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ECOLOGICAL STUDIES IN THE BAY OF PARANAGUÁ. I. HORIZONTAL DISTRIBUTION AND SEASONAL DYNAMICS OF THE PHYTOPLANKTON

Frederico P. BRANDINI

Centro de Biologia Marinha da Universidade Federal do Paraná (Caixa Postal 8341, 80.000 Curitiba, PR)

Synopsis

Five stations were sampled monthly in the Bay of Paranaguá during one year cycle (1983-1984) to measure basic environmental parameters, phytoplankton biomass and photosynthesis with the purpose of understanding the principal factors that regulate the phytoplankton growth and distribution throughout the year. Surface temperature varied from 17 to 30°C. The yearly average values for salinity, dissolved oxygen and pH ranged from 9.38 to 32.00°/oo, 5.17 to 5.53 ml/l and 7.46 to 8.18, respectively. Average concentrations of total inorganic nitrogen, phosphate and silicate varied from 3.31 to 8.48, 0.38 to 0.97 and 27.68 to 98.36 µg-at/l, respectively, with increasing concentrations toward the inner bay. Chlorophyll-a at the surface varied between 2.86 and 13.99 mg/m³ with high concentrations in the inner bay associated with high nutrient contents and lower salinities. Low photosynthetic rates were measured at the surface, varying from 0.01 to 7.36 mgC/m³/h. Phytoflagellates and Skeletonema costatum dominated the phytoplankton population during the study period. The temporal fluctuations in the inner bay are associated with the rainfall regime. High amounts of precipitation increase the concentrations of nutrients and consequently improve the phytoplankton growth. This is however limited by nitrogen deficiency (as indicated by the low N to P ratios observed) and turbidity.

Descriptors: Mangrove swamps, Phytoplankton, Horizontal distribution, Biomass, Photosynthesis, Environmental factors, Paranaguá Bay: Brazil.
Descritores: Manguezais, Fitoplâncton, Distribuição horizontal, Biomassa, Fotossíntese, Fatores ambientais, Baía de Paranaguá: PR.

Introduction

The Bay of Paranaguá is a large area located in the southern Brazilian State of Paraná (Lat. 25°16' to 25°34'S 25°34'S; Long. 48°17' to 48°42'W) surrounded by typical mangrove forests. Its outermost part is greatly influenced by the adjacent sea. Several rivers and numerous mangrove channels ("marigots") with freshwater drainage impart an estuarine character to the inner bay. This includes the Antonina area (Fig. 1).

In the Cananéia mangal situated 70 km north from Paranaguá, the phytoplankton production and biomass have been extensively studied during the past 20 years (Teixeira & Kutner, 1963; Teixeira *et al.*, 1969; Teixeira, 1969; Tundisi, 1969; Tundisi *et al.*, 1973, 1978). However, in the Paranaguá mangal this information is practically unknown and phytoplankton studies recently started at the taxonomic level (Moreira Filho *et al.*, 1975; Valente-Moreira *et al.*, 1981).

The structure and dynamics of the detritus based food-web is certainly not different from that of a typical mangal ecosystem (Por, 1984) and was described recently in adjacent areas (Knoppers & Opitz, 1984).

The present study was performed in order to provide preliminary information about the physico-chemical conditions throughout the Bay of Paranaguá as well as quantitative data of phytoplankton biomass and its spatial and temporal changes in relation to environmental parameters. This was deemed necessary due to ecological and economical importance of the bay as a nursery and feeding ground for commercial crabs, oysters, shrimps, fishes and potencial aquaculture implements.

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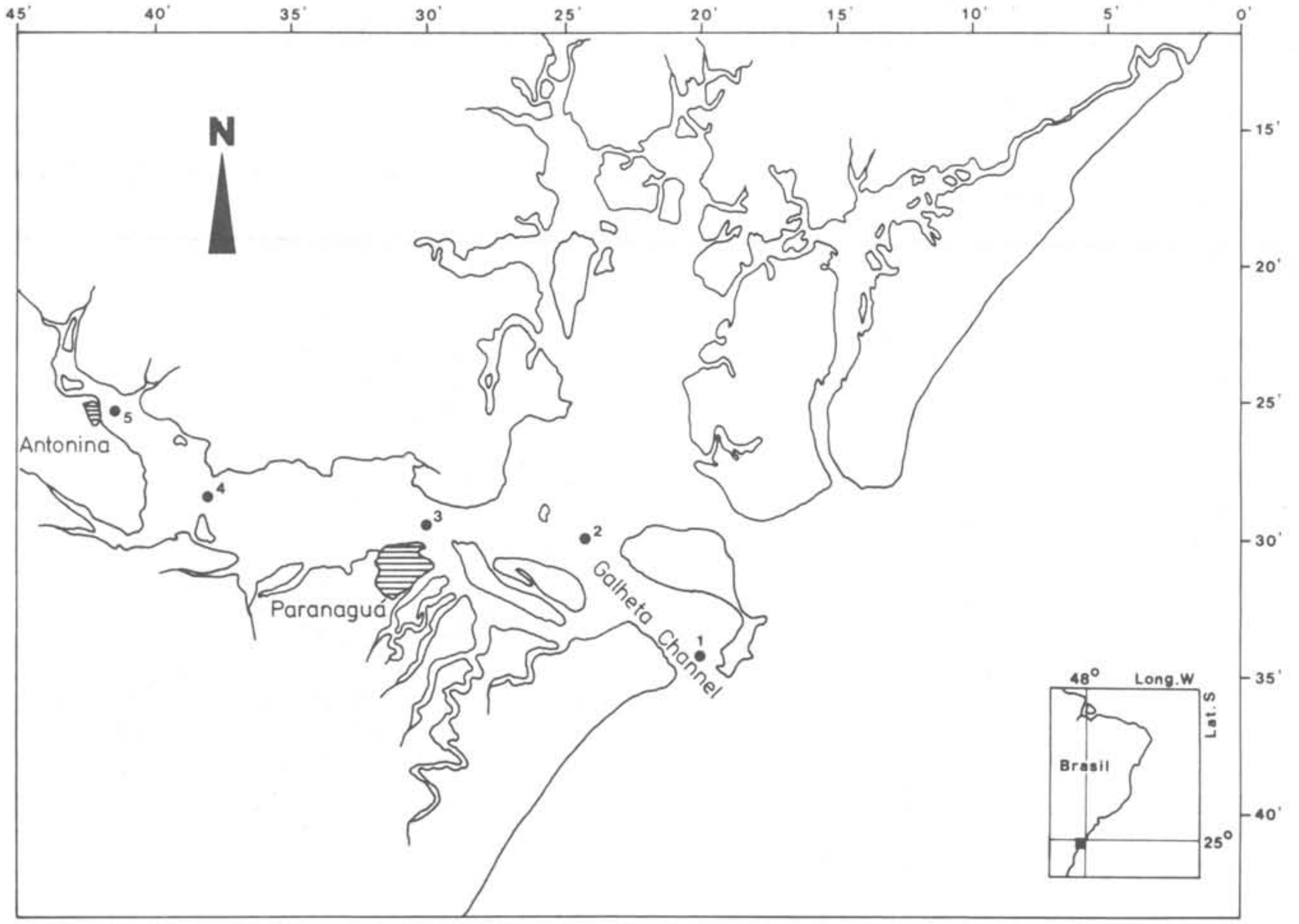

Fig. 1. Stations location in the Bay of Paranaguá.

Material and methods

Five stations distributed from near the entrance of the Galheta Channel till the inner Antonina area (Fig. 1) were sampled monthly from July 1983 to June 1984, during a total of 15 sampling trips.

Observations with the Secchi disk were performed; surface and vertical samples (only at stn 3) were taken with a plastic bucket or with Van Dorn bottles for measuring the temperature and pH by conventional methods, salinity (Harvey) and dissolved oxygen (Winkler). Phosphate, nitrate, nitrite, ammonia, silicate and seston smaller than 300 µm were measured according to Strickland & Parsons (1972).

Subsamples were filtered through Whatmann GF/C filters for spectrophotometric measurements of photosynthetic pigments; the equations of Jeffrey & Humphrey (1975) for chlorophyll-*a* and Parsons & Strickland (1963) for total carotenoids were used.

The photosynthetic rate of surface were obtained only during sunny days and, in December 12, the photosynthesis X light curve of the surface were obtained at station 3, using the C-14 technique (Steemann-Nielsen, 1952).

The general composition of the phytoplankton population was analysed using an inverted microscope (Utermöhl, 1958).

Due to problems of logistics, most of the chemical parameters (except the pH and total CO_2) had to be measured at the laboratory of the Centro de Biologia Marinha (Universidade Federal do Paraná) located at Pontal do Sul, six hours after the sampling. Meteorological informations were provided by Portobras-INPH Agency.

Results

Despite the daily fluctuations due to tide cycle and biological activity, the spatial distribution of chemical and biological parameters, except the temperature, will be presented as *yearly averages* from the sampling period (Tables 1-2).

Physico-chemical parameters

The annual variation of the surface temperature ranged from 17 to 30°C (Fig. 2A), with maximum in February 1984 and minimum in July 1983.

Physico-chemical parameters for each station are presented as yearly average values in Table 1. The salinity showed yearly average values ranging from 9.38 to 32.00°/₀₀, decreasing from the outer- to the inner part of the bay. Increasing averages of dissolved oxygen concentrations were observed at the

Table 1. Average values of physico-chemical parameters in the surface of Paranaguá Bay. Inorganic nutrients in µg-at/l. Maxima and minima values in brackets

Station	S(°/₀₀)	D.O.(ml/l)	pH	NH_4-N	NO_2-N	NO_3-N	TIN*	PO_4-P	SiO_2-Si
1	32.00	5.17	8.18	1.58	0.12	1.61	3.31	0.38	27.68
	(24.0-33.0)	(4.8-5.8)	(8.12-8.25)	(0.29-4,51)	(0.0-0.36)	(1.05-2.63)		(0.30-0.49)	(19.06-37.80)
2	25.83	-	8.16	1.99	0.06	2.20	4.25	0.42	-
	(20.0-29.6)		(8.10-8.23)	(0.74-5.39)	(0.0-0.16)	(1:64-2.53)		(0.26-0.51)	
3	22.28	5.27	8.09	1.63	0.39	1.68	3.70	0.55	43.33
	(15.0-27.3)	(4.3-6.5)	(8.00-8.16)	(0.23-3.74)	(0.0-0.53)	(0.79-3.16)		(0.25-0.79)	(32.86-48.51)
4	16.08	-	7.98	2.43	0.13	1.77	4.33	0.71	72.41
	(10.0-23.8)		(7.94-8.05)	(0.58-5.39)	(0.01-0.28)	(0.74-4.19)		(0.35-0.87)	(63.96-80.86)
5	9.38	5.53	7.46	4.37	0.44	3.64	8.48	0.97	98.36
	(2.0-20.6)	(5.0-5.9)	(6.99-7.81)	(0.74-9.57)	(0.02-0.48)	(1.79-3.67)		(0.48-1.93)	(20.81-148.63)

*Total inorganic nitrogen

Table 2. Average values of transparency, seston and biological parameters in the surface of Paranaguá Bay. Maxima and minima values in brackets

Station	Secchi (m)	Seston (mg/l)	Chlor. *a* (mg/m³)	Carot. (m-SPU/m³)	Carot./Chlor. *a*	mgC/m³/h
1	2.9	6.82	2.86	4.49	1.11	1.14
	(1.6-5.0)	(3.18-13.52)	(1.24-6.39)	(1.50-7.74)	(1.21-1.11)	(0.01-2.38)
2	2.6	4.77	3.05	3.22	1.11	-
	(1.4-3.9)	(1.07-13.35)	(1.92-4.78)	(2.05-5.76)	(1.06-1.20)	
3	2.0	6.33	5.78	5.20	0.89	1.85
	(1.4-2.8)	(1.94-13.55)	(2.60-13.61)	(1.27-9.90)	(0.48-0.72)	(0.32-3.20)
4	1.5	9.03	13.99	9.47	0.73	5.62
	(0.9-0.2)	(4.60-13.17)	(5.61-29.18)	(2.53-18.40)	(0.45-0.63)	(3.89-7.36)
5	1.0	14.27	11.13	11.35	0.98	4.31
	(0.5-1.3)	(9.66-25.26	(3.82-22.02)	(1.15-21.60)	(0.51-0.98)	(3.51-5.12)

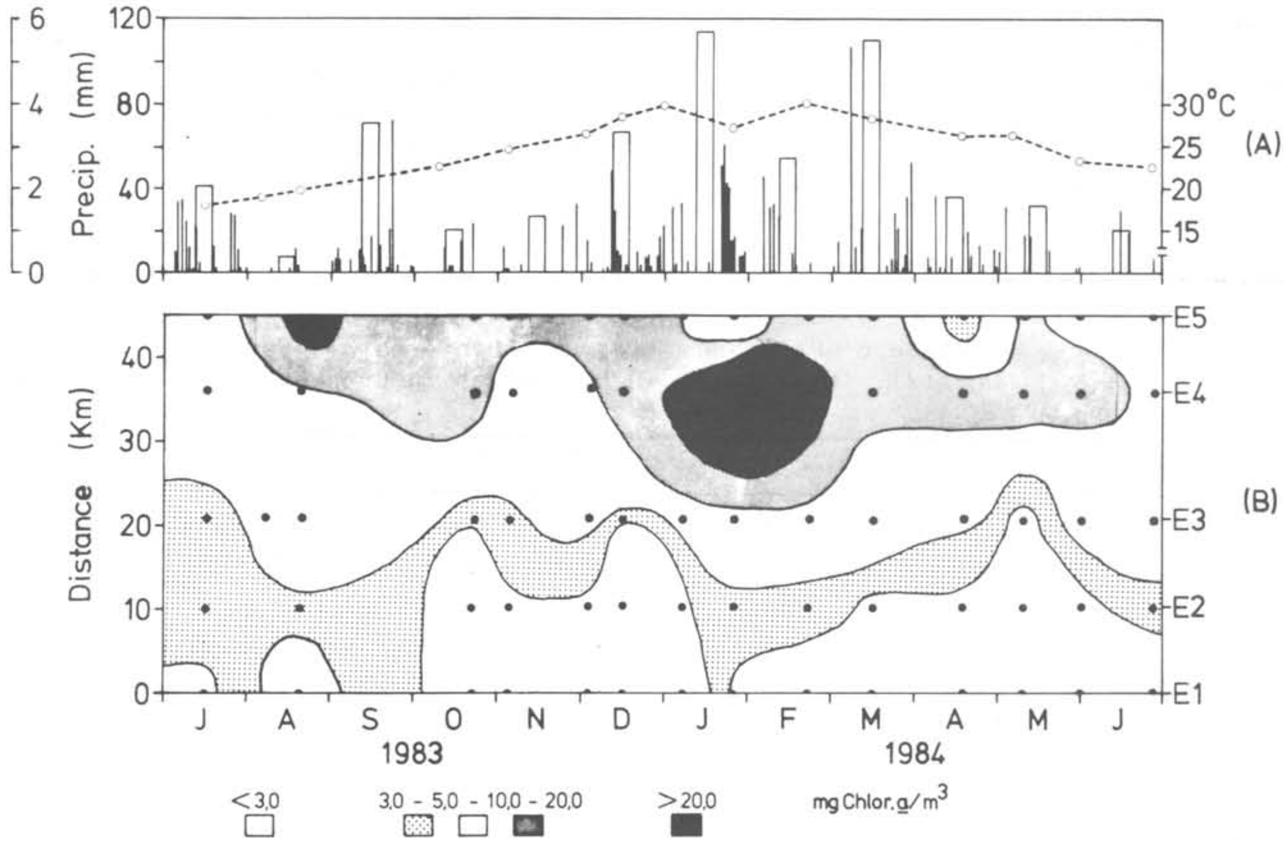

Fig. 2. Annual variation of temperature and precipitation (A), and horizontal distribution of chlorophyll-*a* (B) in the surface of Paranaguá Bay.

surface toward the interior part of the bay, ranging from 5.17 to 5.53 ml/l. The surface average of pH and total CO_2 at station 1 were 8.18 and 35.0 mg/l, respectively, decreasing to 7.46 and 5.21 mg/l at station 5.

The yearly average concentration of total inorganic nitrogen, phosphate and silicate ranged from 3.31 to 8.48, 0.38 to 0.97 and 27.68 to 98.36 µg-at/l, respectively, with the highest often observed in the inner-most station 5 located near Antonina.

The yearly average of seston at the surface (Table 2) varied from 4.77 to 14.27 mg/l increasing toward the back of the bay and consequently the water transparency decreases (Secchi disk). The vertical distributions of seston at station 3 (Fig. 3) presents a general tendency of accumulation near the bottom. Due to technical problems some plots were excluded in the Figure 3.

Biological parameters

The horizontal and temporal distribution of surface chlorophyll-*a* throughout the sampling area can be seen in Figure 2B. The highest concentrations were found at station 4 during the rainy periods of January and February 1984 and at station 5 during the dry period of August and September 1983. The seasonal fluctuations were more intense in the inner- than in the outer part of the bay; the average concentrations ranged from 2.86 mg/m^3 at station 1, to 13.99 mg/m^3 at station 4 (Table 2). The vertical distribution of chlorophyll-*a* obtained in different periods (Fig. 3) was usually homogeneous, with the exception of February 22. Integrated values throughout the water column varied from 51.62 to 199.61 mg/m^2, the maximum being observed during summer. Total carotenoids at the surface varied from 3.22 to 11.35 $m\text{-}SPU/m^3$ at stations 2 and 5, respectively.

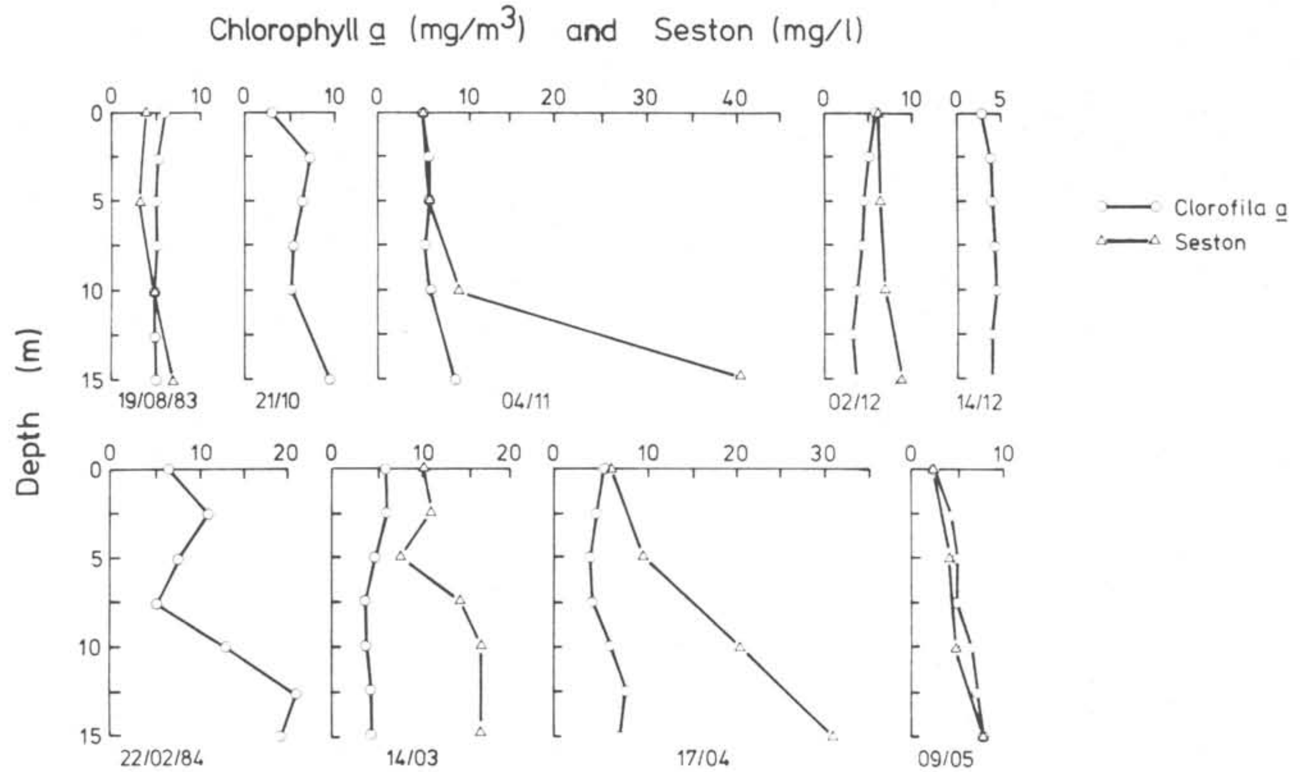

Fig. 3. Vertical distribution of chlorophyll-*a* and seston at Stn, 3, in different sampling periods.

The photosynthetic rate at the surface varied from 0.01 to 7.36 $mgC/m^3/h$ averaging 1.14, 1.85, 5.62 and 4.31 $mgC/m^3/h$ at stations 1, 3, 4 and 5, respectively. The higher rates were always observed in the inner bay.

The nannoplankton was always numerically dominated by phytoflagellates smaller than 10 µm. *Skeletonema costatum* was the most abundant diatom during the study period. *Thalassionema nitzschioides*, *Leptocylindrus minimus*, *Nitzschia* spp., *Chaetoceros* spp., *Rhizosolenia* spp. and *Asterionella glacialis* were also very frequent occasionally. Among the dinoflagellates, *Protoperidinium* spp., *Ceratium* spp., *Ceratium furca*, *Prorocentrum micans* and *P. minimum* were the most important species. *Dinophysis* sp. and *Prorocentrum maximum* were occasionally abundant.

Discussion

The organic component of the seston represents the base of the food-chain in the mangal ecosystems. In the Bay of Paranaguá, the particulate organic material is basically detritic and, to a lesser extent, contains alive phytoplankton cells. The detritus is originated from the litter of leaves produced in the mangrove forests around the bay, and forms the substrate for a heterotrophic microcommunity composed by bacteria, fungi, protozooplankton and even benthic diatoms (Odum & Heald, 1975; Knoppers & Opitz, 1984; Por, 1984).

The phytoplankton production and its relationships with the environmental factors in such tropical and subtropical mangals was recently described by Ricard (1984) and Por *et al.* (1984), with emphasis on the Cananéia region which is near Paranaguá Bay. The ecological characteristics of both environments are similar and may be compared.

The low N:P that can be calculated from Table 1, is apparently the best evidence that the phytoplankton production in Paranaguá Bay is limited by the amount of nitrogen as is the case in most of the marine ecosystems (Ryther & Dunstan, 1971).

The increasing concentrations of chlorophyll-*a* toward Antonina is related with the increasing amount of inorganic nutrients (Tables 1-2).

Usually, the concentrations of ammonium make up approximately 50% of the dissolved inorganic nitrogen. The maximum values of ammonium observed in the inner Antonina area, may be due to a great amount of organic material from the mangrove forests being constantly oxidized (specially during the hot periods), to bottom regeneration and, in a lesser extent, to animal excretion. In this case, it would be expected that the average dissolved oxygen concentrations in this area would be lower than at the mouth of the bay. However, these tendency was often distorted due to the interactions of many factors such as, photosynthetic activity (sampling was always carried during day time), respiration, atmospheric changes, tidal cycle, etc.

Tundisi *et al.* (1978) observed a seasonal fluctuation in nutrient concentrations with the rainfall regime in the Cananéia region. This, in turn, was responsible for the annual changes of the phytoplankton biomass inside the bay. This is probably the case in the Bay of Paranaguá during the present study period, although correlations between nutrient concentrations and rainfall regime were not performed due to the scarcity of data. However, according to Figures 2A and B, pluviosity seems to affect the annual changes of the phytoplankton biomass, specially in the inner bay.

The maximum surface values of chlorophyll-*a* measured at station 4 coincided with the rainy periods of summer, from December 1983 to March 1984. During the dry seasons, particularly in July 1983 and June 1984, with low temperature and precipitation, the concentrations of chlorophyll-*a* at the surface decreased and were similar in stations 3 and 5. The same situation almost repeated in November 1983 probably due to the low precipitation of that month.

The increase of dissolved nutrients in the water due to high precipitation in the bay (Knoppers & Opitz, 1984) is counteracted by the increase of suspended particulate and dissolved material. Consequently, the water transparency is reduced. This can be partially illustrated in Figure 4 ($r = -0.76$; $\alpha = 0.05$) were the scattering of points may be due to the dissolved humic substances which greatly limit the ligth penetration in such environments (Tundisi, 1969; Teixeira *et al.*, 1969).

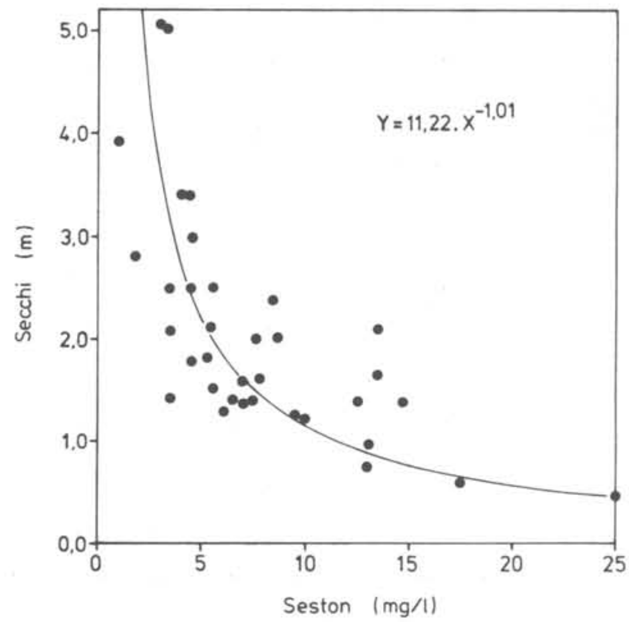

Fig. 4. Relationship between transparency and seston (<300 µm) in Paranaguá Bay.

Photosynthesis and chlorophyll-*a* tend to increase toward the interior of the bay where there is an increase of dissolved nutrients. However, the maxima of chlorophyll-*a* were usually found at station 4 where the average transparency was higher and the average amount of nutrients were still high enough, and not in station 5 where the maxima of nutrients were always measured (Tables 1-2). Certainly, ligth penetration is also an important parameter which regulates phytoplankton growth in such mangrove waters (Teixeira *et al.*, 1965, 1969; Ricard, 1984). Photoinhibition of photosynthesis must be considered as well. Previous works (Teixeira *et al.*, 1969; Tundisi *et al.*, 1973, 1978) have reported values of photosynthesis in Cananéia many orders of magnitude higher than those obtained during the present investigation. Tundisi *et al.* (1973) have obtained their high values of approximately 5 to 70 $mgC/m^3/h$ under cloudy conditions, and photosynthesis-ligth curves obtained in the present study from the surface of station 3 (Fig. 5) indicate a strong inhibition of photosynthesis under high ligth intensities. This fact may explain the lower photosynthetic rates observed in Paranaquã Bay as most of the incubation experiments were performed in the deck of the sampling boat during bright sunny days.

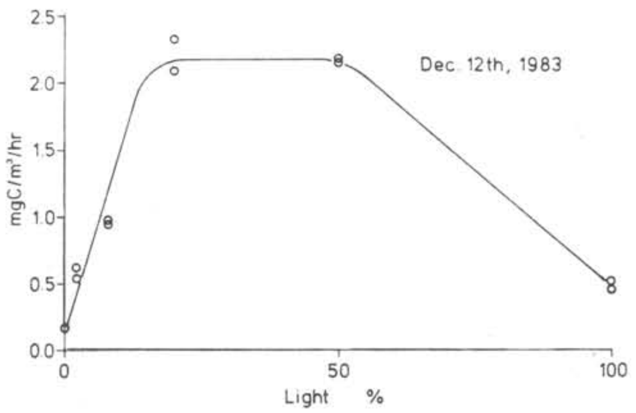

Fig. 5. Photosynthesis-light curve of the surface phytoplankton collected at Stn 3, in Paranaguã Bay.

The average ratios of carotenoids to chlorophyll-*a* (Table 2), may be used to characterize the physiological status of the phytoplankton population throughout the bay. The lowest average observed in station 4 indicates optimal condition for phytoplankton growth in this area. In stations 1 and 2, an area greatly affected by the adjacent sea, the higher than unity carotenoids to chlorophyll-*a* ratios usually observed, reflect deficiency of nitrogen (Antia *et al.*, 1963; Tundisi & Tundisi, 1975). In stations 4 and 5 where the maxima averages of photosynthesis and chlorophyll-*a* were observed, the salinity fluctuated around the optimum values reported for phytoplankton development in estuarine areas (10-15°/₀₀ according to Ricard, 1984). Therefore, also salinity together with nutrients concentration, turbidity and light inhibition jointly control the phytoplankton growth and distribution in the bay.

Conclusions

The low N to P and high carotenoids to chlorophyll-*a* ratios observed during the present study indicate the nitrogen deficiency for phytoplankton growth in Paranaguã Bay, specially in the outer part influenced by the open sea.

The rainfall regime seems to be one of the most important factors which indirectly affects long term changes of phytoplankton growth in the inner bay. Comparatively higher nutrients concentrations and probably lower salinities induce phytoplankton development during the rainy periods of the summer.

Light inhibition of surface photosynthesis and turbidity, however, limit the phytoplankton population complicating the relationships between growth and environmental parameters.

Resumo

Foram feitas coletas mensais na Baĩa de Paranaguã (Paranã) em 5 estações fixas durante um ano (1983-1984) para se medir parâmetros ambientais bãsicos, biomassa e fotossĩntese do fitoplâncton durante um perĩodo sazonal. A temperatura na superfĩcie variou de 17 a 30°C. As mé-dias anuais de salinidade, oxigênio dissolvido e pH variaram de 9,38-32,00°/₀₀, 5,17-5,53 ml/l e 7,46-8,18, respectivamente. As concentra-ções médias do nitrogênio inorgânico total, fosfato e silicato variaram de 3,31-8,48, 0,38-0,97 e 27,68-98,36 µg-at/l, respectivamente, com os mã-ximos obtidos na parte mais interna da baĩa. A clorofila-*a* na superfĩcie variou entre 2,86 e 13,99 mg/m^3 com mãximos na parte mais interna da baĩa associadas ãs altas concentrações de nutrientes e salinidades mais baixas. As taxas de fotossĩntese obtidas na superfĩcie variaram entre 0,01 e 7,36 $mgC/m^3/h$, com mãximos na região mais interna da baĩa. Fitoflagelados e *Skeletonema costatum* dominaram a popu-lação fitoplanctônica durante o perĩo-do estudado. As variações temporais no interior da baĩa foram associadas ao regime de chuvas. A alta pluviosidade aumenta a concentração de nutrientes e conseqüentemente, estimula o desen-volvimento do fitoplâncton que ẽ, no entanto, limitado pela deficiência em nitrogênio e pela turbidez da ãgua.

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