

Microalgae of the continental shelf off Paraná State, southeastern Brazil: a review of studies

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- **Abstract:** The paper reviews the taxonomic and ecological works on marine microalgae (phytoplankton and microphytobenthos) off Paraná State, Southeastern Brazil. Various studies refer to the taxonomy of benthic diatoms. Few descriptive field works in coastal and adjacent shelf waters contribute to the understanding of phytoplankton dynamics in coastal and shelf areas. Patterns of geographic distribution and changes in the phytoplankton community are described in relation to water masses and seasonal variations in the hydrographic regime. During summertime, when warm oligotrophic waters predominate over the shelf, the phytoplankton is numerically dominated by small phytoflagellates, dinoflagellates, coccolithophorids and filaments of cyanobacteria. During wintertime, the abundance of micro-size diatoms over the shelf increase due to the dominance of cold nutrient-rich waters from the South Atlantic Central Water and wind-driven vertical circulation. The phytoplankton community off Paraná State may be classified into two categories: the diatom-dominated coastal assemblage, mainly controlled by nutrient inputs from land drainage and resuspension of bottom sediments, and the flagellate-dominated shelf assemblage, more affected by the seasonality of local hydrographic regime.
 - **Resumo:** O trabalho é uma revisão dos estudos taxonômicos e ecológicos das microalgas (plancônicas e bentônicas) realizados no Estado do Paraná. A maioria dos trabalhos sobre microfítobentos são de caráter taxonômico e, basicamente, referem-se à diatomáceas bênticas sobre macroalgas ou fundos lodosos e consolidados. Poucos trabalhos contribuíram para o estudo da dinâmica espaço-temporal do fitoplâncton em áreas costeiras e de plataforma. São descritos os padrões de distribuição geográfica e as mudanças sazonais na comunidade fitoplancônica em relação ao regime hidrográfico. No verão, quando águas quentes oligotróficas predominam na superfície, o fitoplâncton é numericamente dominado por nanoflagelados, dinoflagelados, cocolitoforídeos e cianobactérias filamentosas. No inverno, as diatomáceas do microplâncton são em geral mais abundantes devido ao domínio de águas frias ricas em nutrientes. A comunidade fitoplancônica da plataforma paranaense pode ser classificada em duas categorias: as associações costeira, sujeitas ao aporte de nutrientes pela drenagem continental e ressuspensão do sedimento, e a comunidade da plataforma afastada da costa, mais afetada pela sazonalidade do regime hidrográfico.
 - **Descriptors:** Phytoplankton, Microphytobenthos, Taxonomy, Paraná State, Southeastern Brazil.
 - **Descritores:** Fitoplâncton, Microfítobentos, Taxonomia, Estado do Paraná, Região sueste do Brasil.
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The Paraná littoral and plane region

The coastline of Paraná State, Southeast Brazil, runs from north to south between 25°12' - 58°S Lat. along the 48°W Long. The continental shelf is extensive, with the isobath of 200 meters starting at approximately 175-190 km from the coastline. The littoral plane is not extent (10-20 km, with a maximum of 50 km in the Bay of Paranaguá) due to its proximity to the Serra do Mar. Consequently, the continental drainage is small, despite the high precipitation (Bigarella, 1978), being concentrated in the inner bays of Paranaguá and Guaratuba. Heavy rains generally occur in summer, as the result of the constant stationing of polar fronts. In winter, less solar radiation, coupled with the frequent passage of a polar anticyclone, makes the atmosphere drier and colder (Bigarella, 1978; Nimer, 1990)

The littoral between the bays of Paranaguá and Guaratuba is basically formed by a single extensive sandy beach exposed to the open sea, but the inner bays are bordered by extensive mangrove forests producing organic detritus which is then transported by continental drainage and tidal currents towards the adjacent sea.

In the coastal region, the patterns of circulation on a regional scale are governed by tides, wind and precipitation patterns, draining the continent and carrying nutrients to the coastal waters. Meanwhile, it is impossible to disassociate the characteristics of the hydrographic system of the mid-shelf and the contiguous oceanic areas from the general oceanographic structure of the southern Brazil (see Emilsson, 1961) which is directly related to the seasonal dynamics of the Brazil Current and the proximity of the Subtropical Convergence.

Studies in shelf and oceanic areas

The first oceanographic studies of the Southwest Atlantic Ocean were made in the 1920's, during the expeditions of the R/V "Meteor" (Wüst, 1932; Defant, 1936) and R/V "Discovery" (Deacon, 1933, 1937). However, the data collected at that time permitted only a general and simplified vision of the water masses.

Oceanographic studies in shelf areas off Brazil were systematically begun only in the 1950's. Phytoplankton samples were collected in mid- and outer-shelf off Paraná State within a larger sampling program covering large parts of the south and southeast regions of Brazil. Earlier informations on the physical-chemical characteristics of the water masses in this region were described by Emilsson (1959, 1961), based on data obtained during expeditions of the Brazilian Navy, with the corvettes "Iguatemi", "Solimões" and the R/V "Almirante Saldanha".

The latitudinal displacements of the Subtropical Convergence, as the consequence of seasonal changes in the wind systems of the Southwest Atlantic, change completely the hydrography of the shelf. Northeasterly winds predominate during summer transporting Tropical Water (TW) from the Brazil Current (Emilsson, 1961; Miranda, 1982; Matsuura, 1986; Brandini 1990a). In winter, the southeasterly winds predominate, allowing the penetration and mixing of subantarctic waters along with shelf and tropical waters (Fig. 1). Strong gradients of temperature were observed along the shelf off Santa Catarina and Paraná, indicating the penetration of cold waters. The isohaline of 36.0 psu, which represents the limits of Tropical Water from the Brazil Current, extended along the slope during winter 1982, but it was close to the coast during summer 1984. In the vertical plane, the main hydrographic features affecting the physical-chemical conditions of shelf waters and the planktonic community are (i) the formation of a well-defined seasonal thermocline in summer and (ii) the shelf-break upwellings (Fig 2).

Between May 1976 and June 1978 work was done on the shelf between Cabo Frio-RJ (22°S and 42°W) and Cabo de Santa Marta Grande - RS (28°S and 48°W) during various cruises of the R/V "Prof. W. Besnard" (IOUSP), supported by the Financier of Studies and Projects (FINEP). The sampling of phytoplankton material, restricted to the surface layer, included some stations off Paraná State. Aidar-Aragão *et al.* (1980) published the first information on the potential primary production of phytoplankton in the surface, using the C-14 technique of Steemann-Nielsen (1952) and analysis of chlorophyll-a. During the same period, Vieira & Teixeira (1981) completed the physiological studies by means of excretion of dissolved organic material, and Soares (1983) described the taxonomic structure and the distribution of the dominant phytoplankton groups. The diatoms were abundant in neritic stations and the more significant species were *Skeletonema costatum*, *Leptocylindrus danicus*, *L. mediterraneus*, *Thalassionema nitzschioides*, *Bacteriastrum* sp, *Thalassiosira* sp, *Nitzschia* spp and *Chaetoceros* spp, followed by *Proboscia* (= *Rhizosolenia*) *alata*, *R. calcaravis*, *R. robusta*, *Guinardia flaccida*, *Guinardia striata* (= *Rhizosolenia stolterfothii*), *Hemiaulus membranaceus* and *H. hauckii*. *Climacodium frauenfeldianum* was significant in one of the three cruises, but associated with tropical dinoflagellates, dominated by typical neritic and oceanic representatives of the Brazil Current (e.g., *Amphisolenia bidentata*, *Ceratium hexacanthum*, *C. fusus*, *C. karstenii*, *C. massiliensis*, *C. trichoceros*, *C. tripos*, *Diplopsalis* sp., *Goniodoma poliedricum*, *Protoperidinium grande* and *Pyrophacus steinii*).

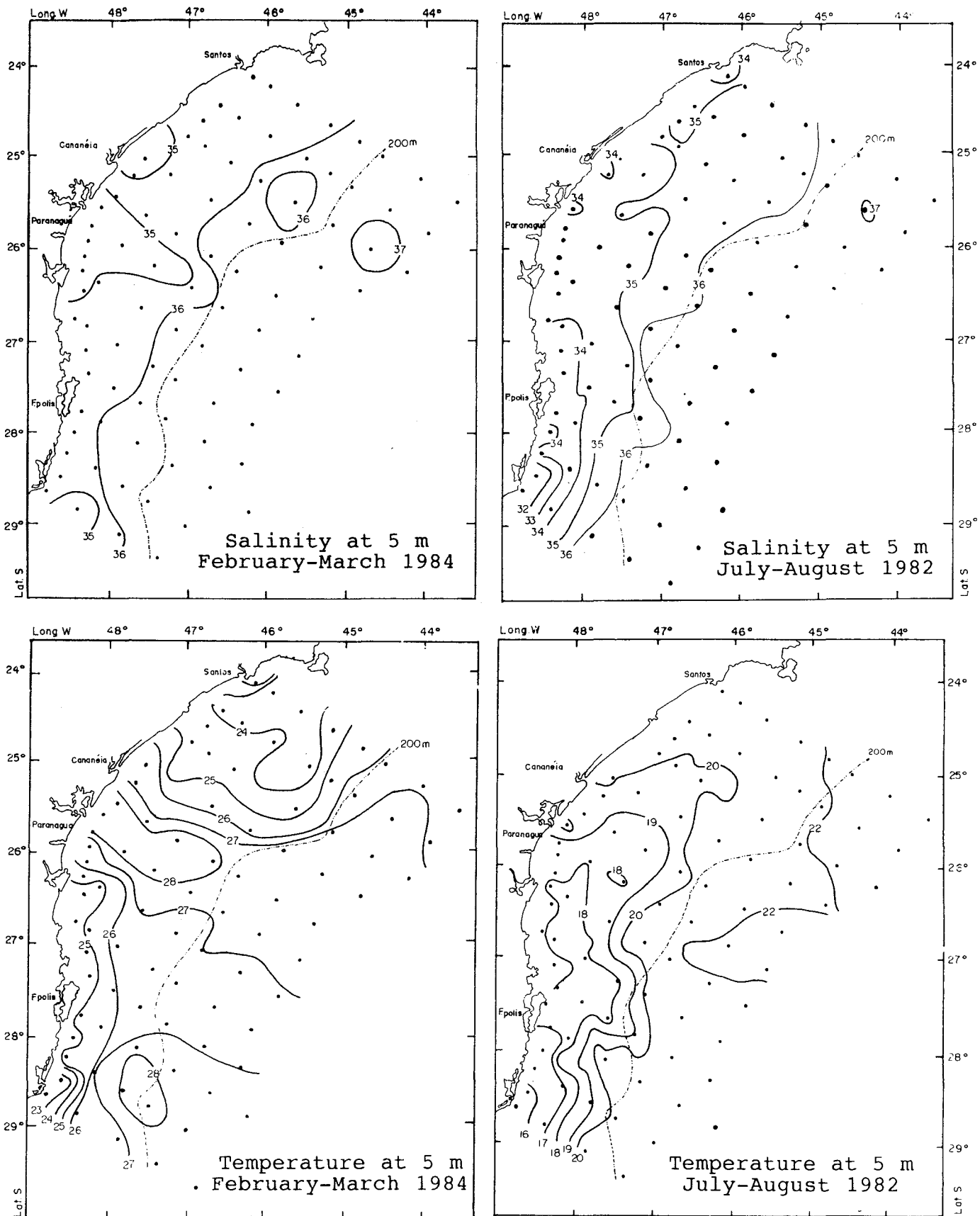


Fig. 1. Geographical distributions of temperature and salinity at 5 meters in Southeast Brazil, in July-August 1982 and February-March 1984 (modified from Brandini, 1990).

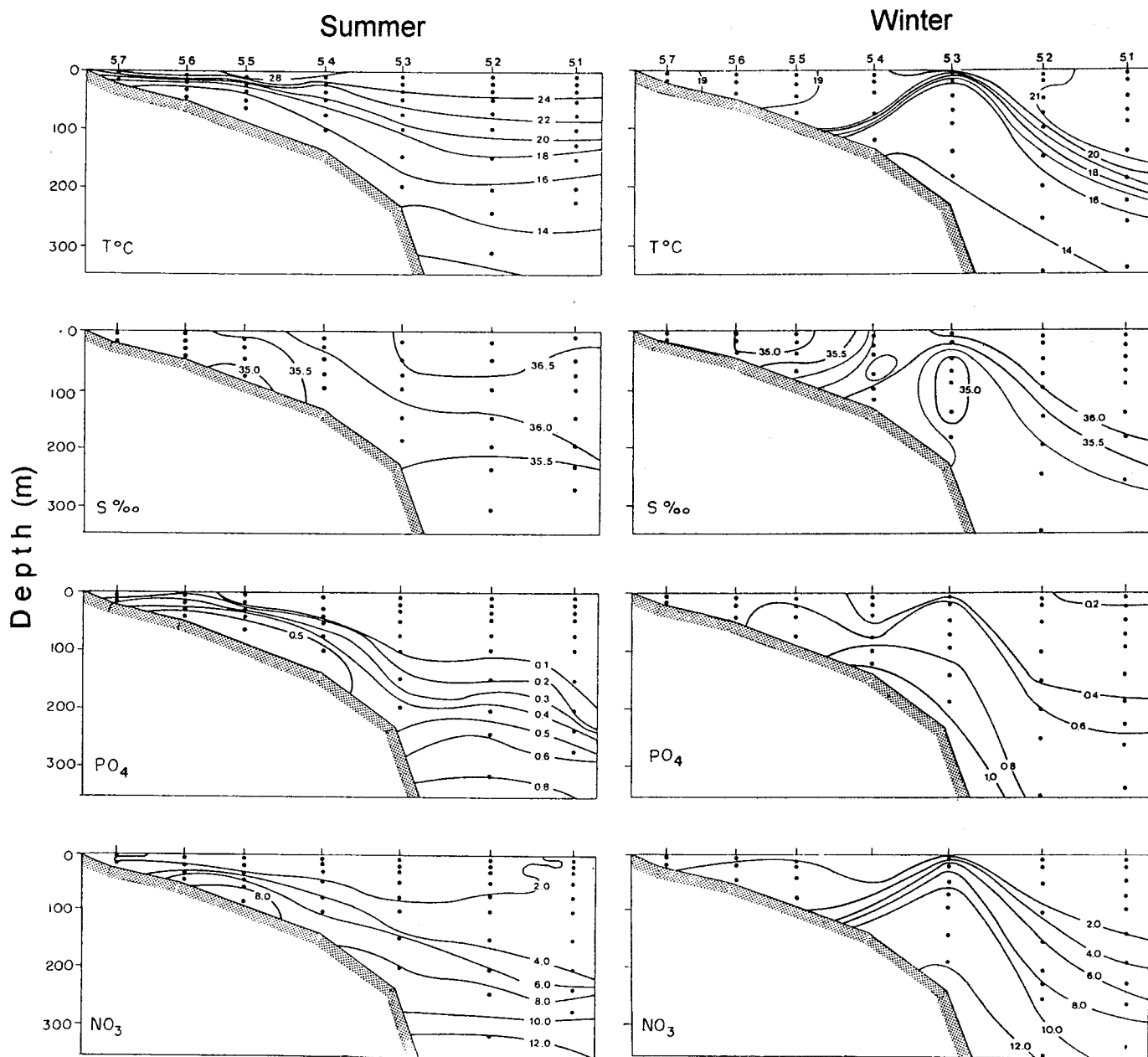


Fig. 2. Cross-shelf distributions of temperature, salinity and nutrients off the Bay of Paranaguá, Paraná State, in the summer 1982 and in the winter 1983 (modified from Brandini, 1990a).

At the end of the 1970's, the expedition "Conversut I" of the Brazilian Navy studied the hydrographical and biological aspects of the Subtropical Convergence, comprising the shelves of southern Brazil, Uruguay and part of Argentina (DHN, 1980; Hubold, 1980).

From July 1982 until November 1985, another important seasonal sampling program was carried out by the Brazilian Navy; the expeditions "SUESTE" (DHN, 1985; 1986a; 1986b, 1987) were conducted by the R/V "Almirante Saldanha", covering a sampling network of 90 oceanographic stations in each cruise, organized in 12 cross-shelf transects off São Paulo, Paraná and Santa Catarina states. During these expeditions, the shelf-break upwelling of SACW (Mesquita *et al.*, 1983) were detected in different seasons of the year off the Bay of Paranaguá (Brandini *et al.*, 1989; Brandini, 1990a). These upwellings fertilize the base of the euphotic zone of the oceanic oligotrophic regions, stimulating the production of phytoplankton and the development of the pelagic ecosystem.

The collection of phytoplankton material produced data on cell density, floristic composition, photosynthetic pigments, rates of photosynthesis, estimates of potential and *in situ* primary production in the euphotic zone and photosynthetic characteristics of phytoplankton. The dynamics of the phytoplankton community were associated with the oceanographic structure of the region (Brandini, 1988a; Brandini, 1988b; Brandini, 1990a; Brandini *et al.*, 1989). The expedition "Monitor IV" collected hydrographical and biological data during summer (DHN, 1989), off Rio de Janeiro, São Paulo and Paraná States.

Brandini & Moraes (1986) and Brandini (1988b) described the patterns of geographic distribution of dominant phytoplankton groups in relation to the water masses. During winter, Brandini (1988b) showed the difference between cold water assemblages of sub-antarctic origin, dominated by diatoms, and the assemblages of the Brazil Current, dominated by cyanophyceans, coccolithophorids and dinoflagellates. A similar pattern in the neritic region was observed by Fernandes (1992) during a seasonal study in front of the Bay of Paranaguá. From these, it was deduced that seasonal changes in the structure of the phytoplankton community off Paraná State, occurred as a result of changes in the oceanographic structure. With the predominance of Tropical Water in summer, prevails a regenerative type production system (*sensu* Dugdale & Goering, 1967) in which nanoplanktonic phytoflagellates, coccolithophorids and cyanophyceans are the dominant phytoplankters. During winter, the intrusion of cold and nutrient-rich

waters increases the relative contribution of microplanktonic diatoms.

In the vertical plane, the structure of the phytoplanktonic community in the euphotic zone changes in the region of the continental slope due to shelf-break upwellings. The occurrence of such upwellings has important implications on the primary production of oceanic areas, where the contribution of nutrients to the euphotic zone from deeper layers is generally limited by the presence of the permanent thermocline. The upward motions of the SACW fertilizes the base of the euphotic zone, increasing the production of phytoplankton and, consequently, that of the higher trophic levels (Brandini *et al.*, 1988). These authors observed that the most representative modifications in the phytoplankton community were the increases in concentrations of micro- and nanoplanktonic coccolithophorids (*Umbilicosphaera sibogae*, *Emiliana huxleyii*, *Gephyrocapsa oceanica*), diatoms (*Pleurosigma* sp, *Coscinosira* sp, *Eucampia* sp.), cyanophyceans (*Oscillatoria erythraea*) and dinoflagellates. The cyanophycean *Trichodesmium* (= *Oscillatoria*) occurred in the coastal areas and in the sub-surface in oceanic areas (Fig. 3a). Diatoms predominate in coastal regions, mainly in sub-surface layers due to sedimentation (Fig. 3b). Dinoflagellates and coccolithophorids were more abundant in offshore regions (Fig. 3c and d), associated with the shelf-break upwellings of the South Atlantic Central Water (Fig. 3e).

The photosynthetic rates in the euphotic zone and its seasonal variation were attributed to changes in the hydrography and in the taxonomic structure of phytoplankton (Brandini, 1988a, 1988b, 1990a). Brandini (1990b) estimated the primary production rates in the coast (0.04 - 0.32 gC/m²/day) in the intermediate shelf (0.13 - 0.45 gC/m²/day), and in the oceanic (0.10 - 0.45 gC/m²/day) regions, and compared the potential organic production in the southeastern Brazil with data obtained in other seas. In the same work, the photosynthetic characteristics of the phytoplanktonic community were described during the stratification periods of summer, through the relations between the rates of photosynthesis and light, and by observing photo- adaptations occurring in the development of communities physiologically distinct throughout the euphotic zone.

Studies in the coastal region

Since the end of the 1950's, many works have contributed to the knowledge of diatoms in the coastal regions between the Bays of Paranaguá and Guaratuba

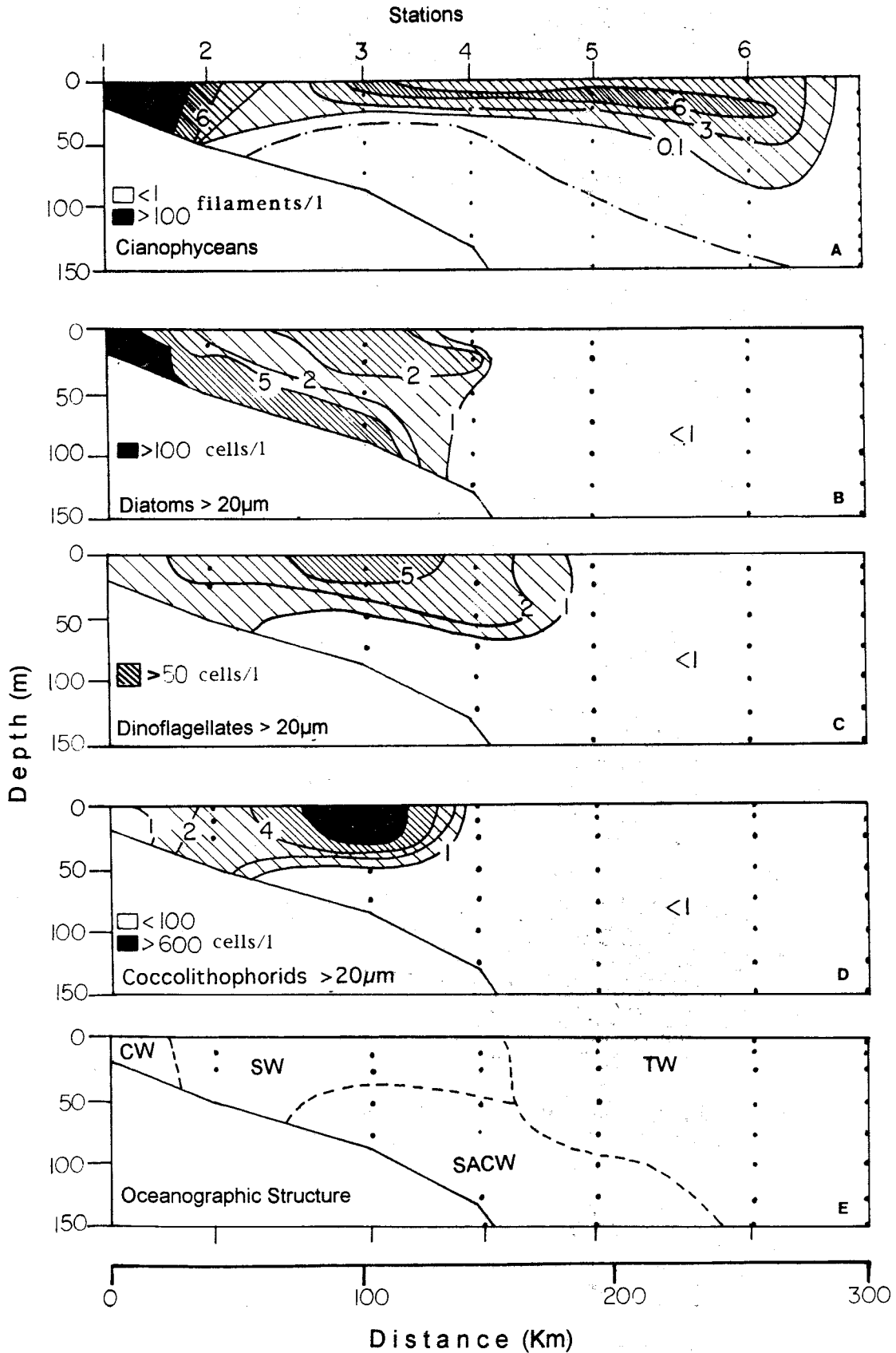


Fig. 3. Cross-shelf distribution of the phytoplankton community and the vertical oceanographic structure off the Bay of Paranaguá, Paraná State, in November of 1987. CW: coastal waters; TW: Tropical Water; SACW: South Atlantic Central Water. Multiply numerical labels of isolines in (A), (B) and (C) by 10, and in (D) by 100 (modified from Brandini, 1989).

(Moreira Filho & Fernandes, 1958; Moreira-Filho, 1959; Moreira-Filho, 1961; Moreira-Filho & Kutner, 1962; Moreira Filho & Mômoli, 1962; Moreira-Filho, 1968; Aidar, 1970; Moreira-Filho *et al.*, 1975; Moreira-Filho & Valente-Moreira, 1979; Moreira-Filho & Valente-Moreira, 1980; Valente-Moreira & Moreira-Filho, 1981; Oliveira, 1983; Oliveira, 1984; Moreira-Filho & Valente-Moreira, 1984; Valente-Moreira *et al.*, 1985; Valente-Moreira, 1987; Cunha, 1989; Moreira-Filho *et al.*, 1990).

The main objectives of these works were to perform floristic and taxonomic surveys of diatoms in the Paraná coast. Moreira-Filho (1959) began by publishing the first information about epiphytic microalgae on *Sargassum cymosum* collected from the beach of Caiobá. In this work, 31 species of diatoms and two species of silicoflagellates were identified. Moreira-Filho & Kutner (1962) studied the community of diatoms in sediments of Alexandra mangrove (Bay of Paranaguá), identifying various planktonic species. A series of works followed, surveying the floristic of epiphytic microalgae on macroalgae (Moreira-Filho *et al.*, 1977; Moreira-Filho & Valente-Moreira, 1980; Valente-Moreira *et al.*, 1980; Moreira-Filho & Valente-Moreira, 1981; Paula, 1990), in shell deposits (Hurt & Blasi, 1960; Moreira-Filho & Mômoli, 1962) and in the digestive tract of invertebrates (Moreira-Filho, 1960; Valente-Moreira *et al.*, 1994) and in fish (Valente-Moreira *et al.*, *op.cit.*). The quantitatively most significant species were *Achnanthes brevipes*, *A. longipes*, *Biddulphia pulchella*, *Cocconeis heteroidea*, *C. pellucida*, *C. scutellum*, *Grammatophora marina*, *G. oceanica*, *Licmophora abbreviata*, *Mastogloia binotata*, *M. crucicola*, *M. splendida*, *Paralia sulcata* and *Synedra tabulata*. Cunha (1989) described the temporary variations in the structure of diatom community in the Galheta Channel, Bay of Paranaguá, on a seasonal scale. Moreira-Filho *et al.*, (1990) performed a survey of diatoms identified in the whole State of Paraná, noting the occurrence of 636 species distributed in 115 classes, surpassing all the other groups of phytoplankton. In relation to benthic microalgae in the neritic area, it is difficult to establish any pattern of dominance and seasonal variation, since few works have been performed in Paraná. Meanwhile, recent investigations of Brandini *et al.* (in preparation) and Pellizzari¹ (1994) on the seasonal dynamics of the periphitic community in artificial substrates in the Bay of Paranaguá supply the first indications that they could

assume a major role in the local ecosystem, by-passing phytoplanktonic biomass in certain sections of the bay, besides becoming available for the planktonic community (e.g. *Cylindrotheca closterium* and *Pleurosigma* sp). These authors noted the dominance of the diatom *Navicula* sp during rainy periods of summer, followed by *Melosira* sp, *Coscinodiscus* sp, *Thalassiosira* sp, *Cylindrotheca closterium*, *Licmophora* sp, *Nitzschia aff. longissima* and *Pleurosigma* sp (Fig.4), suggesting that the production of the community is controlled mainly by temperature. Concentrations of chlorophyll-a were in accordance with diatom densities. Fernandes (1992) studied the annual variation of phytoplankton on the continental shelf off the Bay of Paranaguá and recorded the presence of various benthic species in the water column, possibly due to resuspension by tidal and wind-induced turbulence. The most significant were *Cyclotella stylum*, *Paralia sulcata* (mainly), *Anorthoneis eurystroma*, *Delphineis surirella*, *Rhaphoneis ampiceros* and *Thalassiosira* spp (3 species of valvar diameter inferior to 20 µm, coated with grains of sediment). There also occurred the epiphytes *Biddulphia* sp, *Licmophora ehrenbergii*, *L. flabellata* and *Podocystis adriatica*, and the planktonic genus *Chaetoceros*, which forms benthic resting-spores.

Since the 1980's works have been initiated in the Bay of Paranaguá with the purpose of studying the patterns of spatial and temporal variation of phytoplankton in relation to hydrographic and climatological parameters. The preliminary works concentrated on the analysis of daily variations of phytoplankton concentration and hydrographic parameters in relation to tides (Oliveira² *et al.*, 1983; Freitas, 1989). Brandini (1985a) described the changes in the phytoplanktonic community structure in a fixed station, in relation to pluviosity. Brandini (1985b) and Brandini *et al.* (1988) studied the seasonal variation and the spatial distribution of chlorophyll-a and basic hydrographic parameters within the Bay of Paranaguá.

Recently, besides the local climatology, the annual variation studies described the effects of the hydrographic regime in the adjacent shelf on the seasonal dynamics of phytoplankton in the bay (Rezende & Brandini³, 1988; Rebello & Brandini, 1990; Fernandes, 1992; Brandini &

(1) Pellizzari, F. M. 1994. Ecologia do perifíton da Baía de Paranaguá, Paraná. In: EVENTO DE INICIAÇÃO CIENTÍFICA da Universidade Federal do Paraná (EVINCI - 94/resumos). Anais. Curitiba, UFPR/PRPPG, p. 121.

(2) Oliveira, C.; Dortas, E. M.; Sert, M. A.; Soares, F. S. & Brandini, F. P. 1983. Variação nictemeral do fitoplâncton da Baía de Paranaguá. In: SIMPÓSIO DE ESTAGIÁRIOS, 3. Resumos. Londrina, 1983. Fund. Univ. Estadual de Londrina, p. 5.

(3) Rezende, K. R. V. & Brandini, F. P. 1988. Variação temporal do fitoplâncton em um ponto fixo da praia de Pontal do Sul (Paraná). In: ENCONTRO BRASILEIRO DE PLÂNCTON, 3. Resumos. Universidade Federal do Paraná. Centro de Biologia Marinha, 1988. p. 45.

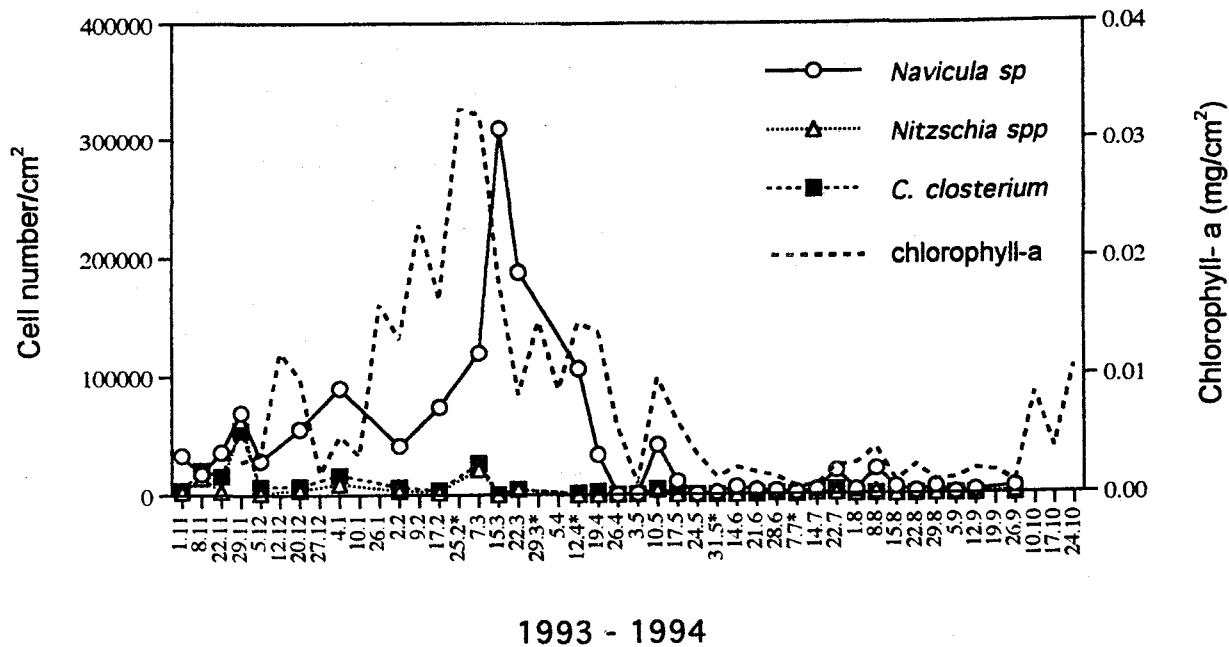


Fig. 4. Seasonal variation in the abundance of benthic diatoms in external sections of the Bay of Paranaguá, Paraná State. Abundance is expressed in terms of accumulation of cells and chlorophyll-a per area, after 7 days of submersion of artificial substrates (from Brandini *et al.* 1985).

Thamm, 1994). As a basis for these works, it was noted that the structure of the microalgae community is dominated by diatoms (see below) in summer, when occurs an enrichment of the water column with inorganic nutrients due to higher precipitation (Brandini, 1985a) (Fig. 5). Meanwhile, the turbulence generated by the stronger winds of winter, resuspending nutrients from the bottom, could also increase the density of diatoms in the coastal areas adjacent to the Bay of Paranaguá, with a significant contribution of benthic species such as *Paralia sulcata*, *Delphineis surirella* and *Cyclotella stylonum* (Fernandes, 1992). During winter, the presence of cold water species, such as *Bacteriastrum hyalinum*, *B. varians*, *Eucampia cornuta*, *Lauderia annulata*, *Detonula pumila* (= *Schroederella delicatula*), *Thalassiosira punctigera*, *Thalassiosira tumida*, *Thalassiothrix mediterranea*, *Dinophysis rotundata*, *Oxyphysis oxytoxoides* and *Protoperidinium oceanicum*, indicate the influence of sub-antarctic waters. Fernandes (1992) also observed a bloom of *Phaeocystis* sp immediately after the diatoms bloom, similar to what occurs in coastal regions of the North Sea (Lancelot *et al.*, 1991).

Phytoplankton assemblages in the shelf off Paraná State

The accomplished works in the coastal area and in the intermediate shelf allow for the distinguishing of the following phytoplanktonic associations:

a) The **coastal assemblage**, dominated by diatoms, mainly *Pseudonitzschia seriata*, *Pseudonitzschia*

delicatissima, *Leptocylindrus danicus*, *Leptocylindrus minimus*, *Chaetoceros affinis*, *Chaetoceros debilis*, *Chaetoceros didymus*, *Chaetoceros curvisetum*, *Chaetoceros compressum*, *Guinardia* (= *Rhizosolenia*) *striata*, *G.* (= *Rhizosolenia*) *delicatula*, *Dactyliosolen fragillissimus* (= *Rhizosolenia fragillissima*), *Cerataulina bergonii*, *Hemiaulus hauckii*, *H. sinensis*, *Asterionellopsis glacialis*, *Thalassionema nitzschioides* and *Skeletonema costatum*. Dinoflagellates are less abundant, and numerically dominated by the genus *Gymnodinium*, *Amphidinium*, *Cochlodinium*, *Gyrodinium* and *Torodinium robustum*, followed by *Ceratium furca*, *Ceratium fusus*, *Protoperidinium depressum*, *Protoperidinium* spp, *Prorocentrum balticum*, *Prorocentrum compressum*, *Prorocentrum micans*, *Prorocentrum minimum*, *Podolampas palmipes*, *Podolampas spinifera*, *Dinophysis acuminata*, *Dinophysis caudata*, *Dinophysis rotundata* and *Noctiluca miliaris*. Occasionally, some of these species may cause blooms. The predominant silicoflagellate is *Dictyocha fibula*. The coccolithophorids are normally represented by *Gephyrocapsa oceanica* and *Emiliania huxleyii*, followed by *Anoplosolenia* sp, *Antosphaera* sp, *Calciopapus* sp, *Calciosolenia* sp, *Corisphaera* sp, *Crycosphaera* sp and *Helichosphaera carterae*, which occurred in low concentrations.

b) The **shelf assemblage**, greatly influenced by oligotrophic waters of the Brazil Current, where dinoflagellates are dominated by *Ceratium azoricum*, *C. gravidum*, *C. massiliensis*, *C. trichoceros*, *C. vultur*, *Protoperidinium elegans*, *Amphisolenia bidentata*,

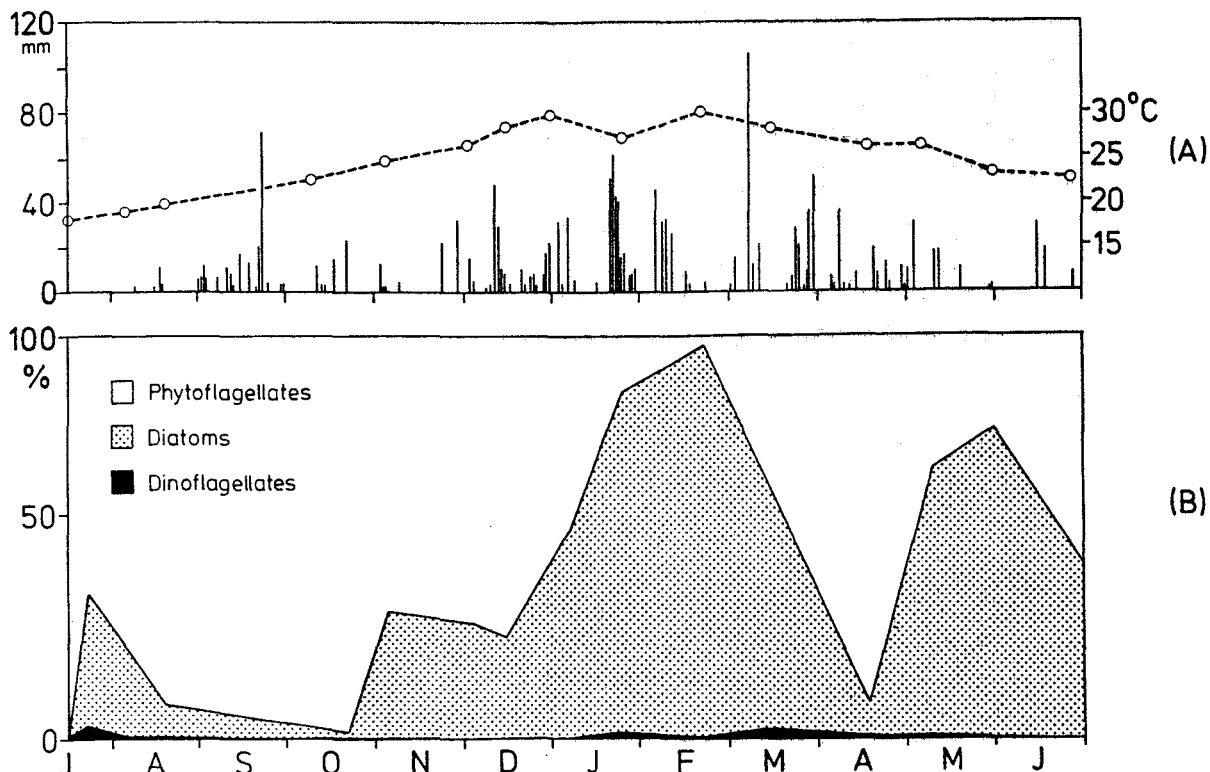


Fig. 5. Precipitation, air temperature (A) and relative abundance of the phytoplanktonic groups (B) at the surface of the Bay of Paranaguá. The figure shows the domain of diatoms in the warmer and rainier periods, and of flagellate forms during winter with less continental drainage (modified from Brandini, 1985a).

Goniodoma polyedricum, *Pyrophacus steinii*, *Gonyaulax* spp and *Ceratium* spp (see review of Balech, 1988). The coccolithophorids are essentially represented by *Gephyrocapsa oceanica*, *Emiliana huxleyii* and *Umblicosphaera sibogae*. Secondly, occurred the diatoms *Climacodium frauenfeldianum*, *Coscinodiscus gigas*, *C. centralis*, *Proboscia* (= *Rhizosolenia*) *alata*, *Hemiaulus membranaceus* and *Fragilariopsis* (= *Pseudoeunotia*) *doliolus*. The species *Gosleria tropica* and *Planktoniella sol* are rare but always present in net samples. The cyanobacteria *Oscillatoria erythraea* is common, forming sometimes extensive patches. During summer, these species also occur in inner-shelf regions, being mixed with the coastal assemblage.

Final remarks

The climatology and the seasonal variation of the oceanographic structure of the region, renders even more complex the space- temporal dynamics of the microalgae communities. Although the studies on the composition and biogeography of microalgal species are more or less advanced, there is missing physioecological data to complement the interpretation of patterns of distribution

and development in relation to environmental parameters. From that point on, it will be possible to evaluate quantitatively the role of microalgae in the marine ecosystem on the Paraná shelf, and to trace ecological models which will allow to foresee regularities and variations in the community over a longer period of time.

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(Manuscript received 17 July 1995; revised 04 December 1995; accepted 20 March 1996)