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Primary Production Studies in the South-West Indian Ocean 1961-1963

by

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Introduction

The International Indian Ocean Expedition (I.I.O.E.), planned by the Special Committee on Oceanographic Research (S.C.O.R.) of the International Council of Scientific Unions and sponsored by UNESCO, provided impetus to oceanographic research in the Indian Ocean, and oceanographers of many nations have participated in physical, chemical, biological, geological, meteorological and other programmes throughout the Indian Ocean. Part of the Republic of South Africa's contribution to the I.I.O.E. programme consisted of a general oceanographic investigation of the south-west Indian Ocean, conducted by the Division of Sea Fisheries' research ship AFRICANA II. The investigation, comprising three cruises, was carried out during the period 1961 - 1963.

Cruise 1 took place in subtropical waters south of Madagascar, and consisted of three transects. The first transect extended from Lourenço Marques eastwards for 900 miles, from there the second transect extended south-west (interrupted by an unscheduled visit to Mauritius), and the third transect extended back to the coast at Port St. Johns (Fig. 1). Cruise 2 consisted of a transect from Port Elizabeth to Marion Island, from there to the Crozet

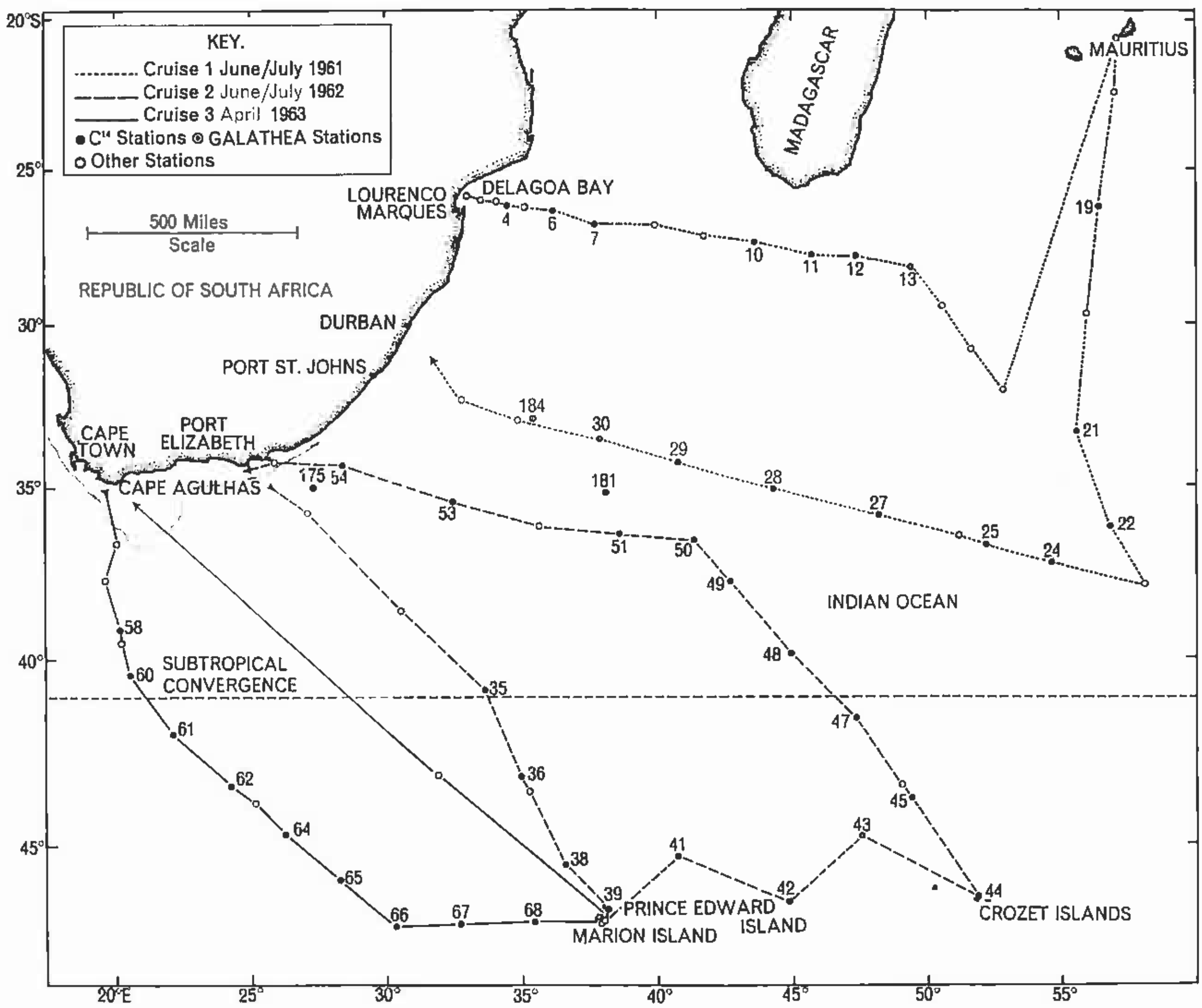

FIG. 1. Position of stations occupied during cruises of *Africana II* in the south-west Indian Ocean.

Islands and a return transect back to Port Elizabeth (Fig. 1). Cruise 3 consisted of stations extending southwards from Cape Agulhas to Marion Island (Fig. 1), where it was terminated due to unforeseen circumstances. The first cruise took place in June/July 1961, the second in June/July, 1962 and the third cruise in April, 1963.

During these cruises physical, chemical, biological and meteorological observations were carried out. The biological studies included measurements of primary productivity, the estimation of standing crop by means of phytoplankton counts and phytoplankton and zooplankton net hauls for taxonomic and distribution studies. This report is concerned with the measurement of primary productivity during the three I.I.O.E. cruises of AFRICANA II.

Methods

Primary Production Measurements

The rate of carbon assimilation by phytoplankton was measured by the C^{14} technique of Steemann Nielsen (1952). At each station occupied, water samples for productivity measurements were collected in a plexiglass-lined Nansen-Pettersson bottle from the three depths in the euphotic zone to which 100 per cent, 10 per cent and 1 per cent of the surface light penetrated. The light penetration into the sea was measured using a submarine photometer fitted with an Evans electroselenium photocell, as described by Steemann Nielsen and Jensen (1957). When sea conditions were unfavourable, only surface samples were taken.

The water samples were dispensed into glass-stoppered Jena glass bottles and after inoculation with 1 cc of radiocarbon solution of activity 4 microcurie, the samples were incubated for four hours in artificial light of intensity approximately 20,000 lux, in a water bath maintained at approximately sea surface temperature by means of circulating sea water. The water bath was similar to that described by Steemann Nielsen and Jensen (1957). The bottles were covered by neutral glass filters (ON 31 and ON 32, manufactured by Chance-Pilkington Optical Works) which transmitted the same fraction of the incident radiation as found *in situ* at the depths sampled. Dark bottles, similarly exposed, were used as controls.

After the incubation period, the samples were filtered through membrane filters (group 2, Membranfilter, Göttingen) to retain the phytoplankton; the filters were then dried in special holders to prevent shrinkage and were stored in plastic containers in a desiccator containing silica gel.

In the laboratory ashore, the filters were exposed to fuming hydrochloric acid for 20 minutes to remove all traces of inorganic radioactive carbon. A Geiger-Müller counter tube with a Philips scaler (type 111.531) was used to measure the activity of both the phytoplankton samples and the radiocarbon solution.

In the calculations of the rate of carbon fixation, the carbonate-carbon content of sea water was assumed to be 25 mg/l. A correction for non-photosynthetic uptake of C^{14} was applied by subtracting the dark bottle counts; no correction was applied for the isotope effect. Production rates were expressed as milligrams of carbon per cubic metre per hour (mgC/m^3/hr).

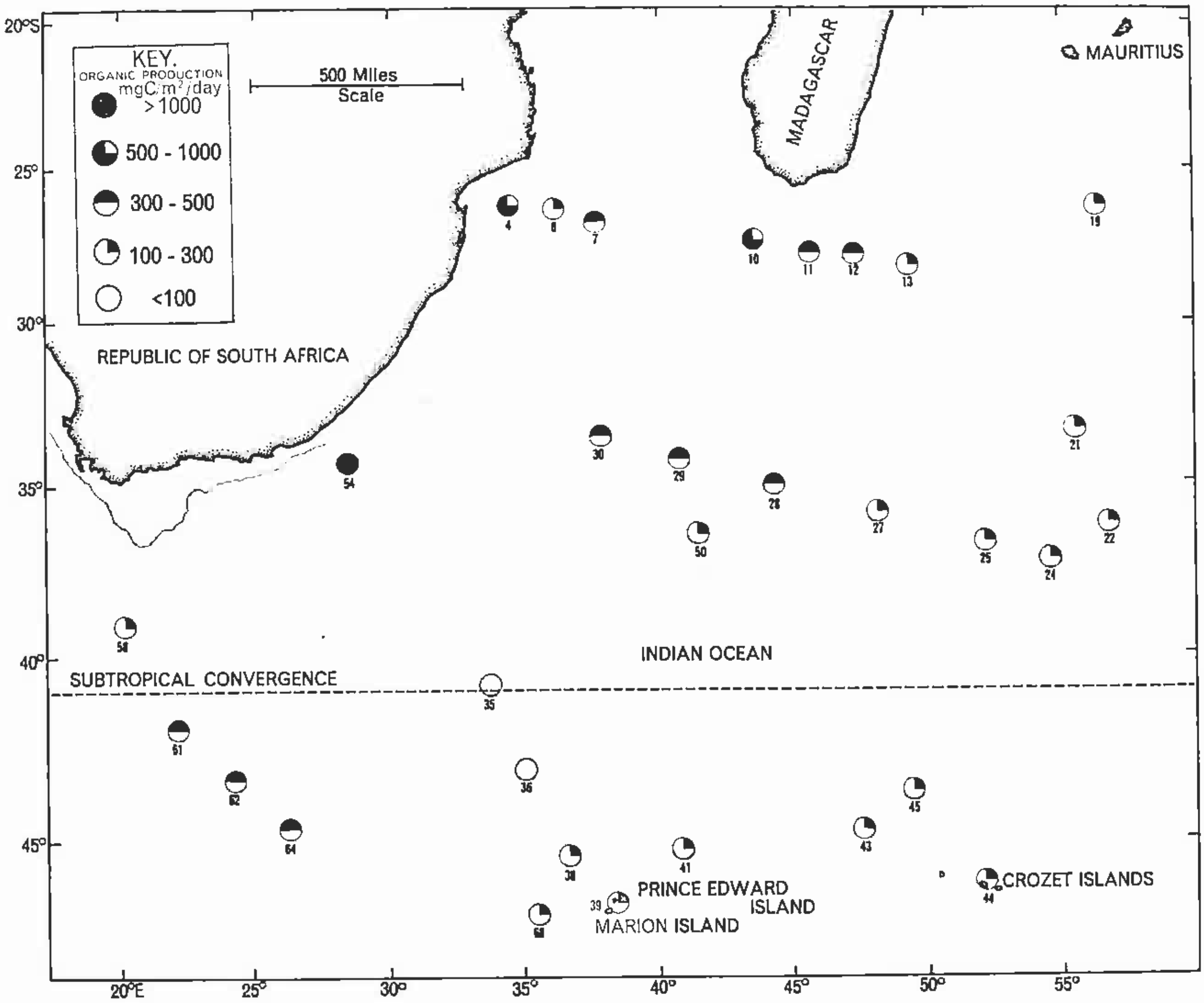

FIG. 2. Distribution of organic production in the south-west Indian Ocean.

By integration the production in the water column beneath one square metre surface was calculated and results were expressed as milligrams of carbon per square metre per day ($mgC/m^2/day$). The hours of daylight (to the nearest 0.25 hour) between sunrise and sunset were used in the calculations of daily production. The production data are given in Tables I, II and III, and a chart showing the distribution of productivity is given in Fig. 2.

Hydrographic Data

The hydrographic data were provided by the Division of Sea Fisheries. These included temperature, salinity and inorganic phosphate data and are presented in Tables IV, V, and VI. The molybdenum-blue colorimetric method was used to determine the concentration of inorganic phosphate, and salinity was measured conductometrically using a Thermostat Salinity Meter. A description of the methods used is given by Orren (1963) and Rand (1965).

Hydrography

Since the existence and growth of phytoplankton are intimately related to the environment in which they live, a brief description of the main hydrographic features of the surface waters of the south-west Indian Ocean is given below. A detailed description of the hydrography of this region is given in papers by Clowes (1950), Orren (1963, 1964), Darbyshire (1964), Visser and van Niekerk (1965) and others.

Water Masses, Currents and Eddies

In the south-west Indian Ocean, surface water masses of tropical, subtropical and sub-Antarctic origin are present. The tropical surface water of high temperature and low salinity was present only in the extreme north of the area; and the Tropical Convergence, marking the boundary between tropical and subtropical waters, was found at approximately 24°S (Orren, 1963).

The Subtropical Convergence, found at about 42°S, forms the boundary between the surface waters of subtropical origin and those of sub-Antarctic origin. (The approximate position of this Convergence is shown in Figs. 1 and 2). In general, the surface waters of subtropical origin are warm, highly saline and have a low nutrient salt content, whereas surface waters of sub-Antarctic origin are colder, less saline and have a high nutrient salt content.

During the cruises which took place in winter and autumn, surface temperatures varied from 25.87°C at Mauritius to 3.90°C at Possession Island (Tables IV, V, and VI). The highest temperatures were found in the north and in the Moçambique/Agulhas Current system to the west of this area. At the core of the Moçambique Current off Delagoa Bay, temperatures of 24.58°C and 24.64°C were recorded (Orren, 1963), and farther south in the Agulhas Current, temperatures of 20°C were found. During summer, higher temperatures would be expected. East and south of the Moçambique/Agulhas Current system there was a gradual decrease in temperature. At the Subtropical Convergence there was a sharp fall in temperature, often as much as 11°C, and south of the Convergence temperatures decreased gradually to approximately 5°C off Marion Island.

At the northern stations, 1 - 13, and at the coastal station 32, a marked thermocline was present. The temperature gradient became less marked farther south and a thick well-mixed surface layer extended to 150 - 200 metres (Orren, 1963). South of the Convergence, the waters were generally well mixed from the surface to depths of 150 metres and over.

Surface salinities were relatively low in the northern part of the area ranging from 35.21 to 35.49$^0/_{00}$, but increased southwards; along the line of stations 23-32 salinities ranged from 35.40 to 35.60$^0/_{00}$. Across the Subtropical Convergence a sharp drop in salinity was experienced, as much as 1.7$^0/_{00}$ along some lines, to salinities of 33.8$^0/_{00}$ in waters of sub-Antarctic origin.

The Subtropical Convergence is subject to seasonal variation. During winter it advances to about 41°S, whereas during summer it retreats to approximately 43°S (Orren, 1964). The variation in position of the Convergence is apparently associated with seasonal variations in the flow of the Agulhas Current, which is strongest in April and weakest in October (Darbyshire, 1964).

Numerous eddies occur in the current system (Darbyshire, 1964), for example, one was present over the Moçambique Terrace and another was found off Delagoa Bay between the main current and the coast (Orren, 1963); the small-scale sub-surface upwelling associated with this eddy resulted in increased phosphate values in the surface waters (see below). Approximately one hundred miles off Port Elizabeth, high productivity values and large plankton concentrations were obtained on the outer edge of the Agulhas Current, in an area of mixing along the interfaces between the Agulhas Current and the north-flowing counter-current (Orren, 1965).

Distribution of Inorganic Phosphate

In the area covered by cruise 1, excluding coastal stations 1 - 4 which were in an area of upwelling, the surface phosphate values ranged from 0.25 to 0.54 mg-at./m^3, with the highest values found at stations 23-32. There was a gradual increase in phosphate content with depth, but high concentrations (1.0 mg-at./m^3) were only found far below the euphotic zone (Table VI).

Small-scale upwelling occurred along the inner boundary of the Moçambique Current off Delagoa Bay, and at stations 1 - 4 situated in this area, higher phosphate values were found than at the stations situated farther off-shore. At stations 1, 2 and 3 the surface phosphate values were 1.14, 0.75 and 0.72 mg-at./m^3, respectively; there was a marked increase in phosphate content with depth and at 100 metres values of 1.9 mg-at./m^3 were found. Station 4 was situated on the edge of the area of upwelling and here the phosphate values were less than those found at stations 1, 2 and 3; the surface value at station 4 was 0.59 mg-at./m^3, whereas at 100 metres the concentration was 0.69 mg-at./m^3 (Table IV).

As the Subtropical Convergence was approached from the north, higher surface phosphate values were obtained and at several stations on the edge of the region of the Convergence, the phosphate concentrations were as high as 1.0 mg-at./m^3 (Table V). South of the Subtropical Convergence, values as high as 2.0 mg-at./m^3 were obtained at certain stations (Table VI).

Primary Production Results

Primary production values in the south-west Indian Ocean varied from 30 to 1080 mgC/m^2/day. This wide range is not altogether surprising considering that in the area covered by the cruises, stretching from latitudes 26° to 47°S, water masses of tropical, subtropical and sub-Antarctic origin were encountered. The production results from the 3 cruises are given in Tables I - III and Figs. 2 and 3.

Geographic Variation in Productivity

In the region north of the Convergence the production rates were very variable ranging from 30 to 1080 mgC/m^2/day, yet at 11 out of 21 stations production rates did not exceed 300 mgC/m^2/day (Fig. 2). Pockets of high productivity (>500 mgC/m^2/day) were found in Delagoa Bay and off Port Elizabeth in areas where moderate upwelling and pronounced mixing occur. Production rates measured in the summer in this region north of the Convergence during the Galathea Expedition (Fig. 1), ranged from 100 - 240 mgC/m^2/day (Steemann Nielsen and Jensen, 1957).

South of the Convergence in the temperate region production rates were

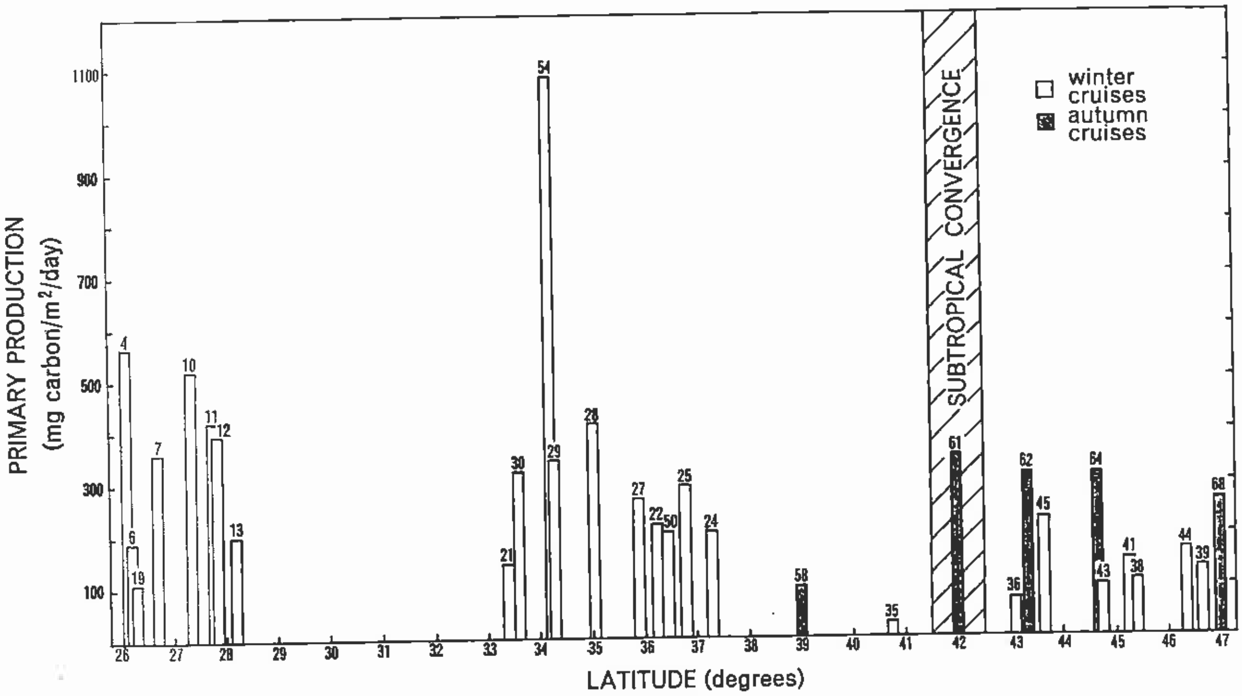

FIG. 3. The variation of primary production with latitude in south-west Indian Ocean.

less variable and ranged from 260 - 350 mgC/m²/day during the autumn months. During the winter production did not exceed 250 mgC/m²/day.

Environmental Factors Controlling Production

Illumination and nutrient availability are considered the two environmental factors of greatest significance in determining the production of organic matter in the open ocean, and as pointed out by Ryther (1963), "It is the variability of these factors and of the hydrographic features which control their availability that are responsible for the geographic variation in marine productivity." (See also reviews by Raymont, 1963; Steemann Nielsen, 1963; and Strickland, 1965 amongst others.)

Nutrients

In the subtropical region north of the Convergence there was considerable variation in the inorganic phosphate content of surface waters (and presumably of other nutrients as well) depending on the local hydrographic conditions (page 6). Except in those areas where hydrographic conditions promote enrichment of the surface waters, the euphotic zone was phosphate-deficient and in general the 1.0 mg-at./m³ phosphate isopleth lay well below it. In contrast, in the temperate region south of the Convergence, high concentrations of phosphate (up to 2.0 mg-at./m³) were present in the surface waters.

The paucity of nutrients in the surface waters was most pronounced at the most northerly stations where a thermocline was generally well developed. At stations 6, 13, 19 and 21 the lowest production rates on cruise 1 were obtained. It is of interest to note that the lowest production rate, 109 mgC/m²/day, was at station 19, the only station in waters of tropical origin where primary production was measured on this cruise. Here, the surface phosphate value was very low (0.26 mg-at./m³).

Where nutrient enrichment of the euphotic zone occurs, a high rate of production may generally be observed. Upwelling causes large scale enrichment, but other hydrographic conditions promoting turbulence and mixing may cause enrichment on a smaller scale (Strickland, 1965). A number of the areas where enrichment occurs are discussed below.

Areas of Upwelling. — Station 4 was situated on the edge of an area of upwelling in Delagoa Bay (Figs. 1 and 2). Here, the rate of production was 565 $mgC/m^2/day$, showing that under conditions where nutrient enrichment occurs, high rates of carbon assimilation are obtained.

Boundaries of Currents. — The highest production rate, 1080 $mgC/m^2/day$, was at station 54, situated approximately one hundred miles off Port Elizabeth. This station was in an area of extensive mixing along the boundary of the Agulhas Current and the northward flowing counter-current. High phytoplankton counts and zooplankton volumes were also obtained here (personal communication, Elizabeth A. Nel).

Bottom Topography. — Enrichment of the euphotic zone resulting from the upward deflection of nutrient-rich water by submarine ridges probably accounts for several of the other high values recorded. Thus, at stations 10, 11, 12 and 28 situated in the vicinity of the Madagascar Ridge moderately high levels of production (390 - 520 $mgC/m^2/day$) were obtained.

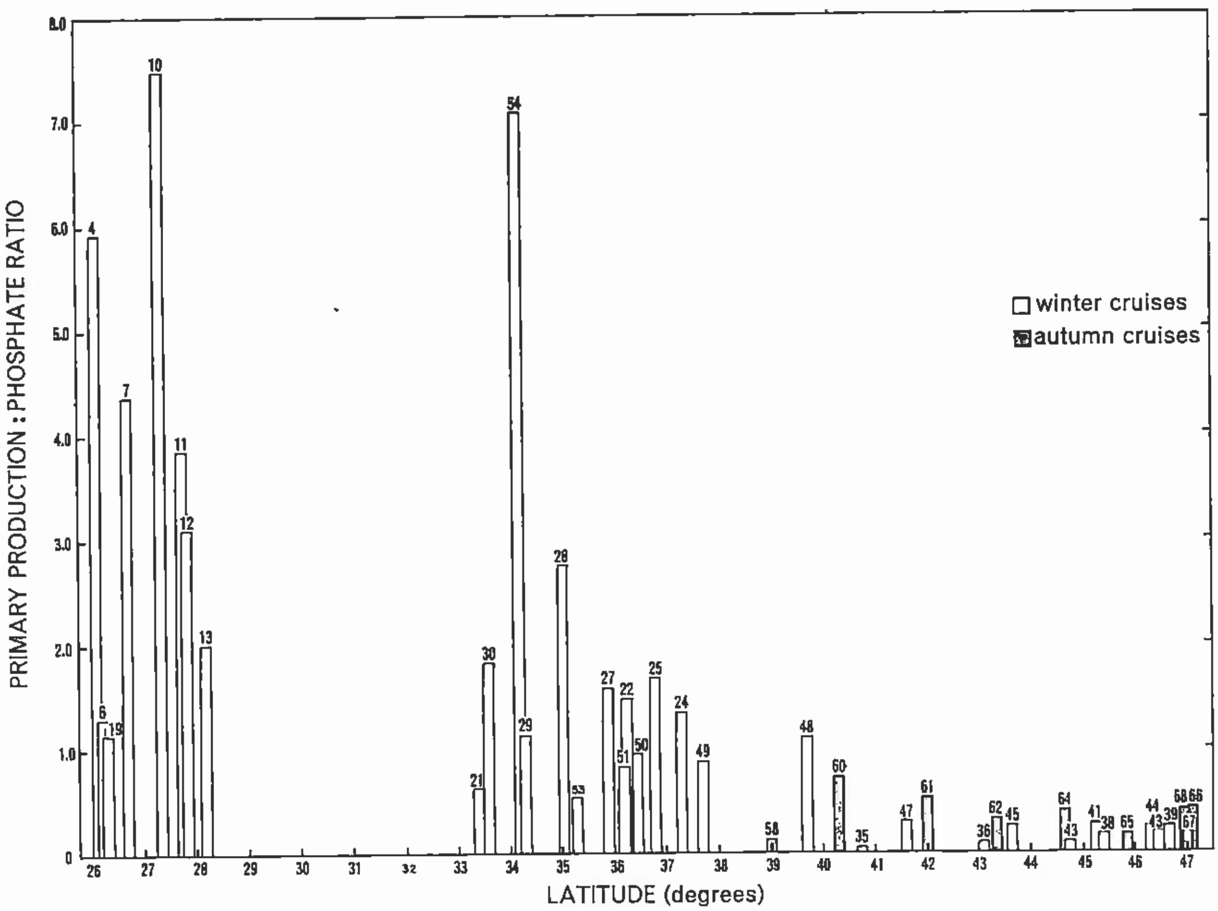

FIG. 4. The variation with latitude of the ratio, primary production: phosphate, in the south-west Indian Ocean.

Primary Production: Phosphate Relationships

The geographic variation of the primary production: phosphate ratio in surface waters is shown in Fig. 4. This ratio is very variable in the region between latitudes 26° and 42°S. Much less variable and lower values were found in the temperate waters south of the Convergence.

It is interesting to speculate on the possible causes of the large variation in the production: phosphate ratio at stations in subtropical waters. A very low ratio may be due to a low production rate caused by the paucity of nutrients. Strickland (1965), considers that in the marine environment a shortage of nitrogen rather than phosphate is usually responsible for limiting phytoplankton photosynthesis. A sparse phytoplankton standing crop resulting from heavy grazing or from the effects of instability of the water column may also contribute to low production values and therefore to *low* production: phosphate ratios. A possible reason for the very *high* ratios is that nutrient determinations do not reflect the rate of replenishment or regeneration of the nutrient in the euphotic zone, for, when optimum conditions for photosynthesis exist, nutrients may be used up as fast as they are mixed into the euphotic zone. For example, at stations 4, 10 and 54 where both the highest production rates and production: phosphate ratios were obtained, enrichment of the euphotic zone occurs to a greater or lesser degree (page 9).

At all stations south of the Convergence very low production: phosphate ratios were obtained (Fig. 4). Inorganic phosphate concentrations were high (>1.00 mg-at./m^3) and thus unlikely to have been limiting production. Since these stations were occupied in winter and autumn, it is likely that light was the critical factor limiting production. However, the effects of grazing and instability of the water column (mixing extended from the surface to depths greater than 150 m) may also be important in controlling the size of the phytoplankton crop and hence the production. Temperature is considered to have little or no direct effect on phytoplankton production (Raymont, 1963).

Radiation

During winter months in temperate regions light is considered the most important environmental factor limiting production (Steemann Nielsen, 1954). This hypothesis is supported by these results, for the primary production levels in temperate waters were lower than levels in subtropical waters, despite the high concentrations of phosphate and presumably of other nutrients as well. Furthermore, the amount of carbon fixed per unit phosphate in surface waters was much less in the southern region than in the northern region (Fig. 4). Finally, primary production rates during winter were lower than levels obtained in autumn when light conditions are more favourable for phytoplankton photosynthesis.

Various aspects of the radiation factor, such as the amount of light available to the phytoplankton in a column of water and the length of the daylight period, are of significance in affecting production. To illustrate the latitudinal variation of these factors, a comparison was made of the depth of the euphotic zone and the daylight period between the northern-most and southern-most stations; unfortunately comparisons of the incident radiation could not be made. The average daylight period and depth of the euphotic zone at stations at approximately 27°S was 10.25 hours and 80 metres, respectively, whereas at stations at about 47°S the average daylight period was 8.5 hours and the depth of the euphotic zone was 54 metres.

Seasonal Variation of Productivity

Light conditions vary latitudinally and seasonally. In autumn at 47°S the mean daylight period was nearly 11 hours, whereas during winter it was only 8.5 hours. The average depth of the euphotic zone in autumn was 60 metres and in winter was 54 metres. Thus, light conditions were generally more favourable for photosynthesis in autumn than in winter. Production levels were correspondingly higher and ranged from 260 to 350 mgC/m²/day in autumn, but did not exceed 250 mgC/m²/day in winter (Fig. 3).

Summary

1. Three cruises were undertaken by R.S. AFRICANA II, in the south-west Indian Ocean as part of the I.I.O.E. programme. The first cruise took place during winter, 1961, the second in winter, 1962 and the third in autumn, 1963.

2. The area covered by the cruises lay between latitudes 26° and 47°S. Water masses of tropical, subtropical and sub-Antarctic origin are present in this region. The Tropical Convergence forms the boundary between the tropical and the subtropical waters, and the Subtropical Convergence marks the boundary between the waters of subtropical and sub-Antarctic origin.

3. The geographical variation in production in this area from 26° to 47°S was discussed. Production ranged from 30-1080 mgC/m²/day. In the area north of the Subtropical Convergence, the paucity of nutrients in the surface waters was considered the main factor limiting production. In areas where hydrographic conditions resulted in increased availability of nutrients, higher production values were obtained. Pockets of high productivity (>500 mgC/m²/day) were found in Delagoa Bay and off Port Elizabeth. Radiation was considered to become increasingly important as a factor limiting production as one moved southwards, and in the area south of the Convergence it was considered the most important limiting factor.

4. Seasonal variation in productivity was apparent at stations south of the Convergence. Production values obtained during autumn (260-350 mgC/m²/day) were higher than those obtained during the winter (<250 mgC/m²/day). Seasonal variation in production was largely attributed to the variation in radiation.

Acknowledgments

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TABLE I. PRIMARY PRODUCTION DATA FROM CRUISE 1, JUNE/JULY, 1961

Station	Sampling Depth metres	Hours Daylight	Organic Production	
			mgC/m³/hr	mgC/m²/day
4	0	10.25	3.50	
	28		0.18	565
	66		0.01	
6	0	10.25	0.45	
	22		0.35	188
	75		0.01	
7	0	10.25	1.49	
	39		0.14	360
	86		0	
10	0	10.25	2.39	
	34		0.26	521
	75		0.02	
11	0	10.25	1.00	
	46		0.35	419
	99		0.02	
12	0	10.25	1.43	
	37		0.30	395
	78		0.02	
13	0	10.25	0.76	
	41		0.09	202
	74		0.05	
19	0	10.50	0.30	
	32		0.12	109
	78		0.04	
21	0	10.25	0.30	
	50		0.12	143
	103		0.01	
22	0	10.00	0.66	
	25		0.42	218
	55		0.13	
24	0	10.00	0.61	
	36		0.23	206
	75		0.05	
25	0	10.00	0.85	
	37		0.27	296
	89		0.07	
27	0	10.00	0.58	
	32		0.45	270
	69		0.12	
28	0	10.00	1.45	
	32		0.45	415
	69		0.15	
29	0	10.00	0.54	
	42		0.50	343
	85		0.08	
30	0	10.25	0.99	
	32		0.46	321
	65		0.03	

TABLE II. **PRIMARY PRODUCTION DATA FROM CRUISE 2, JUNE/JULY, 1962**

Station	Sampling Depth metres	Hours Daylight	Organic Production	
			mgC/m³/hr	mgC/m²/day
35	0	9.25	0.04	
	35		0.05	29
	69		0.04	
36	0	9.00	0.10	
	32		0.13	77
	66		0.16	
38	0	8.75	0.25	
	33		0.17	110
	66		0.17	
39	0	8.50	0.37	
	25		0.27	135
	51		0.34	
41	0	8.75	0.42	
	25		0.38	
	47		0.29	
42	0	8.75	0.36	
43	0	8.75	0.20	
	19		0.26	.01
	41		0.39	
44	0	8.50	0.41	
	36		0.30	168
	64		0.20	
45	0	9.00	0.45	
	27		0.46	232
	59		0.38	
47	0	9.25	0.31	
48	0	9.50	1.11	
49	0		0.39	
50	0	9.75	0.52	
	31		0.20	204
	67		0.34	
51	0	9.75	0.50	
53	0	10.00	0.16	
54	0	10.00	2.83	
	19		3.11	1079
	39		2.04	

TABLE III. PRIMARY PRODUCTION DATA FROM CRUISE 3, APRIL, 1963

Station	Sampling Depth metres	Hours Daylight	Organic Production	
			mgC/m³/hr	mgC/m²/day
58	0	11.50	0.09	
	35		0.16	100
	64		0.14	
60	0	11.50	1.11	
61	0	11.25	0.76	
	33		0.46	349
	62		0.29	
62	0	11.25	0.74	
	26		0.45	313
	59		0.30	
64	0	11.25	0.60	
	33		0.51	315
	62		0.16	
65	0	11.00	0.42	
66	0	11.00	0.75	
67	0	11.00	0.38	
68	0	10.75	0.50	
	40		0.37	266
	64		0.24	

TABLE IV. HYDROLOGICAL DATA FROM CRUISE 1, JUNE/JULY, 1961

Station	Position	Sounding metres	Sampling Depth metres	Temp. °C	Salinity ‰	Phosphate mg-at./m³
4	26° 09′ S	800	0	24.58	35.41	0.59
(A1227)	34° 30′ E		20	24.57	35.41	0.59
			50	24.56	35.43	0.61
			100	20.12	35.26	0.69
6	26° 12′ S	2090	0	24.01	35.40	0.35
(A1229)	36° 12′ E		20	23.97	35.40	0.43
			50	22.58	35.33	0.61
			100	21.02	35.53	0.35
7	26° 42′ S	4575	0	23.74	35.31	0.34
(A1230)	37° 41′ E		20	23.69	35.30	0.43
			50	23.68	35.30	0.45
			100	23.27	35.38	0.46
10	27° 22′ S	4130	0	22.77	35.37	0.32
(A1233)	43° 35′ E		20	22.67	—	0.39
			50	22.57	35.37	0.33
			100	20.55	35.49	—
11	27° 47′ S	2450	0	23.27	35.34	0.26
(A1234)	45° 41′ E		20	23.25	35.30	0.29
			50	22.58	35.42	0.33
			100	20.97	35.41	0.63

Table IV continued

Station	Position	Sounding metres	Sampling Depth metres	Temp. °C	Salinity ‰	Phosphate mg–at./m³
12 (A1235)	27° 48′ S 47° 19′ E	2220	0	22.69	35.31	0.46
			20	22.69	35.33	0.65
			50	22.64	35.32	0.73
			100	22.39	35.41	0.77
13 (A1236)	28° 11′ S 49° 20′ E	4650	0	21.11	35.49	0.38
			20	21.10	35.46	0.36
			50	20.60	35.69	0.41
			100	17.85	—	0.58
19 (A1242)	26° 16′ S 56° 21′ E	5220	0	22.48	—	0.26
			20	22.48	35.34	0.29
			50	22.46	35.35	0.35
			100	17.71	35.60	0.53
21 (A1244)	33° 24′ S 55° 32′ E	2960	0	17.65	35.55	0.48
			20	17.67	35.54	0.57
			50	17.66	35.53	0.56
			100	16.80	35.50	0.59
22 (A1245)	36° 16′ S 56° 45′ E	3900	0	15.92	35.50	0.45
			20	15.92	35.50	0.56
			50	15.91	35.52	0.62
			100	15.93	35.52	0.65
24 (A1247)	37° 17.5′ S 54° 36′ E	3640	0	15.80	35.47	0.45
			20	15.79	35.46	0.53
			50	15.79	35.48	0.56
			100	15.79	35.48	0.71
25 (A1248)	36° 48′ S 52° 08′ E	310	0	16.39	35.54	0.51
			20	16.39	35.53	0.52
			50	16.31	35.51	0.54
			100	16.29	35.52	0.57
27 (A1250)	35° 55′ S 48° 06′ E	3800	0	16.89	35.56	0.37
			20	16.89	35.55	0.43
			50	16.89	35.56	0.47
			100	16.91	35.55	0.55
28 (A1251)	35° 04′ S 44° 17′ E	1140	0	17.43	35.59	0.53
			20	17.42	35.57	0.53
			50	17.42	35.58	0.66
			100	17.30	35.56	0.78
29 (A1252)	34° 17′ S 40° 46′ E	5000	0	18.03	35.58	0.48
			20	18.03	35.58	0.51
			50	18.03	35.57	0.54
			100	18.05	35.58	0.71
30 (A1253)	33° 35′ S 37° 51′ E	5200	0	19.99	35.48	0.54
			20	19.97	35.50	0.56
			50	19.97	35.52	0.69
			100	18.91	35.51	0.74

TABLE V HYDROLOGICAL DATA FROM CRUISE 2, JUNE/JULY, 1962

Station	Position	Sounding metres	Sampling Depth metres	Temp. ° C	Salinity ‰	Phosphate mg–at./m³
35 (A1877)	40° 44′ S 33° 36′ E	5600	0	11.48	34.75	1.00
			20	11.48	34.75	—
			50	11.48	34.76	1.05
			100	11.50	34.75	—
36 (A1878)	43° 07′ S 34° 57′ E	4080	0	7.44	33.81	1.10
			20	7.16	33.82	—
			50	6.96	33.83	1.20
			100	7.19	33.90	1.50
38 (A1880)	45° 25′ S 36° 32′ E	2650	0	6.45	33.77	1.50
			20	6.28	33.77	—
			50	6.28	33.78	1.55
			100	6.00	33.81	1.45
39 (A1881)	46° 40′ S 38° 00′ E	0155	0	4.12	33.81	1.55
			20	4.27	33.84	—
			50	4.04	33.84	1.50
			100	3.99	33.85	1.50
41 (A1883)	45° 16′ S 40° 41′ E	2130	0	6.34	33.69	1.50
			20	6.30	33.68	—
			50	6.27	33.67	1.55
			100	6.27	33.69	1.55
42 (A1884)	46° 27′ S 44° 42′ E	2280	0	5.10	33.73	1.75
			20	4.99	33.73	—
			50	4.99	33.73	1.95
			100	4.79	33.75	1.65
43 (A1885)	44° 45′ S 47° 24′ E	2400	0	4.80	33.72	1.95
			20	4.78	33.72	—
			50	4.78	33.72	2.00
			100	4.79	33.72	2.00
44 (A1886)	46° 20′ S 51° 46′ E	0161	0	3.90	33.79	1.65
			20	3.88	33.77	—
			50	3.79	33.82	1.95
			100	3.59	33.88	2.00
45 (A1887)	43° 38′ S 49° 20′ E	2760	0	4.48	33.72	1.85
			20	4.48	33.71	—
			50	4.39	33.72	1.70
			100	3.88	33.79	1.95
47 (A1889)	41° 37′ S 47° 14′ E	3540	0	13.48	35.12	1.05
			20	13.48	35.14	—
			50	13.56	35.14	1.10
			100	13.40	35.10	1.05
48 (A1890)	39° 41′ S 44° 56′ E	3200	0	13.18	35.02	1.00
			20	12.95	34.94	—
			50	12.69	34.87	0.90
			100	12.67	34.89	0.95

Table V continued

Station	Position	Sounding metres	Sampling Depth metres	Temp. ° C	Salinity ‰	Phosphate mg–at./m³
49 (A1891)	37° 42′ S 42° 38′ E	3920	0	17.74	35.52	0.45
			20	17.76	35.52	—
			50	17.76	35.52	0.50
			100	17.75	35.52	0.50
50 (A1892)	36° 28′ S 41° 22′ E	5160	0	17.81	35.55	0.55
			20	17.81	35.55	—
			50	17.80	35.55	0.50
			100	17.70	35.56	0.55
51 (A1893)	36° 16′ S 38° 37′ E	5360	0	17.90	35.50	0.60
			20	17.88	35.50	—
			50	17.86	35.52	0.50
			100	17.84	35.52	0.55
53 (A1895)	35° 19′ S 32° 25′ E	4180	0	19.71	35.51	0 30
			20	19.69	35.51	—
			50	19.69	35.51	0.40
			100	19.65	35.50	0.35
54 (A1896)	34° 12′ S 28° 24′ E	3760	0	20.60	35.47	0.40
			20	20.57	35.47	—
			50	20.40	35.55	0.50
			100	18.94	35.53	0.50

TABLE VI. HYDROLOGICAL DATA FROM CRUISE 3, APRIL, 1963

Station	Position	Sounding metres	Sampling Depth metres	Temp. °C	Salinity ‰	Phosphate mg–at./m^3
58	39° 01′ S	5080	0	21.26	35.46	0.70
(A2388)	20° 04′ E		20	21.12	35.47	—
			50	20.82	35.50	0.90
			100	20.55	35.49	1.05
60	40° 18′ S	4800	0	13.67	34.64	1.55
(A2390)	20° 26′ E		20	12.37	34.43	—
			50	12.01	34 39	1.50
			100	9 60	34.30	1.60
61	41° 58.5′ S	5000	0	17.32	35.35	1.45
(A2391)	21° 59′ E		20	17.33	35.31	—
			50	17.32	35.33	1.25
			100	14.85	35.15	1.85
62	43° 22′ S	5000	0	10.79	34.42	2.25
(A2392)	24° 04′ E		20	10.80	34.35	—
			50	10.93	34.29	2.30
			100	11.32	34.51	2.20
64	44° 40′ S	4860	0	10.61	34.42	1.55
(A2394)	26° 05′ E		20	10 61	34.42	—
			50	10.77	34 47	1.65
			100	10.90	34.51	1.60
65	45° 51′ S	5640	0	9.16	34 05	2.40
(A2395)	28° 05′ E		20	9.26	34 00	—
			50	8 50	33.90	2.60
			100	7.53	34.18	2.65
66	47° 03′ S	5260	0	9 00	34 05	1 80
(A2396)	30° 05′ E		20	8 95	34 05	—
			50	8 90	34 04	2.00
			100	8 39	34.22	1.70
67	47° 01′ S	3400	0	5.73	33.85	2.05
(A2397)	32° 28′ E		20	5 69	33 84	—
			50	5 67	33 84	1.90
			100	5.50	33.84	1.95
68	46° 59′ S	3400	0	5 99	33 80	1.25
(A2398)	35° 11′ E		20	5.98	33.80	—
			50	5.97	33 80	1.45
			100	5.98	33.81	1.40