

Phytoplankton distribution in relation to sea ice, hydrography and nutrients in the northwestern Weddell Sea in early spring 1988 during EPOS*

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Summary. Phytoplankton biomass and distribution of major phytoplankton groups were investigated in relation to sea ice conditions, hydrography and nutrients along three north-south transects in the north western Weddell Sea in early spring 1988 during the EPOS Study (European *Polarstern* Study), Leg 1. Three different zones along the transects could be distinguished: 1) the Open Water Zone (OWZ) from 58° to 60°S with high chlorophyll *a* concentrations up to 3.5 $\mu\text{g l}^{-1}$; 2) the Marginal Ice Zone (MIZ) from 60° to about 62.5° with chlorophyll *a* concentrations between 0.1 and 0.3 $\mu\text{g l}^{-1}$, and 3) the closed pack-ice zone (CPI) from 62.5° to 63.2°S with chlorophyll *a* concentrations below 0.1 $\mu\text{g l}^{-1}$. Nutrient concentrations increased towards the south showing winter values under the closed pack-ice. Centric diatoms such as *Thalassiosira gravida* and *Chaetoceros neglectum* forming large colonies dominated the phytoplankton assemblage in terms of biomass in open water together with large, long chain forming, pennate diatoms, whereas small pennate diatoms such as *Nitzschia* spp., and nanoflagellates prevailed in ice covered areas. Fairly low concentrations of phytoplankton cells were encountered at the southernmost stations and many empty diatom frustules were found in the samples. The enhanced phytoplankton biomass in the Weddell-Scotia-Confluence area is achieved through sea ice melting in the frontal zone of two different water masses, the Weddell and the Scotia Sea surface waters.

Introduction

Biomass, distribution and productivity of phytoplankton in relation to the physical and chemical properties of

the water column have been investigated by Hart (1942), Hasle (1969), El-Sayed (1967), Holm-Hansen et al. (1977), El-Sayed and Taguchi (1981), El-Sayed et al. (1983), Hayes et al. (1984), Weber and El-Sayed (1988) and others. Their results have shown that most parts of the Southern Ocean are characterized by a fairly low phytoplankton standing stock throughout the year. Reasons for this are the strong seasonality, the extensive ice cover, a highly turbulent environment as well as grazing pressure. Higher biomass only occurs in some areas such as ice edge zones and shallow shelf areas during the growth season. Nutrients occur in excess most of the time, and only iron was considered as a possible limiting factor (e.g. Sakshaug and Holm-Hansen 1984; Nelson et al. 1989; Smetacek et al. 1990; Martin et al. 1990). Although the overall productivity of phytoplankton in the Southern Ocean is low, the large numbers of Krill observed in certain areas could lead to the assumption of much higher primary production in those particular areas.

High abundances of Krill are a common feature in the northwestern part of the Weddell Sea and the adjacent Scotia Sea (i.e. Priddle et al. 1988). Sedimentation rates of Krill faeces in the eastern Bransfield Strait were high and the lowest sedimentation rates ever found were measured in the central Weddell Sea (von Bodungen et al. 1987; Wefer et al. 1990). This implies indirectly that phytoplankton biomass in the northwestern part of the Weddell Sea and the Scotia Sea should be higher than in other areas of the Weddell Sea. Reasons for this patchy distribution of phytoplankton and Krill are not yet clear.

The "European *Polarstern* Study" (EPOS) expedition from October 1988 to February 1989 with the German icebreaking research vessel *Polarstern*, was an excellent opportunity for a multinational and interdisciplinary study of the development and seasonality in the pelagic ecosystem of the northwestern Weddell Sea from early spring to late summer. In this paper we will focus on simultaneous observations of physical, chemical and bio-

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logical parameters in early spring during the first leg (Leg 1) of EPOS from October 15 to November 12, 1988 in the northwestern part of the Weddell Sea. The main objectives during EPOS Leg 1 were:

- to follow the spring development of phytoplankton
- to relate phytoplankton biomass and species composition to the hydrographic properties of the water column and to the nutrient distributions
- to determine the significance of sea ice cover and ice melting on phytoplankton development in spring.

Material and methods

Samples were taken along four transects perpendicular to the ice-edge from October 15 to November 12, 1988 in the northwestern part of the Weddell Sea (Fig. 1). In this paper we will concentrate on transects 2, 3, and 4 (transect 1 is not shown because it was very short and only represents the pack-ice zone).

Hydrographic data were recorded with a CTD probe (Neil Brown 'Mark III') down to 600 m. Water samples were obtained from surface to 300 m water depth with Niskin bottles (12 × 121) attached to a rosette sampler. They were used for the measurement of inorganic macronutrients (nitrate, nitrite, ammonia, phosphate, silicate), particulate organic carbon, chlorophyll *a*, and for the enumeration of phytoplankton. Phytoplankton samples were counted from selected stations along transect 3 and 4 from 2, 20, 40 and 80 m depth. Phytoplankton carbon was calculated by multiplying cell or plasma (for diatoms) volume by 0.11 (Strathmann 1967) and by 0.13 for thecate dinoflagellates (Smetacek 1975). Particulate organic carbon samples were taken at selected stations along transect 3 and 4; chlorophyll *a* was measured at all stations and nutrient samples were collected from selected depths at each station. Dissolved inorganic nutrients were analyzed immediately on board according to Strickland and Parsons (1972) and Graßhoff (1986). Analyses of nitrite, nitrate and silicate were performed on filtered samples using a Technicon Autoanalyzer. Phosphate and ammonia were analyzed manually on unfiltered samples using a spectrophotometer with 5 and 10 cm cells respectively.

For chlorophyll *a* (Chl *a*) measurements, 1 l of water from all standard depths was collected and filtered through Whatman GF/C glass fiber filters. We compared GF/C and GF/F filters on one station and recorded no differences in concentrations measured (negative pressure during filtration was about 0.4 kg cm⁻² in all cases). Chl *a* measurements followed the standard fluorometric technique of Evans and O'Reilly (1983) with a modification of Derenbach (1969). The Chl *a* content in the extract was measured with a Turner Design fluorometer. Particulate organic carbon (POC) was obtained in the same manner as Chl *a* samples. However, samples were prefiltered with a 200 μm mesh size nylon net before filtering on precombusted (at 450°C overnight) Whatman GF/C glass fiber filters. Filters were kept at -20°C until analysis in the home laboratory. Inorganic carbon was removed by exposing to HCl vapor for 24–48 h at room temperature after which filters were removed and heated at 50°C to remove residual HCl and water. A Perkin Elmer 2400 CHN elemental analyzer was used to analyse POC (Sharp 1974; Hedges and Stern 1984). All samples were analyzed in a single run; standards were run after every 40 samples.

Phytoplankton samples were preserved in hexamine-buffered formalin (final concentration of formalin ca. 0.5%). Samples were counted in the lab about one year after the cruise using settling chambers and an inverted microscope (Utermöhl 1958). A minimum of 50–100 cells of the dominant species or groups were counted in aliquots of 50 ml settled for 48 h. Cell sizes were measured to calculate cell volume (Edler 1979). In a few cases, we found less than 50 cells of the dominant species. Phytoplankton carbon was calculated by multiplying cell or plasma (for diatoms) volume by 0.11

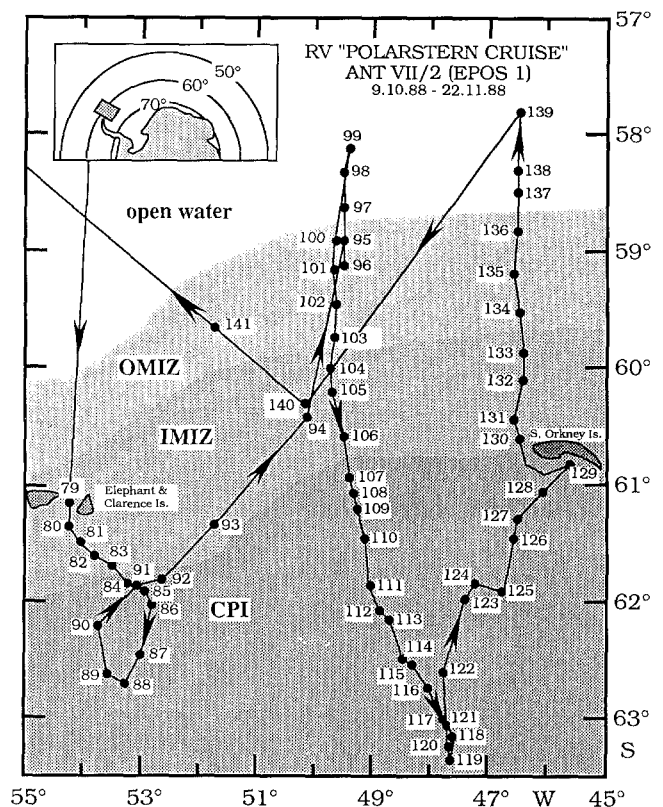


Fig. 1. Cruise track and station sites (●) and numbers (Stn) during the EPOS-leg 1 expedition with RV *Polarstern* in October/November 1988. Transect 1: Stn 79–88, Transect 2: Stn 88–99, Transect 3: Stn 99–119, Transect 4: 119–139. Changes in ice conditions are marked; CPI is the closed pack-ice zone, IMIZ and OMIZ stands for inner and outer marginal ice zone

(Strathmann 1967) and by 0.13 for thecate dinoflagellates (Smetacek 1975).

Results

Sea ice and weather conditions, physical structure, and chemical properties of the water column

The area of investigation could be separated into three main regions based on the different ice conditions encountered: the open water zone (OWZ), the marginal ice zone (MIZ), and the closed pack-ice zone (CPI). The MIZ was further separated into two subzones, the outer marginal ice zone (OMIZ) and the inner marginal ice zone (IMIZ) (Fig. 1). This pattern is also reflected in the variables focussed on in this paper. The CPI began between 61° and 62°S showing the characteristics of sea ice during the winter (Eicken and Lange in Hempel 1989): Floes were large and measured up to several kilometers and were only occasionally interrupted by leads. In most cases snow cover was between 0.4 and 0.6 m. The IMIZ (ca 62–60°S) was still covered with heavy pack ice but floes were smaller, while the OMIZ (ca 60–58°30'S) had a more sparse floe distribution with a significant decrease in floe thickness and size. During the investigation the OWZ

consisted only of a small area between 58° 30' and 58°S. In this study we consider the OMIZ as open water since only small amounts of sea ice were observed. During the entire period of investigation only small changes were observed in the sea ice pattern. Some melting was observed during the last transect, indicating the onset of receding sea ice typical for spring. More detailed information concerning the weather and sea ice condition during the cruise is provided by Hempel (1989) and Eicken and Lange (in Hempel 1989).

The boundary between the clockwise flowing Weddell Gyre and the eastward flowing Antarctic Circumpolar Current is called the Weddell-Scotia Confluence (WSC). The southern border of the WSC, the Weddell Front was clearly recorded in all our temperature sections (Fig. 2b) with nearly vertical isotherms between latitude 58.5 and 59.5°S. The Antarctic Surface Water mass was found in the surface layer, extending down to 50–100 m beginning at the WSC and reaching southwards to approximately 61.5–60.5°S (Fig. 2a, b). In this water mass the highest

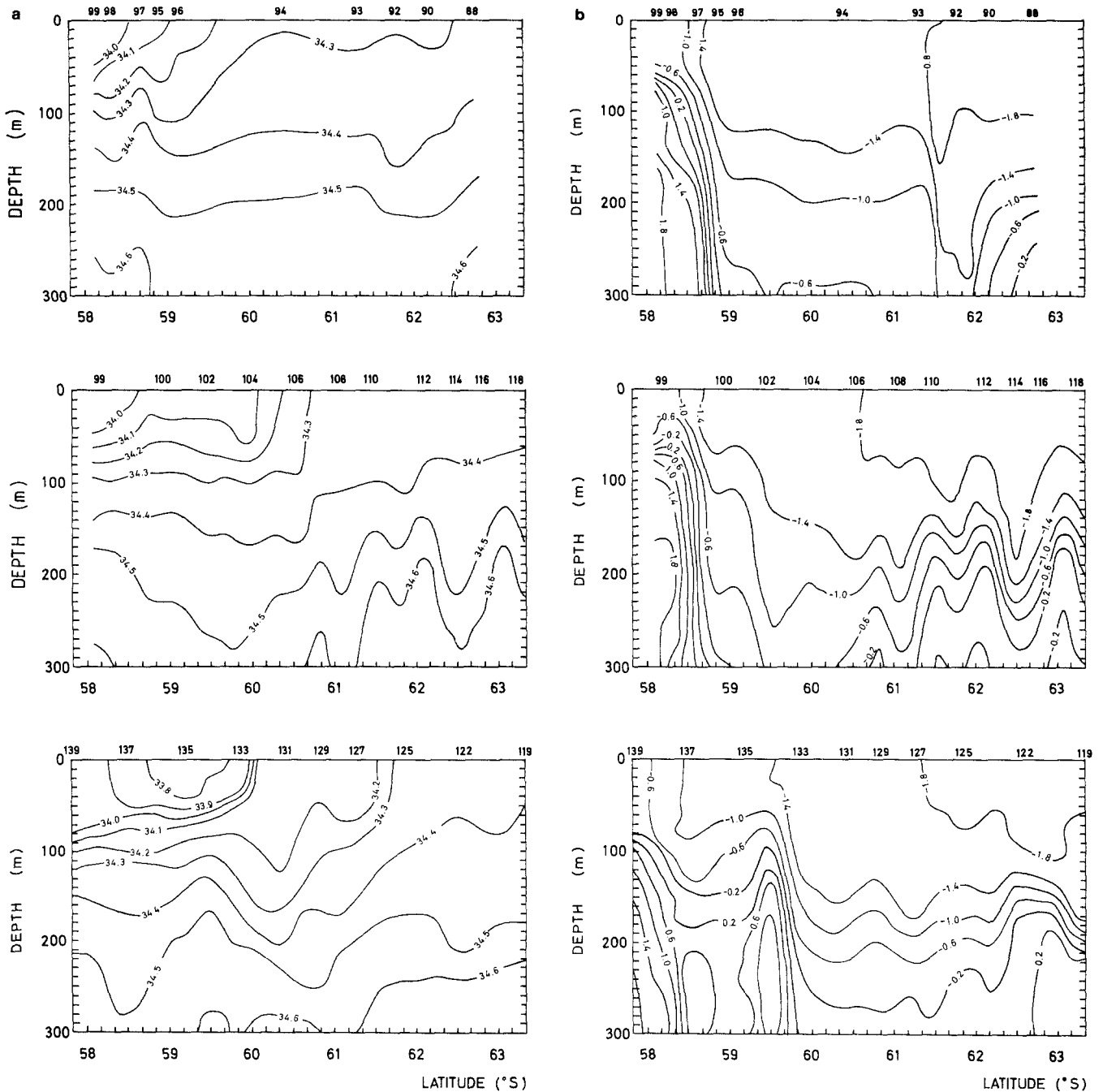


Fig. 2. a Salinity (psu) sections; b Temperature (°C) sections on the transects 2 (top), 3 (middle), and 4 (bottom) during the EPOS-leg 1 expedition in October/November 1988

temperatures recorded were just below 0°C and the salinities varied from 34.0 to 34.3 psu. Further south in the Weddell Sea Winter Water the surface temperatures were lower (-1.8°C) and the salinities were higher (34.3–34.4 psu). The lowest water temperature recorded was -1.8°C which is just above the freezing point at the corresponding salinity. Salinity differences inside the two surface water masses were due to ice-melting and ice-formation. Below the surface waters and the pycnocline area, the Warm Deep Water (WDW) was found. This

water mass had temperatures just above 0°C and salinities of 34.6–34.7 psu.

The water column was mostly weakly stratified and a pycnocline could only be identified north of about 60°S . The most remarkable feature was, that the thermoclines and haloclines became shallower and weaker as latitude increased. Hydrographic patterns coincided with patterns of sea ice distribution: the OMIZ being the zone of transition from heavy pack-ice to open water as well as from Weddell Sea Winter Water to Antarctic Surface

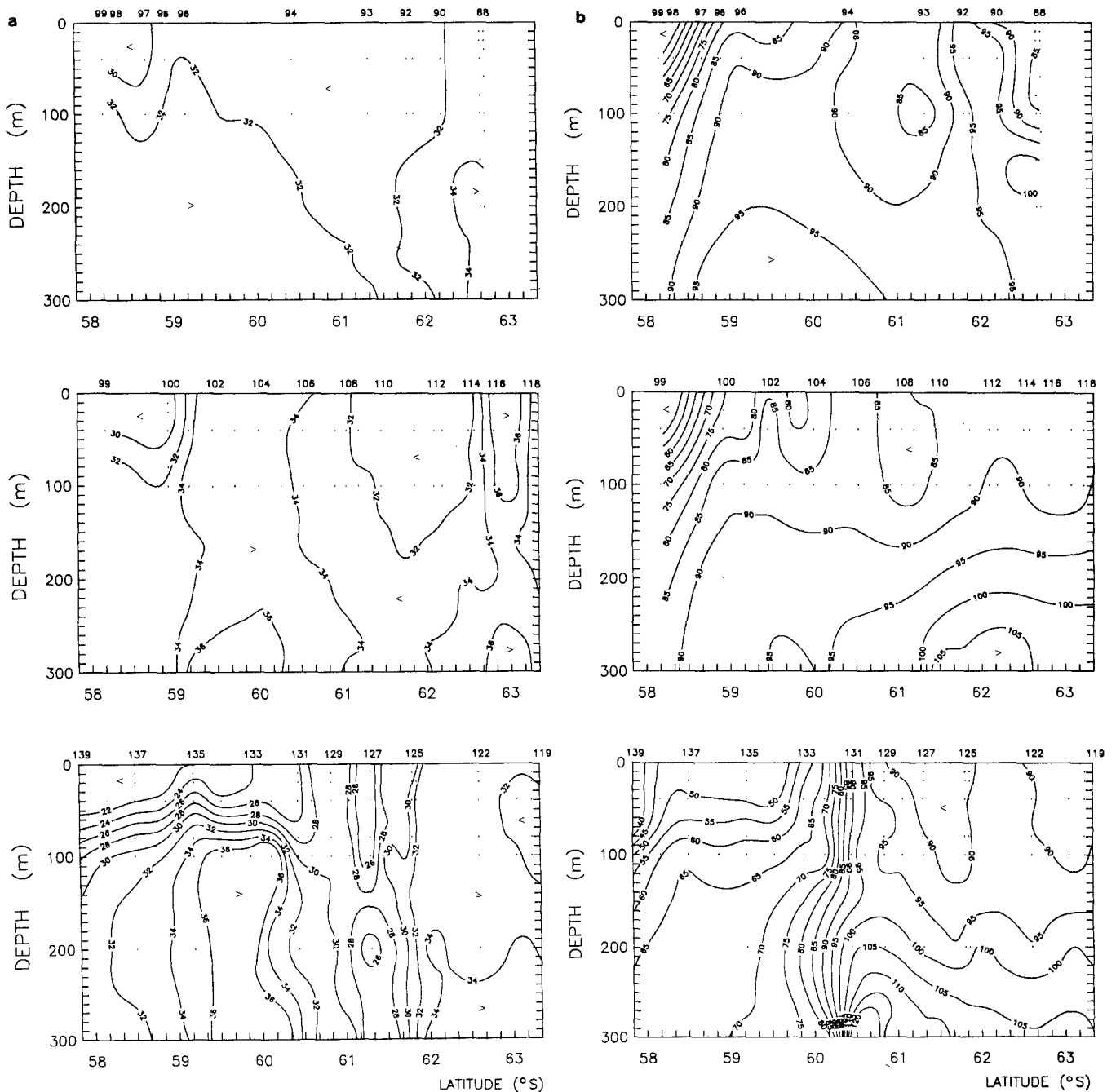


Fig. 3. **a** Nitrate ($\mu\text{mol l}^{-1}$) sections; **b** Silicate ($\mu\text{mol l}^{-1}$) on the transects 2 (top), 3 (middle), and 4 (bottom) during the EPOS-leg 1 expedition in October/November 1988

Water. The change of temperatures and salinities in the upper 150 m occurred over a core of warm water which is a feature of the Weddell Scotia Confluence area. Thus the WSC could be identified as the most northern border of the OMIZ. Stabilization of the upper water masses over the core of warm water most probably increased due to the increasing melt water introduction into that region as the season progressed. Further north, from station 132 to 139 the upper 80 m were relatively well stratified (Fig. 2.)

To demonstrate the nutrient distribution along the transects, we chose nitrate and silicate (Fig. 3a, b). The distribution pattern of these two macronutrients showed features similar to the physical properties on transects 2, 3, 4. Throughout the 2nd and 3rd transect, nutrient concen-

trations were high and reflected typical winter values (Nöthig et al. 1991) in the south. In the northern part of the transects they were only slightly below winter values. Along the fourth transect, however, a significant depletion of nitrate (about $6 \mu\text{mol l}^{-1}$) and silicate (about $20 \mu\text{mol l}^{-1}$) was observed between station 132 and 139 situated in the relatively well stratified water of the Weddell Scotia Confluence area. Further to the south, at the transition from the stratified surface water to the CPI, nitrate and silicate appear to be low and well mixed throughout the entire 300 m (station 125–132). We have no explanation for this and cannot rule out artifacts, since isolines are based on only few values, indicated as dots in Fig. 3.

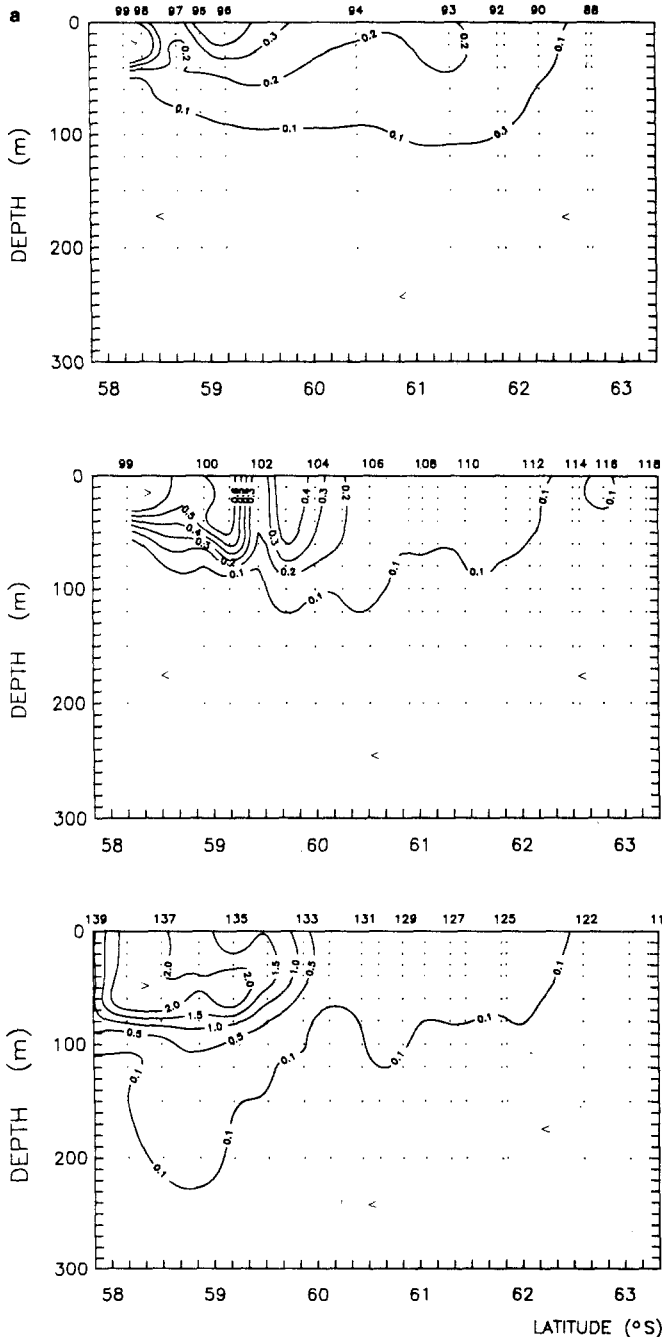
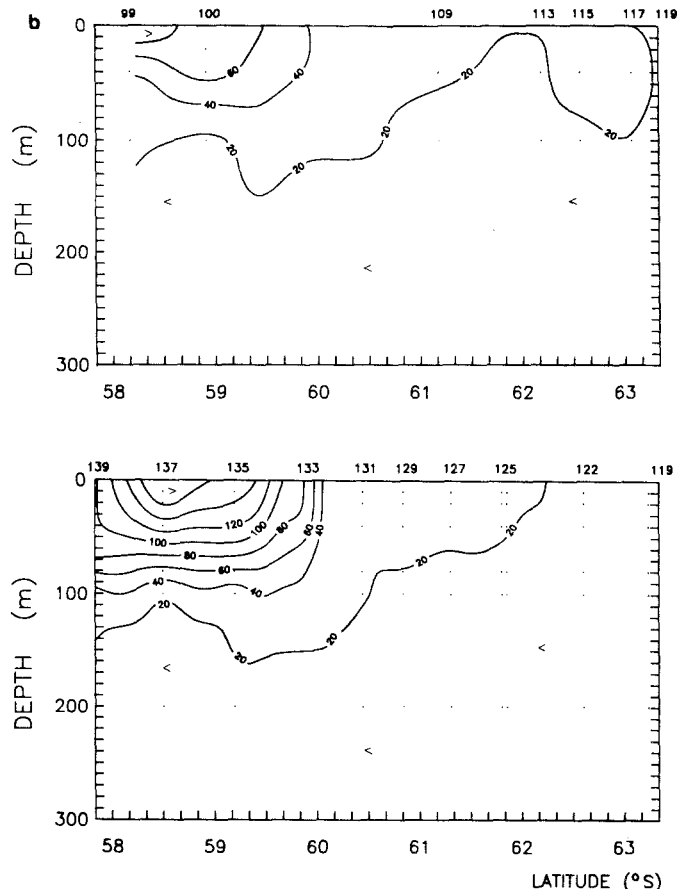


Fig. 4. a Chlorophyll a (Chl a in $\mu\text{g l}^{-1}$) sections on the transects 2 (top), 3 (middle), and 4 (bottom); b Particulate organic carbon (POC in $\mu\text{g l}^{-1}$) sections on the transects 3 (middle), and 4 (bottom) during the EPOS-leg 1 expedition in October/November 1988. Isolines have a different spacing in a, bottom



Distribution of POC, phytoplankton biomass and species composition

Chlorophyll *a* concentrations were low in the CPI at the southernmost stations along the transect. Values ranged between 0.05 and 0.1 $\mu\text{g l}^{-1}$ in the upper 300 m and were more or less well mixed in the upper 100 m. Within the IMIZ chlorophyll *a* concentrations increased slightly up

to approximately 0.25 $\mu\text{g l}^{-1}$ in the surface layers. Maximum chlorophyll *a* concentrations were found in the zone characterized by low sea ice concentration and more open water. On the second transect chlorophyll *a* values attained a maximum of 1 $\mu\text{g l}^{-1}$ (Stn 99, 30 m) and on the fourth transect the phytoplankton biomass increased to a maximum of 3, 5 $\mu\text{g l}^{-1}$ (Stn 138, 60 m). The distribution of chlorophyll *a* concentrations corresponds well with the

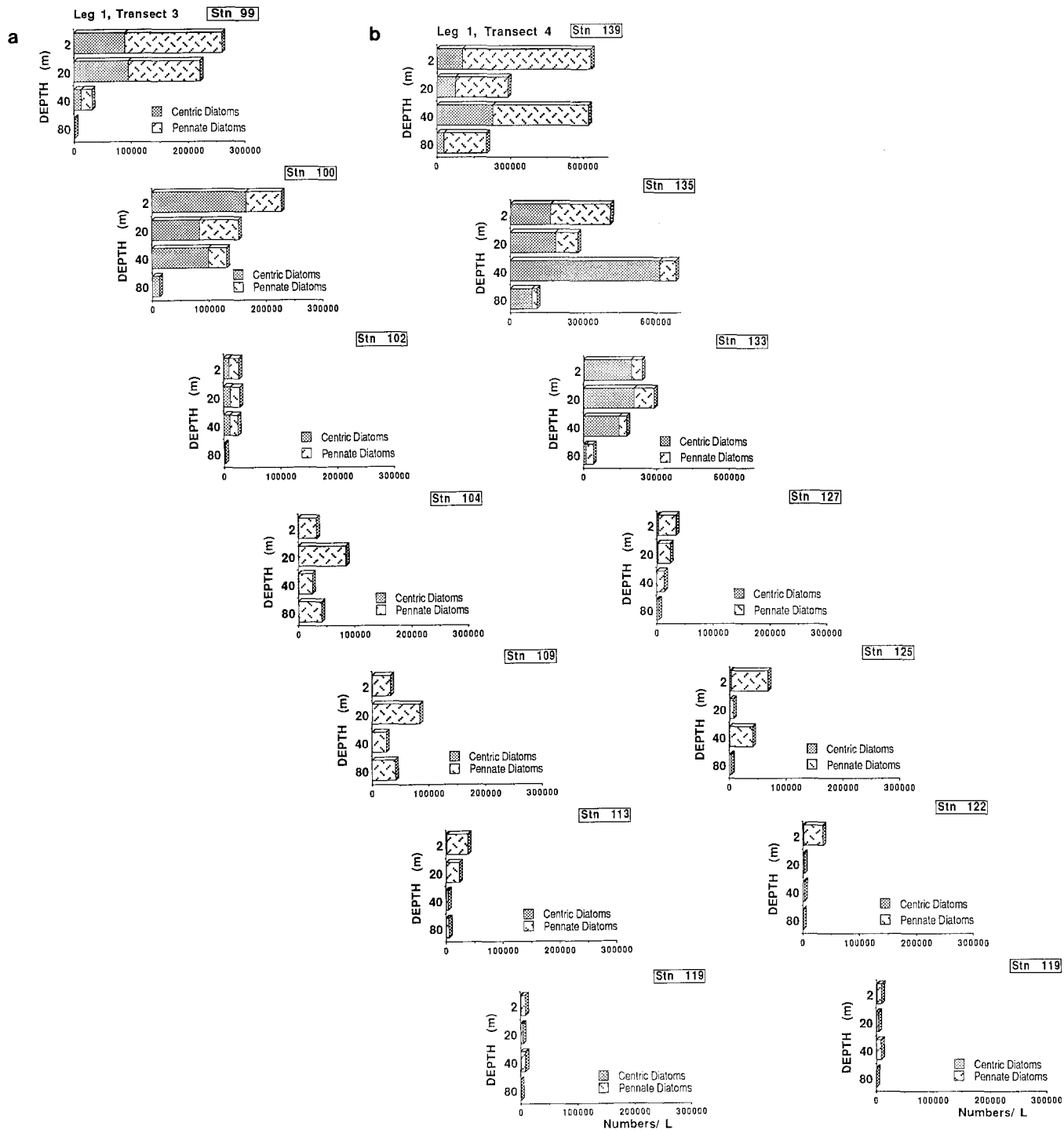


Fig. 5. Centric and pennate diatoms (numbers l^{-1}) on the transects 3 (a) and 4 (b) during the EPOS-leg 1 expedition in October/November 1988. Note different scales of x-axis

physical properties as well as with the nutrient data. (Fig. 4a).

Particulate organic carbon concentration also reflected the chlorophyll *a* distribution (Fig. 4b). Values were below $40 \mu\text{gC l}^{-1}$ in the closed pack-ice zone where less than 10% of POC was represented by phytoplankton. Higher POC values were found in the OMIZ. They increased towards the open water where values above

$100 \mu\text{g l}^{-1}$ were measured (maximum $193 \mu\text{gC l}^{-1}$). Here phytoplankton contributed more than 50% to POC.

Phytoplankton species (Figs. 5a,b; 6a, b; Tables 1 and 2), had similar distribution patterns on two transects (3 and 4) examined. In both cases a different phytoplankton assemblage could be observed in all the three zones (open water and OMIZ, IMIZ, CPI). The differences between the pack-ice assemblage and the two others were greater than

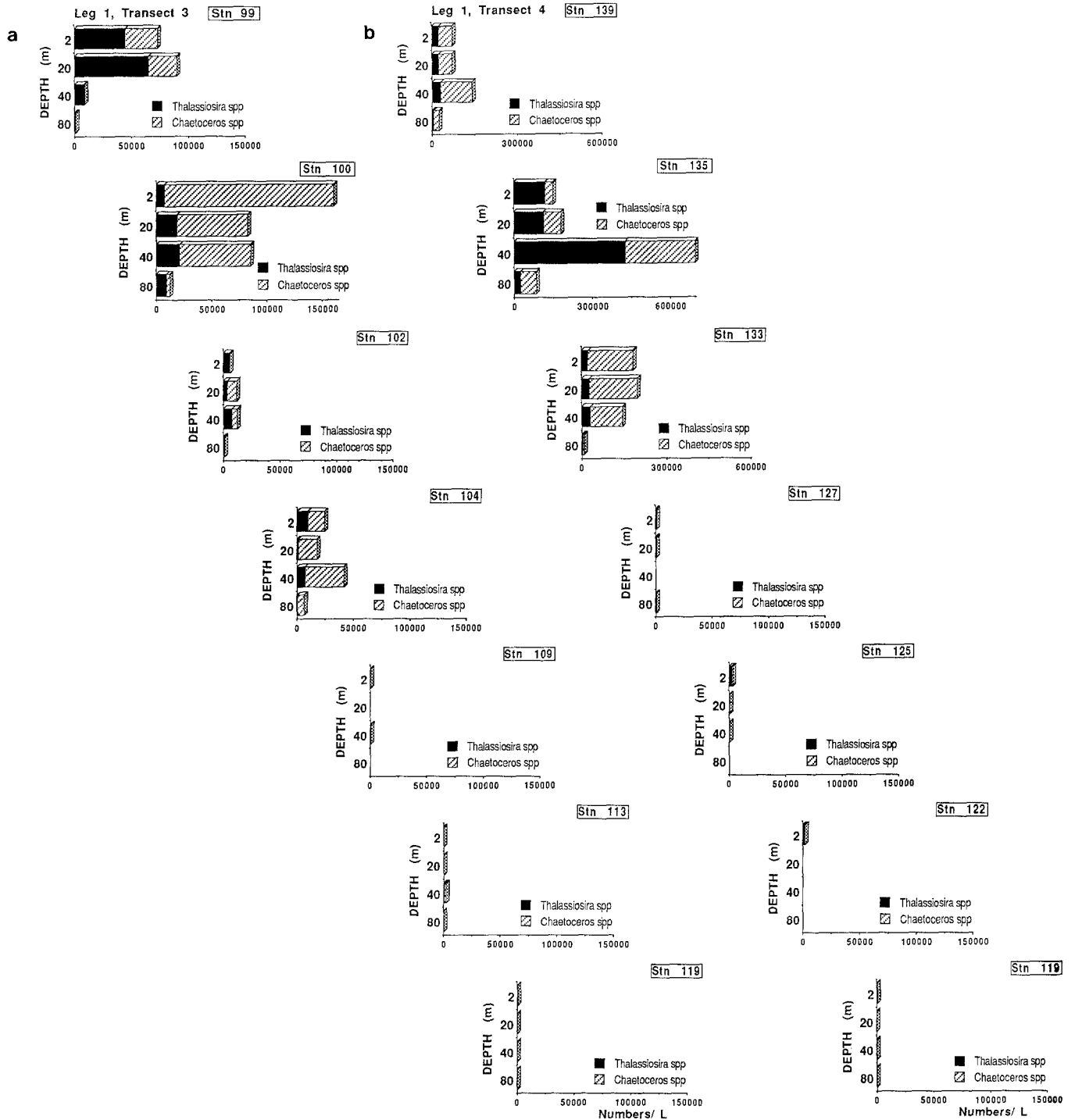


Fig. 6. Dominant centric diatoms (*Thalassiosira* spp. and *Chaetoceros* spp.) (numbers l^{-1}) on the transects 3 (a) and 4 (b) during the EPOS-leg 1 expedition in October/November 1988. Note different scales of x-axis

the differences between the IMIZ and the open water-OMIZ assemblages (Table 1; Figs. 5 and 6). Cell numbers of the respective dominant species in the zone of enhanced biomass increased from transect 3 to 4.

The concentrations of diatoms were fairly low in the CPI, and many empty frustules of mainly pennate diatoms were found in the samples. Large amounts of detritus and disrupted zooplankton faeces were also observed in net samples obtained from the upper 10 m of the water column. More living phytoplankton cells were found further north. In the MIZ, single cells of pennate diatoms of mainly small *Nitzschia* spp. such as *Nitzschia cylindrus* dominated the phytoplankton. At the transition from the OMIZ to open water, large colony forming centric diatoms such as *Thalassiosira gravida* and *Chaetoceros neglectum* dominated the phytoplankton assemblage.

Table 1. Numbers (log cell number $10^{-1} + 1$) and standard deviation (in parentheses) of selected large centric diatoms from 2 and 40 m of transect 3 and 4 in the closed pack-ice zone (CPI), the marginal ice zone (MIZ), and the open water (OWZ)

Species name	CPI	MIZ	OWZ
<i>Chaetoceros</i> spp	1.45 (1.37)	4.47 (0.80)	4.34 (0.86)
<i>Corethron criophilum</i>	1.14 (1.28)	1.63 (1.36)	0
<i>Dactyliosolen antarcticum</i>	0.54 (0.96)	1.72 (1.76)	2.63 (1.10)
<i>Dictyocha speculum</i>	0.39 (0.89)	1.25 (1.31)	3.58 (0.46)
<i>Eucampia antarcticum</i>	0	1.55 (1.53)	1.38 (0.85)
<i>Odontella weissflogii</i>	0	0.64 (1.03)	1.14 (1.23)
<i>Rhizosolenia</i> spp	0.23 (0.73)	1.57 (1.66)	2.99 (0.74)
<i>Thalassiosira</i> spp	2.58 (0.85)	4.29 (0.65)	4.36 (0.27)
<i>Thalassiotrix antarctica</i>	0.41 (0.92)	0.74 (1.11)	2.23 (1.54)

Table 2. Percentage of diatoms on the sum of autotrophic nanoflagellates plus diatoms at selected stations along transects 3 and 4 during the EPOS-leg 1 expedition in October/November 1988. The stations are listed from north (top) to south (bottom); OMIZ = outer marginal ice zone, IMIZ = inner marginal ice zone, CPI = closed pack-ice zone

Station number location	Depth (m)	Transect 3	Station number location	Depth (m)	Transect 4
99 open water	2	26	139 open water	2	35
	20	16		20	13
	40	9		40	30
	80	0.7		80	11
100 OMIZ	2	10	135 OMIZ	2	44
	20	7		20	26
	40	7		40	76
	80	2		80	26
104 IMIZ	2	4	127 CPI	2	3
	20	4		20	2
	40	7		40	2
	80	3		80	2
109 CPI	2	3	125 CPI	2	9
	20	7		20	1
	40	4		40	9
	80	16		80	0.6
113 CPI	2	5	122 CPI	2	7
	20	3		20	0.5
	40	0.6		40	0.7
	80	1		80	0.2
119 CPI	2	1	119 CPI	2	1
	20	1		20	1
	40	2		40	2
	80	0.2		80	0.2

Thalassiosira gravida had maximum cell numbers where chlorophyll *a* was at its maximum while *Chaetoceros neglectum* occurred in higher abundances north and south of the biomass maximum (6a, b). Pennate diatoms were again dominant at the northernmost stations on both transects (3 and 4) but comprised larger organisms of the *Nitzschia* spp. occurring as very long chains.

Autotrophic nanoflagellates occurred in higher numbers than the diatoms. The percentage of diatoms on total phytoplankton cell numbers in the IMIZ and CPI was less than 10% with one exception. In the OMIZ and in open water the percentage of diatoms was higher ranging from 0.7% to 76%. Due to their smaller size the contribution of autotrophic nanoflagellates to the total phytoplankton biomass was less than that of larger diatoms. The relative importance of autotrophic nanoflagellates increased in the ice zone as well as in deeper water depths below 50 m at almost all stations (Table 2). In the CPI they were the dominant phytoplankton group besides the small pennate diatoms, and consisted mainly of single flagellates of *Phaeocystis* sp. and others such as cryptophytes and *Pyramimonas* sp.. The silicoflagellate *Dictyocha speculum* increased towards the north (Table 1). Autotrophic dinoflagellates seemed to be of minor importance.

Discussion

Phytoplankton biomass distribution

Abiotic factors such as irradiance, stability of the water column as well as the availability of key nutrients, are

the most important abiotic factors constraining phytoplankton growth in the ocean. Light is the most important factor controlling phytoplankton growth in Antarctic waters (reviewed in Sakshaug and Holm-Hansen 1984; Sakshaug 1989). In ice-covered areas, sea ice plus snow cover strongly attenuate incoming light, and growth in the water column only begins when sea ice melts. The transition zone between the ice cover and the water column can provide a stable environment for algal biomass accumulation (Smith 1987; Sullivan et al. 1988; Comiso et al. 1990). Thus, the ice-edge zone can sustain high spring phytoplankton production associated with a shallow surface layer stabilized by addition of melt water.

The sea-ice and the ice-edge zone are characteristic features of polar marine ecosystems. The Weddell Sea in particular is characterized by a strong seasonality in sea ice cover with an annual decrease of sea ice cover from $20 \times 10^6 \text{ km}^2$ in late winter to $4.5 \times 10^6 \text{ km}^2$ in summer (Hibler and Ackley 1983; Zwally et al. 1983). The hydrography is determined by the large scale cyclonic gyre with inflow in the east and outflow in the west (Deacon 1979; Comiso and Gordon 1987). Therefore, the northwestern Weddell Sea and the adjacent waters to the north comprising the outflow region of the Weddell Gyre, resemble a spatially variable MIZ. In this zone, pack ice is continuously transported out of the Weddell Sea by currents and moves over the slightly warmer water masses of the Weddell-Scotia Confluence and subsequently to the Scotia Sea. Thus, melting occurs in the Weddell-Scotia Confluence area during all seasons. This proliferation of meltwater enhances the stability of the upper water masses in the area and could therefore have a positive affect on the development of more phytoplankton biomass. Satellite data from the northwestern Weddell Sea and its outflow show that enhanced phytoplankton biomass occurs over a larger area in that region (Sullivan et al. 1988; Comiso et al. 1990). In addition, the Weddell Scotia Confluence is characterized by complex hydrography (Patterson and Sievers 1980; Heywood 1985) which could result in the frontal system favouring enhanced phytoplankton growth. On the other hand, the complexity of the system could result in a patchy distribution of phytoplankton biomass such as observed on satellite images.

For the duration of our investigation, the only significant accumulation of phytoplankton biomass was indeed observed in the Weddell-Scotia Confluence area. This was also reflected in a decrease in nutrient concentrations. Phytoplankton biomass decreased markedly from north to south, i.e. from the Scotia Sea towards the Weddell Sea and nutrients remained relatively high, particularly in the Weddell Sea. The enhanced biomass in the Weddell-Scotia Confluence area can be attributed to the stabilization of the upper water column initiated by melting sea ice, as well as to the frontal system itself. The lower biomass found in the IMIZ and in the pack ice zone is likely to be the consequence of a less stabilized water column and the heavy ice cover which reduces irradiance drastically (Nöthig, unpublished data).

The possible fate of phytoplankton biomass build up in the stabilized zone in the north of the transects could be grazing, sinking or a large amount could have been

transferred into the dissolved organic pool. This cannot be resolved since we did not measure the vertical particle flux nor DOC. However, we assume that a large proportion must have been grazed by heterotrophic organisms such as protozoans, copepods and krill which is supported by relatively high POC: Chl *a* ratios. No investigations were carried out to estimate secondary production. More field work and experimental work is needed in the future to understand the fate of phytoplankton biomass in this relatively productive area of the Southern Ocean.

Phytoplankton species distribution

Recent studies have shown a strong dominance of nano-flagellates in the Southern Ocean throughout the season (von Bröckel 1981; Hewes et al. 1985; Garrison and Buck 1989). We found this type of community under sea ice in the Weddell Sea where winter conditions still prevailed. During EPOS Leg 2, nanoflagellates dominated for most of the time, except in the north and at the beginning of the investigation. Thus, the proposed scheme by Smetacek et al. (1990) which postulates that flagellates are representative of typical phytoplankton in the Antarctic pelagial with some occasional blooms of large diatoms in special areas may indeed prevail.

The species composition of the dominant phytoplankton in the Weddell-Scotia Confluence area showed a composition similar to that reported by others (e.g. Garrison et al. 1987; Fryxell and Kendrick 1988). Garrison et al. (1987) also observed a maximal development of phytoplankton in the frontal system north of the ice edge in late November, early December 1983 and as in our study, large chain-forming centric diatoms such as *Thalassiosira gravida* and *Chaetoceros neglectum* together with other relatively large diatoms dominated the phytoplankton assemblage. This species composition was also found during EPOS leg 2 on the first transect (Schloss and Estrada, personal communication). Thus, these species seem to be typical for that particular region during spring. Similar species assemblages have been reported from the Bransfield Strait area where large centric diatoms usually dominate the phytoplankton assemblage (Hart 1942; El-Sayed 1967; von Bodungen 1986; von Bodungen et al. 1986, 1987). Whether the species assemblage we found advected from the Bransfield Strait area or Drake passage or was seeded from Weddell Sea melt water could not be established. However, we assume that the assemblage we found was the result of a mixture of surface water advecting into the investigation area from the West towards the East and water flowing out of the Weddell Sea towards the Northeast. Nelson et al. (1987) speculate that the advanced stage of the ice edge bloom they observed in late November, early December 1983, resulted from a seed population that was advected from ice free regions of the Drake Passage.

The importance of algae released from sea ice in the spring as an inoculum for the water column has been inferred by Garrison et al. (1987), but is still open to conjecture. Garrison and Buck (1985) and Garrison et al. (1987) found a strong correspondence between ice algal

assemblages and the algal assemblage in the adjacent water column. In the latter study, Garrison et al. (1987) found that abundances of species typically found in sea ice were high in an ice edge bloom in the same area we investigated, suggesting that seeding from ice was a strong likelihood. However, we did not find the dominant species, *Thalassiosira gravida* and *Chaetoceros neglectum*, to be frequent in sea ice. Garrison et al. (1987) also did not find these two species in the sea ice. This would indicate that the above mentioned hypothesis of a mixture of two different water masses, one being less influenced by sea ice melting and the other being Weddell Sea water, exhibit a special case of ice edge phytoplankton bloom development in this particular area.

Conclusions

We conclude that it is not only the receding of the ice in the summer which produces a MIZ in the northwestern Weddell Sea, but that the strong outflow of the sea ice over warm water in the Weddell-Scotia Confluence area also favours the growth of phytoplankton. Thus favorable conditions for growth in the region of strong outflow of sea ice over the warm confluence water exist early in spring long before they are found in other areas. This also has consequences for the grazers as is revealed by the high abundances of krill in that area (Priddle et al. 1988).

Plankton studies in Antarctic waters have mostly been carried out in ice-free seasons and regions, or in the MIZ during the growth season from spring to autumn (e.g. El-Sayed 1967; El-Sayed and Taguchi 1981; Sakshaug and Holm-Hansen 1984; Smith and Nelson 1985; Sullivan et al. 1988). Relatively little work has been done in late winter and early spring (Nöthig et al. 1991). Our study was initiated in the very early growth season. The physical structure of the water column clearly showed an enhanced stabilization of the water masses of the upper 80 m north of 58° 30'S at approximately 47°W. This stabilization of water masses intensified towards the end of the investigation. A similar pattern of water mass distribution in that area and a correspondingly high phytoplankton biomass was found during the first transect of the EPOS 2 investigation somewhat further to the West at 49°W (Jacques and Panouse 1991). During the 2nd transect of EPOS 2 at 47°, however, less biomass was found and the grazing down by a krill swarm was considered to be the main reason for that (Jacques and Panouse 1989 in Hempel et al. 1989).

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