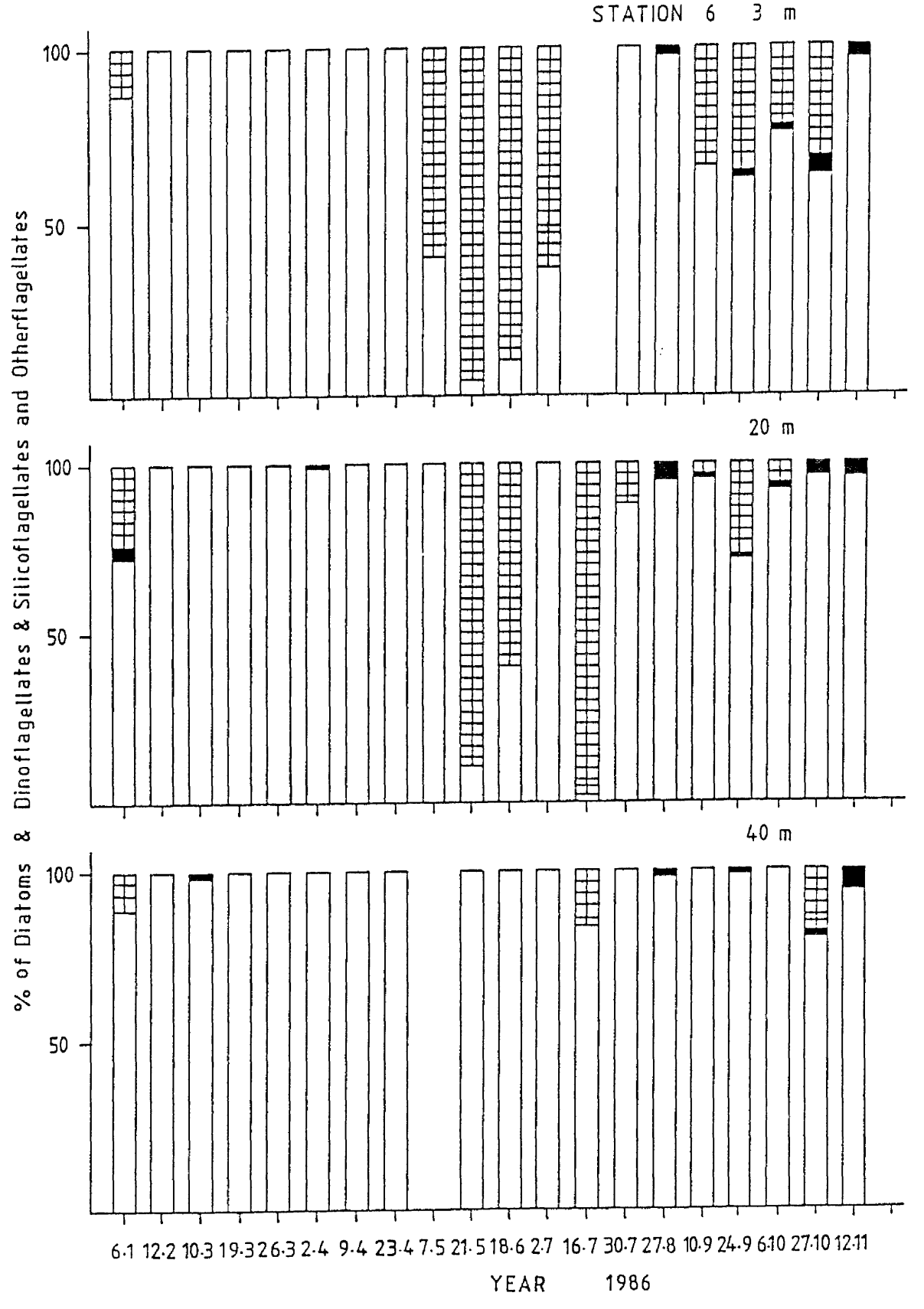

STATION 6 3 m
20 m
40 m
100
50
% of Diatoms & Dinoflagellates & Silicoflagellates and Otherflagellates
6·1 12·2 10·3 19·3 26·3 2·4 9·4 23·4 7·5 21·5 18·6 2·7 16·7 30·7 27·8 10·9 24·9 6·10 27·10 12·11
YEAR 1986

Fig. 6. 15. The contributions of diatoms, dinoflagellates, green flagellates and silicoflagellates (in percentage) to the total biomass for 3 m, 20 m and 40 m samples at stations 3 and 6 through the period January to March 1987 for station 3 and to April 1987 for station 6.

Diatoms

Dinoflagellates

Green flagellates

Silicoflagellates

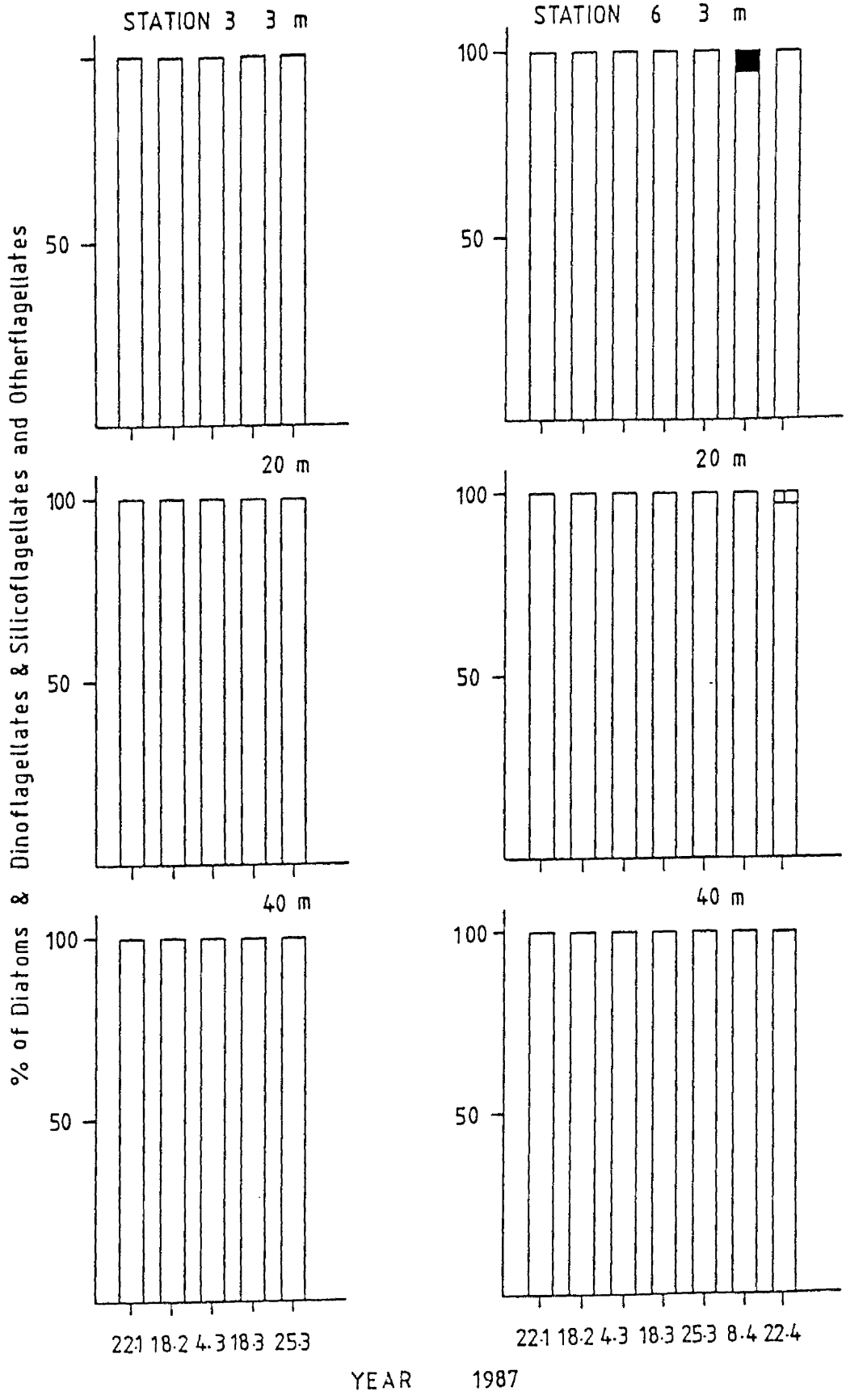

STATION 3 3 m
STATION 6 3 m
20 m
20 m
40 m
40 m
100
50
% of Diatoms & Dinoflagellates & Silicoflagellates and Otherflagellates
22·1 18·2 4·3 18·3 25·3
22·1 18·2 4·3 18·3 25·3 8·4 22·4
YEAR 1987

Table 6.29

% composition of suspended algae on 6 January 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell Numbers ($x10^3$) per liter		11.10	13.5	9.70	4.69	8.45	8.45
Green flagellates		22.2	17.8	6.5	13.3	24.1	11.1
Amphora spp.	*	-	2.2	3.2	-	-	-
Ceratium fusus		2.6	-	-	-	-	-
Coscinodiscus spp.		7.9	13.3	19.4	10.0	11.1	11.1
Diatoma elongata		5.3	2.2	-	-	3.7	16.7
Fragilaria spp.	*	-	-	3.2	3.3	-	-
Grammatophora marina	*	-	-	4.8	-	-	-
Leptocylindrus danicus		6.6	4.5	-	-	-	-
Melosira sp.		-	-	-	6.7	-	-
Navicula spp.	*	13.2	20.0	21.0	20.0	14.8	7.4
Nitzschia frigida		4.0	-	-	-	-	-
Pinnularia spp.	*	5.3	5.6	3.2	6.7	3.7	-
Rhabdonema sp.	*	-	-	-	-	-	9.3
Skeletonema costatum		11.8	10.0	-	26.7	20.4	-
Synedra undulata	*	4.0	4.4	-	-	-	-
Thalassiosira spp.		17.1	17.8	38.7	13.3	18.5	44.4
Dictyocha speculum		-	-	-	-	3.7	-
% of Dinoflagellates		2.6	-	-	-	-	-
% of Green flagellates		22.2	17.8	6.5	13.3	24.1	11.1
% of Diatoms		75.2	82.2	93.5	86.7	72.2	88.9
% of Planktonic species		77.5	67.8	64.6	70.0	81.5	83.3
% of Benthic and Epiphytic species(*)		22.5	32.2	35.4	30.0	18.5	16.7

Table 6.30

% composition of suspended algae on 12 February 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^3$)		7.40	7.94	15.9	6.26	6.10	7.98
Green flagellates		-	-	4.6	-	-	-
Amphora sp.	*	-	-	-	-	-	3.9
Caloneis sp.	*	-	3.0	-	-	-	-
Coscinodiscus spp.		46.6	21.2	20.0	20.0	15.4	23.5
Diatoma elongata		6.7	-	-	-	-	17.7
Fragilaria spp.	*	-	-	4.6	-	-	5.9
Melosira sp.		-	27.3	-	-	-	-
Navicula spp.	*	20.0	18.2	4.6	20.0	18.0	19.6
Nitzschia frigida		6.7	9.1	29.2	-	-	3.9
Pinnularia spp.	*	-	-	4.6	10.0	7.7	7.8
Pleurosigma sp.	*	-	-	-	-	5.1	-
Skeletonema costatum		-	-	13.9	30.0	-	-
Synedra ulna	*	-	-	-	-	38.4	-
Thalassiosira spp.		20.0	18.2	18.5	20.0	15.4	17.7
Dictyocha speculum		-	3.0	-	-	-	-
% of Green flagellates		-	-	4.6	-	-	-
% of Diatoms		100	97.0	95.4	100	100	100
% of Planktonic species		80.0	78.8	86.2	70.0	30.8	62.8
% of Benthic and Epiphytic species	(*)	20.0	21.2	13.8	30.0	69.2	37.2

March 1986 (Tables 6.31-6.33)

Skeletonema costatum dominated the population of phytoplankton on 10 March with an appearance of *Nitzschia closterium* and *N. seriata* at all depths at the two stations. Station 3 was quite distinct from station 6 by the presence of green flagellates and *Leptocylindrus danicus* at all depths at station 3, whilst *Amphora* spp. and *Diatoma elongata* appeared at all depths at station 6.

On 19 March similar species compositions were obtained at both stations with abundance of three species at different depths at both stations. These organisms were *Skeletonema costatum* which dominated at 3 m at station 3 and at 40 m at station 6, whilst *Thalassiosira* spp. was dominant at 20 m depths at both stations and at 40 m at station 3. *Nitzschia closterium* contributed to the biomass in large numbers in deep water samples, whilst there were small numbers in the surface water samples at both stations.

On 26 March *Leptocylindrus danicus* appeared suddenly at both stations adding to the abundance of the phytoplankton population in the 3 m samples, there were also high contributions from *Skeletonema costatum* and *Thalassiosira* spp. at 20 m at station 6, whilst *Skeletonema* made up the bulk of the population at 20 m at station 3. *Nitzschia closterium* constituted the majority of species composition at 40 m depths at both stations accompanied by *Thalassiosira* at station 3 and by *Skeletonema costatum* at station 6. Slight variations of composition were found at station 3.

April 1986 (Tables 6.34-6.36)

The population of phytoplankton was dominated by *Skeletonema costatum* on 2 April at all depths at both stations, at a time when the spring outburst was evident. A similar species composition was found on 9 April in all samples collected from stations 3 and

Table 6.31

% composition of suspended algae on 10 March 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		7.90	3.58	4.14	3.51	2.75	3.95
Green flagellates		4.7	3.5	1.6	-	-	-
Amphora spp.	*	-	-	1.1	3.1	1.7	2.4
Diatoma elongata		-	-	1.6	5.0	2.6	1.8
Leptocylindrus danicus		2.7	4.4	8.1	-	-	3.1
Licmophora sp.	*	1.3	-	-	-	-	-
Navicula spp.	*	6.6	12.3	4.3	9.4	14.6	4.3
Nitzschia closterium		7.0	6.2	7.6	6.3	5.2	12.2
N. seriata		0.7	5.3	6.0	6.3	6.9	6.1
Pinnularia spp.	*	-	-	1.6	1.3	2.6	1.2
Skeletonema costatum		58.7	53.3	52.4	51.3	41.4	33.6
Surirella spp.	*	-	-	-	1.9	-	-
Synedra ulna	*	-	-	-	-	-	11.6
Thalassiosira spp.		17.3	15.0	15.7	15.6	25.0	21.3
Dictyocha speculum		1.0	-	-	-	-	2.4
% of Green flagellates		4.7	3.5	1.6	-	-	-
% of Diatoms		94.3	96.5	98.4	100	100	97.6
% of Planktonic species		92.1	87.7	93.0	84.3	81.1	80.5
% of Benthic and Epiphytic species	(*)	7.9	12.3	7.0	15.7	18.9	19.5

Table 6.32

% composition of suspended algae on 19 March 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		3.80	1.95	1.68	1.57	1.67	3.20
Amphora spp.	*	1.8	-	1.6	-	2.7	-
Cocconeis spp.	*	0.9	-	3.3	3.2	2.7	-
Diatoma elongata		1.8	5.8	6.6	3.2	8.0	2.4
Fragilaria sp.	*	-	2.3	-	3.2	-	-
Leptocylindrus danicus		-	-	-	6.5	-	-
Licmophora spp.	*	1.8	-	3.3	-	-	2.4
Navicula spp.	*	9.1	10.3	11.5	8.1	17.3	3.3
Nitzschia closterium		10.0	18.4	21.1	17.7	20.0	17.9
N. seriata		2.7	13.8	13.1	3.3	8.0	17.1
Pinnularia sp.	*	1.8	-	-	-	-	-
Skeletonema costatum		48.2	14.9	-	-	13.3	30.1
Synedra ulna	*	0.9	-	11.5	12.9	4.0	1.6
Thalassiosira spp.		18.2	34.5	28.0	41.9	24.0	25.2
Dictyocha speculum		2.8	-	-	-	-	-
% of Diatoms		97.2	100	100	100	100	100
% of Planktonic species		83.7	87.4	68.8	72.6	73.3	92.7
% of Benthic and Epiphytic species	(*)	16.3	12.6	31.2	27.4	26.7	7.3

Table 6.33

% composition of suspended algae on 26 March 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		40.5	1.36	1.34	23.6	2.41	1.17
Amphora spp.	*	0.2	3.3	-	0.3	-	-
Amphiprora spp.	*	0.2	-	3.7	-	-	-
Cocconeis sp.	*	0.2	-	-	-	-	-
Diatoma elongata		0.3	4.9	-	-	-	-
Diploneis sp.	*	-	-	-	-	-	4.2
Fragilaria sp.	*	-	-	-	0.4	-	-
Leptocylindrus danicus		89.1	13.1	9.3	84.0	35.0	10.4
Licmophora spp.	*	0.3	-	-	0.3	-	-
Navicula spp.	*	0.9	3.3	11.1	2.9	7.0	14.5
Nitzschia closterium		0.2	9.8	38.8	0.9	10.0	23.0
N. seriata		-	4.9	-	-	-	-
Pinnularia sp.	*	-	-	-	0.4	-	-
Skeletonema costatum		4.4	42.6	-	6.8	24.0	33.3
Synedra ulna	*	0.2	-	-	0.7	1.0	-
Thalassiosira spp.		4.0	18.1	31.5	3.3	23.0	14.6
Dictyocha speculum		-	-	5.6	-	-	-
% of Diatoms		100	100	94.4	100	100	100
% of Planktonic species		98	93.4	85.2	95.0	92.0	81.3
% of Benthic and Epiphytic species	(*)	2.0	6.6	14.8	5.0	8.0	18.7

Table 6.34

% composition of suspended algae on 2 April 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		154.0	13.6	3.80	86.8	6.10	5.35
Amphora spp.	*	-	-	-	0.1	-	0.8
Fragilaria sp.	*	0.1	-	-	0.1	-	-
Grammatophora marina	*	-	-	-	-	-	0.8
Leptocylindrus danicus		3.4	-	-	5.9	-	3.7
Licmophora sp.	*	-	-	-	-	-	1.2
Navicula spp.	*	0.3	2.0	3.4	0.3	5.5	6.1
Nitzschia closterium		-	2.8	9.8	-	5.5	4.5
Pinnularia spp.	*	0.1	-	-	-	-	0.8
Rhaphoneis surirella	*	-	0.7	-	-	-	-
Skeletonema costatum		93.6	82.4	65.1	91.5	76.3	65.8
Synedra ulna	*	0.1	0.3	1.1	-	-	-
Thalassiosira spp.		2.4	11.8	20.6	2.1	11.7	16.3
Dictyocha speculum		-	-	-	-	1.0	-
% of Diatoms		100	100	100	100	99.0	100
% of Planktonic species		99.4	97.0	95.5	99.5	94.5	90.3
% of Benthic and Epiphytic species	(*)	0.6	3.0	4.5	0.5	5.5	9.7

Table 6.35
% composition of suspended algae on 9 April 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^5$)		17.7	3.95	1.48	4.32	4.87	1.25
Amphora spp.	*	0.1	-	-	0.2	-	-
Diatom elongata		0.1	-	-	0.2	-	0.4
Leptocylindrus danicus		-	-	1.1	-	-	-
Licmophora spp.	*	-	0.2	-	0.2	-	-
Navicula spp.	*	0.2	0.9	2.1	1.0	0.8	2.7
Nitzschia closterium		0.1	1.3	0.7	-	0.1	1.3
Pinnularia sp.	*	-	-	-	-	-	0.6
Rhaphoneis surirella	*	-	-	0.4	0.5	-	-
Rhabdonema sp.	*	0.2	-	-	-	-	-
Skeletonema costatum		98.2	93.4	88.5	95.4	96.1	88.3
Synedra ulna	*	0.1	-	0.7	0.3	0.3	-
Thalassiosira spp.		1.0	4.2	6.5	2.2	2.7	6.7
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		99.4	98.9	96.8	97.8	98.9	96.7
% of Benthic and Epiphytic species	(*)	0.6	1.1	3.2	2.2	1.1	3.3

Table 6.36

% composition of suspended algae on 23 April 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^5$)		18.4	12.5	12.3	12.9	7.31	7.24
Diatoma elongata		0.03	0.1	-	-	-	-
Grammatophora marina	*	-	-	0.1	-	-	-
Leptocylindrus danicus		-	-	-	0.1	-	-
Melosira sp.		-	-	-	0.2	-	-
Navicula spp.	*	0.08	0.2	0.5	0.1	0.2	0.2
Nitzschia closterium		0.07	0.1	0.1	0.1	-	0.4
Pinnularia spp.	*	0.01	-	-	-	-	-
Skeletonema costatum		98.18	95.3	95.0	96.8	93.9	93.8
Synedra ulna	*	0.03	-	0.2	-	-	-
Thalassiosira spp.		1.6	4.3	4.1	2.7	5.9	5.6
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		99.88	99.8	99.2	99.8	99.8	99.8
% of Benthic and Epiphytic species	(*)	0.12	0.2	0.8	0.2	0.2	0.2

6, and this pattern of species composition also observed on 23 April.

May 1986 (Tables 6.37 and 6.38)

Skeletonema costatum still contributed highly in large numbers to the populations at depth samples on 7 May accompanied by *Thalassiosira* spp., whilst in the 3 m samples the population was dominated by green flagellates with high contributions also from *Skeletonema costatum*. Benthic species were recorded in large numbers at 20 m at the two stations.

On 21 May the dominance of green flagellates was evident at 3 m and 20 m depths at both stations, whilst *Skeletonema costatum* was the majority of phytoplankton population at 40 m with *Thalassiosira* spp. at the two stations and with *Diatoma elongata* at station 3 only.

June 1986 (Table 6.39)

Diverse phytoplankton components made up the populations on 18 June although dominated by green flagellates at 3 m and 20 m depths at stations 3 and 6, whilst at 40 m *Skeletonema* was associated with large numbers of *Coscinodiscus* spp. and with green flagellates and *Thalassiosira* spp. at station 3. *Coscinodiscus* spp.was dominant at station 6 obtained with high numbers of *Skeletonema costatum* and *Thalassiosira* spp.

July 1986 (Tables 6.40-6.42)

On 2 July, *Coscinodiscus* , *Skeletonema costatum* and *Thalassiosira* spp. made the main component of phytoplankton in the populations at all depths at both stations along with

Table 6.37

% composition of suspended algae on 7 May 1986

sample at 40 m was not available due to the destroying of the slide's sample

		station 3			station 6	
		3 m	20 m	40 m	3 m	20 m
Cell numbers ($x10^4$)		37.9	2.77	6.79	23.8	4.14
Green flagellates		49.2	1.6	-	60.0	-
Amphora sp.	*	-	-	-	0.2	-
Cocconeis sp.	*	-	-	-	0.5	-
Diatoma elongata		-	-	-	-	1.1
Grammatophora marina	*	-	-	-	-	2.2
Licmophora spp.	*	-	4.0	0.8	-	2.7
Leptocylindrus danicus		-	-	-	11.6	-
Melosira spp.		-	9.7	5.0	1.7	-
Navicula spp.	*	2.8	-	0.6	0.5	8.7
Nitzschia closterium		-	2.5	0.8	-	-
Pinnularia spp.	*	-	1.6	-	0.3	-
Skeletonema costatum		44.2	66.1	73.4	22.6	69.1
Synedra ulna	*	-	-	-	0.4	1.6
Thalassiosira spp.		3.8	14.5	19.4	2.2	14.6
% of Green flagellates		49.2	1.6	-	60.0	-
% of Diatoms		50.8	98.4	100	40.0	100
% of Planktonic species		97.2	94.4	98.6	98.1	84.8
% of Benthic and Epiphytic species	(*)	2.8	5.6	1.4	1.9	15.2

Table 6.38
% composition of suspended algae on 21 May 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		64.1	19.7	2.29	32.9	21.4	0.595
Green flagellates		98.5	91.5	-	95.6	89.2	-
Amphora sp.	*	-	-	-	0.2	-	-
Diatoma elongata		-	-	28.0	-	-	-
Melosira sp.		-	-	7.5	-	-	-
Navicula spp.	*	0.1	0.3	-	-	0.2	5.3
Nitzschia closterium		-	-	2.8	-	-	-
Skeletonema costatum		1.0	6.2	43.0	3.2	9.6	68.4
Thalassiosira spp.		0.4	2.0	18.7	1.0	1.0	26.3
% of Green flagellates		98.5	91.5	-	95.6	89.2	-
% of Diatoms		1.5	8.5	100	4.4	10.8	100
% of Planktonic species		99.9	99.7	100	99.8	99.8	94.7
% of Benthic and Epiphytic species	(*)	0.1	0.3	-	0.2	0.2	5.3

Table 6.39

% composition of suspended algae on 18 June 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		13.5	5.48	4.10	13.5	8.70	2.03
Green flagellates		93.5	68.6	16.2	90.3	59.8	-
Amphora sp.	*	-	-	1.1	-	-	-
Biddulphia sp.		-	1.1	-	-	-	-
Coscinodiscus spp.		1.7	11.1	15.2	0.9	22.6	40.3
Diatoma elongata		-	-	0.5	3.1	-	2.9
Fragilaria spp	*	-	-	1.1	0.5	-	2.9
Pinnularia sp.	*	-	-	-	-	-	1.9
Leptocylindrus danicus		3.5	1.9	7.3	3.2	2.6	-
Licmophora sp.	*	-	-	-	0.5	-	-
Navicula spp.	*	1.3	0.6	2.6	1.0	0.7	5.8
Rhabdonema sp.	*	-	-	-	-	-	3.9
Rhizosolenia spp.		-	0.6	-	0.5	-	-
Skeletonema costatum		-	11.8	43.4	-	10.8	23.1
Thalassiosira spp.		-	5.4	11.5	-	3.5	19.2
Dictyocha speculum		-	-	-	-	-	-
% of Green flagellates		93.5	68.6	16.2	90.3	59.8	-
% of Diatoms		6.5	31.4	83.8	9.7	40.2	100
% of Planktonic species		98.7	99.4	95.2	98.0	99.3	85.5
% of Benthic and Epiphytic species	(*)	1.3	0.6	4.8	2.0	0.7	14.5

Table 6.40

% composition of suspended algae on 2 July 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		7.89	2.71	1.64	16.2	6.59	2.65
Green flagellates		-	9.8	-	61.2	-	-
Coscinodiscus spp.		19.1	29.4	34.9	5.7	30.6	46.3
Diatoma elongata		0.8	-	6.1	-	0.8	-
Fragilaria spp.	*	-	-	3.0	0.4	-	-
Grammatophora marina	*	-	2.9	-	-	-	-
Navicula spp.	*	0.8	2.9	4.6	0.2	1.7	3.2
Pinnularia sp.	*	-	-	3.0	-	-	-
Skeletonema costatum		16.7	34.4	25.7	32.1	36.8	35.5
Synedra ulna	*	-	-	-	-	0.9	-
Thalassiosira spp.		62.6	20.6	22.7	0.4	29.2	15.0
% of Green flagellates		-	9.8	-	61.2	-	-
% of Diatoms		100	90.2	100	38.8	100	100
% of Planktonic species		99.2	94.2	89.4	99.4	97.4	96.8
% of Benthic and Epiphytic species	(*)	0.8	5.8	10.6	0.6	2.6	3.2

large numbers of green flagellates at 3 m at station 6.

On 16 July green flagellates contributed to the total biomass in large numbers at 20 m and 40 m depths at both stations, with the dominancy of *Skeletonema costatum* at 40 m at station 6. The population at 3 m at station 3 was dominated by *Leptocylindrus danicus*. The 3 m sample from station 6 was not available.

The domination of *Leptocylindrus danicus* continued on 30 July in 3 m samples despite the association of *Coscinodiscus* spp. and *Skeletonema costatum* , whilst the latter species made the highest contributions to the populations at 20 m depths at both stations together with large numbers of *Coscinodiscus* spp. and green flagellates at 20 m depths at the two stations. Similar quantities of *Coscinodiscus* spp. and *Thalassiosira* spp. were obtained at 40 m at station 3, so representing the highest numbers of the biomass, whilst *Skeletonema costatum* was dominant at 40 m at station 6 along with large numbers of *Cosciondiscus* spp., *Leptocylindrus danicus* and *Thalassiosira* spp..

August 1986 (Table 6.43)

For the first time in this investigation *Chaetoceros* spp. dominated the populations at 3 m and 20 m depths at the two stations, with *Skeletonema costatum* predominating in 40 m samples at stations 3 m and 6. *Skeletonema costatum*,*Thalassiosira* spp. and *Dictyocha speculum* also contributed highly to the biomass in the depth samples.

September 1986 (Tables 6.44 and 6.45)

A similar species compositon was obtained on 10 September at all depths at both stations. *Skeletonema costatum* tended to be dominant at all depths except for 3 m at station 6 where green flagellates overtook *Skeletonema* in spite its contribution being

Table 6.41

% composition of suspended algae on 16 July 1986

		station 3			station 6	
		3 m	20 m	40 m	20 m	40 m
Cell numbers ($x10^4$)		14.7	21.2	2.60	10.3	1.66
Green flagellates		12.4	83.2	52.8	98.3	19.7
Amphora sp.	*	-	-	-	0.4	-
Coscinodiscus spp.		0.7	0.4	7.6	0.6	10.3
Grammatophora marina	*	-	-	2.8	-	1.4
Leptcylindrus danicus		84.7	-	-	-	-
Licmophora sp.	*	-	1.0	-	-	-
Navicula spp.	*	-	-	2.8	-	2.6
Nitzschia closterium		0.4	-	-	-	-
Pinnularia sp.	*	0.2	-	-	-	-
Skeletonema costatum		1.6	15.4	27.4	-	48.2
Thalassiosira spp.		-	-	6.6	0.7	18.5
% of Green flagellates		12.4	83.2	52.8	98.3	19.7
% of Diatoms		87.6	16.8	47.2	1.7	96.0
% of Planktonic species		99.8	99.0	94.4	99.6	96.0
% of Benthic and Epiphytic species	(*)	0.2	1.0	5.6	0.4	4.0

Table 6.42

% composition of suspended algae on 30 July 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^3$)		519	21.5	6.42	190	11.9	6.34
Green flagellates		-	13.6	-	-	11.8	-
Coscinodiscus spp.		24.3	14.6	26.8	26.4	21.1	24.5
Coconneis spp.	*	-	-	-	-	1.3	1.9
Fragilaria sp.	*	-	1.8	-	-	-	-
Grammatophora marina	*	-	1.8	-	-	-	-
Leptocylindrus danicus		59.8	6.4	24.4	50.6	2.6	14.2
Licmophora sp.	*	-	-	-	-	-	1.9
Melosira spp.		0.1	-	-	-	-	1.9
Navicula spp.	*	0.1	3.6	4.9	1.0	5.3	4.7
Nitzschia closterium		-	-	-	-	-	2.8
Pinnularia sp.	*	-	-	-	-	2.6	-
Skeletonema costatum		15.1	53.6	17.1	20.7	38.2	34.0
Synedra ulna	*	-	-	-	-	1.3	-
Thalassiosira spp.		0.6	4.6	26.8	1.3	15.8	14.1
% of Green flagellates		-	13.6	-	-	11.8	-
% of Diatoms		100	86.4	100	100	88.2	100
% of Planktonic species		99.9	92.8	95.1	99.0	89.5	91.5
% of Benthic and Epiphytic species	(*)	00.1	7.2	4.9	1.0	10.5	8.5

Table 6.43

% composition of suspended algae on 27 August 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		13.8	4.11	2.72	18.9	4.10	2.85
Green flagellates		3.7	12.4	-	-	-	-
Amphora spp.	*	0.4	0.9	3.0	-	-	1.2
Chaetoceros spp.		79.9	37.6	-	64.9	44.4	-
Coscinodiscus spp.		0.2	8.6	-	26.4	3.1	-
Diatoma elongata		-	-	1.0	-	-	3.2
Licmophora sp.	*	-	-	-	0.3	-	-
Navicula spp.	*	-	2.1	4.0	0.2	-	5.0
Pinnularia spp.	*	-	-	-	0.7	-	0.8
Skeletonema costatum		11.3	20.9	59.6	28.8	27.2	53.1
Thalassiosira spp.		3.1	14.5	29.4	2.9	17.3	34.7
Dictyocha speculum		1.4	3.0	3.0	1.6	8.0	2.0
% of Green flagellates		3.7	12.4	-	-	-	-
% of Diatoms		94.9	84.6	97.0	98.4	92.0	98.0
% of Planktonic species		99.6	97.0	93.0	98.8	100	93.0
% of Benthic and Epiphytic species	(*)	0.4	3.0	7.0	1.2	-	7.0

Table 6.44

% composition of suspended algae on 10 September 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^5$)		1.90	1.08	2.51	3.35	1.46	1.23
Green flagellates		-	-	9.9	34.2	3.0	-
Amphora sp.	*	-	-	-	-	-	0.8
Chaetoceros spp.		20.8	20.6	22.9	22.1	15.4	15.3
Coscinodiscus spp.		1.1	1.9	-	-	-	-
Cocconeis spp.	*	-	0.7	-	-	-	-
Diatoma elongata		-	0.3	-	-	-	0.4
Grammatophora marina	*	-	1.2	-	0.7	0.3	-
Leptocylindrus danicus		13.2	2.0	2.11	0.5	-	2.8
Melosira spp.		8.9	5.7	1.4	0.4	12.7	3.8
Navicula spp.	*	0.7	1.0	0.7	-	0.3	-
Rhizosolenia spp.		12.8	0.8	2.9	1.1	-	2.2
Skeletonema costatum		26.8	53.5	45.6	26.8	47.5	62.7
Thalasiossira spp.		15.0	11.9	14.5	14.1	19.8	12.0
Dictyocha speculum		0.7	0.4	-	0.1	1.0	-
% of Green flagellates		-	-	9.9	34.2	3.0	-
% of Diatoms		99.3	99.6	99.1	65.7	96.0	100
% of Planktonic species		99.3	97.1	99.3	99.3	99.4	99.2
% of Benthic and Epiphytic species	(*)	0.7	2.9	0.7	0.7	0.6	0.8

high at this depth along with *Chaetoceros* spp. and *Thalassiosira* spp. both of which made large contributions to the total. *Skeletonema costatum* was present in large numbers in the depth samples at both stations, whilst *Leptocylindrus danicus* and *Rhizosolenia delicatula* made significant contributions at 3 m at station 3.

On 24 September no significant variations in the phytoplankton components was observed although the domination of *Thalassiosira* spp. occurred at 3 m at station 3 and of green flagellates at 20m at station 6. Dinoflagellates were observed in small numbers at 3 m in station 3. This may well be due to the time factor of sampling.

October 1986 (Tables 6.46 and 6.47)

The similar quantities of green flagellates and *Skeletonema costatum* made the major biomass contributions at 3 m at both stations with the green flagellates the more numerous. *Skeletonema costatum* was dominant in the depth samples at station 3, accompanied by large numbers of *Thalassiosira* spp., which dominated the species composition at depth samples at station 6, with *Skeletonema costatum* next in quantity.

This abundance of *Thalassiosira* spp. was obtained again on 27 October at all depths at station 3 and 20 m and 40 m depths at station 6, with the highest numbers in the depth samples. The dominance of green flagellates at 3 m coincided with the large numbers of *Thalassiosira* spp and *Skeletonema costatum* which made also sizeable contributions to the biomass in all the samples from station 6. *Navicula* spp. and *Dictyocha speculum* were found at all depths. The benthic species were numerous at all depths, with maxima at 3 m at the two stations.

Table 6.45
% composition of suspended algae on 24 September 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		4.20	7.80	7.99	8.64	10.1	6.92
Green flagellates		-	8.3	-	35.2	28.4	-
Biddulphia sp.		-	-	0.8	-	-	-
Caloneis sp.	*	-	-	-	0.5	-	-
Ceratium tripos		1.2	-	-	-	-	-
Chaetoceros spp.		12.4	18.6	19.3	12.3	7.7	10.9
Cocconeis sp.	*	-	-	-	0.5	-	-
Diatoma elongata		-	-	-	-	0.7	-
Leptocylindrus danicus		21.7	14.6	7.6	21.8	5.0	10.0
Melosira spp.		3.1	-	10.4	3.7	14.4	3.9
Navicula spp.	*	2.5	-	1.4	0.5	1.6	0.9
Nitzschia clostrum		-	-	-	0.5	-	-
N. seriata		6.2	-	-	1.3	-	2.9
Rhizosolenia spp.		3.1	0.9	1.1	3.2	4.6	1.1
Skeletonema costatum		23.1	36.1	40.9	13.4	18.4	46.7
Synedra ulna		-	-	-	-	-	0.2
Thalassiosira spp.		25.5	19.8	17.9	6.6	18.7	22.9
Dictyocha speculum		1.2	1.7	0.6	0.5	0.5	0.5
% of Green flagellates		-	8.3	-	35.2	28.4	-
% of Dinoflagellates		1.2	-	-	-	-	-
% of Diatoms		97.6	90.0	99.4	64.3	71.1	99.5
% of Planktonic species		97.5	100	98.6	98.5	98.4	98.9
% of Benthic and Epiphytic species	(*)	2.5	-	1.4	1.5	1.6	1.1

Table 6.46

% composition of suspended algae on 6 October 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		3.85	4.82	3.49	3.41	2.96	2.97
Green flagellates		35.6	18.2	7.0	22.4	6.5	-
Amphora	*	-	-	1.3	1.2	-	1.3
Chaetoceros spp.		9.3	-	-	4.1	2.6	-
Cocconeis sp.	*	-	-	-	-	1.3	-
Coscinodiscus spp.		0.6	1.1	3.2	2.4	1.0	-
Diatoma elongata		-	1.1	1.3	1.8	-	-
Fragilaria spp.	*	-	-	-	0.6	1.0	-
Grammatophora marina	*	-	-	1.3	1.8	1.3	-
Leptocylindrus danicus		8.8	6.3	3.2	10.6	-	4.0
Licmophora	*	0.6	-	1.3	-	3.3	1.3
Melosira spp.		-	-	-	11.2	-	6.6
Navicula spp.	*	1.7	1.6	2.5	2.9	5.3	2.0
Pinnularia spp.	*	-	-	1.9	-	-	1.3
Rhizosolenia sp.		1.7	-	-	-	-	-
Skeletonema costatum		30.7	37.1	43.0	21.2	32.0	39.5
Surirella straitula	*	0.6	-	-	-	-	-
Synedra ulna	*	-	-	-	1.2	-	-
Thalassiosira spp.		9.3	33.0	34.0	17.4	44.4	44.0
Dictyocha speculum		1.1	1.6	-	1.2	1.3	-
% of Green flagellates		35.6	18.2	7.0	22.4	6.5	-
% of Diatoms		63.3	80.2	93.0	76.4	92.2	100
% of Planktonic species		97.1	98.4	91.7	92.3	89.8	94.1
% of Benthic and Epiphytic species	(*)	2.9	1.6	8.3	7.7	12.2	5.9

Table 6.47

% composition of suspended algae on 27 October 1986

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		3.42	2.04	1.44	4.33	2.65	1.74
Green flagellates		20.0	6.1	-	31.1	-	18.7
Amphora spp.	*	-	2.0	-	2.1	-	-
Chaetoceros spp.		4.6	-	-	1.3	-	-
Cocconeis spp.	*	2.9	-	4.2	0.9	2.1	-
Coscinodiscus spp.		-	3.0	-	2.1	-	4.4
Diatoma elongata		2.3	-	-	-	-	-
Fragilaria sp.	*	1.4	-	-	-	-	-
Leptocylindrus danicus		3.6	10.1	-	3.0	5.6	-
Licmophora spp.	*	-	3.0	-	0.9	-	-
Melosira sp.		2.9	-	-	-	-	-
Navicula spp.	*	11.4	4.0	4.2	6.0	2.8	6.6
Nitzschia closterium		2.9	-	-	-	-	-
Pinnularia spp.	*	1.4	3.0	-	-	-	-
PLeurosigma sp.	*	-	-	-	-	1.4	-
Rhabdonema arcuatum	*	-	-	-	3.0	-	-
Rhizosolenia spp.		-	7.1	-	4.3	4.9	4.4
Skeletonema costatum		1.4	-	7.0	14.6	19.6	15.4
Synedra ulna	*	2.4	3.0	4.2	0.9	-	-
Thalassiosira spp.		38.5	53.5	76.1	25.2	60.	49.4
Dictyocha speculum		4.3	5.2	4.3	4.6	3.5	1.1
% of Green flagellates		20.0	6.1	-	31.1	-	18.7
% of Diatoms		75.7	88.7	95.7	64.3	96.5	80.2
% of Planktonic species		80.5	85.0	87.4	86.2	93.7	93.4
% of Benthic and Epiphytic species	(*)	19.5	15.0	12.6	13.8	6.3	6.6

November 1986 (Table 6.48)

Samples from station 3 were not available during this month (caused by failure of sampler), whilst the samples from station 6 were dominated by *Thalassiosira* spp. accompanied by large numbers of *Melosira* sp. and with benthic component especially in the 3 m sample.

December 1986 (Table 6.49)

With the low population quantities, *Thalassiosira* spp. were still numerous, together with large numbers of benthic species at 3 m and at 40 m. Due to the failure of the apparatus the sample from 20 m and from all samples in station 6 could not be collected.

January 1987 (Table 6.50)

Thalassiosira spp. continued their contribution of the samples from the two stations, except with 40 m sample at station 6, where high numbers of *Melosira* sp. was obtained. Large numbers of *Nitzschia closterium* was found in the surface waters only, whilst the benthic biomass increased at all depths.

February 1987 (Table 6.51)

The dominant species this month was *Skeletonema costatum* at 3 m and 40 m at station 3 and in all samples from station 6, in addition *Thalassiosira* was dominant in the population at 20 m depth at station 3 accompanied by large numbers of *Navicula* spp. and *Nitzschia closterium*. Benthic species remained predominant in the depth samples.

Table 6.48

% composition of suspended algae on 11 November 1986

Samples from station 3 were not collected due to the failure of sampler

		Station 6		
		3 m	20 m	40 m
Cell numbers ($x10^4$)		1.02	1.19	1.25
Green flagellates		-	-	-
Cocconeis spp.	*	6.2	-	4.2
Diatoma elongata		9.2	5.8	-
Fragilaria spp	*	3.1	2.9	-
Licmophora spp	*	4.6	2.9	-
Melosira spp.		18.5	17.4	5.6
Navicula spp.	*	21.5	14.5	14.2
Pinnularia sp.	*	3.1	-	-
Rhizosoliena sp.		-	-	5.6
Surirella spp.	*	6.1	-	-
Synedra ulna	*	-	5.8	11.3
Thalassiosira spp.		24.6	46.3	53.5
Dictyocha speculum		3.1	4.4	5.6
% of Diatoms		96.9	95.6	94.4
% of Planktonic species		55.4	73.9	70.3
% of Benthic and Epiphytic species	(*)	44.6	26.1	29.7

Table6.49

% composition of suspended algae on 16 December 1986

Sample from 20 m at station 3 and all samples in station 6 were not available due to failure of sea water sampler.

		station 3	
		3 m	40 m
Cell numbers ($x10^3$)		6.83	4.70
Amphora spp.	*	5.3	1.6
Caloneis spp.	*	5.3	-
Cocconeis spp.	*	5.3	3.2
Diatoma elongata		5.3	7.4
Fragilaria spp.	*	5.3	6.4
Grammatophora marina	*	13.2	10.3
Melosira sp.		-	12.6
Navicula spp.	*	15.8	16.1
Nitzschia seriata		13.2	-
Pinnularia spp.	*	0.8	1.8
Skeletonema costatum		6.8	-
Thalassiosira spp.		23.7	40.6
% of Diatoms		100	100
% of Planktonic species		49.0	60.6
% of Benthic and Epiphytic species	(*)	51.0	39.4

Table 6.50

% composition of suspended algae on 22 January 1987

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^3$)		4.47	2.66	4.64	5.35	3.81	2.70
Amphora sp.	*	-	-	-	7.4	-	-
Caloneis sp.	*	-	-	-	7.4	-	-
Cocconeis spp.	*	4.2	11.8	8.3	-	15.8	14.3
Diatoma elongata		8.3	5.9	-	7.4	-	-
Diploneis crabro	*	-	17.7	-	-	5.3	-
Fragilaria spp.	*	-	-	-	7.4	-	-
Licmophora spp.	*	-	-	-	-	5.3	-
Mastogloia spendida	*	-	-	-	-	-	7.1
Melosira sp.		-	-	41.7	-	-	-
Navicula spp.	*	29.2	-	12.5	18.5	10.5	-
Nitzschia closterium		25.0	-	-	14.8	-	-
Pinnularia sp.	*	-	-	-	-	5.3	-
PLeurosigma aestuarii	*	-	-	4.2	-	-	-
Thalassiosira spp.		33.3	64.6	33.3	37.1	57.8	78.6
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		66.6	70.5	75.0	59.3	57.8	78.6
% of Benthic and Epiphytic species	(*)	33.4	29.5	25.0	40.7	42.2	21.4

Table 6.51

% composition of suspended algae on 18 Febraury 1987

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^3$)		12.5	2.19	5.63	14.6	14.6	6.57
Cocconeis spp.	*	2.5	-	5.6	-	2.2	-
Coscinodiscus spp.		-	-	13.9	-	2.2	9.5
Diatoma elongata		3.8	-	-	-	-	-
Licmophora sp.	*	-	-	-	4.3	-	-
Melosira sp.		-	-	-	-	5.4	-
Navicula spp.	*	3.8	21.4	5.6	1.1	4.3	14.3
Nitzschia closterium		-	21.4	8.3	-	2.2	11.9
N. seriata		-	-	-	10.6	5.4	-
PLeurosigma aestuarii	*	-	-	2.8	-	-	-
Skeletonema costatum		67.4	-	38.8	71.3	68.6	50.0
Synedra ulna	*	3.8	-	-	1.1	-	-
Thalassiosira spp.		18.7	57.2	25.0	11.6	9.7	14.3
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		89.9	78.6	86.0	93.5	93.5	85.7
% of Benthic and Epiphytic species	(*)	10.1	21.4	14.0	6.5	6.5	14.3

March 1987 (Table 6.52-6.54)

All samples from station 3 and 6 were dominated by *Skeletonema costatum* with smaller numbers of *Thalassiosira* spp. on 4 March.

On 18 March and 25 March a similar species composition was obtained at all depths with the appearence of small numbers of *Nitzschia closterium* in all samples and *Nitzschia seriata* at most depths at the two stations.

April 1987 (Tables 6.55 and 6.56)

Samples were collected only from station 6 where the populations were still dominated by *Skeletonema costatum*, with maxima at 40 m on 8 April and at 3 m on 22 April.

Throughout the study period, the suspended algae, at all depths, consisted predominantly of planktonic representatives, with the benthic and epiphytic species (those usually found attached to substrata and tychopelagic - the species which temporarily assume the planktonic habit due to dislodgement) representing but a small proportion. These benthic species were more noticeable in the autumn and winter months. On occasions the proportion of benthic species was higher in the deeper water, possibly a reflection of their tendencies to sink more rapidly.

As shown in the Tables of data, the principal components of the phytoplankton were diatoms, dinoflagellates, silicoflagellates and avariety of small green flagellates which could not be identified with certainty. For the most part, at all depths, the diatoms dominated the populations. The dinoflagellates were more numerous during the summer and autumn, and tended to accumulate in the surface waters. The green flagellates on occasions dominated the populations in the 3 m and 20

Table 6.52
% composition of suspended algae on 4 March 1987

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^6$)		3.24	1.90	2.61	2.66	1.56	1.47
Amphora sp.	*	0.1	-	-	-	-	-
Biddulphia sp.		-	-	-	0.03	-	-
Chaetoceros spp.		0.2	0.2	-	0.3	-	-
Cocconeis spp.	*	-	-	-	0.03	0.1	-
Coscinodiscus spp.		-	-	0.1	0.03	-	-
Diatoma elongata		-	-	-	0.03	-	-
Fragilaria sp.	*	-	0.1	-	-	-	-
Leptocylindrus danicus		0.1	-	-	-	-	-
Licmophora sp.	*	-	-	-	0.03	-	-
Navicula spp.	*	0.1	0.1	0.1	0.18	-	0.1
Nitzschia closterium		0.1	0.1	0.1	-	-	0.1
N. seriata		0.1	0.4	-	0.1	0.1	0.2
Pinnularia spp.	*	-	0.1	0.1	0.04	-	-
Rhabdonema sp.	*	-	0.1	-	-	-	-
Rhizosolenia spp.		-	-	-	0.03	-	0.1
Skeletonema costatum		95.4	94.5	96.4	95.2	94.5	95.7
Thalassiosira spp.		3.9	4.4	3.2	4.0	5.3	3.8
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		99.8	99.6	99.8	99.8	99.9	99.9
% of Benthic and Epiphytic species	(*)	0.2	0.4	0.2	0.3	0.1	0.1

Table 6,53

% composition of suspended algae on 18 March 1987

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^5$)		13.9	12.7	11.0	11.4	11.1	8.50
Green flagellates		0.43	-	-	-	-	-
Chaetoceros spp.		0.07	0.13	-	-	-	-
Caloneis spp.	*	-	-	-	-	0.06	-
Cocconeis spp.	*	-	-	0.06	-	0.04	-
Coscinodiscus spp.		0.03	-	-	-	-	0.13
Melosira spp.		-	0.07	-	-	-	0.29
Navicula spp.	*	0.08	0.05	0.06	0.04	-	0.1
Nitzschia closterium		0.07	0.03	0.02	0.05	0.05	0.05
N. seriata		-	0.10	0.10	0.04	-	0.05
Pleurosigma spp.	*	-	0.02	-	-	-	-
Rhizosolenia spp.		-	-	0.04	-	-	-
Skeletonema costatum		97.6	97.74	97.64	97.81	98.36	97.42
Synedra spp.	*	0.02	0.03	0.04	-	-	-
Thalassiosira spp.		1.7	1.83	2.04	2.06	1.49	1.96
% of Diatoms		99.6	100	100	100	100	100
% of Planktonic species		99.9	99.9	99.84	99.96	99.9	99.9
% of Benthic and Epiphytic species	(*)	0.1	0.1	0.16	0.04	0.1	0.1

Table 6.54

% composition of suspended algae on 25 March 1987

		station 3			station 6		
		3 m	20 m	40 m	3 m	20 m	40 m
Cell numbers ($x10^4$)		11.5	9.04	12.8	9.29	8.36	11.0
Cocconeis spp.	*	0.4	-	-	0.4	-	-
Diatoma elongata		-	-	-	0.4	0.4	-
Grammatophora marina	*	-	-	-	-	1.1	-
Melosira spp.		-	3.0	5.7	1.5	2.2	-
Navicula spp.	*	1.6	1.1	0.6	0.6	0.7	-
Nitzschia closterium		0.8	-	-	-	-	81.4
Pinnularia spp.	*	-	0.4	-	0.4	-	-
Rhabdonema sp.	*	-	-	0.3	-	-	-
Skeletonema costatum		90.0	84.2	84.2	91.6	88.3	4.5
Synedra spp.	*	0.4	-	-	-	-	0.4
Thalassiosira spp.		6.8	11.3	9.2	5.1	7.3	13.7
% of Diatoms		100	100	100	100	100	100
% of Planktonic species		97.6	98.5	99.1	98.6	98.2	99.6
% of Benthic and Epiphytic species	(*)	2.4	1.5	0.9	1.4	1.8	0.4

Table 6.55
% composition of suspended algae on 8 April 1987

		station 6		
		3 m	20 m	40 m
Cell numbers ($x10^4$)		3.13	3.01	3.17
Amphora sp.	*	-	1.3	-
Cocconeis sp.	*	-	2.0	-
Diatoma elongata		1.3	-	1.3
Fragilaria sp.	*	1.3	-	-
Grammatophora marina	*	-	2.6	-
Leptocylindrus danicus		-	3.3	-
Navicula spp.	*	1.9	4.6	-
Nitzschia closterium		4.4	4.6	3.2
N. seriata		-	1.3	-
Pleurosigma aestuarii	*	-	-	1.3
Skeletonema costatum		63.5	60.2	89.1
Synedra sp.	*	3.8	-	-
Thalassiosira spp.		18.8	20.1	5.1
Dictyocha speculum		5.0	-	-
% of Diatoms		95.0	100	100
% of Planktonic species		93.0	89.5	98.7
% of Benthic and Epiphytic species	(*)	7.0	10.5	1.3

Table 6.56

% composition of suspended algae on 22 April 1987

		station 6		
		3 m	20 m	40 m
Cell numbers ($x10^5$)		36.6	7.75	3.42
Green flagellates		-	2.6	-
Diatoma elongata		-	0.1	0.1
Melosira spp.		-	-	0.8
Navicula spp.	*	0.03	0.1	0.3
Nitzschia clostrium		0.01	0.1	0.1
Pinnularia spp.	*	0.01	-	-
Skeletonema costatum		90.45	81.5	75.6
Thalassiosira spp.		9.5	15.6	23.0
Dictyocha speculum		-	-	0.1
% of Diatoms		100	97.4	99.9
% of Planktonic species		99.96	99.9	99.7
% of Benthic and Epiphytic species	(*)	0.04	0.1	0.3

m samples, especially during the summer months, and were then usually present in large numbers in the 40 m samples. The silicoflagellate *Dicytocha speculum* was present on occasions in small numbers.

When the species composition is examined (for diatoms and dinoflagellates), as shown in Tables 6.11 to 6.56, there is little convincing evidence that any species is confined in its distribution to one depth, although the dinoflagellates tended to be the more restricted. Thus when *Skeletonema costatum* or *Thalassiosira* spp. were prominent in the surface waters they were similarly the most abundant species in the deeper water, although usually in smaller numbers. A similar result was to be seen with *Leptocylindrus danicus*. When much smaller numbers of a species occured there was, on occasions, same restriction - this more a measure of patchy distribution and sampling error. An overview of these data would suggest that, in the same way that numerical abundance in the surface water is reflected in the depths, so too is the species composition, as far as most abundant representatives are concenred.

Biomass measurements in terms of chlorophyll *a*, phaeopigments, cell numbers and species composition for the different depths give no real information on the photosynthetic potential of the populations concerned. For these reasons measurements of carbon fixation were carried out, although over limited period, as reported in the next Chapter.

7. CARBON FIXATION STUDIES, WITH OBSERVATIONS ON TOTAL PARTICULATE ORGANIC MATTER AND TOTAL OXIDIZABLE CARBON

7.1. CARBON FIXATION

The most convenient way to measure algal production directly is to determine the rate of carbon fixation. The results reported here fall into two parts. The values of carbon fixation in 3 m, 20 m and 40 m samples from stations 3 and 6 (incubated under laboratory conditions) were measured from March 1986 to March 1987 (Figs 7.1 and 7.2). The second part of results (for comparison) were obtained from samples incubated *in situ* for surface, 1 m, 5 m, 10 m and 40 m depths during April 1987 accompanied by comparable data obtained from the same samples incubated in the laboratory. The data found in previous years indicated the spring increases occurred in April and May 1976 with a high fixation rate in the surface waters during July 1976 (Hannah 1979). The general seasonal pattern in the previous investigation was closely paralleled by the seasonal pattern in this present investigation for the surface water samples.

Spring 1986 (Table 7.1)

Throughout April and May the quantities of carbon fixed by the suspended algae in the 3 m (surface) samples from both stations were higher than at 20 m and 40 m. On one day (7 May) the fixation rates were minimal at all depths at both stations. Particularly high levels of photosynthetic activity were obtained with the 3 m samples on 2 April and 21 May for station 3, and for station 6. For 20 m and 40 m depths there were sizeable fixation by the suspended algae, with the exception of 7 May. Whilst there were exceptions, the carbon fixed was frequently of a similar order of magnitude at the

Fig. 7. 1. Carbon fixation rates (mg C. m^{-3}. h^{-1}) in the 3 m, 20 m and 40 m samples at station 3 during March 1986 to March 1987.

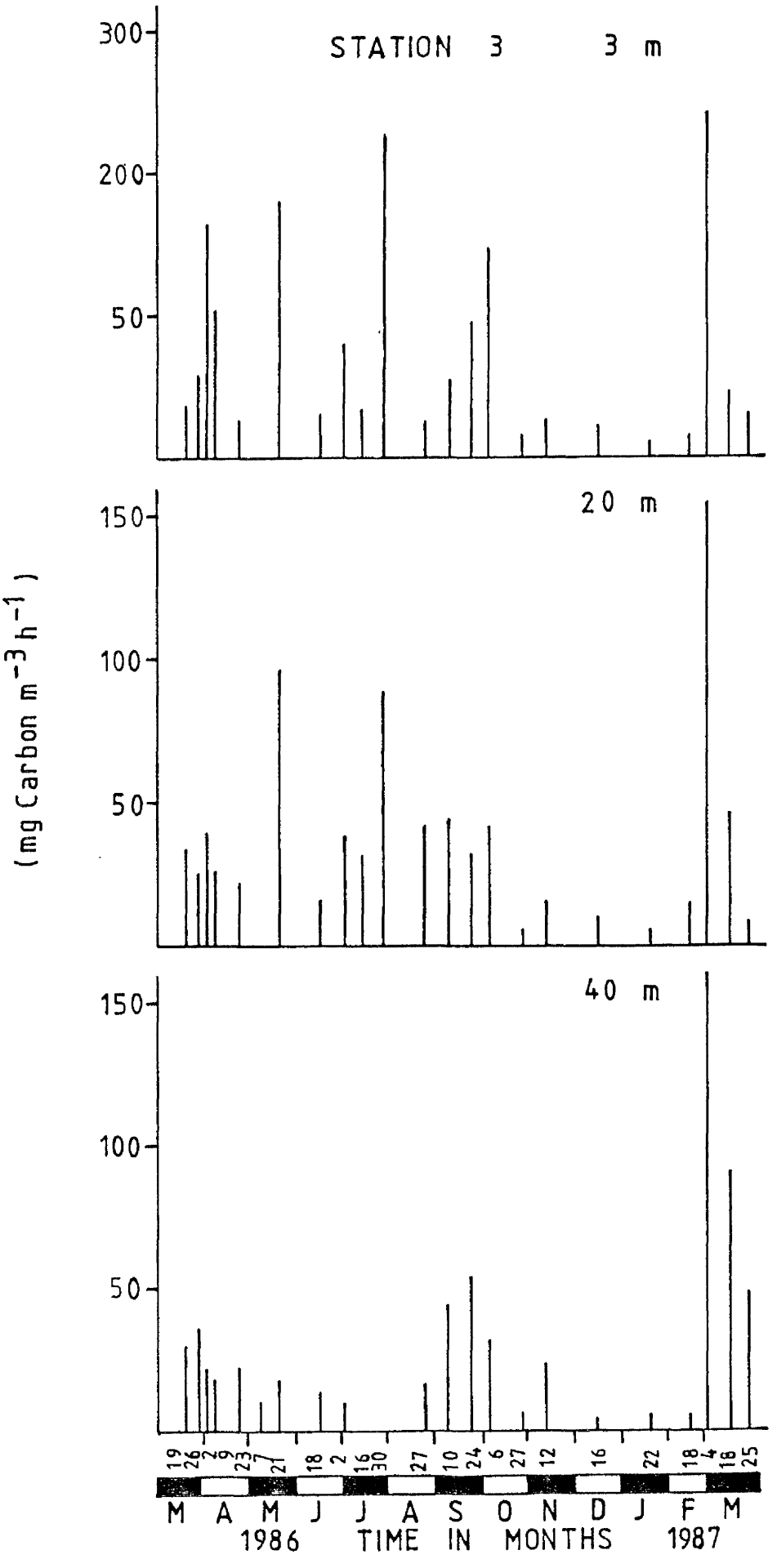
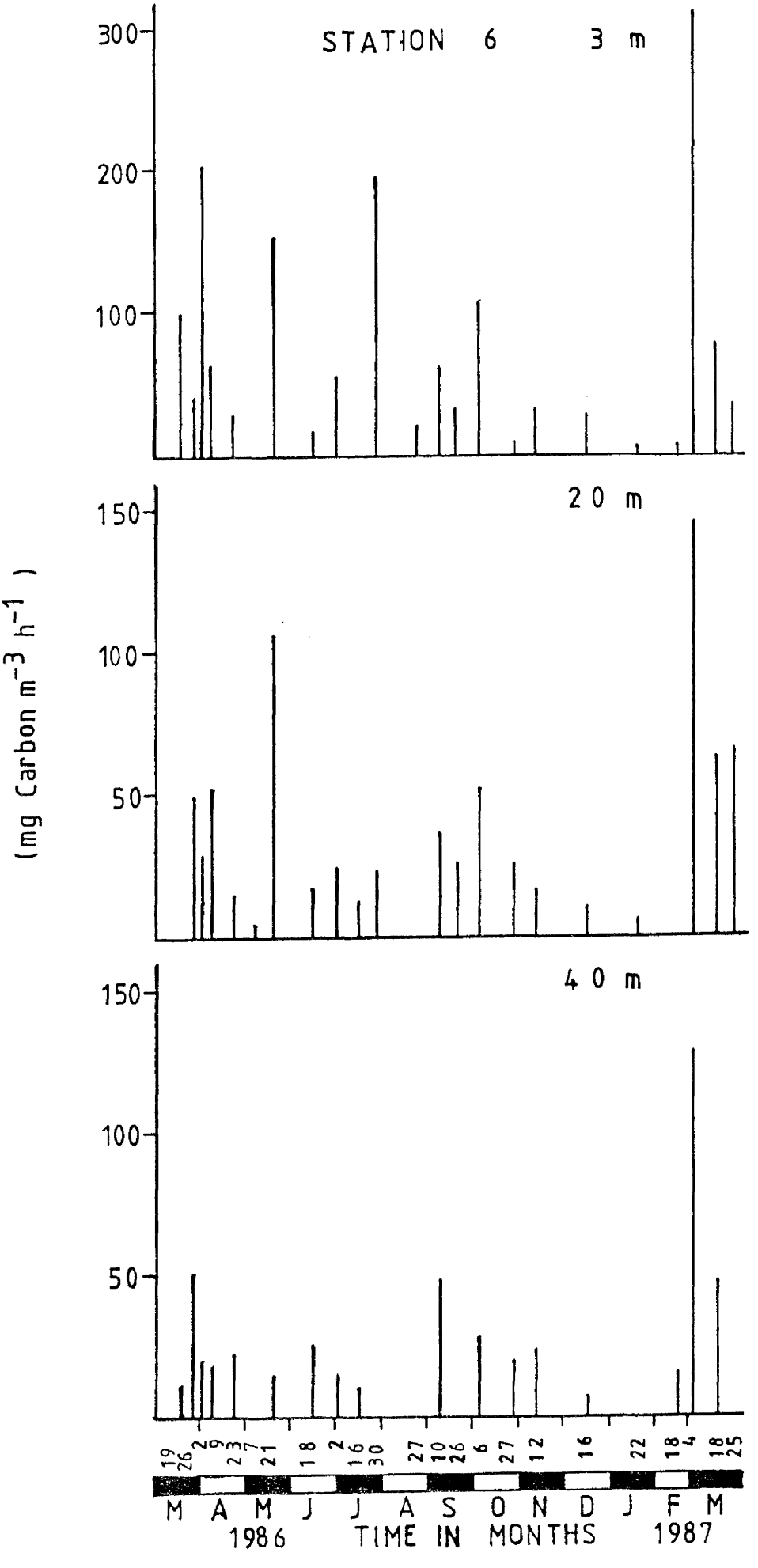

STATION 3 3 m
300
200
50
20 m
150
100
50
40 m
150
100
50
(mg Carbon m⁻³ h⁻¹)
19 26 2 9 23 7 21 18 2 16 30 27 10 24 6 27 12 16 22 18 4 18 25
M A M J J A S O N D J F M
1986 TIME IN MONTHS 1987

Fig. 7. 2. Carbon fixation rates (mg C. m^{-1}. h^{-1}) for the 3 m, 20 m and 40 m samples from station 6 during March 1986 to March 1987.


STATION 6 3 m
300
200
100
20 m
150
100
50
40 m
150
100
50
(mg Carbon m^{-3} h^{-1})
19 26 2 9 23 7 21 18 2 16 30 27 10 26 6 27 12 16 22 18 4 18 25
M A M J J A S O N D J F M
1986 TIME IN MONTHS 1987

two depths, and it is especially noticeable that the 40 m samples on occasions were as productive as the 20 m samples.

Table 7.1

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) for the Spring of 1986

(based on laboratory incubations) 0a= analytical zero

	Station 3			Station 6		
Depths	3 m	20 m	40 m	3 m	20 m	40 m
Dates						
19.3.	34.13	33.21	29.50	99.80	0a	12.13
26.3.	59.00	26.12	33.90	36.50	47.50	47.30
02.4.	162.81	39.00	20.00	200.14	27.60	19.33
09.4.	101.40	24.60	18.11	62.90	51.19	17.63
23.4.	29.00	21.60	21.80	26.00	13.82	21.30
07.5.	03.23	0a	09.30	0a	04.20	0a
21.5.	173.00	93.50	18.00	150.11	102.81	14.33

Summer 1986 (Table 7.2.)

In general the levels of carbon fixation fluctuated during the summer months at 3 m and 20 m at both stations, whilst the quantities of carbon fixed by suspended algae in the 40 m samples reduced gradually over the summer at station 3 and especially at station 6, to

reach analytical zero on 16 and 30 July at station 3 and on 30 July and 27 August at station 6. Generally the carbon fixation rates in the surface samples (3 m) were higher than in the depth samples throughout June, July and August with the exception of 16 July at station 6 and of 27 August at station 3 where the level at 20 m depth was higher than that at 3 m depth. The highest fixation in the 3 m samples were obtained on 2 July and on 30 July (the latter exceeding those obtained at the time of the spring increases) at both stations. High levels of photosynthetic activity was recorded at 20 m on 30 July and 27 August for station 3.

Table 7.2

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) for the Summer of 1986

	Station 3			Station 6		
Depths	3 m	20m	40m	3m	20 m	40 m
Dates						
18.6.	33.44	17.10	13.50	15.74	17.40	24.10
02.7.	82.00	37.30	09.73	54.86	24.00	12.32
16.7.	35.43	31.60	0a	01.50	12.90	09.50
30.7.	224.22	84.80	0a	192.00	24.00	0a
27.8.	23.73	50.31	15.20	19.80	00.40	0a

Autumn 1986 (Table 7.3)

A similar order of fluctuating levels of fixation was obtained also during the autumn with slight increases observed on 10 September at all depths at both stations after the lower values in August. Similar levels of carbon fixation were obtained over the autumn months at the two stations (exceptions on some occasions as seen in Table 7.3.) with highest levels in the 3 m samples, except for station 6 on 27 October. The highest levels in 3 m samples occurred on 6 October. For 20 m and 40 m depths there were sizeable fixations by the suspanded populations which were slightly higher than in the summer at station 3 and all depth samples at station 6. Tha minimum fixation was obtained on 27 October at all depths at the two stations.

Table 7.3

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) for the Autumn of 1986

	Station 3			Station 6		
Depths	3 m	20 m	40 m	3 m	20 m	40 m
Dates						
10.9.	56.30	52.30	41.70	63.13	35.00	46.11
24.9.	93.60	30.70	52.10	30.00	24.00	0a
06.10.	148.00	41.00	30.00	89.30	51.00	27.00
27.10.	18.00	06.00	06.00	09.30	26.00	20.30
12.11.	-	-	-	27.54	16.40	24.00

Winter 1986-7 (Table 4.7.4)

The data throughout December 1985, January and February 1987 showed the expected low levels at all depths, reaching analytical zero at 20 m and 40 m at station 6 on occasions. The values of carbon fixation at 20 m at station 6 on 22 January and at station 3 on 18 February were higher than those for the 3 m samples, being the same as the value obtained for 40 m at station 6 on 18 February 1987.

Table 7.4

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) for the Winter of 1986-7

	Station 3			Station 6		
Depths	3 m	20 m	40 m	3 m	20 m	40 m
Dates						
16.12.	24.50	-	05.30	-	-	-
22.1.	12.04	02.30	06.53	05.02	06.60	0a
18.2.	14.40	16.50	04.80	05.21	0a	13.24

Spring 1987 (Table 7.5)

The values of carbon fixed by the phytoplankton populations were very high at all depths at both stations on 4 March exceeding 100 mg $C.m^{-3}.hr^{-1}$, followed by a sharp reduction in the values within two weeks though remaining relatively high at 40 m depth at station 3 on 18th and 25th and at 20 m at station 6 on 18 and 25 March. The available measurements of carbon fixation rates at station 6 only showed the highest fixation rate in the 3 m and 20 m samples during March and April was obtained on 22 April, whilst at 40 m depth the level recorded was lower.

Table 7.5

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) for the Spring of 1987

	Station 3			Station 6		
Depths	3 m	20 m	40 m	3 m	20 m	40 m
Dates						
04.3.	235.53	149.00	153.40	303.64	165.12	123.30
18.3.	46.23	45.03	86.82	78.00	60.30	45.42
25.3.	29.30	05.60	46.34	35.10	65.12	0a
22.4.	-	-	-	419.70	263.60	77.50

Comparative measurements in laboratory and in the sea (Table 7.6)

For comparison the measurements of carbon fixation were obtained with surface, 1 m, 5 m, 10 m and 40 m depth samples from station 6 (incubated in the sea and in the laboratory) during April showed throughout, as expected, the laboratory incubations gave higher fixation values. In general, however , these increased levels bore some relationship to those made *in situ*. Low *in situ* levels were accompanied by relatively low values from laboratory fixations, and high levels of activity in the laboratory were similarly reflected in the sea . Thus it would seem that the measurements based on laboratory incubation give valid indications of the potential productivity of the samples in nature. In general, maximal activity was obtained with samples collected on the surface water, both in laboratory and *in situ*.

With 40 m samples (Table 7.7) incubated *In situ* nearer the surface than normal it would seem that the laboratory incubations give fixation values of similar orders of magnitude to those obtained in the sea.

Table 7.6.

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) during April of 1987

for samples incubated in laboratory and *in situ*

Station 6

Date	Depth	in laboratory	*in situ*
1.4.	Surface	38.9	17.2
	1 m	17.4	12.2
	5 m	59.9	10.8
	10 m	17.7	13.7
15.4.	Surface	145.3	44.1
	1 m	156.9	54.5
	5 m	120.0	48.1
	10 m	119.9	9.6
27.4.	Surface	381.5	256.2
	1 m	563.3	265.3
	5 m	199.5	75.3
	10 m	143.0	25.6

Table 7.7

Carbon fixation rate (mg $C.m^{-3}.hr^{-1}$) of 40 m samples from station 6 during April 1987, measured in the laboratory and *in situ*

Date	in laboratory	*in situ*			
		surface	1 m	5 m	10 m
01.4.	19.5	13.3	6.1	13.4	0a
15.4.	14.7	22.3	19.5	44.1	0a
27.4.	47.5	30.7	18.3	50.6	24.2

7.2. PARTICULATE ORGANIC MATTER AND OXIDIZABLE ORGANIC CARBON

The major proportion of particulate organic material is composed of four main components: detritus, phytoplankton, bacteria and zooplankton, with most in the form of detritus (dead organic matter) which is an important source of energy for bacteria and for a significant number of benthic animals. The estimation of the mass is indirect measurement which is probably the most common primary measurement of total organic matter. This is determined by loss in weight after the ignition of a sample. The determination of potential energy rather than mass is a more imoprtant primary measurement of organic matter (cf. Mac Fadyen, 1948). By oxidising the organic matter with potassium dichromate, a measurement can be obtained which will give a rough estimate of the amount of organic matter available for assimilation or use as an energy source.

The total organic matter and oxidizable organic carbon results in terms of mass or energy are described here, commencing from 26 March 1986 until 25 March 1987 for 3 m, 20 m and 40 m samples from stations 3 and 6.

Spring 1986 (Table 7.8)

Similar quantities of total prticulate matter at both stations for the 3 m samples and even for 40 m samples occurred on 26 March with the highest in surface water sample at station 6 and in 20 m sample at station 3. The oxidizable organic carbon amounts showed a similar pattern with exception at 20 m at station 6 where the level of oxidizable carbon was high.

On 2 April the total organic material measurements showed reduced values in general

for all samples of station 3 and for the 20 m sample of station 6, with high levels in depth samples from station 3 and in surface sample for station 6. These measurements were associated with high increases in the oxidizable amounts at all depths except with 20 m at station 6. In spite of the high quantities of the oxidizable carbon at surface waters, the highest values were recorded in depth samples at 20 m at station 3 and at 40 m depth at station 6.

Increases in the values of total organic material were observed on 23 April with equal quantitis obtained in all samples at station 3 and in the 20 m and 40 m samples at station 6. These coincided with decreases in the total oxidizable carbon at all depths at the two stations with a high level at 40 m at station 6.

On 7 May the total particulate material and oxidizable carbon showed reduction for all of the station 6 samples, togather with 40 m from station 3 for particulate matter and in all samples from both station except 20 m from station 6 for oxidizable carbon. The quqntities of organic matter showed a gradual reduction with depth at station 3, whilst at station 6 equal measurements were obtained in all samples. The oxidiable carbon was high in the depth samples for the two stations.

On 21 May the increases in particulate material at 3 m and at 40 m at station 3 with 20 m from station 6 were associated with increases in the amounts of oxidizable carbon in all samples from stations 3 and 6 except for 20 m depth from station 3. These amounts were higher in the depth samples (40 m from station 3 and both depths from station 6) comared with the surface water samples.

Table 7.8

Total particulate organic matter (T.P.O.M) and Total oxidizable organic carbon (T.O.O.C) ($mg.m^{-3}$) during the spring of 1986.

		station 3		station 6	
Date	Depth	(T.P.O.M)	(T.O.O.C)	(T.P.O.M)	(T.O.O.C)
26.03	3 m	4000	356.1	4000	327.5
	20 m	4500	307.0	3000	496.2
	40 m	3500	231.0	3500	213.4
2.04.	3 m	2500	595.2	4000	596.0
	20 m	3000	731.0	2500	308.5
	40 m	3000	398.0	3500	771.1
23.04.	3 m	4500	447.2	8000	567.0
	20 m	4500	397.7	5000	176.5
	40 m	4500	390.6	5000	650.9
7.05.	3 m	5000	228.7	4500	213.7
	20 m	4500	265.4	4500	238.2
	40 m	4000	249.0	4500	348.0
21.05.	3 m	6000	253.4	4500	294.3
	20 m	4000	212.0	5000	353.9
	40 m	5000	299.5	4000	570.2

Summer 1986 (Table 7.9)

Particulate organic matter decreased on 18 June at all depths at both stations with equal quantities at the two stations in the 3 m sample in addition to 20 m samples. These decreases coincided with increases in oxidizable carbon values at all depths at station 3 and 3 m depth at station 6. The surface water samples contained high concentrations of both substances more than the depth samples at both stations.

On 2 July the particulate material concentrations increased at all depths at both stations, whilst oxidizable organic carbon decreased slightly at most depths at the two stations. The highest amounts of both total organic material and oxidizable carbon were recorded at 40 m, although the value of organic matter equalled to that in the 3 m samples and to that in the 20 m sample from station 3.

From 16 July to the end of summer the total particulate matter measurements in the surface water samples from the two stations fell gradually, whilst the quantities in the depth samples fluctuated, approaching the highest value (7500 $mg.m^{-3}$) during summer on 27 August for 40 m samples for both stations, associated with the lowest amounts of oxidizable carbon. Oxidizable carbon at this time fluctuated at all depths at the two stations with slight increases on 30 July in the surface samples at the two stations and with a high value in the 40 m sample from station 3.

Autumn 1986 (Table 7.10)

Particulate organic matter and oxidizable carbon measurements increased on 10 September at stations 3 and 6 for 3 m and 20 m samples and with 40 m samples for oxidizable carbon. The highest values were recorded at 40 m for particulate organic matter and at 3 m for oxidizable carbon.

Table 7.9

Total particulate organic matter (T.P.O.M) and Total oxidizable organic carbon (T.O.O.C) ($mg.m^{-3}$) during the summer of 1986.

		station 3		station 6	
Date	Depth	(T.P.O.M)	(T.O.O.C)	(T.P.O.M)	(T.O.O.C)
18.06.	3 m	4500	383.6	4500	488.4
	20 m	3000	335.0	3000	231.8
	40 m	3500	359.6	3000	334.5
2.07.	3 m	5000	270.0	5000	450.0
	20 m	3000	330.0	4500	231.0
	40 m	6000	362.0	5000	334.5
16.07.	3 m	4500	271.9	4500	350.9
	20 m	2000	325.6	4000	307.0
	40 m	4000	200.0	4000	197.4
30.07.	3 m	3500	327.5	4000	417.5
	20 m	4000	150.3	3000	123.8
	40 m	4000	422.1	2500	150.5
27.08.	3 m	3000	247.6	2000	196.5
	20 m	2000	277.3	3800	174.0
	40 m	7500	059.4	7500	081.9

On 24 September the organic matter showed high concentrations in the depth samples more than at surface against a high value of oxidizable carbon recorded at 3 m at station 3. There were high levels of total particulate matter at 3 m depth and of oxidizable carbon at 20 m at station 6.

On 6 October reductions in total organic matter and oxidizable carbon were observed at the two stations in some depths. The high quqntities of both substances coincided at 3 m at station 3 and at 40 m at station 6.

Large increases of total particulate organic matter were obtained on 27 October at both stations with the maximum in the depth samples. Sharp reductions were found for all samples at station 3 plus 20 m depth from station 6 accompanied by increases in the remaining depths from station 6. Maxima was recorded for 3 m depth at the two stations.

Due to the failure of sea water sampler, measurements for station 3 were not available on 12 November , whilst the organic matter recorded the highest values over this year at all depths with maxima of organic matter and oxidizable carbon at 3 m depth were not obtained from station 6.

Winter 1986-7 (Table 7.11)

The measurements of total particulat organic carbon and total oxidizable carbon obtained on 16 December for 3 m and 40 m depths from station 3 showed the higher value of particulate material at 3 m although the reduction in general was accompanied by low level of oxidizable carbon with the higher level at 40 m ($818.7 mg.m^{-3}$)

On 22 January 1987 the organic material and oxidizable carbon were higher in the 20 m and 40 m samples from station 3 and in 40 m sample from station 6.

Table 7.10

Total particulate organic matter (T.P.O.M) and Total oxidizable organic carbon (T.O.O.C) ($mg.m^{-3}$) during the autumn of 1986.

		station 3		station 6	
Date	Depth	(T.P.O.M)	(T.O.O.C)	(T.P.O.M)	(T.O.O.C)
10.09.	3 m	4000	317.3	4000	382.4
	20 m	2500	228.9	4500	276.6
	40 m	6000	286.5	5000	338.6
24.09.	3 m	2500	368.4	3500	307.0
	20 m	4000	204.7	2500	384.2
	40 m	3500	332.6	3000	163.7
6.10.	3 m	3400	348.0	1850	189.3
	20 m	1960	240.7	1400	143.3
	40 m	2000	307.0	3300	337.7
27.10.	3 m	4000	158.1	3000	491.2
	20 m	4500	098.2	3500	007.7
	40 m	4000	200.0	4000	419.1
12.11.	3 m	-	-	9500	286.5
	20 m	-	-	8500	291.6
	40 m	-	-	8500	220.0

Table 7.11

Total particulate organic matter (T.P.O.M) and Total oxidizable organic carbon (T.O.O.C) ($mg.m^{-3}$) during the winter of 1986-7.

		station 3		station 6	
Date	Depth	(T.P.O.M)	(T.O.O.C)	(T.P.O.M)	(T.O.O.C)
16.12.	3 m	2800	135.1	-	-
	20 m	-	-	-	-
	40 m	2400	818.7	-	-
22.01.87	3 m	2000	362.3	3500	398.6
	20 m	3000	393.0	2000	368.4
	40 m	2700	417.5	4800	423.7
18.02.	3 m	3000	417.0	2000	373.8
	20 m	1500	405.0	2500	460.5
	40 m	1500	421.2	2500	416.7

On 18 February 1987, the pariculate organic matter was reduced at all depths at both stations except with the 3 m sample from station 3 and 20 m sample from station 6. The concentration of organic matter at 3 m at station 3 overtook the cncentrations at 20 m and 40 m, whilst the oxidizable carbon was high in the depth samples at both stations with high values organic material at 20 m and 40 m at station 6.

March 1987 (Table 7.12)

Both amounts of total particulate organic matter and oxidizable organic carbon increased on 4 March in all samples for the two stations. High levels of both were obtained at 40 m depths at stations 3 and 6.

A general reduction occurred on 18 March at all depths at both stations except with 3 m depth at station 6 where the level of particulate organic matter increased. The high value of organic matter coincided with high level of oxidizable carbon at 3 m at station 3, whilst the highest measurement at station 6 was recorded at 20 m depth although the highest of organic matter was obtained at 3 m.

In spite of the increases observed on 25 March in particulate material for 3 m at station 3 and for both 40 m depths at the two stations the levels decreased at 3 m at station 6 and for 20 m samples from both stations, whilst the highest values were recorded at 40 m depths. Oxidizable carbon increased in the 3 m and 20 m samples from both station with the highest was obtained at 20 m at the two stations, whilst there were reductions and low levels at 40 m deths.

Table 7.12

Total particulate organic matter (T.P.O.M) and Total oxidizable organic carbon (T.O.O.C) ($mg.m^{-3}$) during March 1987.

		station 3		station 6	
Date	Depth	(T.P.O.M)	(T.O.O.C)	(T.P.O.M)	(T.O.O.C)
4.03.	3 m	4000	501.5	2500	593.6
	20 m	3000	480.0	2500	614.0
	40 m	4000	593.6	3000	851.3
18.03.	3 m	1000	137.1	3000	193.5
	20 m	2000	112.6	2000	241.2
	40 m	2500	168.9	1500	159.0
25.03.	3 m	2000	279.4	2000	207.2
	20 m	1500	314.7	1500	875.0
	40 m	4000	161.2	3000	139.6

Measurements of carbon fixation offer a further dimension to biomass studies. Such assays seek to answer questions regarding a feature indicated (but not established) by chlorophyll measurements, and not fully indicated with numerical assessments of organisms. As already stated, laboratory incubations were used as a means of estimating the potential activity of the populations - to carry out routine seasonal studies *in situ* with 20 m and 40 m depth samples presents appreciable logistic and physical difficulties. However, when comparisons were made with *in situ* and laboratory incubations (Table 7.6), whilst there were variations, in general the laboratory measurements were of similar orders of magnitude to those *in situ*, although the former were appreciably higher due to the more favourable light and temperature conditions and to the absence of attenuation of light with increasing depth.

It was also noted that the *in situ* measurements of samples from the surface down to 10 m made in April 1987 wre similar to those obtained by Hannah (1979) in April 1976 and 1977.

As expected, the 3 m samples for the most part showed the higher levels of carbon fixation depending on season. However, during spring, summer and autumn, it was rarely that no measurable fixations were obtained with the deep water samples. At most times the carbon fixed by the depth samples was lower than with the surface. On occasions, however, high levels of fixation were measured with surface and depth samples (eg. April 1986, July 1986 and March 1987). Whilst the lower levels of fixation are due to some extent to lower biomass, this is not always the case. The results amply demonstrate that the phytoplankton in the deep water remains, perhaps in part, a viable population, retaining the capability for carbon fixation if returned to lighted regions.

This potential was also demonstrated in the combined *in situ* and laboratory incubations carried out in April 1987, when phytoplankton taken from 40 m depth were incubated in the laboratory and *in situ* in the photic zone.

On two occasions (1st and 15th April) the quantities of carbon fixed in the laboratory and *in situ* were of a similar order down to 5 m depth, but no fixation was obtained at 10 m. On 27th April the higher fixation rate in the laboratory was similarly reflected *in situ*, down to 10 m depth. Hence it would seem that the laboratory incubations of samples from the deeper water are genuine examples of potential activity, and not an overreaction to the higher light levels and temperatures of the laboratory.

The phytoplankton, whilst making contributions to both T.P.O.M. and T.O.O.C., is not necessarly the principal component. The measurements made were to determine whether significant changes were obtained with season and depth. As expected, the lowest values were obtained in the winter months. In the spring there were similar values at all depths, perhaps reflecting the general high productivity reflected in the deeper water by sinking and/ or mixing. Similar results for the early summer but with higher values in the surface water possibly reflect the more localised higher productivity.

In late August the T.P.O.M. quantities were appreciably higher at 40 m, with low T.O.O.C., possibly indicating a sedimentation process, a condition extending into the early autumn. Samples generally indicated increased productivity ,as with the spring data.

8. COMPARATIVE DISCUSSION ON BIOLOGICAL WITH PHYSICAL AND CHEMICAL DATA

The data obtained from April 1984 to the end of April 1987 in this present investigation are here discussed comparatively, including biological aspects and physical and chemical features.

Spring 1984

Data obtained in May from 20 m and 40 m depths at the two stations showed low levels of chlorophyll *a* (0.4-2.0 mg m^{-3} and higher values of phaeopigments (0.7-22 mg m^{-3}) which would suggest that, at these depths, the results of zooplankton grazing on phytoplankton in the surface waters are to be seen. The fall in levels of dissolved silica in the deep water betwen April and May rather indicates that the main spring growth of diatoms had preceded the measurements made in May. Similar decreases were observed with nitrate nitrogen and phosphate phosphorus. The factors which trigger the spring increase are well known- a period of increased sunshine accompanied by calmer seas. From the available data this would have been between 29 March and 3 April, with sunshine hours ranging between 6.2 - 10 h per day, and daily mean wind speeds from 4.9 to 12 knots, mainly from the north east quarter (see Appendix II). The sampling points are mainly open to wind action from the west, south west and east, and sheltered from north and north east and north west. In the previous weeks in March the wind speed had been lighter. A second period of increased daily sunshine and reduced winds was from 22 - 28 April (11.7 - 13.5 h per day), with low winds (except on 26 April). The May sampling programme would probably have been yielding biological data in the deeper water representing the end of the first major spring growth.

Summer 1984

Same higher levels of chlorophyll *a* were recorded in the depth samples in early June, decreasing through July and August, but accompanied by very low levels of phaeopigments (sometimes reaching analytical zero). Nutrient levels were higher than at the end of the spring growth, and tended to increase towards the end of summer period. June 1984 was a poor month for sunshine, less than in May, and there were periods of quite high winds, especially towards the end of the month. The high level of chlorophyll *a* at the begining of the month probably represents a biomass increase following the increased sunshine at the end of May and relatively low wind action. The wind speeds increased during the days prior to sampling (12 knots on two days from the north) so that the chlorophyll measurement may have been for a living population (low in phaeopigments) carried down into the deeper water. July was a better month for sunshine than June, but there were periods of more continuous and steady wind (11-7 knots) from 9 - 21 July accompanied by days with relatively lower periods of bright sunshine (no sun on some days; up to 4 h most of this same period). Hence the relatively low chlorophyll *a* values and almost total absence of phaeopigments may well have recorded a phytoplankton population in a well mixed water column. Whilst the hours of sunshine per day were not all that better in August 1984, there was a period of reduced wind action (3.9-6 knots between 9 - 20th) which could have favoured thermocline formation. The slow build up of nutrients in this period may have represented the breakdown of organic matter in the deeper water below the thermocline.

Autumn 1984

An autumnal peak of chlorophyll *a* was observed on 19 September with decreasing chlorophyll *a* amounts thereafter into the winter period to reach very low values (7.2 - 0.1 mg m^{-3}). The undetectable level of phaeopigments in September (during the time of increasing chlorophyll *a* measurements) was followed by the phaeopigments values

increasing through October and November (0.8 - 2.6 mg m^{-3}), and could be attributed to the feeding activity by zooplankton and/ or to chlorophyllase activity associated with the very short period of sunshine in the days preceded the sampling days (17 October and 21 November) and a consequent boost in the surface phytoplankton . Nutrient concentrations doubled during this autumn period through October and November following the breakdown of the stratification by strong winds. The increases in nutrients could have followed vertical mixing and breakdown of organic material. Such increases also probably stimulated the autumnal outburst which commenced on 19 September. The number of hours of the bright sunshine decreased sharply during autumnal months towards the winter period, accompanied by high velocity winds in general. From 28 August through September, October and November the short period of sunshine ranged between 0.3 to 10.2 h per day and coincided with very windy periods (12 - 26 knots from the north and south west on most days). The preceding lighter winds on the sampling day (19 September) with the increased nutrients might have triggered the autumnal increases of the chlorophyll *a* and the total cell numbers. Strong winds blew from the south west (16 - 30 knots) recorded from the middle of October to the middle of November and for 8 days in the end of this month from the same direction there was another windy period (18.4 - 29.5 knots). As already noted, the south west quarter is the one from which wind action is likely to have most effects in the mixing process.

Winter 1984-85

The very low activity of the phytoplankton was indicated by very low levels of chlorophyll *a* accompanied by an initial sparse total biomass (13.5-15.7x10^3 cells.l^{-1} on 3 January 1985) and short periods of bright sunshine per day. The highest number of sunshine hours per day were 5.4 h (obtained on a few days), whilst windy days with gales would have caused turbulent mixing of nutrient rich deep water. In December two periods of high wind speed started blowing on 3rd over the sampling day (5th) to 10th

(12.7-27.8 knots) from south west and from south and north west with high speeds (13.6-20.5 knots) in the second period (17-25) of this month. Despite the lighter daily mean speed (10.0 knots) of winds recorded during January 1985 two short periods (21st- 23rd and 30th-31st) of high winds (16.3-30.5 knots) blew from south west, with 75 hours of gusts (over 34 knots). During winter period changes in nutrients are mainly due to non-biological environmental factors, and the combined effects of vertical mixing and low radiation input kept the phytoplankton populations low at all depths.

Spring 1985

Chlorophyll *a* remained around its winter levels during the first half of March associated with similar high concentration of nutrients exceeding on occasions the winter increase mainly with dissolved silica (16.4-23μg at. l^{-1}). On 20 March the chlorophyll *a* increased (10.2 mg. m^{-3} from a previous measure of 0.3 mg m^{-3}), followed by a gradual decrease in levels during April and May (except on 22 May). The physical and chemical factors were satisfactory, so this decrease might be due to the abundance of zooplankton and grazing during this period. The second pulse of chlorophyll *a* increase during spring was measured on 22 May (3.4- 8.4 mg. m^{-3}) but was less than in March. Correspondingly high levels of phaeopigments during March and May (grazing activity) were associated with both increases in chlorophyll *a* levels and the total of biomass, which rose up dramatically from the initial sparse population on the winter period to exceed 3 million cells. l^{-1}, indicating the spring outburst of phytoplankton during late March and early April with signs of a population decline through April. On 3 April the total cell numbers (1.7-2.3x10^6 cells. l^{-1}) in the bottom (40 m) exceeded the total population in the upper layer (20 m) of the aphotic zone, which could be regarded as evidence of the sinking of phytoplankton cells . The second spring outburst of biomass population increase in May (4.9x10^5- 1.5x10^6 cells. l^{-1}) and the chlorophyll increase may be considered to result from the effects of the lower grazing rate, upwelling of the nutrient enriched water column and long periods of

sunshine . Nutrients did not become depleted till the late spring when the rapid multiplication of phytoplankton removed nutrients from the water column. So in early March 1985 the nutrients were of similar high levels to those in winter with an increase in dissolved silica concentration (16.4 - 23.0 μg at. l^{-1}). A decline of dissolved silica and phosphate P levels (from 23.0 to 4.5 μg at. l^{-1} and from 2.6 to 0.8 μ at. l^{-1}), continued towards the end of the spring period, whilst nitrate N levels remained higher (3.7 - 9.4 μg at. l^{-1}) but with fluctuations. Sunshine periods increased to reach 122 hours during March with increasing day lengths to record the highest periods of daily sunshine on 13th to 20th (6.8 - 10.2 hours per day) preceding the sampling day, accompanied by some wind (daily mean of 12.1 - 19.0 knots from south and north west). A short bright sunshine period (0.3 - 4.1 h) preceded the sampling day on 3 April, but with some wind action (12.5 - 15.7 knots) mainly from the south west. Factors such as these could caused the dissipation of the measured phytoplankton population. Daily sunshine periods from the middle of April exceeded 10 h per day to reach the highest period of 14.4 h per day in May. During this month the wind speed remained high, blowing mainly from the south west, rarely from the north.

Summer 1985

High levels of chlorophyll *a* and phaeopigment remained in June (the brightest month with calm seas) with highest values obtained on 26th in the photic zone (9.3 mg. chlorophyll *a*.m^{-3} and 8.5 mg phaeopigments m^{-3}) and the top layer (20 m) of the deeper water (6.0 mg chlorophyll *a* m^{-3} and 4.9 mg phaeopigments m^{-3}). The increases of chlorophyll *a* accompanied probably by heavy grazing indicated by high levels of phaeopigment with corresponding increased population ($9.8x10^5$ in the surface water and $7.9x10^5$ cells. l^{-1} in the deep layers) followed the increased bright sunshine hours per day in two periods (13.8 - 15.8 h per day from 29 May - 5 June and 10.9 - 13.8 h per day from 13 - 26 June) and lighter winds in the same time (less than 7 knots)

blowing from south west and north east in the first period and lower than 12 knots on most days mainly from south and north west in the second period. As the water became warmer during summer (11 - 14 ^{o}C) the phytoplankton population was characterized by increased numbers of flagellates and a more diverse species composition. Thus green flagellates tended to be dominant in the photic zone and aphotic zone in early June and shared the dominancy with *Leptocylindrus danicus* in the photic zone and the bottom of the aphotic zone in the end of this month. Nutrients became depleted in the surface waters by the increase of phytoplankton in this time, whereas the levels remained measurable in the deeper water (1.6 μg at. N. l^{-1}, 2.1 μg at Si. l^{-1} and 0.5 μg at P l^{-1}) although the decreases from 8.2, 7.9 and from 1.0 μg at.N,Si and P respectively were obtained in the previous month. The concentrations increased again in July (22nd) and then decreased sharply in August for nitrate N and phosphate P mainly in the surface waters. Phaeopigments were higher (22 July) than chlorophyll *a*, associated with the preceding short period of sunshine(0.9-8.7 h per day) and a windy period which started on 14 July and lasted for 7 days (13.0-19.6 knots mainly from north east) which included 13 hours of gusts of more than 34 knots which might have brought up the reservoir of nutrient rich water below 20 m into the upper layer. The population of phytoplankton in this month was dominated by *Leptocylindrus danicus* (69.3-82.3% of the total cells) and *Nitzschia seriata* (8.1-25.3%) and small contributions of dinoflagellates and green flagellates. Sunshine hours per day decreased gradually throughout July and August towards the autumnal season, whilst wind speeds increased to reach the monthly mean of 14. 1 knots (a windy August). The direction of the winds during August was mainly from south west with north west and east at some days. In this month with vertical mixing of the water column dissolved silica increased in the photic zone which might have stimulated the phytoplankton population increase to reach $6.8x10^{5}$-$1.8x10^{6}$ cells. l^{-1}, whilst the chlorophyll *a* averaged between 3.1- 12.9 mg. m^{-3} in the surface waters. Phaeopigments were low in the surface waters and high in the deep layers. *Leptocylindrus danicus* and green flagellates were predominant in the photic zone, whereas the domination of green flagellates was obtained in the deeper waters (96 - 100%) in early August. On 21 August the dinoflagellates dominated the

surface water population (75.9-81.4%) whereas *Thalassiosira* spp. was dominant in the deeper waters, which increased the proportion of the diatoms in this region, whilst planktonic species remained high (92-100%) with small contributions from benthic species in the aphotic zone (3.1- 8.4%), again suggesting some sinking of the surface flora.

Autumn 1985

An autumnal increase of chlorophyll *a* recorded on 18 September through the water column reached 8.1 mg. m^{-3} at surface and 1.9 mg. m^{-3} in the deeper water. Correspondly high levels of phaeopigment (less than chlorophyll *a*) could be due to the decrease in the number of sunshine hours and windy weather. In this period total cell numbers increased also to $4.9x10^5$ at surface and between $3.3\text{-}4.9x10^5$ cells.l^{-1} in the deeper waters. There populations were dominated by *Skeletonema costatum* (91.3-93.2%) in the surface waters and by *Thalassiosira* spp. (37.7-66.6%) in the deeper waters . The benthic contributions to the population below 20 m were high (6.7-18.0%). Dissolved silica and phosphate P decreased (compared with the July and August levels), whilst nitrate N showed the lowest values in the autumn on 19 September. During October and November the increases of both nitrate N (0.8-4.7 μg at.l^{-1} at surface and 1.7-6.4 μg at. l^{-1} at depth) and phosphate P (0.4-1.0 μg at.l^{-1} in the photic zone and 0.2-2.1 μg at.l^{-1} in the aphotic zone) were obtained with fluctuations in phosphate P level for the surface waters. Dissolved silica showed the contrasting pattern of high levels at the time of autumnal phytoplankton increase and then declined from 5.0-1.8 μg at.l^{-1} in the surface samples and from 8.3-2.0 μg at.l^{-1} in the depth samples. In spite of the general decrease of chlorophyll *a* and biomass population numbers towards the end of the autumn period togather with less favourable physical factors, the chlorophyll *a* level recorded was the maximum (8.5 mg. m^{-3}) in the surface water at station 3 by 9 October. After this time the phytoplankton outburst was over (chlorophyll *a* fell to analytical zero and phytoplankton cell numbers to less than $6.6x10^4$ cells.$^{-1}$ in the

surface water and $3.1x10^4$ cells.l^{-1} in the deeper waters). Low levels of phaeopigment were measured during October, whereas the level increased slightly in November (0.4-0.8 mg. m^{-3}) to exceed the chlorophyll values. *Thalassiosira* spp. exceeded *Skeletonema costatum* in the populations in both the photic and aphotic zones during October (92.9% of the total) and in the deep layers at the end of November, whilst the *Skeletonema* dominancy was at the surface with high contributions of green flagellates. Benthic species increased with the vertical mixing by winds from the end of October in the surface (6-13%) and deeper waters (7.4- 20.1%). The sunshine periods decreased gradually (80-66 h per month during the autumn) . A very short period of low sunlight started on the 29 August for 7 days (0.1-0.7 h per day except 5.6 h in one day). Another 10 days from 10th September (including the sampling day on the 19th) recorded better sunshine levels (3.6-8.7 h per day) with absolutely no sunshine over a few days. From 26 September to 9 October the hours of bright sunshine recorded daily fluctuation between 0.1-6.9 h per day and also during another period (23 October to 3 November), ranging from 1.4-8.4 h per day followed by reduced sunshine in the last 12 days of November (0.1-5.3 h per day). Strong winds (11.2-23.9 knots) in many days of September included the sampling day (19th) when the autumnal increases were measured. From 11th to 22nd September there were 45 hours of gusts over 34 knots blowing from south and north west whilst the rest of the month was dominated by light winds of less than 10 knots. The windy period in October was from 2nd to 11th (13.6-25.5 knots from south west) with gales over 34 knots for 54 hours from south west. A similar windy period in the first 11 days of November (12-23 knots from south and north west plus east north) with gales for 51 hours whereas the light wind speeds were less than 11 and 10 in October and November respectively. Sea temperature during the autumnal months fell from 13-9 ^{o}C. Hence the biomass changes in the later weeks of the autumn were those of a population markedly affected by the climatic conditions.

Winter 1985-86

Unmeasurable chlorophyll *a* and phaeopigments were obtained over winter period

except for a low level of phaeopigments detected on 12 February 1986 (0.2-1 mg m^{-3}) which coincided with sparse phytoplankton standing crop, which dropped from $1.9x10^4$ to $0.6x10^4$ cells.l^{-1} with noticeably higher cell numbers in the deeper waters. Nutrient concentrations increased considerably with the highest records in this period of 15.4 µg at. Si.l^{-1}, 7.9µg at. N.l^{-1} and 1.8µg at. P.l^{-1} for surface waters and with 16.2µg at Si.l^{-1}, 11.8µg at. N.l^{-1} and 2.94µg at P. l^{-1} for deeper waters. The day lengths, temperature and of the sunshine periods decreased sharply in this period to reach the minimum in December (34.2 h mean per month) and there were long periods without bright sunshine. For most days again there was no measurable sunshine, only up to 6.2 h for a few days in late January, and up to 7 h for a few days at the end of February. Most days in December and January had strong winds with averages of 12.9 knots in December and 15.6 knots in January. The strong winds in these two months contained gusts for 102 hours and 233 hours respectively, whilst February was a calm month compared with the two previous months. The direction of these winds were variable, but mainly from south west and north west and north east - the quarter which most influence the sampling area. The thorough mixing of the early winter months, with the subsequent minimal biomass measurements was thus followed by a small biomass increase in the calmer month of February.

Spring 1986

The chlorophyll *a* levels increased gradually during March and April to reach the highest levels at the surface and deep layers on 23 April (2.7-3.2 mg. m^{-3} in the surface samples and 2.2-4.2 mg m^{-3} in the depth samples) along with improvements in the sunshine periods sea temperature, and calmer seas, whereas phaeopigment levels fluctuated during this period until the obvious increases obtained also on 23rd (2.1-2.4 and 0.8-2.8 mg m^{-3}) at both layers respectively. A corresponding increase in the total biomass was observed from the begining of March through April in the surface and depth samples ($1.2-1.8x10^6$ cells. l^{-1}) at the end of April, although the highest carbon

fixation rate in the laboratory was recorded on 2 April for surface samples only (200 mg C. $m^{-3}.h^{-1}$). *Skeletonema* dominated the population during March with *Nitzschia closterium* at the end of March, whereas the first organism again dominated the phytoplankton population (65.8-98.2%) during April with small contributions from *Thalassiosira* spp. on 2 April in the deeper water. The salinity during this period was between 30-35% with lower values in the surface, whilst temperature increased from low in the winter to reach 8.8 ^{o}C at surface and 7.4 ^{o}C at deep layers. Nutrient concentrations remained high during March, but the levels of nitrate N and dissolved silica declined in April, probably due to the consumption linked with the diatom outburst. The gradual increases of chlorophyll *a* and biomass corresponded with the gradual increases of sunshine periods during March and April (124 and 138h per month). The number of sunshine hours during March fluctuated between 0.1-10.3 h per day with unmeasurable sunshine for 6 days. From 30 March to 11 April there was a relatively high period of daily sunshine (2.3-10.9 h per day) in addition to another period from April 17-29 ranging 0.7- 10 h per day. No bright sunshine was recorded for 3 days (7th,30th and 31st) and short sunshine periods per day scattered over 16 days (0.1- 5.6 h per day) with 12 days with sunshine ranging from 6.1-12.4 h per day. March was a windy month (mean of 14.0 knots) with winds mostly from the south west with range of 12-29 knots in three periods (3rd-8th, 12th-17th and 20-29th). Gusts (over 34 knots) blew for 106 hours in this month, whilst by comparison April was quite calm (mean value of 10.5 knots) and characterized by winds fluctuating from light to strong with short periods (14-16th and 28-30th) of these strong winds (in order, 14.7-22.3 knots from the north east and 13.3-19.9 knots from the south west). Two strong windy periods were obtained in May (10th-18th and 21st-30th) exceeding 11 knots to reach 19.1 knots from the south west. In this month the second pulse of chlorophyll *a* (2.2 and 1.3 mg m^{-3} for the surface and upper depth samples respectively) and standing crop was obtained on 21st when the fixed carbon increased to 173 mg $m^{-3}.h^{-1}$ in the surface samples and 102 mg $m^{-3}.h^{-1}$ for the upper depth samples (20 m). Phaeopigment concentrations were 3.6 and 1.5 mg m^{-3} for both layer samples exceeding the chlorophyll *a*, which would suggest that the results of zooplankton grazing

accompanied by the two short periods of sunshine (1st to 6th and 17 to 21st) ranging ,in order, 0.3-10.3 and 0.6-4.1 h per day. The phytoplankton population of the photic zone and in the deeper waters in the early part of this month was dominated by green flagellates (with the upper layer of deeper waters in late May) with high contributions of *Skeletonema costatum*, whereas this species made up the majority of the population with relatively high components of *Thalassiosira* spp. in the deeper waters, possibly representing a sinking biomass. Planktonic species were dominant in both layers during the spring period with contributions of benthic species high in the depth samples (18%) mainly in March and April, probably a result of the more severe wind action in March and thorough mixing.

Summer 1986

There was a general decline in chlorophyll and phaeopigments, although the phaeopigments exceeded the chlorophyll values (probably due to a heavy grazing rate in summer) during June (in deep sea) and in July (both layers) coincided with similar decreases in total biomass and carbon fixation rate. On 30 July high levels of chlorophyll *a* were measured in the both surface and deeper waters (7.9 and 1mg m^{-3} respectively) although a low number of sunshine hours were recorded in the seven days, which preceded this day (no sunlight) consisting of around 1 h per day for 3 days and between 2.3-7.9 for 3 days and was associated with calm sea (5.0- 12 knots from north west) except on 29th when the mean speed recorded 16.0 knots. The increased phytoplankton populations ($5.2x10^5$ cells.l^{-1}) and high levels of carbon fixation (224.2 mg.m^{-3}.h^{-1}) which were obtained in the surface samples only coincided with the increased chlorophyll *a* and were then followed by reduction in these three parameters on 27 August, whilst phaeopigment values increased in the both surface and deeper waters (2.5 and 2.3 mg. m^{-3} respectively). Thermal stratification probably developed during June when the temperature increased throughout July, tending to be high in the surface water (11.4-14.4 ^{o}C) and lower in the deeper water (7.4-11.2 ^{o}C), whilst the salinity

ranged between 31-33%. at surface and 32.6-34.1%. in deeper layers. Green flagellates dominated the surface samples and the upper deeper layer, and *Skeletonema costatum*, and *Coscinodiscus* spp. in the depth samples during June.*Thalassiosira* spp. replaced green flagellates on 2 July which was predominant in the depth samples with *Leptocylindrus danicus* in the surface waters on 16 July. The latter species was dominant in all samples through water column at the end of July with high contributions of *Skeletonema costatum* and *Coscinodiscus* spp. during all July mainly in the depth samples. In August the populations were dominated by *Chaetoceros* in the surface samples and with *Skeletonema*, *Coscinodiscuso* and *Thalassiosira* spp. in the depth samples. *Skeletonema costatum* made up the majority of the population in the bottom of the deeper waters. The number of sunshine hours fluctuated during summer period (207.6, 118.3 and 184.2 h per month respectively). High sunshine hours occurred over scattered days in June (5-6, 11, 15, 19-22 and 28-30) ranging between 10.1-14.9 h per day, whilst on most days in this month they ranged from 0.2-8.7h, accompanied by two windy periods (3- 10th and 17-23rd) with winds from north and south west (13.3-16.8 knots) and from north east and west (11.8-18.3 knots). Sunshine never exceeded 9 hours per day except for three days (1st, 8th and 23rd) in July and 8-9th, 11th, 14th, 23rd and 30th in August. The sampling days in July (2nd, 16th and 30th) were preceded by light wind mainly in the period of 9-16th (4-11 knots from south west) and 24-30th (5.0-12 knots from north and south west and north east). In August there were light winds except from the 15th when strong winds blew for four days from north and south west (12-21 knots) and for five days (26-30th) from north east and west (13.7-17.5 knots). It is likely that the thermocline was long lasting, with *Skeletonema* and *Thalassiosira* remaining in the deeper water in the late summer.

Autumn 1986

The chlorophyll *a* levels increased according to the August values to record the autumnal peak on 10 September at the surface (4.3 mg. m^{-3}) and deep layers (2.7 mg.

m^{-3}). The increase in deeper waters in autumn were higher than that in the summer seasons, whilst phaeopigments remained high at this time (in September) accompanied by the increase of total cell numbers in both layers ($3.4x10^5$ and $2.5x10^5$ cells.l^{-1} respectively). Carbon fixation rate increased slightly compared with that in August, but the climax of the fixation was recorded on 6 October (148 and 51.0 mg C. $m^{-3}.h^{-1}$ at both surface and deeper waters respectively) when the chlorophyll *a* remained high (less on 10 September), whilst total biomass decreased towards the end the autumn period associated with a similar decline in chlorophyll *a* and carbon fixation after the high levels recorded on 6 October. Phaeopigments recorded the highest values on 27 October for deeper water (4.0 mg m^{-3}) and on 12 November for surface waters (3.7 mg m^{-3}). Planktonic species dominated the population, although there was a high contribution of benthic species during October and November with diatoms dominant. High contributions of *Skeletonema costatum*, *Chaetoceros* spp. and *Thalassiosira* spp. were obtained in this time. Sunshine periods decreased during autumn from 151.7 to 45.9 h per month. In November no bright sunshine was recorded for 12 days, whilst the rest ranged between 0.3-8.4 h per day probably with other factors (decreased day length, strong winds and zooplankton grazing) probably affected the high values of phaeopigments in this month. High strong winds (14.4-17.7 knots from south west continued till 7 September when the light wind (4.5-10.5 knots from north east) blew till 18 September, and was followed by another period of strong winds from 22nd to the end of this month. The windy period (12.5-30.7 knots) in October started on 9th for the rest days of this month, whereas the gusts (more than 34 knots) blew for 136 hours during this period from south west and north west. The most windy month during autumn was November with winds speed more than 15.2 knots most days in the month with maximum mean daily wind speed 32.3 knots, whilst winds over that speed blew for 213 hours. Hence the fall in the late autumn biomass, with the short lived autumnal outburst coming between the main windy periods in September and October.

Winter 1986-87

As usual the winter months were characterized by unsuitable physical and chemical factors for phytoplankton growth. The chlorophyll *a* and total biomass and carbon fixations and even phaeopigment levels were very low. Sunshine periods were also reduced sharply throughout the winter, although there was a small gradual increase from December to February. Strong winds were obtained, with a monthly mean of 17.7 knots and winds over 34 knots recorded for 211 hours. The predominant winds blew from south and north west. The first two weeks of January 1987 had winds over 12 knots mainly from the north east, followed by light winds during the rest of this month. A short period (3 days) of strong winds (4-6 February) ranged between 16.3-26.5 knots and for one day (11th) reached 18.6 knots. The direction of these winds was from south west - again, the most exposed quarter for the sampling area. As suggested by the biological data, for most of the winter a small phytoplankton population was dispersed throughout a thoroughly mixed water column

Spring 1987

The early phytoplankton outburst was obtained on 4 March. The chlorophyll *a* levels increased suddenly to over 13.3 mg m^{-3} at the surface and 10.3 mg m^{-3} in the deeper waters, coinciding with increased total biomass exceeding $3x10^6$ and $2x10^6$ cells. l^{-1} in the surface and depth samples respectively. Carbon fixation reached ,in order, 303.6 and 165.1 mg $m^{-3}.h^{-1}$ at both layers. Thereafter the levels of these parameters reduced during the rest of March. Despite the increase in the total number of sunshine hours to 108.7 hours in March the sunshine period never exceeded 10.0 hours per day, and was lower than 6 hours on most days (22 days) accompanied by 21 days when winds ranged between 12.5-27.4 knots, mostly from the south west. This would suggest that the early spring diatom growth was rapidly dispersed by the mixing of the water column due to wind action, with low sunshine.

9. GENERAL DISCUSSION

Nutrient concentrations observed in the Fairlie Channel in this present study were similar to those found by Hinton (1974) and Hannah (1979), mainly for the photic zone, in both the seasonal variations and annual patterns, although higher levels of maximum values of dissolved silica and phosphate P. and lower minimum amounts of dissolved silica and nitrate N. were obtained in the present work. The concentrations of nutrients in the Fairlie Channel found by Hinton (1974) were generally higher than those recorded for any other coastal areas in Britain when their nutrient levels are compared with those in the Firth of Clyde. The similar results for micronutrients in the present investigation with those in 1972-1973 (Hinton 1974) and 1976-1977 (Hannah 1979) might be due to correlative biological data in the surface water. The data obtained from the deeper water will also be discussed comparatively in this section. Hinton (1974) found that phosphate P. during 1972-1973 in the Clyde Sea area was considerably richer than any other areas. The winter maximum for phosphate P. of 1.63 was found in 1973 whilst the winter levels observed by Hannah (1979) during 1976-1977 were normally above 1 μg at. l^{-1}, reaching 1.8 μg at. l^{-1}. The very high maximum winter levels of 4.7 μg at. l^{-1} recorded in January 1985 in the present study were for deeper water, a level similar to the high values of 3.93 μg at. l^{-1} for surface waters in Gareloch which suffers from considerable pollution from the Clyde Estuary, as reported by Hinton (1974). In 1986 the maximum levels were recorded in February (1.8 for surface waters and 2.94 μg at. l^{-1} for deeper waters). According to Hinton (1974) the lowest levels of phosphate P. were obtained for the Fairlie Channel surface waters in early June 1973 (0.2 μg at. l^{-1}), whilst on 24 June 1976, 0.1 μg at. l^{-1} was measured (Hannah 1979). The minimum values in the present work recorded during 1984-1985 were at the similar time and over similar ranges to those obtained by Hinton (1974) and Hannah (1979) for surface and deeper waters (0.2 and 0.3 μg at. l^{-1} respectively) with a higher value (0.5 μg at. l^{-1}) for the deeper water in 1985. When compared with the winter maximum in the deeper water, it would seem that a

utilization of phosphate had occurred throughout the water column. Nitrate N. concentrations in winter are generally higher (25%) than that of North Sea due both to nutrient addition from the River Clyde and Irish Sea (Steele *et al.*, 1973). The nitrate N. levels in the upper Firth were found to be markedly higher to the west of Cumbrae Island (12-14 μg at. l^{-1}) than to the east (10.5-12 μg at. l^{-1}, Hinton, 1974). The highest recorded level of this nutrient for the photic zone in Fairlie Channel was found by Hinton (1974) at the end of January 1973 (23.7 μg at. l^{-1}). In 1972 a peak of 14.3 μg at. l^{-1} was recorded, whilst in 1976 and 1977 the maximum winter levels was recorded in February at around 21 μg at. l^{-1} for both years (Hannah, 1979). The present investigation showed that the winter maximum was recorded in early January 1985 (12.5 μg at. l^{-1} and also in early December 1985 (7.9 μg at. l^{-1} for surface samples and 11.8 μg at. l^{-1} for depth samples). The actual maximum may have been missed due to the longer sampling interval - Hinton (1974) used a daily sampling programme; Hannah (1979) sampled weekly or fortnightly). Nitrate N. fell to below 0.5 μg at. l^{-1} during June 1973 (Hinton, 1974) whilst Hannah (1979) found a minimum level of around 1 μg at. l^{-1} in July 1976 and 1977. In this present study the lowest values of nitrate N. were recorded at a similar time (June 1984 for deeper water and in 1985 throughout the water column ,as seen for phosphate P. levels, and in July and August for surface waters). Dissolved silica levels in the Fairlie Channel in winter were similar in both 1972 and 1973, with maxima of 13.4 and 14.95 μg at. l^{-1} respectively (Hinton, 1974). Maxima of this nutrient was recorded in November 1976 and March 1977 at around 13 μg at. l^{-1} (Hannah, 1979), whilst in this present study the highest levels were recorded in December 1984 (15.1 μg at. l^{-1}) and in December 1985 for surface water (15.4 μg at, l^{-1}), although the level in February 1986 was still high (15.2 μg at. l^{-1}), but the winter maximum for deeper waters was recorded in February 1986 (16.2 μg at. l^{-1}). The dissolved silica reached the highest levels of 23.0 μg at. l^{-1} during March 1985 in the deep water (40 m), higher than that in the past studies in the surface waters, underlining the role played by regeneration processes in the deeper water in releasing dissolved silica, probably from broken diatom frustules. The minimum recorded for dissolved silica in the Fairlie Channel lay between 0.4 and 0.5 μg at. l^{-1} in 1972 and

1973 (June and July) according to Hinton (1974), whilst Hannah (1979) found the lowest recorded level on 5 May 1976 (0.21 μg at. l^{-1}) and on 21 April 1977 (0.95 μg at. l^{-1}). In 1984 the levels reached analytical zero (upper layer of deeper water) on 6 June, whilst the lowest values for the deep water (40 m) was recorded on 11 July. The levels in June 1985 reached analytical zero again in the surface samples and some area of deeper water (20 m) whilst 40 m samples recorded lower levels but was still high (between 2.7 and 3.1 μg at. l^{-1}) compared with the other depths. From a comparison of the results for the three nutrients in the surface water from the past studies and in the present work (although no comparisons can be made for the deeper water), it is apparent that the levels in deep waters were generally higher than those in the surface waters. This was probably due to the less active phytoplankton populations in deep water and their low utilization of these nutrients, and to the processes of organic and inorganic breakdown which proceed below the photic zone. The results indicate that, except at times of high phytoplankton activity together with deep mixing of the water column, the deeper water can act as an accumulating nutrient reservoir.

The lower and less active phytoplankton population in the deeper water was indicated in the present work by the data on chlorophyll *a* and phaeopigments, carbon fixation rates and total biomass. Hinton (1974) and Hannah (1979) investigated the phytoplankton and the primary production in the Firth of Clyde for the surface waters, whilst Wood *et al.* (1973) and Gowen (1981) studied both the surface and deeper waters in Loch Etive (Wood *et al.*, 1973) and Loch Etive with Creran by Gowen (1981). These two sea lochs in Argyll are on the west coast of Scotland. Fogg (1965) reported that the classical pattern of seasonal variation in phytoplankton biomass in the open sea and deep fresh water lakes in temperate regions is that of spring increase followed by reduction in activity during summer, a small autumnal increase and low winter levels, The sequences in the Firth of Clyde deviate rather from this basic pattern in that successive peaks of chlorophyll *a* were recorded throughout the summer by Hannah (1979) and also in this present study (these peaks being sometimes higher than spring and autumn). The timing of the peak growth during spring over the past years varied

between the months of March and April. Marshall & Orr (1930) compared the timing, composition and magnitude of the spring increase in successive years and showed that, in general, the increase occurred within a week of March 20. In Hinton (1974) the chlorophyll *a* peak of 8.3 mg. m^{-3} was obtained on 23 March 1973 for the surface water, whilst the spring increase (measured as chlorophyll *a*) was found in mid and late April 1976 (10.0 mg.m^{-3}) and 1977 (4.8 mg. m^{-3}) respectively (Hannah, 1979). The spring increases of chlorophyll *a* for the surface water in this work were recorded on 23 April 1986 (3.2 mg. m^{-3}, the lowest spring peak comparing with Hinton 1974,) along with the highest peak recorded in the Firth of Clyde (13.3 mg. m^{-3}) obtained on 3 March 1987 (the earlist spring increase). In both Loch Creran and Loch Etive maximum chlorophyll concentrations apparently occurred at the same time at all depths from the surface water (5 m) to the deeper water (15, 25, 35 m for Creran and 17, 27, 45 m for Etive); (Gowen, 1981). The data obtained from Loch Etive by Wood *et al.* (1973) showed similar increases of chlorophyll *a* in both surface layer (0-10 m) and deep water layer (10-50 m). The increases of chlorophyll in the present work for deeper water similarly paralleled the increases in the surface water. The spring increases were recorded in March 1971 for Loch Etive (Wood *et al.*, 1973) and in April for Creran and Etive (Gowen, 1981). Wood *et al.* (1973) showed that the standing crop was always higher in the top 10 m of the water column. In the present investigation the values of chlorophyll *a* were also higher in the surface water at most times, although occasionally lower values were obtained in the surface, which might have resulted from the replacement of deeper water by sea water with a large phytoplankton populations, or be due to the sinking down of cells to the deep water. In 1985 the spring increase was measured on 20 March for deeper water, with a high value (10.2 mg chlorophyll *a*. m^{-3}) which was comparable with surface values. Fluctuating high and low levels of chlorophyll *a* during the summer appear to be typical of the Firth of Clyde, as described by Marshall & Orr (1934); Hinton (1974) and Hannah (1979).

The amounts of chlorophyll *a* found throughout different seasons for the photic zone in the present work were similar in magnitude to those obtained by Hinton

(1974), Hannah (1979) and also by the data reported by Hannah (1979) which were obtained from the Clyde River Purification Board at their Main Channel Stations (CRPB, 1976). Hinton (1974) recorded the presence of successive pulses of phytoplankton following the first spring peak on 23 March 1973, each successive pulse being smaller than the one preceding. Wood *et al.* (1973) found similar results in 1971 for Loch Etive. Successive peaks in the standing crop were observed during 1976 and 1977 (Hannah, 1979) becoming progressively smaller until July when the values of these peaks exceeded or were comparable to the spring peaks. A similar pattern was obtained also at a 10 m depth although with lower values. In the present study the seasonal pattern of phytoplankton standing crop observed in the surface and deeper waters during 1984-87 also appeared to be fairly typical. In 1984 the value of chlorophyll *a* recorded on 6 June was 8.3 mg. m^{-3}, being lower on 29 August (4.5 mg. m^{-3}) in the deeper water, whilst the high values recorded in 1985 were 26 June for surface water (9.3 mg. m^{-3}) and for deeper water (6.0 mg. m^{-3}), mainly in the upper deep water,) which were comparable with the spring increase. In August 1985 again an increase of chlorophyll *a* was obtained in the surface water (12.9 mg. m^{-3}) again exceeding the spring values. The autumnal peak in 1977 (Hannah 1979) was in September, and in the present work the autumnal increase again ocurred in September in both 1985 and 1986. The quantity of chlorophyll *a* in particulate material decreases with depth so that below the photic zone most of the chlorophyll *a* has either disappeared or been converted to phaeophytin or phaeophorbide according to Lorenzen (1965). In the present work data were obtained in agreement with Lorenzen's view when the chlorophyll *a* levels were higher in the surface water than the deeper water. Any increased values in the latter layer coincided with similar changes in the surface water during the spring, and on some occasions in summer and autumn. The phaeopigment amounts on some occasions exceeded the amounts of chlorophyll *a* in the surface water, and at most times in the deeper waters. This phenomenon was also observed by Gowen (1981) for the spring period in Lochs Creran and Etive. At the end of spring outburst in the present investigation during May and begining of summer (June and July) there were high values of phaeopigments and a rapid decrease in the

concentrations of chlorophyll *a*. This may be due in part to algal removal by turbulence and /or algal sinking (Ansell, 1974), but could also be due to chlorophyll breakdown following zooplankton grazing which might be one of the main factors leading to the formation of phaeopigments (Currie, 1962; Lorenzen, 1967 and Jeffrey, 1974), although little is known about the processes involved in the breakdown of the chlorophyll. The presence of large amounts of phaeopigments at the same time as there were high levels of chlorophyll *a* was surprising. This pigment is not photosynthetically active (Treibst & Avron, 1977) and may have been from additional phaeopigments produced by the macroalgae in the intertidal and subtidal zones. In temperate coastal waters the first and largest outburst usually consists of diatoms with the sequence of *Skeletonema costatum* togather with *Thalassiosira* spp. *Skeletonema* is known to contain the enzyme chlorophyllase (Barrat & Jeffrey, 1971), which converts chlorophyll *a* into chlorophyllide *a* and might result in formation of these high values of phaeopigments.

The variations of chlorophyll *a* in 1976, 1977 were closely paralleled by carbon fixation rates obtained in the field (Hannah, 1979). The highest fixation rates were recorded on 29 July 1976 (Hannah, 1979) at the surface, whilst the fixation at 10 m was greatly reduced from that at surface. Wood *et al.* (1973) found also that the highest carbon fixation at the surface was recorded in July 1971 in Loch Etive, whereas the carbon assimilation declined markedly from the surface downwards. Similarly, on 30 July 1986, based on laboratory incubations, the highest rate of carbon fixation (224.2 mg C. m^{-3} h^{-1}) was obtained in the present study for surface water along with 84.8 mg C. m^{-3}. h^{-1} in the deeper water, although this level was lower than the spring increase of 102.8 mg C. m^{-3}. h^{-1} in the deeper water. Hence , although using laboratory incubations, the results from the present work were similar to those obtained by Hannah (1979) and Wood *et al.* (1973) in the decline of carbon fixation observed with depth in this work. High dark fixation levels in marine samples have previously been reported by Morris, *et al.* (1971) from Florida Strait and Taguchi & Platt (1977) in the Bedford Basin. The latter authors found the dark assimilation was comparable to, or exceeded, photosynthetic production from November through February. During the rest of the

year, photosynthesis was higher than dark fixation. Hannah (1979) reported that dark fixation was normally low representing only a few percent of the light fixation but during a period in January 1977 the dark fixation levels were high, comparable with or exceeding those of the light fixation in the Firth of Clyde. In the present work the light fixation of carbon was usually higher than dark fixation in the surface and deeper waters. On some occasions during summer, autumn and winter 1986-87 the fixation in the dark was higher than in the light in the deeper water. During October 1986, January and February 1987, the carbon assimilation in samples from the deeper water was higher than that in the surface water. This might have resulted from the high dark fixation in the surface samples, possibly due to the heterotrophic bacterial uptake or it may represent the presence of a more photosynthetically active component temporarly resident in the deeper water and which under the experimental conditions demonstrated this activity. An autumnal increase was recorded on 22 September 1977 (Hannah, 1979), whilst in this investigation the levels of fixation increased on 10 September 1986, although the highest level recorded on 6 October was for surface water samples only.

For north temperate seas it is known that a threshold of solar radiation input and stabilisation of the water column are the main triggering processes for the spring diatom outburst (Sakshaug & Myklested, 1973). Diatoms constitute the first and the largest outburst in temperate costal waters, with a similar pattern of genera but not necessarily of species from year to year (Riley & Chester, 1971). Marshall & Orr (1930) stated that a total phytoplankton population exceeding $2x10^5$ cells.l^{-1} signals the onset of the spring growth in the Clyde Sea. This population size was reached when the chemical and physical conditions improved on the morning of 12 March 1973, with *Thalassiosira* some 90% of the cell total, whilst the maximum abundance ($14x10^6$) of phytoplankton occurred on 23 March 1973, with dominance of *Skeletonema costatum* (Hinton, 1974). This species was found by Hannah (1979) to be a dominant organism with *Thalassiosira* in the spring diatom increase during 1976 and 1977 and similar results were obtained for the surface waters in this study . There is considerable

evidence for existence of large healthy populations of photosynthetic organisms (mainly ccocolithophores, but also flagellates and diatoms) at depths far below the euphotic zone in some parts of the oceans(Bernard, 1953; 1961, and Kimball *et al.*, 1963). This phenomenon was observed in the Fairlie Channel during this survey. In 1985 the total biomass in the deeper water (aphotic zone) exceeded $3.4x10^6$ cell.l^{-1} on 20 March. This population size exceeded the spring increase of total biomass on the surface water during April 1986 and March 1987 (1.84 and $3.24x10^6$ cells.l^{-1}), whilst the spring peaks for the deeper water during this periods comparable with that in the surface water (1.3 and $1.9x10^6$ cells.l^{-1} respectively). The population was dominated by *Skeletonema costatum* during March and April with small numbers of *Thalassiosira*, which replaced the *Skeletonema* during May in the surface samples and the depth samples, although the latter species constituted high numbers in early May 1985 at all depths, similar to the events described by Hinton (1974). The summer phytoplankton pulses which were obtained during June ($9.6x10^5$ cells.l^{-1}) and August ($1.8x10^6$ cells.l^{-1}) 1985 were similar to that found by Hinton (1974), although the summer peak in 1986 was in July. The increase in June 1985 and July 1986 were for the both surface and deeper layers, whilst the increase in August 1985 was confined to the surface water. Green flagellates contributed considerably to the population during summer, autumn and winter throughout this work for both the surface and depth waters in the Firth of Clyde. Boney (1986) stated that green flagellates were more numerous in spring, summer and autumn but also present in winter. At Keppel Pier and Loch Striven, Marshall, Nicholls & Orr (1934) and Nicholls (1933) had previously noted that minute flagellates occurred in large numbers during summer. High numbers of μ-flagellates had previously been found in Loch Craiglin in the winter months (Marshall, 1947) and in Loch Etive where the μ-flagellates were observed to make an important contribution to the biomass, their relative abundance was greater in autumn and winter (Wood *et al.*, 1973). The sinking of this population feature could have occured from the photic to the aphotic zone in this investigation. Riley & Chester (1971) reported that sinking of phytoplankton below the photic zone under the influence of turbulence, or through lack of buoyancy of the cells, can exert an important influence on the bloom and its eventual dissipation. They stated

also that sinking rate varied considerably from one species of algae to another according to their size, shape and density in addition to other environmental variations. The evidence for phytoplankton sinking has been shown in the present survey when the abundance of species, usually *Skeletonema* and *Thalassiosira* and *Cheatoceros* (rarely) and green flagellates in the deeper waters were preceded by the highest total biomass in the surface water. Hinton (1974) observed similar phenomena in the vertical profiles for 11 and 16 May 1973 when the maximum abundance of phytoplankton was below the surface. This indicates that under the fairly calm conditions prevailing, the population was sinking out of the photic zone, and that the *Skeletonema* cells were sinking faster. The sinking rate of *Skeletonema* cells has been estimated (from natural population) as around 1.4 $m.d^{-1}$ (Marshall & Orr, 1930), and once *Skeletonema* chains reach 10 m depth they begin to sink very quickly through the rest of the water column (Orr & Marshall 1969). Dinoflagellates became common during August, particularly *Protoperidinium* spp., which showed their greatest abundance in the surface waters (Hinton, 1974), whilst in the present study dinoflagellates contributed in small numbers to the biomass through July to October 1985 with the greatest abundance on 21 August in the surface waters when they made up 81% of the total biomass. An autumnal phytoplankton increase ($2.95x10^6$ $cells.l^{-1}$) was recorded during September 1972 (Hinton, 1974) and was composed almost entirely of diatoms (*Leptocylindrus danicus* and *Eucumpia zodiacus*), although *Skeletonema* was dominant on 26 September 1972 accompanied by *Thalassiosira* and *Nitzschia seriata*). In 1985 and 1986 the autumnal peaks were recorded through September and were dominated by *Skeletonema* in the surface water and *Thalassiosira* in the deeper water in 1985, and with *Skeletonema* accompanied by *Chaetoceros* and *Thalassiosira* in both layers in 1986. The 1972-73 diatoms population in the winter was sparse and frequantly dominated by non-planktonic species particularly naviculoid diatoms, with the appearance of *Thalassiosira* (Hinton, 1974). Similar characteristics for the winter period was obtained in the present survey. During 1985- 1986, *Thalassiosira* dominated the population in the deeper water most times togather with *Coscinodiscus*, *Navicula*, green flagellates and *Skeletonema*.

To summarize these data obtained from the Firth of Clyde throughout this survey period (1984-1987), it is clear that the nutrient levels were comparable to those found by Hinton (1974) and Hannah (1979) for the photic zone in Fairlie Channel. Generally the nutrients decreased in 1984 and 1985 after the spring diatom increase, leading to the very low levels, obtained in June 1984 and 1985. The dissolved silica was stripped completely in the photic and the upper part (20 m) of the aphotic zone in both years. This depletion could be attributed to utilization by phytoplankton during the spring growth and the stabilization of the water column. The build up of nutrients starting during the autumn (September) reaching the highest in the winter months coincided with the turbulence of the Firth of Clyde during autumn and winter periods. The seasonal trends of nutrients in the aphotic zone followed the seasonal pattern in the photic zone mainly in the upper layer (20 m).

The general chlorophyll *a* trends obtained throughout 1984- 1987 were similar in both the photic and aphotic zones and also typical to that observed in the previous years for the photic zone in the Firth of Clyde. The spring peaks occurred in late March 1985, despite most days in this month having strong winds, and in early March 1987 when sea was calm. The spring increase in 1986 was delayed until April and was lower than the other spring increases in 1985 and 1987. This might have been due the very high winds obtained in March 1986, accompanied by low sunshine levels even in April. The second pulse in the spring occurred during May in 1985 and 1986, which was smaller than those preceding. The summer months during this survey were characterized by a series of chlorophyll *a* increases, occasionally higher than the spring peaks - such as very high level obtained in August 1985 for the photic zone. These summer peaks were obtained during June and August through 1984 for the aphotic zone and for both regions in 1985, preceded by long periods of light winds during June in both years whilst the peaks on 29 and 21 August in 1984 and 1985 respectively were preceded by interrupted windy periods. In 1986 the summer peak was observed at the end of July for the photic zone and for the 20 m samples from the aphotic zone, being preceded by five days with light winds and one windy day. The typical autumnal peak

usually occurred in September 1984, 1985 and 1986. These short high values were clearly observed in both the photic and aphotic zones. The peaks in this period were preceded by light winds for five days interrupted by scattered and windy two days in 1984, strong winds for seven days except the day before the peak time in 1985 and a windy period for seven days followed by two days with light winds in 1986. The expected low winter levels of chlorophyll were measured during this survey, with accompaning windy days and very short sunshine periods.

Measured carbon fixation rates based on laboratory incubations were greater with samples from the photic zone than from the aphotic layers over the investigation period during 1986 and four months of 1987. These laboratory incubations have given some indication of the productivity potential of phytoplankton in their natural environments, although this population activity in the samples from the aphotic zone would not be possible in nature because of the lack of the essential factor (light) for carbon fixation, while these populations in this zone produced measurable carbon fixations in the suitable environmental conditions in the laboratory or when the 40 m samples were incubated *in situ* in the photic zone (surface, 1 m, 5 m and 10 m) during April 1987. From both the laboratory and *in situ* observations there were distinctly higher values of carbon fixation in the photic zone rather than the aphotic zone. The low values obtained from the laboratory incubations for the selected depths (20 m and 40 m) in the aphotic layer were similar, although slightly reduced at 40 m, except during the spring increase and summer pulses when the aphotic zone pattern (mainly at 20 m) followed that in the photic zone. Raised levels of carbon fixation during the spring increase were observed in April 1986 only in the photic zone , whilst the carbon fixation in the samples from the aphotic zone was very low, although the sunshine period increased from 29 March ranging 4.8-10.3 h per day and the sea was calm from 30 March which they might have been stimulated the first increase during the spring time (2nd April). The total biomass (in terms of cell numbers) obtained in the samples from the aphotic zone was low (ranging $1.4x10^5$ to $4.5x10^4$ cells.l^{-1}) compared with the photic zone exceeding $1.5x10^6$ cells.l^{-1}. Since the sea was calm in this time this low

population in the aphotic zone could be attributed to a concentration of the phytoplankton in the photic zone. The second pulse of carbon fixation values by the phytoplankton during spring was found in May for the photic layer, and at the same time the first distinct high levels of fixation were obtained for the 20 m layer in the aphotic zone. The values in the summer fluctuated with the peak of activity in July exceeding the spring peak values in the photic region, whilst in the 20 m sample from the aphotic zone recorded the similar pattern in this time, but still lower than the spring increase seen in May. The water column was mixed by the very strong winds exceeding 15 knots per hour on 22nd and 23rd July followed by light winds for five days and a very windy day (16 knots) mixed up the water column and probably enriched the upper layers with sufficient nutrients stimulating the phytoplankton activity, accompanied by a 10 days sunshine period averaging 4.1 h per day. Similar autumnal peaks of carbon fixation to the chlorophyll *a* and total biomass peaks were obtained in September 1986. The fixation of carbon was barely detectable in the winter months 1986-87. The high spring fixation values were obtained early in March 1987 in both the photic and aphotic zones, including both depths (20 m and 40 m) in the latter zone.

The seasonal variations in the size of the total biomass of phytoplankton (in the terms of cell numbers) in this study in the photic and aphotic zones followed the chlorophyll *a* changes. The spring sequence in the Firth of Clyde seems to be fairly typical of the Clyde Sea area (Marshall & Boney, 1974). *Skeletonema costatum* always dominated the populations in the spring, constituting 92-98% of the total biomass during 1985-1987 in the photic and aphotic zones. This species was replaced by *Thalassiosira* spp. during May in the both zones. The summer months were characterized by series of phytoplankton increases, involving a diversity of phytoplankton species. The sequence of population changes during the summer period in the aphotic region were similar to those observed in the photic region. The dominance of green flagellates in both regions was observed during June 1985 and 1986, with high contribution of *Leptocylindrus danicus* in June for photic zone and *Skeletonema* plus *Thalassiosira* for the bottom of the aphotic zone in 1985. The latter

three species with *Coscinodiscus* and *Nitzschia seriata* were common in the aphotic zone in the summer time of 1986. Dinoflagellates, mainly *Ceratium tripos*, were present in large numbers in the photic zone for the summer 1985, whilst in 1986 they were barely observed with numerous concentrations of *Chaetoceros* to the photic population. *Skeletonema*, *Thalassiosira* and green flagellates continued their majority in the photic and aphotic zones through the autumn months in 1985 and 1986 with high *Chaetoceros* and *Leptocylindrus* danicus in 1986 for both zones. The winter phytoplankton flora was composed mainly of *Thalassiosira*, *Coscinodiscus*, *Navicula*, green flagellates and *Skeletonema costatum* with small numbers of other species. The dominance of *Thalassiosira* in the aphotic zone population was observed most times in the winter.

Bernard & Lecal (1960) and Subba Rao & Sameoto (1988), for tropical seas, have described the close links between increases in the phytoplnakton biomass of the photic zone and the population in the aphotic zone, i.e, that a vertical flux of surface production existed. The results of the present investigation have confirmed that a similar viewpoint can be applied to the temperate waters of the inner Firth of Clyde. It has also been shown that the species balance of the aphotic region phytoplankton is usually similar to that in the surface waters - the former most probably being derived from the latter. The fate of this aphotic zone phytoplankton population will depend on environmental circumstances. In a situation of vertical mixing the cells can be carried up into the surface waters; with thermal stratification they are more likely to remain trapped in the deeper waters. Just how effective this presumably aphotic zone population will be in terms of productivity after residence in the dark regions has been demonstrated. The carbon fixation measurements of the aphotic populations show that they remain capable of photosynthetic activity once returned to lighted conditions. This phenomenon has also been described by Yentsch (1965) and Platt *et al.*(1983) in tropical seas, and has been demonstrated both in laboratory incubations, and in *in situ* measurements in the present study. The results suggest that chlorophyll *a* and phaeopigment assays of the biomass in the photic and aphotic zones need to be accompanied by measurements of carbon fixation to establish the viability of the

populations. The vertical flux of surface productivity described above can be regarded as being of twofold significance. Sufficient of the aphotic population may remain viable enough to act as species reservoirs if vertical mixing returns the cells to the surface waters after a period of heavy grazing by zooplankton on the surface population. On the other hand, if the aphotic population remains trapped in the dark water, its death and decomposition will allow the nutrient build up to proceed, and supply organic matter to bottom-living filter feeding animals.

Appendices

Appendix I : Sunshine hours data

Daily sunshine hours during March to December 1984 ($h.d^{-1}$)

	Months									
Day	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	7.0	12.4	0.0	2.4	7.5	0.0	3.1	0.0	0.0
2	7.8	10.2	11.4	14.2	14.7	0.1	0.8	0.0	4.4	0.9
3	0.5	9.3	11.3	2.5	15.3	3.4	1.7	0.2	0.0	0.0
4	0.1	1.5	9.5	6.1	14.4	5.2	9.1	7.5	6.2	0.0
5	1.2	0.0	12.0	3.6	12.7	14.0	4.1	7.4	5.6	0.0
6	0.3	7.7	1.1	0.9	4.5	0.0	0.1	7.1	6.2	4.6
7	0.0	0.2	13.6	14.0	10.6	12.2	3.1	5.2	0.0	0.0
8	0.0	6.3	13.5	15.8	9.3	0.6	0.7	0.1	0.0	0.0
9	0.0	0.4	5.1	9.8	0.3	7.2	7.1	7.1	0.1	0.0
10	0.0	0.0	12.9	3.5	4.4	14.1	0.2	0.0	0.6	0.3
11	0.3	6.8	9.0	0.0	0.0	9.6	6.8	7.2	0.0	0.7
12	4.6	0.0	14.5	2.8	3.9	9.8	0.0	0.0	0.7	0.0
13	1.1	3.0	13.5	1.6	4.6	6.8	0.0	0.0	3.4	0.0
14	0.0	2.2	10.0	5.1	4.5	4.6	0.9	2.6	0.0	0.0
15	1.2	7.7	0.1	0.9	7.0	10.3	10.2	0.0	3.2	3.9
16	9.8	10.3	4.9	8.8	3.2	10.9	2.3	0.1	1.9	5.0
17	6.3	5.9	0.0	0.8	0.0	8.2	0.6	1.2	0.0	0.0
18	3.4	0.0	13.9	0.1	14.9	0.0	1.2	0.0	0.0	2.8
19	0.2	0.0	1.9	0.9	9.8	11.2	2.8	2.1	4.9	0.3
20	0.2	1.2	3.9	0.8	14.0	11.3	3.3	0.4	4.2	0.0
21	0.0	6.5	5.3	5.8	12.6	6.8	2.2	1.2	0.5	0.0
22	0.3	3.5	0.5	9.5	6.7	10.2	1.9	1.4	0.9	0.0
23	0.0	12.9	8.7	1.9	11.9	6.0	2.5	6.8	2.0	0.5
24	0.0	3.4	11.6	2.2	14.7	4.0	2.7	0.0	0.9	4.2
25	2.7	13.3	0.4	6.5	14.5	11.7	7.1	0.0	0.1	1.1
26	0.0	13.1	7.4	2.6	13.0	6.3	8.4	4.9	4.2	1.4
27	5.1	11.7	13.0	8.8	0.0	7.1	0.1	5.0	0.0	2.1
28	2.3	12.0	11.9	13.3	0.0	0.0	2.3	0.0	3.2	0.0
29	6.2	9.8	4.4	11.2	3.0	0.3	6.2	0.5	0.0	0.0
30	7.8	10.9	0.8	15.1	0.1	0.0	5.3	0.5	0.0	0.0
31	9.2		6.2		5.7	0.1		5.6		4.9
total	70.6	196.8	244.7	169.1	232.7	199.5	93.7	76.6	53.2	32.7

Daily sunshine hours during January to December 1985 ($h.d^{-1}$)

Day	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5.9	0.0	0.0	0.3	12.9	14.9	3.5	0.5	5.6	0.5	1.4	0.0
2	4.7	2.8	0.0	1.9	13.1	14.8	3.7	4.3	0.0	2.5	8.0	0.0
3	5.4	0.2	0.0	4.9	5.4	15.8	0.0	6.3	0.7	3.6	1.5	0.0
4	6.3	0.0	1.1	1.4	0.3	8.9	7.8	1.3	0.0	1.7	0.0	0.0
5	1.0	4.2	6.8	2.3	0.0	0.5	0.0	11.4	9.2	2.7	2.4	0.4
6	4.6	4.8	6.2	1.3	0.6	3.5	3.6	9.2	5.7	9.7	5.7	0.0
7	2.3	0.0	7.6	4.9	10.3	7.9	2.4	2.9	0.0	6.9	4.5	0.0
8	3.2	0.0	1.4	0.6	9.8	2.4	0.0	0.9	0.0	0.5	0.0	0.0
9	3.5	0.0	0.0	0.0	1.8	7.2	2.7	7.1	0.0	3.8	0.1	3.3
10	0.0	2.2	8.4	0.1	0.4	8.1	0.0	8.1	7.2	0.0	5.8	0.0
11	5.5	7.2	8.7	5.1	13.1	0.3	0.0	0.0	0.0	6.7	5.3	1.7
12	0.0	6.3	0.5	0.5	13.9	6.4	0.9	4.7	3.6	0.7	6.3	0.0
13	0.0	2.5	6.8	3.2	4.2	10.9	4.6	1.9	3.9	0.0	0.9	0.9
14	0.0	6.8	7.1	9.3	0.4	13.8	13.2	0.0	4.5	1.8	0.0	0.0
15	3.2	8.4	5.9	0.0	0.0	12.6	4.9	0.4	5.4	0.0	2.8	0.0
16	0.0	8.2	10.2	0.0	5.8	12.8	2.7	0.3	0.0	1.8	1.1	0.0
17	0.0	3.9	9.9	10.1	0.0	0.5	0.9	10.9	8.7	0.0	0.0	0.0
18	0.0	1.0	8.9	10.6	4.8	9.5	2.3	0.0	0.0	8.3	0.0	3.2
19	0.0	1.5	7.8	5.6	0.8	12.3	8.5	3.1	7.9	0.0	0.8	0.0
20	1.3	0.2	4.2	11.1	10.4	13.6	5.5	0.2	0.1	0.0	0.1	0.0
21	0.0	4.1	3.4	10.9	10.8	0.0	8.7	0.2	0.0	3.1	1.3	0.0
22	0.2	1.9	0.1	9.9	0.3	0.8	6.3	4.6	0.0	0.0	0.1	1.6
23	4.6	0.0	0.6	11.9	1.3	0.5	0.6	0.0	0.0	5.9	5.0	2.8
24	0.0	4.4	0.0	4.6	4.3	1.7	0.5	6.1	0.3	2.8	3.4	0.5
25	0.2	2.3	0.0	11.1	2.1	5.2	5.1	1.1	0.0	4.6	2.9	0.0
26	7.1	2.1	8.1	2.1	0.5	1.1	0.0	2.5	5.6	4.7	4.0	3.9
27	0.0	3.8	8.9	12.4	0.6	2.7	3.2	0.0	0.2	0.5	3.8	3.7
28	0.8	7.3	4.1	0.0	11.2	3.9	0.6	3.6	6.6	2.8	0.0	6.0
29	0.2		0.0	0.1	14.4	5.8	1.3	0.1	4.7	6.2	5.3	6.0
30	0.0		0.0	2.7	13.9	2.2	11.4	0.3	0.1	2.1	0.0	0.0
31	2.1		0.4		13.8		2.4	0.4		8.4		0.0
Tot.	62.3	87.5	122.2	138.2	184.1	200.7	108.9	88.8	84	88.3	66.8	34

Daily sunshine hours during January to December 1986 ($h.d^{-1}$)

	Months											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10.0	0.0	8.9	7.8	10.3	0.0	12.7	4.3	8.2	0.0	8.4	1.7
2	1.4	0.1	7.8	8.3	8.1	1.6	2.0	0.0	1.8	5.3	0.3	0.0
3	6.5	0.0	1.8	10.9	0.3	8.7	3.5	4.1	12.2	4.1	2.8	0.0
4	0.0	0.0	0.0	10.8	6.8	4.1	2.4	4.3	0.0	6.9	0.0	0.0
5	0.1	4.6	6.8	5.7	0.4	12.3	6.8	3.6	0.0	0.5	2.7	1.0
6	1.3	1.8	5.3	6.9	8.7	14.9	1.3	0.3	6.9	1.9	2.3	4.3
7	0.0	7.2	5.6	6.8	0.0	4.7	5.6	2.3	2.8	0.6	0.0	0.0
8	0.0	0.0	0.1	3.5	1.6	1.1	13.8	13.3	11.6	0.4	2.2	0.0
9	0.0	0.0	4.0	7.9	0.9	5.2	0.1	11.2	8.5	2.6	0.6	1.7
10	3.3	0.3	4.0	7.1	0.7	0.0	1.4	4.5	10.7	8.8	0.5	0.0
11	0.3	0.0	0.0	2.3	6.5	14.7	9.7	13.3	10.4	7.2	1.2	0.3
12	1.2	1.6	2.8	0.0	0.8	0.0	5.4	8.5	8.6	5.3	0.0	0.0
13	0.0	7.5	0.0	3.2	0.1	1.1	0.0	0.2	8.5	4.7	0.0	1.5
14	0.0	0.0	0.0	0.0	0.2	5.2	0.0	10.6	11.3	2.3	0.0	3.1
15	4.4	0.0	0.0	0.0	10.4	14.1	0.9	7.1	9.5	5.5	5.2	1.0
16	0.0	0.0	1.6	0.0	11.6	8.9	0.6	7.9	7.8	2.5	3.0	0.2
17	0.0	2.8	9.7	3.2	0.7	0.6	5.2	6.3	4.0	5.0	2.2	0.0
18	0.0	6.2	5.6	1.3	0.6	5.8	1.6	9.9	7.9	0.2	2.0	0.0
19	1.2	0.3	8.8	0.0	2.3	10.4	0.0	4.6	0.3	3.1	3.6	0.8
20	0.0	2.8	0.9	8.1	4.1	12.4	4.1	6.8	2.2	3.2	3.3	2.4
21	1.5	1.8	1.2	4.4	6.1	14.9	4.4	0.0	0.0	0.8	2.5	3.4
22	0.8	9.3	0.0	0.7	12.4	10.8	4.9	1.9	0.1	0.0	0.0	5.7
23	5.5	7.8	4.6	2.7	5.6	0.7	11.6	12.9	4.1	8.1	1.4	0.1
24	6.7	6.8	5.6	10.8	2.3	0.2	1.7	9.4	4.5	0.0	0.0	0.0
25	5.3	2.5	7.8	5.3	6.9	5.7	1.2	0.4	1.3	0.2	0.0	0.8
26	0.0	7.2	3.7	0.9	6.6	6.1	4.1	3.7	0.0	2.3	0.0	2.0
27	3.5	7.7	4.8	8.7	5.4	8.2	2.3	5.9	0.0	0.0	0.0	0.3
28	0.0	7.5	0.8	5.3	11.5	10.1	0.8	9.8	0.0	1.6	1.7	0.0
29	2.7		4.1	5.4	4.3	11.8	7.9	5.0	3.3	4.1	0.0	0.0
30	0.8		7.6	0.0	0.0	13.3	0.0	10.9	5.2	1.4	0.0	0.0
31	0.0		10.3		0.0		2.3	1.2		2.7		0.0
Tot.	46.2	85.8	124.2	138.4	136.4	207.6	118.3	184.2	151.7	89.7	45.9	30

Daily sunshine hours during January to April 1987 ($h.d^{-1}$)

	Months			
Day	Jan	Feb	Mar	Apr
1	0.0	0.0	0.0	0.0
2	5.1	0.0	8.3	1.2
3	0.0	0.1	3.0	0.0
4	1.6	0.2	5.6	0.0
5	0.6	0.0	0.0	0.0
6	6.1	4.4	0.0	0.0
7	5.8	0.0	0.0	2.5
8	0.0	1.7	0.0	0.1
9	0.0	0.0	0.0	0.2
10	0.0	4.3	9.4	3.0
11	5.7	3.9	10.0	8.8
12	3.5	6.2	6.5	8.4
13	2.9	6.3	2.4	4.0
14	0.0	6.5	3.4	0.0
15	0.0	7.2	6.3	0.1
16	0.0	8.9	0.0	9.5
17	0.0	4.3	2.8	11.1
18	0.0	7.9	8.0	0.8
19	0.0	2.4	7.9	1.9
20	0.0	2.6	3.3	7.8
21	0.0	0.0	1.8	0.2
22	0.0	8.4	3.6	1.4
23	0.9	0.0	0.8	0.8
24	0.0	0.0	0.8	7.9
25	0.5	0.0	6.7	11.4
26	3.6	0.0	3.2	8.6
27	0.0	0.9	0.0	8.3
28	5.4	1.6	8.4	10.8
29	0.0		4.7	8.1
30	0.0		1.6	0.7
31	5.6		0.2	
Tot.	47.3	77.8	108.7	117.6

Appendix II : Wind data

Daily mean wind speeds (KN)during March to December 1984

	Months									
Day	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	15	9.4	11.7	4.0	14.5	4.0	9.7	6.1	17.0	7.8
2	33	4.8	5.2	8.3	9.6	15.3	13.7	8.6	6.4	5.5
3	13.2	10.3	5.4	11.2	10.7	16.1	14.0	6.5	13.5	12.5
4	15.7	9.5	8.1	7.1	4.1	5.8	15.5	6.1	10.6	13.6
5	5.8	5.1	6.5	12.3	4.6	9.1	10.5	10.0	4.1	6.4
6	11.6	7.1	10.7	12.2	5.0	10.9	2.7	16.3	12.7	19.3
7	6.1	3.1	7.5	5.2	5.5	10.1	7.3	17.4	14.0	27.8
8	4.1	12.4	6.4	5.4	5.5	3.1	12.8	18.3	13.1	18.7
9	4.6	8.9	11.6	11.6	5.7	6.7	26.0	16.2	11.4	15.8
10	9.7	10.0	12.9	12.4	12.6	4.9	19.8	20.3	11.5	13.5
11	16.3	16.7	7.0	5.3	12.7	4.0	17.3	14.3	20.6	11.7
12	10.8	14.4	5.5	16.8	10.4	5.6	4.7	10.0	12.1	8.5
13	11.2	15.8	6.7	7.7	11.9	3.9	11.0	18.0	12.6	12.7
14	14.0	17.2	8.3	10.7	11.1	4.6	13.3	5.8	12.3	8.2
15	9.1	12.8	7.7	5.0	17.5	8.7	5.9	8.7	5.7	10.6
16	4.9	15.0	7.4	3.6	12.2	5.7	9.0	11.4	7.7	8.9
17	5.3	7.7	6.9	5.7	11.0	4.6	4.9	10.1	5.7	19.0
18	3.3	13.8	10.9	4.8	14.1	6.9	12.7	30.4	7.4	14.7
19	4.3	10.0	8.7	5.0	5.0	2.9	24.9	16.6	6.5	18.4
20	6.9	9.6	5.5	12.0	11.4	6.3	16.0	29.2	5.5	17.8
21	8.5	12.0	4.3	16.5	14.8	13.4	9.0	18.1	9.7	20.5
22	7.7	4.5	11.0	21.2	11.0	12.5	13.1	15.0	18.4	13.6
23	18.0	6.5	6.7	11.3	4.1	15.6	18.3	17.6	20.8	18.8
24	9.7	3.8	13.1	14.0	6.9	15.8	15.4	13.0	27.6	17.5
25	11.3	3.2	10.3	22.5	8.7	11.3	10.7	17.2	21.0	17.3
26	13.3	10.7	6.8	17.0	11.4	7.5	4.3	18.7	18.5	10.3
27	7.0	5.5	6.2	20.5	14.8	6.1	9.3	18.1	29.5	8.1
28	7.6	7.1	7.3	18.0	9.5	15.2	6.0	14.5	24.5	8.1
29	4.9	9.7	8.3	17.6	7.0	14.1	5.0	16.1	21.1	8.3
30	8.9	9.3	5.2	10.9	6.9	18.9	18.5	15.3	20.8	10.2
31	12.4		10.8		13.8	11.4		19.7		24.7

Daily mean wind speeds (KN) during January to December 1985

Day	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10.8	26.9	14.5	12.5	19.0	3.3	7.6	13.0	21.2	9.9	12.8	18
2	3.5	20.0	10.3	15.7	11.2	4.2	4.8	18.7	8.6	13.3	12.5	12
3	5.0	9.7	12.5	15.5	4.6	7.0	4.0	15.0	7.9	18.1	12.0	24
4	7.3	8.6	16.5	10.7	4.1	12.8	4.7	9.4	4.8	25.5	21.1	11
5	6.0	12.9	11.7	10.3	7.3	9.9	10.3	16.6	18.5	19.4	20.9	11
6	11.0	14.0	17.0	7.0	7.6	7.6	13.9	17.3	13.2	17.2	23.3	6
7	3.0	13.9	7.4	10.7	6.9	9.2	9.8	10.4	7.8	17.2	15.6	11
8	8.0	19.6	15.2	10.9	9.3	9.5	12.9	12.3	8.8	13.6	13.2	12
9	2.3	19.6	14.1	8.3	13.3	11.3	14.1	16.1	8.6	14.6	17.0	5
10	5.0	15.3	15.7	10.1	7.6	11.8	9.7	14.5	6.7	16.0	16.8	8
11	4.0	12.7	8.0	17.4	6.9	11.0	16.8	8.6	5.8	18.7	13.2	13
12	8.5	11.8	16.5	16.6	11.5	16.9	11.9	13.4	11.2	4.7	6.5	17
13	6.5	11.5	16.0	18.7	16.1	12.3	3.9	10.5	16.3	5.3	7.0	11
14	5.8	13.0	19.0	26.5	12.7	11.1	14.2	18.8	23.5	4.1	13.1	14
15	9.8	6.1	17.7	7.8	16.0	9.7	15.9	16.9	22.6	3.9	7.5	15
16	8.8	7.4	15.7	13.7	6.2	7.0	13.4	16.4	16.1	5.5	13.1	19
17	7.3	12.6	8.9	3.8	2.8	8.9	14.6	7.3	18.9	5.3	5.7	11
18	9.2	19.6	12.1	4.7	10.4	6.5	19.7	9.6	9.0	6.4	8.8	16
19	5.5	20.2	14.1	25.4	14.9	3.2	13.0	6.6	16.4	6.6	6.9	21
20	8.5	5.0	13.1	16.1	17.0	6.0	15.7	14.8	14.3	9.5	6.2	22
21	16.3	7.3	13.8	10.4	13.3	12.9	10.8	15.3	15.9	3.1	6.2	20
22	30.5	15.7	14.7	7.6	7.3	10.7	11.5	15.6	15.8	6.9	6.9	16
23	24.5	19.0	8.3	10.7	6.6	4.7	12.6	17.3	9.4	7.5	6.8	19
24	9.7	12.3	2.9	15.8	11.4	10.0	8.5	18.8	6.1	6.4	5.2	10
25	11.6	7.7	5.5	12.1	8.3	10.5	5.9	23.0	4.4	12.8	3.4	13
26	5.3	4.9	5.7	14.7	13.5	15.5	13.8	13.3	5.8	7.2	7.2	11
27	11.5	4.3	15.4	18.5	13.8	18.0	13.0	20.7	2.5	5.9	16.0	7
28	7.1	14.6	13.4	8.5	14.0	15.9	9.7	11.9	7.2	10.5	5.2	5
29	11.6		13.7	2.7	7.5	8.8	10.0	7.3	6.2	2.5	9.5	4
30	21.7		13.2	14.3	3.3	3.7	6.3	12.3	12.6	7.1	13.6	12
31	24.1		10.4		3.4	11.4		19.7		24.7		8

Daily mean wind speeds (KN) during January to December 1986

Day	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	7.8	12.1	7.6	5.9	14.9	8.0	6.3	9.2	14.4	16.0	9.3	20
2	13.7	12.0	2.7	6.1	10.4	7.9	5.5	21.2	16.4	12.5	13.6	18
3	6.4	11.7	16.3	6.5	12.4	16.8	8.7	6.0	14.6	5.5	15.2	23
4	8.0	9.0	20.1	4.7	12.2	16.4	9.8	4.0	14.7	6.7	15.7	15
5	8.4	9.7	19.3	5.3	10.5	13.3	10.4	7.2	16.6	12.0	23.8	24
6	6.5	9.6	17.9	10.6	10.7	3.3	14.2	12.6	14.1	11.8	19.3	18
7	13.1	7.5	12.2	16.7	11.6	14.7	14.2	19.6	17.7	11.6	18.5	19
8	9.3	4.3	20.9	12.0	9.7	13.1	14.4	15.7	7.4	8.7	22.1	14
9	15.9	5.1	10.6	10.3	7.3	16.7	10.1	3.8	10.5	12.5	27.6	16
10	29.7	15.8	4.6	8.3	18.3	13.7	11.0	8.7	6.9	13.4	23.7	19
11	28.7	10.5	10.4	13.2	15.1	8.7	5.3	9.5	5.1	13.3	11.9	17
12	28.6	9.0	15.2	7.7	6.7	11.6	7.6	4.6	4.8	15.3	17.0	22
13	26.0	15.7	10.9	6.9	19.1	5.7	2.5	9.5	4.5	9.4	16.7	15
14	34.5	13.0	15.3	14.7	11.7	5.1	8.5	9.8	11.9	11.0	13.5	12
15	16.7	12.0	19.8	22.3	15.6	6.2	4.0	13.5	7.6	11.5	16.6	18
16	8.2	11.5	13.3	13.8	5.8	9.7	16.1	21.0	8.9	9.4	22.6	19
17	10.3	13.7	11.1	8.3	14.5	18.3	19.3	15.5	6.5	16.5	18.2	20
18	14.0	6.0	10.4	6.0	15.5	11.1	8.2	12.0	6.7	19.0	16.7	19
19	14.3	3.0	8.3	10.3	5.3	11.8	10.3	8.8	11.5	17.7	9.3	21
20	22.6	6.1	29.1	11.7	9.1	14.4	11.1	5.5	13.0	19.0	11.6	23
21	15.7	7.9	16.6	11.2	17.9	15.1	11.1	7.1	13.5	16.8	10.0	19
22	22.0	4.5	21.3	8.3	17.0	14.6	15.0	11.7	11.6	18.3	32.3	9
23	27.9	7.5	19.9	6.3	16.3	4.2	15.7	4.7	8.7	19.0	24.3	10
24	19.6	2.7	15.0	8.7	12.9	5.9	7.6	3.7	6.0	29.8	18.5	18
25	11.3	6.7	15.7	7.1	13.5	10.0	10.0	15.1	4.7	29.1	20.2	12
26	10.0	9.1	12.3	10.0	14.5	7.3	10.2	17.5	5.7	16.5	19.1	20
27	16.5	10.7	16.0	10.7	19.9	12.0	12.4	13.8	10.0	16.7	20.1	27
28	13.0	10.1	11.1	13.3	11.0	8.2	5.0	15.9	16.8	11.4	19.7	24
29	4.8		13.6	15.6	11.9	10.7	16.0	13.7	10.9	23.3	10.0	14
30	15.7		9.3	18.9	13.3	14.1	9.7	10.0	9.3	30.7	18.3	14
31	13.1		4.7		11.9		14.4	10.2		13.6		12

Daily mean wind speeds (KN) during January to April 1987

	Months			
Day	Jan	Feb	Mar	Apr
1	14.3	9.7	11.3	8.5
2	11.5	8.6	19.6	4.0
3	9.9	11.0	11.8	14.7
4	23.6	16.3	10.6	23.5
5	28.7	20.7	13.6	16.7
6	19.1	26.5	12.9	15.6
7	4.2	10.6	15.3	15.1
8	8.1	10.0	9.8	8.6
9	11.5	11.5	12.7	12.8
10	10.2	18.6	11.2	15.4
11	8.0	7.2	10.8	18.4
12	12.5	3.4	6.0	7.5
13	13.6	8.8	6.1	13.7
14	13.5	3.8	16.2	8.0
15	8.0	2.9	18.5	9.0
16	10.7	7.9	13.3	6.5
17	13.6	6.9	22.5	5.0
18	10.3	5.3	18.7	10.1
19	12.5	6.4	18.3	15.2
20	10.8	5.3	10.3	16.6
21	10.6	3.2	8.6	8.6
22	6.1	7.3	11.7	5.8
23	1.3	6.7	7.1	4.7
24	2.3	6.7	13.1	6.7
25	12.5	9.7	15.7	9.8
26	4.9	11.6	16.2	4.4
27	3.0	9.2	22.3	5.6
28	2.8	8.9	27.4	3.5
29	3.3		17.3	8.0
30	5.3		12.5	11.6
31	5.7		17.5	

Appendix III : Sea salinity measurements

Sea salinity data on the sampling date during March 1986 to April 1987

	station		3	station		6
	3 m	20 m	40 m	3 m	20 m	40m
10. 3.86	34.5	35.0	35.0	34.5	35.0	35.0
19. 3.86	32.3	32.7	35.5	32.3	33.1	33.4
26. 3.86	30.0	33.5	33.6	30.5	33.7	33.7
2. 4.86	30.0	32.0	33.0	30.0	31.3	32.0
9. 4.86	33.2	33.6	33.7	33.4	33.6	33.8
23. 4.86	32.8	33.0	33.4	32.7	33.1	33.5
7. 5.86	32.6	33.4	33.8	32.5	33.3	35.8
21. 5.86	32.3	32.8	33.2	32.3	32.7	33.4
18. 6.86	31.6	32.9	33.0	31.5	32.9	33.0
2. 7.86	32.9	32.2	33.5	32.0	33.3	33.7
16. 7.86	32.5	33.0	33.1	32.7	33.0	33.2
30. 7.86	32.6	32.5	32.5	32.8	32.8	32.8
27. 8.86	33.2	33.6	34.1	33.3	33.4	34.1
10. 9.86	33.9	33.9	33.9	33.8	33.9	34.0
24. 9.86	33.7	33.7	33.6	33.8	33.8	33.7
6.10.86	33.4	33.5	33.7	33.5	33.5	33.6
29.10.86	27.4	27.7	28.0	27.8	28.0	28.3
6.12.86	29.0	-	32.3	-	-	-
22. 1.87	29.5	29.5	30.0	29.5	29.8	30.0
18. 2.87	33.2	33.8	33.8	33.0	33.3	33.5
4. 3.87	33.0	33.4	33.7	33.0	33.0	33.0
18. 3.87	33.4	33.5	33.7	33.4	33.6	33.8
25. 3.87	33.4	33.8	33.7	33.1	33.5	33.6
1. 4.87	-	-	-	-	-	33.5
15. 4.87	-	-	-	-	-	33.5
22. 4.87	-	-	-	33.3	33.2	33.2
27. 4.87	-	-	-	-	-	34.5

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