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Research Article

Microphytoplankton composition, chlorophyll-*a* concentration and environmental variables of the Maranhão Continental Shelf, Northern Brazil

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ABSTRACT. The distribution of phytoplankton in a coastal gradient located in the pelagic area of the Maranhão continental shelf was analyzed. Samples were collected in six bimonthly campaigns with seven sampling stations from November 2013 to September 2014. Simultaneously, environmental parameters were obtained, such as rainfall, salinity, conductivity, pH, dissolved oxygen, suspended particulate matter (SPM), water temperature, water transparency, nitrite, phosphate and silicate concentrations. The values of SPM showed a decreasing profile toward the ocean. The nutrients showed a clear seasonal cycle. The pH maintained alkaline during all the study period. There was an increase in electrical conductivity in direction of the ocean, the same pattern was observed for salinity. Chlorophyll-*a* concentration presented the highest values during the dry season and the lowest in the rainy one. The total chlorophyll-*a* also showed a decreasing profile toward the ocean in both dry and rainy season and was very low if compared with other studies in northern Brazil. The scenario observed in this study showed a clear seasonal cycle, with the highest contribution of the phytoplankton in the dry period; also it was observed the predominance of the Bacillariophyta division over the other identified divisions found, based on the obtained qualitative data.

Keywords: phytoplankton, distribution, seasonal cycle, algal biomass, chlorophyll-*a*, northern Brazil.

Composición de microfitoplancton, concentración de clorofila-*a* y variables ambientales en la plataforma continental de Maranhão, norte de Brasil

RESUMEN. Se analizó la distribución de fitoplancton en un gradiente costero situado en la zona pelágica de la plataforma continental del Maranhão. Las muestras se colectaron en seis campañas bimestrales con siete estaciones de muestreo entre noviembre 2013 y septiembre 2014. Simultáneamente, se obtuvieron diferentes parámetros ambientales, como pluviosidad, salinidad, conductividad, pH, oxígeno disuelto, material particulado en suspensión (MPS), temperatura, transparencia y concentraciones de nitrito, fosfato y silicato. Los valores de MPS mostraron un perfil decreciente en dirección al océano. Los nutrientes mostraron un claro ciclo estacional. El pH se mantuvo alcalino durante todo el período de estudio. Se determinó un aumento en la conductividad eléctrica en dirección al océano y un patrón similar se observó para la salinidad. La concentración de clorofila-*a* presentó los valores mayores durante la estación seca y los menores en la lluviosa. La clorofila-*a* total también mostró un perfil decreciente en dirección al océano en las estaciones seca y lluviosa, y fue muy baja en comparación con otros estudios realizados en el norte de Brasil. El escenario observado en este estudio mostró un claro ciclo estacional, con la mayor contribución de fitoplancton en el período seco; también se determinó el predominio de la división Bacillariophyta sobre las otras divisiones identificadas, según los datos cualitativos obtenidos.

Palabras clave: fitoplancton, distribución, ciclo estacional, biomassa algal, clorofila-*a*, norte de Brasil.

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INTRODUCTION

The continental shelf of Maranhão has a quite varied coastline: in the west the coast is indented by numerous "false rivers" named “Reentrâncias Maranhenses”: in the east the coast is linear, formed by dune fields, and these two coastal physiographies are divided by the Maranhense Gulf, with a wide opening (100 km) to the Atlantic Ocean (Pontes & El-Robrini, 2008). The coastal zone of the Amazonian states of Amapá, Pará, and Maranhão encompasses more than a third of the 7,400 km long coastline of Brazil (Isaac & Barthem, 1995). This region is characterized by complex hydrodynamic processes resulting from the action of winds and currents (Nittrouer & DeMaster, 1996) and the discharge of freshwater, with solutes and suspended particulate material from the Amazon, Tocantins (Smith & Demaster, 1996) and Maranhão rivers.

As primary producers of the ocean, phytoplankton play significant roles in regulating the marine ecosystem and global carbon cycle by photosynthesis and thus providing energy for other organisms (Falkowski & Woodhead, 1992). Due to the strong interaction between land and ocean, the physical and chemical environment of continental shelves tends to be highly variable both spatially and temporally, which greatly contributes to the complexity of phytoplankton communities in these areas (Zhu *et al.*, 2009).

In tropical marine waters, the phytoplankton communities consist of autotrophic, heterotrophic and mixotrophic organisms of variable size. While diatoms dominate in terms of the species diversity in coastal and shelf regions, their relative importance is gradually reduced toward the open ocean, where the contribution of dinoflagellates increases significantly (Fernandes & Brandini, 2004). On continental shelves, the contribution of nanoplanktonic haptophytes is also important (Simon *et al.*, 2009). In open seas, picoplankton (primarily consisting of cyanobacteria and small eukaryotes) dominate both the photosynthetic biomass and production (Vaulot *et al.*, 2008).

Despite the potential economic importance of the phytoplankton community, and its unique hydrodynamic characteristics, few data are available for the distribution of phytoplankton in the continental shelf in northern Brazil and incipient in the state of Maranhão. The present study aimed to evaluate the spatial and temporal distribution in the structure (microphytoplankton composition, occurrence frequency and biomass) of the phytoplankton community, the environmental parameters and the seasonality of the region in a coastal gradient located in the pelagic area of the Maranhão continental shelf.

MATERIALS AND METHODS

Description of the area

The Maranhão continental shelf is located between 01°01'-02°36'S and 41°48'-48°40'W, extending from the mouth of the Gurupi River (Pará State) to the mouth of the Parnaíba River (Piauí State) (Pontes & El-Robrini, 2008). The pelagic productivity of the northern shelf Brazil is low compared to the other Brazilian shelf areas. The availability of nutrients for the maintenance of the plankton community in its coastal region is due to the continental drainage, benthic regeneration (Yoneda, 1999), and the influence of estuaries that maintain direct contact with the coastal zone (Day *et al.*, 1989).

The study area is located on the west bank of the Equatorial Atlantic region, where occurs great part of the transport of heat and mass between the hemispheres (Stramma *et al.*, 2003, 2005). This equatorial Atlantic region is under the influence of the spatial and temporal variability of the Intertropical Convergence Zone, ITCZ (Silva *et al.*, 2007). Thus, rain is observed more often during the months from January to June, a period in which the ITCZ is found in a position further south, reaching the coastal and oceanic area. On the other hand, the months from September to November are marked by lower rainfall rates.

Samples were taken every two months between November 2013 and September 2014, during the dry season (November 2013, July 2014, September 2014) and rainy (January 2014, March 2014, May 2014) at fixed stations: (MA1, MA2, MA3, MA4, MA5, MA6 and MA7) with distance from the coast as follows: 0.5, 10, 20, 30, 40 and 50 nautical miles, following a profile towards the break of the continental shelf (Fig. 1).

Sampling

Field work

The subsurface water samples were obtained with Van Dorn bottles (2 L) for nutrient analysis and determination of chlorophyll-*a*. Estimates of water transparency *in situ* were obtained using the Secchi disk. At each sampling station a profiling was carried out of the subsurface water column with a Castway CTD (conductivity, temperature and depth), in order to obtain depth data, temperature, salinity and conductivity. The pH value was determined *in situ* at the subsurface water column with the aid of a multi-parameter probe Hanna HI 9828, with accuracy of ±0.02.

For the qualitative analysis of microphytoplankton horizontal hauls were taken in the subsurface by plankton net with mesh size of 20 µm. Samples were

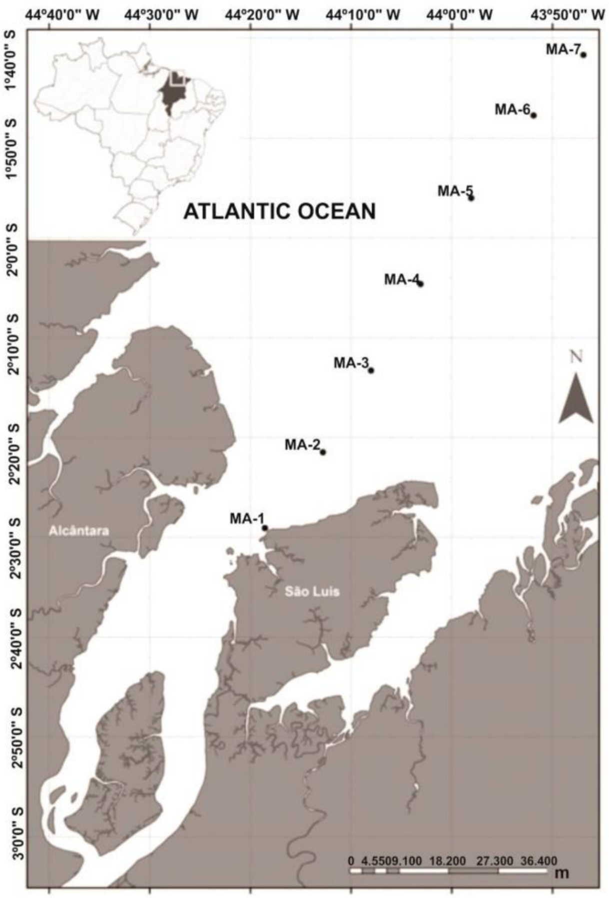

Figure 1. Study area of the Maranhão continental shelf, São Luís-MA. Source: INCT AMBTROPIC-CNPq.

transferred to plastic bottles and on board immediately fixed in formaldehyde (4%), buffered with sodium tetraborate.

Phytoplankton was analyzed in terms of chlorophyll-*a* by collecting 2 L of water in the subsurface. The samples were placed on frosted flasks and were immediately filtered through Whatman GF/C glass fibre filters (particulate retention efficiency of 1.2 µm and 47 mm of diameter). For each collection station, replicas were made using a volume of 150 mL. To obtain the fractional values of chlorophyll-*a*, water subsamples were passed through a PVC tube with a 20 µm mesh, to separate different fractions of the phytoplankton community (>20 µm microphytoplankton and <20 µm nano/picophytoplankton) and then filtered. After drying, the filters were kept in a freezer at -18°C until analysis.

Laboratory analysis

The dissolved oxygen was determined by the chemical method of Winkler according to Strickland & Parsons (1972). The turbidity was determined through Tecnopon TB-1000 turbidimeter, previously calibrated, presenting the range 0-1100 NTU with an accuracy of ±2% or 0.05 to readings below 100 NTU. The concentrations of nitrite, phosphate and silicate were determined by the method of Grasshoff *et al.* (1999). The suspended particulate matter (SPM) was analyzed according to APHA (2012). Qualitative phytoplankton analyses were performed from the preparation of semi-permanent and permanent blades according to the Müller-Melchers & Ferrando (1956) method for taxonomic identification with an optical microscope. The taxonomic identification, in optical microscope, was realized with a specialized bibliography (Anagnostidis & Komárek, 1988; Komárek & Anagnostidis, 1989; Licea *et al.*, 1995; Moreno *et al.*, 1996). The taxonomic classification of diatoms was made according to Round *et al.* (1992), the classification of dinoflagellates according to Tomas (1997), and of cyanobacteria according to Anagnostidis & Komárek (1988).

Filters were placed in test tubes to extract chlorophyll pigments, adding 10 mL of 90% acetone to each tube. After a rest of 24 h the material was centrifuged and the supernatant placed in glass cuvettes with 10 mm optical path. The determination of the chlorophyll-*a* was performed using a fluorometer TD-700 (Turner Designs), calibrated with pure chlorophyll (Sigma® C-6144). The estimated detection limit (EDL) was 0.04 mg m^{-3}. The equation presented by Arar & Collins (1997) was applied for chlorophyll estimations (mg m^{-3}).

Statistical analysis of the data

The analysis of the frequency of occurrence (%) was calculated using the formula: Fo = (Ta x 100) / TA (Fo: frequency of occurrence; Ta: number of samples in which taxon occurs; TA: total number of samples). To estimate the frequency of occurrence of each taxon the scale Neumann-Leitão (1994) was used, considering occurrences >70% very frequent; 70-40% frequent; 40-10% low frequency; <10% sporadic.

After standardizing all data, the Principal Component Analysis (PCA) was performed in order to verify the correlation between physical, chemical and biological parameters, using the software Statistica 7.0. The data of rainfall were granted by the National Institute of Meteorology (INMET).

RESULTS

Environment variables

The amounts of precipitation showed a clear seasonal cycle. The rainy season (January/June) showed mean values of 445.13 ± 343.81 mm and the dry period

(July/December) showed mean values of 30.87 ± 39.84 mm.

Physical and chemical variables

A growing profile toward the ocean was observed in all campaigns for the water transparency, with overall mean of 5.64 ± 1.88 m in the rainy season, while in the dry season was 4.91 ± 1.75 m The average depths in each station were: 11m/MA1, 17m/MA2, 27m/MA3, 43m/MA4, 34.4m/MA5, 25m/MA6 and 47m/MA7, respectively (Table 1).

Dissolved oxygen levels showed overall mean values of 4.26 ± 0.31 mg L^{-1} in the rainy season, while in the dry season showed 4.41 ± 0.22 mg L^{-1}. The highest values were observed during the dry season while the lowest values were observed in the rainy season. The turbidity of the water showed a decreasing profile toward the ocean, with overall mean values of 15.51 ± 10.45 NTU in the rainy season, while in the dry season was 12.97 ± 11.99 NTU (Table 1).

The pH maintained alkaline during all the study period and showed overall mean values of 8.01 ± 0.23 in the rainy season, and in the dry season of 8.03 ± 0.28. The values of SPM showed a decreasing profile toward the ocean, with overall mean values of 23.37 ± 14.93 mg L^{-1} in the rainy season, while in the dry season of 35.94 ± 32.61 mg L^{-1}. The temperature of the water remained stable throughout the study with overall mean values in the rainy season of 29.01 ± 0.47ºC, while in the dry season 28.24 ± 0.43ºC (Table 1).

The electrical conductivity overall mean values of the Maranhão continental shelf were 53.53 ± 5.51 µS cm^{-1} in the rainy season, and 52.68 ± 2.85 µS cm^{-1} in the dry season. Overall mean values of salinity were 35.04 ± 2.58 in the rainy season, and 34.16 ± 1.60 in the dry season (Table 1). There was an increase in electrical conductivity in direction of the ocean, the same pattern was observed for salinity.

Nutrients

Overall mean concentrations of nitrite of the Maranhão continental shelf showed results of 0.06 ± 0.05 µmol L^{-1} in the rainy season, while in the dry season showed 0.15 ± 0.19 µmol L^{-1} (Table 2). Their major contri-butions were in the dry season, and their highest values towards the coast. Conversely, the lowest values were recorded towards the ocean mostly in the rainy season. Phosphate overall mean values were 0.23 ± 0.27 µmol L^{-1} in the rainy season, and 0.35 ± 0.21 µmol L^{-1} in the dry season (Table 2). The highest phosphate values were observed in the first stations during the dry season, while in the rainy season the lowest values were observed in the first stations. The silicate overall mean values were 4.75 ± 1.82 µmol L^{-1} in the rainy season, and 3.73 ± 1.66 µmol L^{-1} in the dry season (Table 2). The silicate concentrations also showed a decreasing profile toward the ocean in both dry and rainy season.

Microphytoplankton composition

The microphytoplankton community was represented by 128 generic and infrageneric taxa, distributed in three divisions, five classes, twenty-four orders, thirty-six families, forty-seven genera and two varieties. The division showing the highest percentage of species was Bacillariophyta, representing 86.7%, followed by Dinophyta with 12.5% and Cyanophyta with 0.8%. The Table 3 shows the predominant species in this study.

Of the 128 identified species, the highest percentage (fifty-six species, 43%) was classified as sporadic, distributed among the Bacillariophyta divisions (50 species), Dinophyta (4 species), and Cyanophyta (2 species). For the category of low frequency 38 species (30%) have been found, belonging to the Bacilla-riophyta division (33 species) and the Dinophyta division (5 species). The category frequent was represented by 20 species (15%), followed by very frequent with 13 species (12%). The diatoms species occurring in all stations were *Bacteriastrum delicatulum* Cleve, *Bacteriastrum furcatum* Shadbolt, *Bellerochea malleus* (Brightwell) Van Heurck, *Chaetoceros affinis* Lauder, *Chaetoceros compressus* Lauder, *Chaetoceros peruvianus* Brightwell, *Coscinodiscus granii* L. F. Gough, *Coscinodiscus jonesianus* (Greville) Ostenfeld, *Coscinodiscus radiatus* Ehrenberg, *Coscinodiscus rothii* (Ehrenberg) Grunow, *Paralia sulcata* (Ehrenberg) Cleve, *Odontella mobiliensis* (J. W. Bailey), *Odontella regia* (Schultze) and *Thalassiosira nitzschioides* (Grunow) Mereschkowsky. The microphytoplankton composition in transect of the Maranhão continental shelf showed the highest representation during the dry season and a lower one in the rainy period. This may be explained by the nutrient input arriving from the continent, which is observed in the study area.

Chlorophyll-*a* concentration

The chlorophyll-*a* (chl-*a*) concentration showed a clear seasonal cycle. The total chl-*a* presented the lowest values during the rainy season and the highest in the dry one, with overall mean values of 0.008 ± 0.007 mg m^{-3} in the rainy period, and in the dry period of 0.014 ± 0.018 mg m^{-3} (Table 4). The total chl-*a* also showed a decreasing profile toward the ocean in both dry and rainy season. For fractional chl-*a*, the predominance of nano/picophytoplankton was noted in the dry season too, with overall mean values of 0.005 ± 0.004 mg m^{-3}, while in the rainy season of 0.005 ± 0.005 mg m^{-3}. The same was noted in the microphytoplankton, which pre-

Table 1. Mean values, standard deviation and overall mean (OM) of abiotic data from transect of the continental shelf in the seven sampling stations during the rainy (January to May / 2014) and dry season (November 2013 to July and September 2014). São Luís-MA, Brazil. SPM: suspended particulate matter.

Stations	Transparency (m)	DO (mg L^{-1})	Turbidity (NTU)	pH	SPM (mg L^{-1})	Temperature (ºC)	Conductivity (µS cm^{-1})	Salinity
Rainy period								
MA1	0.27 ± 0.14	4.25 ± 0.10	53.00 ± 19.75	7.80 ± 0.20	118.0 ± 39.23	29.34 ± 0.66	49.05 ± 8.80	31.54 ± 4.46
MA2	0.74 ± 0.55	4.20 ± 0.26	36.53 ± 37.74	7.97 ± 0.12	61.73 ± 36.64	28.69 ± 0.84	50.05 ± 8.44	32.96 ± 3.09
MA3	4.66 ±1.73	4.41 ± 0.43	5.30 ± 3.40	8.09 ± 0.33	30.93 ± 36.75	28.90 ± 0.59	54.39 ± 4.66	34.91 ± 2.65
MA4	5.83 ± 1.54	4.49 ± 0.44	3.83 ± 2.99	7.92 ± 0.19	26.60 ± 32.48	29.26 ± 0.63	54.94 ± 5.42	35.39 ± 3.09
MA5	7.90 ± 2.75	4.26 ± 0.30	3.25 ± 3.11	8.06 ± 0.26	0.67 ± 1.15	29.30 ± 0.63	56.37 ± 3.70	36.40 ± 1.64
MA6	8.63 ± 3.11	4.06 ± 0.24	3.06 ± 2.96	8.09 ±0.26	23.20 ± 35.04	29.11 ± 0.21	57.00 ± 3.00	37.01 ± 1.27
MA7	11.28 ± 3.62	4.15 ± 0.41	3.59 ± 3.23	8.12 ± 0.23	8.93 ± 11.15	28.54 ± 0.46	52.88 ± 4.58	36.82 ± 1.31
O M	5.64 ± 1.88	4.26 ± 0.31	15.51 ± 10.45	8.01 ± 0.23	23.37 ± 14.93	29.01 ± 0.47	53.53 ± 5.51	35.04 ± 2.58
Dry period								
Stations	Transparency (m)	DO (mg.L^{-1})	Turbidity (NTU)	pH	SPM (mg.L^{-1})	Temperature (ºC)	Conductivity (µS.cm^{-1})	Salinity
MA1	0.72 ± 0.94	4.49 ± 0.45	37.20 ± 28.65	7.96 ± 0.12	85.03 ± 68.27	28.63 ± 0.37	48.83 ± 5.26	31.51 ± 3.31
MA2	1.20 ± 1.03	4.47 ± 0.26	21.40 ± 17.42	8.08 ± 0.22	62.34 ± 48.17	28.32 ± 0.07	50.22 ± 4.99	32.47 ± 2.96
MA3	3.06 ± 1.03	4.42 ± 0.06	5.63 ± 2.95	7.98 ± 0.28	38.10 ± 31.59	28.91 ± 1.24	53.44 ± 2.39	34.78 ± 1.06
MA4	5.46 ± 0.24	4.22 ± 0.51	2.74 ± 3.49	8.07 ± 0.36	26.17 ± 31.85	28.41 ± 0.59	54.02 ± 1.25	35.48 ± 0.43
MA5	7.07 ± 2.76	4.34 ± 0.02	2.76 ± 3.65	8.06 ± 0.35	2.67 ± 4.62	28.16 ± 0.38	54.02 ± 1.75	35.20 ± 0.74
MA6	8.83 ± 2.51	4.42 ± 0.15	4.17 ± 3.50	8.02 ± 0.30	25.95 ± 32.87	27.81 ± 0.18	54.03 ± 1.95	35.23 ± 1.04
MA7	10.78 ± 1.07	4.53 ± 0.08	16.89 ± 24.25	8.02 ± 0.33	11.35 ± 10.93	27.46 ± 0.16	54.22 ± 2.34	35.12 ± 1.12
O M	4.91 ± 1.75	4.41 ± 0.22	12.97 ± 11.99	8.03 ± 0.28	35.94 ± 32.61	28.24 ± 0.43	52.68 ± 2.85	34.16 ± 1.60

Table 2. Mean values, standard deviation and overall mean (OM) of nutrients data from transect of the continental shelf in the seven sampling stations during the rainy (January to May / 2014) and dry season (November /2013 to July and September /2014). São Luís-MA, Brazil.

Station	Nitrite (µmol L^{-1})	Phosphate (µmol L^{-1})	Silicate (µmol L^{-1})
Rainy period			
MA1	0.18 ± 0.12	0.13 ± 0.03	12.87 ± 0.11
MA2	0.08 ± 0.25	0.10 ± 0.04	6.07 ± 3.92
MA3	0.04 ± 0.04	0.29 ± 0.36	3.50 ± 2.18
MA4	0.01 ± 0.02	0.29 ± 0.41	3.14 ± 2.56
MA5	0.03 ± 0.02	0.27 ± 0.34	2.47 ± 1.42
MA6	0.05 ± 0.09	0.24 ± 0.31	1.54 ± 0.61
MA7	0.02 ± 0.03	0.28 ± 0.39	3.64 ± 1.95
O M	0.06 ± 0.05	0.23 ± 0.27	4.75 ± 1.82
Dry period			
Station	Nitrite (µmol L^{-1})	Phosphate (µmol L^{-1})	Silicate (µmol L^{-1})
MA1	0.31 ± 0.29	0.63 ±0.26	9.84 ± 2.07
MA2	0.28 ± 0.25	0.55 ± 0.37	7.67 ± 2.49
MA3	0.11± 0.20	0.24 ± 0.21	1.85 ± 0.54
MA4	0.09 ± 0.12	0.19 ± 0.18	1.45 ± 0.35
MA5	0.02 ± 0.03	0.23 ± 0.13	1.89 ± 2.20
MA6	0.15 ± 0.25	0.33 ± 0.24	2.01 ± 2.27
MA7	0.10 ± 0.18	0.29 ± 0.12	1.42 ± 1.71
O M	0.15 ± 0.19	0.35 ± 0.21	3.73 ± 1.66

sented their highest values in the dry season, with overall mean of 0.005 ± 0.006 mg m^{-3}, and in the rainy season of 0.004 ± 0.003 mg m^{-3}; these concentrations also showed a decreasing profile toward the ocean (Table 4).

Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) with all parameters, obtained in the seven stations during the dry season, explained 36.40% of total variance in the dry season, presenting a negative correlation of the parameters transparency (-0.69), pH (-0.39) and DO (-0.31) with temperature (0.44), rainfall (12.18), turbidity (0.63), SPM (0.83), nitrite (0.38) and silicate (0.82). The second component explains about 20% of the total variance and has as main elements: chlorophyll-*a* (0.68) nano/picophytoplankton (0.71), microphyto-plankton (0.60) and phosphate (0.50), which were directly associated with: salinity (0.19), conductivity (0.10) and depth (0.02) (Fig. 2).

The PCA explained 40.41% of the total variance. It can be interpreted as a contrast, appearing on one side the SPM (-0.90), nitrite (-0.72) and silicate (-0.85), which are correlating negatively with pH (0.42), DO (0.60), phosphate (0.29), transparency (0.76), depth (0.77) and rainfall (0.18). The second component explains 21.7% of the total variance. It presents as main elements: chlorophyll-*a* (0.32), salinity (0.80), conduc-

Table 3. Predominant species along transect of the continental shelf during the rainy and dry season, São Luís-MA, Brazil.

Bacillariophyta	Dinophyta	Cyanophyta
Actinoptychus annulatus (G.C. Wallich) Grunow	*Ceratium carriense* Gourret	Genus *Geitlerinema*
A. aster J.J. Brun	*C. closterium* Perty	Genus *Oscillatoria*
A. minutus Greville	*C. contrarium* (Gourret) Pavillard	
A. parvus A. Mann	*C. declinatum* (Karsten) Jørgensen	
A. splendens (Shadbolt) Ralfs	*C. deflexum* (Kofoid) E.G. Jørgensen	
A. vulgaris Schumann	*C. furca* (Ehrenberg) Claparède & Lachmann	
Coscinodiscus centralis Ehrenberg	*C. fusus* (Ehrenberg) Dujardin	
C. gigas Ehrenberg	*C. horridum* (Cleve) Gran	
C. granii L.F. Gough	*C. longirostrum* Gourret	
C. jonesianus (Greville) Ostenfeld	*C. macroceros* (Ehrenberg) Vanhöffen	
C. oculus-iridis (Ehrenberg) Ehrenberg	*C. pentagonum* Gourret	
C. radiatus Ehrenberg	*C. tripos (*O.F. Müller) Nitzsch	
C. rothii (Ehrenberg) Grunow	*Podolampas palmipes* Stein	
Gyrosigma balticum (Ehrenberg) Rabenhorst	*Protoperidinium* sp.	
G. fasciola (Ehrenberg) J.W. Griffith & Henfrey		
G. hippocampus Hassall, nom. illeg.		
G. tenuissima (Strömfelt) Rosenvinge		
Odontella aurita (Lyngbye) Agardh		
O. dubia (Brightwell) Cleve		
O. longicruris (Greville) M.A. Hoban		
O. mobiliensis (J.W. Bailey) Grunow		
O. regia (Schultze) Simonsen		
O. sinensis (Greville) Grunow		
Thalassiosira eccentrica (Ehrenberg) Cleve		
T. leptopus (Grunow ex Van Heurck) Hasle & G. Fryxell		
T. lineata Jousé		
T. oestrupii (Ostenfeld) Hasle		
T. plicata H. J. Schrader		
T. simonsenii Hasle & G. Fryxell		
T. subtilis (Ostenfeld) Gran		

Table 4. Mean values, standard deviation and overall mean (OM) of total chlorophyll-*a*, nano/picophytoplankton (nano) and microphytoplankton (micro) concentrations along transect of the continental shelf during the rainy and dry season. São Luís-MA, Brazil.

Rainy period			
Station	Total Chlorophyll-*a* (mg m^{-3})	Nano (mg m^{-3})	Micro (mg m^{-3})
MA1	0.022 ± 0.017	0.002 ± 0.002	0.011 ± 0.011
MA2	0.013 ± 0.016	0.011 ± 0.013	0.002 ± 0.001
MA3	0.005 ± 0.005	0.010 ±0.012	0.005 ± 0.003
MA4	0.004 ± 0.003	0.003 ±0.002	0.001 ± 0.001
MA5	0.005 ± 0.002	0.003 ±0.002	0.002 ± 0.001
MA6	0.004 ± 0.002	0.002 ± 0.002	0.002 ± 0.001
MA7	0.005 ± 0.003	0.002 ± 0.001	0.003 ± 0.002
O M	0.008 ± 0.007	0.005 ± 0.005	0.004 ± 0.003
Dry period			
Station	Total Chlorophyll-*a* (mg m^{-3})	Nano (mg m^{-3})	Micro (mg m^{-3})
MA1	0.026 ± 0.035	0.010 ± 0.009	0.016 ± 0.027
MA2	0.046 ± 0.067	0.006 ± 0.003	0.006 ± 0.002
MA3	0.006 ± 0.006	0.004 ± 0.005	0.001 ± 0.001
MA4	0.006 ± 0.006	0.003 ± 0.002	0.008 ± 0.006
MA5	0.005 ± 0.004	0.005 ± 0.003	0.000 ± 0.000
MA6	0.007 ± 0.006	0.005 ± 0.002	0.002 ± 0.003
MA7	0.005 ± 0.002	0.004 ± 0.002	0.000 ± 0.001
O M	0.014 ± 0.018	0.005 ± 0.004	0.005 ± 0.006

tivity (0.79) and turbidity (0.03) correlating negatively with the temperature (-0.43) (Fig. 3).

DISCUSSION

Weather conditions have a considerable effect on hydrological variables, and thus on biological characteristics of pelagic and benthic organisms (Costa *et al.*, 2011). In tropical and subtropical regions the rainfall seems to be the major factor controlling the distribution and abundance of phytoplankton organisms (Lacerda *et al.*, 2004), since it modifies the availability of nutrients and the optical qualities of water (Bastos *et al*., 2005).

In the Maranhense region of the continental platform rainfall occurred within the expected pattern. According to Azevedo *et al.* (2008), the Maranhão coast presents a defined seasonal cycle, with a rainy season from January to June, with maximum rainfall in May, and a dry season from July to December. Similar values of the water temperature in the Maranhão continental shelf observed in this study were registered in previous studies by Pontes & El-Robrini (2008). These authors identified a pattern with higher temperature near the coast and lower values toward the ocean.

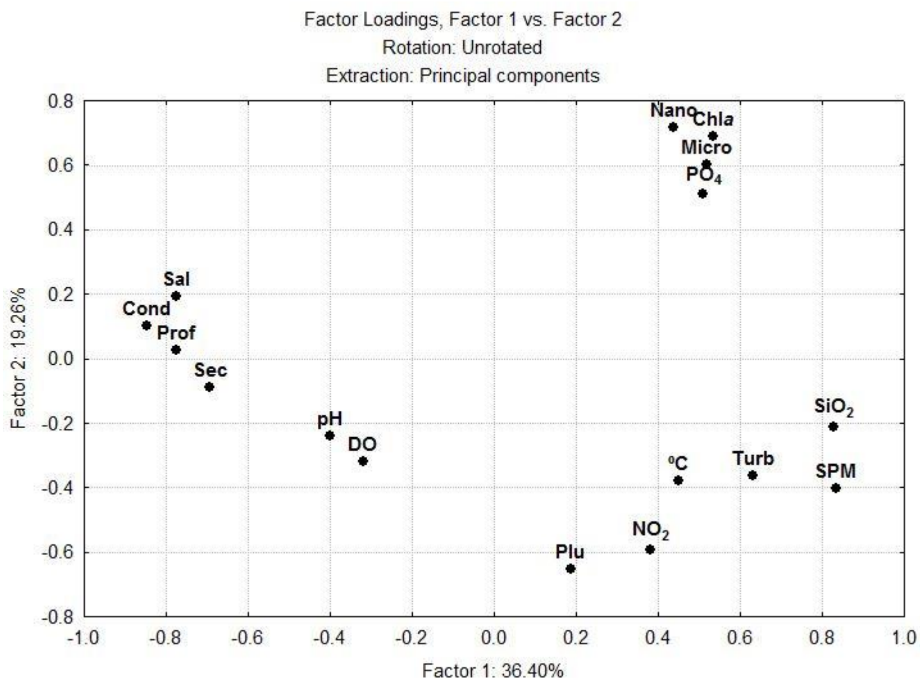

Figure 2. Two-dimensional projection of the PCA of the hydrogenionic potential (pH), salinity (Sal), dissolved oxygen (DO), temperature of water (°C), transparency-Secchi (Sec), depth-profundity (Prof), turbidity (Turb), suspended particulate matter (SPM), conductivity (Cond), nitrite (NO_2), phosphate (PO_4), silicate (SiO_2), chlorophyll-*a* concentrations (Chl-*a*), Nano/picophytoplankton (Nano), microphytoplankton (Micro), rainfall-pluviosity (Plu) in transect of the continental shelf, dry season. São Luís-MA, Brazil.

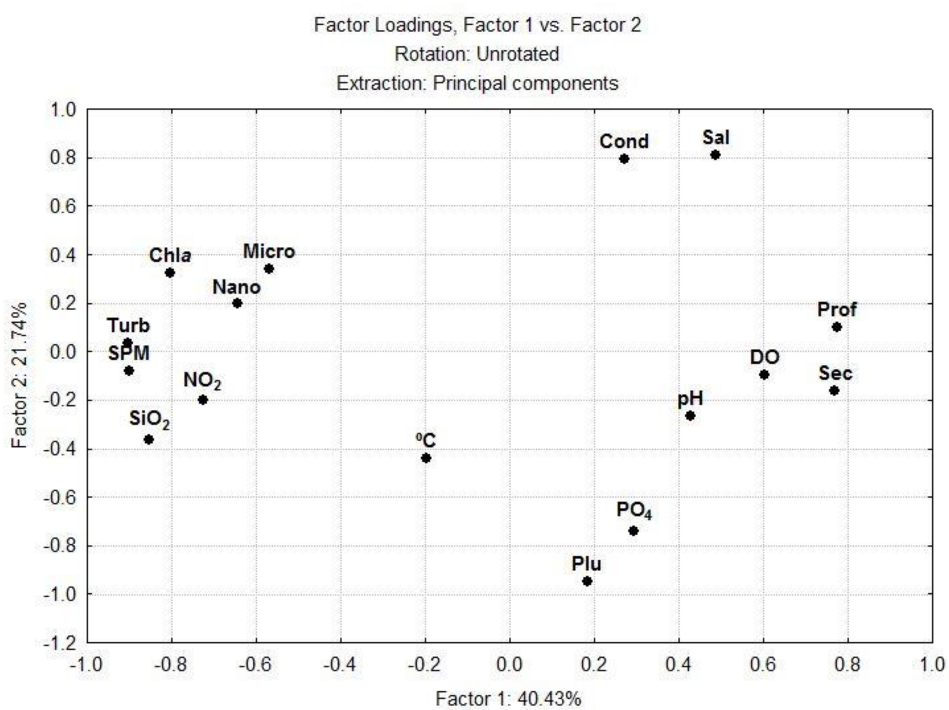

Figure 3. Two-dimensional projection of the PCA of the hydrogenionic potential (pH), salinity (Sal), dissolved oxygen (DO), temperature of water (°C), transparency-Secchi (Sec), depth-profundity (Prof), turbidity (Turb), suspended particulate matter (SPM), conductivity (Cond), nitrite (NO_2), phosphate (PO_4), silicate (SiO_2), chlorophyll-*a* concentrations (Chl-*a*), Nano/picophytoplankton (Nano), microphytoplankton (Micro), rainfall-pluviosity (Plu) in transect of the continental shelf, rainy season. São Luís-MA, Brazil.

The transparency, conductivity, and salinity of the water had showed clearly a growing profile toward the ocean in all campaigns, in the dry and rainy season, with the lowest values in the first stations and the highest in the last ones. Intense carrying of nutrients and suspended materials in the coastal area of the continental shelf maranhense directly influences the levels of these data in this region. The turbidity of the continental shelf of Maranhão showed a decreasing profile toward the ocean. These highest values in the first stations also can be explained by the nutrients coming from the estuaries, the influence of estuaries reduces along the ocean, causing the turbidity values decrease. Dissolved oxygen remained stable during the entire study, according to Sen-Gupta & Machaincastillo (1993) in marine waters the dissolved oxygen concentrations may vary between 0 and 8 mL L^{-1}, with a more common variation between 1 and 6 mL L^{-1}, which is consistent with the study area.

Silva *et al.* (2007) comment that the inner continental shelf of the Maranhão is affected by the continental supply of fresh water and suspended material that was evident by the high regional rainfall observed in their sample data. The same was found in the first sample stations of this study. According to Flores-Montes (2003) the typical features of tropical oceanic regions are high temperatures and salinity and a small thermal oscillation. Also according to this author, the pH remains always alkaline and its highest values coincide with the largest concentrations of dissolved oxygen. In station MA3 (May/2014) the observed results were of accord to those described by this author.

The phosphate in the continental shelf of the Maranhão showed a clear seasonal cycle in this study, with the highest values observed in the first stations during the dry season, while in the rainy season the lowest values were observed in the first stations, thus presenting a defined seasonal variation. The nitrite and silicate values were higher towards the coast and lower towards the ocean, in dry and rainy season. The same distribution pattern was observed by Eça *et al.* (2014) in studies of the eastern continental shelf of Brazil. The higher nutrient concentrations in the Maranhão continental shelf were normally associated with the rainy season, the very direct precipitation or by a higher contribution of inputs by the rivers. The contribution of primary production by the entry of nutrients regenerated in the marine aquatic environment should also be considered. Although this region has a low primary production, it manages to maintain a more constant small production throughout the year.

These inorganic nutrients are some of the principal needs required for growth and reproduction of phytoplankton. Diatoms, for example, require large amounts of silicate for their development. The studies focusing on the relationship between phytoplankton and nutrients are important, especially considering that in general the nutrients occur in low concentrations in seawater. The oceans of the earth can be considered as true deserts because they are low in nutrients compared to the continents, as observed in this study. Thus, in most natural conditions, the nutrients are limiting factors to productivity of phytoplankton (Pereira & Soares-Gomes, 2009).

According to Phlips *et al.* (2002) the structure of phytoplankton populations is directly related to the physical and chemical characteristics of water along with other environmental factors. These characteristics and environmental factors, acting together or separately, are conditioning the establishment of populations adapted to environmental changes. The phytoplankton composition of the Maranhão continental shelf was represented by the divisions of Bacillariophyta, Dinophyta and Cyanophyta. The same pattern was observed by Costa *et al.* (2011) in studies in the region of the Amazon continental shelf.

Microplanktonic diatoms are associated with conditions of high turbulence and nutrient availability (Falkowski, 1980). Many diatom species can be considered R-strategists (disturbance tolerant, or ruderal), presenting a high surface/volume ratio that affords them the ability to harvest light energy under strong mixing conditions, but with high nutrient concentrations (Reynolds, 2006; Alves-de-Souza *et al.*, 2008). The generally high maximum uptake rates observed in diatoms may be advantageous under conditions of high or fluctuating nutrient availability (Grover, 1991; Litchman *et al.*, 2007).

In this study a clear seasonal cycle was observed for the chlorophyll-*a* concentrations, with the lowest values during the rainy season and the highest in the dry one. The biggest determinant for the concentrations of chlorophyll-*a* is the rain, because it can both contribute to the enrichment of nutrient salts, which can lead to an increase of biomass, but can also increase the amount of suspended material. This limits the photic layer and may affect the development of the phytoplankton and decrease the biomass concentrations (Losada, 2000). A decreasing profile toward the ocean was also observed in this study, showing the influence of the large contribution of sediments coming from estuarine waters in the first stations.

The chlorophyll-*a* concentrations in the study area remained low compared to other studies carried out in Pará State, northern Brazil (Sousa *et al.*, 2009; Costa *et al.*, 2011; Matos *et al.*, 2011, 2012). This region has a coast populated by mangroves and is under the strong influence of continental discharge of the Amazon River as it is also observed in the Maranhense Gulf (Azevedo *et al.*, 2008) where eutrophic characteristics are very common (rich in nutrients). However, the low chlorophyll concentrations identified in the Maranhense continental shelf are characteristic of oligotrophic regions (poor in nutrients).

The values of total and fractional chlorophyll-*a* presented analogous results to those obtained by Armbrecht *et al*. (2014) on the continental shelf east of Australia, which is also a tropical region. Although low, the chlorophyll-*a* concentrations in tropical waters are quite variable, but always with concentrations less than those of coastal waters regardless of the season. This overall pattern commonly results from the low nutrient concentrations typical of oligotrophic waters transported by Brazil current (Brandini, 1990; Braga & Niencheski, 2006; Castro *et al.*, 2006).

CONCLUSIONS

The scenario observed in this study showed a clear seasonal cycle, with the highest contribution of the phytoplankton in the dry period; also it was possible to observe the predominance of the Bacillariophyta division over the other identified divisions found, based on the obtained qualitative data. Regarding quantitative data (chlorophyll-*a*), nano/picophytoplankton and microphytoplankton had greater representation also in the dry season. The intense carrying of nutrients and suspended materials in the coastal area of the continental shelf maranhense directly influenced the abiotic variables in this region such as the transparency, the turbidity, conductivity and salinity. Due to the lack of data from the Maranhense continental shelf it is impossible to draw comparisons with greater precision in relation to the data surveyed in this study.

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