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STANDING-STOCK AND POTENTIAL OF PHYTOPLANKTON PRODUCTION IN THE BAY OF SANTOS, BRAZIL

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Synopsis

Phytoplankton primary production and the maximum photosynthetic index ($P^{b}m$) from the region of Bay of Santos were measured every two months during 1976 by simulated incubations using ^{14}C method and incandescent lamps (737 $\mu E.m^{-2}.s^{-1} \cong 40$ klux). The results obtained for production rates (maximum of 204.6 $mgC.m^{-3}.hr^{-1}$ in winter and 488.3 $mgC\ m^{-3}.hr^{-1}$ in summer) are among the highest recorded for tropical marine environments. A high capability of light adaptation under high temperatures was also verified. The photosynthetic indexes obtained were also very high and seems to be due to the high nutrient level of the region. The eutrophic state is supported by the high nutrient and chlorophyll-a concentrations and by the phytoplankton cells number.

Introduction

The region of the Estuary and Bay of Santos (24°00'S; 46°26'W), Brazil (Fig. 1) receives a great contribution of domestic and industrial wastes, besides those arising from the activities of the Port of Santos. These inputs into the area, an environment with natural eutrophic features, not only increase the speed of the eutrophication process but also contribute significantly to the pollution of the environment.

The study area has been subjected to an intense research program with the objective of providing a comprehensive ecosystem study and the necessary data for further studies and for the management of the area. A cooperative program between the Companhia de Tecnologia de Saneamento Ambiental (CETESB) and the Instituto Oceanográfico da Universidade de São Paulo was established. By this cooperative program, the hidrological, chemical and biological surveys of the Estuary and Bay were conducted from 1974 through 1977. The present work is based on data collected during 1976, under the mentioned program.

The study of the phytoplankton primary production was undertaken in the present work because this parameter may be a reasonable indicator of eutrophication of the environment and of its progress with time.

Studies on primary production in bays and estuarine regions have been carried out in Brazil by many authors (Garcia-Occhipinti *et al.*, 1961; Teixeira, 1969, 1980; Teixeira *et al.*, 1969; Tundisi, 1969; Tundisi *et al.*, 1973) but no one of them, were concerned to polluted environments.

Material and methods

Samples were taken every two months from February through December, 1976, only at surface and at three stations shown in Figure 1.

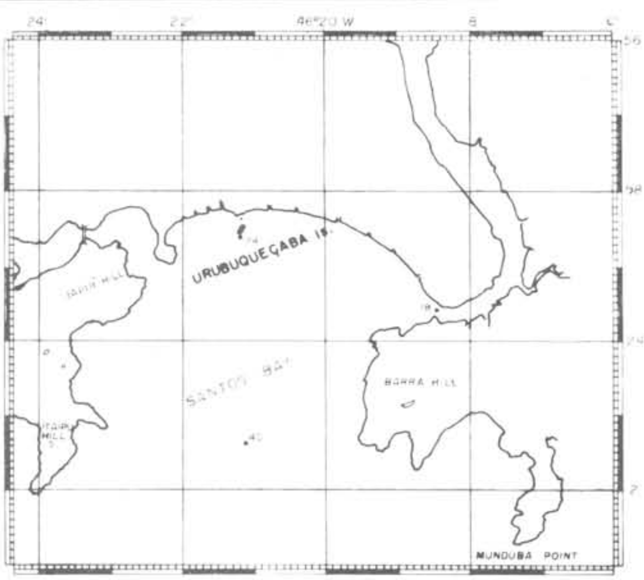

Fig. 1. Map of the Bay of Santos with the location of the Stations.

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Hydrological and chemical analyses - salinity, dissolved oxygen, pH, nutrients (nitrite, nitrate, ammonia, orthophosphate) and Hg - were made by CETESB according to A.P.H.A. (1971).

Since the dissolved inorganic carbon in the samples could not be determined, the standard value of 90 $mgCO_2 l^{-1}$ (Gargas, 1975) was assumed for the present work.

Sub-samples for phytoplankton counts were fixed with formol solution to a final concentration of 5%. The counts were determined in sedimentation chambers using an inverted microscope, according to Utermöhl (1958).

For the spectrophotometric chlorophyll-*a* analysis, a volume of 0.25 ℓ seawater was filtered through 0.45 µm Millipore HA filters. Pigments were extracted in 90% acetone. Details of the methodology and equations used are described in Strickland & Parsons (1968).

Primary production was measured according to the ^{14}C method (Steemann-Nielsen, 1952). Samples were inoculated with tracer (16 µCi in 750 ml of seawater) and transferred to 80 ml glass bottles. They were incubated for three hours in an incubator with incandescent light (737 $\mu E.cm^{-2}.s^{-1}$ or 40 klux) under different light intensities, obtained by means of neutral filters: 2.0, 5.6, 25.6, 56.5%. A 150.0% value was obtained using a mirror behind the bottle. Two (2) light bottles and one (1) black were used for each light level.

After incubation, 25 ml sub-samples from each bottle were filtered through 0.45 µm Millipore filters.

The filters were submitted to HCl fumes to eliminate the inorganic carbon. Filter activities were determined by liquid scintillation method according to Ward & Nakanishi (1971). Calibration was performed by means of automatic external standardization. The fluor was a Bray solution (Bray, 1960) alkalized at 10% with hyamin hidroxide 10-X (Packard).

The total light energy was measured with a LIQUOR quantameter, equipped with an underwater sensor for incident photon flux density (LI-192S).

Results

Table 1 shows the results of hydrological and chemical data. The D.O. saturation percentages were always high (>70.7%) several times showing oversaturation. Salinity was between 28.38 and 33.5% at Stations 40 and 24 but at Station 18 it was between 18.48 and 32.41%. Temperature was high during all the sampling period (between 19.86 and 27.51°C). pH varied little but a high pH value (8.7) was observed in December, at Station 24, concomitantly with a high value of dissolved oxygen.

Both phosphate and inorganic nitrogen showed a gradient increasing toward the estuary entrance. Mean values for Stations 40, 24 and 18 were respectively 1.44, 1.98 and 4.22 µg $P\text{-}PO_4.l^{-1}$ and 10.84, 15.97 and 21.53 µg$N\text{-}(NO_3+NO_2+NH_3).l^{-1}$. The N:P ratio never exceeded 10.

Hg concentrations were high occasionally. During winter they were ten times higher than the maximum level found by Fitzgerald & Lions (1973) in seawater (0.003 to 0.364 $\mu g.l^{-1}$). The

Table I - Hydrological and chemical parameters

Parameter	Feb	Apr	Jun	Aug	Oct	Dec
Station 40 (local depth: 12m)						
Tide	high	high	low	low	high	high
Sampling time	14:45	17:45	17:30	16:20	13:45	14:45
Light extinction coef.	1.20	0.90	0.90	1.06	0.85	1.20
Water temperature (°C)	26.20	26.30	21.20	21.20	21.33	25.05
Salinity (°/₀₀)	32.33	30.83	29.68	30.90	33.03	33.50
D.O. saturation (%)	90.8	82.9	107.7	127.3	102.9	148.0
pH	8.0	8.2	8.1	8.0	8.1	8.3
$N\text{-}NH_3$ ($\mu g\ at.l^{-1}$)	0.00	0.00	0.00	0.70	0.00	0.00
$N\text{-}NO_2$ ($\mu g\ at.l^{-1}$)	0.70	1.42	2.14	2.85	0.00	0.00
$N\text{-}NO_3$ ($\mu g\ at.l^{-1}$)	6.43	13.57	12.14	12.85	0.70	0.70
ΣN ($\mu g\ at.l^{-1}$)	7.13	14.99	14.28	16.40	0.70	0.70
$P\text{-}PO_4$ ($\mu g\ at.l^{-1}$)	0.96	1.54	3.61	2.13	0.19	0.19
$N\text{-}NO_3$: $P\text{-}PO_4$	6.7	8.8	3.4	6.0	3.7	3.7
Hg ($\mu g.l^{-1}$)	0.00	0.00	2.05	1.50	0.07	0.00
Station 24 (local depth: 6m)						
Tide	high	low	-	high	high	low
Sampling time	16.45	14.25	-	14.45	15.55	15.00
Light extinction coef.	1.50	1.20	-	1.70	2.10	1.20
Water temperature (°C)	26.70	26.20	-	19.86	21.37	27.51
Salinity (°/₀₀)	29.32	28.38	-	31.67	31.21	30.18
D.O. saturation (%)	70.7	128.3	-	83.4	160.0	250.0
pH	8.2	8.1	-	8.1	8.3	8.7
$N\text{-}NH_3$ ($\mu g\ at.l^{-1}$)	3.57	0.00	-	0.70	0.70	-
$N\text{-}NO_2$ ($\mu g\ at.l^{-1}$)	1.42	2.14	-	2.14	2.14	-
$N\text{-}NO_3$ ($\mu g\ at.l^{-1}$)	14.28	19.28	-	7.86	10.00	-
ΣN ($\mu g\ at.l^{-1}$)	19.27	21.42	-	10.70	12.48	-
$P\text{-}PO_4$ ($\mu g\ at.l^{-1}$)	1.60	2.29	-	2.26	2.45	1.29
$N\text{-}NO_3$: $P\text{-}PO_4$	8.9	8.4	-	3.5	4.1	-
Hg ($\mu g.l^{-1}$)	0.00	0.06	-	0.15	0.25	0.00
Station 18 (local depth: 12m)						
Tide	high	high	low	high	high	high
Sampling time	13.30	13.50	13.40	15.20	13.40	14.40
Light extinction coef.	1.90	1.00	1.70	0.90	1.20	1.20
Water temperature (°C)	26.70	24.70	21.20	20.34	20.37	24.39
Salinity (°/₀₀)	18.48	30.79	22.66	28.83	29.76	32.41
D.O. saturation (%)	100.0	112.3	90.0	76.3	92.8	96.7
pH	7.9	8.4	7.8	8.0	8.0	8.1
$N\text{-}NH_3$ ($\mu g\ at.l^{-1}$)	50.00	0.00	2.14	4.28	2.14	0.00
$N\text{-}NO_2$ ($\mu g\ at.l^{-1}$)	7.85	0.70	1.42	3.57	1.42	2.73
$N\text{-}NO_3$ ($\mu g\ at.l^{-1}$)	0.70	7.86	5.71	17.85	12.85	9.28
ΣN ($\mu g\ at.l^{-1}$)	58.55	8.56	9.27	25.70	16.41	10.70
$P\text{-}PO_4$ ($\mu g\ at.l^{-1}$)	3.80	0.60	9.16	4.13	3.06	4.54
$N\text{-}NO_3$: $P\text{-}PO_4$	0.2	13.1	0.1	4.3	4.2	2.0
Hg ($\mu g.l^{-1}$)	0.00	0.85	0.55	3.64	0.10	0.00

highest values occurred at Station 18 (3.64 $\mu g.l^{-1}$ in August), but Station 40, located in the entrance of the Bay, also indicated a concentration of 2.05 $\mu g.l^{-1}$ in June.

The results of the phytoplankton counts at each sampling period are summarized in Table II. In general, highest cell concentrations occurred during the warmer months. Four diatom genera, *Skeletonema* (45%), *Cyclotella* (14%), *Leptocylindrus* (13%), and *Chaetoceros* (11%) made up about 83% of the annual total cell number. Diatoms from the genus *Skeletonema* and phytoflagellate organisms occurred all time and at sampling stations. However, phytoflagellates represented only 4% of the annual total cell number.

The maximum concentration of *Skeletonema* was 39.22 x 10^6 $cells.l^{-1}$, and was found in December. Phytoflagellate highest concentration (3.37 x 10^3 $cells.l^{-1}$) occurred in February.

Chlorophyll-*a* concentration (Tab. II) was high during summer and relatively low in winter.

The light/photosynthesis curves are shown in Figures 2-4. An inhibition at the maximum energy level could be noted only in samples from Station 24, April, December. On the other hand, the results of five experiments (Station 40, February, April; Station 24, February and Station 18 February and June) indicate that the limiting light level can be over the maximum used.

Maximum production rates were generally higher during summer (34.3 to 488.4 $mgC.m^{-3}.h^{-1}$) than during winter (21.6 to 204.3 $mgC.m^{-3}.h^{-1}$) (Tab. II). Daily rates varied from 237 to 2.247 $mgC.m^{-3}.day^{-1}$ during winter (11 h of light) and from 446 to 6.347 $mgC.m^{-3}.day^{-1}$ during summer.

The I_k index was graphycally determined according to Talling (1957). The values determined were usually high, (239.5 to 525.1 $\mu E.m^{-2}.s^{-1}$) but they can be higher yet in the experiments that did not show light saturation.

The photosynthetic indexes (P^b_m) ($mgC.mg$ chl-$a.h^{-1}$) obtained under the optimum light energy levels are showed in Table II. About 83% of the samples studied showed P^b_m values above 5.

From the time of sampling through the end of the incubation period, samples suffered an increase in the temperatures, averaging 3°C (Tab. III). In three cases the experimental temperature had a variation of 5°C: Station 40, December Station 18, August and December, and just the two lower values of P^b_m were obtained in Station 40, December and Station 18, August, showing a possible adverse influence of an excessive increase of temperature during the experiments.

Table II - Maximum primary production rates and related factors for the Bay of Santos

	Feb	Apr	Jun	Aug	Oct	Dec
			Station 40			
P_m ($mgC.m^{-3}.h^{-1}$)	89.0	156.7	29.2	101.1	34.3	48.0
I_k ($uE.m^{-2}.s^{-1}$)	423.8	515.9	313.6	331.6	285.6	460.6
P_m ($mgC.mgchl$-$a.h^{-1}$)	6.9	7.9	7.5	6.3	5.7	2.8
cl-a ($mg.m^{-3}$)	14.3	19.6	4.0	13.4	5.7	17.0
cell nº $10^6.l^{-1}$	24.8	18.9	0.8	4.1	0.7	36.3
			Station 24			
P^b_m ($mgC.m^{-3}.h^{-1}$)	269,9	150.4	23.2	21.6	219.6	410.8
I_k (u $E.m^{-2}.s^{-1}$)	525.1	239.5	396.1	276.4	239.5	350.1
P^b_m ($mgC.mgchl$-$a.h^{-1}$)	7.7	8.2	6.5	5.5	4.0	13.2
cl-a ($mg.m^{-3}$)	35.3	28.9	3.6	4.0	55.3	36.9
cell nº $10^6.l^{-1}$	36.4	-	0.1	0.3	30.9	39.5
			Station 18			
P_m ($mgC.m^{-3}.h^{-1}$)	430.4	113.8	204.3	21.7	79.2	110.3
I_k ($uE.m^{-2}.s^{-1}$)	423.8	322.4	313.2	433.0	285.6	322.4
P^b_m ($mgC.mgchl$-$a.h^{-1}$)	12.7	5.7	9.3	3.1	5.3	5.8
cl-a ($mg.m^{-3}$)	34.2	20.4	22.0	7.3	15.0	19.2
cell nº $10^6.l^{-1}$	51.2	-	20.9	0.3	2.5	13.1

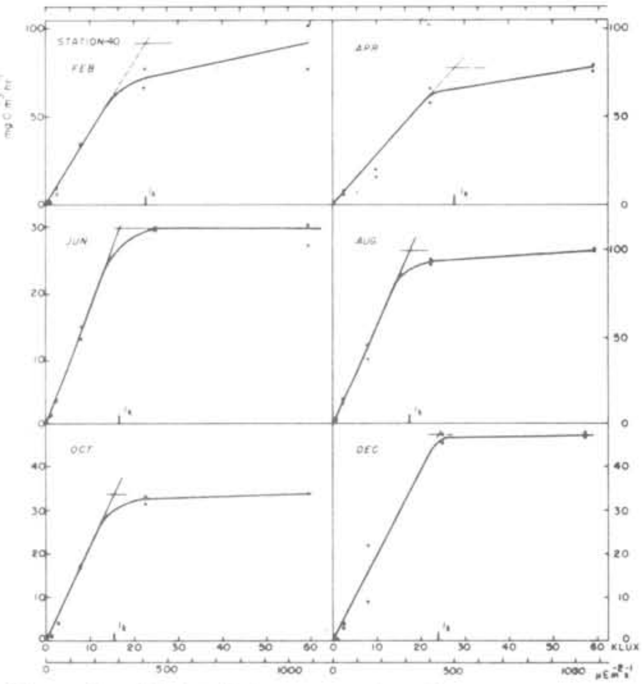

Fig. 2. Light/photosynthesis curves and I_k values determined in klux and $\mu E.m^{-2}.s^{-1}$ for Station 40.

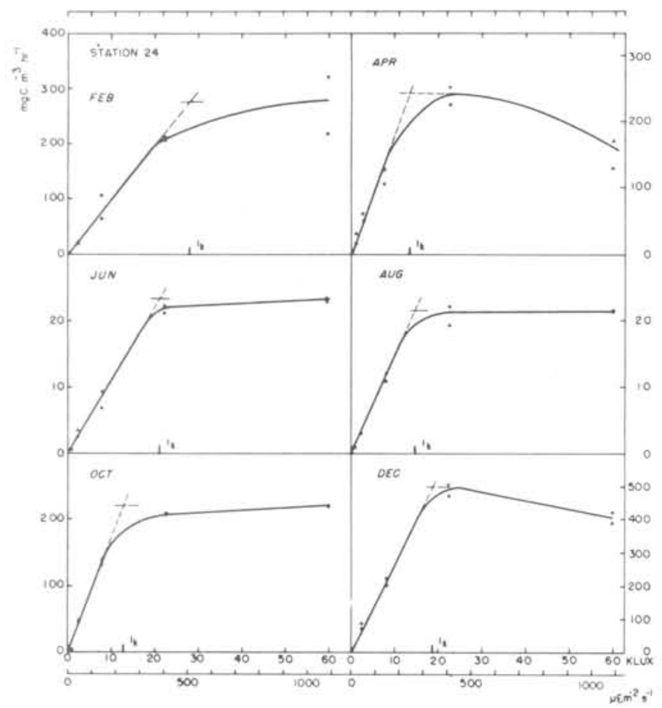

Fig. 3. Light/photosynthesis curves and I_k values determined in klux and $\mu E.m^{-2}.s^{-1}$ for Station 24.

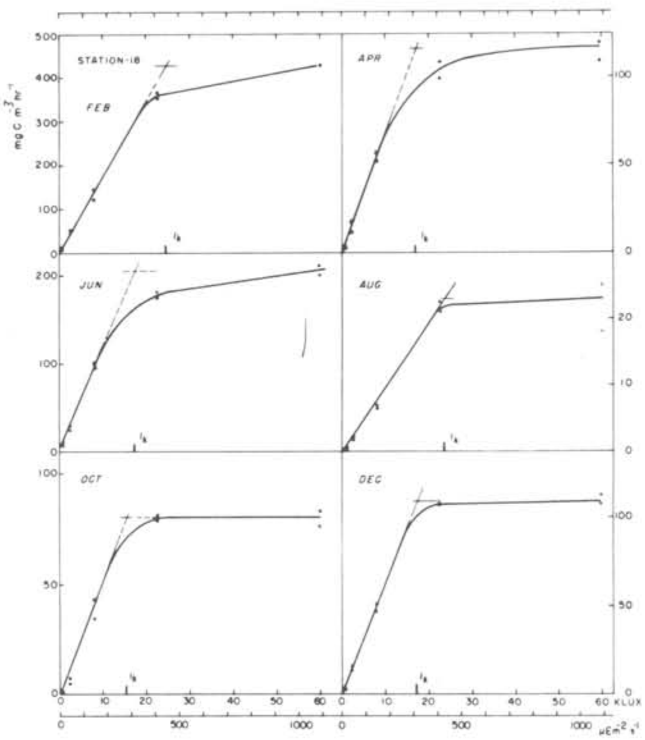

Fig. 4. Light/photosynthesis curves and I_k values determined in klux and $\mu E.m^{-2}.s^{-1}$ for Station 18.

Table III - Experimental temperature data

	Feb	Apr	Jun	Aug	Oct	Dec
Station 40						
Temperature at sampling time	26.0	26.0	21.0	21.0	21.0	25.0
Temperature at end of incubation	29.0	28.0	24.0	25.0	22.0	32.0
Maximum experimental temperature variation	2.0	2.0	3.0	4.0	1.0	7.0
Station 24						
Temperature at sampling time	27.0	26.0	19.0	20.0	21.0	28.0
Temperature at end of incubation	26.0	29.0	23.0	21.5	24.0	31.0
Maximum experimental temperature variation	-1.0	3.0	4.0	1.5	3.0	3.0
Station 18						
Temperature at sampling time	27.0	25.0	21.0	20.0	20.0	24.0
Temperature at end of incubation	29.0	27.0	24.0	25.0	23.0	30.0
Maximum experimental temperature variation	2.0	2.0	3.0	5.0	3.0	6.0

Discussion and conclusions

The mean annual nutrients gradients recorded agrees with the circulation model suggested by Garcia-Occhipinti (1972). According to this author, during high tide the water affluence occurs through the bottom with an affluence occurring at the surface layer (0-1 m) which circulates from the Estuary out-put, (Station 18) turn round Urubuqueçaba Island (near Station 24) and go off the Bay toward SSW (near Station 40); according to Garcia-Occhipinti (*op. cit.*), this pattern remains for about 85% of the time.

A comparison between nutrient data from the Bay of Santos and from other nearby regions (Tab. IV) shows that the region under observation is highly eutrophicated.

Nutrient concentrations from surface coastal waters facing the studied region (Brasil. Ministério da Marinha, 1967) are remarkably lower and confirm the eutrophication of the Bay of Santos.

Caperon *et al.* (1971) measuring $P\text{-}PO_4$ concentrations at the out-puts of the sewages in Kanehoe Bay, found a mean value of 3.94 $\mu gP\text{-}PO_4.l^{-1}$, which is slightly lower than the annual mean value for Station 18 in the Bay of Santos.

In non-polluted waters it is possible to find high nutrient values under upwelling conditions. Wooster & Cronwell (1958) obtained 2.5 - 3.0 $\mu gP\text{-}PO_4.l^{-1}$ in Peru coast and Valentin (1974) observed 1.2 $\mu gP\text{-}PO_4.l^{-1}$ in the region of Cabo Frio (RJ). Also nitrogen can be found in relatively high concentrations in upwelling situations, like those determined by Yoneshigue-Braga *et al.* (1979) in the region of Cabo Frio: 12.58 $\mu gat.l^{-1}$ of total inorganic nitrogen. In rich waters of the tropical Pacific Ocean, Thomas (1970) recorded 6.33 $\mu gat.l^{-1}$ of total inorganic nitrogen. In polluted estuaries these values can rise up to 43.0 $\mu gat.l^{-1}$ of $N\text{-}NO_3$, like those determined by Berland *et al.* (1973) at the estuary out-fall of the Grand Rhone.

Teixeira & Gianesella-Galvão (in preparation), working on bioassays with waters from the Bay of Santos demonstrate that populations of *Phaeodactylum tricornutum* can be mantained at very high densities (about 40.10^6 $cell.l^{-1}$).

The low N:P ratios found in the present work are due to high phosphate concentrations and not to low nitrogen concentrations.

The annual fluctuations of the phytoplankton standing-stock, with higher values in summer and lower in winter are typical for coastal regions at nearby latitudes (Teixeira, 1969; 1980) due to the maxima of solar radiation and precipitation that occur in summer. However, at this time of the year there is a sharp increasing in the organic pollution of domestic origin in the Bay of Santos, due to the increasing of population in Santos and São Vicente towns. This fact, with no doubt, causes a preponderant fertilizing effect in the Bay of Santos waters.

Table IV - Nutrient data from the Bay of Santos and other nearby regions

Region	Nitrate ($\mu gN.l^{-1}$)	Phosphate ($\mu gP.l^{-1}$)	Author
Cananéia (estuary)	<0.1 -3.0	<0.1 -0.7	Kato, 1966
Ubatuba (bay)	0.06-0.60	0.01-0.25	Teixeira, 1980
Santos (coastal waters)	0.3 -0.50	0.1	Brasil, Ministério da Marinha, 1967
Santos (bay)	0.00-19.28	0.19-9.16	This study

The standing-stock data found during the summer were high even compared with those from other eutrophic regions. In Cananéia, Kutner (1972) found about 19.10^6 $cell.l^{-1}$ in summer, during the standing-stock peak. In Santos, the highest value was 51.2×10^6 $cell.l^{-1}$.

Benon *et al.* (1977) observed in the Golfe de Marseille (polluted), phytoplankton populations higher than 10^6 $cell.l^{-1}$. In that region, *Skeletonema costatum* always dominated in the phytoplankton (up to 99% of the total phytoplankton). Blanc *et al.* (1975) studying the Golfe de Fos also found *S. costatum* populations representing about 95% of total phytoplankton that reached up to 73.10^6 $cells.l^{-1}$. Kutner (*op. cit.*) observed *S. costatum* attaining 88% of the total phytoplankton in the region of Cananéia. In Santos, *Skeletonema* reached up to 99% during the summer.

Chlorophyll-*a* concentrations were rather high and McCormich & Quinn (1975) obtained similar values (3.0-81.0 $mgchl\text{-}a.m^{-3}$) in a polluted estuary (Newark Bay, New Jersey). In spite of the climatic differences, both regions present similar pollution problems (domestic wastes, petrochemical plants, harbours). Teixeira (pers. comm.)* observed chlorophyll-*a* concentrations around 100 $mg.m^{-3}$ in the Bay of Santos.

The phytoplankton primary production rates were very high, higher than those obtained for other tropical estuaries and bays (Table V). However, mercury concentrations may be affecting the production rates: highest mercury values observed (Station 40, June and Station 18, August) occurred concomitantly with lowest production rates. High mercury concentrations affect some algae species significantly, and *Skeletonema costatum* is one of the more sensitive (Overnell, 1976).

The I_k values were also very high. Harris (1978) looking over published data verified that most of the values recorded fall within the range of 50-120 $\mu E.m^{-2}.s^{-1}$ of the photosynthetic active radiation. However the present experiment was done under simulated conditions, and consequently our data are not comparable to those obtained by

* Teixeira, C. - Inst. oceanogr. da USP, 1976.

Harris (*op. cit.*). Teixeira (1980), working with natural phytoplankton populations from Ubatuba region, made incubation experiments similar to that of the present study (incandescent light, maximum of 831.1 $\mu E.m^{-2}.s^{-1}$) and also obtained very high I_k values: 460.6 to 813.4 $\mu Em^{-2}.s^{-1}$.

High I_k values indicate that the phytoplankton from the Bay of Santos presents a "sun pattern" behaviour. This phenomenon is likely to be due to the high temperature of the water throughout the year and to the thermohaline stratification of the Bay.

The effect of the temperature over the light adaptation speed has been verified in recent works. Hitchcock (1980) working with cultures of *Skeletonema costatum* growing under temperatures of 2, 10 and 25°C, verified that the maximum adaptation speed was obtained at the latter, more similar to the surface temperature from the studied region. This effect is due to the thermal dependence of the enzimatic activities of photosynthesis. Malone & Neale (1981) working with I_k index also emphasize the temperature effect over it.

The thermohaline isolation of the surface layer in region, could allow the phytoplankton to remain there and adapt to high light radiations. A rapid adaptation to new light conditions was verified by Marra (1978) who concluded that the changes in the photosynthetic capability depend mainly on the time of exposure at each radiation level. Vincent (1980) also verified the fastness of photosynthetic adaptation in natural assemblages by changes in the photosynthetic capability. In this case, the adaptation process seems to have occurred with time intervals shorter than a generation. Therefore, the proposed mechanism of adaptation might be sufficient to explain the absence of superficial inhibition phenomena observed at the production profiles in the present work.

Gianesella-Galvão (1981) studying the primary production and temperature profiles in reservoirs of São Paulo State (approximately the same latitudes as those of the Bay of Santos) observed a high percentage of production profiles with surface maxima during thermal isolation of the surface layer during the diurnal heating. Due to this adaptation ability and the favourable nutritional conditions, it could be expected that a high P^b_m would occur during summer.

An excessive increase in temperature during incubation probably affected the cell metabolism and accounted for some of the low P^b_m values obtained in December (Stations 40 and 18). Also the relatively low P^b_m value obtained in August (Station 24) may have resulted from the same technical problem.

Recently, the P^b_m index has been carefully studied by several authors (Gargas *et al.*, 1979; Teixeira, 1980) who have emphasized the influence of diel variations on this parameter, besides those effects due to temperature (Eppley *et al.*, 1972; Malone & Neale, 1981), nutritional conditions (Glooschenko & Curl Jr., 1971; Thomas, 1980), light regime (Vincent, 1980; Marra, 1978) and species composition (Parsons *et al.*, 1977).

As field work does not always allow a high accuracy level, this index has been used for comparing productivity aspects of several regions of the world in spite of being problematic. The standardization of the light conditions, however, permits more comparable results on the primary production potential of the region than those obtained by "in situ" simulated experiments.

Holmes (1958) doing "in situ" experiments with natural populations of phytoplankton from the tropical Pacific obtained values higher than those from simulated experiments at 10 Klux. In the present work the illumination level was higher (60 Klux) and quantitatively closer to natural conditions. But even so, since incandescent light does not reproduce integrally the solar spectrum, the photosynthetic structure might not have been fully utilized and the P^b_m can be subestimated again.

Although there seems to be a possibility of the P^b_m values having been underestimated, as discussed, previously, the results obtained in the Bay of Santos are comparable to those of other eutrophic environments (Tab. V), and are generally included in the range suggested by Curl Jr. & Small (1965) as typical for eutrophic waters.

Table V - Primary production ($mgC.m^{-3}.hr^{-1}$) and P_m^b indexes ($mgC.mgchl_a^{-1}.h^{-1}$) at several tropical marine environments

Region	Incubation	Illumination	Primary production* ($mgC.m^{-3}.h^{-1}$)	P_m^b indexes ($mgC.mgchl_a^{-1}.h^{-1}$)	Authors
Breton Sound 29°30'N; 89°20'W	"in situ" or "in situ" simulated	natural	0.7-221.0	-	Thomas & Simmons (1960)
Blind Bay 29°10'N; 89°00'W			2.6-189.0		
Kaneohe Bay 21°27'N; 157°47'W	simulated	artificial	5.0- 10.0	6.15- 7.94	Doty & Capurro (1961)
Idem	"in situ" simulated	natural	4.8- 37.9	7.15-14.54	Caperon *et al.* (1971)
Ala Way Canal 21°15'N; 157°50'W	"in situ"	natural	231.0 (annual average)	12.22-16.31	Harris (1975)
Cananéia Br (SP) 25°04'S; 47°54'W	simulated	57 Klux	65.32-206.12** 54.37-117.37***	11.80-24.00	Teixeira (1969)
Idem	simulated	16 Klux	9.86- 70.59	3.28- 6.25	Tundisi (1969)
Idem	"in situ"	natural	3.00- 72.00	0.27-21.18	Tundisi *et al.* (1973)
Ubatuba Br (SP) 23°30'S; 45°06'W	"in situ"	natural	1.01- 28.16** 0.24- 16.24***	5.08- 9.65	Teixeira (1973)
Idem	simulated	≈ 45 Klux	-	1.36- 6.80	Teixeira (1980)
Bay of Santos Br (SP) 24°00'S; 46°26'W	simulated	60 Klux	34.3-488.4** 21.6-204.3***	2.81-13.2	This study

* ^{14}C method
** Summer
*** Winter

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