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Phytoplankton and nutrient distributions off the northern South Shetland Islands (summer 1984-BIOMASS/SIBEX)*

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Abstract: During the 1984 summer cruise as a part of the BIOMASS/SIBEX Program the Brazilian R/V Professor W. Besnard surveyed the "B" sector north of the South Shetland Archipelago from January 21 to 28. Water samples were collected with Nansen bottles from the surface to 500 m depth for the analyses of total plankton cells and physico-chemical parameters. The study area was dominated by Antarctic Surface Water, shelf water of the Antarctic Peninsula and cold water originating from the Weddell Sea. During the mixing of these watermasses, the distribution patterns of nitrate and silicate in the euphotic zone depicted a clear non-conservative behaviour due to phytoplankton uptake. The mean concentrations of nitrate and silicate in the euphotic zone varied from 14 to 26 and from 20 to 50 μg-at. l^{-1}, respectively. The phosphate distribution was not as much affected as nitrate and silicate by biological uptake, and the mean concentration in the euphotic zone varied from 1.0 to 1.6 μg-at. l^{-}. The phytoplankton population was numerically dominated by phytoflagellates and monads smaller than 10 μm in shelf areas and by nanoplanktonic diatoms (*Chaetoceros neglectus*, *C. tortissimum* and small chain-forming pennate cells) of 6 to 9 μm in size in offshore waters of the Drake Passage. Hydrography, bottom topography and biological uptake were the main factors governing the distribution of nutrients. For phytoplankton distribution, the trophic interrelation between planktonic organisms must be taken into account.

1. Introduction

The pelagic environments in the northern part of the South Shetland Islands waters may be characterized by physico-chemical gradients due to (i) the mixing of Antarctic Surface Water with colder and more saline water of the Weddell Sea, as a part of the Weddell-Scotia confluence, and (ii) the upwelling of Deep Circumpolar Water at the emergence zone (PATTERSON and SIEVERS, 1980; FISHER, 1980; STEIN, 1981; SIEVERS, 1982; LIPSKI, 1982). Strong bathymetric gradients are also characteristic of this zone (CLOWES, 1934) and certainly affect the hydrographic regime in the surface euphotic layers above shelf and off-shelf areas.

During the second Brazilian expedition to the Antarctic Peninsula in the summer of 1984, total phytoplankton samples and hydrographic data were obtained in this southernmost part of the Drake Passage ("B" sector, BIOMASS/SIBEX). The sampling cruise offered a good opportunity to study the pattern of horizontal distribution of plankton cells in relation to not only hydrography and bottom topography but also the consequence of trophic interactions among the planktonic organisms. The trophic relationship between nanoplankton and ciliates has been discussed recently (HEWES *et al.*, 1985; BRANDINI and KUTNER, 1986) and it is considered as one of the most important topics concerning the lower trophic levels of the Antarctic food web. For this reason, the analyses of the distribution patterns of these organisms are performed in the present study with the hope that it might help to elucidate the initial step of the pelagic food web in the Antarctic seas. For comparative purposes, the phytoplankton distribution (mainly diatoms) reported previously in the same area (URIBE, 1982; KOPCZYNSKA and LIGOWSKI,

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1982; LIPSKI, 1982) is discussed.

2. Materials and methods

A total of 16 oceanographic stations were sampled by the R/V "Professor W. Besnard" from Januray 21 to 28 consisting of the "B" sector of the BIOMASS program (Fig. 1). Vertical water samples were obtained at standard depths using Nansen bottles until 500 m. The temperature was measured with reversing thermometers and the salinity with an Autolab salinometer. The analyses of nitrate, phosphate and silicate were undertaken at the Oceanographic Institute of São Paulo University according to STRICKLAND and PARSONS (1972).

Water samples for total phytoplankton were collected from the Nansen bottles within the euphotic zone of each station (0, 25, 50, 100 and 150 m depth) and preserved with 0.4 % formalin solution. Fifty mililiters were used for the settling technique of UTERMÖHL (1958) and cell counts were performed with a Zeiss inverted phase contrast microscope. Nanoplankton was counted at magnification of 400× considering various size categories (<3, 3-6, 6-9, 9-12, 12-15 and 15-20 μm) and microplankton, including most of the ciliate cells, was counted at lower magnification (130×) in one half of the total chamber area.

3. Results

a. Hydrography and physico-chemical parameters

The bathymetric chart (Fig. 1) was redrawn from that obtained by the Polish R/V "Professor Siedlecki" during the BIOMASS/FIBEX. The continental shelf, represented by the shaded area, is bordered by the 500 m isobath occupying approximately one third of the whole sampling area. The bottom topography indicates a clearly defined continental slope, bounding the shelf water of the Shetland Archipelago and the offshore water of the Drake Passage.

The greater part of the study area was dominated by the Antarctic Surface Water carried by the Antarctic Circumpolar Current from the Bellingshausen Sea. The horizontal distribution of surface temperature (Fig. 2) indicates a well-defined gradient decreasing eastward from a maximum of 2.5°C in the oceanic water of the Drake Passage (Stns. 4462 and 4463) to a minimum of 0.1°C in the vicinity of the Elefant and Clarence Islands (Stns. 4458 and 4459). The salinity at the surface (Fig. 3) ranged from 33.31×10^{-3} with lowest values observed in oceanic water of the western part of the study area (Stns. 4469, 4470 and 4471), increasing eastward to a maximum value of 34.48×10^{-3} observed around Clarence Island (Stns. 4458 and 4459).

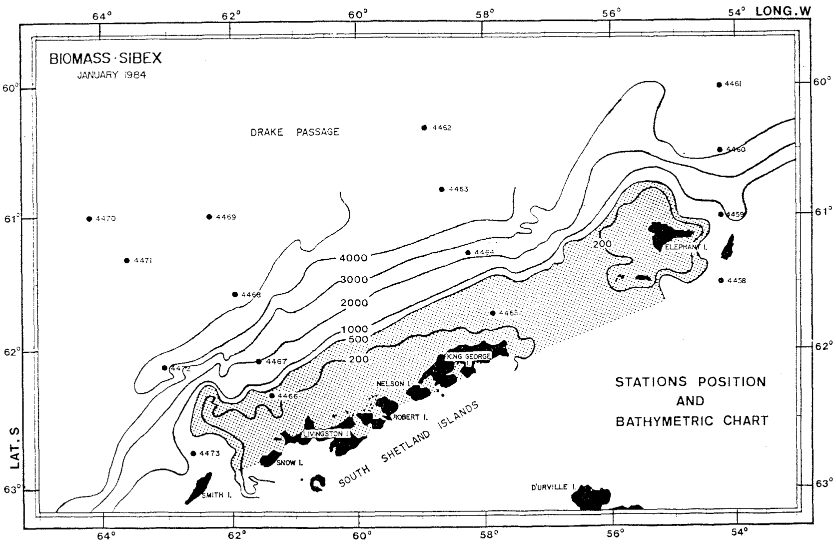

Fig. 1. Station positions and the bathymetric chart of the surveyed area.

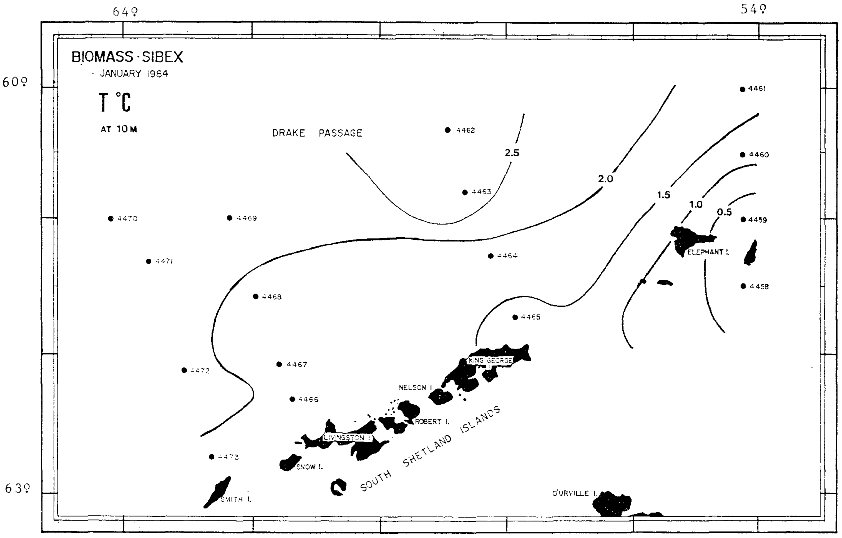

Fig. 2. Horizontal distribution of temperature at 10 meters.

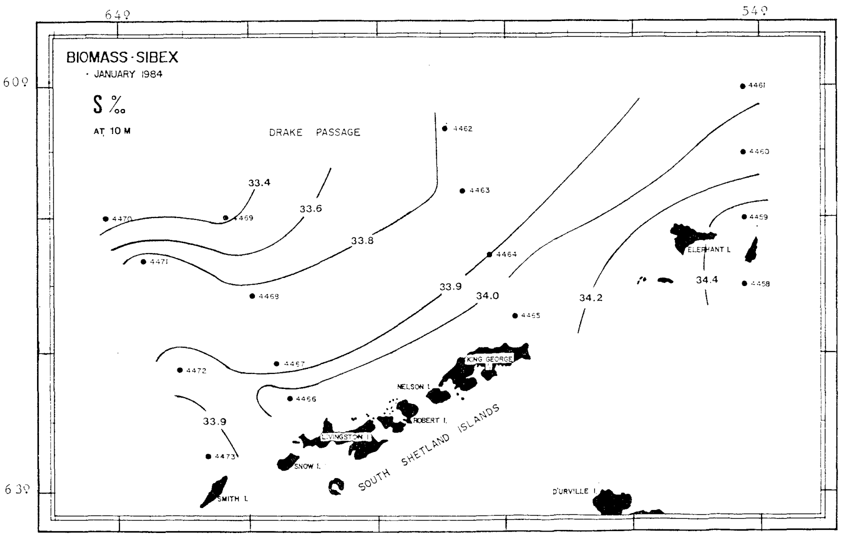

Fig. 3. Horizontal distribution of salinity at 10 meters.

The mean concentrations of dissolved nutrients between 0 and 150 m and between 150 and 300 m depth were considered in order to analyse more accurately the geographical distributions in the upper euphotic and deeper aphotic layers, respectively. The nitrate in the euphotic layer (Fig. 4) ranged from 14 to 26 μg-at. l^{-1} with the highest concentration measured in shelf water decreasing northward with a sharp gradient over the continental shelf zone. The lowest value was found in offshore area around Stn. 4462. In the aphotic layer (Fig. 5) the mean concentration varied between 18 and 38 μg-at. l^{-1}. Gradients over the continental slope were also observed but they increased northward. Hence, the distribution patterns in both of the layers were completely different.

The distributions of phosphate in the euphotic and aphotic layers (Figs. 6 and 7) were very similar with the mean concentrations varying

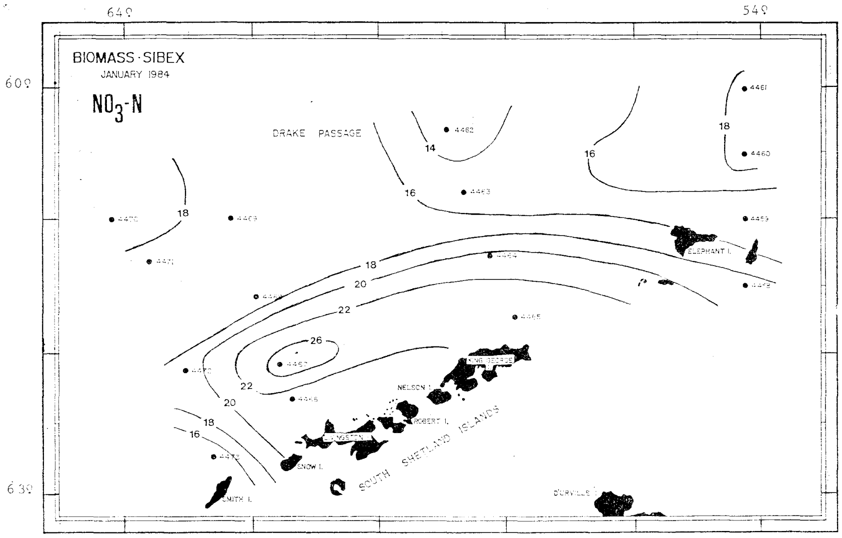

Fig. 4. Geographical distribution of the mean concentration of nitrate (μg-at. l^{-1}) in the euphotic layer.

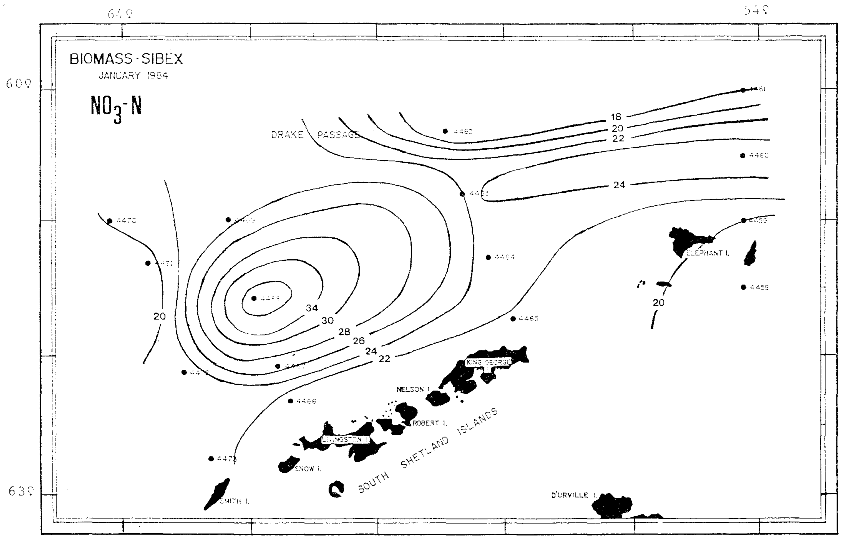

Fig. 5. Geographical distribution of the mean concentration of nitrate (μg-at. l^{-1}) in the aphotic layer.

from 1.0 to 1.6 μg-at. l^{-1} and from 1.2 to 1.8 μg-at. l^{-1}, respectively. In both layers, the distribution was homogeneous in almost the whole study area, with sharp gradients observed only in the western sector.

The mean concentration of silicate in the euphotic zone (Fig. 8) greatly varied from 20 to 50 μg-at. l^{-1} with increasing gradients towards the confluence with the Weddell Sea water in the proximity of the Elefant and Clarence Islands. In the deeper aphtic layer (Fig. 9) the distribution was homogeneous over the whole sampling area with concentrations ranging between 40 and 50 μg-at. l^{-1}.

b. Biological parameters

The highest concentration of total phyto-

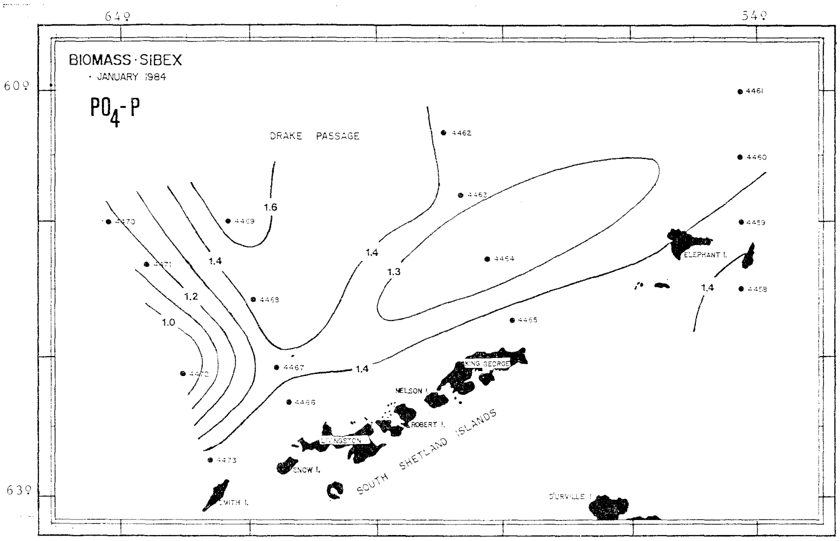

Fig. 6. Geographical distribution of the mean concentration of phosphate (μg-at. l^{-1}) in the euphotic layer.

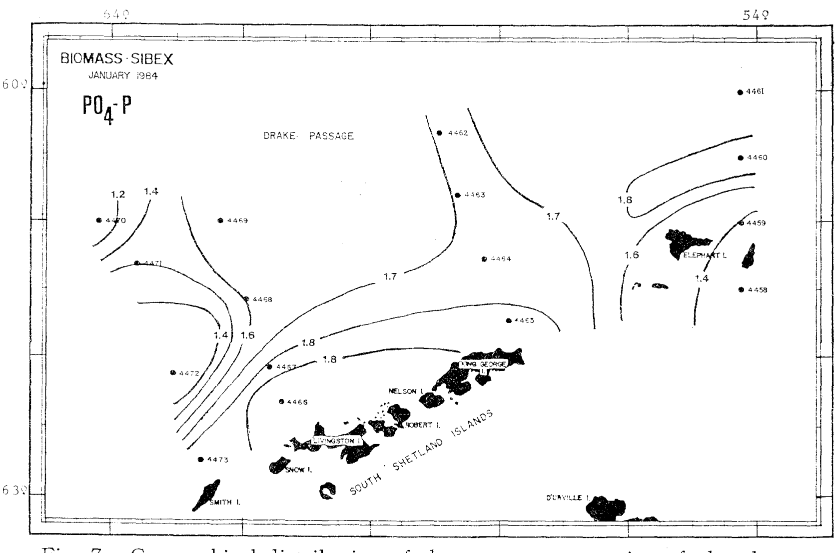

Fig. 7. Geographical distribution of the mean concentration of phosphate (μg-at. l^{-1}) in the aphotic layer.

plankton cells in the euphotic zone (Fig. 10) was 160×10^9 cells$\cdot$m^{-2} observed in shelf waters off Livingston Inland (Stns. 4466 and 4467), decreasing northward to ca. 50–75$\times10^9$ cells$\cdot$m^{-2} in offshore water of the Drake Passage. A minimum of 25×10^9 cells$\cdot$m^{-2} was observed at Stn. 4459 near Elefant Island.

The concentration of total phytoflagellates in the euphotic zone varied from 25 to more than 150×10^9 cells$\cdot$m^{-2} with the lowest density observed near Elefant and Clarence Islands and the maximum in shelf waters north of Livingston Island. In the continental shelf zone, more than 90% of the total phytoplankton community was numerically dominated by phytoflagellates and monads smaller than 10 μm (Fig. 11). In these areas, 50% of the nanoplanktonic organisms were flagellates and monads of less than 3 μm.

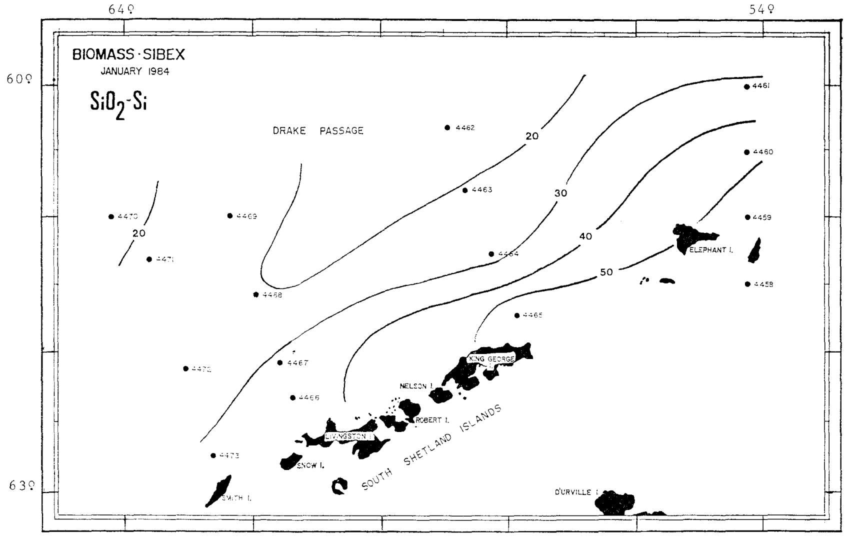

Fig. 8. Geographical distribution of the mean concentration of silicate (μg-at. l^{-1}) in the euphotic layer.

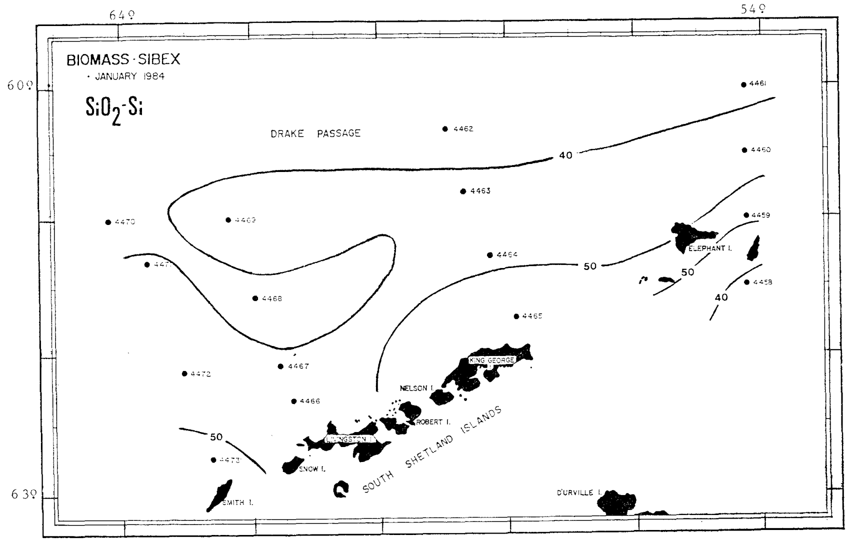

Fig. 9. Geographical distribution of the mean concentration of silicate (μg-at. l^{-1}) in the aphotic layer.

In the northern most oceanic areas, nanoplanktonic diatoms of 6 to 9 μm contributed to 50 % of the total phytoplankton cells (Fig. 12). These small diatoms mainly consisted of *Chaetoceros neglectus*, *C. tortissimum* and chains of unidentified pennate cells presumably to be identified as *Fragilariopsis nana* mentioned recently by HEWES *et al.* (1985) as dominant in water of the West Wind Drift.

The population of diatoms was almost completely restricted to the oceanic area of the Drake Passage. Decreasing gradients were observed towards the shelf waters of the Shetland Archipelago reaching the minimum value less than 10^9 cells$\cdot$m^{-2} found at the eastern stations near Elefant and Clarence Islands, and at Stn. 4466 located north of Livingston Island. The highest density of ca. 60×10^9 cells$\cdot$m^{-2} was

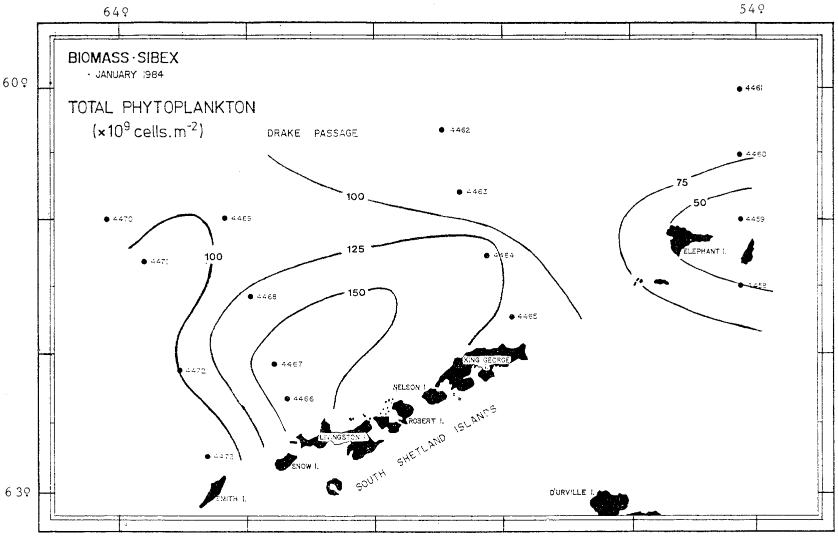

Fig. 10. Geographical distribution of total phytoplankton cells per m^2 in the euphotic layer.

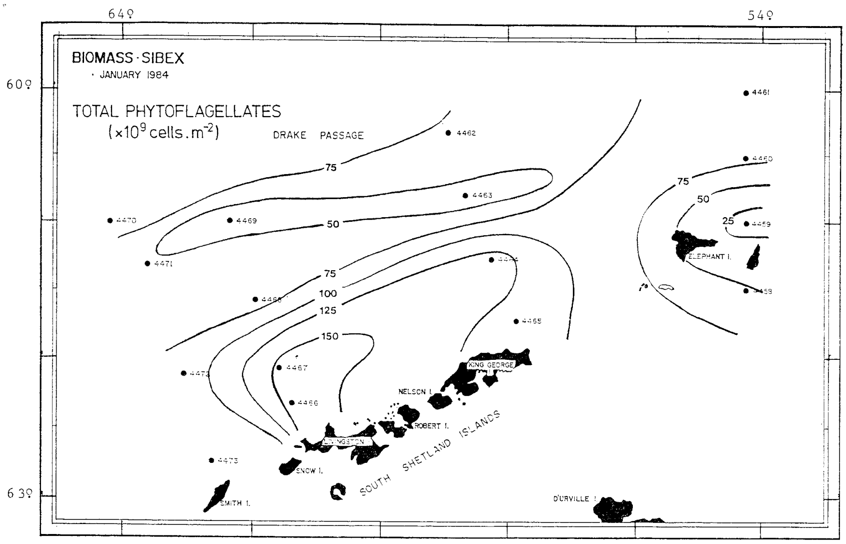

Fig. 11. Geographical distribution of total phytoflagellates and monads per m^2 in the euphotic layer.

found around Stn. 4469.

The abundance of the protozooplankton, mainly ciliates, was estimated at each station as the number of organisms per m^2 surface in the euphotic zone (Fig. 13). High concentrations of 150 to 175×10^3 org$\cdot$m^{-2} were observed in shelf waters between Livingston and King George Islands, and in the west sector of the study area around Stn. 4471. Gradients were observed over the continental slope with concentrations decreasing northward and towards Elefant and Clarence Islands. The low densities were found at Stn. 4468 in the offshore area, and at Stns. 4458 and 4459.

4. Discussion

a. Hydrography and chemical parameters

The discussions and comments about the

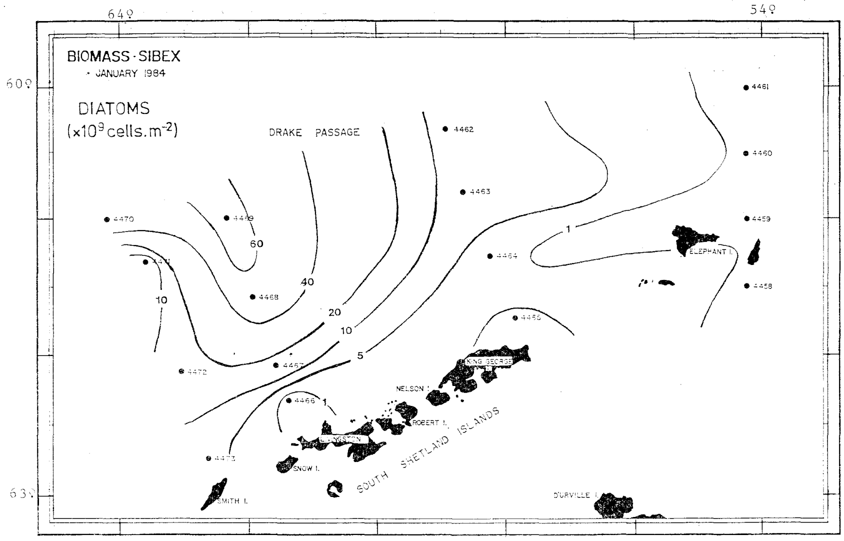

Fig. 12. Geographical distribution of diatoms per m^2 in the euphotic layer.

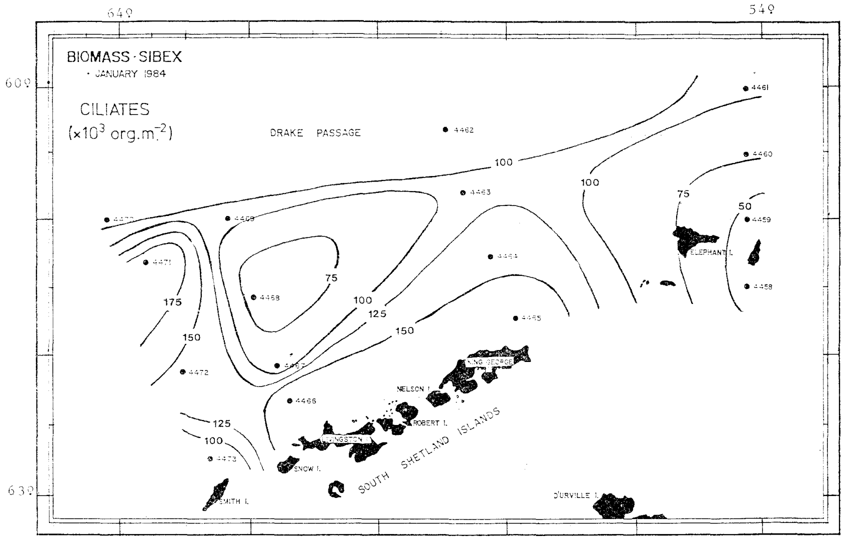

Fig. 13. Geographical distribution of ciliates per m^2 in the euphotic layer.

relationships between biological and physico-chemical factors will depend on the observation and comparison of the geographical distribution patterns of these parameters.

The greater part of the sector "B" was dominated by the Antarctic Surface water carried by the Antarctic Circumpolar Current from the Bellingshausen Sea. This water meets the colder and more saline water of the Weddell Sea near the northeastern end of the Shetland Archipelago causing gradients of temperature and salinity (observed in Figs. 2 and 3, respectively). The mixing of these watermasses is a part of the Weddell-Scotia Confluence (STEIN, 1981; SIEVERS, 1982; LIPSKI, 1982). In this study, not only the convergence of watermasses but also the bathymetric characteristics of the area were considered important for determination of the distribution patterns of both biological and chemical parameters. In fact, the sharp gradients observed in the distributions of nitrate, phytoflagellates, diatoms and ciliates are interrelated, but they occurred precisely above the continental slope due to the topographic gradients of this zone which was previously described as the Continental Water Boundary (WHITHWORTH, 1980) separating the Antarctic Surface Water from the Shelf Water of the Antarctic Peninsula (LIPSKI, 1982).

It has generally been accepted that nutrients do not limit the phytoplankton development in Antarctic seas, and even during local blooms when the growth rate is maximum, the concentrations are still above the levels required by phytoplankton cells (HOLM-HANSEN *et al.*, 1977; SAKSHAUG and HOLM-HANSEN, 1984; EL-SAYED, 1984). However, this may not be applied to exceptional cases where the amount of silicate may decrease down to limiting levels for some diatoms in certain areas. JACQUES (1983) reported that the half saturation constant (K_s) for the uptake of silica by Antarctic diatoms is very high, varying between 12 and 22 μg-at. l^{-1}. According to his experiments, concentrations of ca. 50 μg-at. l^{-1} would be necessary during the period of the maximum growth rate. Looking at Figs. 8 and 12, it is clear that concentrations of this magnitude were only measured in the shelf water around the northeastern side of the Shetland Archipelago, while in the oceanic areas dominated by diatoms the uptake may have lowered the amount of silica to limiting levels for at least certain species as previously argued by JACQUES (1983). SAKSHAUG and HOLM-HANSEN (1984) reported that concentrations of silica are seldom below 50 μg-at. l^{-1} in offshore waters. The low concentration level observed in the present investigation was probably one of the rare occasions and it was certainly due to the uptake by diatoms. In the deeper aphotic layers, the absence of photosynthetic activity maintained high concentrations homogeneously distributed in a more conservative manner.

Like silicate, the distribution pattern of nitrate in the euphotic zone depicted a clear non-conservative behaviour during the mixing of water-masses due to phytoplankton activity, although the concentrations were high above the levels required for a maximum growth rate.

In the case of phosphate, although the mean concentrations in the euphotic zone were lower than those in the aphotic zone, the uptake by phytoplankton cells did not reduce it to limiting levels and also did not affect intensively the pattern of horizontal distribution as they were very similar in both layers.

b. Biological parameters

During the BIOMASS/FIBEX summer cruise of 1981, the same area was surveyed by URIBE (1982), LIPSKI (1982) and KOPCZYNSKA and LIGOWSKI (1982), and the phytoplankton distribution patterns reported by these authors were very similar. Although they did not mention the phytoflagellates during their plankton analyses, they reported that diatoms were dominating the phytoplankton population. Therefore, at least the diatom distribution patterns of the 1981 and 1984 cruises my be compared.

KOPCZYNSKA and LIGOWSKI (1982) found high diatom densities as cell numbers per m^2 in the euphotic layer in the shelf water of the Shetland Archipelago and in the Weddell confluence area. The same pattern was confirmed for the chlorophyll *a* distribution reported by LIPSKI (1982). These authors found also *Chaetoceros neglectus* and *C. tortissimum* as dominants in the area north of Livingston Island. It is interesting to note that URIBE (1982) observed an opposite trend few weeks before with low densities of diatoms, mainly *C. tortissimum*, dominating the phytoplankton population in the shelf waters off Livingston and King George Islands increasing abruptly northwards (his values of chlorophyll *a* were 3 to 5 times higher than those reported by LIPSKI (1982) in the same oceanic areas). Coincidently, we observed the same pattern of diatom distribution in 1984 in a similar seasonal period and also with small *Chaetoceros* spp. being apart of the dominant groups. Few weeks before the Brazilian cruise, KOPCZYNSKA and LIGOWSKI (1985) reported for the "B" sector approximately the same range of diatom densities per m^2 in the euphotic layer (0.01×10^8–53.3×10^9 cells$\cdot$m^{-2}) as observed in the present investigation (0.36×10^8–60×10^9 cells$\cdot$m^{-2}), although they used a different methodology for phytoplankton sampling. They also observed a similar distribution pattern with the minimum density in shelf water between

Elefant and King George Islands as well as high densities in offshore water of the Drake Passage dominated by *Chaetoceros neglectus* and *C. tortissium*. However, they did not mention *Fragilariopsis* cf. *nana* as a part of their phytoplankton samples. We presume that *F. nana* is too small to be caught during the net hauls performed by the Polish scientists.

The ecological importance of the protozooplankton in the pelagic ecosystems of Antarctic seas has been emphasized in recent years (BRÖCKEL, 1981; HEWES *et al.*, 1985), suggesting that ciliates in the Antarctic food web represent a more efficient path for the transfer of organic matter accumulated in the nanoplankton community to higher trophic levels (HEWES *et al.*, 1985; BRANDINI and KUTNER, 1986) rather than the classic diatoms→krill based food web which, actually, is considered to be only part of a more complex food web proposed recently (HEWES *et al.*, 1985; EL-SAYED, 1984).

In the present study, high densities of ciliates were observed in shelf waters off Livingston and King George Islands (Fig. 13). The decreasing gradient towards the offshore water of the Drake Passage and towards the confluence with the Weddell Sea water was clearly defined. The same pattern of distribution was observed for phytoflagellates (Fig. 11). Apparently, a trophic relationship between both organisms is not evident by just comparing their distribution maps. On the other hand, an inverse relation may be recognized between the abundance of nanoplanktonic diatoms (Fig. 12) and ciliates (Fig. 13). For example, the maximum concentrations of ciliates found in the shelf water between Stns. 4465 and 4466, and also in the west sector of the study area between Stns. 4471 and 4472, counteract the minimum concentrations of diatoms observed in the same areas. Therefore, it may be suggested that the ciliates were grazing more efficiently the nanoplankton diatoms due to their immobility rather than the actively swimming phytoflagellates.

The relationships between environmental and biological parameters in the "B" sector during the 1983 Brazilian BIOMASS/SIBEX cruise may be summarized as follows: Hydrography, bottom topography and mainly biological activity jointly control the distribution patterns of nutrients. For phytoplankton distribution, the trophic interaction between the planktonic organisms must be taken into account in order to better understand their patterns.

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南シェットランド諸島北方海域における植物プランクトンと栄養塩の分布(1984年夏-BIOMASS/SIBEX)

F. P. BRANDINI • M. B. B. KUTNER

要旨: 1984年夏（1月21～28日），BIOMASS計画/SIBEX の一部としてブラジルの研究船 Professor W. Besnard は南シェットランド諸島北方海域を調査した。表面から深度500mまでの各層の試水を採取し，プランクトンおよび物理化学的項目を分析した。調査海域は，南極表層水，南極半島陸棚水，およびウェッデル海起源の冷水域によって占められていた。これ等水塊は混合するが，有光層内の硝酸塩と珪酸塩の分布は植物プランクトンによる吸収のため明らかに非保存的であり，平均濃度は硝酸塩が 14～16，珪酸塩が 20～50μg-at. l^{-1} であった。リン酸塩の分布は生物の吸収によって硝酸塩や珪酸塩ほどには影響されず，有光層内のリン酸塩平均濃度は 1.0～1.6 μg-at. l^{-1} であった。植物プランクトン群集は，陸棚域では 10 μm より小さい鞭毛藻類とモナス類が優占し，Drake Passage の沖合域では 6～9 μm の微小珪藻類（*Chaetoceros neglectus, C. tortissima,* および鎖状の小型羽状珪藻）が優占していた。栄養塩の分布を支配している主要要因は，水理，海底地形，生物による吸収であった。植物プランクトンの分布に関しては，浮遊生物間の捕食・被食相互関係が考慮されなければならない。