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*Primary Productivity in the Gerlache and Bransfield Straits of Antarctica*¹

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ABSTRACT

Distribution of the standing crop of phytoplankton and primary productivity in the Gerlache and Bransfield straits was studied during February and March 1965 aboard the Argentine Navy Icebreaker GENERAL SAN MARTIN. Relatively high standing-crop values, expressed in chlorophyll *a* per square meter, were exhibited in the euphotic zone, with ranges of 86–209 mg/m² in the Gerlache Strait area and 20–209 mg/m² in the Bransfield Strait area. Primary productivity was also high in both areas, but not commensurate with what might be expected for the standing crop in Gerlache Strait. Productivity values ranged from 0.21 to 1.58 gC/m²/day in the Bransfield area and from 0.58 to 1.20 gC/m²/day in the Gerlache area. Photosynthesis-light intensity relationships of phytoplankton obtained from standard depths and incubated in a light incubator showed low average assimilation numbers, at light saturation, e.g., 0.7 mg C hr/mg chl. *a* for Gerlache populations and 2.5 mg C hr/mg chl. *a* for Bransfield Strait populations. A high proportion of the total phytoplankton was found in the hypophotic layer of Gerlache Strait. Apparently old cells, characterized by low photosynthetic efficiency, settle downward into the nutrient-rich aphotic region. Complementary observations were also made in the oceanic region off the western coast of the Antarctic Peninsula, where standing crops and productivity were somewhat less than in the other neritic areas.

Introduction. In the years following Hart's (1934) publication concerning phytoplankton in the Bransfield and Gerlache straits, few papers have appeared on the primary productivity and biomass of this region. During the summer of 1959, Burkholder and Sieburth (1961) observed rich blooms of diatoms in the neritic areas between the Anvers and Brabant islands and the Antarctic Peninsula. In 1964 El Sayed et al. published data about chlorophyll *a* and carbon assimilation in the central area of Bransfield Strait. During February and March 1965, a plan to study the entire area was carried out.

The present investigation, at the end of the Antarctic summer, extends previous investigations concerning standing crop and primary productivity in

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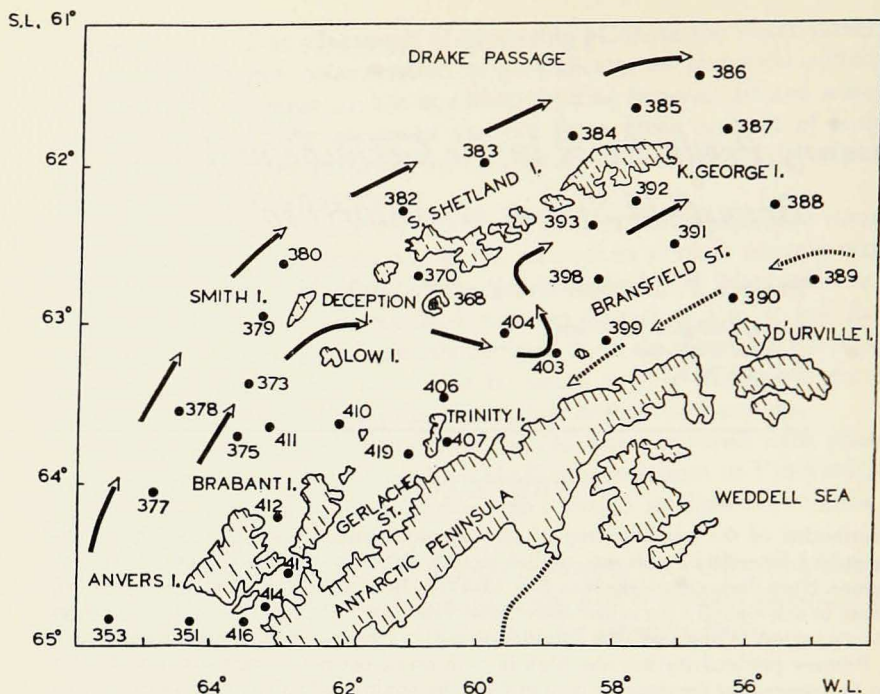


Figure 1. The Bransfield and Gerlache straits area, showing the number and position of the stations. The solid arrows indicate the approximate course of the Bellingshausen surface current, and the dotted arrows, the Weddell surface current.

the Gerlache-Bransfield area. Thirty-five stations were occupied in the Gerlache and Bransfield straits and in the surrounding oceanic area (Fig. 1).

Methods. At each station, samples of seawater were obtained at standard depths, from the surface to 100 m, by using nontoxic Van Dorn-type water bottles.

Sunlight penetration into the sea was determined either with a submarine photometer or a Secchi disc. Continuous recordings of incident solar radiation were made with an Eppley 50-junction pyranometer, and a Weston photonic cell, attached to a Bausch and Lomb chart recorder.

Generally, three liters of seawater were filtered through HA Millipore^R filters (pore size $0.45 \mu \pm 0.02$), with the addition of a small amount of magnesium carbonate. The samples were dried over anhydrous silica gel and kept dry, dark, and cold. The method and formula of Parsons and Strickland (1963) were employed in making spectrophotometric determinations of chlorophyll *a*.

Productivity measurements were made daily at "noon" stations, according

to the recommendations made by the International Council for the Exploration of the Sea (Ryther et al. 1958).

At each "noon" station, 200-ml samples, obtained at different depths from the surface to 50 m, were inoculated with 5 or 10 μC of labeled sodium carbonate (six samples for each depth). One bottle was exposed directly to fluorescent light, one was kept in darkness, and the other four were covered with neutral nylon filters, simulating an approximate reduction of 50, 25, 10, and 1% of the light in the incubator. All samples were incubated according to the general methods of Steeman-Nielsen (1952). Incubation was carried out in three G.M.^R incubators, cooled with ice and circulating seawater during a period of four hours, with maximal illumination of about 50 kilolux.

Filtration was accomplished rapidly by use of a 6-funnel filtering apparatus; each filtered sample was rinsed three times with 10 ml of filtered seawater. The filters were placed in individual pillboxes and stored in desiccators with anhydrous silica gel. Geiger counting was done at the Lamont Geological Observatory in an automatic Tracerlab gas flow counter having a background of approximately two counts per minute.

After counting, calculations were made, including correction for dark bottle uptake, background, C^{14} strength, variation in inorganic carbon contained in the seawater, and isotope effect. Correction for respiration was not made. Water samples from each depth were also used to determine pH, alkalinity, dissolved oxygen, and salinity.

Results. **HYDROGRAPHY.** Hydrological observations in Bransfield Strait were made on the R.R.S. *DISCOVERY* in April 1927, repeated and augmented on the R.R.S. *WILLIAM SCORESBY* during February 1929 (Clowes 1934).

Two main features of the currents in the Bransfield Strait area were observed (Fig. 1). (i) Part of the warm, light water of the surface current that flows northeastward from the Bellingshausen Sea enters the Bransfield Strait between the Snow, Smith, and Low islands, and in the vicinity of Deception Island it bends slightly southeastward; near Astrolabe Island it shifts to a northwesterly direction and finally flows northeastward again along the South Shetland Islands. Part of this surface water passes through the various straits of the South Shetland Islands and flows southwestward to form a counter-clockwise circulation around the islands. (ii) Another current, which brings a large amount of cold dense water from the Weddell Sea, enters Bransfield Strait north of D'Urville Island and flows southwestward; in the vicinity of Trinity Island it meets the slight northeasterly set from Gerlache Strait.

SURFACE DISTRIBUTION OF CHLOROPHYLL *a*. The stations sampled were located in three different areas:

(i) Bransfield Strait, from the tip of the Antarctic Peninsula to the area in which the Bellingshausen Sea water enters the strait between Smith and Low

islands, and where the Weddell Sea water meets the Gerlache Strait water near Trinity Island.

(ii) Gerlache Strait, including its boundaries with Bismarck Strait, Dallman Bay, and Orleans Strait.

(iii) The oceanic area off the western coast of Anvers and Brabant islands and off the northeastern coast of King George I Island in the South Shetland Islands.

In the Bransfield Strait area, the surface distribution of chlorophyll *a* showed a rich area in the central part of the strait, with values of 6.49 mg/m³ at the southwestern end and 1.40 mg/m³ at the northeastern end. A remarkable center of blooming, with 25 mg/m³, was observed in Foster Harbor, Deception Island.

In the Gerlache area, the highest values, 23.4 mg/m³, were obtained in the central area of the strait. The values in the boundary areas of the Bellingshausen Sea and Bransfield Strait fluctuated between 5.5 and 15.83 mg/m³.

In the oceanic region, the lowest values, with an average of 0.29 mg/m³, were found in the area where the Bellingshausen Sea water enters Bransfield Strait near Smith, Snow, and Low islands. In the rest of the area, the results varied from 0.30 mg/m³ near King George I Island to 6.7 mg/m³ southwest of Anvers Island.

VERTICAL DISTRIBUTION OF CHLOROPHYLL *a*. Several stations were selected in the different areas surveyed in order to show the characteristic vertical distribution of chlorophyll *a* within the euphotic zone in each region (Fig. 2).

The curves representing the Bransfield Strait area exhibit appreciable concentrations of chlorophyll *a*, 6.8 and 1.6 mg/m³, in the euphotic zone, especially in the layer of 0–10 m. The Gerlache Strait curves also show maximal chlorophyll content at the 0 to 10-m level, 23 and 13 mg/m³, but there was more chlorophyll *a* below the euphotic zone in Gerlache Strait than in the hypophotic zones in other areas.

For the oceanic area, the curves for vertical distribution of chlorophyll *a* in phytoplankton communities show maximal values for the base of the euphotic zone. The stations were sampled generally in the boundary between the Bellingshausen Sea waters and the rich neritic waters of the Gerlache and Bransfield straits.

High concentrations of chlorophyll *a* at the base of the euphotic zone have been observed in other regions. Riley et al. (1949) mentioned that this high concentration is observed when the rate of vertical diffusion is low. The sinking of planktonic cells from the surface is accompanied by an increase in the depth of the euphotic zone. Based on a mathematical model, Riley showed that this maximum (if it is productive) must be above the compensatory depth. Steele and Yentsch (1960), however, observed other maxima just at, or below, the compensatory depth. The factors responsible for these maxima are not clear, but the physiological condition of the cells appears to be closely related to their buoyancy.

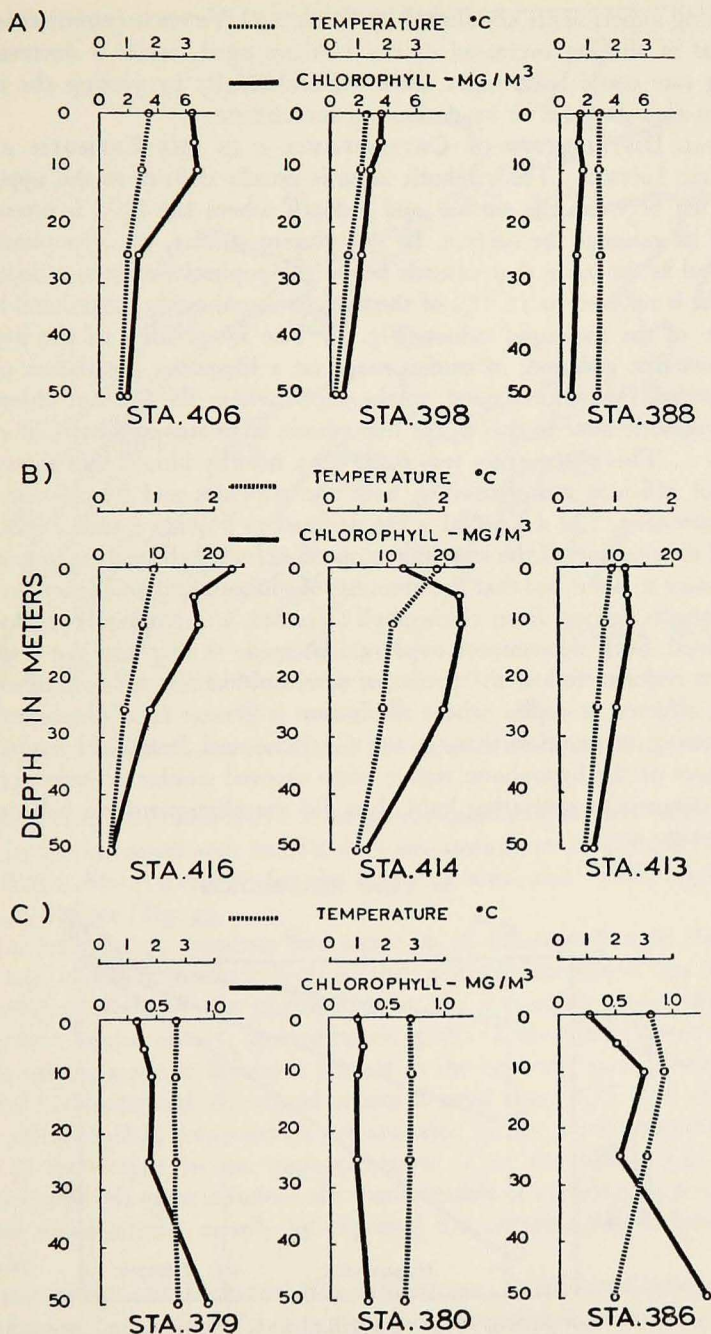


Figure 2. Vertical distribution of chlorophyll *a* and temperature at selected stations: (A) Bransfield Strait, (B) Gerlache Strait, and (C) oceanic area.

Sinking experiments conducted by Steele and Yentsch (1960) showed that the rate of sinking increased as the cultures aged, while a decrease in the sinking rate could be brought about experimentally by placing the cells in a nutrient-rich medium or by darkening the culture.

AREAL DISTRIBUTION OF CHLOROPHYLL *a* IN THE EUPHOTIC AND HYPOPHOTIC LAYERS. The euphotic zone is usually defined as the upper region of the sea between the surface and a depth where the light is attenuated to 1% of its value at the surface. In our present studies, the hypophotic region is defined as the zone that extends below the euphotic layer to a depth where the light is reduced to 10^{-4} % of the surface illumination, calculated by extrapolation of the measured values (Fig. 3). The lower limit of the hypophotic layer was first assigned, in studies made on a blooming population of phytoplankton off Deception Island, to the depth where the ratio of chlorophyll *a* in the euphotic zone to that in the hypophotic layer was equal to $\text{Chl } a \text{ Eu}/\text{Chl } a \text{ Hy} = 1$. This observation was made on a healthy bloom that showed capability for efficient assimilation in both the euphotic and hypophotic regions. The expression, $\text{Chl } a \text{ Eu}/\text{Chl } a \text{ Hy}$, seemed to provide a useful index to the vertical distribution of the standing crop of chlorophyll-bearing organisms. It is necessary to point out that the amounts of phaeophytin and other decomposition products derived from chlorophyll (Yentsch and Menzel 1963) were not determined. Such determinations should be made throughout the history of a bloom in order to follow the course of deterioration and survival of organisms that are situated at depths where respiration is greater than photosynthesis. It is interesting to mention that, in the Gerlache and Bransfield straits, planktonic algae of the hypophotic region often showed similar or better photosynthetic responses to saturating light than did the phytoplankton collected from the euphotic zone.

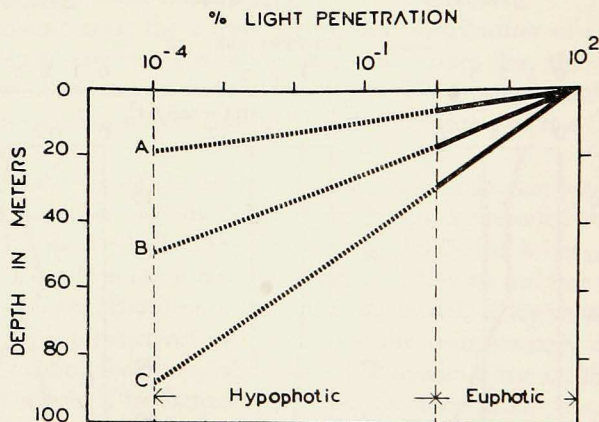


Figure 3. Characteristic per cent of light penetration in the different regions of the studied area: (A) Gerlache Strait, (B) Bransfield Strait, and (C) oceanic boundary.

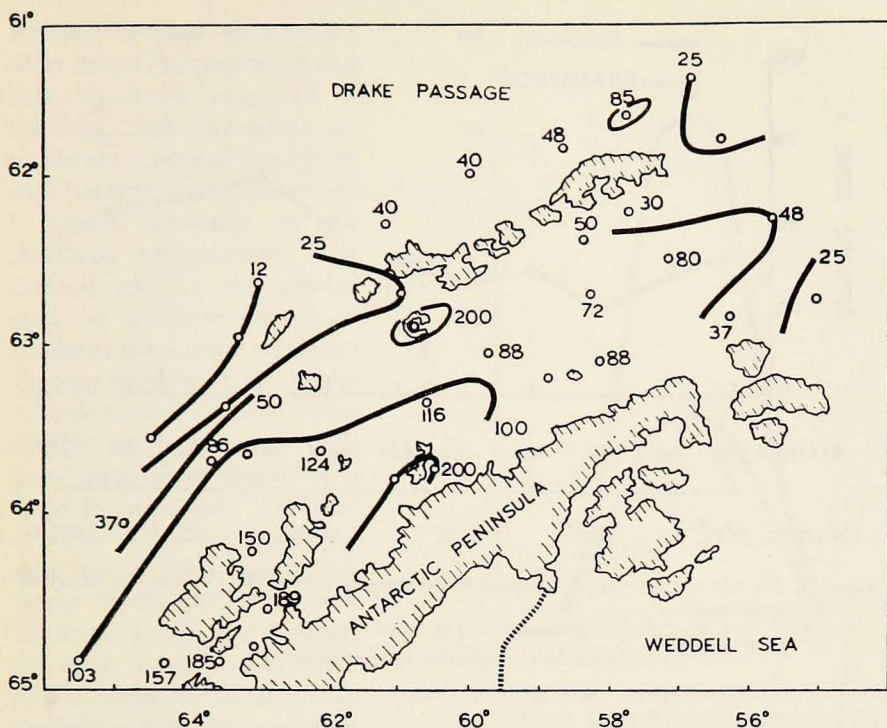


Figure 4. Horizontal distribution of chlorophyll *a* (in mg/m^2) in the euphotic zone of the studied area.

The amount of chlorophyll *a* contained in phytoplankton of the euphotic zone in the surveyed area exhibited values around 20–209 mg/m^2 for Bransfield Strait, 86–209 mg/m^2 for the Gerlache area, and 11–85 mg/m^2 for the oceanic stations (Fig. 4).

The assimilation numbers and amounts of chlorophyll *a* in the euphotic zone and in the hypophotic layer provide some indications of the history and physiological state of the phytoplankters. In a healthy bloom, like that in Deception Island waters, approximately 50% of the total chlorophyll *a* (euphotic and hypophotic layers) is present in the euphotic zone. Determinations for the Gerlache and Bransfield straits showed that 33% and 55% of the total chlorophyll *a*, respectively, are available for the photosynthetic processes (Fig. 5) that occur in the euphotic layer. That the planktonic population below the photic zone is indeed alive and capable of carrying on photosynthesis can be demonstrated merely by exposing the organisms to suitable amounts of light.

PHOTOSYNTHESIS-PIGMENT RELATIONSHIPS. Strickland (1960) and other investigators have referred to a fairly constant relationship between chlorophyll and photosynthesis in different species of planktonic algae, over a wide range

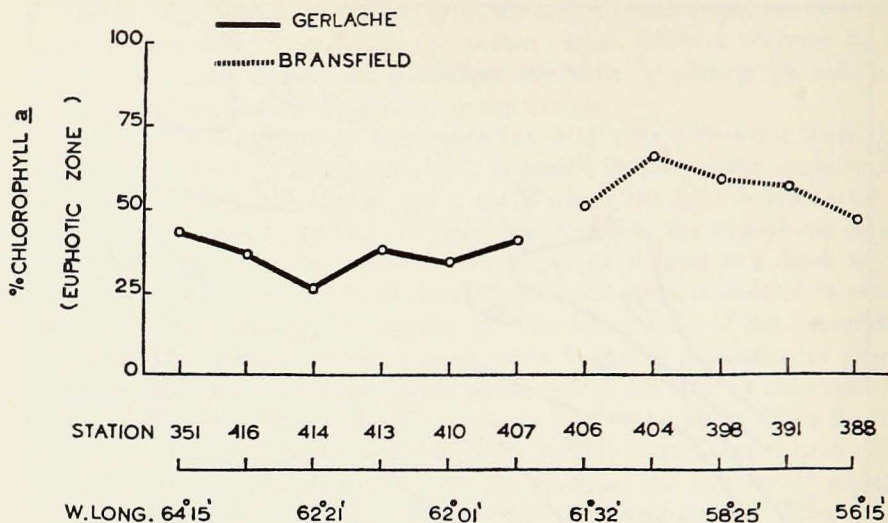


Figure 5. Per cent of chlorophyll *a* contained in the euphotic layer of the Gerlache and Bransfield straits area.

$$\text{Euphotic layer} = \frac{\text{chlorophyll } a \text{ in the euphotic layer}}{\text{chlorophyll } a \text{ euphotic} + \text{hypophotic zones}} \times 100.$$

of chlorophyll content. However, with natural populations subjected to optimal light intensities, it was found that photosynthesis-pigment relationships varied widely from less than 1 to 10 mgC/hr/mg chl. *a*, according to geographical distribution, environmental conditions, season of the year, and other factors.

In the present study of Antarctic neritic populations during the late summer, surface values ranging from 0.4 to 3.50 mgC/hr/mg chl. *a* were determined for the Bransfield and Gerlache straits. The lower assimilation numbers were determined from old blooms located in the euphotic zone in the central waters of Gerlache Strait. In the Bransfield Strait and Bellingshausen Sea communities, the assimilation number for surface populations showed similar values of about 2.5 mgC/hr/mg chl. *a*. A high assimilation number (5.2 mgC/hr/mg chl. *a*) was observed in subsurface plankton from Foster Harbor in Deception Island. The planktonic species in this area were different taxonomically from those in the rest of the area, possibly due to the different prevailing environmental conditions.

The low assimilation number of the phytoplankton populations in Gerlache Strait during March seems to indicate that the phytoplankters are in the summer lapse following the spring bloom.

PRODUCTIVITY DETERMINATIONS. It is possible to calculate the primary productivity of a planktonic community in several ways. Perhaps the most widely accepted way is to make determinations *in situ* at different depths.

Another method would simulate the *in situ* procedure, and then, by direct integration of the data, obtain the carbon assimilation expressed in $\text{g C/m}^2/\text{day}$. Neither of these methods is readily applicable in the Antarctic environment. The method used in the present study to calculate carbon assimilated per square meter per day was based upon the determinations of the photosynthesis-light intensity curves with populations from depths of 0 to 50 m, with daily curves of incident solar radiation, and with the available light at different depths (Burkholder and Mandelli 1965). Fig. 6 shows the main incident solar radiation averages for the Gerlache and Bransfield straits areas. Most of the days in the Bransfield area were overcast during

February 1965. The mid-day average was about 20 kilolux. However, the Gerlache area exhibited better light conditions, with mid-day averages of 50 kilolux.

The light penetration into the sea varied with the density of the planktonic populations. In the Gerlache area, the depth of the euphotic zone was about 10 m, and in the Bransfield Strait area, between 15 and 30 m. The average length of daylight in February at the latitude of the Antarctic Peninsula ($62\text{--}65^\circ\text{S}$) was about 18 hours.

The amount of carbon assimilated at different depths, determined from photosynthesis-light intensity curves, was plotted for five selected light intensities corresponding to the value of solar radiation for every hour of the day. Then the area under each curve was determined as $\text{mgC/m}^3/\text{day}$. These data were then plotted for each depth, and by graphical integration of the under area, the productivity of the water column was found in terms of $\text{gC/m}^2/\text{day}$.

In this type of calculation, the possibility of diurnal variations in productivity (Doty and Oguri 1957) are not taken into consideration because of the use of noontime photosynthesis-light intensity curves. Calculations were made according to the described noontime procedure for several stations in the surveyed areas.

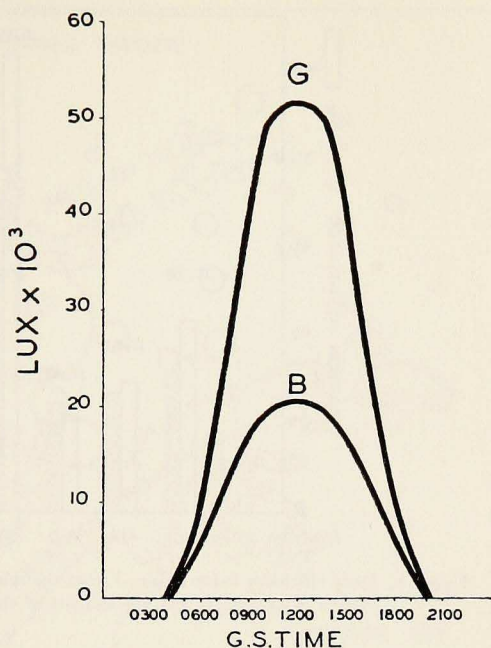


Figure 6. Daily averages of illumination recorded during February 1965. B Bransfield Strait, G Gerlache Strait.

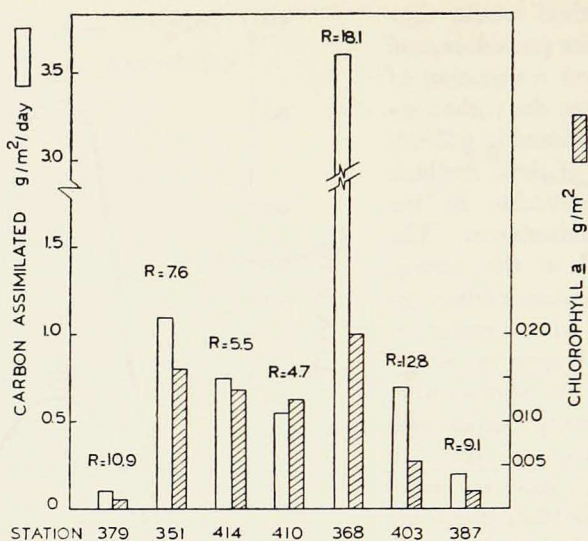


Figure 7. Daily efficiency index obtained from the relationship between the carbon assimilation expressed in $\text{gC}/\text{m}^2/\text{day}$ and the amount of chlorophyll a g/m^2 in the euphotic zone.

Based upon the primary productivity values and the chlorophyll a content in the euphotic zone, average daily efficiency indices (Fig. 7) were calculated for the water columns at different stations. These efficiency indices were then applied to other stations sampled at different times in the same area in order to calculate daily primary productivity based upon the amount of chlorophyll a contained in the planktonic populations of the euphotic zone. Values of productivity determined by direct and indirect calculations in the area are shown in Fig. 8. Values between 0.21 and $1.59 \text{ gC}/\text{m}^2/\text{day}$ were found for the Bransfield Strait area, 0.58 to $1.20 \text{ gC}/\text{m}^2/\text{day}$ for Gerlache Strait, and 0.12 to $0.93 \text{ gC}/\text{m}^2/\text{day}$ for the oceanic area.

Discussion. A summary of the results obtained in the present study is presented in Table I. In a relatively small area of Antarctica, such as the Bransfield and Gerlache straits, high values of chlorophyll a were observed in standing crops, but great differences occurred in the biological "vitality" of these phytoplanktonic populations during February and March 1965. It appears that differences in the species composition and dominance in Gerlache Strait compared with Bransfield Strait are not sufficient to account for observed differences in assimilation numbers in the two areas. Hart (1934) pointed out that, as the Antarctic summer season progresses, there are changes in the dominance and composition of the species in the Bransfield Strait area. It seems probable, however, that in the channels of the Palmer Archipelago a

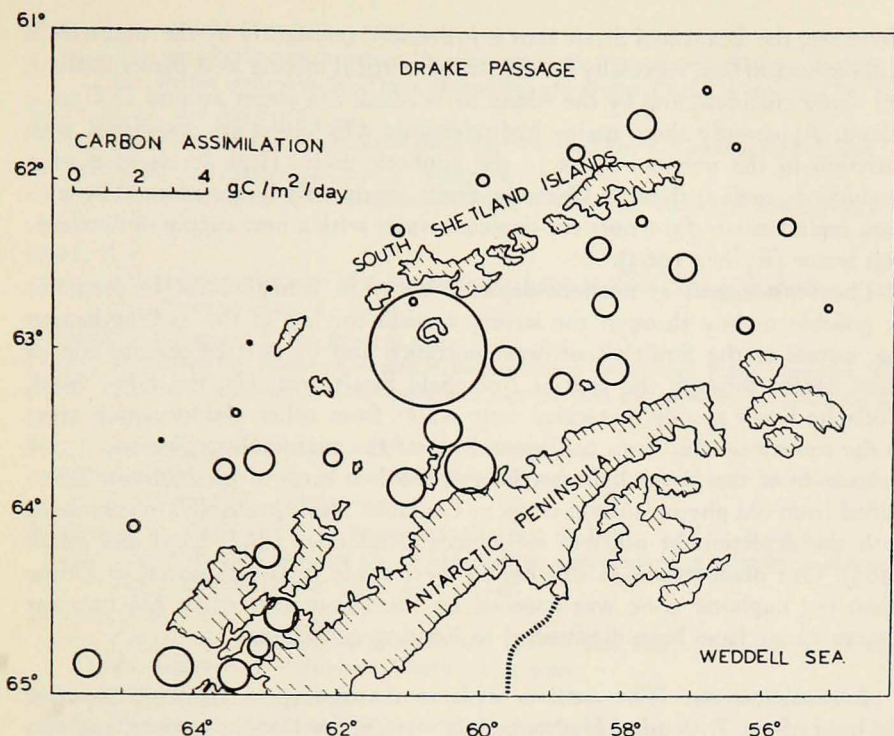


Figure 8. Horizontal distribution of the primary productivity in the euphotic zone of the Gerlache and Bransfield straits and in the oceanic surroundings, expressed in $\text{g C/m}^2/\text{day}$, February and March 1965. The size of the circle is proportionate to the quantity of chlorophyll *a* in the euphotic zone.

rich local planktonic community of *Biddulphia striata* and associated species may persist during the major part of the season.

It is important to consider certain environmental conditions in relation to the observed differences in the abundance and activity of the phytoplankton in different areas. The Gerlache Strait neritic communities live in a well-protected area surrounded by islands, where intense vertical mixing is absent.

Table I. Maximum, minimum, and mean values of chlorophyll *a* and carbon assimilation for the Gerlach and Bransfield straits and surrounding oceanic area during February and March 1965.

Area and number of stations sampled	Chlorophyll <i>a</i> in the euphotic zone (mg/m^2)			Daily production ($\text{gC/m}^2/\text{day}$)		
	Max.	Min.	Mean	Max.	Min.	Mean
Oceanic area (10)	85	11	34	0.93	0.12	0.37
Bransfield Strait (14)	209	20	68	1.59	0.21	0.70
Gerlache Strait (10)	209	86	151	1.20	0.58	0.86
Deception Island (1)	200	—	200	3.62	—	3.62

However, the Bransfield Strait area is influenced constantly by the water from Bellingshausen Sea, especially by the strong vertical mixing as it passes through the island channels, and by the eddies in Weddell Sea water around D'Urville Island. Apparently these major hydrodynamic differences are associated with variation in the nutrient levels in the euphotic zone. High levels of marine production, such as those in Gerlache Strait, could only be maintained by constant replacement of the nutrient-depleted water with a new supply of nutrient-rich water (Ryther 1963).

The replacement of nutrient-depleted water in Bransfield Strait seems to be possible mainly through the strong vertical mixing of the Bellingshausen Sea waters at the Strait's southwest entrance and by surface distribution of these waters through the central Bransfield Strait area. On the other hand, Gerlache Strait is able to receive only water from other plankton-rich areas to the southwest and from continental ice of the surrounding glaciers.

In spite of the better light conditions, the low rates of productivity determined from old phytoplankton crops in Gerlache Strait probably are correlated with the depletion of nutrient substances (Anderson 1964, Curl and Small 1965). Our observations in this region were made in late summer, at a time when the euphotic zone was lessened by the bloom and when the nutrient reservoir may have been diminished to limiting conditions.

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