ENVIRONMENTAL SCIENCES Vol. 2, No. 1, 21~28
Bulletin of the Korean Environmental Sciences Society

Integrated Phytoplankton Data of the west Pacific Sector of the Southern Ocean: 140-148 °E transect

Hak Young Lee, In Sook Cho, Richard M. Greene* and Jong Won Kim

Department of Biology, Pusan National University, Pusan 609-735, Korea
**Department of Oceanography, Texas A&M University, College Station, TX77843*

(Manuscript received on 4 April, 1998)

A total of 94 taxa were identified from the Southern Ocean, 140-148 °E and 40-53 °S, as an early austral summer phytoplankton. They were 53 diatoms, 37 dinoflagellates, 2 silicoflagellates, 1 prymnesiophyte, and 1 coccolithophorid. Integrated cell numbers of nanoplankton dominated microphytoplankton from 8 stations, especially from Subantarctic zone, but integrated biomass was lower than microphytoplankton. Integrated cell numbers of diatoms dominated dinoflagellates, coccolithophorids, and prymnesiophyte, but integrated biomass of microphytoplankton were dependent to the biomass of dinoflagellates except north of the Subtropical convergence zone and south of the Antractic convergence zone. Phytoplankton community changed across the fronts and 3 different communities were observed. Fronts seem to influence on the phytoplankton community from the west Pacific Sector of the Southern Ocean.

Key words : Southern Ocean, fronts, phytoplankton, integrated cell number and biomass.

1. Introduction

The Southern Ocean has unique physical and chemical characteristics; that is, the circumpolar zonations divide the Southern Ocean into several different environments (El-Sayed, 1988a; El-Sayed, 1993; Knox, 1994). This circumpolarity influences the distribution, abundance, productivity and behavior of the Southern Ocean marine organisms (Knox, 1994; Stein, 1994). The phytoplankton species composition, abundance, biomass, and productivity also change across these circumpolar fronts (El-Sayed, 1988a; Yamamoto, 1986; Froneman, 1995).

The distribution, productivity and ecology of the phytoplankton of the Southern Ocean have been studied extensively since the establishment of Scientific Committee on Antarctic Research (SCAR) in 1957 (El-Sayed, 1988a; b; 1990; Knox, 1970; 1994; Hosaka and Nemoto, 1986; Jacques and Fukuchi, 1994; Sakshaug and Holm-Hansen, 1984). Technological achievements and several Antarctic research programs also have made great progress on the phytoplankton ecosystem of the Southern Ocean (El-Sayed, 1993). However, many ecological environments have been changed since the 1980s, and the data of the phytoplankton distribution pattern across the frontal system is sparse (El-Sayed, 1993; Knox, 1994). Therefore, analysis of the phytoplankton community of the Southern Ocean is needed to assay the effect of recent environmental changes.

The current study was undertaken to identify the integrated phytoplankton biomass in the west Pacific Sector of the Southern Ocean during early austral summer of 1995/6.

2. Materials and Methods

Samples for this study were collected on board the *Southern Surveyor* from Nov. 16 1995 to Dec. 8 1995, early austral summer. The station locations are shown in Table 1. Stations CG-P1 (CG1), ES-P1 (ES1), Trans-P1 (TP1), Trans-T1 (TT1), Trans-T2 (TT2), and Trans-P2 (TP2) are located in the historical position of the Subtropical Zone. Stations Trans-T3 (TT3), Trans-P3 (TP3), Trans-T6 (TT6), Trans-P4 (TP4), and Trans-T8 (TT8) are located in the historical position of the Subantarctic zone. Station Trans-P5 (TP5) is located in the historical position of the north part of the Polar Frontal zone. Subtropical front supposed to run between TP2 and TT3, and Subantarctic front between TT8 and TP5 (Nowlin, 1986). Water samples were collected at discrete depths (0, 20, 40, 60, and 80 m) within the upper 80 m of the water column. Subsamples of 1 liter were fixed with 1% glutaldehyde and a glass coverslip was added to each subsample to avoid silica dissolution. Each 1 liter water sample was settled for at least 2 days and approximately 900 ml of upper layer were carefully removed with a small tube. The remnant was settled in a 50 ml settling chamber for 24 h and examined under an inverted microscope (Zeiss ICM 405) under ×400 magnification with phase contrast illumination. All phytoplankton larger than 2 μm (i.e., nanoplankton; 2-20 μm, and microphytoplankton; > 20 μm) were counted and sized, and species identifications were made for microphytoplankton. A minimum of 500 cells was counted for each sample to obtain more that 95% probability of encountings, a taxon present at an 1% level (Shaw, 1964). Finally, the entire bottom of the settling chamber was scanned at low magnifications (×100 and ×200) to enumerate the larger and less frequent phytoplankton. Biomass (cell carbon) was calculated using formula of Smayda (1978) for diatoms and Verity et al. (1992) for non-diatom phytoplankton. Cell number and biomass of each station were integrated through the sampled depths.

3. Results and Discussion

3.1. Phytoplankton species composition

During the early austral summer of 1995/6, a total of 94 phytoplankton species and groups were encountered: 53 taxa of diatoms, 37 dinoflagellates,

Table 1. The sampling stations and date.

Station	Date (GMT)	Time (GMT)	Latitude	Longitude
CG-P1	18 Nov. 1995	01:15	-40 45.09	+143 25.93
ES-P1	19 Nov. 1995	04:19	-41 23.03	+142 07.59
Trans-P1	20 Nov. 1995	01:12	-41 59.27	+139 56.49
Trans-T1	21 Nov. 1995	05:56	-43 00.03	+140 53.82
Trans-T2	21 Nov. 1995	15:44	-43 59.54	+141 49.66
Trans-P2	22 Nov. 1995	08:08	-44 58.87	+143 43.72
Trans-T3	23 Nov. 1995	19:44	-45 59.87	+143 37.65
Trans-P3	24 Nov. 1995	23:06	-47 58.97	+145 31.90
Trans-T6	26 Nov. 1995	03:04	-49 02.27	+145 24.31
Trans-P4	30 Nov. 1995	16:39	-49 57.88	+145 45.88
Trans-T8	28 Nov. 1995	13:46	-52 25.18	+147 27.80
Trans-T5	27 Nov. 1995	10:15	-53 12.96	+145 28.53

+ East, - South

2 silicoflagellates, 1 prymnesiophyte, and 1 coccolithophorid. The species richness of the phytoplankton in this region was low compared to over 100 species of diatoms, some 60 species of dinoflagellates, and a few species of other algal species of microphytoplankton flora of Antarctic waters (Heywood, 1984; Knox, 1994).

The species composition of microphytoplankton was not uniform throughout the stations. Only 18 species (12 diatoms, 5 dinoflagellates, and 1 silicoflagellate) were observed from all the stations and 26 species (17 diatoms, 8 dinoflagellates, and 1 silicoflagellates) were observed more than 8 sampled stations. Diatoms such as *Chaetoceros* spp., *Corethron criophilum*, *Nitzschia* spp., *Pseudonitzschia* spp. *Thalassiosira gravida*, and dinoflagellates such as *Exuviella* spp., *Gymnodinium* spp., *Oxytoxum variable*, and *Protoperidinium antarcticum* were recovered in abundance from all the stations. The dominance of these species appears to be typical of many regions of the Southern Ocean (Heywood, 1984; El-Sayed, 1993) although other species may dominate under certain conditions (Knox, 1994). These dominant chainforming diatoms seem to have benefits of protection against small grazers and minimizing sinking (El-Sayed, 1993).

The most diverse phytoplankton species was identified from station TT2 with 57 species (42 diatoms, 13 dinoflagellates, 1 silicoflagellates, and 1 prymnesiophyte), and the least from station TT3 with 48 species (30 diatoms, 14 dinoflagellates, 2 silicoflagellates, 1 prymnesiophyte, and 1 coccolithophorid). Species number of diatoms ranged from 30 species (station TT3) to 42 species (station TT2), and dinoflagellates from 16 species (stations TP3 and TT6) to 9 species (station TT8). Total species number of subtropical and subantarctic zones were nearly the same. Only species number of diatoms decreased slightly in the subantarctic zone while dinoflagellates decreased slightly in the subtropical zone. In the subtropical zone, 50 diatoms, 28 dinoflagellates, 2 silicoflagellates and 1 prymnesiophyte were observed, whereas in the subantarctic zone 48 diatoms, 32 dinoflagellates, 2 silicoflagellates and 1 prymnesiophyte were observed.

Species composition changed across all fronts. Phytoplankton species such as *Azpeitia africanus* and *Planktoniella sol* were only found from subtropical zone and *Chaetoceros bulbosus* and *Eucampia antarctica* were only found in the subantarctic zone. The Southern Ocean is known to have higher (80-85%) endemism of the phytoplankton than any other oceanic region (Knox, 1994) and we found several endemic species of Antarctic water (Heywood, 1984). However, *Ceratium* which is known to be absent south of the Antarctic convergence zone (Hasle, 1976; Kopczynska, 1986; Knox, 1994) was observed in all stations (*Ceratium lineatum*) including TP5, which is supposed to lie south of the Antarctic convergence zone.

3.2. Cell numbers of phytoplankton

The highest integrated cell numbers of phytoplankton were observed from CG1 (3.4×10^{10} cells/m^2), followed by TT6 and TT8 ($> 2.5\times10^{10}$ cells/m^2); the lowest were observed TT3 ($< 1.0\times 10^{10}$ cells/m^2) (Fig. 1). Stations CG1and ES1, which were adjacent to Australia and Tasmania Island, showed high integrated cell numbers both nanophytoplankton and microphytoplankton. Localized high productivity and biomass are common in the vicinity of oceanic islands (Grindley, 1985; Le Jehan, 1985; Perissinotto, 1992), in the presence of dissolved iron (Martin, 1990; Martin, 1990), input of nutrients from depth as a result of turbulence around the island (Simpson, 1982), and turbulence-indunced variations of light regime (El-Sayed, 1993). Though the continents seem to

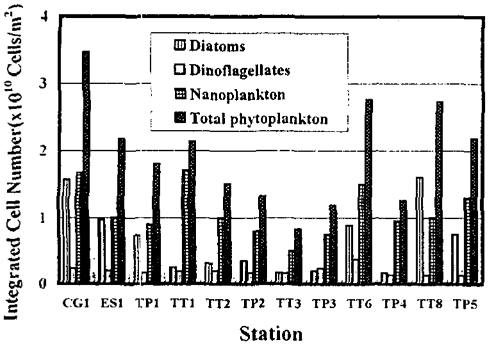

Fig. 1. Integrated cell numbers of each phytoplankton group from west Pacific Sector of the Southern Ocean.

influence the phytoplankton distribution of our sampled stations, no contiments originated freshwater phytoplankton was observed.

Integrated diatom cell numbers varied from station to station. High abundance of diatoms at CG1, ES1, TT6 and TT8 resulted in peaks of total integrated phytoplankton cell numbers. Integrated cell numbers of diatoms were more than three times higher from CG1, ES1, TT6 and TT8 than from TT1 to TP3, while dinoflagellates and other microphytoplankton remained nearly the same throughout all stations. At all stations, nanophytoplankton were the major contributer to the total integrated cell numbers. In TT1, nanophytoplankton accounted for 75% of the total integrated cell number of phytoplankton. Major peaks in integrated nanophytoplankton cell numbers were recorded from CG1, TT1 and TT6; these peaks led to the major peaks of total integrated phytoplankton cell numbers. The integrated microphytoplankton cell number was highest at stations CG1 and TT8 with 1.9×10^{10} cells/m^2 which exceeded integrated the cell number of nanophytoplankton. Diatoms were the most important component of the microphytoplankton and accounted for 44.2-93.5% of integrated cell numbers of microphytoplankton and 13.5-66.2% of total integrated phytoplankton cell numbers. The dominance of diatoms over dinoflagellates from our stations seems to have resulted from the lack of krill grazing (Kopczynska, 1992). Less than five diatom species or groups of species accounted for more than 80% of total integrated cell numbers of all the diatoms identified (Fig. 2). Only 12 species of diatoms composed more than 95% of total integrated diatom cell numbers. Species of the genera *Pseudonitzschia*, *Chaetoceros*, and *Thalassiosira gravida* were abundant elements of the diatom flora.

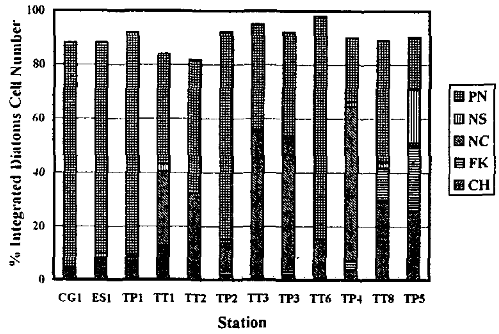

Fig. 2. Percent integrated cell numbers of diatoms from west Pacific Sector of the Southern Ocean.
PN, *Pseudonitzschia* spp.; NS, *Nitzschia* spp.; NC, *Nitzschia closterium*; FK, *Fragillariopsis kergulensis*; CH, *Chaetoceros* spp.

Dinoflagellates occurred less frequently than diatoms. They never exceeded 20% of total integrated cell numbers of phytoplankton (Fig. 1). However, dinoflagellates accounted for approximately 50% of integrated microphytoplankton cell numbers at TT1, TT3, TP3 and TP4. Three species of dinoflagellates, *Gymnodinium* spp., *Oxytoxum varible*, and *Exuviaella* spp., accounted for more than 90% of the total integrated cell numbers of dinoflagellates (Fig. 3). The most abundant dinoflagellates, *Gymnodinium* spp., predominated among all the

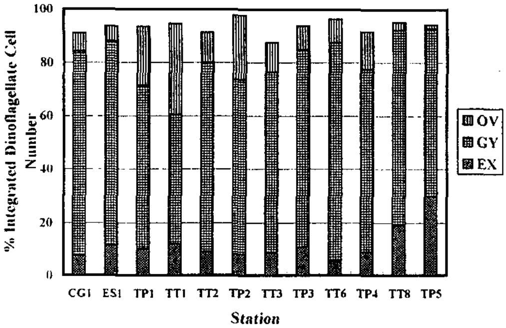

Fig. 3. Percent integrated cell numbers of dinoflagellates from west Pacific Sector of the Southern Ocean.
OV, *Oxytoxum variable*; GY, *Gymnodinium* spp.; EX, *Exuviaella* spp.

dinoflagellates with more than 60% of relative abundance except TT1. *Oxytoxum variable* showed around 30% of relative abundance at TT1.

Other phytoplanktons such as silicoflagellates, prymnesiophytes, and coccolithophorids were observed less than 0.5% of total integrated cell numbers of phytoplankton throughout the stations (Fig. 1). Coccolithophorids were only found from CG1 and TT3 with low numbers. However, large numbers of coccolithophorids were observed from samples collected during this cruise for cell cycle analysis from TP3. Therefore, coccolithophorids are considered as one of the most common phytoplankton groups in this area. Integrated phytoplankton cell numbers showed 4 peaks; two peaks in north of TP3 and 2 peaks in the south of TP3. The taxonomic groups proportion changed at TP1, TT3 and TP4 where physicochemical characters of water masses seemed to change by fronts or continents.

Integrated cell numbers of each phytoplankton species changed across the frontal system. *Pseudonitzschia* spp. and *Fragillariopsis kergulensis* showed high abundance from TT8 and TP5 and *Nitzschia closterium* occurred highly from TT2 to TP4. *Gymnodinium* spp. and *Oxytoxum variable* showed high abundance from all the stations, but less than the cell numbers of dominant diatoms.

3.3. Biomass of phytoplankton

Distribution profiles of the integrated carbon biomass of total phytoplankton showed a pattern similar to total integrated cell numbers profile (Fig. 4). However, total integrated phytoplankton biomass profile followed the biomass profile of microphytoplankton. The maximum integrated biomass was observed at ES1 with 2,000 mg C/m^2, and a minimum at TT3 with 700 mg C/m^2. Nanophytoplankton which dominated diatoms and dinoflagellates in integrated cell numbers showed a lower integrated biomass. Nanophytoplankton never exceeded 20% of the total integrated phytoplankton biomass. The maximum integrated biomass was observed from CG1 and TT1 with 300 mg C/m^2. Low integrated biomass of the nanophytoplankton from this research were uncertain, because the percentage of nanophyto-plankton was too low compared to other data (Fay, 1973; Weber, 1985; Knox, 1994). Hasle (1969) found the less abundant medium-sized and occasionally the large species of phytoplankton to

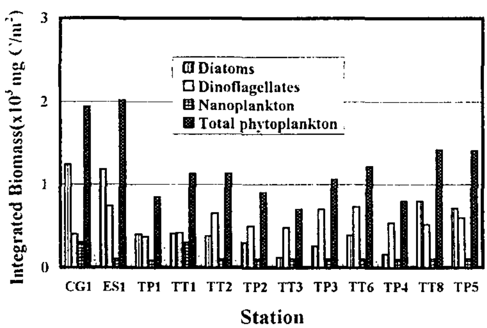

Fig. 4. Integrated biomass of each phytoplankton group from west Pacific Sector of the Southern Ocean.

be dominant in the Pacific region of the Southern Ocean.

Distribution of each taxonomic group showed little difference across frontal zones. Only the integrated biomass of each dominant species changed from zone to zone. Diatoms, which dominated dinoflagellates in integrated cell number, showed higher biomass than dinoflagellates from the north of the subtropical convergence zone and south of TP4, but dinoflagellates exceeded the value of diatoms except for those 4 stations. Integrated biomass of diatoms fluctuated drastically from minimum of 164 mg C/m^2 at TP4 to a maximum of 1248 mg C/m^2 at CG1, but dinoflagellate showed no big differences from a maximum of 700 mg C/m^2 at ES1 to a minimum of 300 mg C/m^2 at TP1.

All of the phytoplankton groups showed low integrated biomass at TP1, TT3, and TP4; total integrated biomass of these three stations showed the lowest level among the stations. The integrated biomass of phytoplankton across the subtropical and subantarctic zones. Northern stations of subtropical convergence zone and southern stations of station TP4 showed great differences from the other stations. .

Five groups of diatoms, *Chaetoceros* spp., *Pseudonitzschia* spp., *Rhizosolenia* spp., *Thalassiosira gravida*, and *Tropidoneis antarctica* occupied more than 50% of the total integrated biomass of diatoms except TT3 and TP3 where *Hemidiscus cuneiformis* var. *ventricosa* and *Coscinodiscus* spp. occupied more than 50% of total diatom biomass (Fig. 5). *Thalassiosira gravida* showed a large relative biomass except in TP3 and TT6. Biomass of *Tropidoneis antarctica* varied widely from north of TP2 and south of TP4. *Pseudonitzschia* showed more than 40% of the total diatom biomass from stations TP2 and TT6.

The integrated biomass of dinoflagellates was determined by *Exuviella* spp., *Gymnodinium* spp., and *Protoperidinium* spp. These three species occupied more than 70% of the total integrated dinoflagellate biomass (Fig. 6). From stations CG1, TT2, and TP2, *Protoperidinium* spp. showed maximum relative biomass, in stations ES1, TT3, and TP5, *Gymnodinium* spp. had maximum relative biomass, and stations TT1 and TT8, *Exuviella* spp. had maximum relative biomass.

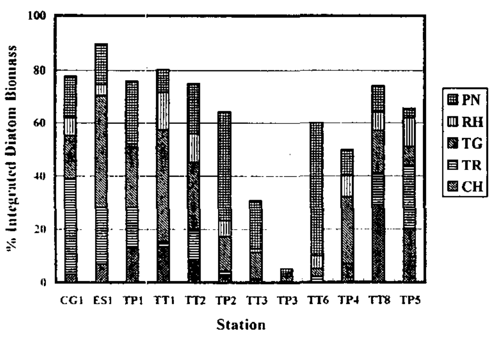

Fig. 5. Percent integrated biomass of diatoms from west Pacific Sector of the Southern Ocean. PN, *Pseudonitzschia* spp.; RH, *Rhizosolenia* spp.; TG, *Thalassiosira gravida*; TR, *Tropidoneis antarctica*; CH, *Chaetoceros* spp.

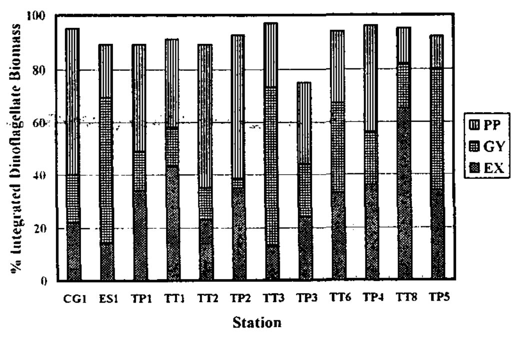

Fig. 6. Percent integrated biomass of dinoflagellates from west Pacific Sector of the Southern Ocean.
PP, *Protoperidinium* spp.; GY, *Gymnodinium* spp.; EX, *Exuviaella* spp.

The distribution of phytoplankton in the Southern Ocean is known to be implicated with circumpolarity of water mass (El-Sayed, 1993; Knox, 1994), and the different phytoplankton communities of this studied region also seem to be partially implicated with frontal system. The horizontal distribution of species number, integrated cell number and biomass of phytoplankton from our stations showed the transition across each frontal system where physicochemical factors of water mass are changed. However, the lack of the physicochemical data in this region during the study made the identification and effects of these fronts impossible. More frequent and sufficient sampling can reveal the macroscale geographical positions of the phytoplankton communities associated with water massess or hydrographic features.

References

El-Sayed, S. Z., 1988a, Seasonal and interannual variabilities in Antarctic phytoplankton with reference to krill distribution. *In* Antarctic Ocean and Resources Variability, Sahrhage, D. (ed.), Springer-Verlag, Berlin & Heidelberg, pp 101-119.

El-Sayed, S. Z., 1988b, *Comparative Biochemistry & Physiology*, 90, 489-498.

El-Sayed, S. Z. and G. A. Fryxell, 1993, Phytoplankton. *In*: Antarctic Microbiology, Friedmann, E. I. (ed.), Wiley-Liss, Inc., New York, pp 65-122.

Fay, R. R, 1973, Significance of nanoplankton in primary production of the Ross Sea, Antarctica, during the 1972 austral summer, PhD thesis, Texas A&M University, College Station, Texas, p 184.

Froneman, P. W., C. D. McQuaid and R. Perissinotto, 1995, *J. Plankton Res.*, 17, 1791-1802.

Grindley, J. R. and P. David, 1985, Nutrient upwellings and its effects in the lee of Marion Island. *In* Antarctic nutrient cycles and food webs, Siegfried, W. R., P. R., Condy, and R. M. Laws (eds.), Springer, Berlin, Heidelberg, and New York, p 120.

Hasle, G. R., 1969, Phytoplankton and hydrography of the Pacific part of the Antarctic Ocean, *Nature* (London), 177, 616-617.

Hasle, G. R., 1976, *Deep-Sea Res.*, 23, 319-338.

Heywood, R. B. and T. M. Whitaker, 1984, The Antarctic marine flora. *In* Antarctic Ecology, Vol. 2, Laws, R. M. (ed.), Academic Press, London, pp 373-419.

Hosaka, N. and T. Nemoto, 1986, Size structure of phytoplankton carbon and primary production in the Southern Ocean south of Australia during the summer of 1983-1984, *Memoirs National Institute of Polar Research, Special Issue*, 40, 15-24.

Jaques G. and M. Fukuchi, 1994, Phytoplankton of the Indian Antarctic Ocean. *In* Southern Ocean Ecology: the Biomass Perspective, El-Sayed, S. E. (ed.), Cambridge University Press, London, pp 63-78.

Knox, G. A., 1970, Antarctic marine ecosystems. *In* Antarctic Ecology, Vol. 1. Holdgate, M. W. (ed.), Academic Press, London, pp 69-96.

Knox, G. A, 1994, The Biology of the Southern Ocean. Cambridge University Press, London, p 444.

Kopczynska, E. E., 1992, *J. Plankton Res.*, 14, 1031-1054.

Kopczynska, E. E., L. H. Weber, and S. Z. El-Sayed, 1986, *Polar Biol.*, 6, 161-169.

Le Jehan, S. and P. Trequer, 1985, The distribution of inorganic nitrogen, phosphorus, silicon and dissolved organic matter in the surface and deep waters of the Southern Ocean. *In* Antarctic Nutrient Cycles and

Food Webs, Siegfried, W. R., P. R. Condy, and R. M. Laws (eds.), Springer-Verlag, Berlin pp 22-41.

Martin, J. H., 1990, *Paleoceanography*, 5, 1-13.

Martin, J. H., R. M. Gordon, and S. E. Fitzwater, 1990, *Nature*, 345, 156-158.

Nowlin, W. D. and J. M. Klinck, 1986, *Revs. Geophys.*, 24, 469-491.

Pakhomov, E. A. and C. D. McQuaid, 1996, *Polar Biol.*, 16, 271-286.

Perissinotto, R., R. K. Laubscher, and C. D. McQuaid, 1992, *Mar. Ecol. Prog. Ser.*, 88, 41-53.

Sakshaug, E. and O. Holm-Hansen, 1984, Factors governing pelagic production in polar oceans. *In* Marine Phytoplankton and Productivity, Holm-Hansen, O., L. Bolis, and R. Gilles (eds.), Springer-Verlag, Berlin, pp 1-18.

Shaw, A. B., 1964, Time in Stratigraphy, McGraw-Hill, New York, p 109.

Simpson, J. H., P. B. Terr, M. L. Argote-Espinoza, A. Edwards, H. J. Jones, and G. Savidge, 1982, *Continental Shelf Research*, 1, 15-31.

Smayda, T. J., 1978, From phytoplankters to biomass. *In* Phytoplankton Manual, Sournia, A. (ed.), Unesco, New York, pp 273-279.

Stein, M. and R. B. Heywood, 1994, Antarctic environment-physical oceanography: the Antarctic Peninsula and Southwest Atlantic region of the Southern Ocean. *In* Southern Ocean Ecology: the Biomass Perspective, El-Sayed, S. E. (ed.), Cambridge University Press, London. pp 11-24.

Verity, P. G., C. Y. Robertson, C. R. Tronzo, M. G. Andews, J. R. Nelson, and M. E. Sieracki, 1992, *Limnol. Oceanogr.*, 37, 1434-1446.

Weber, L. H. and S. Z. El-Sayed, 1985, Spatial variability of phytoplankton and the distribution and abundance of krill in the Indian sector of the Southern Ocean. *In* Antarctic Nutrient Cycles and Food Webs, Siegfried, W. R., P. R. Condy, and R. M. Laws (eds.), Springer-Verlag, Berlin, pp 284-293.

Yamamoto, T., 1986, *Memoirs National Institute of Polar Research, Special Issue*, 40, 25-41.