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Phytoplankton Chlorophyll Stocks in the Antarctic Ocean*

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Abstract: Phytoplankton chlorophyll stocks in the Indian sector of the Antarctic Ocean were estimated on the basis of published data collected from nine cruises of the Icebreaker, FUJI in 1965-1976, during routine observations of the Japanese Antarctic Research Expedition (JARE). Surface chlorophyll *a* concentration, measured at 631 stations in waters south of 35°S, ranged from 0.01 to 3.01 mg m^{-3}. At about half of the stations the values were less than 0.24 mg and at only 29 stations were high values more than 1.00 mg m^{-3} recorded. The levels of surface chlorophyll *a* stocks were estimated in three groups; (1) data obtained on the southward leg through the eastern Indian sector (middle-late December), (2) those on the northward leg through the western Indian sector (late February-early March) and (3) those on the northward leg through the eastern Atlantic sector (late February-early March). Furthermore, mean values and standard deviations were calculated for each of six different water masses from north to south, *i. e.*, subtropical water between 35°S and the Subtropical Convergence (STC) zone, water within the STC zone, Subantarctic Upper Water, water within the Antarctic Convergence (AC) zone, Antarctic Surface Water between the AC zone and 63°S, and Antarctic Surface Water south of 63°S. Mean values of surface chlorophyll *a* concentrations for each of the six water masses on the three legs ranged from 0.15 to 0.58 mg m^{-3} and were comparable to those reported by other workers previously. Seasonal periodicity of phytoplankton chlorophyll stock is discussed. The surface chlorophyll stock in the oceanic water of the Antarctic Ocean does not seem to be so high as previously believed.

1. Introduction

Phytoplankton investigation in the Antarctic Ocean was initiated by floristic surveys carried out on various expeditions during the nineteenth century. Many comprehensive treatises on phytoplankton flora and their biogeography in the Ocean resulted from these expeditions. These were followed by quantitative surveys on geographical distribution of the phytoplankton standing stock by cell counting and chlorophyll determination methods. Recently, productivity studies of phytoplankton have also been conducted. The historical background of phytoplankton investigation in the Ocean is reviewed by HASLE (1969).

Among several methods in assessing phytoplankton standing stock in the Antarctic Ocean, the measurement of chlorophyll *a* concentration of sea water has been employed by most workers. Fig. 1 shows the stations where such measurements at the surface have been made; although there are many stations both in the Pacific sector and in the Atlantic sector, tnere are comparatively few stations in the Indian sector.

Since 1965 the Japanese Antarctic Research Expedition (JARE) has routinely conducted chlorophyll *a* measurements in surface water along the cruise tracks of the Icebreaker, FUJI to and from Antarctica. These observations, fortunately, are mainly concentrated in the Indian sector (Fig. 1, hatched area), where previous observations are scarce. Although all the data obtained on each JARE cruise have been published in series, it is worthwhile compiling the data in order to yield an average figure of the phytoplankton standing stock in the Indian sector of the Antarctic Ocean. This average is necessary to evaluate the round stock of Antarctic phytoplankton for comparison with previous data reported from the Pacific and Atlantic sectors.

2. Data source and data processing

The routine samplings and analyses of the surface water were carried out three times a

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Fig. 1. Stations where surface chlorophyll *a* measurements were made by previous workers. The hatched part shows the area covered by the Japanese Antarctic Research Expedition in 1965/66 (JARE-7)~1976/77 (JARE-18).
■: ICHIMURA and FUKUSHIMA (1963); ▲: SAIJO and KAWASHIMA (1964); ○: BURKHOLDER and BURKHOLDER (1967); ●: EL-SAYED (1968b); □: EL-SAYED and TURNER (1977); △: PLANCKE (1977).

day, usually at 0800, 1200 and 1800 local time, on board the FUJI during every JARE cruise. The biological program includes the analyses of chlorophyll *a* while related items such as water temparature, salinity, pH, dissolved oxygen, silicate, phosphate, nitrate, nitrite and ammonia are measured for the physico-chemical program. All the data obtained on every cruise have been published in series in "Antarctic Record" (Table 1). Data on the latter program are treated in another paper which will be published elsewhere. The present work is devoted to evaluation of phytoplankton chlorophyll stocks in the Antarctic Ocean.

Chlorophyll *a* concentration was determined by the colorimetric method on seven cruises, with two exceptions on JARE-9 (1965/1966) and JARE-14 (1972/1973) when the fluorometric method was employed (Table 1). A total of 632 stations located south of 35°S is dealt with in this paper (Fig. 2).

Since the duration of the cruise of the "FUJI" was too long compared with the short duration of summer in high latitudes, pooled data were divided into the following two groups according to the sampling period: (1) data obtained on the southward leg from Fremantle, Australia, to Syōwa Station (69°00'S, 39°35'E) through

Table 1. Data source for the present work, collected during nine JARE cruises aboard the FUJI.

Cruise No.	Year	Author	Number of data	Method
JARE 7	1965/1966	HOSHIAI (1968)	88	Colorimetric
JARE 9	1967/1968	TOMINAGA (1971)	52*	Fluorometric
JARE 10	1968/1969	TAKAHASHI (1969)	75	Colorimetric
JARE 12	1970/1971	NISHIWAKI (1972)	41	Colorimetric
JARE 14	1972/1973	KURODA (1978)	50	Fluorometric
JARE 15	1973/1974	HOSHINO (1974)	111	Colorimetric
JARE 16	1974/1975	OHNO (1976)	89	Colorimetric
JARE 17	1975/1976	OHYAMA & MAYAMA (1976)	48	Colorimetric
JARE 18	1976/1977	FUKUCHI (1977)	78	Colorimetric

* Of 52 data, one datum was excluded from further calculation (see p. 76).

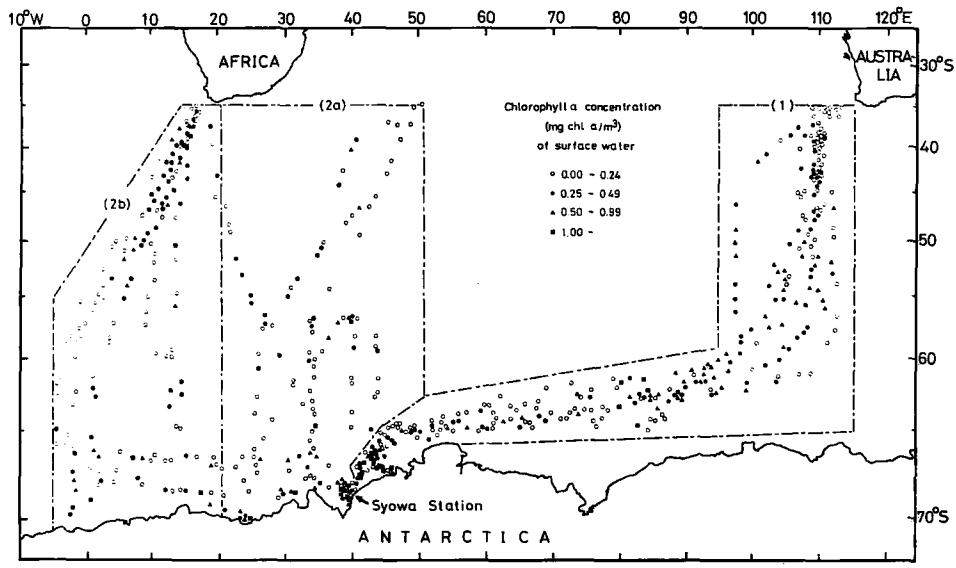

Fig. 2. Stations and surface chlorophyll *a* concentration observed aboard the FUJI during nine cruises in 1965/66 (JARE-7)~1976/77 (JARE-18). (1) Southward leg through the eastern Indian sector; (2a) Northward leg through the western Indian sector; (2b) Northward leg through the eastern Atlantic sector. For details see text.

the eastern Indian sector in latter half of December, (2) those on the northward leg from Syowa Station to Cape Town, South Africa, or Port Louis, Mauritius, in late February-early March. Furthermore, the latter group was subdivided into two subgroups according to the sampling area; (2a) data obtained in the western Indian sector and (2b) those in the eastern Atlantic sector (see Fig. 2). There was a time lag of about two months between the southward leg and the northward leg. The number of available data in each group is listed in Table 2.

It is well known that two convergence zones, the Subtropical Convergence (STC) and the Antarctic Convergence (AC), are recognized in the Antarctic Ocean. These convergences are detected by sharp changes in surface temperature rather than in absolute temperature values (DEACON, 1937; MACKINTOSH, 1946). In our case, surface temperature was measured only three times a day or at 50~170 mile intervals. Therefore, the most large and consistent change of surface temperature over two to four subsequent stations was employed to locate the Convergences. The middle positions of the STC and AC zones were then taken to lie at the center of these stations. Data on these

Table 2. Number of data obtained on three legs of nine JARE cruises. This grouping by cruise itinerary is necessary to evaluate seasonal variation of phytoplankton stocks in the Antarctic Ocean.

	Atlantic sector (5°W-20°E)	Indian sector (20°E-115°E)		Total
	Northward leg (2b)	Northward leg (2a)	Southward leg (1)	
35°S-63°S	116	73	199	388
63°S-70°S	48	70	125	243
Total	164	143	324	631

convergence zones and their middle position detected on every JARE cruise are summarized in Appendix 1.

Since two Convergences encircle Antarctica, surface waters can be classified into the following six water masses from north to south, *i. e.*, (1) subtropical water between 35°S and the northern boundary of the STC zone, (2) water within the STC zone, (3) Subantarctic Upper Water south of the STC zone down to the AC zone, (4) water within the AC zone, (5) Antarctic Surface Water between the latter and 63°S, and (6) Antarctic Surface Water south of 63°S. The latitude of 63°S is used here as an arbitrary boundary between oceanic waters in the north and waters along the Antarctic Continent in the South. Those stations near the Antarctic Continent should be treated separately from the northern stations, because there are usually many icebergs and much pack ice south of 63°S and their distribution is thought to have a great influence on chlorophyll *a* distribution.

Mean and standard deviation of chlorophyll *a* concentration in each of the above-mentioned six different water masses for all three legs of every cruise was then calculated (Appendix 2).

3. Average figures of phytoplankton chlorophyll stocks obtained from JARE data

Chlorophyll *a* concentration in the surface water varied from 0.01 to 3.01mg m^{-3} throughout the JARE investigations, except for one extraordinary high value of 72.8mg m^{-3}, which was obtained at one station in the Ongul Strait near Syowa Station (TOMINAGA, 1971). However, at about a half of the 631 stations, the values were less than 0.24mg m^{-3}. Most values

Table 3. Number and frequency of the JARE data with respect to surface chlorophyll *a* concentration.

Range of chlorophyll *a* (mg m^{-3})	Number of data	Frequency (%)
0.01-0.24	303	48.0
0.25-0.49	198	31.4
0.50-0.99	101	16.0
1.00-1.99	19	3.0
2.00-2.99	9	1.4
3.00-3.01	1	0.2
Total	631	100.0

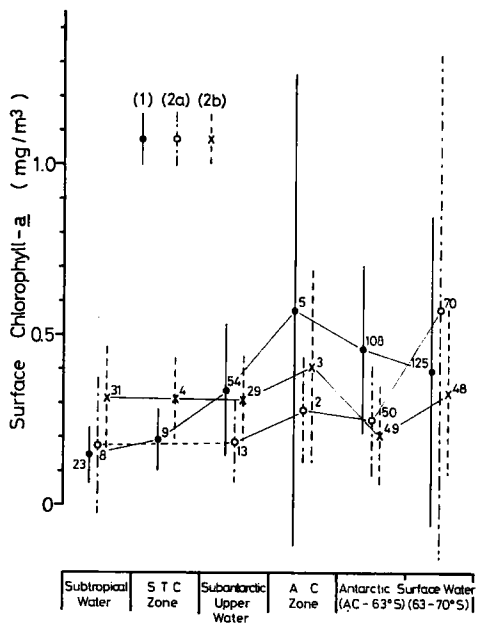

Fig. 3. Mean and standard deviation of surface chlorophyll *a* for each of six different water masses for three legs over nine cruises during JARE-7~JARE-18. Data groups of (1), (2a) and (2b) as in Fig. 2. Numerals indicate the number of data pooled.

did not exceed 1.00mg m^{-3}. High values more than 1.00mg m^{-3} were recorded at only 29 stations, less than 5% of the total number of stations (Table 3).

3.1. Regional distribution of phytoplankton chlorophyll stocks

To show the gross pattern of chlorophyll distribution in the investigated area, the mean and standard deviation of chlorophyll *a* concentration for each of six different water masses for three legs over nine cruises were calculated

(Appendix 2). They are illustrated in Fig. 3.

(*1*) *Southward leg through the eastern Indian sector* (*middle-late December*)

Mean surface chlorophyll *a* increased rapidly southwards from 0.15mg m^{-3} in the subtropical water to 0.57mg m^{-3} in the AC zone, and then decreased slightly to 0.39mg m^{-3} in the southernmost water. Standard deviations were very large in the AC zone and in the Antarctic Surface Water south of 63°S, as shown by the long vertical lines in Fig. 3. The large deviation in the AC zone is partly due to the scarcity of data (5 sets) as well as to a marked fluctuation of chlorophyll *a* concentration from 0.11 to 1.71mg m^{-3}. On the other hand, a large number of data (125 sets) were available in the Antarctic Surface Water south of 63°S, and thus the calculated large deviation is a true reflection of the widely variable surface chlorophyll stock in this water. This is probably caused by an uneven phytoplankton distribution under complicated hydrographic conditions, which are, in turn, related to the uneven distribution of pack ice and icebergs.

(*2a*) *Northward leg through the western Indian sector* (*late February-early March*)

This leg was carried out about two months later than the southward leg. Mean values on this leg are lower than those on the southward leg in every water masses except in the southernmost water south of 63°S, where the highest mean value (0.58mg m^{-3}) of all legs was observed. The largest standard deviation on this leg was also observed in this water. The mean value decreased simply northward to a minimum value of 0.18mg m^{-3} in the subtropical water.

(*2b*) *Northward leg through the eastern Atlantic sector* (*late February-early March*)

This leg was also carried out about two months later than the southward leg. In general, the gross pattern of geographical variation of chlorophyll *a* concentration on this leg is similar to that on the northward leg in the western Indian sector, while mean values are higher (0.31-0.41mg m^{-3}) in the northern part of the AC zone but lower (0.21-0.33mg m^{-3}) in the Antarctic Surface Water compared to the values obtained in the western Indian sector.

3.2. Seasonal change of chlorophyll stocks

As shown in Fig. 3, it is clear that the latitudinal variations of surface chlorophyll *a* stock differ among the three legs or seasons. In the latter half of December, the highest mean surface chlorophyll *a* concentration is seen in the AC zone on the southward leg through the eastern Indian sector (Fig. 3). After two months in late February-early March, on the northward leg through the western Indian sector, the highest value is observed in the southernmost water south of 63°S and low values elsewhere; the area of maximum chlorophyll *a* stock shifts from the waters of the AC zone to the southernmost waters. This phenomenon seems to be related to the seasonal periodicity of phytoplankton production as stated by HART (1942) and HASLE (1969). They mentioned that the "peak of phytoplankton density appears more and more to the south as the season advances during the austral summer season." EL-SAYED and TURNER (1977) observed surface chlorophyll *a* concentration in the waters between 35°S and 64°S along 115°E in early summer from late November to December. While higher values were observed in the Antarctic region than in the subantarctic region, the maximum value of 0.60mg m^{-3} was reported from just north of the AC. Their results support the view that the maximum phytoplankton stocks occur in the AC zone in early summer.

PLANCKE (1977) investigated surface chlorophyll *a* contents in the subantarctic region of the southwestern Indian Ocean (40°S-55°S, 20°E-75°E) during the spring (November), summer (January) and autumn (March-April) and concluded that the maximum biomass appeared in spring and decreased thereafter. FUKASE (1962) counted phytoplankton cell number in waters between Cape Town and Syowa Station on JARE-4 (1959/1960). He mentioned that the cell number observed on the northward leg (late February-early March) was smaller than that observed on the southward leg (middle-late December). These results also demonstrate the seasonal variation of phytoplankton in the subantarctic region and are consistent with the principle stated by HART (1942) and HASLE (1969).

On the northward leg through the eastern Atlantic sector, however, the peak of surface chlorophyll *a* stock is not seen in the southernmost water, but in the AC zone. This implies that there is a lag in the timing of phytoplankton

blooms between the Indian and Atlantic sectors. It can not be determined from the present results which bloom occurs first.

4. Previous works other than JARE investigations

Among many previous works on the surface chlorophyll *a* stocks in the Antarctic Ocean, the results reported from offshore water (see Fig. 1) are summarized in Table 4.

4. 1. Pacific sector of the Antarctic Ocean

The most numerous data are reported from the Pacific sector of the Antarctic Ocean. Most reported values of mean surface chlorophyll *a* concentration in this sector range from 0. 12 to 0. 29mg m^{-3}, while exceptionally high mean values of 0. 66 and 0. 46mg m^{-3} were recorded. The former high value was reported from the water near New Zealand where the so-called "island mass effect" is induced (BURKHOLDER and BURKHOLDER, 1967). The latter high value was reported by EL-SAYED and TURNER (1977) from the waters of the Ross Ice Shelf.

4. 2. Atlantic sector of the Antarctic Ocean

Reported means of the surface chlorophyll *a* concentration are 0. 19mg m^{-3} (SAIJO and KAWASHIMA, 1964) and 0.89mg m^{-3} (EL-SAYED 1968b). As EL-SAYED (1968b) mentioned, because a large number of his stations were distributed in waters around the Argentine coast,

Table 4. Previously reported values of surface chlorophyll *a* from the Antarctic Ocean during cruises other than JARE.

Sector	Author	Cruise	Date	Area		Surface Chlorophyll *a* (mg m^{-3}) Range	Mean±S.D.	(N)
Pacific sector:								
	BURKHOLDER & BURKHOLDER (1967)	Eltanin 14	May-July 1964	80°W-175°W	ST[1)]		0. 29	7
				,,	SA[2)]		0. 16	34
				,,	A[3)]		0. 12	35
	,,	Eltanin 15	July-Sept. 1964	,,	ST		0. 18	10
				,,	SA		0. 18	18
				,,	A		0. 17	26
	,,	Eltanin 15	Oct.-Dec. 1964	,,	ST	0. 18-2. 58	0. 66	70
				,,	SA		0. 22	22
				,,	A		0. 24	22
	EL-SAYED (1986b)	Eltanin 18-21 & 23-28	1965-1966	75°W-145°W, 35° S-77° S		0. 01-5. 80	0. 26±0. 34	723
	EL-SAYED & TURNER (1977)	Eltanin 38	Mar.-May 1968	150° E-152° E, 42° S-64° S		0. 11-0. 28	0. 17±0. 07	6
	,,	Eltanin 51	Jan.-Feb. 1972	166° E-158° E, 45° S-78° S		0. 05-1. 14	0. 46±0. 36	20
Atlantic sector:								
	SAIJO & KAWASHIMA (1964)	Umitaka Maru	Jan. 1962	16° E-35°W, 47° S-60° S		0. 05-0. 50	0. 19±0. 15†	25
	EL-SAYED (1968b)	9 cruises of Canepa, Zapiola, San Martin	1962-1965	10°W-65°W, 35° S-77° S		0. 01-18. 35	0. 89±1. 31	518
Indian sector:								
	ICHIMURA & FUKUSHIMA (1963)	Soya (JARE 5)	Nov. 1960-Apr. 1961	20° E-55° E, 35° S-70° S		0. 15-0. 60		*ca.* 30
	SAIJO & KAWASHIMA (1964)	Umitaka Maru	Dec. 1961	19° E-106° E, 38° S-65° S		0. 04-0. 72	0. 18±0. 19†	19
	EL-SAYED & TURNER (1977)	Eltanin 46	Nov. 1970-Jan. 1971	70° E-116° E, 35° S-65° S		0. 02-1. 13	0. 30±0. 31	20
	PLANCKE (1977)	3 cruises of Marion Dufresne	Nov. 1973-Apr. 1974	20° E-75° E, 40° S-55° S	ST		0. 32	53
					SA		0. 17	199

1)~3) ST: Subtropical; SA: Subantarctic; A: Antarctic.

† Mean values were re-calculated by the present author.

the Drake Passage, South Shetland, South Orkney and South Sandwich Islands, his mean is not a representative value of the oceanic water. EL-SAYED (1968a) showed that chlorophyll *a* content in the Antarctic Surface Water was five times higher in the inshore water (2.12 mg m^{-3}) than in the offshore water (0.42mg m^{-3}), and in the Subantarctic waters the inshore value (0.79mg m^{-3}) was also higher than the offshore value (0.32mg m^{-3}). Therefore, the values of 0.19–0.42mg m^{-3} should be taken as representative of the surface chlorophyll *a* stock in oceanic waters in the Atlantic sector.

4.3. Indian sector of the Antarctic Ocean

While only a small number of stations were occupied in this sector, all mean values (0.17–0.32mg m^{-3}) listed in Table 4 can be regarded as of the oceanic waters. Only two of 20 stations occupied by EL-SAYED and TURNER (1977) seemed to be under the "island mass effect"; at Stn. 16 located near Heard Island and Stn. 17A just southeast of Kerguelen Island, chlorophyll *a* concentrations were high, 0.89 and 1.13mg m^{-3}, respectively.

Although extraordinarily high surface chlorophyll *a* cencentrations (18.4–26.8mg m^{-3}) were reported from relatively narrow coastal waters such as Drake Passage, the Gerlache Strait and their vicinities (BURKHOLDER and SIEBURTH, 1961; EL-SAYED, 1968a), the levels of mean chlorophyll *a* concentration over oceanic waters are in the ranges of 0.19–0.42, 0.17–0.32 and 0.12–0.29mg m^{-3} in the Atlantic, Indian and Pacific sectors of the Antarctic Ocean, respectively. From these facts it seems to be reasonable to conclude that in general the level of phytoplankton standing stock in oceanic water is at approximately the same level throughout the three sectors of the Antarctic Ocean.

5. Discussion

The present paper is intended to yield average figures of phytoplankton chlorophyll stocks in the Indian sector and adjacent waters of the Antarctic Ocean, on the basis of 631 surface chlorophyll *a* observations performed during nine cruises aboard the FUJI of the Japanese Antarctic Research Expedition. Average figures of different water masses are illustrated for the subtropical water in the north to the Antarctic Surface Water in the south. Except for two high mean values observed in the AC zone (0.57mg m^{-3}) and in the southernmost water (0.58mg m^{-3}), the range of mean values obtained from the JARE investigations (0.15–0.46 mgm^{-3}) is comparable to the values reported and discussed in the preceding section. The mean chlorophyll *a* concentrations over the entire oceanic waters between 35°S and 63°S, excluding the southernmost waters, are calculated to be 0.38mg m^{-3} (southward leg through the eastern Indian sector), 0.23mg m^{-3} (northward leg through the western Indian sector) and 0.27 mg m^{-3} (northward leg through the eastern Atlantic sector). Also, the seasonal periodicity of phytoplankton standing stock is evident.

In the Antarctic Surface Water south of 63°S, surface chlorophyll *a* content fluctuated greatly. This would suggest an "uneven distribution" (HARDY, 1936) of phytoplankton. The number of data pooled in the present work is so large that the calculated mean value is thought to yield a representative average figure, though its standard deviation is large.

In order to place the level of the Antarctic surface chlorophyll stocks calculated here in perspective, the average surface chlorophyll *a* concentrations reported from the different world oceans are summarized in Table 5. The mean surface chlorophyll *a* concentrations from oceanic waters in the three sectors of the Antarctic Ocean range from 0.12 to 0.42mg m^{-3} (see the preceding section). These values are much lower than those reported from upwelling areas but higher than those in the North Equatorial Current and the central Indian Ocean. They are lower than those in the Bering Sea, the counter part in the northern hemisphere, which is one of the most productive seas in the world (see HOOD and KELLEY, 1974). Although the Antarctic Ocean occupies latitudes as high as the Bering Sea, the average level of phytoplankton stocks in the Ocean calculated here is equivalent to other areas in middle and low latitudes of the world ocean. Apart from the averages, individual data support this (Table 3); *i.e.*, the number of stations with chlorophyll *a* concentrations less than 0.50mg m^{-3} comprises about 80% of the stations. The number of high values more than 2.00mg m^{-3} are less than 2%, and those high values are found within the southernmost water south of 63°S. The

Table 5. Surface chlorophyll *a* concentration (mg m^{-3}) reported from the Pacific and Indian Oceans.

Area	Month	Chlorophyll *a* (mg m^{-3})		Author
		mean	range	
Pacific Ocean:				
Bering Sea	June-Aug.	0.69-0.93		TANIGUCHI (1972)
Bering Sea	June-July	1.83	0.20-9.90	MCROY *et al.* (1972)
Bering Sea	Feb.-Mar.	0.53	0.10-1.40	MCROY *et al.* (1972)
Bering Strait	June		7.00	MCROY *et al.* (1972)
Alaskan Stream	July	0.20-0.31		TANIGUCHI (1972)
Subarctic Current	June	0.19-0.24		TANIGUCHI (1972)
Okhotsk Sea	Aug.-Sept.	0.11		TANIGUCHI (1972)
North Pacific Current	Aug.	0.45		TANIGUCHI (1972)
Oyashio Current	Apr.-Sept.	0.33-3.42		TANIGUCHI (1972)
Oyashio Current	Aug.	0.93*	0.14-1.89	ARUGA & MONSI (1962)
Kuroshio Current	Aug.	0.21*	0.01-0.76	ARUGA & MONSI (1962)
Kuroshio Current	Nov.-Jan.	0.06-0.61		TANIGUCHI (1972)
North Equatorial Current	Jan.	0.03-0.06		TANIGUCHI (1972)
Upwelling area off Peru (15°S)	Mar.-Apr.	6.00		WALSH (1976)
Upwelling area off Baja California	Mar.-Apr.	7.00		WALSH (1976)
Indian Ocean:				
Central Indian Ocean (10°S-35°S)	June-Sept.		0.05-0.10	KREY (1973)
Arabian Sea	June-Sept.		0.10-0.50	KREY (1973)

* Mean values were re-calculated by the present author.

present results coincide with the opinions stated by HART (1942), SAIJO and KAWASHIMA (1964), WALSH (1969), EL-SAYED and TURNER (1977) and HOLM-HANSEN *et al.* (1977), which can be summarized as follows; the Antarctic Ocean may not be as productive as previously believed, and the overall production of the Ocean may be of the same magnitude as temperate areas of the world ocean.

In conclusion, since the average figures of the phytoplankton chlorophyll *a* stocks shown in the present work are based on a large number of data, these figures are useful for evaluating the round stock of Antarctic phytoplankton and, furthermore, give fundamental knowledge on the Antarctic marine ecosystem.

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Appendix 1. Calculated middle position and temperature at the Subtropical and Antarctic Convergence zones observed during 12 cruises aboard the FUJI in 1965-1977.

(1) Southward leg through the eastern Indian sector:

Expedition No.	Year	Subtropical Convergence		Antarctic Convergence	
		Middle	zone	Middle	zone
JARE 7	1965/1966	37°54′S 14.4°C	36°22′-39°26′S 16.2-12.5°C	52°52′S 3.1°C	51°35′-54°08′S 4.5-1.6°C
JARE 8	1966/1967	39°06′S 14.3°C	38°16′-39°56′S 15.3-13.3°C	52°52′S 3.1°C	51°25′-54°19′S 3.7-2.5°C
JARE 9	1967/1968	40°23′S 13.1°C	37°57′-42°49′S 14.8-11.4°C	51°21′S 3.7°C	50°08′-52°34′S 4.7-2.7°C
JARE 10	1968/1969	41°40′S 12.1°C	40°25′-42°54′S 13.3-10.8°C	50°49′S 4.6°C	49°37′-52°00′S 6.0-3.2°C
JARE 11	1969/1970	42°02′S 13.1°C	40°39′-43°25′S 14.4-11.8°C	49°52′S 5.8°C	48°42′-51°22′S 6.9-4.8°C
JARE 12	1970/1971	40°01′S 12.6°C	38°24′-41°37′S 14.0-11.2°C	50°38′S 5.0°C	49°46′-51°29′S 5.4-4.6°C
JARE 13	1971/1972	38°43′S 14.8°C	36°13′-41°12′S 17.5-12.1°C	50°20′S 4.5°C	49°03′-51°36′S 5.9-3.0°C
JARE 14	1972/1973	39°58′S 13.7°C	38°42′-41°14′S 15.2-12.2°C	51°35′S 4.0°C	50°14′-52°56′S 5.1-2.8°C
JARE 15	1973/1974	37°46′S 16.1°C	35°22′-40°09′S 17.9-14.3°C	51°14′S 3.7°C	50°21′-52°07′S 4.4-3.0°C
JARE 16	1974/1975	38°00′S 14.4°C	35°45′-40°15′S 16.5-12.5°C	52°13′S 3.4°C	51°26′-52°59′S 3.9-2.8°C
JARE 17	1975/1976	40°45′S 12.7°C	39°14′-42°16′S 13.8-11.6°C	51°44′S 4.3°C	50°14′-53°13′S 5.3-3.3°C
JARE 18	1976/1977	41°35′S 14.9°C	40°27′-42°43′S 18.6-11.2°C	51°37′S 5.0°C	49°59′-53°15′S 6.4-3.6°C

(2a) Northward leg through the western Indian sector:

JARE 11	1969/1970	43°31′S 15.0°C	42°23′-44°38′S 20.9-9.0°C	49°48′S 4.8°C	48°38′-50°38′S 5.4-4.2°C
JARE 12	1970/1971			50°01′S 3.7°C	48°21′-51°41′S 5.4-2.0°C
JARE 13	1971/1972	43°30′S 11.2°C	42°14′-44°46′S 14.1-8.2°C	50°03′S 5.0°C	48°28′-51°37′S 6.5-3.4°C
JARE 17	1975/1976	40°29′S 16.5°C	39°14′-41°45′S 20.1-12.9°C	50°06′S 4.9°C	49°33′-50°39′S 5.3-4.4°C
JARE 18	1976/1977	41°38′S 13.1°C	40°25′-42°51′S 16.0-10.1°C	50°49′S 5.3°C	50°09′-51°28′S 5.7-4.8°C

(2b) Northward leg through the eastern Atlantic sector:

JARE 7	1965/1966	41°19′S 12.0°C	39°57′-42°41′S 15.0-9.0°C	50°40′S 3.3°C	50°03′-51°18′S 3.8-2.7°C
JARE 8	1966/1967	41°49′S 12.1°C	40°00′-43°37′S 15.7-8.4°C	51°31′S 3.3°C	50°58′-52°03′S 3.7-2.9°C
JARE 9	1967/1968	40°16′S 14.7°C	39°18′-41°15′S 17.1-12.2°C	48°27′S 4.8°C	47°11′-49°42′S 6.0-3.6°C
JARE 10	1968/1969	43°38′S 11.4°C	41°51′-45°25′S 13.6-9.2°C	51°31′S 3.5°C	49°35′-53°25′S 4.8-2.2°C
JARE 12	1970/1971	44°19′S 11.5°C	43°00′-45°37′S 14.7-8.2°C		
JARE 14	1972/1973	40°41′S 16.9°C	39°13′-42°08′S 21.9-11.9°C	51°04′S 3.2°C	50°22′-51°46′S 4.1-2.2°C
JARE 15	1973/1974	42°32′S 13.1°C	41°53′-43°10′S 15.0-11.2°C	49°48′S 4.3°C	49°14′-50°22′S 5.0-3.6°C
JARE 16	1974/1975	43°22′S 13.4°C	41.54′-44°50′S 17.8-8.9°C	50°44′S 4.3°C	49°45′-51°44′S 5.1-3.4°C

Appendix 2. Range and mean value of surface chlorophyll *a* (mg m^{-3}) in six different water masses observed during nine JARE cruises of the FUJI in 1965–1977.

(1) Southward leg through the eastern Indian sector:

Expedition No.	Year		Subtropical water	Subtropical Convergence zone	Subantarctic Upper Water	Antarctic Convergence zone	Antarctic Surface Water (north of 63°S)	Antarctic Surface Water (south of 63°S)
JARE 7	1965/1966	Range	0.10–0.13	0.28–0.31	0.03–0.75		0.09–0.89	0.09–0.37
		Mean± S.D.(N)	0.12±0.02 (2)	0.30±0.02 (2)	0.48±0.24 (10)		0.44±0.29 (12)	0.19±0.08 (23)
JARE 9	1967/1968	Range	0.03–0.20		0.23–0.91		0.22–0.66	0.05–0.21
		Mean± S.D.(N)	0.12±0.12 (2)	0.24 (1)	0.41±0.33 (4)		0.34±0.13 (9)	0.11±0.06 (6)
JARE 10	1968/1969	Range	0.09–0.15		0.14–0.66		0.10–0.66	0.04–2.10
		Mean± S.D.(N)	0.12±0.02 (5)		0.31±0.24 (4)		0.30±0.17 (14)	0.59±0.66 (19)
JARE 12	1970/1971	Range			0.13–0.28		0.19–1.10	0.07–0.30
		Mean± S.D.(N)	0.15 (1)	0.13 (1)	0.21±0.07 (4)	0.14 (1)	0.61±0.30 (13)	0.15±0.13 (3)
JARE 14	1972/1973	Range	0.08–0.30		0.25–0.52		0.11–0.87	0.12–0.28
		Mean± S.D.(N)	0.21±0.12 (3)		0.40±0.13 (5)		0.51±0.27 (16)	0.20±0.07 (4)
JARE 15	1973/1974	Range		0.07–0.23	0.10–0.37		0.13–1.10	0.15–1.08
		Mean± S.D.(N)	0.06 (1)	0.15±0.11 (2)	0.20±0.09 (8)	0.13 (1)	0.58±0.27 (15)	0.46±0.29 (15)
JARE 16	1974/1975	Range		0.08–0.12	0.18–0.76		0.32–0.99	0.09–2.06
		Mean± S.D.(N)	0.10 (1)	0.10±0.03 (2)	0.36±0.19 (8)	1.71 (1)	0.46±0.20 (10)	0.37±0.39 (30)
JARE 17	1975/1976	Range	0.07–0.29		0.29–0.52		0.13–0.89	0.18–2.49
		Mean± S.D.(N)	0.21±0.12 (3)	0.28 (1)	0.40±0.09 (5)	0.77 (1)	0.46±0.24 (9)	0.59±0.79 (8)
JARE 18	1976/1977	Range	0.04–0.28		0.13–0.32		0.21–0.65	0.11–2.40
		Mean± S.D.(N)	0.16±0.11 (5)		0.21±0.08 (6)	0.11 (1)	0.41±0.16 (10)	0.53±0.54 (17)
Over 9 cruises		Range	0.03–0.30	0.07–0.31	0.03–0.91	0.11–1.71	0.09–1.10	0.04–2.49
		Mean± S.D.(N)	0.15±0.09 (23)	0.19±0.09 (9)	0.34±0.20 (54)	0.57±0.70 (5)	0.46±0.25 (108)	0.39±0.46 (125)

(2a) Northward leg through the western Indian Ocean:

JARE 7	1965/1966	Range						0.21–1.04
		Mean± S.D.(N)						0.46±0.27 (11)
JARE 9	1967/1968	Range						0.08–0.69
		Mean± S.D.(N)						0.29±0.27 (4)
JARE 10	1968/1969	Range						0.15–1.30
		Mean± S.D.(N)						0.51±0.44 (7)
JARE 12	1970/1971	Range			0.07–0.09		0.06–0.44	0.05–0.50
		Mean± S.D.(N)			0.08±0.01 (2)	0.17 (1)	0.30±0.12 (8)	0.21±0.25 (3)
JARE 14	1972/1973	Range						0.10–0.36
		Mean± S.D.(N)						0.18±0.11 (5)
JARE 15	1973/1974	Range					0.05–0.47	0.05–3.01
		Mean± S.D.(N)					0.19±0.10 (15)	1.25±1.01 (21)
JARE 16	1974/1975	Range						0.09–0.71
		Mean± S.D.(N)						0.26±0.23 (6)
JARE 17	1975/1976	Range	0.01–0.10		0.10–0.20		0.03–0.49	0.02–0.24
		Mean± S.D.(N)	0.06±0.05 (3)		0.15±0.04 (5)		0.26±0.16 (8)	0.16±0.09 (5)

Appendix 2. Continued.

Expedition No.	Year		Subtropical water	Subtropical Convergence zone	Subantarctic Upper Water	Antarctic Convergence zone	Antarctic Surface Water (north of 63°S)	Antarctic Surface Water (south of 63°S)
(Northward leg: continued)								
JARE 18	1976/1977	Range	0.06-0.56		0.14-0.53		0.04-0.69	0.04-0.17
		Mean±	0.24±0.23		0.25±0.15	0.39 (1)	0.28±0.20	0.07±0.04
		S.D.(N)	(5)		(6)		(19)	(8)
Over 9 cruises		Range	0.01-0.56		0.07-0.53	0.17-0.39	0.03-0.69	0.02-3.01
		Mean±	0.18±0.20		0.19±0.12	0.28±0.16	0.25±0.16	0.58±0.74
		S.D.(N)	(8)		(13)	(2)	(50)	(70)
(2b) Northward leg through the eastern Atlantic Ocean:								
JARE 7	1965/1966	Range	0.28-0.69		0.16-0.43		0.01-0.45	0.15-0.80
		Mean±	0.43±0.19	0.28 (1)	0.29±0.11		0.16±0.15	0.30±0.25
		S.D.(N)	(4)		(7)		(10)	(6)
JARE 9	1967/1968	Range	0.16-0.60		0.23-0.54		0.12-0.23	0.18-0.46
		Mean±	0.40±0.23		0.34±0.15		0.17±0.04	0.28±0.09
		S.D.(N)	(4)		(4)		(8)	(9)
JARE 10	1968/1969	Range	0.21-0.36		0.13-0.46		0.08-0.26	0.08-1.00
		Mean±	0.28±0.06	0.38 (1)	0.24±0.19	0.21 (1)	0.15±0.07	0.37±0.26
		S.D.(N)	(5)		(3)		(5)	(11)
JARE 12	1970/1971	Range	0.13-0.35					
		Mean±	0.24±0.16	0.43 (1)	0.13 (1)			
		S.D.(N)	(2)					
JARE 14	1972/1973	Range	0.16-0.24		0.21-0.46		0.14-0.53	0.41-0.81
		Mean±	0.21±0.04		0.34±0.10		0.25±0.17	0.57±0.21
		S.D.(N)	(3)		(5)		(6)	(3)
JARE 15	1973/1974	Range	0.11-0.61		0.18-0.41		0.06-0.51	0.14-1.23
		Mean±	0.26±0.16	0.16 (1)	0.27±0.09	0.28 (1)	0.26±0.17	0.48±0.35
		S.D.(N)	(7)		(5)		(10)	(9)
JARE 16	1974/1975	Range	0.25-0.47		0.33-0.54		0.09-0.58	0.09-0.28
		Mean±	0.37±0.10		0.44±0.09	0.74 (1)	0.24±0.16	0.16±0.05
		S.D.(N)	(6)		(4)		(10)	(10)
Over 7 cruises		Range	0.11-0.69	0.16-0.43	0.13-0.54	0.21-0.74	0.01-0.58	0.08-1.23
		Mean±	0.32±0.15	0.31±0.12	0.31±0.12	0.41±0.29	0.21±0.14	0.33±0.25
		S.D.(N)	(31)	(4)	(29)	(3)	(49)	(48)

南極海の植物プランクトン・クロロフィル現存量

福 地 光 男*

要旨: 1965年から1976年の間，日本南極地域観測隊，"ふじ" 船上にて定常観測として行なわれた表面海水中のクロロフィル*a*量の測定結果について，すでに公表された9航海にて得られた資料を基にして南極海インド洋区の植物プランクトン・クロロフィル現存量の算定を行った．南緯35度以南海域の合計631観測点から得られた測定値は，0.01～3.01 mg Chl. *a* m^{-3} の範囲にあった．全観測点の約半分は0.24 mg Chl. *a* 以下の値を示し，わずか29点においてのみ 1.00 mg Chl. *a* 以上の高い値が見られた．全測定値を，観測時期・海域の相異により，東西方向に，(1) 東部インド洋区海域（12月中～下旬），(2) 西部インド洋区海域（2月下旬～3月上旬），(3) 東部大西洋区海域（2月下旬～3月上旬）の3群に分けた．さらに南北方向に，亜熱帯水域，亜熱帯収束線域，亜南極表層水域，南極収束線域，南緯63度以北及び以南の南極表層水域の6水域に分けた．各群・各水域についてクロロフィル*a*量の平均値及び標準偏差を求め，植物プランクトン現存量の地理的分布及びその季節変動を調べた．各水域の平均値は 0.15～0.58 mg Chl. *a* m^{-3} の範囲にあり，過去に南極海域より報告された値とほぼ同様であった．南極海外洋域における表面クロロフィル現存量はそれ程高くないと思われる．

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