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Phytoplankton and environmental factors in the Paraíba do Norte River Estuary, northeastern Brazil: composition, distribution and quantitative remarks

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• *Abstract*: This paper reports the results obtained from studies on the estuarine phytoplankton of the Paraíba do Norte River in northeastern Brazil. Surface and near-bottom samples were taken at four stations numbered seawards, during high and low tides from September 1978 to September 1979. A total of 139 phytoplankters were encountered. Diatoms and dinoflagellates showed highest diversity in most saline areas. Typical freshwater organisms were restricted to stations I and II where salinity was more reduced. Maximum cell densities were: 11,256,000 cells/l, 4,380,000 cells/l, 1,276,000 cells/l and 1,035,000 cells/l, for stations I, II, III and IV, respectively. Sewage enrichments were probably responsible for the greatest values of the first two stations. However, in these stations the turbidity reduces light penetration, limiting phytoplankton growth particularly during the rainy season. The phytoflagellates (maximum of up to 4,874,000 cells/l) and the diatoms *Thalassiosira* spp (maximum of up to 9,262,000 cells/l) were dominant during the annual cycle. Other important taxa were *Navicula* spp, *Cylindrotheca closterium, Paralia sulcata, Thalassionema nitzschioides* and the dinoflagellate *Protoperidinium* spp. Seasonal variations of phytoplankton densities, dissolved oxygen, phosphate, water transparency, temperature, salinity and suspended material are also presented.

• *Descriptors:* Phytoplankton, Estuaries, Environmental factors, Seasonal variations, Community composition, Check lists, Northeast Brazil.

• *Descritores:* Fitoplâncton, Estuários, Fatores ambientais, Variações sazonais, Composição da comunidade, Lista de espécies, Estuário do Rio Paraíba do Norte: PB.

Introduction

Most of the phytoplankton studies carried out in northeastern Brazilian coastal waters were of taxonomic nature and were based on net samples. Quantitative studies showing data based on cell numbers, chlorophyll-*a* and primary productivity are scanty in this region except for some estuaries of the State of Pernambuco (Cavalcanti, 1976; Passavante & Koening, 1978; Passavante, 1979, 1981; Eskinazi-Leça & Koening, 1981; Feitosa, 1988).

The Paraíba River forms the most important estuarine system of Paraíba State, northeastern Brazil. It is a shallow environment with approximately 24 km long and 2 km wide, predominantly influenced by semi-diurnal tides with maximum amplitude of 2.50 m. This river system is bordered by discontinuous mangrove forests dominated by *Rhyzophora* sp and *Laguncularia* sp and is formed by seven tributaries, all subject to low freshwater inflow. Considerable portion of the bottom is covered by silt and mud. In some sectors, banks of sand or mud may be periodically exposed during low tides. Some of these banks are populated by economically important bivalves exploited by local fishermen. Sewage treatment is non-existent for the communities bordering the estuary and large amounts of wastes are discharged into this system (principally via Tambiá River).

In recent years, much attention has been focused to develop a multidisciplinary research program, including biological, physico-chemical and geological aspects. So

far, the first published work on plankton has been that of Singarajah (1978); however, this work was based only on net samples. Recently, some data on chlorophyll-*a* have been published by Sassi & Watanabe (1980).

This paper reports qualitative and quantitative (cell counts) phytoplankton data for this estuarine environment, in order to study their seasonal dynamics in relation to some basic environmental factors.

Material and methods

The field work was performed monthly at four stations (Fig. 1) from September 1978 to September 1979. Surface and near-bottom water samples were collected for biological and chemical analysis twice during the sampling day (low and high tide), using a Van Dorn type bottle. Stations I, II, III and IV have a mean depth of about 2.5, 2.0, 2.5 and 8.0 m respectively, during low tide.

Samples for cell counts were preserved with Lugol solution and analised under a Zeiss inverted microscope according to Utermöhl (1958), with magnificances of up to 625x. Water temperature was measured with an analytical thermometer and salinity with a refractometer. Dissolved oxygen and dissolved inorganic phosphate were analysed according to Strickland & Parsons (1960). Water transparency was measured by the Secchi disc. Suspended materials were determined gravimetrically after filtration of the water in pre-weighed Millipore (HAWP04500) membrane filters. Rainfall data during the study period were obtained at the meteorological station of the federal government, located near the estuary.

Additional net samples were collected in the same stations and preserved with neutralized 4% formaldehyde. These samples were analysed under a standard microscope only for qualitative purposes.

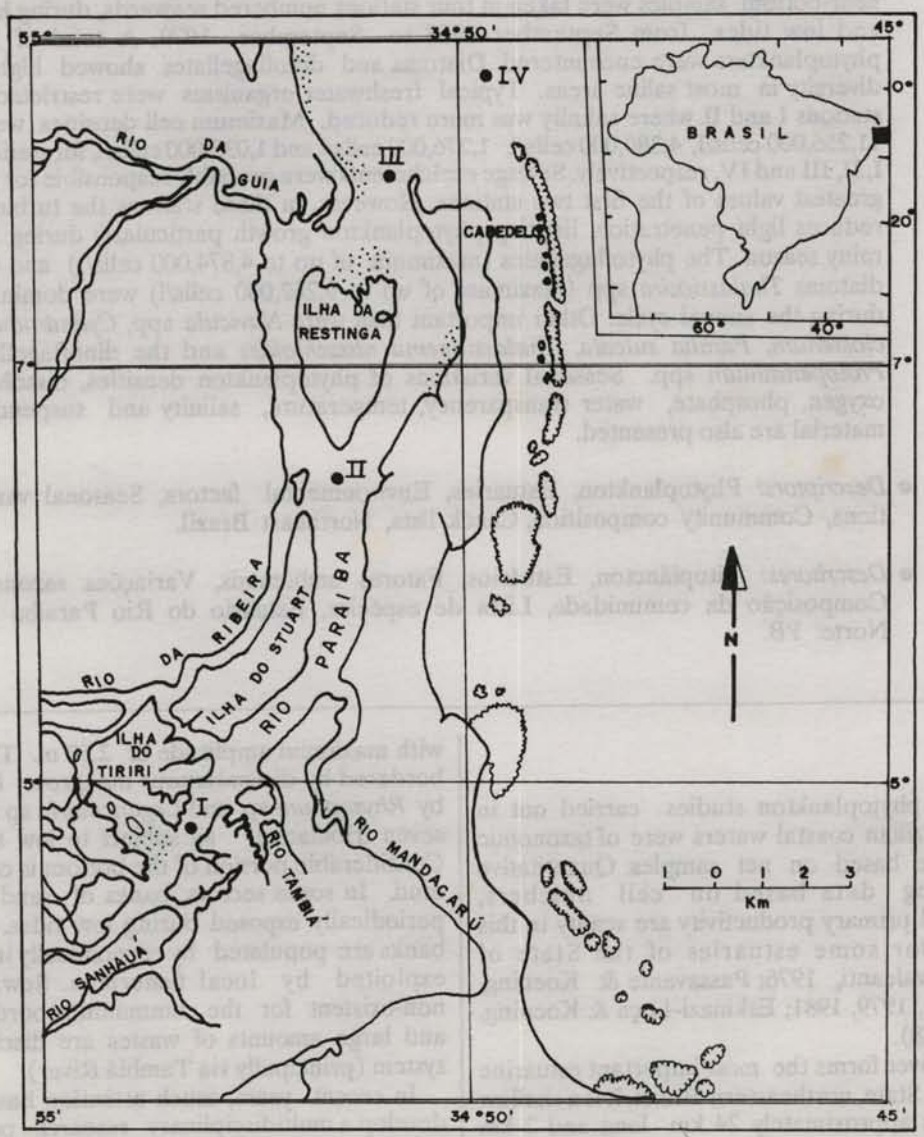

Fig. 1. Map of the study area with stations position.

Results

Environmental factors

Rainfall regime shows highest values among April and September during the study period, reaching up to 340.0 mm in May (Fig. 2).

Water temperature presented a well defined seasonal cycle with maximum (up to 31°C) from December to March and minimum (up to 24.8°C) from May to August. Vertical stratification was not observed in all study sites with surface and bottom differences in temperatures of 1 °C, even between low and high tide measurements (Fig. 3).

A clear seasonal variation was also observed for salinity (Fig. 4). In all stations the salinity was lower between May and August (rainy months), during low tide. This pattern was also evident in Stations I and II during high tide. No clear vertical gradient was observed during the study period; the greatest difference between surface and bottom measurements was 8‰ under high tide condition at Station II (July, 1979). In the upper Stations I and II the salinity values were lower during low tide, while in the Stations III and IV there was practically no differences between low and high tide values.

Dissolved oxygen showed an irregular seasonal pattern during the study period (Fig. 5). As a rule the values of this parameter increased seawards both at low and high tides. Very low values were observed in December at high tide in Station I and in February at low tide, and January and February at high tide in Station III. Maximum value was also registered in January at low tide, reaching 6.10 ml/l in Station II. The minimum was 0.72 ml/l, observed in February at high tide, in Station III. No regular pattern of vertical distribution was observed for this parameter during the study period.

Similarly to dissolved oxygen the water transparency did not show a regular seasonal cycle in all stations surveyed. Maximum values always occurred at high tides, although they were registered at different months in each station (Fig. 6). Usually the highest values were registered during the dry season, although some exception as in Stations II (February and March at low and high tides), III (February and March at low tide) and IV (February at low tide and February and March at high tide), were observed. Minimum and maximum were registered in Station IV and reached respectively 0.25 m (September, 1978) and 2.20 m (January, 1979) both at high tide.

The amount of suspended material measured in the study stations fluctuated between 16.60 mg/l (September, 1979, Station IV, surface, high tide) to 265.33 mg/l (February, 1978, Station II, bottom, low tide) (Fig. 7). Small differences between surface and bottom were occasionally observed during the study period, except in February 1978 (Station II), where these differences accounted for a maximum of 148.13 mg/l. However, a regular seasonal pattern of this parameter, with high values during the rainfall season, was observed particularly in surface and bottom samples of Station I, at low tide, but only in bottom samples at high tide; in bottom samples of Station II, at high tide and in bottom samples of Station III, only at low tide.

The phosphate varied irregularly during the study period, except in Station I during low tide, which showed the highest values during the rainfall season, particularly in surface samples. It always decreased seawards but it was usually higher during low tide than during high tide. The concentrations ranged between 0.04 and 1.49 μg.at/l. The maximum value was observed at Station I in August (bottom sample, low tide) and the minimum was registered at Stations III and IV, respectively in February (surface sample, high tide) and November (bottom sample, low tide) (Fig. 8).

Phytoplankton composition, horizontal distribution and quantitative data

A total of 139 phytoplankters were observed among six taxonomic groups: Bacillariophyceae (112), Dinophyceae (16), Cyanophyceae (6), Chlorophyceae (4) and Chrysophyceae (1). In addition, several unidentified nanoplanktonic flagellates were also observed (Table 1).

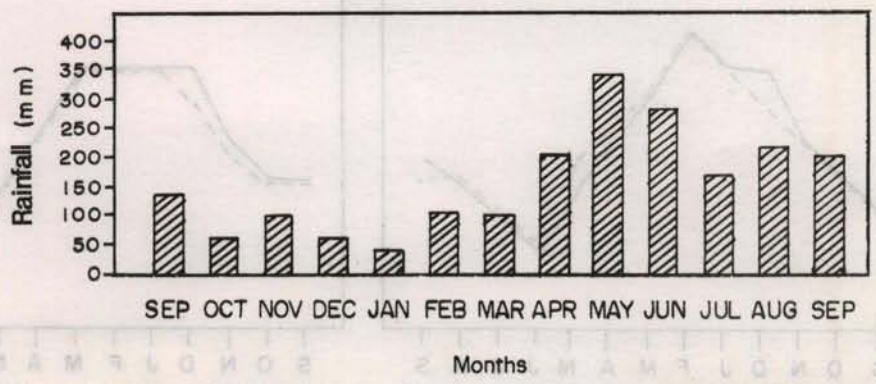

Fig. 2. Rainfall regime during the study period.

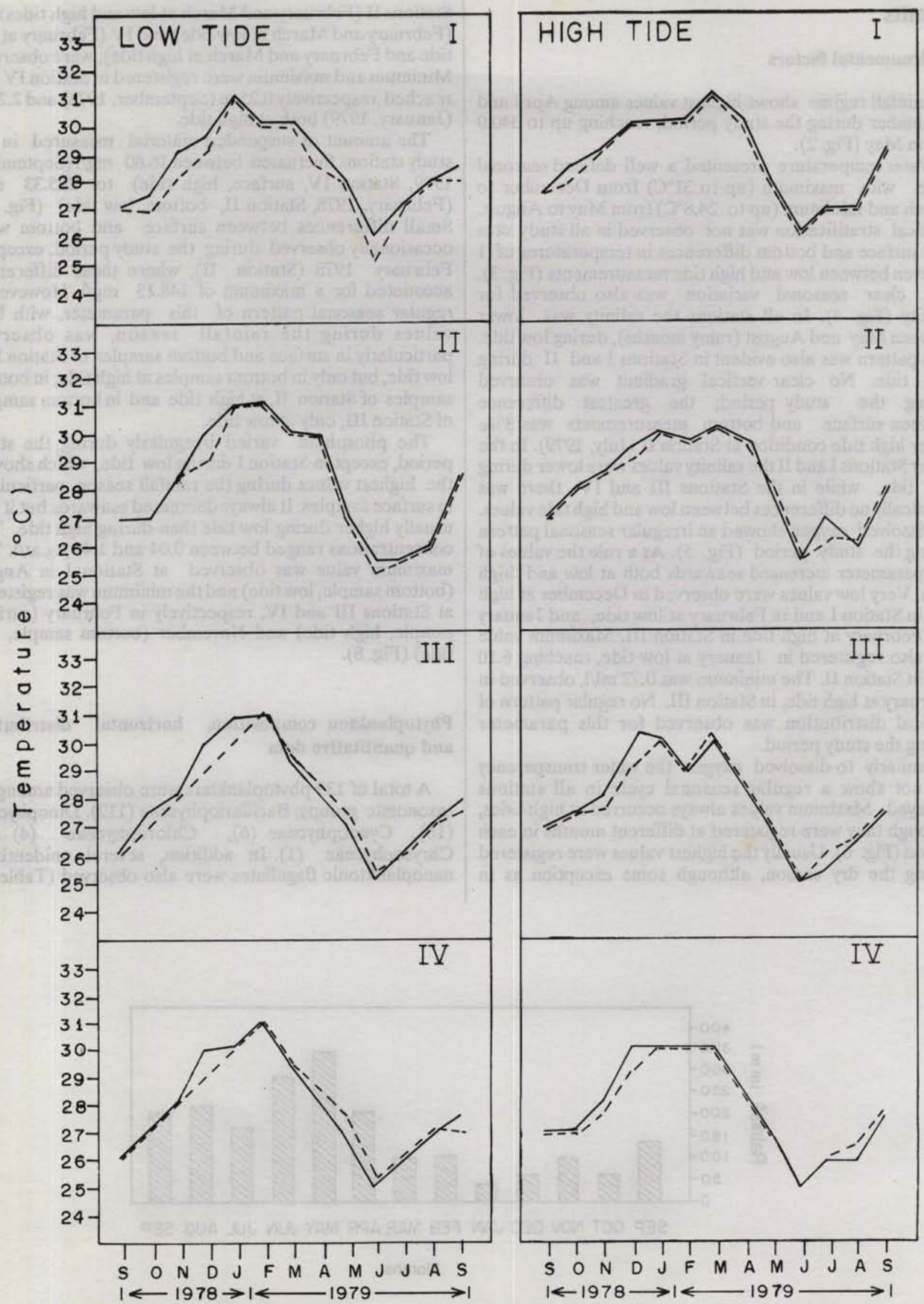

Fig. 3. Seasonal variation of surface (—) and bottom (- - -) temperature in the four study stations.

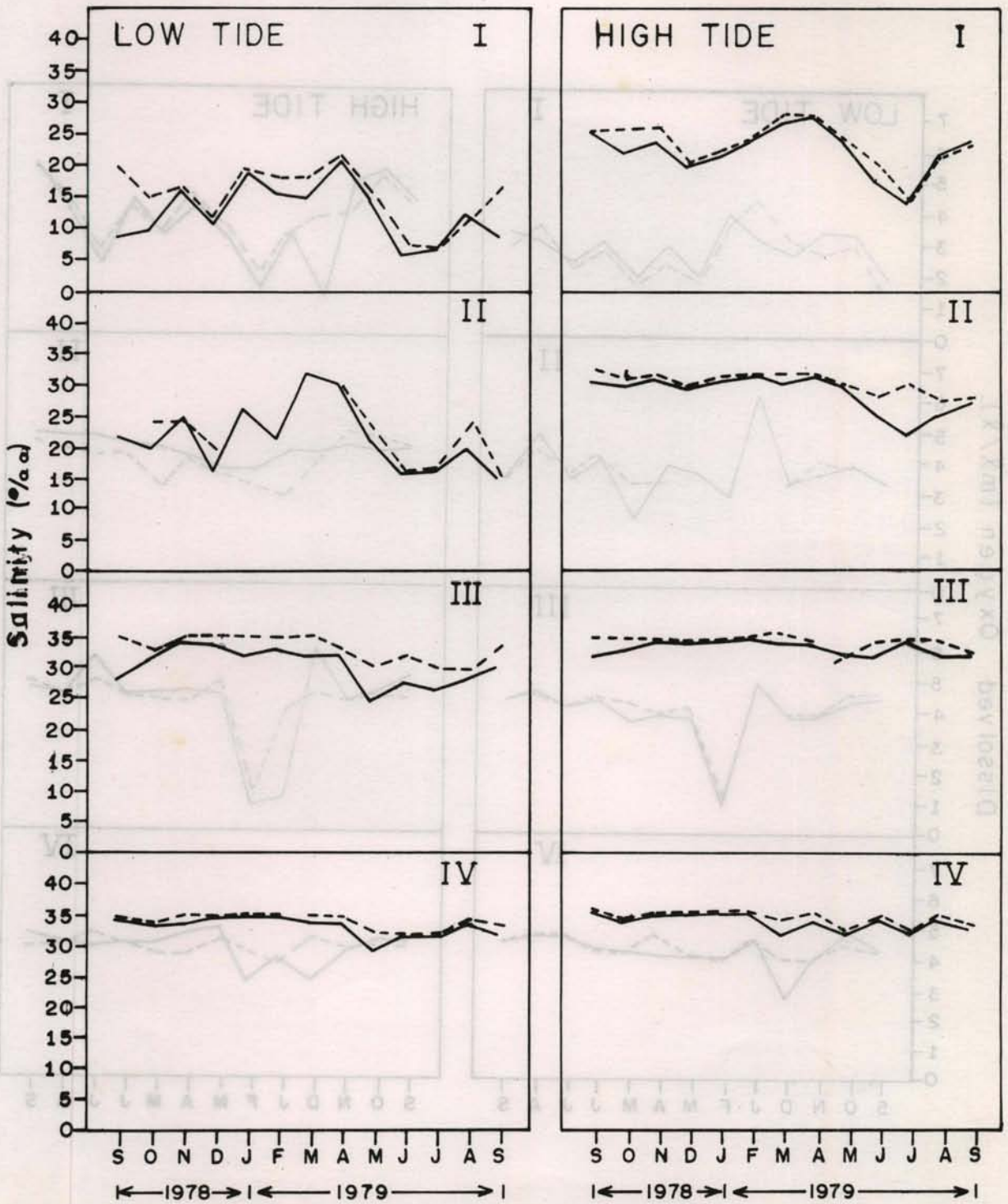

Fig. 4. Seasonal variation of surface (—) and bottom (- - -) salinity in the four study stations.

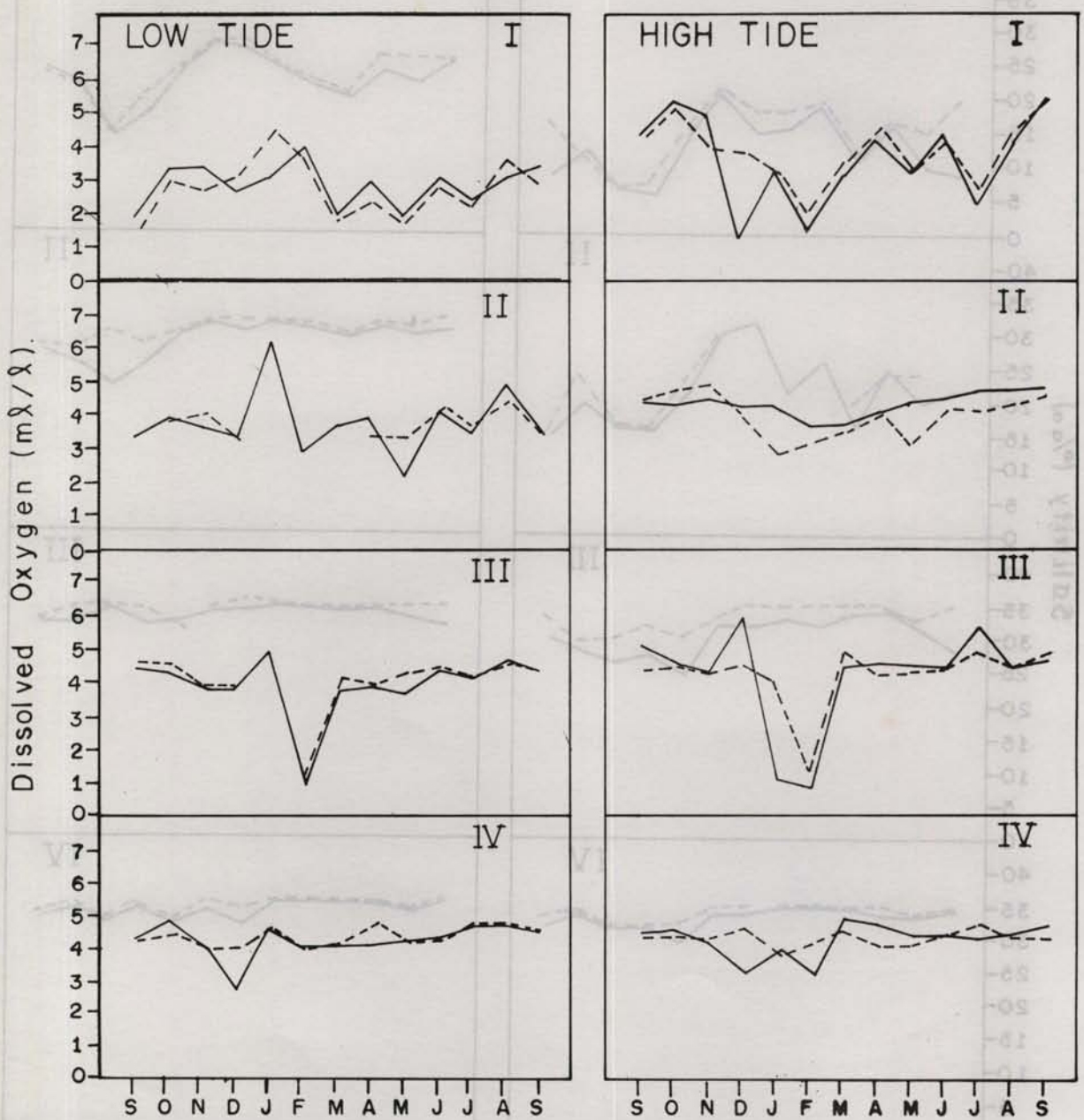

Fig. 5. Seasonal variation of surface (—) and bottom (- - -) dissolved oxygen in the four study stations.

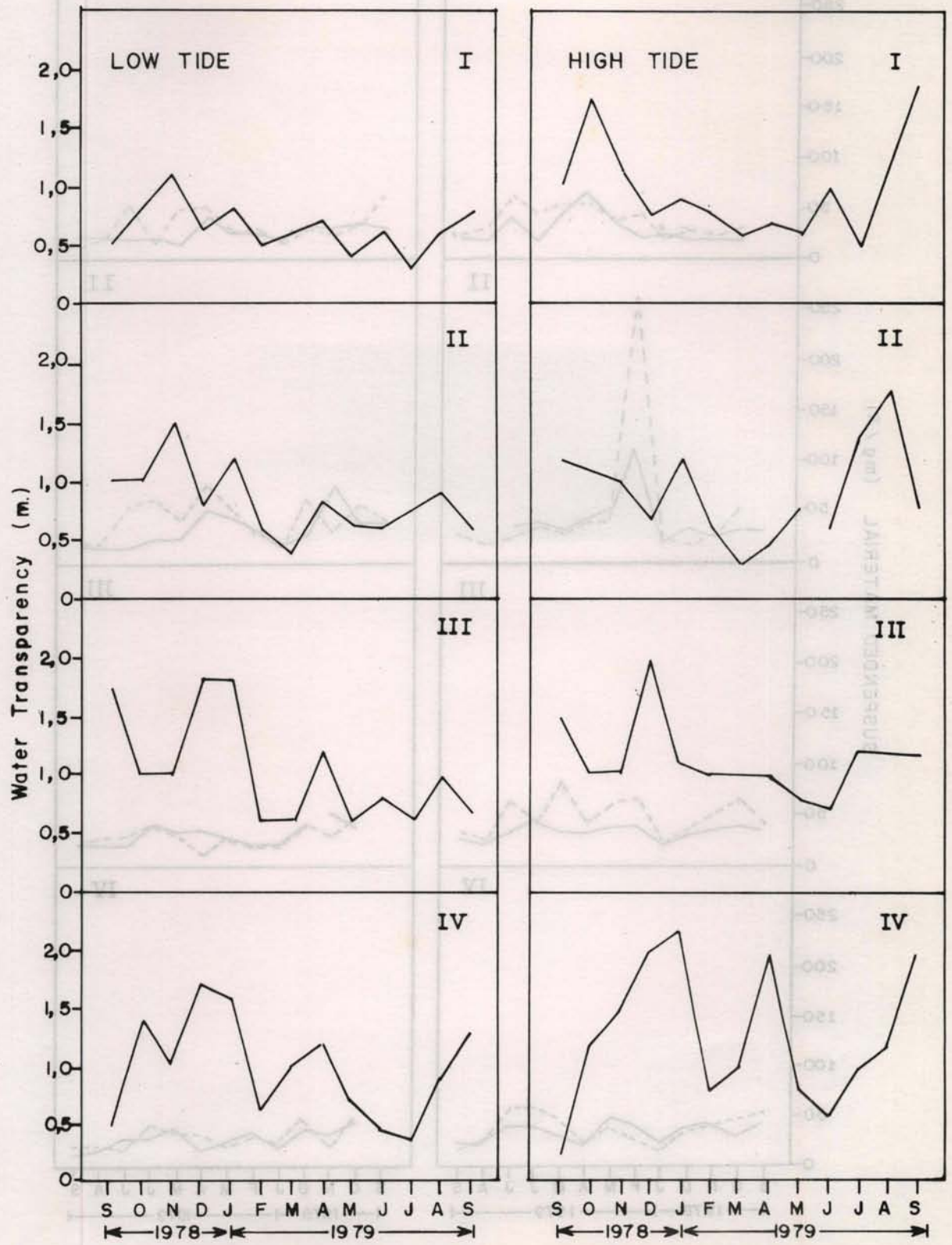

Fig. 6. Seasonal variations of water transparency in the four study stations.

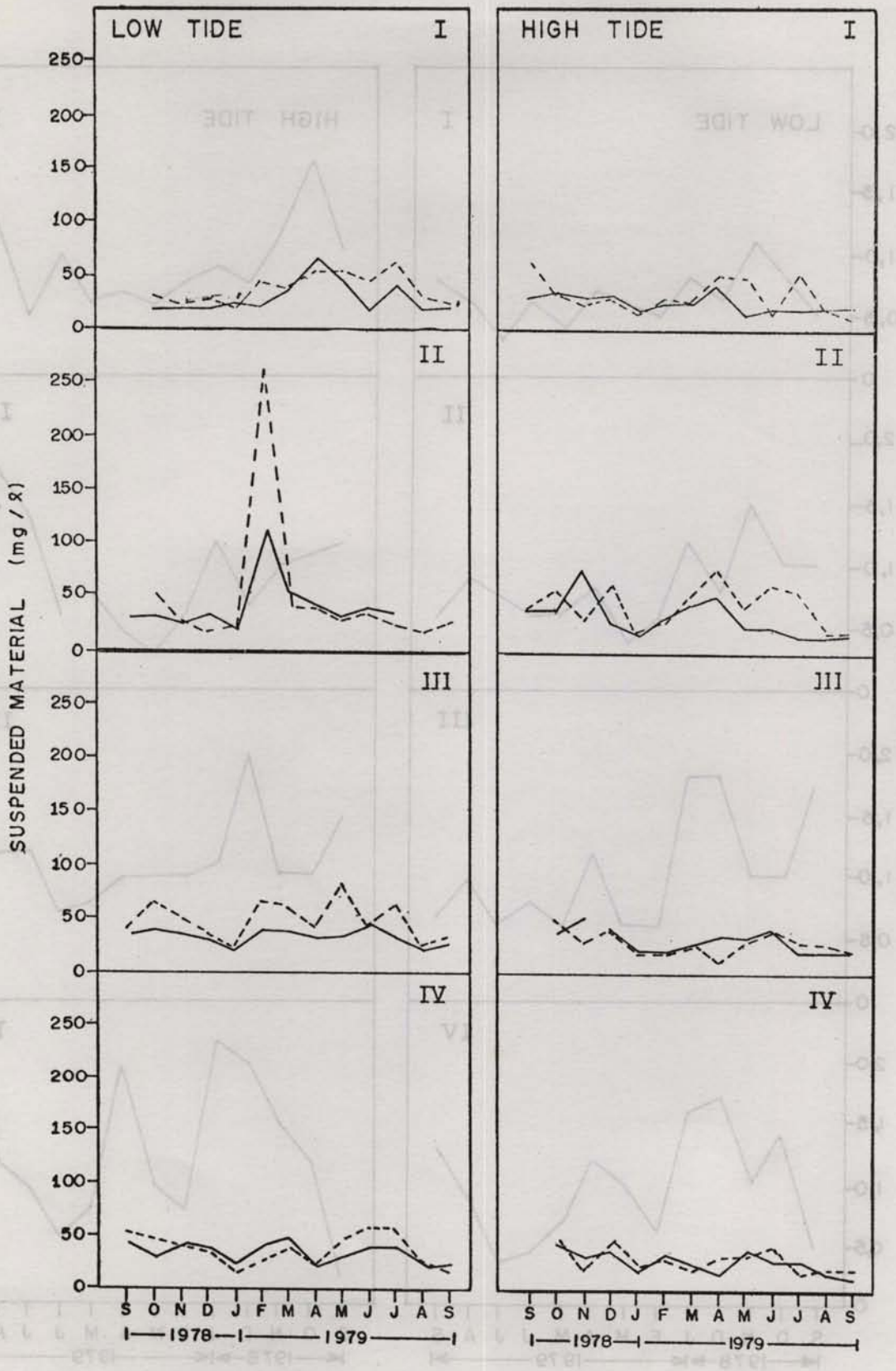

Fig. 7. Seasonal variation of surface (—) and bottom (- - -) suspended material in the four study stations.

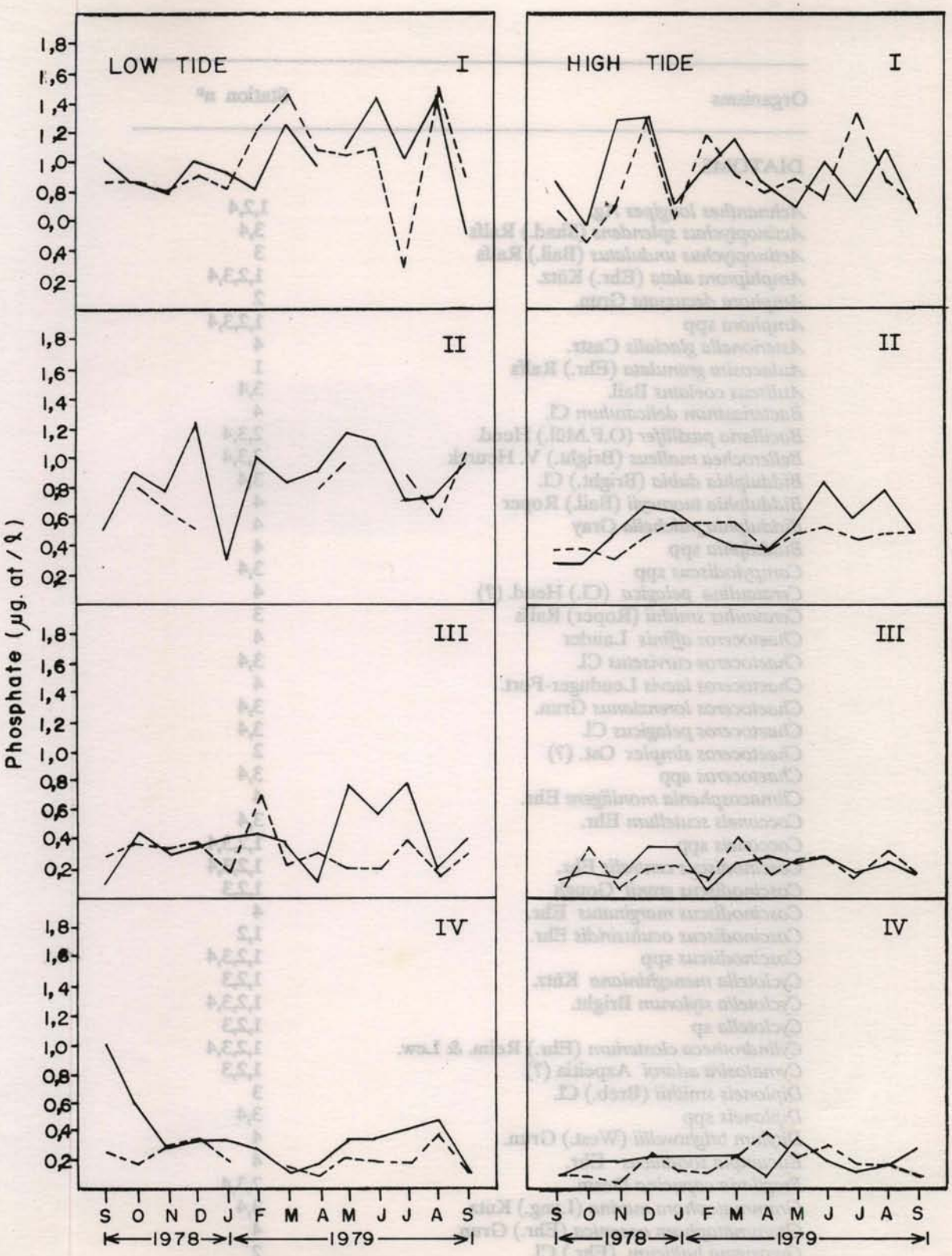

Fig. 8. Seasonal variation of surface (—) and bottom (- - -) dissolved inorganic phosphate in the four study stations.

Table 1. Phytoplankton species found in the Paraíba do Norte River Estuary between September 1978 and September 1979.

Organisms	Station nº
DIATOMS	
Achnanthes longipes Ag.	1,2,4
Actinoptychus splendens (Shad.) Ralfs	3,4
Actinoptychus undulatus (Bail.) Ralfs	3
Amphiprora alata (Ehr.) Kütz.	1,2,3,4
Amphora decussata Grun.	2
Amphora spp	1,2,3,4
Asterionella glacialis Castr.	4
Aulacosira granulata (Ehr.) Ralfs	1
Auliscus coelatus Bail.	3,4
Bacteriastrum delicatulum Cl.	4
Bacillaria paxillifer (O.F.Mül.) Hend.	2,3,4
Bellerochea malleus (Bright.) V. Heurck	2,3,4
Biddulphia dubia (Bright.) Cl.	3,4
Biddulphia tuomeyii (Bail.) Roper	4
Biddulphia pulchella Gray	4
Biddulphia spp	4
Campylodiscus spp	3,4
Cerataulina pelagica (Cl.) Hend. (?)	4
Cerataulus smithii (Roper) Ralfs	3
Chaetoceros affinis Lauder	4
Chaetoceros curvisetus Cl.	3,4
Chaetoceros laevis Leuduger-Fort.	4
Chaetoceros lorenzianus Grun.	3,4
Chaetoceros pelagicus Cl.	3,4
Chaetoceros simplex Ost. (?)	2
Chaetoceros spp	3,4
Climacosphenia moniligera Ehr.	4
Cocconeis scutellum Ehr.	3,4
Cocconeis spp	1,2,3,4
Coscinodiscus centralis Ehr.	1,2,3,4
Coscinodiscus granii Gough	1,2,3
Coscinodiscus marginatus Ehr.	4
Coscinodiscus oculusiridis Ehr.	1,2
Coscinodiscus spp	1,2,3,4
Cyclotella meneghiniana Kütz.	1,2,3
Cyclotella stylorum Bright.	1,2,3,4
Cyclotella sp	1,2,3
Cylindrotheca closterium (Ehr.) Reim. & Lew.	1,2,3,4
Cymatosira adaroi Azpeitia (?)	1,2,3
Diploneis smithii (Breb.) Cl.	3
Diploneis spp	3,4
Ditylum brightwellii (West.) Grun.	4
Eucampia zoodiacus Ehr.	4
Fragilaria capucina Desm.	2,3,4
Grammatophora marina (Lyng.) Kutz.	3,4
Grammatophora oceanica (Ehr.) Grun.	4
Gyrosigma balticum (Ehr.) Cl.	2
Hemiaulus hauckii Grun.	4
Hyalodiscus sp	3,4
Isthmia enervis Ehr.	2,3,4

Table 1. Cont.

Organisms	Stations nº
Leptocylindrus danicus Cl.	4
Licmophora gracilis (Ehr.) Grun.	3,4
Lithodesmium undulatum Ehr.	2,3,4
Melosira moniliformis (O.F.Mül.) Ag.	2,3,4
Navicula distans (W. Smith) Ralfs	4
Navicula lyra Ehr.	3
Navicula pennata A. Schm.	1,3,4
Navicula spp	1,2,3,4
Nitzschia angularis W. Smith	1,2,3
Nitzschia bilobata W. Smith	3
Nitzschia lanceola Gr.	4
Nitzschia longissima (Breb.) Ralfs	1,2,3,4
Nitzschia lorenziana Gr.	1,2,3,4
Nitzschia panduriformis Greg.	1,2,3,4
Nitzschia pungens v. *atlantica* Cl.	3,4
Nitzschia sigma (Kütz.) W. Smith	1,2,3,4
Nitzschia spp	1,2,3,4
Odontella aurita (Lyng.) Ag.	3,4
Odontella longicruris (Grev.) Hoban	2,3,4
Odontella mobiliensis (Bail.) Grun.	1,2,3,4
Odontella rhombus W.Smith	3,4
Odontella sinensis (Grev.) Grun. (?)	2,3
Opephora marthyi Héribaud	3
Paralia sulcata (Ehr.) Cl.	2,3,4
Phaeodactylum tricornutum Bohlin	3,4
Pleurosigma formosum W. Smith	2,4
Pleurosigma naviculaceum Bréb.	2,3,4
Pleurosigma normanii Ralfs	2,3,4
Pleurosigma sp	1,2
Podocystis adriatica (Kütz.) Ralfs	3,4
Rhabdonema punctatum (Harv. et Bail.) Stod.	3,4
Rhaphoneis amphiceros Ehr.	2,3
Rhizosolenia alata Bright.	3,4
Rhizosolenia calcaravis Schul.	2,3,4
Rhizosolenia delicatula Cl.	3,4
Rhizosolenia setigera Bright.	3,4
Rhizosolenia stolterfothii H. Per.	2,3,4
Rhizosolenia styliformis Bright.	2,3,4
Rhopalodia musculus (Kütz.) O.F.Mül.	2,3
Skeletonema costatum (Grev.) Cl.	1,2,3,4
Stauroneis membranacea (Cl.) Hust.	4
Streptotheca thamesis Shrubs.	2,3,4
Striatella unipunctata (Lyng.) Ag.	3,4
Surirella fastuosa Ehr.	2,3,4
Surirella febigerii Lewis	4
Surirella sp	1,2,3,4
Surirella gemma (Ehr.) Kütz.	3,4
Synedra goulardii (Bréb.) Grun.	1,2,3
Synedra ulna (Nitzsch) Ehr.	1,2,3
Synedra spp	1,2,3,4
Terpsinoe musica Ehr.	1,2,3
Thalassionema nitzschioides Grun.	2,3,4
Thalassiosira eccentrica (Ehr.) Cl.	1,2,3,4
Thalassiosira leptopus (Gr.) Has. & Fryx.	1,2,3,4

Table 1. Cont.

Organisms	Stations nº
Thalassiosira sp cf *subtilis* (Ost.) Gran	3,4
Thalassiosira spp	1,2,3,4
Thallassiothrix frauenfeldii Grun.	3
Trachyneis aspera (Ehr.) Cl.	2,3
Triceratium favus Ehr.	3,4
Triceratium favus f. *quadrata* (Ehr.) Grun.	4
Triceratium pentacrinus (Ehr.) Wall.	3,4
Tropidoneis sp	1,2
DINOFLAGELLATES	
Ceratium furca v. *furca* (Ehr.) Clap. & Lac.	3,4
Ceratium fusus (Ehr.) Dujardin	4
Ceratium contortum (Gourret) Cleve	4
Ceratium massiliense (Gourret) Karsten	4
Ceratium teres Kofoid	4
Ceratium tripos (O.F. Mül.) Nitzsch	4
Ceratium vultur Cleve (?)	4
Dinophysis caudata Saville-Kent	3,4
Gonyaulax digitale (Pouchet) Kofoid	1,2,3
Gymnodinium spp	1,2,3,4
Prorocentrum micans Ehr.	3,4
Prorocentrum minimum (Pavillard) Schiller	3
Protoperidinium depressum (Bailey) Balech	2,3,4
Protoperidinium excentricum (Paul.) Balech	2,3,4
Protoperidinium spp	1,2,3,4
Scrippsiella sp	1,2
CYANOPHYCEANS	
Anabaena sp	1,2,3
Lyngbia sp	1,2
Merismopedia sp	1
Oocystis sp	1,2
Oscillatoria spp	1,2,3,4
Spirulina sp	1,2
CHLOROPHYCEANS	
Ankistrodesmus falcatus (Corda) Ralfs	1,2
Closterium sp	1,2
Kirchneriella sp	1,2
Scenedesmus quadricauda (Turpin) Bréb.	1,2,3
SILICOFLAGELLATES	
Dictyocha fibula Ehr.	3,4
PHYTOFLAGELLATES	1,2,3,4
UNIDENTIFIED ORGANISMS	1,2,3,4

Among the Bacillariophyceae, the genus *Nitzschia* showed the greatest number of species (8), followed by *Chaetoceros* (6), *Rhizosolenia* (6) and *Coscinodiscus* (4). Whithin the Dinophyceae the greatest number of species was observed in the genus *Ceratium* (7).

Diatoms and Dinoflagellates were frequently observed in all the stations, but the greatest number of taxa was observed in Stations III and IV, decreasing towards Station I. Freshwater species of Chlorophyceae (*Scenedesmus quadricauda, Ankistrodesmus falcatus, Kirchneriella* spp) and Cyanophyceae (*Lyngbia* sp, *Spirulina* sp) were restricted to the areas of more reduced salinities (Stations I and II).

Higher cell concentrations were usually observed during low tide. In Station I (low and high tide) the highest densities were observed, decreasing towards Station IV, but no regular seasonal cycle could be observed for all stations surveyed during the study period (Figs 9, 10).

For Station I, maximum cell counts (reaching up to 11,256,000 cells/l, bottom sample, low tide, November 1978), occurred from late rainfall season to middle dry season (November 1978 and from June to September 1979). Unfortunately the data are incomplete for the annual cycle of this station, since no sample was collected in January and February.

For Station II, again no sample was collected in February, during low tide, but from November to January the data showed high values (including the samples collected during high tide), reaching up to 4,380,000 cells/l in November, 1978 (surface sample, low tide). Station III showed a polymodal cycle during the year, with maximum cells counts in November 1978, February 1979, and June 1979; the greatest value (1,276,000 cells/l) was registered in June (surface sample, low tide). In Station IV the values were always low and almost constant throughout the year; the highest value was observed in February 1979, at surface during low tide, reaching up to 1,035,000 cells/l.

Great differences between the surface and the bottom values of cell counts were observed at Station I (November, March, June and August at low tides, and June and August at high tide) and at Station II (November at low tide). The greatest difference occurred in August at Station I, during low tide, reaching up to 8,485,000 cells/l.

The phytoflagellates and the diatoms *Thalassiosira* spp were quantitatively the most important organisms in all study stations (Figs 11-14). The former reached up to 4,874,000 cells/l in Station I, September 1979 (bottom, at low tide) and the latter reached up to 9,262,000 cells/l in the same station, in August 1979 (surface, at low tide). These values correspond to 65,67% and 83,68% of the total phytoplankton respectively for the same months. A clear pattern of succession in the index of abundance (% of total cell counts) was observed among these organisms throughout the year for each station.

The diatoms *Cylindrotheca closterium, Navicula* spp and *Paralia sulcata*, the dinoflagellates *Protoperidinium* spp, the Cyanophyceae and the Chlorophyceae also ranked as important quantitatively or in terms of frequency in Station I. *C. closterium* and *Paralia sulcata* were the most abundant, reaching up to 11,042,000 cells/l in November 1978 (bottom, at low tide) and up to 2,954,000 cells/l in March 1979 (surface, at low tide), respectively. These values correspond to 98,10% and 83,33% of the total phytoplankton for the same months, respectively (Fig. 11).

For Station II the diatoms *C. closterium, Navicula* spp, *Paralia sulcata* and *Thalassionema nitzschiodes*, the dinoflagellates *Protoperidinium* spp, the Cyanophyceae and the Chlorophyceae were also considered important quantitatively or in terms of frequency. *Navicula* spp and *Protoperidinium* spp were the most dominant, reaching up to 1,317,000 cells/l in November 1978 (surface, at low tide) and up to 141,000 cells/l in September 1978 (surface, at low tide), respectively. These values correspond to 30.07% and 43.64% of the total phytoplankton of the same months, respectively (Fig. 12).

The Stations III and IV were almost similar in composition and abundance of phytoplankters. Although dominated by phytoflagellates and *Thalassiosira* spp, the diatoms *C. closterium, Navicula* spp, *Paralia sulcata* and *Thalassionema nitzschioides* were also abundant. The dinoflagellates *Protoperidinium* spp occurred in relatively small quantities. All showed differential growth during the study period (Figs 13-14). Among these organisms *P. sulcata* and *T. nitzschioides* were the dominants. The former presents the highest abundance (% of total phytoplankton) in January, March and May at Station III and in September, 1978, October and June at Station IV and the latter was very abundant in April at Station III and in October and April, at Station IV. The highest index of abundance was 33.01% found in April, at Station III, when the total cell number of *T. nitzchioides* reached up to 265,000 cells/l at low tide, in the bottom.

The mean values of cell counts calculated for low and high tides showed highest values in Station I (Fig. 15), decreasing towards the sea. This horizontal pattern showed a direct relationship with the mean values of phosphate and an inverse relationship with the mean values of salinity and water transparency. Nevertheless, no relationship seemed to occur between phytoplankton and water temperature, dissolved oxygen and suspended material.

Discussion

In tropical and sub-tropical areas the rainfall regime appears to be the main factor controlling the distribution, abundance, and seasonal dynamics of the estuarine phytoplankton. The increase of biomass and primary productivity due to inflow of river borne nutrients, after heavy rainy period, has been frequently observed in Brazilian estuaries (Kutner, 1972; Tundisi *et al.*, 1973; Tundisi *et al.*, 1978; Passavante, 1979; Brandini, 1985a,b) and in estuarine waters of India (Subrahmanyan, 1959; Qasim *et al.*, 1969; Devassy & Battathiri, 1974). Although this could be considered as a possible factor, spatial differences on seasonal growth may be found in these ecosystems, due to differential effects of nutrient availability, salinity, turbidity or grazing pressure. The tidal regime and the differences in the lateral inputs of suspended materials or dissolved nutrients are among the causal factors which seem to control these effects.

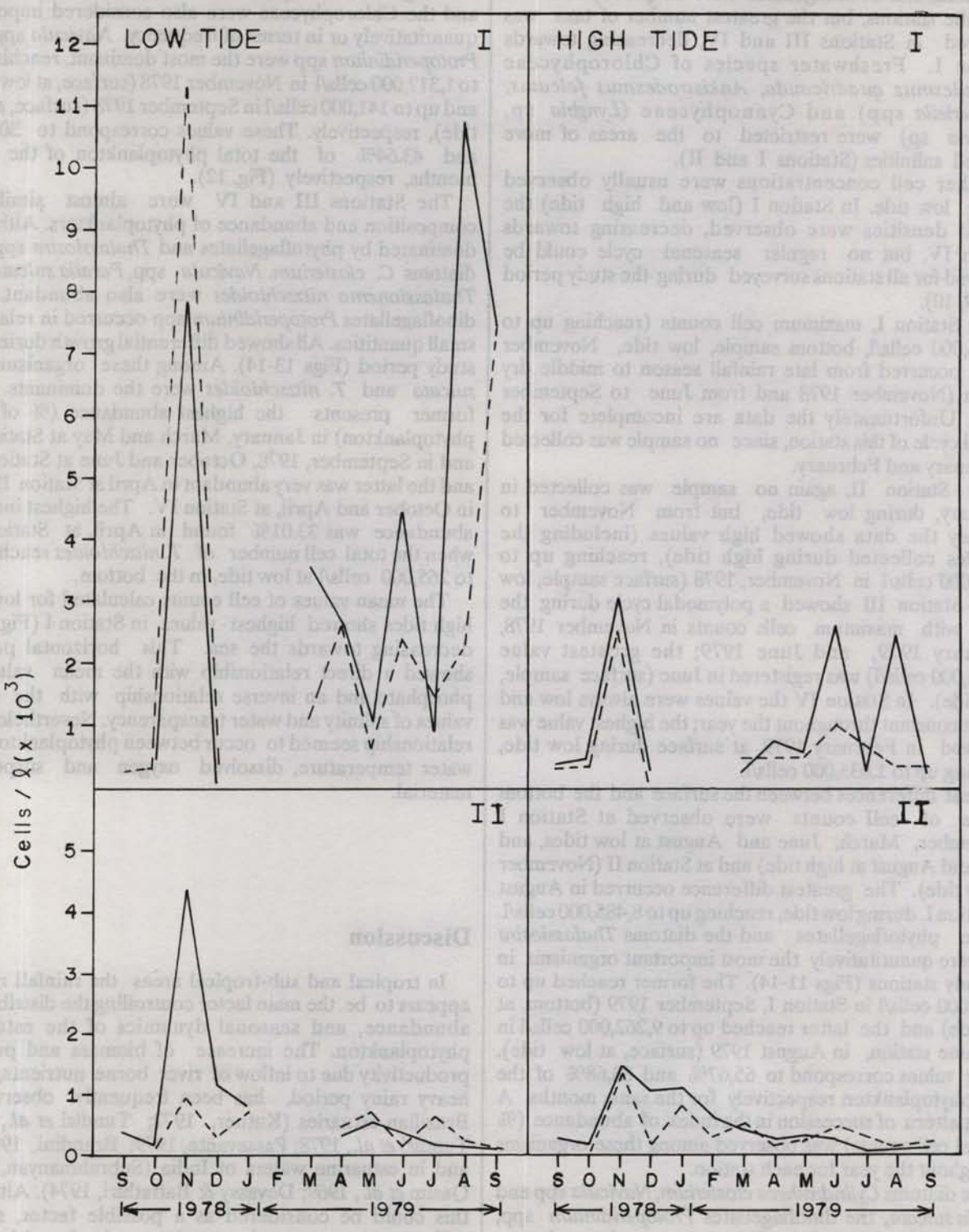

Fig. 9. Seasonal variation of surface (—) and bottom (- - -) total phytoplankton in Stations I and II.

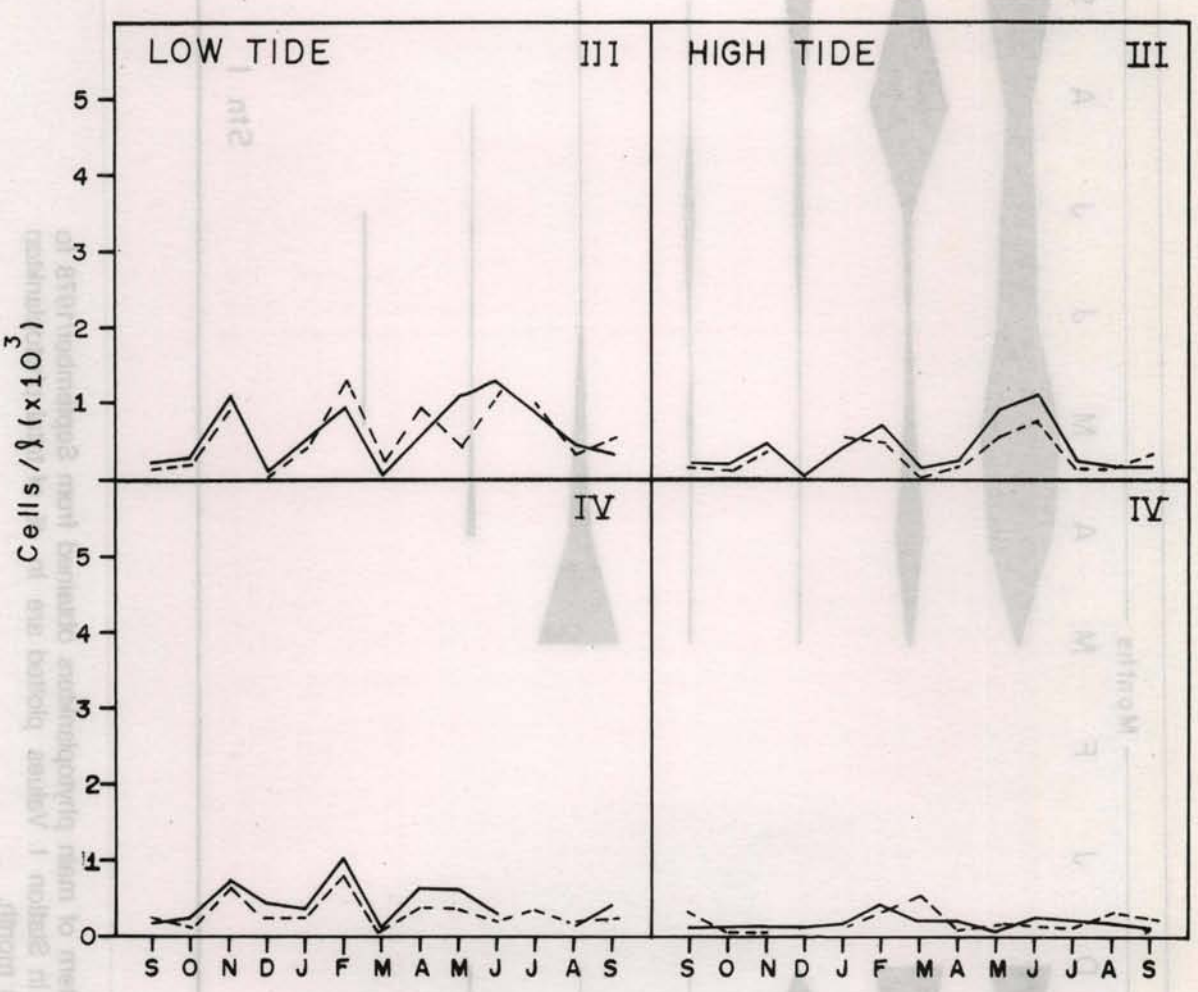

Fig. 10. Seasonal variation of surface (—) and bottom (- - -) total phytoplankton in Stations III and IV.

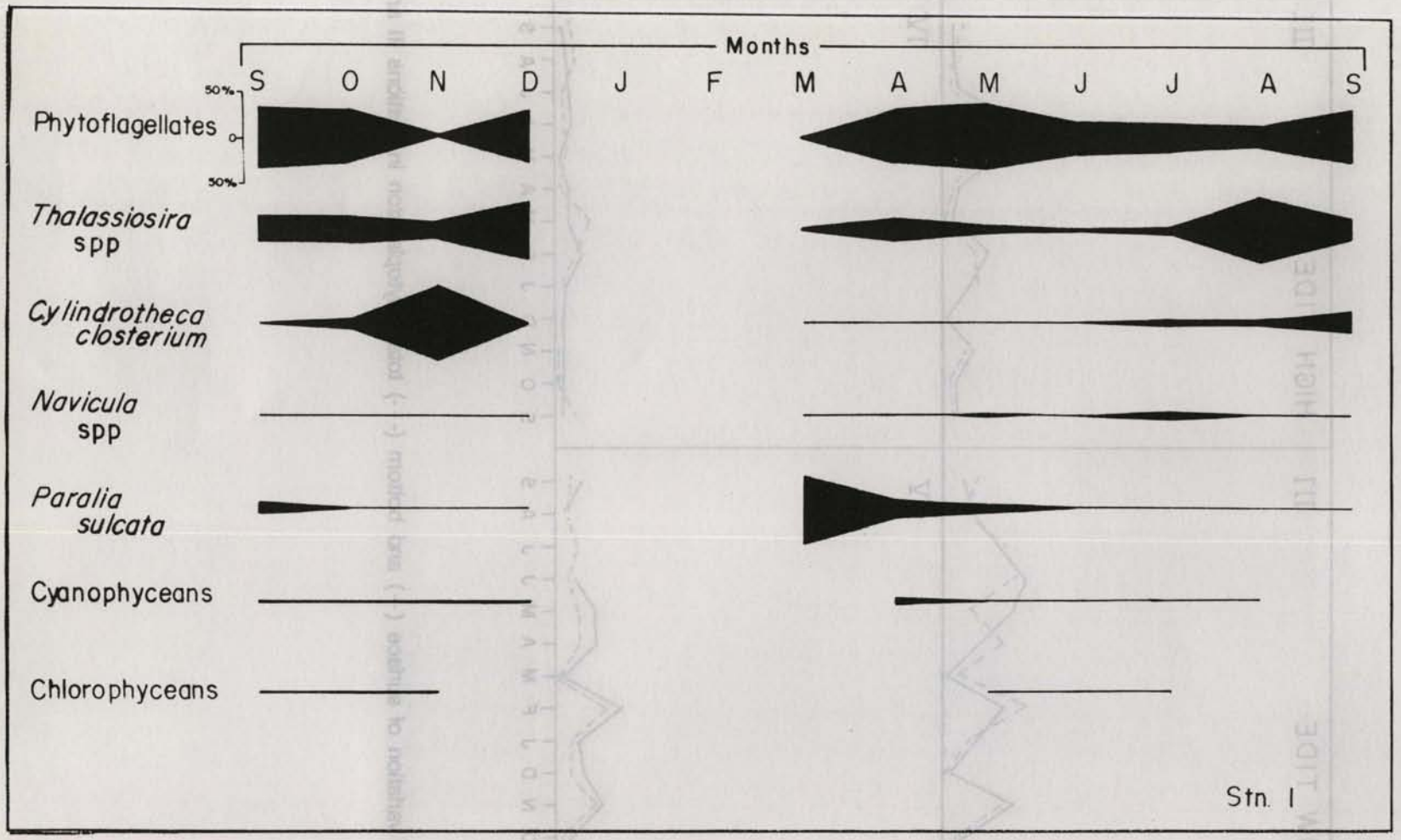

Fig. 11. Successional pattern of main phytoplankters obtained from September/1978 to September/1979 in Station I. Values plotted are in % of total phytoplankton observed in each month.

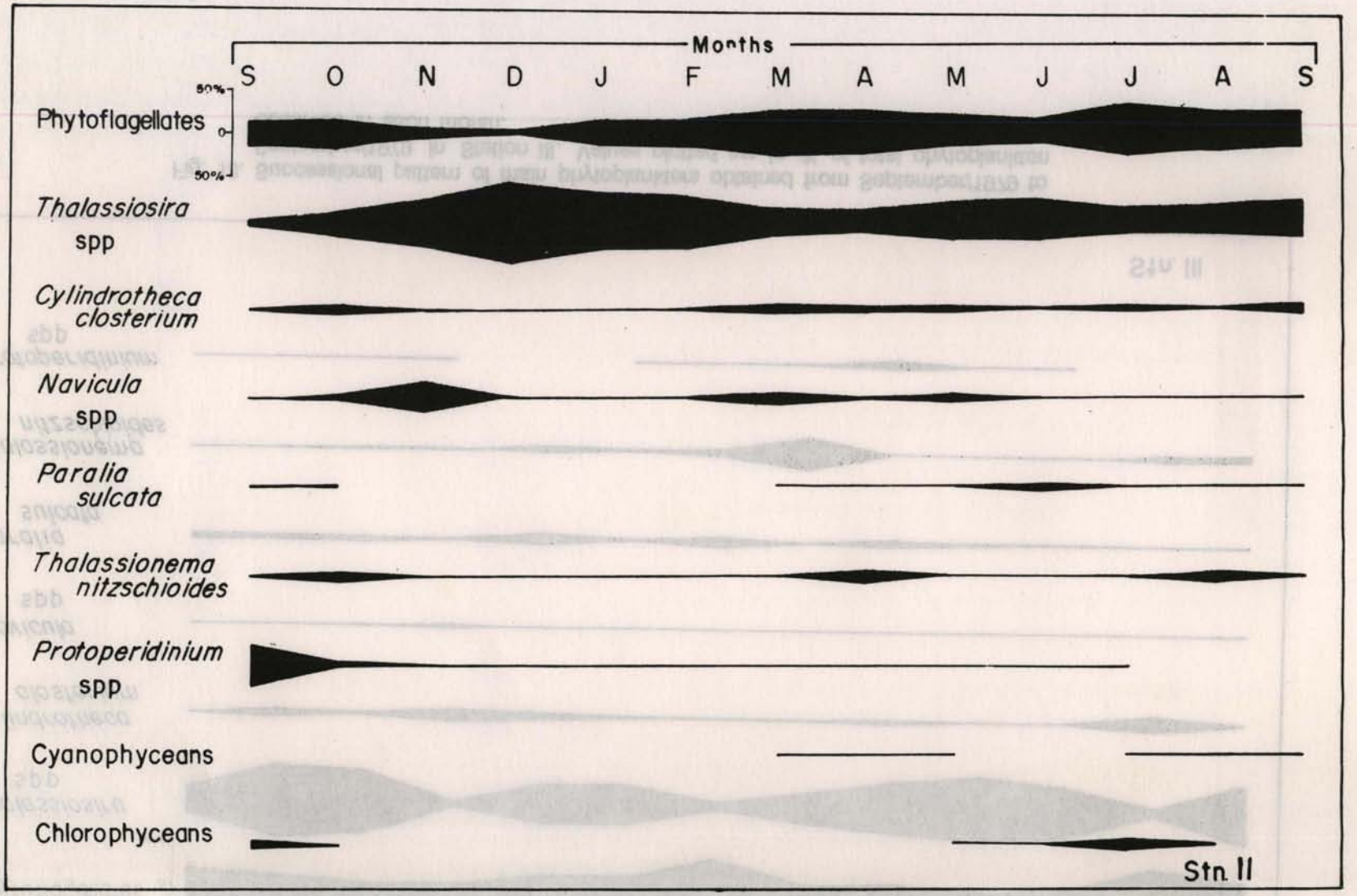

Fig. 12. Successional pattern of main phytoplankters obtained fom September/1978 to September/1979 in Station II. Values plotted are in % of total phytoplankton observed in each month.

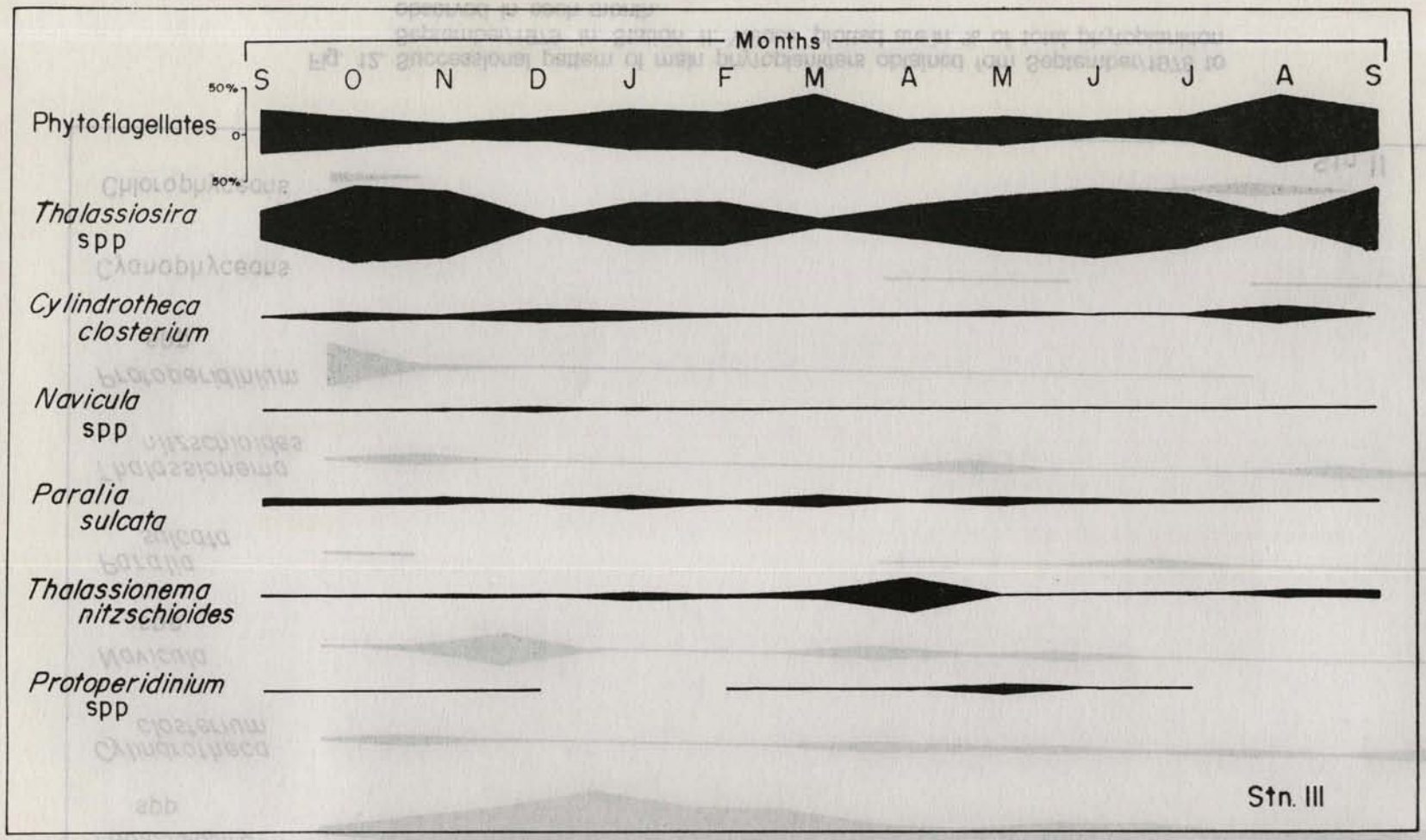

Fig. 13. Successional pattern of main phytoplankters obtained from September/1979 to September/1979 in Station III. Values plotted are in % of total phytoplankton observed in each month.

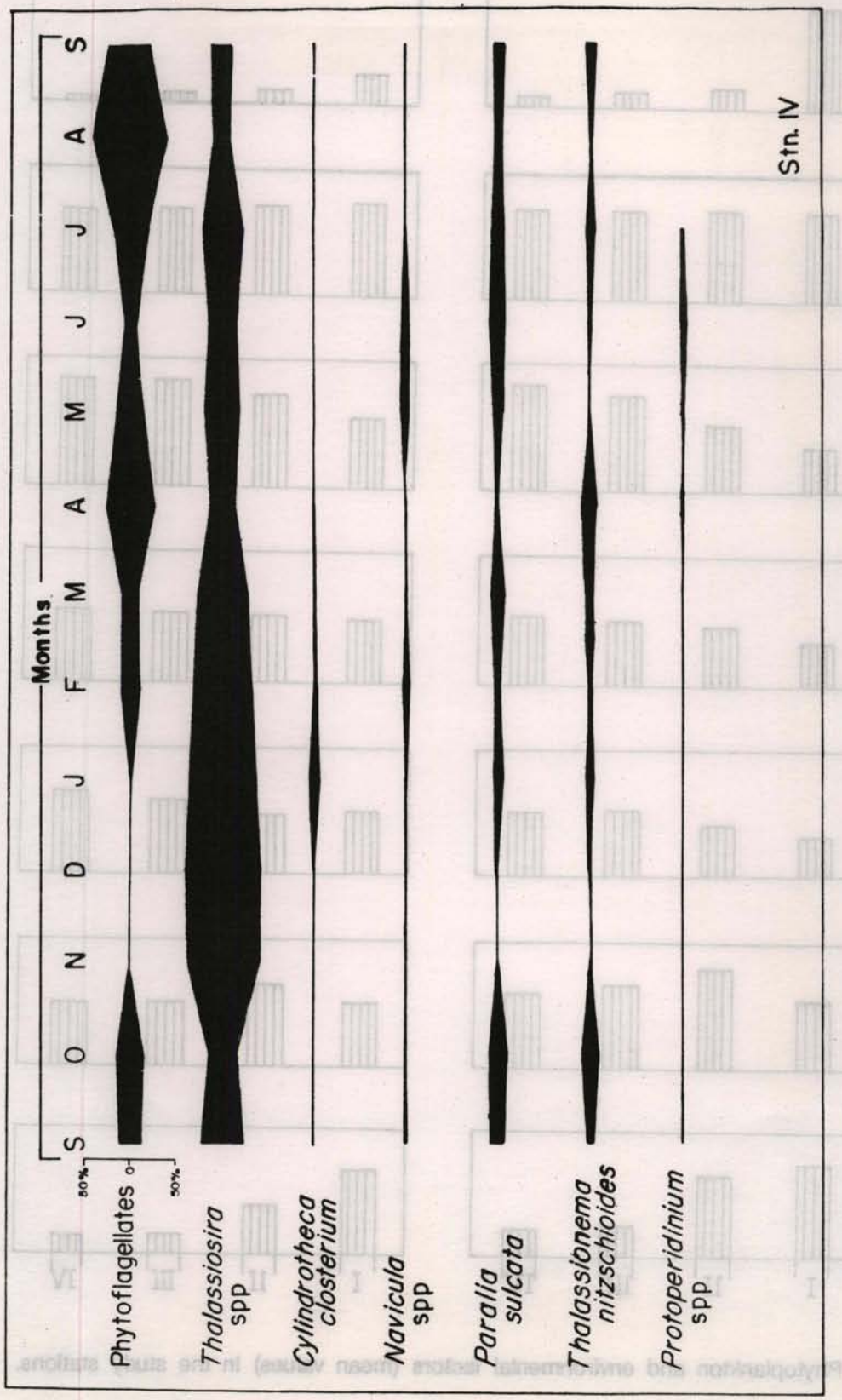

Fig. 14. Successional pattern of main phytoplankters obtained from September/1978 to September/1979 in Station IV. Values plotted are in % of total phytoplankton observed in each month.

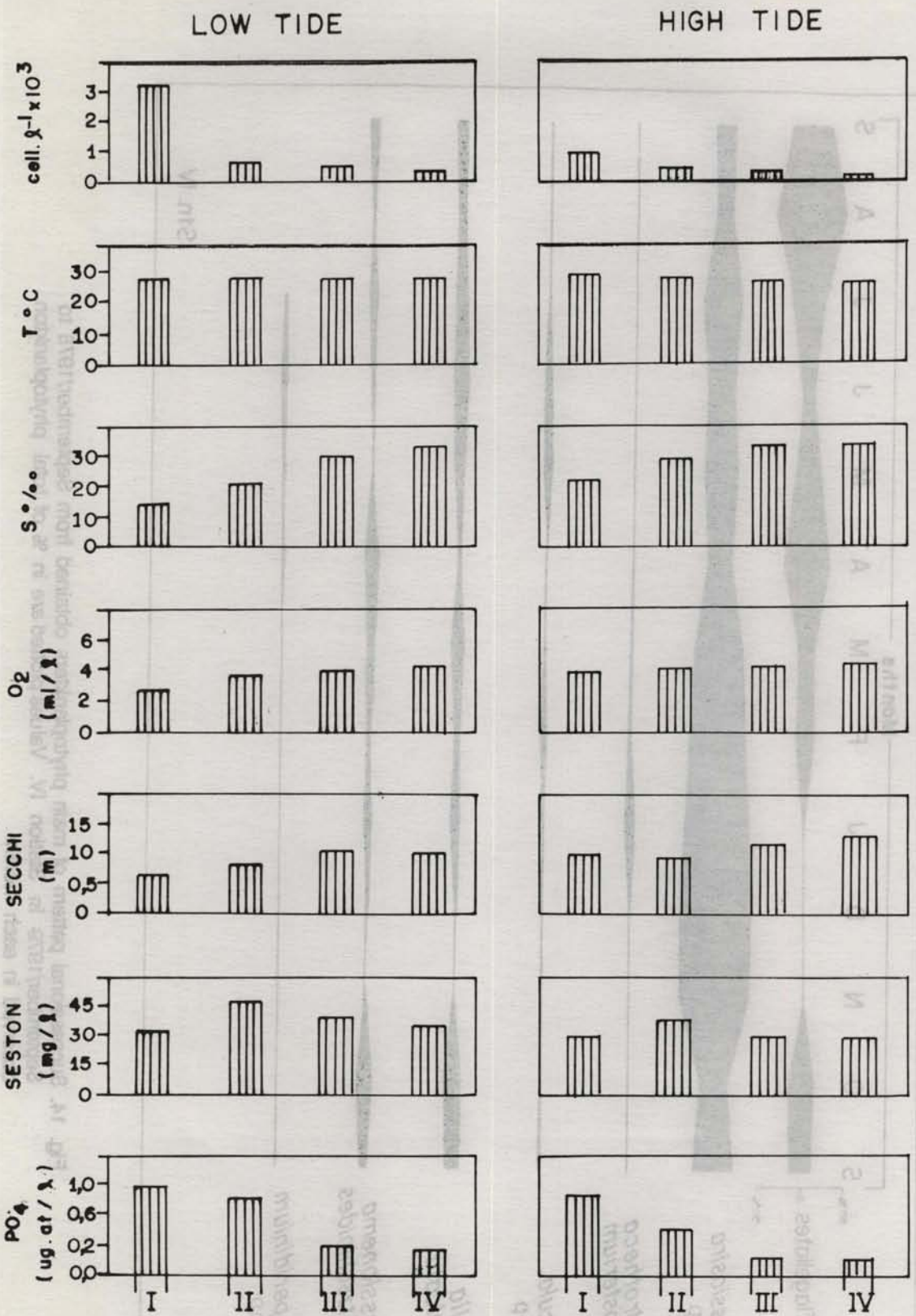

Fig. 15. Phytoplankton and environmental factors (mean values) in the study stations.

Although maximum standing stocks were always observed in the upper portion of the Paraiba River Estuary, no regular seasonal pattern of phytoplankton growth, commom for all stations surveyed, was observed during the study period. Between April and August (rainy months), cells number was low in Stations I (bottom) and II (surface and bottom), high in Station III and nearly of the same magnitude, as the other months, in Station IV. Spatial differences regarding maximum phytoplankton during the rainy season has also been reported by Brandini (1985a) for the Bay of Paranaguá (southeastern Brazil).

The low cell densities obtained at the two upper stations during the rainy months are largely due to bad light conditions for the phytoplankton development, as turbidity is increased by the continental runoff. During these months higher values of suspended material were observed at Stations I (both tides) and II (high tide), and low water transparency were registered for both stations at any tidal level. Light penetration is also affected by dissolved organic compounds (e.g., humic acids) which is abundant in the freshwater inputs. The reduced light penetration into the water of inner tropical estuarine areas due to continental runoff has also been reported by Qasim *et al.* (1969), Brandini (1985a) and Feitosa (1988).

When the runoff decreases, the higher water transparency increases the phytoplankton standing stock in the water column of the inner stations. This was observed in November 1978 (Stations I and II, both tides), December 1978 and January, 1979 (Station II, high tide) and August and September 1979 (Station I, low tide) (Fig. 9). In the other hand, during periods of high precipitation the maximum abundance of phytoplankton standing stock is displaced outward as observed at Station III (Fig. 10). Nevertheless, as water transparency is a function of rainfall and land drainage it could be expected to have light-limited phytoplankton near the sea, in years with most rainy periods. No relationships was observed between cell numbers at Station IV and rainfall regime, as the outermost areas are less affected by the continental runoff.

Except temperature, the other environmental parameters varied spatially and daily. However, surface and bottom values were not different, i.e., no vertical stratification was observed. This suggests the higher marine influence upon this ecosystem during the study period. Indeed, most of phytoplankton species found along the estuary were marine forms.

A clear inverse relationship was observed between cell number and salinity. Similar results has been also reported by Teixeira & Kutner (1963); Teixeira *et al.*, (1965); Qasim *et al.*, (1969); Devassy & Battathiri (1974) and Brandini (1985a).

The maximum cell densities observed in the upper stations may be partially explained by the enrichment due to sewage inflow near this region. Sewage also influences water transparency and dissolved oxygen.

During ebb tides tongues of sewage with different concentrations of nutrient salts and suspended and dissolved materials are displaced seawards and may be irregularly distributed along the estuarine axis by tidal mixing. This could intervene in the light conditions and in the growth of opportunistic species and could contribute to the monthly differences in the standing stock (for total phytoplankton and the dominant organisms) observed for each station.

The spatial differences in phytoplankton densities, during the study period, could also be supported by the occasional or most persistent flourishments of some phytoplankters as those observed for *Cylindrotheca closterium* and *Paralia sulcata* at Station I (Fig. 11), *Navicula* spp, *Thalassionema nitzschioides* and *Protoperidinium* spp at Station II (Fig. 12), *Cylindrotheca closterium*, *Paralia sulcata* and *Thalassionema nitzschioides* at Station III (Fig. 13) and *Paralia sulcata* and *Thalassionema nitzschioides* at Station IV (Fig. 14).

During the study period the unidentified phytoflagellates and the diatoms *Thalassiosira* spp dominated the phytoplankton population. They are certainly opportunistic, forming dense blooms in connection with adequate environmental conditions. *Thalassiosira* spp were also the most important phytoplankters in coastal reefs of the Northeast Brazil (Sassi, 1987). Cortes-Altamirano & Pasten-Miranda (1982) also has registered concentrations of *Thalassiosira* spp of up to 6,200,000 cells/l, in the Urias estuary, Mexico, during summer season. In the present study short chains of small and larger (most hyaline) cells of *Thalassiosira*, and also specimens frequently associated with mineral particles were observed. Nevertheless, the nanoplanktonic specimens predominated.

The dominance of phytoflagellates has been reported in other estuarine or neritic environments along the Brazilian coast (Kutner, 1972; Tundisi *et al.*, 1973; Eskinazi-Leça & Koening, 1981; Sassi & Kutner, 1982; Brandini, 1985a,b; Sassi, 1987). These organisms belong to the nanoplanktonic size categories and therefore are very difficult to be identified with optical microscopy. They were mainly formed by Chryptophycean-like cells (more abundant in the near sea stations), "rounded" flagellated cells of several size, resembling Chlorophyceans and Dinophyceans (irregularly distributed along the estuary) and Euglenophycean-like cells, more abundant in the upper stations during the rainy season.

The dominance of nano-size cells in the Paraíba do Norte River estuary seems to indicate that the growth of large cells is limited by any environmental or biological factor. In the study region, some diatoms (*Biddulphia Coscinodiscus*, etc.) were abundant during the rainy months (Singarajah, 1978), but the small cells always dominated during the entire period of observation. This finding contrasts with other estuarine systems, where seasonal dominance of microplanktonic cells was evident (e.g. Durbin *et al.*, 1975).

It seems to be a general assumption that nanoplankton are the prevalent forms in impoverished waters (Malone, 1971; Garrison, 1976), probably a consequence of the lower half saturation constant (Ks) and lower maximum uptake constant (Vmax) of small species, when compared with the values of large species (Dugdale, 1967; Eppley *et al.*, 1969). Presumably this is a consequence of increases in the surface area-to-volume ratio as cell size decreases (Munk & Riley, 1952).

The dominance of diminute cells in eutrophic environments, as found during this study, seems to disagree with the upper consideration and seems to suggest that in some circumstances they have a higher growth rates than

those of most impoverished waters. This hypothesis may be supported by differences in Ks values of small species occurring in rich as well as in poor waters. Regarding this aspect Carpenter & Guillard (1971) and Guillard *et al.* (1973) have demonstrated that small oceanic diatoms showed lower Ks values, respectively for nitrate and silicate, than estuarine clones of the same species. Recently, Olsen & Paasche (1986) also were able to demonstrate that the small diatom *Thalassiosira pseudonana* presents a higher Ks for Si uptake when cultured in freshwater medium with high concentrations of $SiOH_4$ than when in seawater medium, with low concentrations of that compound. Despite these interesting findings, further comparative studies about nutrient uptake kinetics and seasonal dynamics (in connection with environmental factors) of nanoplanktonic autotrophs need to be carried out in estuarine, coastal and shelf waters to test this hypothesis under natural conditions and to explain the dominance of diminute cells in such apparently rich estuarine system.

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