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PRIMARY PRODUCTION OF THE BENTHIC MICROFLORA LIVING ON INTERTIDAL FLATS IN THE SANTOS ESTUARINE SYSTEM (24°S, 46°W), SÃO PAULO, BRAZIL

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Synopsis

Estimates of primary production of benthic microflora were carried out in the Santos tropical estuary, on the southern coast of Brazil (24°S, 46°W). The samples were obtained seasonally over a one-year period. Six stations with different environmental conditions were chosen. The samples, which consisted of the upper 2 mm of the sediment, were collected in the intertidal zone, according to Grφntved's (1960) methodology. The mean annual value of primary production was 45 mgC/m²/h, ranging from 1.0 to 301.0 mgC/m²/h. The highest values were observed at the more sheltered stations, which contained the highest amount of organic material and the highest input of polluted material. The epipsammic algae contributed with 40% of the total production while the epipelic ones contributed with 60%. The mean value for dark fixation of ^{14}C was 63%.

Descriptors: Benthos, Micro-organisms, Primary production, Intertidal zone, Sediments, Estuaries, Santos - SP.
Descritores: Bentos, Microrganismos, Produção primária, Zona entre-marés, Sedimentos, Estuários, Santos - SP.

Introduction

Santos Estuary is regarded as a highly disturbed and polluted environment. The high density of human population, the industrial development and the intense dock activities have induced environmental perturbations in the area. The physical, chemical and biological properties of the region have extensively studied. In relation to biological aspects the works of Carvalho (1952), Joly (1957), Lima & Vazzoler (1963), CETESB (1978), Gianesella-Galvão (1978), Tommasi (1979) and Monteiro (1980) should be mentioned; the paper of Gianesella-Galvão (*op. cit.*) refers to phytoplankton primary production. This is the first account on phytobenthos primary production undertaken in Brazil.

Benthic primary production is of fundamental importance in estuarine systems where its contribution to the total primary production is often greater than that of the phytoplankton (Hargrove, 1969; Leach, 1970); furthermore, the evaluation of the benthic primary production contributes significantly to a better understanding of the energy dynamics of coastal areas.

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Research concerned to benthic primary production has been carried out in polar zones (Matheke & Horner, 1974), in temperate zones (Grφntved, 1960, 1962, 1966; Gargas, 1970, 1972, 1980; Steele & Baird, 1968; Leach, 1970; Marshall *et al.*, 1971; Colocolloff, 1972; Cadée & Hegeman, 1974, 1977), and in tropical zones (Bunt *et al.*, 1972; Plante-Cuny, 1971, 1973, 1978; Sournia, 1976); however, as far as we are aware, no reference on the subject is available for the coast of Brazil and South America.

The purposes of this study are to evaluate the Santos estuarine system in relation to its potential yield of microbenthic production and to obtain biological information for a better understanding of this estuarine ecosystem.

Description of the sampling area

The Santos estuarine system is located on the coast of São Paulo, south-east of Brazil (24°S, 46°W). It is a tropical estuary with mean annual temperature of 20°C, annual rainfall ranging from 2000 - 2500 mm, and mean insolation of 155 hours monthly in the summer and 164 hours monthly in winter (Santos, 1965).

The 6 sampling stations present different environmental conditions; stations 1, 2 and 3 are located in Santos Bay, stations 4 and 6 in the middle of the estuary, and station 5 in Enseada Beach (Santo Amaro Island) in the open ocean (Fig. 1).

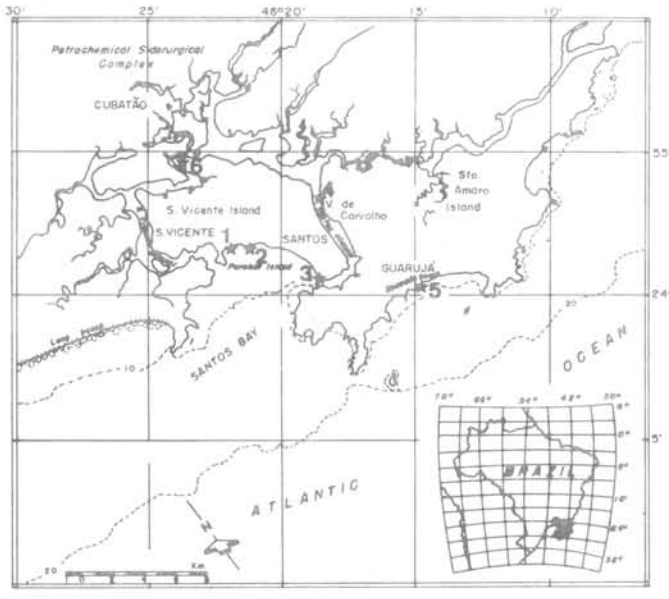

Fig. 1. Map of the estuary of Santos showing the six sampling localities.

Station 1 is exposed to direct wave action; green patches can always be noticed in the sediment. St. 2 is protected by Porchá Island which is quite close to the beach; near the sampling site there is a sewage outlet. St. 3 is located in the entrace of Santos Channel, inside the estuary, being under the influence of fresh water, industrial pollutants and wastes from port activities and sewage. At the sediment surface it can be seen a lot of polychaete's tubes from the genera *Onuphis* and *Diopatra*. St. 4 is located in front of the port area. In this location, salinity is quite variable, for it is affected by the fresh water that reaches this station and by the tides. Organic wastes of domestic origin and a permanent oil film cover the sediment surface. It is a sheltered beach with a permanent subsurface reducing layer. St. 5 is the most exposed to wave action, showing a clean sediment. St. 6 is very sheltered; it is located at Casqueiro River, at the back of the estuary. The salinity here is quite variable, and the sediment is dark. At this place a subsurface permanent reducing layer of decomposed material appears.

Methodology

For the evaluation of the benthic primary production in the intertidal zone, samples comprising the uppermost 2 mm of the sediment were obtained during ebb-tide following the procedure of Grøntved (1960). In the laboratory, the epipelic algae were separated from the sediment containing epipsammic algae by successive washings with filtered sea water (Millipore, HA, 45 µ pore). Water used for washing was collected in the respective sampling areas. After separation of the two algal fractions, two subsamples were taken from each fraction and were put in light and dark bottles. Each bottle received 1 ml of Na $H^{14}CO_3$, 10µCi of activity. The volume of each bottle was completed with filtered sea water. Incubation took place in the laboratory during a period of two hours. The incubator was provided with fluorescent lamps of about 20,000 lux and had constant temperature. Afterwards these samples were strained through a Millipore, HA, 45µ pore filter to obtain the material which had assimilated the ^{14}C.

The amount of ^{14}C assimilated was measured using a Packard Liquid Scintillation Spectrophotometer Model A-C 2425 Tricarb. The scintillation solution was prepared with Triton X-100 and tolluol 1:2, 7.000g PPO and 0.350g POPOP per liter (Bunt *et al.*, 1972).

The efficiency of the scintillation counter varied from 72% to 92% as determined by external standard ratio.

Environmental parameters were determined for each sampling locality. Measurements of the sea water temperature, salinity, dissolved oxygen and estimates of the oxygen saturation levels were made. The sediments were analysed as to temperature, organic matter content and granulometry. Conductivity measurements were carried out using a KAHLSICO Induction Salinometer, model 118 WA 200. Winkler's method was utilized for the determination of dissolved oxygen content of the sea water. Organic matter and granulometric analysis of the uppermost 2 mm of the sediment were determined according to Suguio's (1973) techniques.

Results

Environmental parameters

The water temperature during the study period ranged from 21.0 to 29.5°C while the temperature of the sediment ranged from 22.0°C to 35°C (Tab. 1). The salinity values ranged from 11.4°/oo (St. 6) to 34.7°/oo (St. 1) (Tab. 1). The dissolved oxygen values ranged from 4.1 ml/l (St. 6) to 9.2 ml/l (St. 5). Oxygen oversaturation was recorded in all stations. The percentage of organic matter in the sediment ranged from 0.06% (St. 5) to 3.00% (St. 6). The highest mean values were found in St. 4 (1.00%) and St. 6 (2.00%) and the lowest in St. 5 (0.12%).

The granulometric analysis of the sediment gave MZ ϕ values of 3.1; 3.5; 3.2; 3.3; 3.0 and 2.8 to Sts 1, 2, 3, 4, 5 and 6 respectively, ranging from fine (FS) to very fine sand (VFS) (Tab. 1). A redox layer was visible below the surface at St. 4 and St. 6 throughout the sampling period and only twice at St. 3; in St. 1, in Sts 2 and 5 it was not present.

Benthic primary production

During the study period the diatoms dominated over the other members of the microphytobenthos and were about 90% of the whole microflora population.

The benthic primary productivity values obtained during the study period varied from 1.0 mgC/m^2/h to 301.0 mgC/m^2/h. (Tab. 2). The mean values obtained in each station were 39.6 mgC/m^2/h (St. 1), 9.8 mgC/m^2/h (St. 2),

Table 1. Environmental parameters

Stations	Tide (mm)	Water (T°C)	Sediment (T°C)	Salinity (°/oo)	Dissolved oxygen (ml/l)	Saturation level of oxygen(ml/l)	Organic material content (%)	Granulometry
1	+0.4	25.0	24.0	34.7	6.5	4.7	0.5	VFS
2	+0.4	25.0	25.0	28.3	7.3	4.9	0.3	VFS
3	+0.4	25.0	24.0	21.1	6.6	5.1	0.5	VFS
4	+0.4	25.0	23.0	30.9	7.6	4.8	0.3	VFS
5	+0.4	25.0	24.0	31.2	6.9	4.8	0.09	FS
6	+0.4	25.0	24.0	26.5	6.9	5.0	1.3	VFS
1	+0.4	25.0	23.0	30.9	7.6	4.8	0.7	VFS
2	+0.4	25.0	24.0	31.2	6.9	4.8	0.8	VFS
3	+0.4	25.5	24.0	26.5	6.9	4.9	1.1	VFS
4	+0.3	25.0	24.0	34.7	6.5	4.7	0.4	VFS
5	+0.3	25.0	25.0	28.3	7.3	4.9	0.07	FS
6	+0.3	25.0	24.0	21.0	6.6	5.1	3.0	VFS
1	0.0	21.0	22.0	32.8	8.5	5.1	0.8	VFS
2	0.0	22.0	23.0	31.9	8.8	5.0	0.5	VFS
3	0.0	23.5	24.0	29.2	7.5	5.0	0.5	VFS
4	0.0	23.0	23.0	24.9	6.7	5.2	1.5	VFS
5	0.0	24.0	24.0	33.7	8.1	4.8	0.2	FS
6	0.0	27.0	26.0	17.1	4.1	5.0	2.1	VFS
1	+0.4	23.5	25.0	27.7	7.7	5.1	0.4	VFS
2	+0.4	23.0	27.0	27.3	8.0	5.1	0.4	VFS
3	+0.4	25.0	28.0	21.9	6.9	5.1	1.0	VFS
4	+0.3	25.0	26.0	17.8	5.7	5.2	0.9	VFS
5	+0.3	25.5	25.0	32.3	8.4	4.9	0.06	FS
6	+0.3	26.0	26.0	11.4	4.3	5.3	1.9	VFS
1	+0.1	28.0	32.0	31.2	8.9	4.6	0.7	VFS
2	+0.1	29.5	32.5	27.5	6.0	4.6	0.6	VFS
3	+0.1	29.0	35.0	31.1	6.0	4.5	0.8	VFS
4	+0.3	27.0	28.0	22.9	7.0	4.9	1.8	VFS
5	+0.3	28.0	29.0	30.4	9.2	4.6	0.2	FS
6	+0.3	29.0	30.0	19.3	-	4.8	1.6	VFS

Table 2. Total benthic primary production ($mgC/m^2/h$)

Station	Feb.	Mar.	Sep.	Dec.	Feb.
1	15.0	14.0	117.5	41.0	10.5
2	2.5	13.5	29.0	1.0	3.0
3	1.5	13.5	56.0	1.0	9.0
4	90.0	64.5	22.0	41.0	2.5
5	2.5	5.0	32.5	3.0	1.5
6	301.0	190.5	139.0	63.5	46.0

16.2 $mgC/m^2/h$ (St. 3), 44.0 $mgC/m^2/h$ (St. 5) and 148.0 $mgC/m^2/h$ (St. 6). The highest mean values were obtained at St. 4 and St. 6 respectively. No seasonal variation was observed (Fig. 2*a*-*e*).

The values obtained for ^{14}C dark fixation varied from 10% to more than 100% in 6 samples. In relation to the epipelic fractions, the mean dark fixation value was 63% while for the epipsammic it was 49%. The mean dark fixation value found for each station was about 50% except for St. 2 which showed 71%.

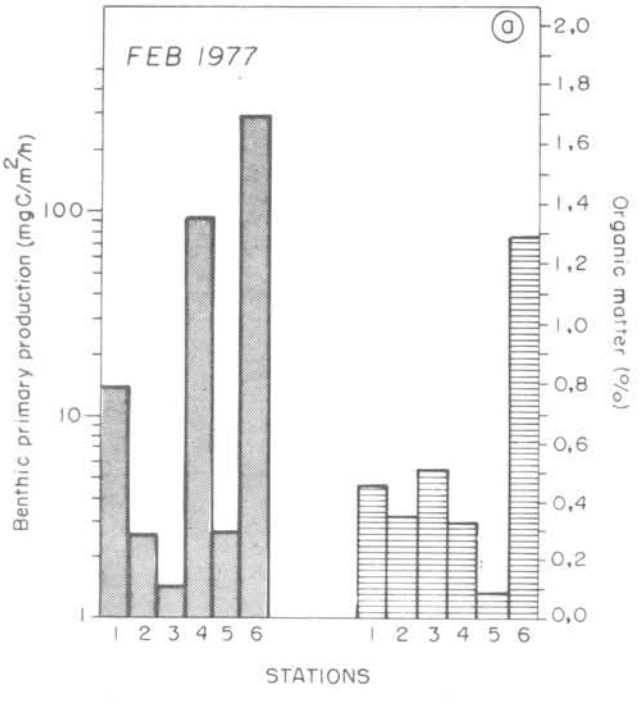

Fig. 2*a*. Benthic primary production ($mgC/m^2/h$) and organic matter (%) of the six stations in February, 1977.

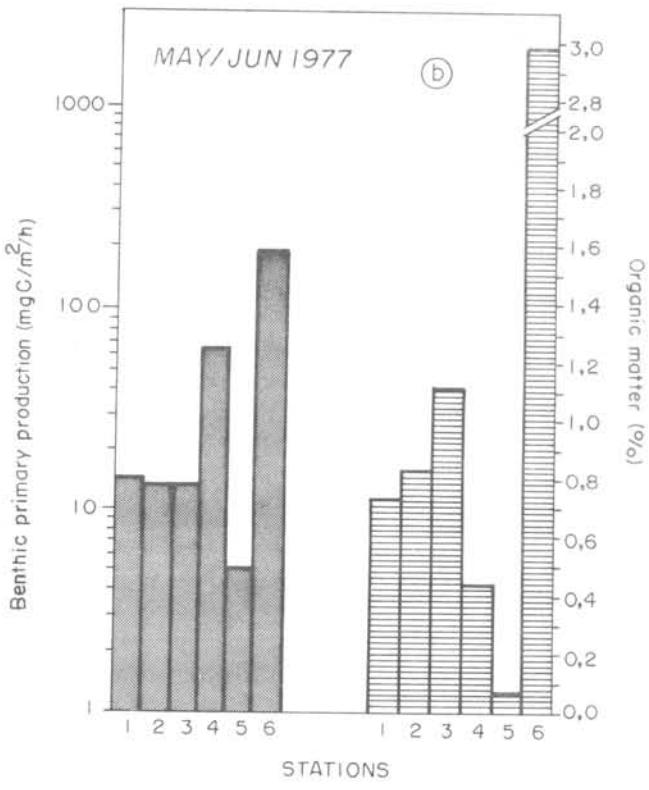

Fig. 2*b*. Benthic primary production ($mgC/m^2/h$) and organic matter (%) of the six stations in May/June, 1977.

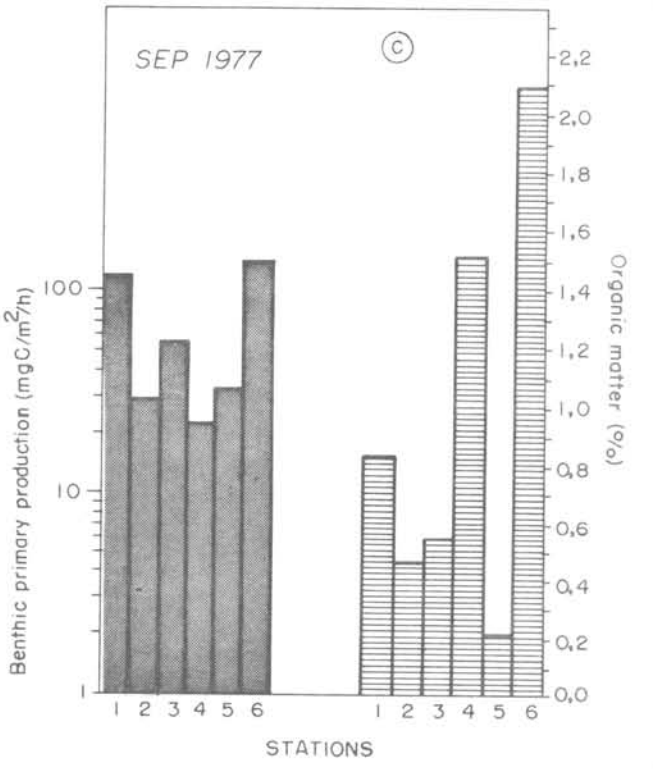

Fig. 2*c*. Benthic primary production ($mgC/m^2/h$) and organic matter (%) of the six stations in September, 1977.

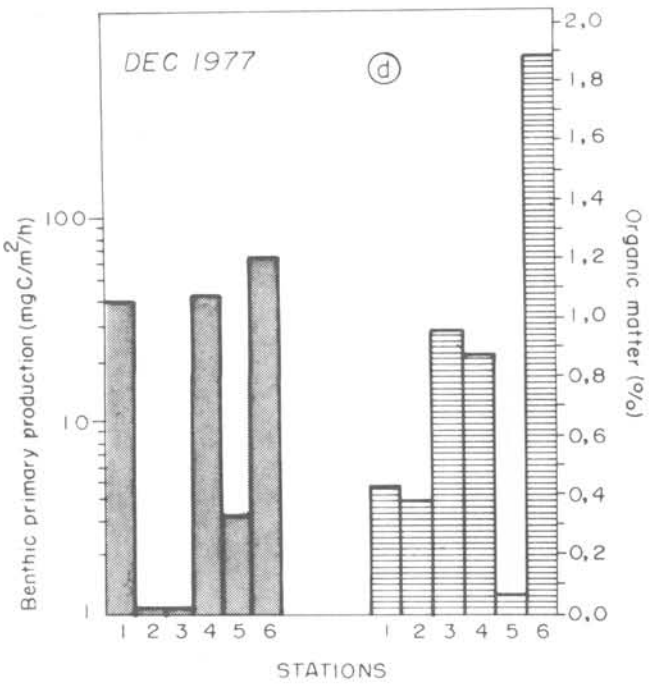

Fig. 2*d*. Benthic primary production (mgC/m^2/h) and organic matter (%) of the six stations in December, 1977.

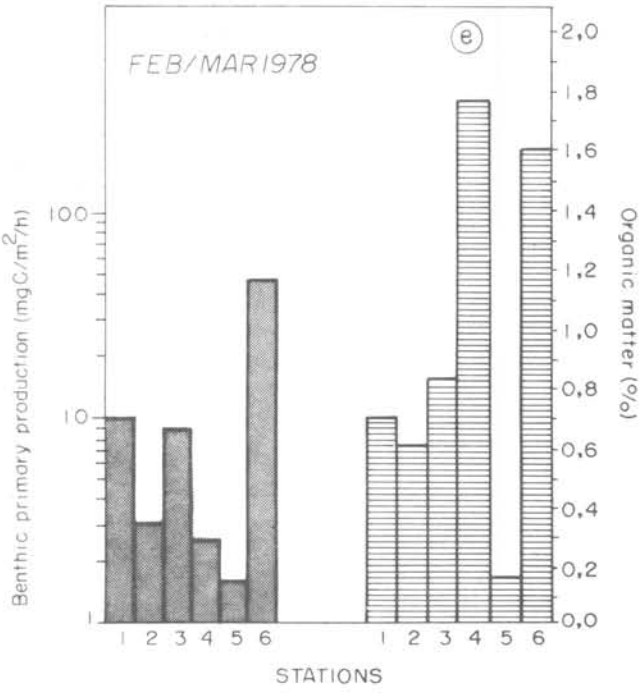

Fig. 2*e*. Benthic primary production (mgC/m^2/h) and organic matter (%) of the six stations in February/March, 1977.

During the study period the mean contribution of the epipelic fraction to the total primary production was 15 mgC/m^2/h while for the epipsammic fraction it was 30 mgC/m^2/h (Fig. 3*a*-*e*).

Discussion

The results presented above refers to the evaluation of some of the parameters affecting the potential benthic primary production of the microphytobenthos of a highly eutrophic region, where the presence of nutrients is not a limiting factor. At this location, the concentration of N-NO_3 in the water can be about 30 times greater than at coastal

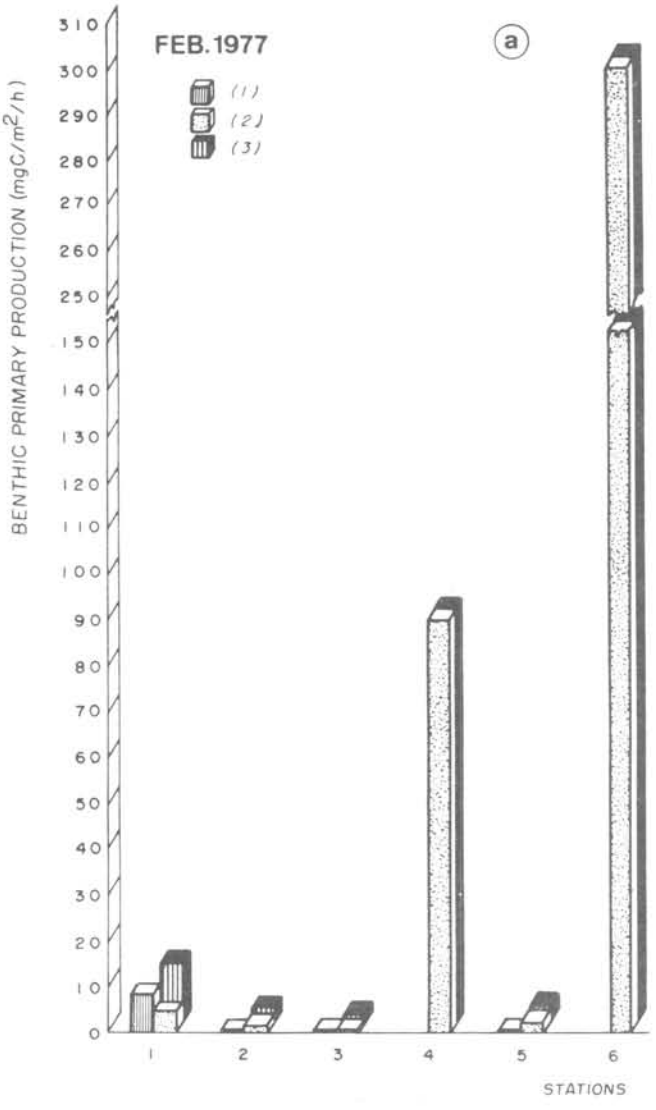

Fig. 3*a*. Benthic primary production (mgC/m^2/h) of epipelic (1) and epipsammic (2) phases and total (3) to the six stations in February, 1977.

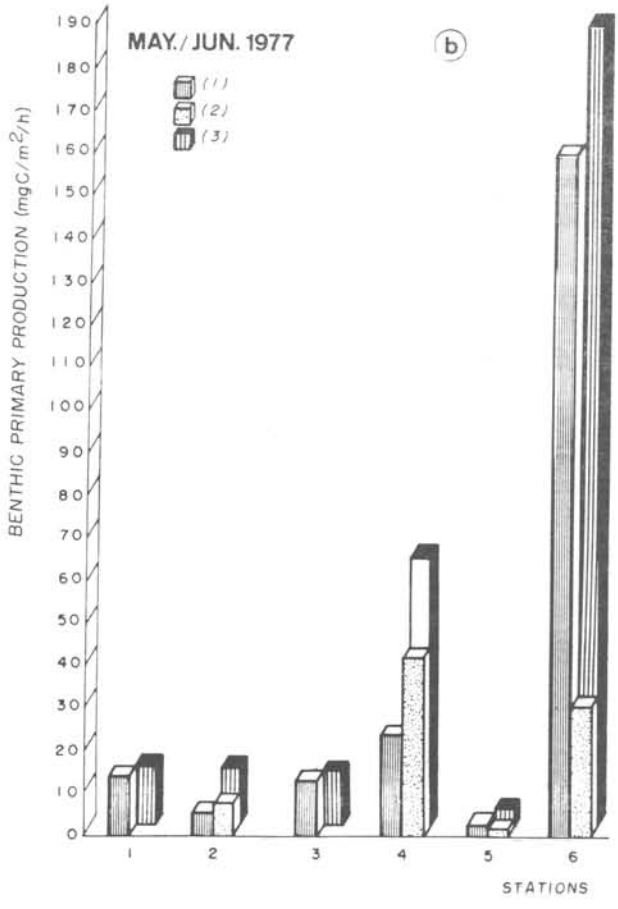

Fig. 3b. Benthic primary production ($mgC/m^2/h$) of epipelic (1) and epipsammic (2) phases and total (3) to the six stations in May/June, 1977).

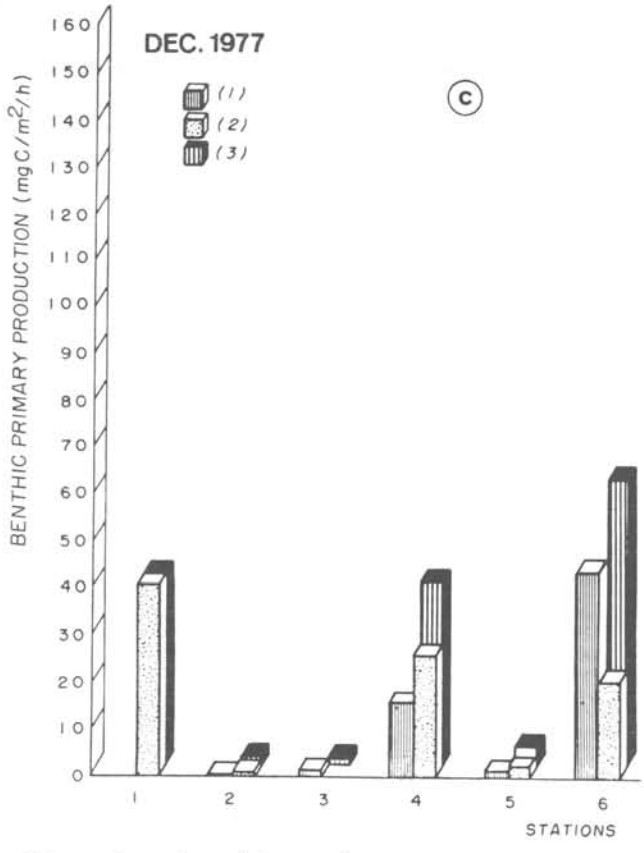

Fig. 3c. Benthic primary production ($mgC/m^2/h$) of epipelic (1) and epipsammic (2) phases and total (3) of the six stations in September, 1977.

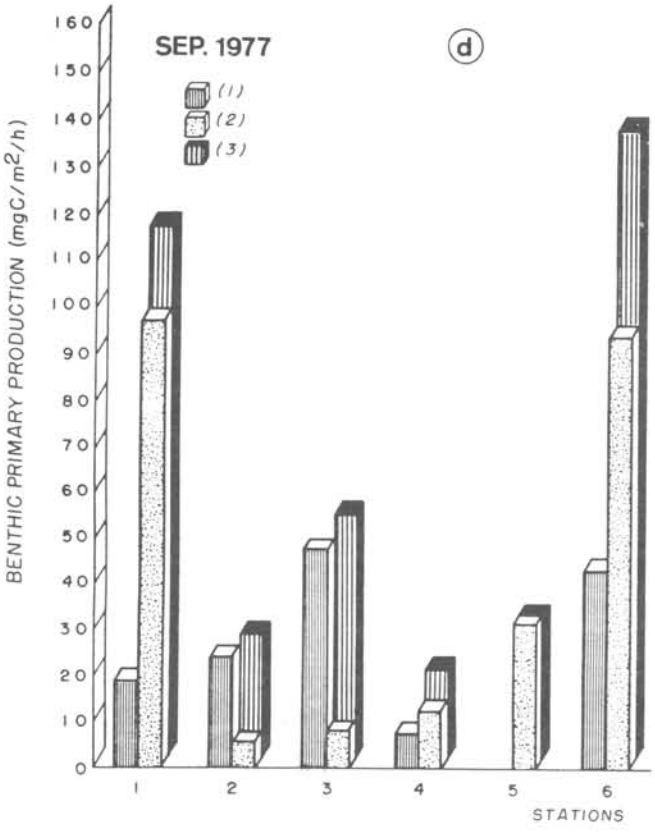

Fig. 3d. Benthic primary production ($mgC/m^2/h$) of epipelic (1) and epipsammic (2) phases and total (3) to the six stations in December, 1977.

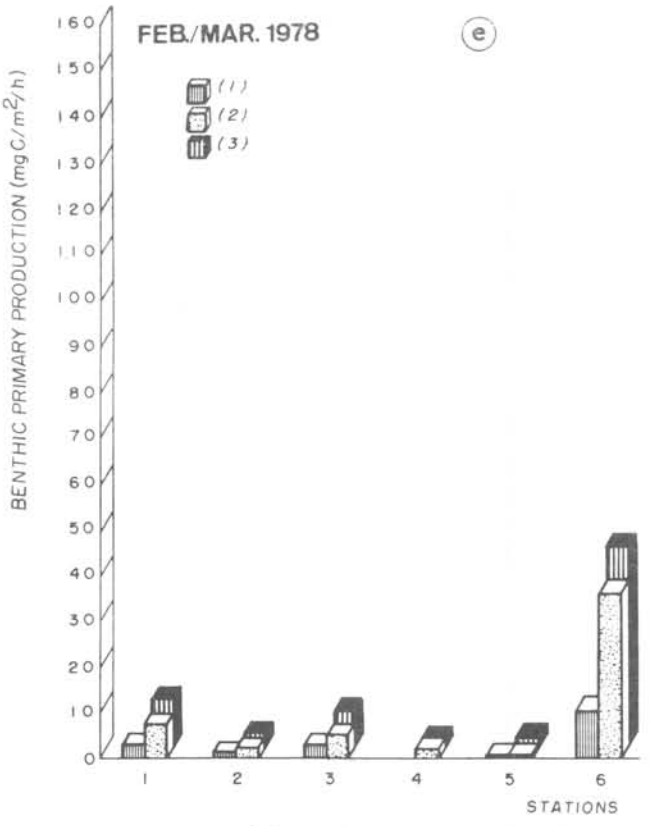

Fig. 3e. Benthic primary production ($mgC/m^2/h$) of epipelic (1) and epipsammic (2) phases and total (3) to the six stations in February/March, 1977.

waters, while that of $P\text{-}PO_4$ is about 20 times. These high levels of nutrients characterize this area as being in a continuous process of eutrophization (Gianesella-Galvão, 1978).

The values given here for benthic primary productivity represent the sum of the values for productivity of the algae fixed to sand grains (psammophytic algae) and those for free ones (pseudobenthic algae).

The highest values for benthic primary production were found at Sts 4 and 6 which are subject to lower hydrodynamism, higher amounts of organic matter and higher percentages of clay in the sediment. St. 5, the least exposed to these factors, showed low values and lower variation in benthic primary production during the period of study. At Sts 1, 2 and 3, located in Santos Bay, a large range of variations was obtained for benthic primary production, probably owing to the greater environmental variation the bay is subject to, as a result of the inflow of continental water from channels with a more or less polluted content.

No seasonal variation of the benthic primary productivity was found in the Santos estuarine system. Grøntved (1960), Taylor (1964), Hunding (1971), Cadée & Hegeman (1974) and Gargas (1980), working under very different conditions, regarding latitude and climate, have found a significant benthic primary productivity seasonality.

The drop in benthic primary productivity observed in December 1977 and February/March 1978 may have occurred as a result of the weather factors influencing the environment at that time. In December 1977, rainfall reached 149 mm during two days preceding sampling. This intense rain must have washed nutrients and algae out of the sediment (Colijn & Dijkema, 1981). On the other hand, in February/March 1978, the temperatures recorded were the highest for the whole sampling period. At this time temperature must have been a limiting factor for the benthic primary production (Rasmussen *et al.*, 1983).

The value for benthic primary production at station 4 in February/March 1978 was also low. Two days before sampling, there had been an oil spill at this site.

In the Santos estuary area, during the whole study period, the pseudobenthic fraction accounted for 40% of total primary production, while the psammophytic fraction accounted for 60%. It was observed that on the exposed beaches 33.5% of all production was due to pseudobenthic algae, while on the sheltered beaches this fraction accounted for 38%. According to Grøntved (1962), places more exposed to the direct action of waves show lower percentages of free organisms, as these are easily washed away by the sea. Grøntved (*op. cit.*) found a variation of 6.6-51.3% for the share of free algae in total primary production, depending on whether the site was sheltered or exposed.

Occasionally, dark fixation of ^{14}C for the samples analysed reached over 100%. Values over 100% for fixation of ^{14}C are characteristic of eutrophic and polluted regions (UNESCO, 1973). According to Gargas (1970), dark fixation of ^{14}C is higher for psammophytic algae. However, the highest values in the

present results were those for pseudobenthic algae. The highest percentage of dark fixation of ^{14}C was that obtained at St. 4, where the mean value was 97%. According to Meadows & Anderson (1968), bacteria attached to sand grains are responsible for a large part of this fixation.

The results for benthic primary productivity during the period of study and for all stations sampled varied between 1 $mgC/m^2/h$ and 301 $mgC/m^2/h$. When working in the Wadden Sea, Grøntved (1962) found a potential benthic primary productivity which varied between 37 $mgC/m^2/h$ and 450 $mgC/m^2/h$. Van Raalte *et al.* (1974), in Massachusetts, performed *in situ* experiments giving a variation between 21.9 ± 2.6 $mgC/m^2/h$ and 64.8 ± 0.7 $mgC/m^2/h$. Grøntved (1962), again studying the same location as mentioned above, obtained a mean value of 95 $mgC/m^2/h$ for a permanently covered zone and an intertidal zone. Hunding (1971) also obtained values which were compatible with these intervals, working on an eutrophic lake in Denmark with extremes between 9.0 $mgC/m^2/h$ and 145.5 $mgC/m^2/h$. Considering the differences in latitude and climate between the locations where those authors have worked and the Santos area it can be stated that the results obtained here are in the same range of variation.

Acknowledgements

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Resumo

Estimativas da produtividade primária bentônica foram efetuadas no estuário tropical de Santos, na costa do Brasil (24°S, 46°S).

As amostras foram obtidas sazonalmente, durante um período de 1 ano. Seis estações com diferentes condições ambientais foram escolhidas para a amostragem. As amostras, compreendendo os 2 mm superficiais de sedimento, foram coletadas na zona entre-marés, de acordo com a metodologia de Grøntved (1960).

O valor médio de produção primária bentônica obtida foi de 45 $mgC/m^2/h$, variando entre 1,0 e 301,0 $mgC/m^2/h$. Os valores anuais mais elevados foram obtidos nas estações mais abrigadas que continham o maior teor de matéria orgânica e estavam sujeitas ao maior afluxo de poluentes. As algas epipsâmicas contribuíram com 40% para a produção total enquanto, as epipélicas, com 60%. O valor médio obtido para fixação do ^{14}C no escuro, durante o período de estudo, foi de 63%.

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