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Phytoplankton Species Composition and Abundance in the Indian Sector of the Antarctic Ocean

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Summary. Water samples collected in the southwestern Indian Ocean between Africa and Antarctica in March 1980 were analyzed quantitatively for phytoplankton. Diatoms dominate the phytoplankton in this region and their numbers generally increase southward with peaks of abundance in both the northern Antarctic Zone and south of the Antarctic Divergence. Average cell numbers (i.e., 6.1×10^5 diatoms l^{-1} in the Antarctic Zone) are comparable to maximum numbers previously reported for the Southern Ocean. Dinoflagellates, flagellates and "monads" occur in highest concentrations north of the Polar Front. Their numbers are somewhat reduced south of the Antarctic Divergence, and are lowest in the Antarctic Zone. Various diatom assemblages are characteristic of different latitudinal zones. Waters north of and in the vicinity of the Polar Front are rich in the *Nitzschia, Pseudonitzschia* group of species. In the Antarctic Zone, *Nitzschia* "nana" and *Dactyliosolen tenuijunctus* dominate. *Nitzschia* species of the *Fragilariopsis* group are most numerous at stations south of the Antarctic Divergence. Striking differences are noted between the species compositions of quantitative and net-haul samples. A few nanoplanktonic diatoms (e.g. *Nitzschia* "nana" and single cells of *Chaetoceros* spp.) and the weakly silicified *Dactyliosolen tenuijunctus*, which are dominant in the quantitative samples, are either entirely absent or present only as solitary cells in the net collections.

Introduction

Quantitative diatom studies in the Indian Ocean between Africa and Antarctica are reported by Kozlova (1964, 1970); Steyaert (1973a, 1974) and Jacques et al. (1979). Jacques et al. (1979) also include dinoflagellates in their report on the late summer phytoplankton west of the Kerguelen Islands. These studies, together with the work of Kawamura and Ichikawa (1984) from southwest of Australia and the work of Hasle (1969) from the southeast Pacific, provide quantitative information on the biogeographical distribution patterns of individual phytoplankton species of the Southern Ocean.

The works of Karsten (1907); Van Heurck (1909); Heiden and Kolbe (1928); Hendey (1937); Kozlova (1964) and Sournia et al. (1979) are valuable references for the floristic analysis of plankton from the southwestern Indian Ocean. Also helpful for diatom studies are the works of Hasle (1965 a, b) on *Pseudonitzschia* and *Fragilariopsis* species, although they have been based on samples obtained from the South Pacific Ocean.

The main objective of the present study has been to gain quantitative information on the composition, abundance, and distribution of the phytoplankton between Africa and Antarctica, as sampled during the March 1980 cruise of the *SA Agulhas* (Fig. 1). Although the majority of stations occupied during this cruise are located south of the Polar Front, most of the various water mass zones and frontal boundary regions located between South Africa and the Antarctic Continent were also sampled (Fig. 2) and the data are interpreted within this physical context. Analysis of the species count data identifies various species assemblages as characteristic of different latitudinal zones and clarifies distributional patterns of individual species. A technical report (Kopczynska et al. 1985), detailing all of the data, is available on request from the authors.

Methods

Sampling was carried out between 5–31 March 1980 at 25 stations located in the southwestern Indian Ocean between 40°00′–69°29′S and 01°47′–28°37′E (Fig. 1). Water was collected by 8-l Niskin samplers from depths corresponding to 100, 54, 30, 16, 8, 1 and 0.1% of surface light intensity as determined by use of a Secchi disc. However, at Stns. 16–24, samples ware taken from 0, 10, 20, 30, 50, and 75-m depths. Aliquots of 200 ml were preserved with 2% formalin (final concentration) buffered with hexamine. Preserved samples from 3–7 depths (median = 6) were analyzed from each station. The deepest depths from

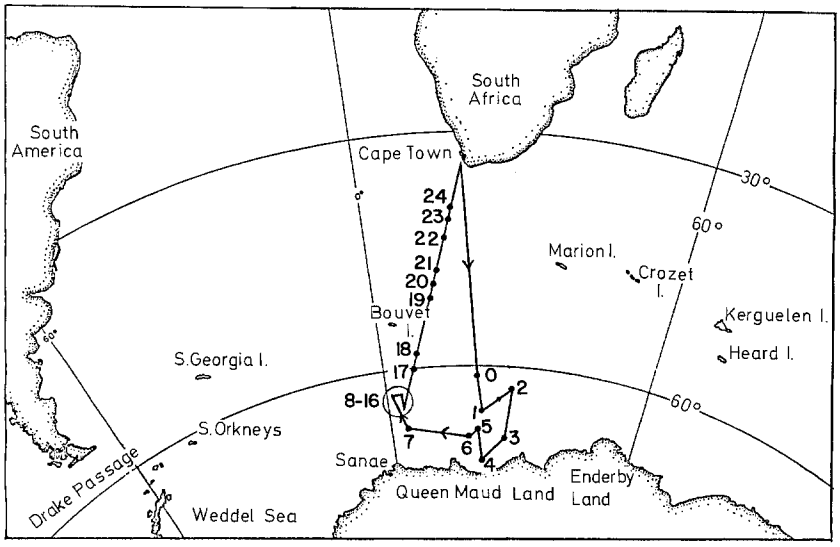

Fig. 1. Track and station positions of the 1980 *SA Agulhas* cruise

which samples were analyzed varied between 44 and 98 m (mean = 63 m). See Kopczynska et al. (1985) for details.

Either 10 or 50 ml from each preserved sample was settled for 24 h in an Utermöhl-type sedimentation chamber. Algal cells were subsequently examined and counted with a Zeiss inverted microscope at 500× magnification. A minimum of 300 cells were counted along one to six transects across the center of the counting chamber. Unless otherwise indicated, reported cell densities represent the mean water column value calculated from the discrete samples from several depths at each station.

At most stations vertical net-hauls were made with a 35-µm mesh net from 200 m to the surface. However, vertical hauls were only to 60 and 100 m at Stns. 0 and 15, respectively. At Stns. 16–19, samples were collected by placing the net in the surface water during the time on station. Two kinds of permanent Hyrax mounts (with algae rinsed of salt and with algae cleaned of organic matter, Fryxell 1975) were examined with a Reichart phase contrast microscope. Species density was judged to be abundant, moderate, few, or rare.

Results

Difference Between Quantitative and Net-Haul Samples

There are striking differences between the species composition in the quantitative and net-haul samples caused by the size-selectivity (35-µm mesh) of the net. Quantitative samples consist mainly of species with cells <10 µm in size such as *Nitzschia* "nana" (cells of *N. cylindrus* (Grun.) Hasle and *N. pseudonana* (Hasle) Hasle 3–6 µm in length), *Chaetoceros* spp. (single 4–10 µm cells of *C. dichaeta* Ehr., *C. atlanticus* Cl., *C. gracilis* Schütt, and *C. simplex* Ostenfeld), and *Navicula* sp. (5–7 µm). These species are rarely present in the net samples. Although entirely absent from the net collections, the weakly silicified *Dactyliosolen tenuijunctus* (Manguin) Hasle (second in abundance only to *Nitzschia* "nana") and the delicate *N. prolongatoides* Hasle and *N. subcurvata* Hasle are present in high numbers in the bottle samples. Among diatoms >20 µm in size, some species (e.g., *N. kerguelensis* (O'Meara) Hasle and *N. turgiduloides* Hasle) are found frequently in both the quantitative and net samples, while other species are more common either in the bottle samples (*Dactyliosolen antarcticus* Castr., *Leptocylindrus mediterraneus* (H. Perag.) Hasle, *Asteromphalus hyalinus* Karst.) or in the net hauls (*Rhizosolenia alata* Brightw. and its variations, *R. hebetata* f. *semispina* (Hensen) Gran, *Asteromphalus parvulus* Karst., *A. hookeri* Ehr., *Chaetoceros criophilus* Castr., *Thalassiothrix antarctica* (Grun.) Cl.).

Differences in apparent species composition caused by size selectivity of the net are also evident for dinoflagellates. Quantitative samples contain mainly the smallest size cells of *Gymnodinium* spp. (8–20 µm), *Gyrodinium* spp. (15–30 µm), and *Prorocentrum* spp. (6–12 µm). In contrast, the presence of the larger sized cells of *Ceratium* spp. and *Dinophysis* spp. is restricted almost entirely to the net collections. Flagellates and monads (2.5–15 µm) are absent from the rinsed, mounted slides of net-collected phytoplankton.

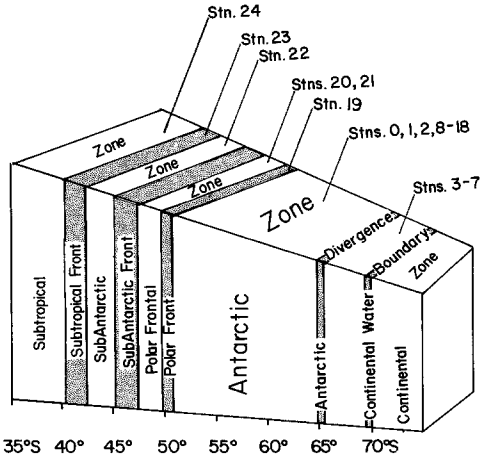

Fig. 2 Schematic representation of the water mass zones and fronts between Africa and Antarctica (diagram after Nowlin and Clifford 1982; data from Lutjeharms and Valentine 1984) and the relative location of the stations occupied during the 1980 *Agulhas* cruise

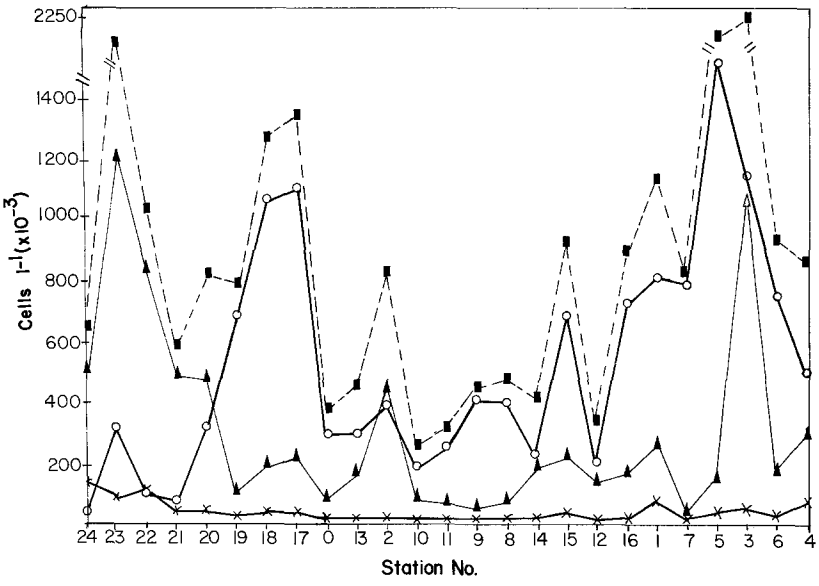

Fig. 3. Mean water column concentrations of the major phytoplankton groups (−■− total phytoplankton; −○− diatoms; −▲− flagellates and monads; −×− dinoflagellates) at stations occupied during the 1980 *Agulhas* cruise. The X-axis does not represent distance, but stations are arranged in order of increasing latitude, with Stn. 24 at 40°S, and Stn. 4 at 69°29′S

Quantitative Results

Latitudinal Distribution of General Taxonomic Groups. The mean abundance of diatoms, dinoflagellates, and monads plus flagellates is given in Table 1 for stations south of the Antarctic Divergence (Stns. 3–7), stations between the Divergence and the Polar Front (Stns. 0, 1, 2, 8–18), and stations at or north of the Polar Front (Stns. 19–24). Diatoms dominate the phytoplankton assemblage south of the Polar Front, contributing an average of 72.5% to the total cell counts (Table 2). Monads and flagellates outnumber diatoms north of the Front, while dinoflagellates are present in low numbers throughout the study area.

The latitudinal distributions of the various phytoplankton groups are shown in Fig. 3. Two diatom peaks are observed: one at Stns. 17 and 18 (60°S and 58°S , respectively), and the other at Stns. 3 and 5 near 67°S. Diatoms are outnumbered by monads and flagellates at all stations north of the Polar Front where counts for this group are upward of 4.50×10^5 cells l^{-1}. The maximum mean water column density (1.21×10^6 cells l^{-1}) of monads and flagellates occurs at Stn. 23 which is located in the region of the Subtropical Convergence. A secondary peak (1.06×10^6 cells l^{-1}) of this group occurs near 67°S (Stn. 3). Excluding Stn. 3, numbers of flagellates and monads at stations south of the Polar Front are comparatively low, ranging between 3.60×10^4 and 4.36×10^5 cells l^{-1}.

Although the quantities of dinoflagellates are low throughout the study area, their mean numbers are significantly greater north of the Polar Front (6.5×10^4

Table 1. Mean densities (cells $l^{-1}\times10^{-3}$) of different phytoplankton groups at stations south of the Antarctic Divergence (Stns. 3–7), between the Polar Front and Antarctic Divergence (Stns. 0, 1, 2, 8–18) and north of the Polar Front (Stns. 19–24)

	Stns. 3–7		Stns. 0, 1, 2, 8–18		Stns. 19–24	
	Mean	SD	Mean	SD	Mean	SD
Diatoms	939[a]	400	489	316	249	244
Dinoflagellates	34	24	17[b]	19	65	44
Monads and flagellates	342	413	161[c]	104	597	379
Total phytoplankton	1315[d]	637	668	377	910	373

[a] Significantly different ($P<0.05$) than means for Stns. 0, 1, 2, 8–18 and Stns. 19–24
[b] Significantly different than mean for Stns. 19–24
[c] Significantly different than mean for Stns. 19–24
[d] Significantly different than mean for Stns. 0, 1, 2, 8–18

Table 2. Percent composition of phytoplankton. Values given for major algal groups are percentages of total phytoplankton, while values for individual diatom species are the percentages of total diatom numbers

Latitude Stations	40–52°S 19–24	58–69°S 0–18
Diatoms	27.4	72.5
Dinoflagellates	7.1	2.6
Monads and flagellates	65.6	24.9
*Dactyliosolen tenuijunctus**	7.5	21.5
Nitzschia "nana"*	18.0	27.8
N. kerguelensis	6.6	8.0
Fragilariopsis group (unidentified)	3.8	7.7
*N. prolongatoides**	0.5	2.5
Chaetoceros spp.*	6.0	8.4
Navicula sp.* (5–7 μm single cells)	2.3	2.9
Dominant diatoms (marked with*) absent from net collections	34.3	63.1

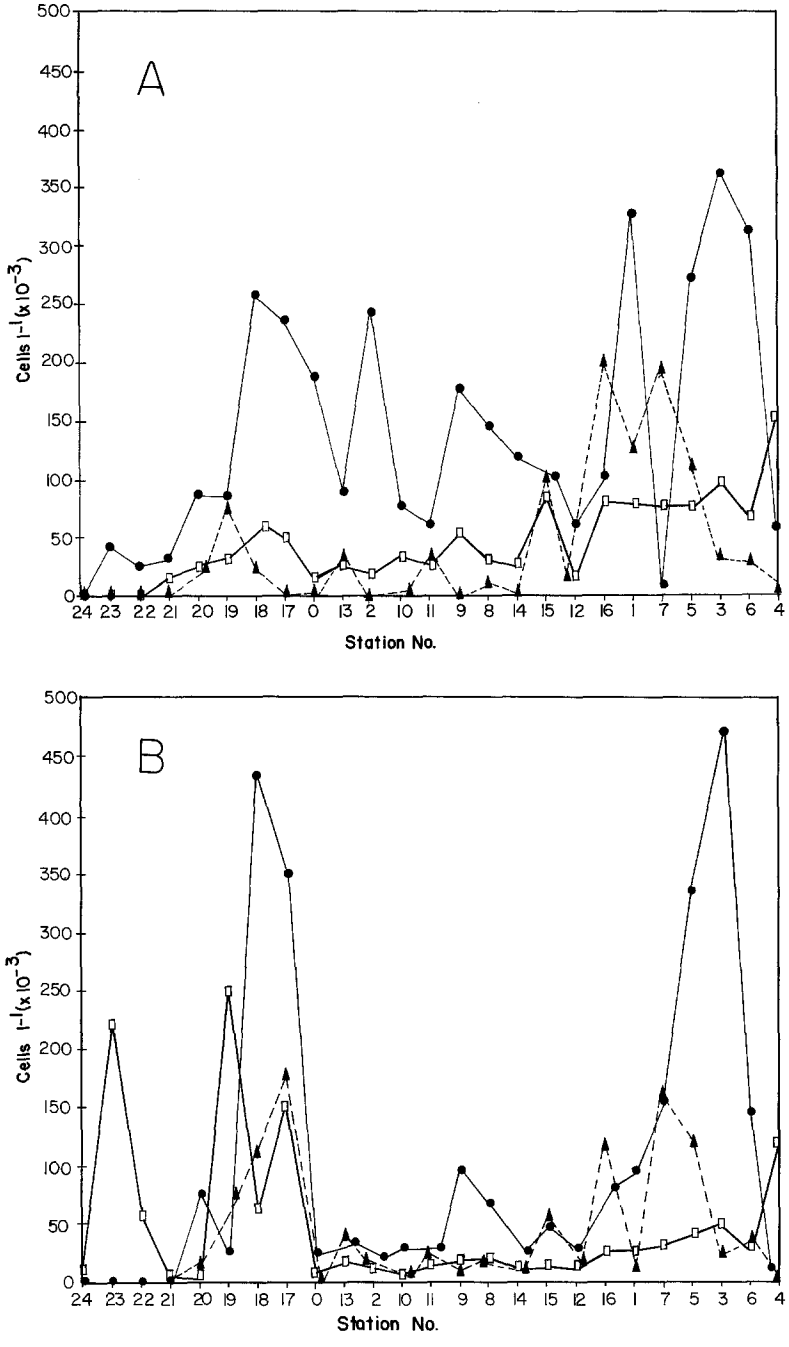

Fig. 4 A, B. Mean water column concentrations of the dominant diatoms at stations occupied during the 1980 *Agulhas* cruise. **A** –●– *Nitzschia* "nana"; –▲– *Nitzschia kerguelensis;* –□– all Fragilariopsis species excluding *N.* "nana" and *N. kerguelensis.* **B** –●– *Dactyliosolen tenuijunctus;* –▲– tiny single-celled *Chaetoceros* spp.; –□– *Pseudonitzschia* species

cells l^{-1}) than in waters between the Polar Front and the Antarctic Divergence (1.7×10^4 cells l^{-1}) (Table 1). Dinoflagellates make up 7.1% and 2.6% of the total phytoplankton counts at stations north (19–24) and south (0–18) of the Polar Front, respectively (Table 2). At Stns. 22 and 24, north of the Polar Front, numbers of dinoflagellates exceed those of the diatoms.

Latitudinal Distribution of Individual Species. The latitudinal distributions of the dominant diatoms are shown in Fig. 4. Abundant species of diatoms belong chiefly to the genera *Nitzschia* (groups *Fragilariopsis* and *Pseudonitzschia*), *Dactyliosolen, Chaetoceros,* and *Thalassiosira.* The most generally abundant diatom within the study area is *Nitzschia* "nana" (cells of both *N. cylindrus* and *N. pseudonana* 3–6 µm in length). *N.* "nana" dominates at most of the stations south of the Polar Front (Fig. 4a), where it contributes 26% to the total number of diatoms (Table 2) and displays peak abundances at Stn. 1 (3.28×10^5 cells l^{-1}) and Stn. 3 (3.63×10^5 cells l^{-1}). Other species from the *Fragilariopsis* group (especially *N. kerguelensis* and *N. curta* (Van Heurck) Hasle) are often third or fourth in abundance among dominant diatoms south of the Polar Front.

Species from the *Pseudonitzschia* group are generally most abundant among diatoms north of the Polar Front

(Fig. 4b). They predominate at Stn. 23 (region of the Subtropical Front) and at Stn. 19 (vicinity of the Polar Front) where they are represented mainly by *N. turgiduloides, N. lineola* Cl., *N. heimii* Manguin, and *N. fraudulenta* Cl. South of the Polar Front, *Pseudonitzschia* species are only abundant at Stn. 17 (60 °S) and Stn. 4 (69 °S). At the latter station, a maximum of 1.42×10^5 cells l^{-1} is recorded at 11 m for the species *N. Prolongatoides.*

Dactyliosolen tenuijunctus is the dominant species at Stns. 3 and 18 where it attains the highest depth-discrete densities recorded for any single species (6.0×10^5 and 7.3×10^5 cells l^{-1}, respectively) during this study. This widespread and generally abundant species contributes 21.5% to the total estimated number of diatoms south of the Polar Front (Table 2).

Cells of small (<10 µm) *Chaetoceros* spp., which are absent north of 50 °S, display peak abundances of 1.76×10^5 and 1.60×10^5 cells l^{-1} at 60 °S and 66 °S (Stns. 17 and 7), respectively. Among *Chaetoceros* species >10 µm in size, *C. atlanticus* contributes substantially to the total cell counts only in the far south (Stns. 4–7), particularly at Stn. 5 (maximum of 4.72×10^5 cells l^{-1} at 4 m). Between 44 °S (Stn. 22) and 65 °S (Stn.1), densities for this species are usually $<2.0\times10^4$ cells l^{-1}. The species *C. dichaeta* is found infrequently and in small quantities in waters between the Polar Front and the Antarctic Divergence. However, like *C. atlanticus*, it also occurs in greater numbers at Stns. 4–7, with average cell counts ranging from $7-33\times10^3$ cells l^{-1}.

The various species of *Thalassiosira* occur in highest abundance ($2.5-7.8\times10^4$ cells l^{-1}) at stations located between 63 °23′–69 °29′S. Somewhat lower quantities are found between 50 °–60 °S at Stns. 17–20, with even lower counts ($<7.0\times10^3$ cells l^{-1}) at all the remaining northern stations. *Thalassiosira gracilis* v. *expecta* G. Fryxell et Hasle is the dominant species of this genus and attains an average water column maximum of 3.9×10^4 cells l^{-1} at Stn. 5.

Among the most abundant dinoflagellate species, the unidentified cells of *Gymnodinium* (8–20 µm long cells) display a density of 1.2×10^4 cells l^{-1} at Stns. 20–24 north of the Polar Front, with a maximum of 4.8×10^4 cells l^{-1} at Stn. 22. *Prorocentrum* spp. (6–12 µm wide cells) are present in moderate numbers at most stations, with peaks in abundance at Stn. 1 (5.9×10^4 cells l^{-1}) and Stn. 4 (3.0×10^4 cells l^{-1}).

Vertical Distribution of Phytoplankton. Although there is some vertical structure to phytoplankton density at individual stations, comparison (Waller-Duncan K-ratio *t*-test, Ray 1982) of mean cell numbers for discrete depth or light levels within individual water mass zones, reveals no significant differences.

Net-Haul Results

Several of the larger (i.e., >20 µm) diatom species which are abundant in the quantitative samples (e.g., the genera *Nitzschia* and *Rhizosolenia*) have the highest relative abundance in the net collections. Species of the *Pseudonitzschia* group (except for *N. prolongatoides* which is not retained by the net) make up a significant portion of the net phytoplankton in Antarctic waters at Stns. 4, 5, 7, 13, and 15, and at or north of the Polar Front at Stns. 19, 22 and 23. Within the *Fragilariopsis* group, *N. kerguelensis* is common north of the Polar Front, and is one of the dominant net diatoms at many of the stations south of 63 °S. *N. curta, N. cylindrus,* and *N. angulata* Hasle are very abundant at the southernmost Stns. 4 and 6.

Of the 11 species of *Rhizosolenia* identified in this study, *R. alata* (mainly the forms *inermis* (Castr.) Hust. and *indica* (Perag.) Hust.) is the most common in net collections from the northern stations, and is often among the dominant net diatoms between 62 ° and 67 °S. *R. hebetata* f. *semispina* and *R. styliformis* Brightw. are also abundant south of 62 °S. *R. curvata* Zacharias is the prevalent net diatom at Stn. 21, located in the Polar Frontal Zone.

As with the quantitative samples, the larger species of *Chaetoceros* are never abundant in the net samples. *C. atlanticus* and *C. criophilus* are the most commonly found species of this genus, both north and south of the Polar Front. *C. dichaeta* is only observed south of the Front.

Other diatom species which are common in the net samples include *Thalassiosira gracilis* v. *expecta, Porosira pseudodenticulata* (Hust.) Zhuse and *Thalassiothrix longissima* Cl. et Grun.. *Thalassionema nitzschioides* (Grun.) Hust., together with the warm water species *Pseudoeunotia doliolus* (Wall.) Grun. and *Nitzschia braarudii* Hasle are observed in samples taken at or north of 44 °S.

Dinoflagellates are common in the net samples from north of the Polar Front. The more abundant species include *Ceratium azoricum* Cl., *C. fusus* (Ehr.) Dujardin, *C. lineatum* (Rhr.) Cl., *C. pentagonum* f. *grande* Mangin, *Dinophysis tuberculata* Mangin, *D. truncata* Cl., and *Protoperidinium adeliense* (Balech) Balech. Only on rare occasions are dinoflagellates present in net samples taken within the Antarctic Zone.

Biogeographical Distribution of Species

The combined results from the net-haul and quantitative samples enable generalizations about the geographical distribution patterns of individual phytoplankton species (Table 3). It is seen that the Polar Front forms an effective barrier to the latitudinal distribution of many species, while other species are found both north and south of this physical feature.

Discussion

Previous quantitative phytoplankton studies in the Indian Ocean between Africa and Antarctica (Fukase 1962;

Table 3. Summary of the distribution patterns of selected species of phytoplankton sampled during the 1980 *SA Agulhas* cruise

Species found both north and south of the Polar Front	Species which occurred only north of the Polar Front
Asteromphalus hyalinus	*Rhizosolenia curvata*
A. hookeri	*Nitzschia bicapitata*
A. parvulus	*N. braarudii*
Chaetoceros atlanticus	*N. sicula*
C. bulbosus	*N. subpacifica*
C. criophilus	*Pleurosigma directum*
C. neglectus	*Pseudoeunotia doliolus*
Chaetoceros spp. (single cells)	*Thalassionema nitzschioides*
Corethron criophilum	*Ceratium azoricum*
Dactyliosolen antarcticus	*C. fusus*
D. tenuijunctus	*C. lineatum*
Porosira pseudodenticulata	*C. pentagonum* f. *grande*
Rhizosolenia alata	*Oxytoxum scolopax*
R. alata f. *gracillima*	*O. variabile*
R. alata f. *indica*	*Podolampas spinifera*
R. alata f. *inermis*	*Dictyocha fibula*
R. hebetata f. *semispina*	
Schimperiella oliverana	Species found only south of the Polar Front
Thalassiosira frenguelli	
T. gracilis	*Chaetoceros atlanticus* v. *skeleton*
T. gracilis v. *expecta*	*C. dichaeta*
T. lentiginosa	*C. flexuosus*
T. tumida	*Charcotia actinochilus*
Navicula sp. (5–7 µm single cells)	*Eucampia antarctica*
Nitzschia angulata	*Rhizosolenia bidens*
N. curta	*R. styliformis*
N. cylindrus	*Nitzschia longissima*
N. kerguelensis	*N. sublineata*
N. pseudonana	*Synedra reinboldii*
N. "nana"	
Nitzschia spp. (*Fragilariopsis* gr.)	
N. heimii	
N. fraudulenta	
N. lineola	
N. prolongatoides	
N. pungens	
N. subcurvata	
N. turgidula	
N. turgiduloides	
Thalassiothrix longissima	
T. antarctica	
Distephanus speculum	

Kozlova 1964; Steyaert 1973a) have found two or three peaks of diatoms, usually one north of the Polar Front and one or two peaks south of the Front. North of the Polar Front, diatom peaks have been typically noted during December or early January in the Indian (Fukase 1962; Steyaert 1973a), Atlantic (Hart 1934) and Pacific (Cassie 1963; Hasle 1969) sectors. In the Antarctic Zone, as summer conditions progress southward, diatom maxima are found at increasingly southerly latitudes in both the Indian (Kozlova 1964, 1970; Zernova 1970; Steyaert 1973a, b; Jacques et al. 1979) and Pacific (Hasle 1956, 1969) sectors. These data corroborate earlier observations by Hart (1942) based on the distribution of plant pigments. Thus, the high concentrations of diatoms noted for the southernmost group of stations from the present study probably represent the late summer stage of a still prolific phytoplankton community.

The mean diatom concentration for the southernmost stations (9.39×10^5 cells l^{-1}) is significantly greater than for Antarctic Zone stations (Table 1). Diatom counts for these southerly stations are of the same order of magnitude as the maximum cell numbers reported by Kozlova (1970) for suface coastal waters of the Indian Ocean Sector during spring and summer and the average number reported by Steyaert (1973b) for the inshore waters of Breid Bay in January 1965.

Maximum diatom counts at discrete depths (1.6×10^6 to 1.9×10^6 cells l^{-1} at Stns. 3, 5, 17, and 18) are somewhat greater than the highest numbers previously reported from the Indian Sector by Steyaert (1973b), but are lower than the maximum reported by Hasle (1969) for the southern region of the southeastern Pacific Sector of the Southern Ocean.

The average number of diatoms (4.89×10^5 l^{-1}) found in the Antarctic Zone (excluding southernmost Stns. 3–7) is similar to the highest count reported by Kozlova (1964) for the open waters between the Antarctic Divergence and the Polar Front, and to the average cell number reported for a grid of suface samples from 100–120°E (Kawamura and Ichikawa 1984). Steyaert (1973a, 1974) reports slightly lower diatom numbers along the 20°E meridian for the summers of 1965 and 1967.

In the present study, lowest diatom concentrations (2.3×10^4 to 3.1×10^5 cells l^{-1}) are noted north of the Polar Front. These densities are greater than the concentrations given by Kozlova (1964, 1970), but are similar to those reported by Steyaert (1973a) for the same region. The present results are also similar to the concentrations reported for waters north of the Polar Front in the Eastern Pacific (Hasle 1969).

Stn. 19, located in the vicinity of the Polar Front, has high diatom numbers (max. 9.9×10^5 cells l^{-1} at 70 m). Somewhat lower numbers have been reported for the vicinity of the Front in the same general area (Steyaert 1973a), as well as for the Pacific (Hasle 1969). However, at one station near the Front (Stn. 17), Hasle (1969) found a concentration comparable to the one reported here. Jacques et al. (1979) noted particularly impoverished phytoplankton assemblages at the edges of both the Subtropical and Polar Fronts west of the Kerguelen Islands in late summer. However, they observed generally low algal numbers between the latitudes 43° and 62°S.

We are not aware of other quantitative estimates of flagellates and monads published for the Indian Ocean Sector. High concentrations of flagellates and monads have been reported for waters in the Continental Zone of the Eastern Pacific (Hasle 1969) as well as at the entrance to the Bransfield Strait (Hasle 1969) and in Admiralty Bay, King George Island (Kopczynska 1981).

Dinoflagellate numbers in the Eastern Pacific (Hasle 1969) are of equal magnitude with those found during

this study. Although Hasle observed greater concentrations in the Subantarctic than in the Antarctic Zone, differences were minimal. Jacques et al. (1979) report that, off the Kerguelen Islands, dinoflagellates make up an important fraction of the nanoplankton north of the Polar Front but decrease in abundance to the south.

There is a relatively uniform distribution of phytoplankton cells within the euphotic zone, most probably resulting from wind-induced vertical mixing of the upper water column. Such mixing is also expressed in the near-uniform distributions of salinity, temperature, and nutrient values found at most stations. At the few individual stations where phytoplankton maxima occur, the upper water column exhibited positive stability. Steyaert (1973a) notes a uniform vertical distribution of diatom cells at a station with neutral stability located near the Polar Front. In contrast, Hart (1942); Hasle (1969) and Steyaert (1973b) report diatom maxima in the upper 20 m of the water column, and phytoplankton maxima have been noted from the bottom of the euphotic zone for both oceanic (El-Sayed 1978) and inshore (Kopczynska 1980) waters of the Antarctic.

The generally most abundant diatoms in the *Agulhas* samples are, in many cases, the same species found to be dominant in ealier works from both the Indian (Kozlova 1964; Steyaert 1973a; Kawamura and Ichikawa 1984) and Eastern Pacific (Hasle 1969) Sectors. The feature common to both the present study and most previous investigations is the predominance among diatoms of the *Pseudonitzschia* species north of the Polar Front and the *Fragilariopsis* species in coastal waters and in the southern Antarctic Zone. Thus, Steyaert (1973a) found *Nitzschia* "barkleyi" (*N. lineola* and *N. turgiduloides* in our samples) and *N. heimii* predominant in the Subantarctic sector of the Indian Ocean, while Hasle (1969) reports great abundance of *N.* "barkleyi" from the Subantarctic East Pacific. In the coastal waters off Princess Ragnhild and Enderby Land, the *Fragilariopsis* species *N. curta, N. rhombica* (O'Meara) Hust. and *N. ritscheri* (Hust.) Hasle constituted 67% of the phytoplankton (Kozlova 1964), while Steyaert's (1973b) coastal samples from Breid Bay contained mainly *N. curta, N.* "nana" and *Pseudonitzschia* species. The southern Antarctic zone of the east Pacific (Hasle 1969) was dominated by *N. cylindrus, N. curta* and *N. subcurvata.* Between 100–120°E in the Indian sector, *N.* "nana", followed by *N. rhombica, N. kerguelensis, N.* "closterioides" (*N. prolongatoides* and *N. subcurvata), N. pungens* Grun., *N. curta* and *Dactyliosolen* spp. were the most abundant species (Kawamura and Ichikawa 1984). For the Antarctic Zone south of Africa, Steyaert (1973a) reports, in roughly decreasing order of abundance, the prevalence of *Chaetoceros atlanticus, Pseudonitzschia* species, *C. dichaeta, C. neglectus* Karst., *N. kerguelensis, N. curta, N.* "nana", and *N.* "closterioides". Likewise, Hasle (1969) found *C. dicheata, C. neglectus, N.* "closterioides", and *N.* "nana" to be the most abundant species in her Pacific samples from the northern Antarctic Zone.

As stated earlier, the present samples obtained south of the Polar Front were dominated by either *N.* "nana" or *Dactyliosolen tenuijunctus.* Single cells of *Chaetoceros* spp. (mostly *C. atlanticus* and *C. dichaeta*) or species of *Fragilariopsis* were usually next in abundance, followed by *Pseudonitzschia* species.

Dactyliosolen tenuijunctus, which is so prevalent in the *Agulhas* samples, has seldom been reported in the Indian Ocean Sector. Kawamura and Ichikawa (1984) found this species to be abundant, and it was noted in the qualitative study of Sournia et al. (1979).

In regard to the net phytoplankton, the several most abundant species in the *Agulhas* samples are often different from those noted by Steyaert (1973a) for the same general area, but earlier in the season. In her study, like in ours, *Pseudonitzschia* species dominated the phytoplankton north of the Polar Front; however, contrary to what we found, *Chaetoceros atlanticus, C. dichaeta,* and to a lesser extent, *N. kerguelensis* were the most abundant species in the Antarctic Zone; and *Corethron criophilum* Castr. predominated at the southernmost coastal stations. The absence of any significant numbers of *Corethron criophilum* during the present study, while in agreement with the quantitative results of Kozlova (1964), is in contrast to this species' reported dominance not only in the coastal waters of the Indian Ocean Sector during early summer (Steyaert 1973a), but also to its dominance in net samples from the Antarctic coastal waters of the Pacific (Cassie 1963) and the Bransfield Strait (Hart 1934, 1942; Hendey 1937; Kopczynska 1980, 1981; Kopczynska and Ligowski 1982). The net phytoplankton species observed to be most abundant at the northern Antarctic stations of the present study are much the same as the dominant species (*N. kerguelensis, Rhizosolenia* spp., and *Thalassiosira* spp.) reported for waters south of the Kerguelen Islands during late summer (Jacques et al. 1979). Cassie (1963) reports that in waters north of the Polar Front in the Pacific Sector south of New Zealand, *N. antarctica* (equals *N. kerguelensis*), *Rhizosolenia* spp., *Chaetoceros* spp., and *N. seriata* Cleve (of the *Pseudonitzschia* group) dominate the net phytoplankton. This assemblage also compares well with the species found to dominate the northern *Agulhas* stations. The results of these several studies show that when comparing the composition of net phytoplankton catches, one must consider differences in both the biological season and the characteristics/location of the water masses sampled.

Striking differences are found in the species compositions of the quantitative and net samples. Many of the diatoms which dominate the quantitative samples are < 10 µm in size. These diatoms, together with the weakly silicified *Dactyliosolen tenuijunctus,* the nanoplanktonic dinoflagellates of the genera *Gyrodinium* and *Gymnodinium*, and flagellates and monads, are either absent from the net collections, or are encountered infrequently as solitary cells. It is interesting to note that for waters south of the Polar Front, 63% of all diatoms in the quantitative samples are species which are absent from the net

hauls (Table 2). With an additional 25% of the total quantitative counts consisting of small flagellates and monads, it is apparent that the nanoplankton completely dominate this Antarctic phytoplankton community. For stations north of the Polar Front, diatom species not retained by the 35-μm net account for a much smaller portion of total diatoms. However, monads and flagellates contribute 66% to the total cell counts from these stations, so that here again, the nanoplankton are numerically dominant. Consistent with the numerical dominance of the nanoplankton, an average of 60 and 85% of the phytoplankton chlorophyll *a* was in the <20-μm size fraction for waters south and north of the Polar Front, respectively (Weber and El-Sayed 1985).

We found that different diatom assemblages characterize the waters of the Indian Ocean Sector north and south of the Polar Front and south of the Antarctic Divergence. The distribution of individual species appears, in some cases, to be limited by the Polar Front, while other species are found both north and south of this boundary. Several of the species encountered exclusively north of the Polar Front (*N. bicapitata* Cl., *N. braarudii, N. sicula* (Castr.) Hust., and *Pseudoeunotia doliolus,* Table 3) are characteristic of the Agulhas Current area (Taylor 1967) and may have been introduced by this current. In the Pacific sector, the warm water species *N. braarudii, N. subpacifica* Hasle, *Ceratium fusus,* and *Dictyocha fibula* Ehr. are restricted to the northern part of the Subantarctic Zone, while *N. bicapitata, N. turgidula* Hust., *Thalassionema nitzschioides* (Grun.) Hust., and *Ceratium pentagonum* are distributed continuously between the Polar and Subtropical Fronts (Hasle 1969, 1976). In the *Agulhas* samples, *N. turgidula* is present at Stns. 19, 21, 22, and 23 north of the Polar Front, but also, in small quantities, at Stns. 5 and 7 to the far south. Kozlova (1964), in fact, only observed this species south of the Polar Front. *Rhizosolenia curvata,* the dominant net diatom at Stn. 21 (Polar Frontal Zone), is regarded by Hasle (1969) as endemic to the Subantarctic. Hasle and others (Hart 1937; Beklemishev 1960; Fukase 1962; Fukase and El-Sayed 1965) found this species to be present only in the colder waters immediately north of the Polar Front. The large dinoflagellates *Ceratium lineatum* and *C. pentagonum,* although occasionally found in Antarctic waters (Balech 1968; Okamoto and Takahashi 1984), are usually confined to waters near or north of the Polar Front (Balech 1970). In the present study, these species are present only north of the Polar Front at Stns. 21–23, and Stns. 20 and 21, respectively.

The widespread distribution of most of the species occurring both north and south of the Polar Front (Table 3) has been previously noted in both the Pacific (Hasle 1965 a, b, 1968, 1969, 1976) and Indian Ocean (Kozlova 1964; Steyaert 1974; Jacques et al. 1979; Sournia et al. 1979) Sectors. A few of the species (*Porosira pseudodenticulata, T. gracilis* (Karst.) Hust., *N. curta,* and *N. kerguelensis*) reportedly occur only in the Southern Hemisphere (Hasle 1976). *N. curta,* thought to be indigenous to the Antarctic Zone (Hasle 1965b), is present in small numbers at Stns. 20 and 21 north of the Polar Front. The observed distribution of *N. kerguelensis* substantiates laboratory studies in which this species failed to grow at temperatures above 5 °C (Jacques 1983). *N. kerguelensis* is numerous at Stn. 20 (surface temperature of 3.7 °C), present only in the net sample from Stn. 21 (surface temperature of 6 °C), and detected only as a single specimen in the quantitative sample from Stn. 22.

Several of the species (*Chaetoceros flexuosus* Mangin, *Charcotia actinochilus* (Ehr.) Hust., and *Nitzschia sublineata* Hasle) which were found only to the south of the Polar Front (Table 3) have been previously reported to be likewise restricted by this physical boundary in both the Pacific (Hasle 1968, 1969) and Indian Ocean (Sournia et al. 1979) Sectors. Although *Synedra reinboldii* Van Heurck has been noted north of the Polar Front by Sournia et al. (1979), it was found only south of the Front during the *Agulhas* cruise, as well as in the samples of Hasle (1968, 1969); Kozlova (1964); Hart (1934, 1937, 1942) and Jacques et al. (1979). The presence of *Chaetoceros dichaeta* and *Eucampia antarctica* (Castr.) Mangin has been reported both north and south of the Polar Front in the Eastern Pacific (Hasle 1969). However, as in the present study, previous works in the Indian Ocean (Kozlova 1964; Steyaert 1974; Jacques et al. 1979) have found *C. dichaeta* to be absent north of the Polar Front.

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