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BENTHIC DIATOMS GROWING ON GLASS SLIDES IN THE PARANAGUÁ BAY, SOUTHERN BRAZIL: TAXONOMIC STRUCTURE AND SEASONAL VARIATION

DIATOMÁCEAS (BACILLARIOPHYTA) BÊNTICAS DA BAÍA DE PARANAGUÁ, PARANÁ, SUL DO BRASIL: ESTRUTURA TAXONÔMICA E VARIAÇÃO ANUAL DA COMUNIDADE EM SUBSTRATO DE VIDRO

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ABSTRACT

The taxonomic structure and the seasonal variation (1993/1994) of benthic diatoms and other microalgae growing on glass slides were investigated in the Paranaguá Bay, Southern Brazil. Sixty taxa were identified, mostly benthic, with some tychoplanktonic and planktonic forms. Some species were observed under the scanning electron microscope as follows: *Cyclotella stylorum*, *Fryxelliella floridana*, *Gyrosigma* cf. *balticum*, *Licmophora* sp., *Melosira moniliformis*, *Navicula phyllepta* and *N. platyventris*. Diatoms largely dominated the microphytobenthosand were divided into 8 morphological groups. Solitary motile, colonial plate-like and tube-dwellling species were the most common. *Cylindrotheca closterium*, *Navicula* cf. *pargemina*, *N. phyllepta*, *N. platyventris* and *Nitzschia* spp. were responsible for peaks in cell abundance and of chlorophyll-a observed from December to May and in October. *Melosira moniliformis* was important in November, March and April. During the study period, the community showed a single-layered structure, numerically dominated by the same species.

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Taxonomic composition was mixed, with representatives of diverse substrates. Filamentous cyanobacteria and *Euglena* sp. occurred in some months. The benthic community growing on glass slides is briefly described.

KEY WORDS: benthic diatoms, microphytobenthos, periphyton, glass substrate; estuary, Paranaguá Bay, Southern Brazil.

RESUMO

A composição taxonômica e a variação sazonal das diatomáceas bênticas e outras microalgas crescendo sobre lâminas de vidro foram investigadas na Baía de Paranaguá, Paraná entre 1993 e 1994. Sessenta taxa foram identificados, a maioria bêntica, com alguns representantes ticoplanctônicos ou planctônicos. Algumas espécies foram observadas sob microscopia eletrônica, e seguem: *Cyclotella stylorum*, *Fryxelliella floridana*, *Gyrosigma* cf. *balticum*, *Licmophora* sp., *Melosira moniliformis*, *Navicula phyllepta* e *N. platyventris*. As diatomáceas dominaram amplamente o microfitobentos, e foram divididas em oito grupos morfológicos. As espécies móveis solitárias, em colônias placóides e incluídas em tubos de mucilagem foram as mais comuns. *Cylindrotheca closterium*, *Navicula* cf. *pargemina*, *N. phyllepta*, *N. platyventris* e *Nitzschia* spp. foram responsáveis pelos picos de densidade e de clorofila-a observados de Dezembro à Maio e em Outubro. *Melosira moniliformis* foi importante em Novembro, Março e Abril. Durante o período estudado, a comunidade apresentou uma estrutura unidimensional, numericamente dominada pelas mesmas espécies. A composição taxonômica foi mista, com representantes de diferentes substratos. Cianobactérias filamentosas e *Euglena* sp. ocorreram em alguns meses. A comunidade bêntica (algas e invertebrados) crescendo sobre as lâminas de vidro é descrita brevemente.

PALAVRAS-CHAVE: diatomáceas bênticas, microfitobentos, perifíton, substrato de vidro, estuário, Baía de Paranaguá, Sul do Brasil.

INTRODUCTION

Benthic diatoms usually dominate the marine microphytobenthos growing on different inorganic or organic substrates. The most common species belong to the biraphid group, and are frequently of small size (<30 µm) (MCINTIRE & MOORE, 1977; CHARPY-ROUBAUD & SOURNIA, 1990; UNDERWOOD, 1994). In coastal and estuarine areas these diatoms are relevant primary producers, contributing an important fraction of biomass to the trophic chain. They also participate in the nutrient exchange between bottom sediments and the overlying water column, and contribute to sediment stabilisation (ROUND, 1984; PATERSON, 1990; UNDERWOOD & PATERSON, 1993).

Methodological problems concerning the separation of algae from sediments, the cell counts, and the small dimensions of dominant taxa hamper correct species identification and planning of ecological studies. In Brazil, despite many taxonomic works on microalgae (see review of BRANDINI *et alii*, 1997), those focusing upon benthic diatoms are scarce (FELÍCIO-FERNANDES *et alii*, 1994; FELÍCIO-FERNANDES & SOUZA-MOSIMANN, 1994; FERNANDES *et alii*, 1990; FELÍCIO-FERNANDES, 1996).

Paranaguá Bay (Paraná state) is an estuarine complex of 256 km^2 located in Southern Brazil (25°25'S-25°35'S and 48°20'W-48°45'W), and is influenced by a subtropical climate with two well-defined seasons: rainy in summer and dry in winter, with annual average rainfall of 1988 mm. Salinity varies from 12 to 34, and the annual average of semidiurnal tides is 2.2 m. Mangroves, salt marshes of *Spartina* spp. and tidal flats are the main environments bordering the estuary. In this system, benthic diatoms contribute to phytoplankton biomass by means of the turbulent resuspension of cells, generated by tidal currents and winds (FERNANDES, 1992; BRANDINI, 1985). Recently, BRANDINI *et alii* (in revision) investigated the seasonal dynamics of biomass and primary production of the microphytobenthos, observing the dominance of diatoms over other groups and showing their preponderant role in benthic production. The biomass found there was high (6.1 to 32.7 mgChl.a/m^2 most of the year) and associated with gradients of temperature and salinity. Such initial observations indicate the importance of benthic diatoms in the food web dynamics of the Paranaguá Bay's ecosystem, also representing an alternative way to autotrophic production, generally thought to be based on phytoplankton.

This work investigated the taxonomic structure and the seasonal fluctuation of benthic diatoms found on glass slides in the Paranaguá Bay during an annual cycle (November 1993 to October 1994). The ecological data and the causal factors of oscillations in biomass and primary productivity are detailed in BRANDINI *et alii* (in revision). A brief description of the benthic community structure (algae and invertebrates) growing on the substrate is also furnished.

MATERIAL AND METHODS

Sampling was carried out from a pier situated on the external region of Paranaguá Bay (local depth 4-6 meters) from November 1993 to October 1994, at seven day intervals. An acrylic panel was used to fix the glass slides in such a way as to allow their periodic replacement. Slides were positioned horizontally. The acrylic panel was tied at a depth of 1 meter in the water column by means of ropes and buoys to maintain its vertical position independent of tidal variation. Both sides of each glass slide (1x6 cm) were available for colonization, comprising a total area of 10,2 cm^2. Twelve slides were used to complete different studies, and those concerning biomass and productivity are discussed in BRANDINI *et alii* (in revision).

After each 7 day incubation, slides were removed from the acrylic panel and replaced by clean ones. Cells were scraped off with a soft brush and washed using prefiltered local seawater. One aliquot of each sample was preserved in formaldehyde (1%) and cells were counted under an inverted microscope (Zeiss mod. ID08). The results were converted to surface area, that is, number of cells per square centimeter of slide (cells/cm^2). In order to facilitate cell counts of densely colonized slides, some samples were diluted with prefiltered seawater, and a portion (2 ml) of the final volume (17-58 ml) was used for counting in settling chambers.

Data on temperature, salinity and nutrients (NO_3-N, PO_4-P, SiO_2-S) (Table I and Fig. 57) were obtained from weekly samplings of seawater with a Van Dorn bottle near the acrylic panel. For chlorophyll-a readings, other set of slides were periodically removed from the acrylic panel and directly placed into centrifuge tubes filled with acetone 90%. Nutrient analysis and chlorophyll-a extraction followed STRICKLAND & PARSONS (1972). Water transparency was measured with a Secchi disk.

Samples for taxonomic studies were selected at 14 day intervals (not weekly, as for quantitative data) for preparation of permanent slides (HASLE & FRYXELL, 1970) to allow examination under the light microscope (LM, Olympus BX40) and scanning electron microscope (SEM, Phillips XL30). The terminology for species description follows ROSS *et alii* (1979) and ROUND *et alii* (1990). Some unprocessed slides were directly observed under a light microscope to describe the *in vivo* structure of the benthic community including ciliates and invertebrate metazoans.

In the Taxonomic Survey section we have included data on abundance, months of occurrence and other comments about some species, based on analysis of permanent slides and *in vivo* samples. The terms rare (<10 cells), not common (>10-50 cells), common (50-200 cells) and abundant (>200 cells) refer to these observations, and only express a relative value, that is, for comparisons of abundances between species. For each taxon we havenoted figure numbers and basic references (in brackets) for our species identifications.

RESULTS

Taxonomic Survey

Achnanthes sp. (*hauckiana* Grunow ?) **Fig 23**
[Patrick & Reimer, 1966:267, Pl. 17, Figs. 25-32; Felício-Fernandes, 1996:101, Fig. 70]
Dimensions: apical axis 25,5-26,6μm; transapical axis 9,5-10,8μm

Actinocyclus ehrenbergii Ralfs var. *crassa* (Wm. Smith) Hustedt **Fig 1**
[Cleve-Euler, 1951:82, Figs. 144c-e; Fernandes *et alii*, 1990:19, Pr. I, Fig. 6]
Dimensions: valvar diameter 18,5-21,4μm

Actinocyclus ehrenbergii var. *tenella* (Brebisson) Hustedt **Figs 2, 5**
[Fernandes *et alii*, 1990:20, Pr. I, Fig. 7; Hustedt, 1927-1966:533, Fig. 302]
Dimensions: valvar diameter 26-42,3μm

Actinoptychus campanulifer A. Schmidt
[Souza-Mosimann, 1984:6, Pr. I, Fig. 6]
Dimensions: valvar diameter 25,2-30 μm

Actinoptychus undulatus (Bailey) Ralfs
[Hendey, 1964:95, Pl. 1, Figs. 1-2]
Dimensions: valvar diameter 35-42,8 μm

Amphora angusta Gregory var. *ventricosa* (Gregory) Cleve
[Fernandes *et alii*, 1990:21, Pl. 1, Fig. 8; Hendey, 1964: 269, Pl. 38, Fig. 12]
Dimensions: apical axis 62-72,5 μm; transapical axis 11-12,2μm

Amphora ostrearia Brébisson var. *lineata* Cleve
[Peragallo et Peragallo, 1897-1908:220, Pl. 49, Figs. 17-18]
Dimensions: apical axis 51-54μm; transapical axis 11μm; 12 transversal striae in 10μm

Amphora cf. *obtusa* Gregory
[Schoemann & Archibald, 1987:126, Pr. 1, Fig. 1-3]
Dimensions: apical axis 85,1-90,4μm; transapical axis25,2-27 μm

Amphora sp. (Section Hallamphora)
Dimensions: apical axis 35-45μm; transapical axis 8-9μm

Comments: very abundant in some months, forming mucilage, plate-like colonies.

Bacillaria paradoxa Gmelin
[Hustedt, 1927-1966:396, Fig. 755]
Dimensions: apical axis 76,3-81μm; transapical axis 6,1μm
Caloneis westii (Wm. Smith) Hendey
[Fernandes *et alii*, 1990:27, Pr. 1, Fig. 14; Felício-Fernandes & Souza-Mosimann, 1994:160, Fig. 4]
Dimensions: apical axis 55-56μm; transapical axis 18μm

Cocconeis dirupta Gregory **Figs 33, 52**
[Hustedt, 1927-1966:354, Fig. 809a-i]
Description: Valves elliptical with rounded apices. Raphe straight, becoming sinuous near the apices (Fig. 52); central area lozenge-like. Rapheless valve with central area narrowed and reaching to the margin. Areolae coarse, arranged in slightly convergent striae, this pattern more evident at the apices.
Dimensions: apical axis 16,8-24,2μm; transapical axis 9,4-10,6μm
Comments: abundant in November, December and February, always attached on stolons of colonial hydroids.

Cyclotella litoralis Lange & Syvertsen
[Lange & Syvertsen, 1989:341-356, Figs. 1-30]
Dimensions: valvar diameter 35,0-45,3μm
Comments: not common or rare; July and August.

Cyclotella striata (Kützing) Grunow
[Hustedt, 1927-1966:344, Fig. 176a-b]
Dimensions: valvar diameter 32-35,6μm

Cyclotella stylorum Brigthwell **Figs 14, 51**
[Hustedt, 1927-1966:348, Fig. 179; Souza-Mosimann, 1984:18, Pr. 6, Fig. 8]
Description: Valve circular, divided in a central region and in a marginal one. The central region is composed by coarser areolae grouped in two different semicircular planes. The marginal region shows small areolae ordered in a radial pattern, and forming sectors bordered by radial ribs. A marginal ring of fultoportulae is located at the basis of the ribs, and alternately (Fig. 51).
Dimensions: valvar diameter 55,5-62,8μm

Cylindrotheca closterium (Ehrenberg) Reimann & Lewin
[Hendey, 1964:283, Pl. 21, Fig. 8]
Dimensions: apical axis 32,1-60,2μm; transapical axis 7-8μm
Comments: abundant in most months.

Cymathodiscus planetophorus (Meister) Hendey **Fig 19**
[Foged, 1978:45, Pl. V, Fig. 6; Hendey, 1958:42, Figs. 5-8]
Dimensions: apical axis 38,3-39,2µm; transapical axis 23µm
Comments: rare, but present in all months.

Cymatotheca weissflogii Hendey **Fig 17**
[Hendey, 1958:41, Pl. 5, Fig. 9]
Dimensions: apical axis 32-34,3µm; transapical axis 21µm
Comments: common from November to December.

Delphineis surirella (Enrenberg) Grunow var. *australis* (Petit) Navarro **Fig 18**
[Hustedt, 1955:14, Pl. 4, Fig. 56; Navarro, 1982a:19, Pl. 14, Fig. 4]
Dimensions: apical axis 40-43,5µm; transapical axis 30-32,3µm

Dimerogramma minor (Gregory) Ralfs **Fig 20**
[Fernandes *et alii*, 1990:37, Pr. II, Fig. 28; Hendey, 1964:156, Pl. 27, Fig. 12]
Dimensions: apical axis 32-34,1µm; transapical axis 10,5µm

Diploneis bombus Ehrenberg
[Hustedt, 1927-1966:704, Fig.1086a-c; Navarro, 1982:323, Fig. 47]
Dimensions: apical axis 35-40,8µm; transapical axis 10,1-12,5µm

Diploneis weissflogii (A. Schmidt) Cleve **Fig 29**
[Navarro, 1982: 324, Figs. 62-63]
Dimensions: apical axis 31-32,6µm; transapical axis 8,5µm

Eupodiscus radiatus Bailey **Figs 3, 4**
[Sullivan, 1986:113, Pls. 1-4]
Dimensions: valvar diameter 42,6-89,7µm; 2-6 ocellii per valve

Fallacia nummularia (Greville) D. G. Mann
[Hustedt 1955:22, Pr. 7, Figs. 15-16]
Dimensions: apical axis 25,6-27µm; transapical axis 18µm

Fallacia sp. **Fig 22**
Dimensions: apical axis 13,4-18,6µm; transapical axis 6,2-7,0µm

Fryxelliella floridana A. K. S. K. Prasad **Figs 8-10, 43-46**
[Prasad *et alii* 1997:305, Figs. 1-35]
Description: Cells cylindrical; valve circular with convex surface, composed of hexagonal areolae in radial and concentric rows. Each areola bears 7-12 cribral

pores at the external surface, opening to the interior by means of a foramen encircled by a thickened rim (Fig. 44). Ocelli marginal and circular, equally spaced one to another, usually in number of 2-3 per valve (Fig. 46). Each ocellus are placed on an elevation, with porelli in concentric rows encircled by a thickened rim. Rimoportulae marginal, in number of 2 or 3, located between the mantle and the valvar surface, and intercalated to the ocellii. Each rimoportula shows an external tube with circular aperture (Fig. 45), and an internal labiate fissure surrounded by a thickened rim. The valvar margin possesses delicate spines bordered by a smooth area, i.e., lacking ornamentation (Fig. 45). On the edge of the valvar margin there are numerous circular openings modified as fissures in the mantle (Fig. 45). Valvar mantle with two strips of silica bearing spines and fissures, and separated by a sulcus. In internal view the mantle is thickened and convex, with pores ordered in transverse rows (Fig. 44). The marginal circunferencial tube may be observed in a fracture of the mantle (Fig. 44).
Dimensions: valvar diameter 24-36µm
Comments: not common, but always present in the samples. Recently, the species was described by PRASAD *et alii* (1997) from east coast of Florida. New occurrence for South America.

Gyrosigma cf. *balticum* (Ehrenberg) Cleve **Figs 54-56**
[Cardinal *et alii*, 1989:15-27; Navarro, 1982:324, Figs 66-68]
Description: Valve linear with parallel sides in the central region and convergent towards the apices. Apices obtuse, in opposite directions. The raphe is central, slightly sigmoid. In internal view, proximal ends of the raphe are straight with circular terminal inflations (Fig. 55). Central bars discrete, appearing as a thin margin surrounding the raphe sternum. Internal central area irregular, oblique in relation to the valvar diameter. Terminal area is a triangular hyaline area. Distal raphe fissure straight and eccentric (Fig. 56). Striae areolate and uniseriate, arranged in transverse rows. External view of the valve was not observed.
Dimensions: apical axis 70-75,5µm; transapical axis 14,2µm, 22-26 striae in 10 µm
Comments: The morphology of raphe fissures, internal central area, central bars and terminal areas are quite similar to *G. balticum* (NAVARRO, 1982; CARDINAL *et alii*, 1989), differing by the smaller size and the higher number of striae. As diagnostic characters (central area, raphe fissures) on the valve surface in external view were not examined, the species identity could not be confirmed.

Licmophora cf. *ehrenbergii* (Kützing) Grunow
[Navarro, 1982:259, Figs. 38-40]

Dimensions: apical axis 102,1-110µm; transapical axis 10-12,2µm (at middle)

Licmophora gracilis (Ehrenberg) Grunow
[Hustedt, 1927-1966:60, Fig. 582]
Dimensions: apical axis 81-95,5µm; transapical axis 19µm
Comments: on invertebrates and slides.

Licmophora sp. **Figs 40-42**
Description: Valve clavate with rounded apices. Valvar surface composed by transversal striae bearing pores. The striae arise from a thin axial sternum (Fig. 40). Apical striae small and more numerososus on the mantle. At the head pole are 1-2 rimoportulae with elongated labiate structure (Fig. 41), opening to the exterior by a 1-2 apertures (Fig. 42).
Dimensions: apical axis 85,3-92,4µm; transapical axis 17,5-19,8µm
Comments: on invertebrates and slides.

Lyrella sp. **Fig 32**
Dimensions: apical axis 42,6µm; transapical axis 38,2µm
Comments: rare; only 3 valves recorded in September.

Margaritum terebro (Leuduger-Fortmorel) H. Moreira **Fig. 12**
[Souza-Mosimann *et alii*, 1997:45, Figs. 1-14]
Dimensions: valvar diameter 32-36,3µm
Comments: not common, but present in all of the year. Its structure under SEM was furtherly described by SOUZA-MOSIMANN *et alii* (1997).

Mastogloia apiculata Wm. Smith **Figs 24-25, 53**
[Hustedt, 1927-1966:515, Fig. 946]
Dimensions: apical axis 65-82,1µm; transapical axis 22-23,3µm

Melosira moniliformis (O. Müller) Agardh **Figs 47-50**
[Crawford, 1977:277-285]
Description: frustules cylindrical; valves circular almost flat (the largest) to strongly convex (the smallest). Valve surface divided in a central valve face and the mantle, separated by a carina (Fig. 49). The valvar face possesses circular openings of rimoportulae; no areolae or restricted to the perifery, that is, near the carina (Fig. 49). Mantle well marked, with rimoportulae, pseudoloculate areolae, spines and broad granules (Fig. 48). Granules more abundant on the marginal area, where they are coarser, each one presenting a robust basis. Valve edge with marginal ring of rimoportulae (Fig. 48). Carina bears short and robust spines, or presenting a continuous silica membrane encircling the valvar face (Figs. 49-50). Areolae

poligonal with many pores on the external surface; and rotae on the internal surface (not illustrated). Cingulum composed by 2-8 ligulate bands (Fig. 47); each band perforated by 6-8 pores arranged in transversal rows (Fig. 48).
Dimensions: valvar diameter 26,8-68,3 µm
Comments: common to abundant; occurred on the rugged edges of the glass slides.

Minidiscus chilensis Rivera **Fig 6**
[Ferrario, 1988:313, Pl. 1, Fig. 3/Pl. 2, Figs. 1-2; Rivera & Koch, 1983:281, Figs. 5-14]
Dimensions: valvar diameter 6,2-8,1µm
Comments: abundant in November, December, February and March; in short chains.

Minidiscus comicus Takano **Fig 7**
[TAKANO, 1981:32, Figs. 1a, 2-13]
Dimensions: valvar diameter 6-9 µm
Comments: see comments for *M. chilensis*.

Navicula cf. *pargemina* Underwood & Yallop **Figs 27, 28**
[Underwood & Yallop, 1994:473-478, Figs. 1-14]
Dimensions: apical axis 15,3-22,7µm; transapical axis 9,5µm
Comments: abundant to dominant in almost all samples, occurring in mucilage plate-like colonies, or solitary.

Navicula phyllepta Kützing **Figs 26, 34-38**
[Cox, 1995:91-111, Figs. 58-66; Lange-Bertalot, 1980:29-50; Riaux & Germain, 1980:265-279]
Description: Valve eliptical-lanceolate with subacute apices. Raphe straight, central nodule thickened; terminal fissures hooked, with a small terminal area (Fig. 36). Central area narrow, more expanded on the central portion due to the small number of areolae in the central striae. In internal view, raphe is continuous and bordered by a thickened sternum (Fig. 38); terminal area surrounding an helictoglossa (Fig. 37). Valvar surface striated; striae radiate, becoming parallell toward the apices, and bordered by transversal ribs. Striae smaller in the central area. Areolae elongated and, in internal view, with rectangular morphology. Cingulum composed by 1-3 bands.
Dimensions: apical axis 20-40,2µm; transapical axis 11-12,3µm
Comments: see for *N.* cf. *pargemina*.

Navicula platyventris Meister **Fig 39**
[Witkowski *et alii*, 1998:92, Figs. 15-22, 77, 78, 80]

Description: Valves eliptical with rostrate apices. Raphe straight, showing a pronounced curve at the poles, bordered by the terminal area. Raphe sternum developed; at the central nodule sternum is shaped like a figure of number "8". Central area ellipsoid, thickened at the centre. Valvar surface flattened. Striae radiate becoming parallell at valves ends, bordered by transverse ribs. Areolae rectangular, and somewhat constricted in the middle. Striae also present in the apices, around the terminal nodules.
Dimensions: apical axis 16-24,7µm; transapical axis 6,0-7,2µm
Comments: abundant in December, January and March; rare or absent in other months.

Nitzschia lanceola Grunow **Fig 31**
[Round & Basson, 1997:347-355, Figs. 13-20]
Dimensions: apical axis 30-36,8µm; transapical axis 9,4-11,6µm

Nitzschia longissima (Brebisson) Grunow
[Navarro, 1982:394, Figs. 29-30]
Dimensions: apical axis 110-300µm; transapical axis 7,3-7,9 µm

Nitzschia sigma (Kützing) Wm. Smith
[Hustedt, 1927-1966:420, Fig. 813]
Dimensions: apical axis 195-202,6µm; transapical axis 9-10µm

Nitzschia ventricosa Kitton
[Fernandes *et alii*, 1990:67, Pr. 8, Figs. 97-98; Giffen, 1970:293, Pl. 56, Fig. 84 (as *N. longissima* (Brébisson) Ralfs forma *costata* Hustedt)]
Dimensions: apical axis 230,6-295,8µm; transapical axis 10,2-12µm

Opephora marina (Gregory) Petit
[Hendey, 1964:160; Hustedt, 1927-1966:136,Fig. 656]
Dimensions: apical axis 25,1-28,5µm; transapical axis 3µm

Paralia sulcata (Ehrenberg) Cleve
[Crawford, 1979:200-210, Figs. 1-33]
Dimensions: valvar diameter 20-35µm
Comments: abundant or common, occurring in short chains of small valves.

Parlibellus delognei (Van Heurck) E. J. Cox
[Cox, 1988:19, Fig. 15]
Dimensions: apical axis 68,4-72,5µm; transapical axis 15,2-15,8µm

Parlibellus hagelsteinii (Hustedt) E. J. Cox
[Cox, 1988:24; Navarro, 1983:123, Fig. 91]
Dimensions: apical axis 45,2-55µm; transapical axis 17-18,3µm
Parlibellus tubulosus (Brun) E. J. Cox
[Cox, 1988:27; Navarro, 1983:123, Figs. 106-107]
Dimensions: apical axis 43,7-47,3µm; transapical axis 11,5µm

Pleurosigma angulatum (Qüeckett) Wm. Smith
[Patrick & Reimer, 1966:331, Pr. 27, Fig.1a-c]
Dimensions: apical axis 220,7-2521µm; transapical axis 34,4-35,3µm
Comments: only observed in association with colonial hydroids.

Pleurosigma elongatum Wm. Smith
[Peragallo et Peragallo, 1897-1908:155, Pl. 21, Fig. 11]
Dimensions: apical axis 158-223,4µm; transapical axis 23,4µm

Psammodycton panduriforme (Grunow) D. G. Mann
[Peragallo et Peragallo, 1897-1908:268, Pl. 70, Fig. 1; Round *et alii*, 1990:612]
Dimensions: apical axis 68,4-73,8µm; transapical axis 26µm

Thalassionema nitzschioides (Grunow) V. Heurck **Fig 21**
[Hallegraeff,1986:57-80, Figs. 1-4]
Dimensions: apical axis 32,5-45,9µm; transapical axis 2,5-2,7µm
Comments: abundant from November to April; common in other months. Small cells predominated.

Thalassiosira eccentrica (Ehrenberg) Cleve
[Hallegraeff, 1984:504, Fig. 115a-d]
Dimensions: valvar diameter 36,9-58,6µm

Thalassiosira nanolineata (Mann) Fryxell & Hasle **Fig 13**
[Fernandes *et alii*, 1990:79, Pr. XI, Figs. 116-117; Hallegraeff, 1984:504, Fig. 19a-e]
Dimensions: valvar diameter 42,2-45,8µm

Thalassiosira oestrupii (Ostenfeld) Cleve **Fig 11**
[Fernandes *et alii*, 1990:79, Pr. 10, Fig. 118; Fryxell & Hasle, 1980:814, Figs. 1-10]
Dimensions: valvar diameter 18,3-21,7µm

Thalassiosira sp.
Dimensions: valvar diameter 15,2-22,5µm

Comments: small chains (2-6 cells) agregating sediment grains by means of tiny mucilage threads. The species resembles to that found by Ernissee & Abbott (1975) in sediments of estuaries from eastern coast of North America.

Triceratium dubium Brightwell **Fig 15**
[Felício-Fernandes *et alii*, 1994:68, Fig. 44; Navarro, 1981:619, Figs. 52-54]
Dimensions: side length 32,1-36,4µm

Triceratium sp. **Fig 16**
[Felício-Fernandes *et alii*, 1994:70, Figs. 45,48; Fernandes *et alii*, 1990:81, Pr. X, Figs. 120-121]
Dimensions: side length 33, 2-38,7µm
Comments: not common. Electron microscope studies revealed it to be a new species (FERNANDES & SOUZA-MOSIMANN, in preparation).

Tryblionella coarctata (Grunow) D. G. Mann
[Felício-Fernandes, 1996:206, Fig. 174]
Dimensions: apical axis 26,3-28,9µm; transapical axis 10,3-11µm

Tryblionella granulata (Grunow) D. G. Mann **Fig 30**
[Navarro, 1982a:53, Fig. 9; Felício-Fernandes, 1996:209, Fig. 178]
Dimensions: apical axis 30,5-34,7µm; transapical axis 10-12,1µm

Seasonal variation of benthic diatoms and of chlorophyll-a on glass slides

The community showed low species richness and was essentially dominated by biraphid diatoms (Fig. 58). Total densities varied from 500 to 310,000 cells/cm^2 , with peaks on November 29 (188000 cells/cm^2), January 04 (118000 cells/cm^2), March (148,000 -310,000 cells/cm^2) and October 10 (25,1000 cells/cm^2). From late April to September densities were lower (<50000 cells/cm^2). Chlorophyll-a generally accompanied those peaks and the general oscilation in cell densities (Fig. 58), varying from 0,06 to 3,27µg/cm^2, with peaks from January to early April (0,84 to 3,27µg/cm^2). *Navicula phyllepta* and *N.* cf. *pargemina* (counted together) were abundant all year round, and are shown in Fig. 58 as *Navicula* spp. Highest values found for these species overlapped with periods of maximum cell accumulation on the slides (see above), reaching 309600 cells/cm^2 on March 15. Other high concentrations were >20000 cells/cm^2 from November to May, and 105000 cells/cm^2 on October 10. *Nitzschia* spp. (mainly *Nitzschia longissima* and *N. sigma*) were abundant from November to April (maximum of 63600 cells/cm^2) and on October (85300 cells/cm^2). *Cylindrotheca closterium* reached maxima in December (54800 cells/cm^2), January (16900 cells/cm^2), March (27000 cells/cm^2) and October (59100 cells/cm^2) (Fig. 58). *Licmophora* sp. appeared in irregular peaks during the year, with highest values in November (2200 cells/cm^2) and May (1620 cells/cm^2). The abundances of centric diatoms were low, except for *Melosira moniliformis*. This diatom was always present in low concentrations (<1200 cells/cm^2), but reached high values in November (2700 cells/cm^2) and March (3900 cells/cm^2). *Thalassiosira* spp., *Pleurosigma* spp. and *Thalassionema nitzschioides* showed similar annual variation, the maxima occurring from November to March, with densities less than 800 cells/cm^2. *Amphora* sp. (Section Hallamphora) appeared in large numbers (>10000 cells/cm^2) on March 15; in other months its density was low. Other species recorded (see Taxonomic Survey, above) were present in most of the samples, but in low densities, usually less than 200 cells/cm^2. Some numerically representative species were detected only during the analysis of permanent slides, probably due to their small size, as *Minidiscus chilensis* and *M. comicus*, from January to March. *Cocconeis dirupta* was abundant from November to February, but only observed in *in vivo* samples, growing on the stolons of a colonial hydroid.

Benthic community structure on the glass slides

A description of the community structure is given below, based on *in vivo* observations of the samples collected during periods of denser accumulation on the slides, and at the seventh day of incubation. Slides were almost entirely recovered by fine grains, silt and a single layer of diatoms. Only a few samples presented low densities of benthic algae: in some instances, the community was already being replaced by colonial invertebrates. As seen above, diatoms largely dominated among the microphytobenthos, scattered or joined in conspicuous patches. *Cylindrotheca closterium*, *Navicula* spp. and *Nitzschia* spp. were abundant, occurring as solitary or colonial forms, enclosed in mucilaginous plates. Motile species of *C. closterium*, *Nitzschia* spp. and *Pleurosigma* spp. were observed crossing the slides. In some months *Cocconeis dirupta* appeared as a film entirely covering the stolons of a colonial hydroid. *Melosira moniliformis* occurred exclusively on the edges of the glass slides. *Amphora* sp. appeared in flat mucilage colonies over the slide. Other algal groups of some importance in the study were cyanobacteria, forming branched filaments; and a large *Euglena* sp. No macroalga was found.

Many sessile and motile ciliates were recorded, mainly belonging to the Families Euplotidae (4 species), Acinetidae (2 sp.) and Dysteriidae (1 sp.), some of them feeding on diatoms (mostly *Navicula* spp.). Among the metazoan invertebrates, colonial techate hydroid (1 sp.) in dichotomic branched stolons, Turbellaria (2 sp.), Cirripedia (1 sp.) and Bryozoa (2 sp. ?) were common groups. One species of Caprellidae and 2 of Amphipoda-Gammaridae (actively feeding on diatoms) were observed attached to the hydroid.

DISCUSSION

Raphid diatoms have been recorded as abundant or dominant in different natural benthic environments or growing on artificial substrates, also representing the bulk of biomass within the community. The representative genera are composed of small sized species, particularly in the case of sediment-inhabiting cells, and are not identified or described at a specific level, making difficult any reliable comparisons between communities from distinct environments. Typically, a small number of species comprised up to 90% of the total densities, and diatoms of the genera *Navicula*, *Nitzschia*, *Amphora*, *Gyrosigma* and *Cocconeis* are regarded as most common (MCINTIRE & MOORE, 1977; FONSECA, 1998; JOHN, 1990; KAWAMURA & HIRANO, 1992). However, a marked seasonal succession has also been observed in some regions, with an alternation between centric, araphid pennate and raphid diatoms (HUDON & BOURGET, 1983; SNOEIJS, 1994). NAVARRO *et alii* (1989) found *Mastogloia*, *Navicula* and *Nitzschia* the most abundant genera growing on diverse marine substrates (organic or inorganic) in the tropical region of Puerto Rico. In our work, *Navicula phyllepta* and *Navicula* cf. *pargemina*, both sediment-inhabiting forms (UNDERWOOD, 1994), were responsible for the highest peaks of biomass, and represented more than 80% of the cells throughout the year. UNDERWOOD (1994) studied the annual variation of epipelic diatoms in the Severn estuary, England, finding *Navicula pargemina*, *Nitzschia epithemioides* Grunow and *Rhaphoneis minutissima* Hustedt as abundant or dominant all year. In addition, the author recorded *C. closterium* in high concentrations only sporadically; as massive blooms on the sediments. In our work, *C. closterium* was more important, appearing in nearly all the samples, and shared with *Navicula* spp. and *Nitzschia* spp. the highest cell concentrations. KAWAMURA & HIRANO (1992) found *Berkeleya rutilans*, *Navicula britannica* and *N. ramosissima* were abundant on glass slides in the Aburatsubo Bay, Japan, with peaks in early spring. In this bay, *Amphora acutiuscula*, *A. coffaeiformis*, *Cocconeis scutellum* var. *parva* and *Nitzschia* spp. also were of some importance, increasing in biomass from July to October.

Navicula phyllepta, *N.* cf. *pargemina* and *Parlibellus delognei* were observed in two growth forms: solitary motile cells and colonial. Such versatility probably confers a better adaptation to the disturbances arising from tidal variations and current velocity; events common in estuaries. The diversification of thallus, allied to the euryhaline characteristics of many benthic species (MCINTIRE & MOORE, 1977; MIZUNO, 1992), may explain their presence and dominance on the glass slides during the study period. HUDON & BOURGET (1983) also observed a correlation between the occurrence of species with diverse thalus (*Berkeleya rutilans*, *Navicula ramosissima*) and their higher frequency and abundance on plastic substrates in the St. Lawrence estuary, Quebéc.

Melosira moniliformis was the only centric diatom appearing in large numbers on the glass slides. Its maxima were restricted to November and March. It was found exclusively attached to the rough edges of the slides; only rarely occurring on the smooth surface, indicating a preference for rugged substrates. Indeed, the species has been recorded as epiphytic on macroalgae or seagrasses, or epilithic, always in large numbers (RENDALL & WILKINSON, 1983; JOHN, 1990; SNOEIJS, 1994). Such preference also exemplifies the selectivity inherent in the utilization of artificial substrates, affecting the community composition and biomass, and has been one of the various criticisms of the method (PATRICK, 1977; EDYVEAN *et alii*, 1985). Our material illustrates another limitation of using artificial substrates: the simultaneous occurrence of species with distinctive substrate preferences, like *Navicula* spp., *Cylindrotheca* spp., *Nitzschia* spp. (epipsamic and epipelic), *Cocconeis dirupta* (epizoic) and *Licmophora* sp. (epiphitic or epilithic). That is, diatoms that grow primarily on invertebrates or plants were found together with sediment-inhabiting species. Therefore, the mixed composition of diatoms colonizing the artificial substrate is evident, and should be taken into account when planning studies related to autotrophic production and biomass of benthic communities. These parameters are clearly affected by variations in the microalgal composition and abundance.

Some tychoplanktonic and planktonic species were fairly common on the slides, such as *Paralia sulcata*, *Thalassionema nitzschioides* and *Thalassiosira* spp. These species generally appear in high numbers in the phytoplankton of Paranaguá Bay (BRANDINI, 1985, 1985a; FERNANDES, 1992), showing a linkage between the water column community and the benthic one. On the other hand, a number of benthic diatoms were numerically abundant in the plankton of the Bay in some periods, and their presence in the water column was related to the turbulent mixing into the estuary (FERNANDES, 1992; BRANDINI & FERNANDES, 1996).

The diatoms were classified into 8 morphological groups, based on their growth forms and motility, as follows:

a. motile solitary species with gliding movement, scattered on the slide (*Navicula phyllepta, Nitzschia longisima, N. sigma, N. ventricosa, Cylindrotheca closterium, Pleurosigma* spp., *Gyrosigma* cf. *balticum, Amphora* spp.);

b. motile colonial cells, but attached to the substrate by means of mucilage pads by the end cell of the colony (*Bacillaria paradoxa*);

c. non-motile colonial cells enclosed in filamentous chains, attached to the substrate by means of mucilage pads (*Licmophora* spp. on the glass slides and on hydroids, and *Melosira moniliformis*);

d. motile colonial species, forming elliptical or irregular plates (*Amphora* sp., *Cylindrotheca closterium, Navicula* cf. *pargemina, Navicula phyllepta*). Some species were also recorded moving over the substrate;

e. motile colonial species enclosed in prostrate mucilage tubes, forming single or branched filaments (*Navicula platyventris, Navicula* cf. *pargemina* ?, *Parlibellus delognei*);

f. arborescent colonies with 12 or more cells joined by means of mucilage threads to a central axis, which is attached to the substrate (*Synedrosphenia* sp.);

g. non-motile prostrate species, forming a film covering thecate hydroids (*Cocconeis dirupta*);

h. tychoplanktonic or planktonic cells, solitary or colonial (*Actinocyclus* spp., *Actinoptychus* spp., *Coscinodiscus* sp., *Cyclotella* spp., *Thalassiosira* spp., *Triceratium* spp.).

Solitary and colonial (plate-like and tube-dwelling) motile diatoms dominated the microphytobenthos, generally structured in a single layer. KAWAMURA & HIRANO (1992) found 7 groups of diatoms growing on glass slides after 10 days incubation in Aburatsubo Bay, Japan, with prostrate solitary cells and tube-dwelling colonies the most abundant. The community structure found in our study also coincides with the first type of community development proposed by HUDON & BOURGET (1983). According to them, substrate colonisation begins with small pennate diatoms and can follow two patterns of development, depending on local conditions of current velocity, light intensity and grazing pressure. Firstly, an unstratified community may develop, subjected to high current velocity and low light intensity, where substrate-associated small species predominate. This type fits well with our findings. Secondly, a densely stratified community develops due to more favourable growth conditions (high light intensity the main factor), with the formation of overstory and understory dominated by larger species loosely attached to the substrate. The above discussion is corroborated by the parallel light-photosynthesis experiments of BRANDINI *et alii* (in revision) carried out during our sampling period. They verified the occurrence of photosynthesis saturation under low light intensities, indicating the species are shade-adapted. The authors also suggested temperature and salinity to be preponderant factors influencing the temporal dynamics of the microphytobenthos.

Therefore, the microphytobenthos on the glass slides in the Paranaguá Bay appears to be maintained in a successional stage dominated by small sediment-inhabiting species, although presenting a mixed composition due to the occurrence of diatoms from different substrates. Perhaps, the biomass and the complexity of the community could have shown a higher development if the time of incubation was longer, for instance 10-15 days as in the studies by HUDON & BOURGET (1983) and KAWAMURA & HIRANO (1992). However, preliminary tests indicated that the largest cell biomass accumulated by the seventh day. In subsequent days, sessile invertebrates colonised the slides, diminishing the attachment of microalgae and also their subsequent growth on the glass slides.

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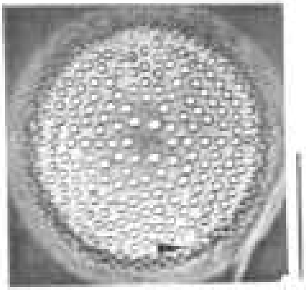
WITKOWSKI, A., LANGE-BERTALOT, H. & STACHURA K., 1998 - New and confused species in the genus *Navicula* (Bacillariophyceae) and the consequences of restrictive generic circumscription. *Cryptogamie, Algologie* 19(1-2):83-108.

Figs 52-56, SEM. Fig. 52. *Cocconeis dirupta*. Internal view. Note the lozenge-like central area. Fig. 53. *Mastogloia apiculata*. Internal view. Figs 54-56. *Gyrosigma* cf. *balticum*, internal views. Fig. 54. General shape of the valve. Fig. 55. Detail of the central region, showing internal central area (IC) and central bars (arrows). Fig. 56. Distal end of the raphe, with triangular terminal area (TA) and eccentric raphe fissure.

LEGENDA FIG. 1-7

Figs 1-7, LM. Fig. 1. *Actinocyclus ehrenbergii* var. *crassa*. Note the pseudonodule (arrowhead). Fig. 2. *Actinocyclus ehrenbergii* var. *tenella*. Note the pseudonodule (arrowhead). Figs 3-4. *Eupodiscus radiatus*, with 2 and 4 marginal ocellii. Fig. 5. *Actinocyclus ehrenbergii* var. *tenella*. Note pseudonodule (arrowhead). Fig. 6. *Minidiscus chilensis*. Fig. 7. *Minidiscus comicus*. Scale bars= 10µm for Figs 1-5; scale bars= 5µm for Figs 6-7.



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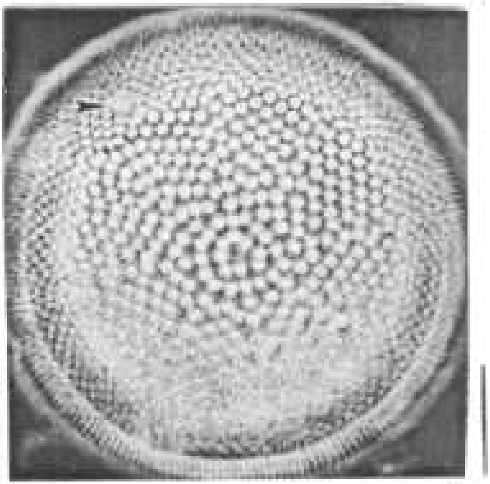

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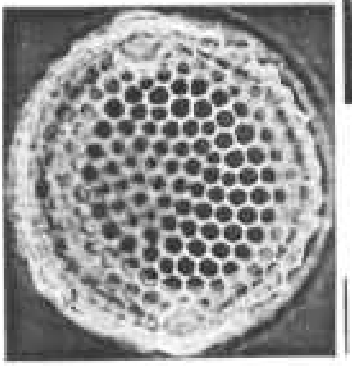

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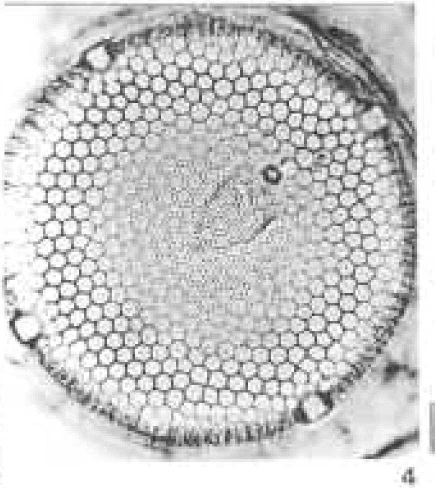

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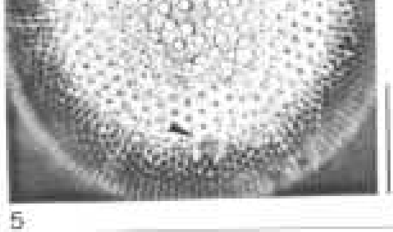

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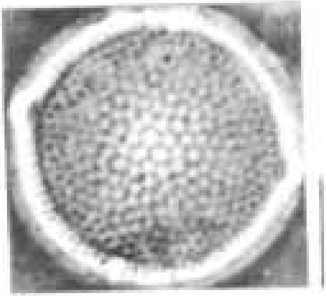
LEGENDA FIG. 8-14

Figs 8-14, LM. Figs 8-10. *Fryxelliella floridana*. Note the number and disposition of rimoportulae (R) and ocellii (O). Fig. 11. *Thalassiosira oestrupii*. Fig. 12. *Margaritum terebro*. Fig. 13. *Thalassiosira nanolineata*. Fig. 14. *Cyclotella stylorum*. All scale bars= 10µm.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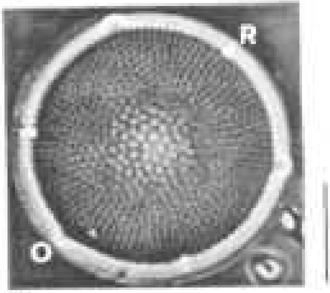

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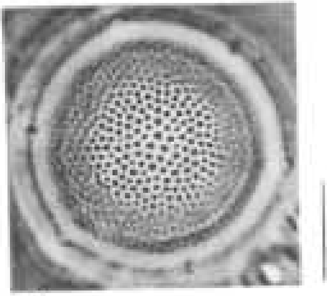
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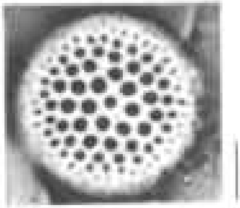
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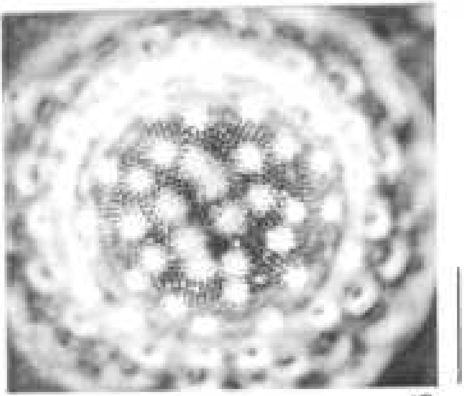
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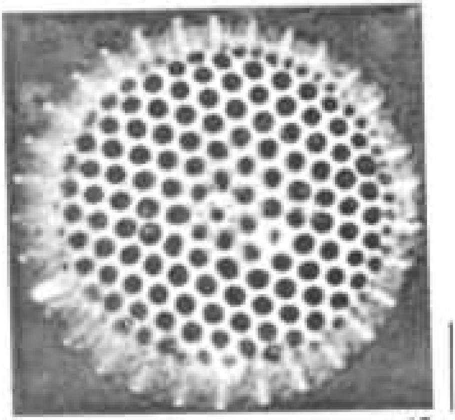
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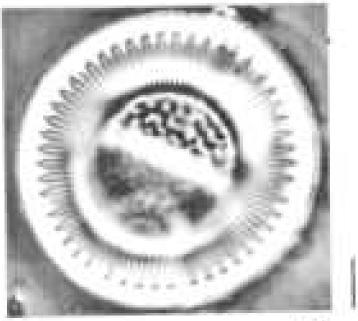
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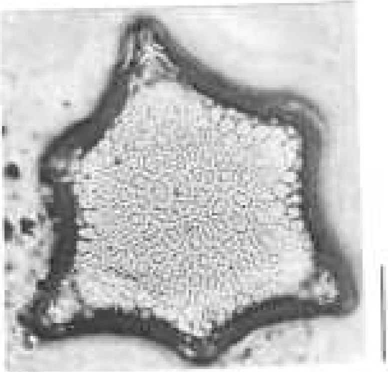
LEGENDA FIG. 15-22

Figs 15-22, LM. Fig. 15. *Triceratium dubium*. Fig. 16. *Triceratium* sp.. Fig. 17. *Cymatotheca weissflogii*. Fig. 18. *Delphineis surirella* var. *australis*. Fig. 19. *Cymathodiscus planetophorus*. Fig. 20. *Dimerogramma minor*. Fig. 21. *Thallassionema nitzschioides*. Fig. 22. *Fallacia* sp.. All scale bars= 10µm.



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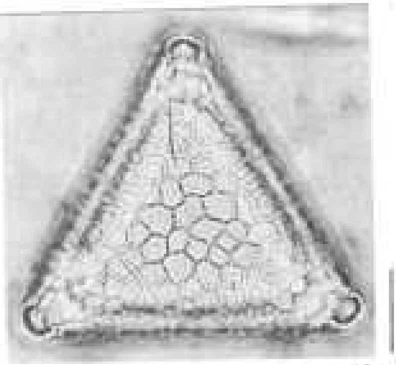

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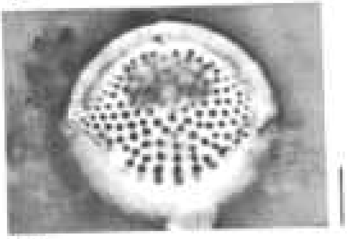

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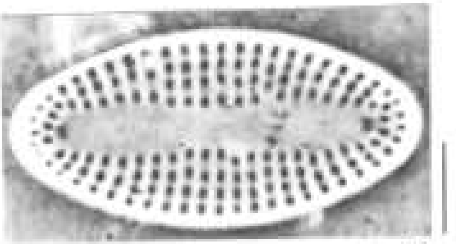

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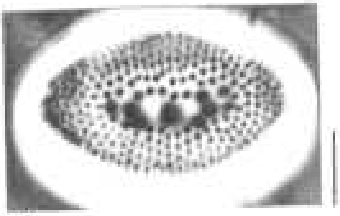

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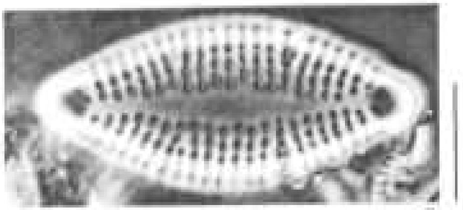

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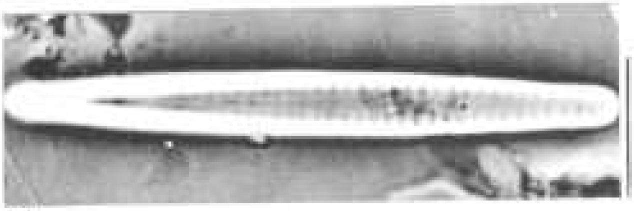

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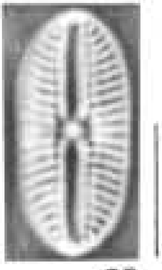

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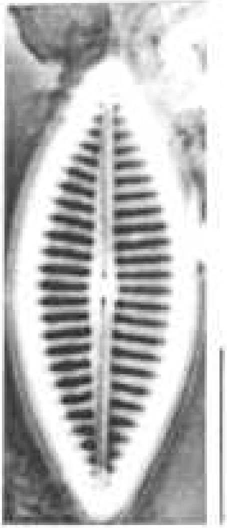
LEGENDA FIG. 23-28

Figs 23-28, LM. Fig. 23. *Achnanthes* sp. (*hauckiana* ?). Figs 24-25. *Mastogloia apiculata*, lower and upper foci. Note the marginal partecta. Fig. 26. *Navicula phyllepta*.

Figs 27-28. *Navicula* cf. *pargemina*. Note cingulum and the two joined valves. All scale bars= 10µm.



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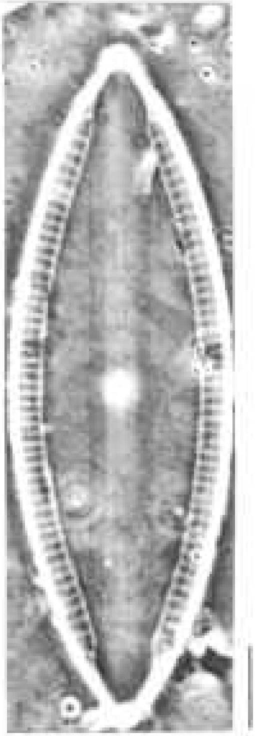

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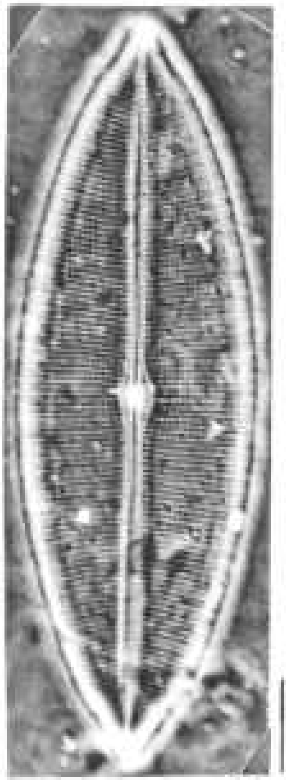

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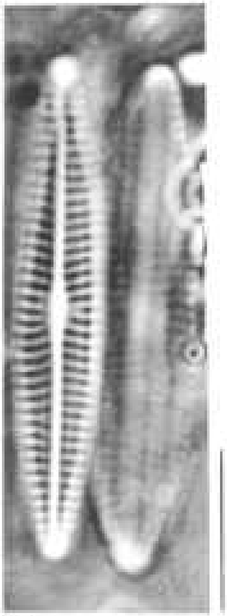

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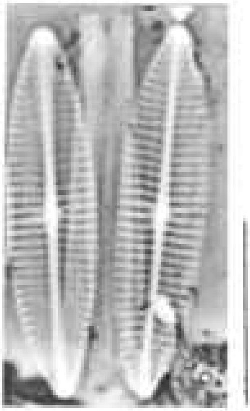

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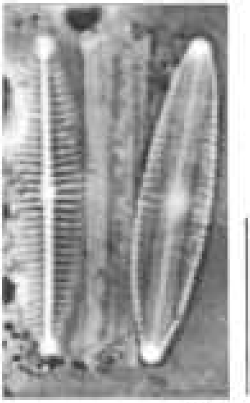

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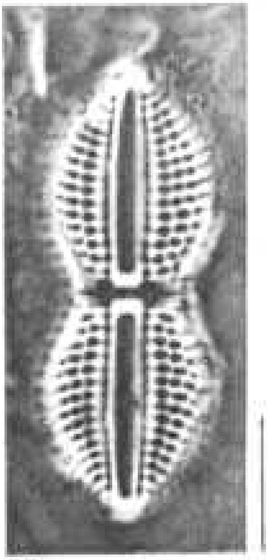
LEGENDA FIG. 29-33
FIG. 31

Figs 29-33, LM e SEM. Fig. 29. *Diploneis weissflogii*. Fig. 30. *Tryblionella granulata*. **Fig. 31**. *Nitzschia lanceola*. Fig. 32. *Lyrella* sp., SEM. Fig. 33. *Cocconeis dirupta*. All scale bars= 10µm.



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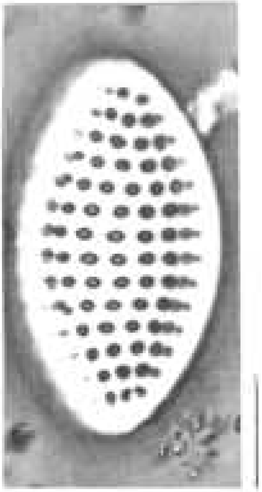

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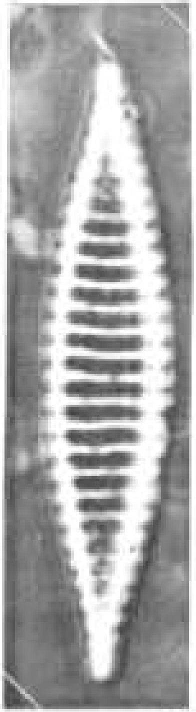

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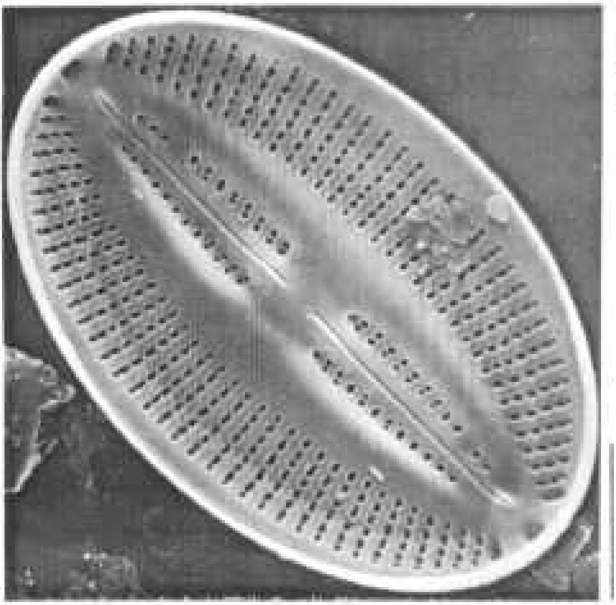

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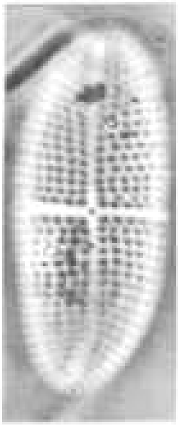

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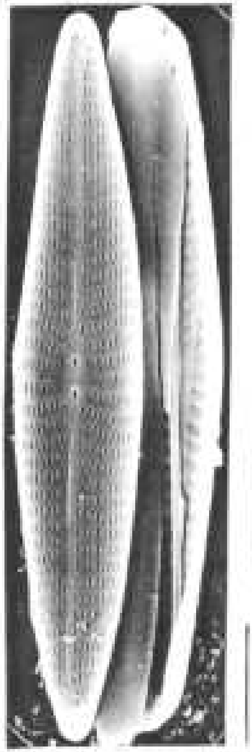
LEGENDA FIG. 34-37

Figs 34-37, *Navicula phyllepta*, SEM. Fig. 34. General view of the frustule. Note striae pattern. Fig. 35. External view, detail of central area. Fig. 36. External view, detail of apex, with hooked terminal nodule. Fig. 37. Internal view; apex. Note helictoglossa and terminal area. All scale bars= 5µm.



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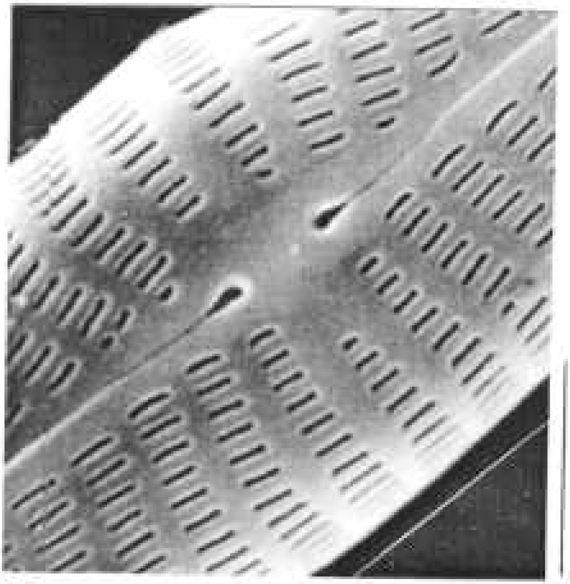

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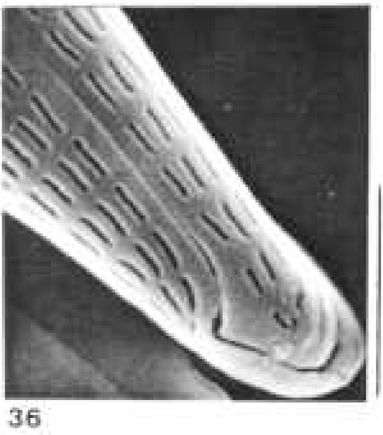

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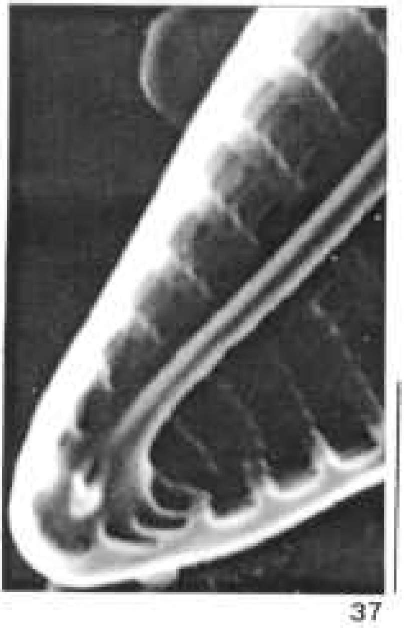

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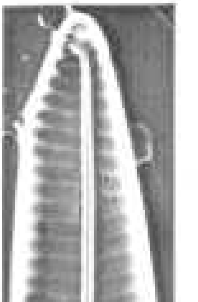
LEGENDA FIG. 1-7

Figs 38-42, SEM. Fig. 38. *Navicula phyllepta.* Internal view. (scale bar= 5µm). Fig. 39. *Navicula platyventris*. Note conspicuous raphe sternum, and like the number "8" at central area. (scale bar= 3µm). Figs 40-42. *Licmophora* sp.. Fig. 40. Internal view. (scale bar= 10µm). Fig. 41. Internal view. Note two labiate structures of rimoportula (scale bar= 5µm). Fig. 42. External view. Note sessile openings of rimoportula and smaller striae on apex. (scale bar= 5µm).



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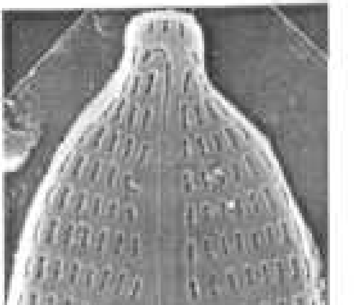

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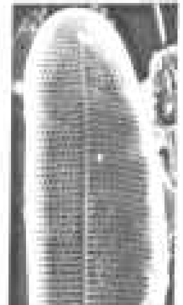

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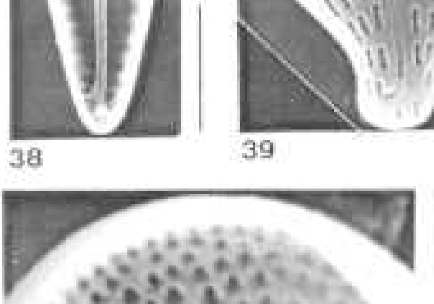

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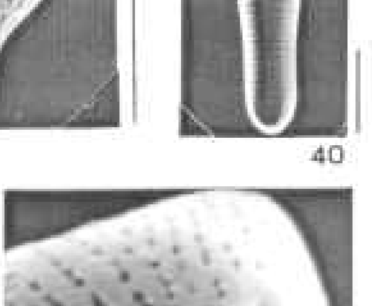

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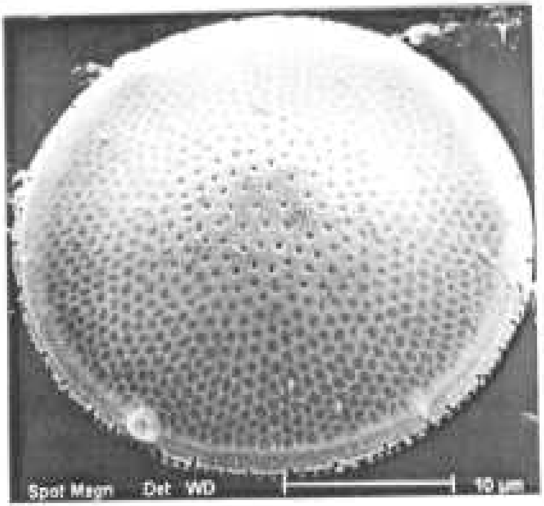
LEGENDA FIG. 43-46

Figs 43-46, *Fryxelliella floridana*, SEM. Fig. 43 External view. Note poligonal areolae and radial array (scale bar= 10μm). Fig. 44. Internal view. Detail of circumferencial marginal tube (T), and pores on the internal margin (scale bar= 5μm). Fig. 45. External view. Detail of margin, showing external opening of the rimoportulae, (R), fissures (F) and granules near the edge (scale bar= 1μm). Fig. 46. Internal view. Note disposition of rimoportulae and ocellii (scale bar= 10μm).



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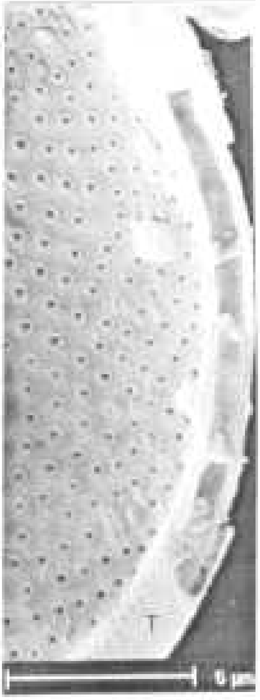

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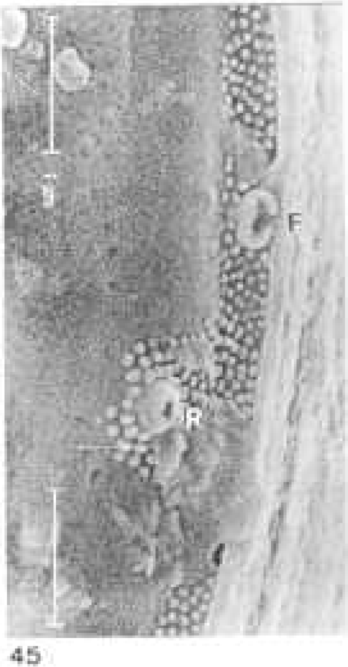

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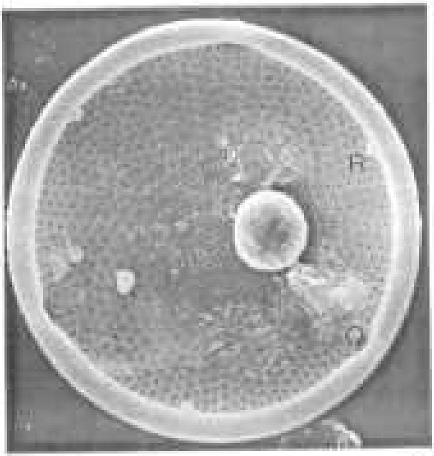

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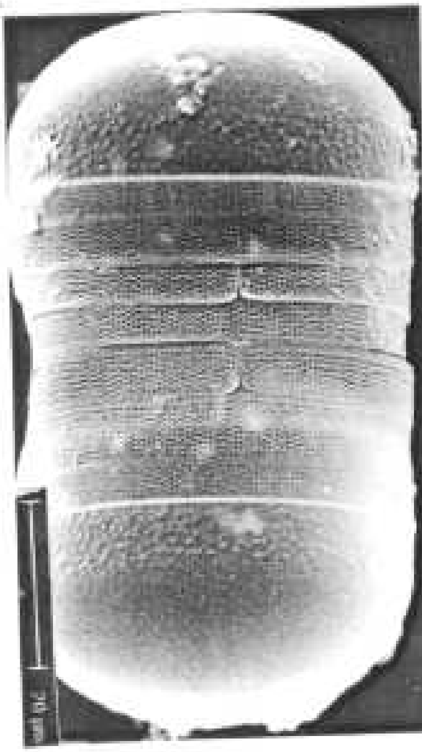
LEGENDA FIG. 47-49

Figs 47-49, *Melosira moniliformis*, SEM. Fig. 47. General view of the frustule, with 4 bands on the epicingulum (scale bar= 20μm). Fig. 48. Detail of frustule in external view. Black arrows indicate 2 rimoportulae of the marginal ring; and white arrows point openings of rimoportulae scattered over the mantle. Observe ligulae and rows of pores at cingular bands (scale bar= 5μm). Fig. 49. External view. Detail of valve face, showing openings of rimoportulae (arrows) and carina (c). Note granules on valve mantle (scale bar= 2μm).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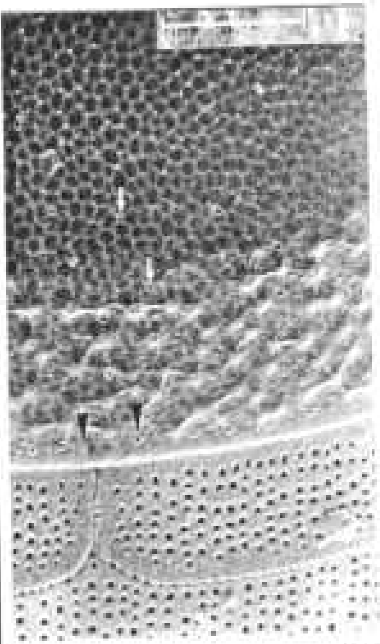
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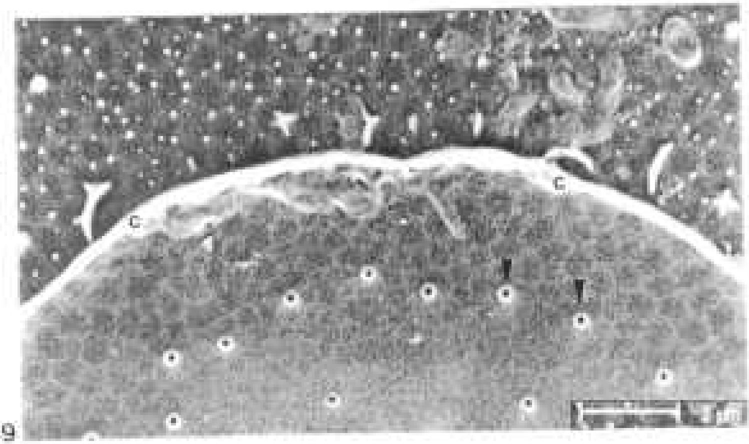

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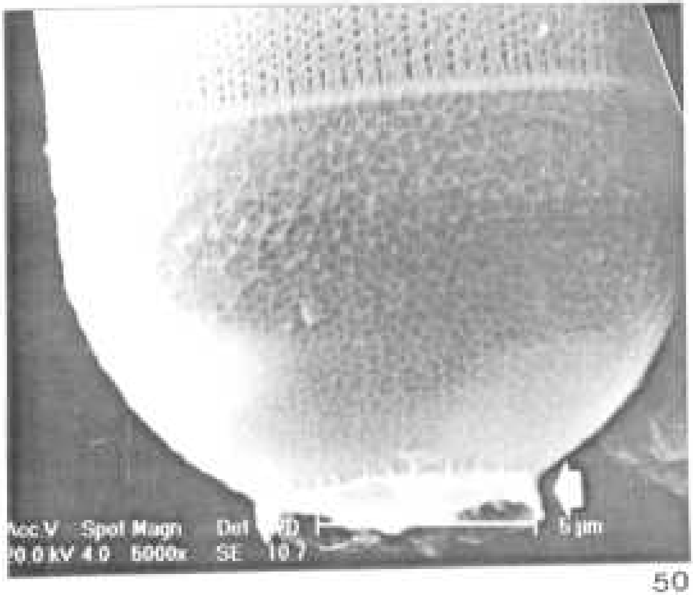
LEGENDA FIG. 50-51

Figs 50-51, SEM. Fig. 50. *Melosira moniliformis*. External view of the valve, showing carina (arrow) composed by a continuous silica membrane (scale bar= 5µm). Fig. 51. *Cyclotella stylorum*. External view. Note external openings of fultoportulae (arrows), and transverse ribs bordering delicate areolae. (scale bar= 10µm).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20.0 kV 4.0 6000x SE 10.7

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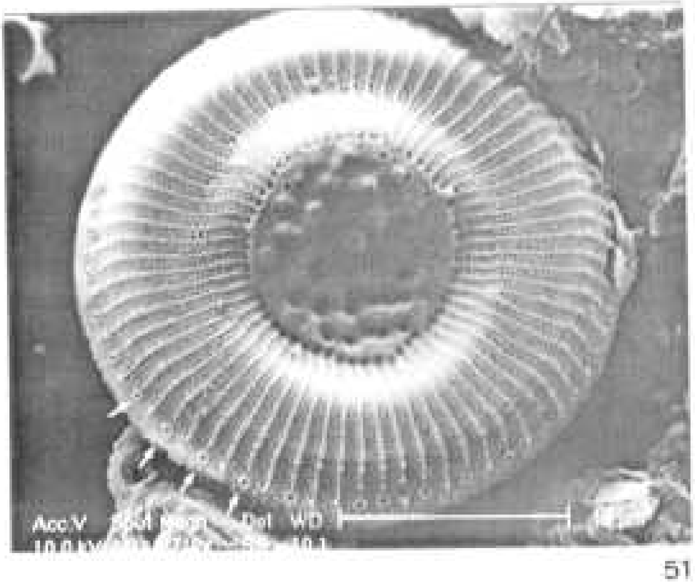
Acc.V Spot Magn Det WD

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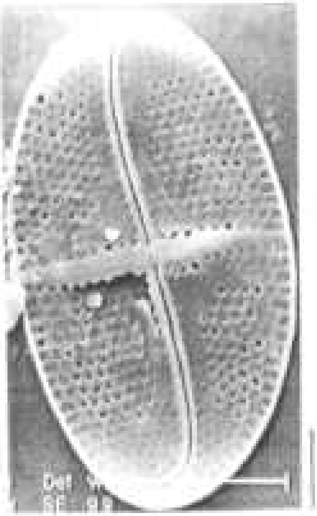
LEGENDA FIG. 52-56

Figs 52-56, SEM. Fig. 52. *Cocconeis dirupta*. Internal view. Note the lozenge-like central area. Fig. 53. *Mastogloia apiculata*. Internal view. Figs 54-56. *Gyrosigma* cf. *balticum*, internal views. Fig. 54. General shape of the valve. Fig. 55. Detail of the central region, showing internal central area (IC) and central bars (arrows). Fig. 56. Distal end of the raphe, with triangular terminal area (TA) and eccentric raphe fissure.



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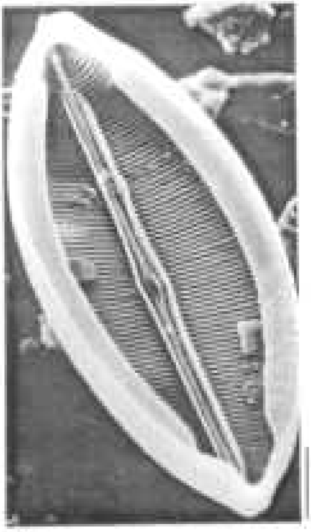

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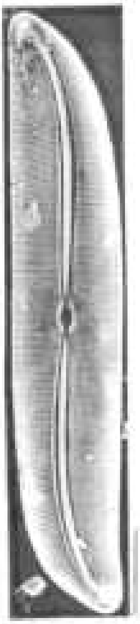

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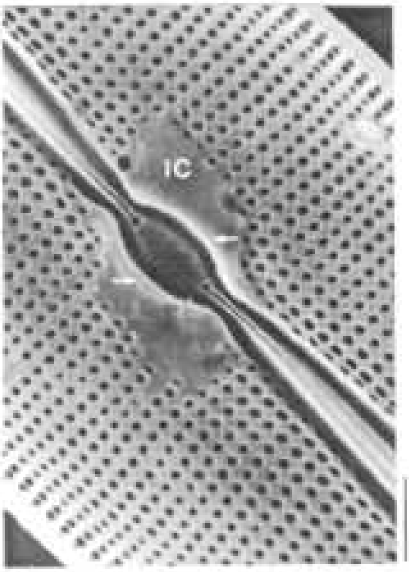

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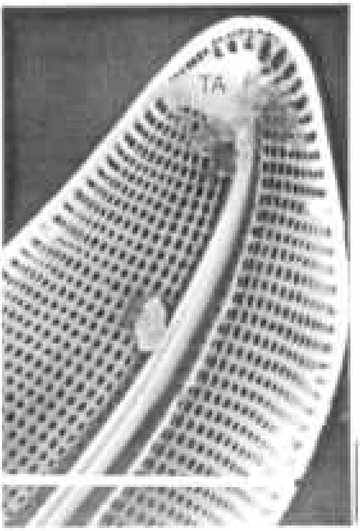

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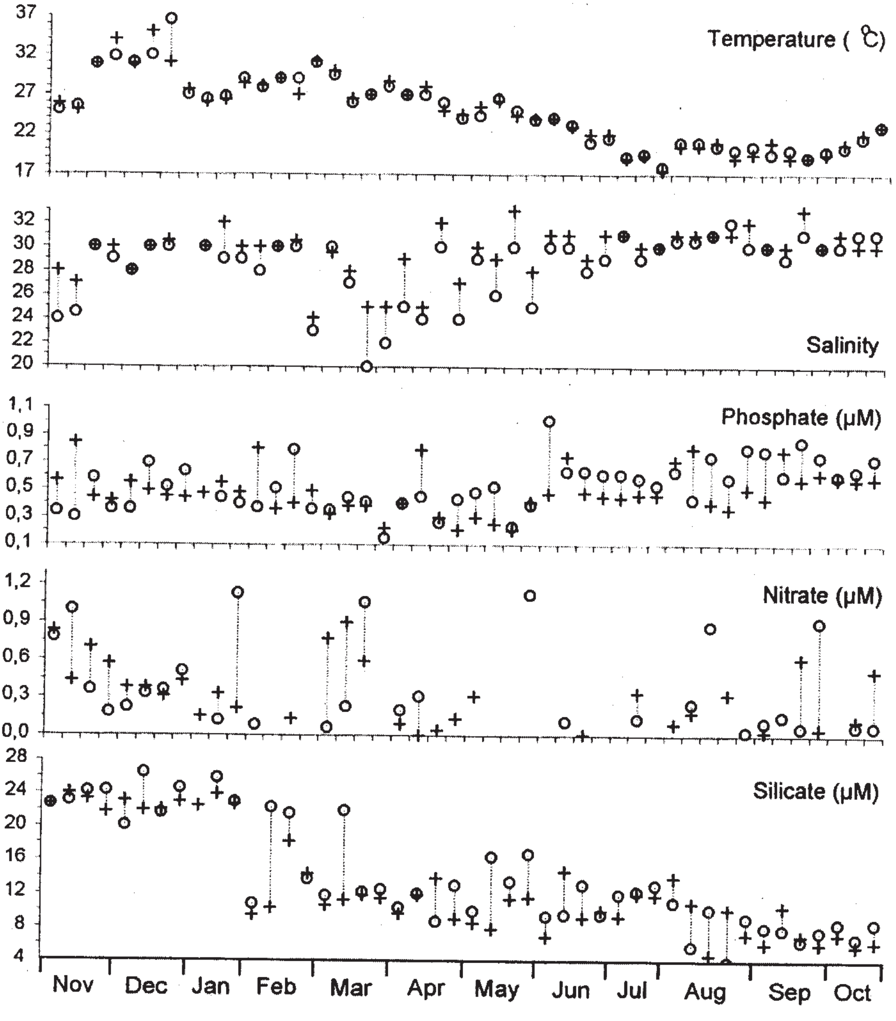

Fig. 57. Temporal variations in the water temperature, salinity and nutrient concentrations at low (o) and high (+) tides in the Paranaguá Bay, Paraná, from November 1993 to October 1994.

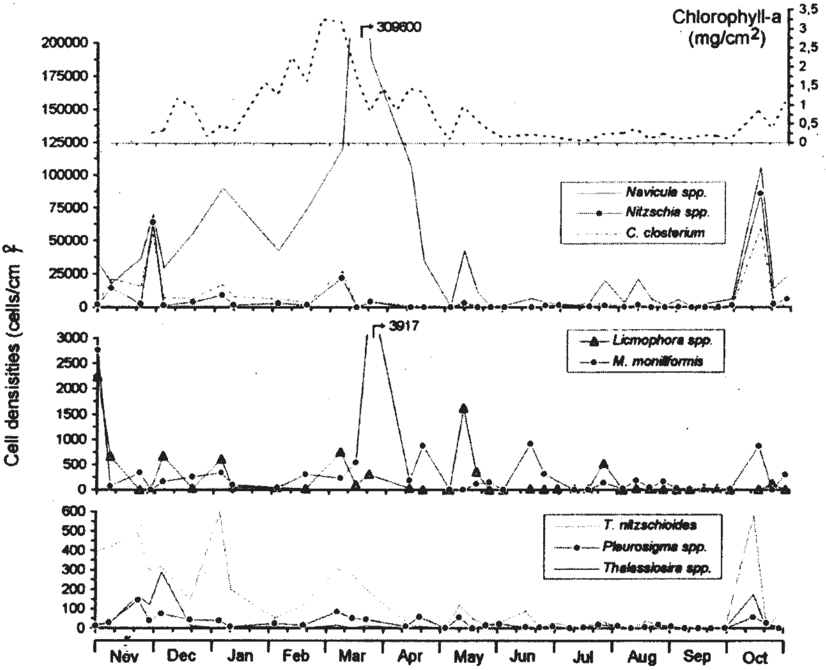

Fig. 58. Temporal variations of chlorophyll-a (upper panel) and of cell densities of dominant diatom taxa in the Paranaguá Bay, Paraná, from November 1993 to October 1994.

Table I: Average (and range) values of environmental parameters measured in the Paranaguá Bay, Paraná between November 1993 and October 1994, for high and low tide levels.

	High tide	Low tide
Temperature (°C)	24.88 (17.4-34.9)	24.89 (17.9-36.0)
Salinity	29.64 (23.0-33.2)	28.43 (20.1-32.0)
Transparency (meters)	2.14 (1.0-3.5)	2.08 (0.8-3.5)
Phosphate (µM)	0.48 (0.21-0.84)	0.53 (0.15-1.01)
Nitrate (µM)	0.34 (<0.10-0.83)	0.38 (<0.10-1.13)
Silicate (µM)	13.06 (6.12-24.03)	14.11 (5.71-26.45)
Chlorophyll-a (µg/cm^2)[1]	0.76 (0.06-3.27)	---
Total diatoms (cells/cm^2)[1]	55,386 (540-310,569)	---

[1]: after 7 day incubation.