Instituto de PESCA

BOLETIM DO INSTITUTO DE PESCA
ISSN 1678-2305 online version
Scientific article

MICROPHYTOPLANKTON DYNAMICS IN CURUPERÉ ESTUARY AT THE AMAZONIAN MANGROVE ECOSYSTEM*

Fernanda Nogueira dos REIS[1]
Lucinice Ferreira BELÚCIO[2]
Fábio Campos PAMPLONA[1]
Luciana Thaila Lopes REIS[2]
Giselle Damasceno da VEIGA[2]
Nuno Filipe Alves Correia de MELO[1]

[1] Universidade Federal Rural da Amazônia, Programa de Pós-Graduação em Aquicultura e Recursos Aquáticos Tropicais, Avenida Presidente Tancredo Neves, CEP: 66.077-830, Belém, Pará, Brasil. nunomelo@uol.com.br (corresponding author).

[2] Universidade Federal do Pará, Rua Augusto Correa - Campus Universitário Guamá, CEP 66075-11, Brasil.

*This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001

Received: March 27, 2019
Approved: September 03, 2019

ABSTRACT

The aim of this study was to evaluate microphytoplankton dynamics and environmental parameters in the estuary of the Curuperé River, located in an Amazonian mangrove ecosystem. Ten sampling sites, where occupied to obtain surface water samples for qualitative and quantitative microphytoplankton analyses, chlorophyll-*a*, temperature, turbidity, salinity, and pH. Samplings were conducted in four months: in February, May, August and November/2015; the first two months corresponding to rainy season and the last two to dry season. Significant spatiotemporal differences were observed, for diversity, equitability and specific dominance of the microphytoplankton community. In total, 212 taxa were identified and this community was dominated by Bacillariophyta (149 taxa), followed by Myzozoa (29 taxa). The abundance varied from 7,700 ind L^{-1}, (May, sampling site 1) to 343,800 ind L^{-1}, in August (sampling site 4). The diatom *Cymatosira belgica* was the dominant species, followed by *Dimeregramma minor* (major peaks of 180,600 ind L^{-1} and 120,400 ind L^{-1}, respectively) in August at point 4. Phytoplankton biomass indicates an eutrophic estuary as Chlorophyll-*a* varied from 13.01 to 112.88 mg m^{-3}, probably due to marine shrimp farm effluents. It was possible to identify species strongly indicative of the environment, through analysis of indicator species (IndVal), and their relations with the main environmental conditions (pH, salinity and rainfall), determined by canonical redundancy analysis (RDA).

Key words: macrotidal amazonian mangrove coast; phytoplankton biomass; eutrophic estuary; *Cymatosira belgica*.

DINÂMICA DO MICROFITOPLÂNCTON NO ESTUÁRIO DO RIO CURUPERÉ EM UM ECOSSISTEMA DE MANGUEZAL AMAZÔNICO

RESUMO

O objetivo deste estudo foi avaliar a dinâmica microfitoplanctônica e os parâmetros ambientais no estuário do rio Curuperé, localizado em um ecossistema de manguezal na Amazônia. Foram realizados dez pontos de amostragem, utilizando amostras de água superficial para análises qualitativas (rede com malha de 20 µm) e quantitativa do microfitoplâncton, bem como para determinação de clorofila *a*, temperatura da água superficial, turbidez, salinidade e pH. As amostragens foram realizadas em quatro meses: fevereiro, maio, agosto e novembro, sendo os dois primeiros correspondentes ao período chuvoso e os dois últimos, ao seco. Foram observadas diferenças significativas entre os meses e relacionadas à posição ao longo do eixo estuarino para diversidade, equitabilidade e dominância específica na comunidade microfitoplanctônica. Foram identificados 212 táxons com dominância de Bacillariophyta (149 taxa), seguido por Myzozoa (29 taxa). O microfitoplâncton variou de 7.700 ind L^{-1}, (maio, ponto 1) a 343.800 ind L^{-1}, em agosto (ponto 4). A diatomácea *Cymatosira belgica* foi a espécie dominante, seguida por *Dimeregramma minor* (maiores picos de 180.600 ind L^{-1} e 120.400 ind L^{-1}, respectivamente) em agosto no ponto 4. Os valores de clorofila *a* permaneceram altos ao longo do ano variando de 13,01 a 112,88 mg m^{-3}, provavelmente devido aos efluentes de fazenda de camarões marinhos. Foi possível identificar espécies fortemente indicativas do ambiente, através da análise de espécies indicadoras (IndVal), e suas relações com as principais condições ambientais (pH, salinidade e precipitação), determinadas pela análise de redundância canônica (RDA).

Palavras-chave: manguezais amazônicos com macromarés; biomassa fitoplanctônica; estuário eutrófico; *Cymatosira belgica*.

INTRODUCTION

Estuaries are highly diverse coastal environments. They also have unique circulation patterns, complex bathymetric and biogeochemical factors that vary according to extensive horizontal and vertical gradients, and distinct temporal dynamics in the transition from the fluvial to the marine areas. These complex processes raise many questions regarding the regulation of biomass and phytoplankton production in estuaries (Boynton et al., 1982; Cloern, 1987), and consequently, they influence the production at higher trophic levels, including species used for feeding (from fishing, aquaculture and capture) (Cloern et al., 2014).

The fate of the material introduced into the coastal zone through the tropical estuaries is controlled by processes very different from those occurring in regions of higher latitude. Warm and humid climate promotes intensive rock abrasion and increased nutrient supply, which in turn can lead to high phytoplankton production, inhibited only by a possible increase in turbidity due to the discharge of fluvial sediments (Nittrouer et al., 1995). In mangrove-dominated estuary like Curuperé River, act as exporting of a large fraction of their net primary production to adjacent coastal areas due to tidal action (Schwendenmann et al., 2006).

Estuaries located in the north of Brazil are home of the world's largest mangrove coast, with a length of 1200 km (Souza-Filho, 2005; Dominguez, 2009). The macrotidal mangroves of the northeast coast of Pará State and northwest of Maranhão State, known as the Macrotidal Amazonian Mangrove Coast (MAMC), extend from Marajó Bay (Pará) to Ponta de Tubarão, in São José Bay (Maranhão), totaling about 650 km (in straight line) coastline. These mangroves extend over approximately 7,600 km^2 and are characterized by irregular geomorphology, with 23 estuaries and 30 catchment areas, draining 330,000 km^2 (Souza-Filho, 2005).

Mangrove estuaries are subject to physical, chemical and biological dynamical processes that influence water quality. These ecosystems also contribute to an additional organic matter load, whose decomposition has some effect on the eutrophication of the adjacent aquatic environment (Souza et al., 2009). This effect was observed by Palheta et al. (2012) when applied a trophic state index (TSI) at a marine shrimp farm in an area adjacent to the present study, it was verified that the farm effluents modified the trophic state (from eutrophic to hypereutrophic) of the estuary at the end of the growing cycle.

In this context, MAMC estuaries are considered extremely complex environments, which are fundamentally important for the economic development of the region, especially fisheries and aquaculture (Sousa et al., 2013).

The MAMC has been the place for studies of the phytoplankton communities carried out by Sousa et al. (2008), Sousa et al. (2009), Matos et al. (2011), Sodré et al. (2011), Matos et al. (2012), Matos et al. (2013) and Matos et al. (2016). In the Curuçá River Estuary, an area adjacent to the present study, few studies were carried out related to the dynamics of the microphytoplankton (Costa, 2010; Silva et al., 2018). However, studies about phytoplankton in the Curuperé river inexist, thus the present study is the first approach in the area.

The purpose of this study is to highlight the microphytoplankton dynamics in the estuary of Curuperé River, which is located in the great estuarine system of Curuçá River, inside MAMC. This study will represent an important basis for new studies in adjacent areas and also will be potentially useful to the implementation of conservation politics for these important coastal ecosystems.

MATERIAL AND METHODS

Study area

The Curuçá Estuary is a marine-dominated system with little freshwater input. It is covered by approximately 116 km^2 of mangrove forest dominated by *Rhizophora mangle* L. mixed with *Avicennia germinans* (L.) Stearn in the more elevated sites (Giarrizzo and Krumme, 2009). Curuperé River (Figure 1) flows into Curuçá River Estuary at Curuçá City. It is located in the northeastern coast of Pará State, inserted in the Mangrove Coast of Amazonian Macrotide (MAMC). This estuary has approximately 3 km of extension, average depth of three meters along its length, and it becomes increasingly shallow towards the source, including the formation of sand banks, making it difficult to navigate. The semidiurnal tide ranges between 3-4 m at neap tides and 4-5 m at spring tides. It should be stressed that at the downstream and upstream of the Curuperé river exist two marine shrimp farms, and their effluents have been the subject of several studies of environmental impact in the adjacent estuary (Paula et al., 2006; Palheta et al., 2012; Brabo et al., 2016; Silva et al., 2018).

The local climate presents high rainfall, with an annual average of 250 mm and low temperature variation with an average of 27 ºC, a minimum of 18 ºC and maximum values occurring from August to October, reaching up to 42 °C (El-Robrini et al., 2006). The rainy period usually extends from December to May, and the dry season extends from approximately from June to November (Moraes et al., 2005).

Sampling design

Sampling sites were established along Curuperé River, with a spacing of approximately 300 m, organized in ascending order from the river source towards the mouth, totaling 10 sample points (Table 1).

Samplings were conducted in four months: in February, May, August and November/2015, the first two months corresponding to rainy season and the last two to dry season (Moraes et al., 2005). The sampling design was standardized according to region tide chart (DHN, 2015), always occurring in daytime syzygy flood tide.

The pH and temperature were measured with a Schott pHmeter and a mercury thermometer, respectively. Salinity were measured using Hanna HI9835 probe, and turbidity analysis, with Hexis model DR890 colorimeter. All these variables were measured *in situ* at water surface.

For the qualitative analysis of the phytoplankton, the tows were accomplished at subsurface water level, using a conical-cylindrical net of 20 µm mesh size. The phytoplankton samples were immediately

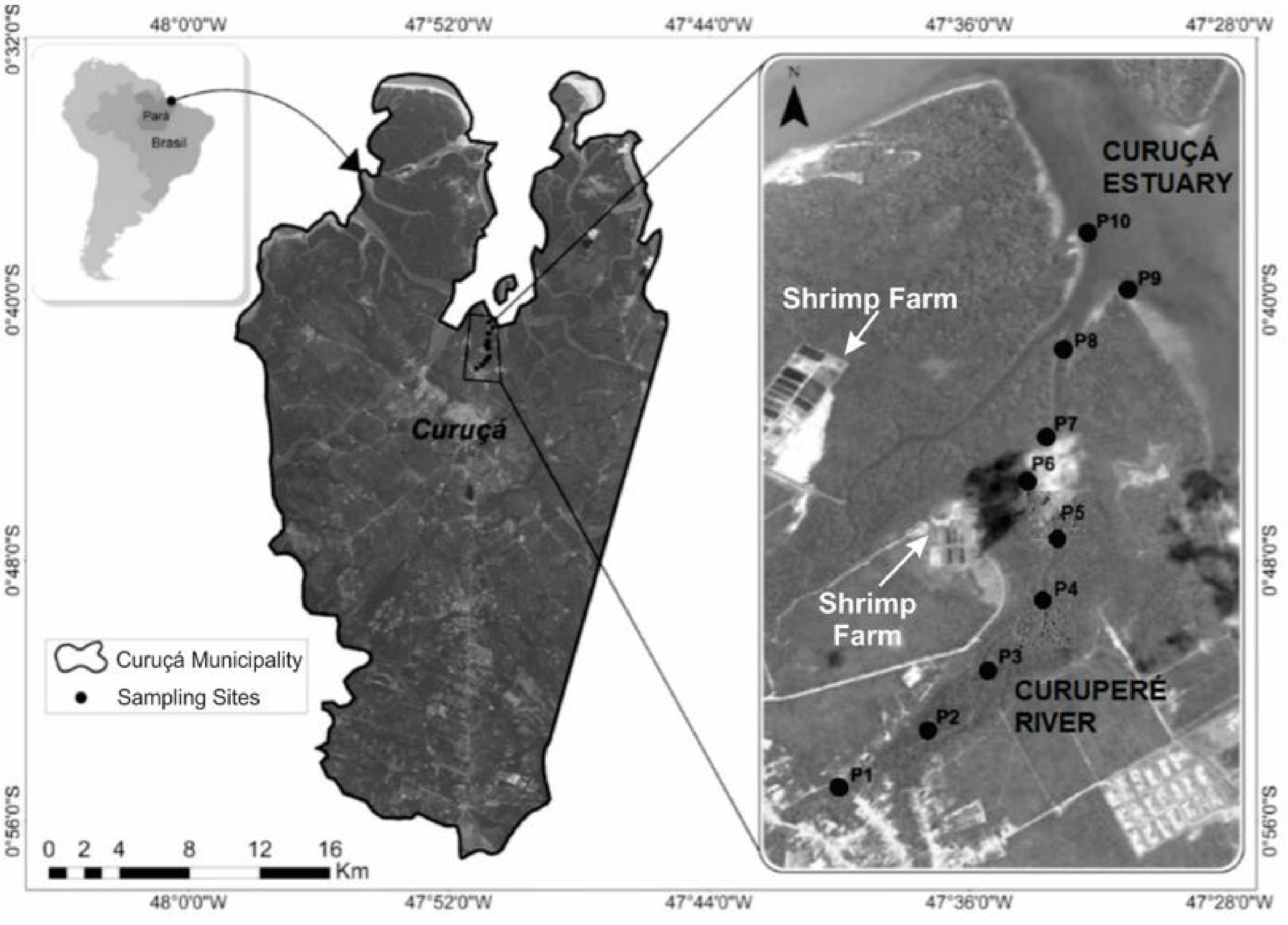

Figure 1. Map of the study area in Curuçá City (PA), with the location of sampling sites.

Table 1. Position of ten sampling sites (P1-P10) along to Curuperé Estuary.

Stations	Latitude	Longitude	River portion
P1	0°42’7.10” S	47°51’8.60” W	source
P2	0°42’0.91” S	47°50’57.48” W	source
P3	0°41’52.46” S	47°50’50.98” W	source
P4	0°41’44.10” S	47°50’48.10” W	intermediate
P5	0°41’29.90” S	47°50’44.60” W	intermediate
P6	0°41’24.40” S	47°50’50.20” W	intermediate
P7	0°41’17.30” S	47°50’46.30” W	intermediate
P8	0°41’2.50” S	47°50’44.30” W	mouth
P9	0°41’51.80” S	47°50’38.70” W	mouth
P10	0°40’41.10” S	47°50’45.60” W	mouth

conditioned in 250 mL plastic containers and fixed in 4% sodium tetraborate buffered formalin and ambient water solution.

For the quantitative analysis of the phytoplankton, samples of subsurface water were immediately conditioned in 180 mL plastic containers (properly labeled) and fixed with the same solution and concentration cited above.

To obtain phytoplankton biomass, the samples were stored in 500 mL plastic containers, protected from light, and cooled for laboratory analysis. The water samples were filtered (Merck™ glass fiber filters grade: AP15; diameter: 47 mm, porosity 0.6 µm) to determine chlorophyll-*a* (Chl-*a*) concentrations. The pigments were extracted from glass fiber filters with 90%

acetone v.v. and determined spectrophotometrically according to Strickland and Parsons (1972).

Aliquots of microphytoplankton samples were counted in a sedimentation chamber according to Utermöhl (1958), with aid of an inverted Coleman microscope model NIB-100. Unicellular organisms, coenobium, trichomes and colonial forms were considered as a single individual. Results were expressed in individuals per liter (ind L^{-1}). The high concentration of suspension particulate matter (16.28 to 81.92 mg L^{-1}, in the dry and rainy periods, respectively – (Costa et al., 2009)) in water samples prevented the nanoplankton fraction analyses, and therefore, only the microphytoplankton fraction was considered in this study.

Shannon's diversity index (Shannon, 1948), Pielou's equitability (Pielou, 1969) and Berger-Parker's index of dominance (Berger and Parker, 1970) were determined based on density data.

Rainfall data from Curuçá City for the last 30 years were obtained from the National Water Agency (ANA, 2016).

Data analysis

The normality of environmental parameter data, microphytoplankton density, Shannon diversity index, Pielou equitability and Berger-Parker index of dominance were tested using Shapiro Wilks W test (Zar, 1999). For normal data, we used Student's T-test, and for non-normal data we used Mann-Whitney U-test to evaluate their significance between rainy and dry periods. In order to evaluate the significance of parameters between the sampled months, ANOVA F-test and its posteriori test, Tukey test (test pairs averages) were used for normal data. For non-normal data, we used non-parametric Kruskall-Wallis H-test, with a posteriori Mann-Whitney U-test (pairwise samples), with Bonferroni correction. In both comparisons (seasonal and monthly) were considered significance level lower than 5% ($p<0.05$). The Spearman nonparametric correlation (rs) was applied to environmental parameters to identify similar patterns during dry and rainy periods.

Two different randomization procedures were used to evaluate significant differences of diversity, equitability and dominance between source and mouth in the four months of sampling, the first being a bootstrap procedure and the second a permutation procedure. All analyzes were performed using the PAST software (Hammer et al., 2001).

Cluster Analysis was performed in the PCORD 5 software (McCune and Mefford, 2011), from which the relation between samples (Mode Q) and phytoplankton species associations (Mode R) was evaluated. Phytoplankton density data were used, being submitted to the criterion of elimination of species with frequency of occurrence greater than 95% and less than 5% (Azeria et al., 2009; Poos and Jackson, 2012). A PERMANOVA bifactorial (Anderson, 2001), performed in PAST software (Hammer et al., 2001), was used to test spatial variability factors (river portions, divided in source samples, intermediate samples and mouth samples) and seasonal (dry and rainy periods) in the grouping of species. The significance of this test was calculated by exchanging the samples between groups, with 9,999 replicates.

The groups of samples formed in Cluster analysis were used to determine species indicative of the studied environment (IndVal - Indicative Value of the species) (Dufrêne and Legendre, 1997). Statistical significance of IndVal was tested by the Monte Carlo technique through 9,999 permutations (Valentin, 2012). PCORD 5 software was used to perform IndVal analysis (McCune and Mefford, 2011). Characteristic ecological habit for each of significant indicator species was classified according to Round et al. (1990), Moro and Fürstenberger (1997) and Eskinazi-Leça et al. (2010) for diatoms, Steidinger and Tangen (1997) and Odebrecht (2010) for dinoflagellates and Desikachary (1959) for cyanobacteria, among other specialized literature. Taxonomic standardization for all groups followed the Algaebase criteria (Guiry and Guiry, 2017).

Finally, in order to correlate environmental variables to phytoplankton community, a Canonical Redundancy Analysis (RDA) were performed with aid of software CANOCO 4.5 (Ter Braak and Milauer, 2002), using the Monte Carlo test (9,999 permutations) to evaluate significance ($p<0.05$) of environmental variables in order to explain the biological variables. For a better graphic visualization, only species with explanatory quantities greater than 20% were selected.

RESULTS

Rainfall regime

Figure 2 shows the historical monthly average rainfall in Curuçá City, followed by monthly average rainfall of 2015. In the months of January and February 2015, the amount of rainfall was below the standard deviation found in the historical average, while the months of March and July showed amounts of rain above the deviation. However, rainfall in the months of sampling (May, August and November) remained within the data natural variability.

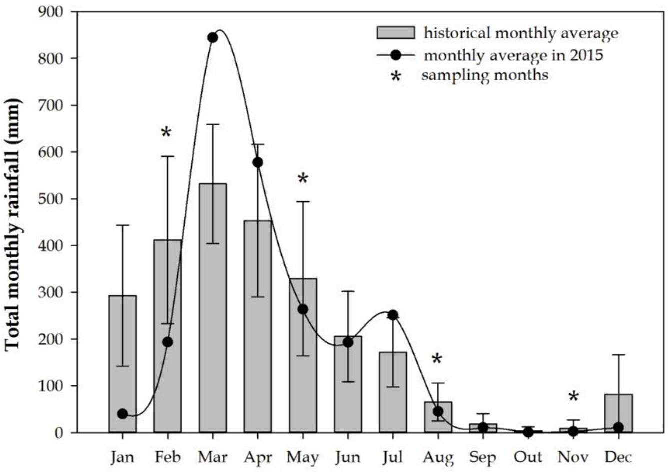

Figure 2. Total monthly rainfall observed during 2015 and the historical monthly average rainfall (1988 - 2018) at Curuçá city, with the standard deviations. Data acquired by National Water Agency (ANA). * Months of samplings.

Seasonal and monthly variation of environmental variables

Significant differences were observed only among pH, salinity ($p<0.001$) and temperature ($p<0.05$) evaluated during rainy and dry periods. These variables had significantly higher values during dry period. Finally, there was also a significant difference between rainfall values between the two periods ($p<0.001$), presenting an inverse pattern (Table 2).

Correlation data for the rainy season showed only a positive correlation among temperature and salinity (rs = 0.54, $p<0.05$). Negative correlations occurred between rainfall with salinity (rs = -0.71, $p<0.001$) and temperature (rs = -0.61, $p<0.01$).

For dry period, there was also a negative correlation among rainfall and salinity (rs = -0.69, $p<0.001$), while turbidity was correlated positively with rainfall (rs = 0.66, $p<0.01$).

Among the sampled months, were observed significant differences for the pH (Figure 3d), tested by ANOVA ($p<0.001$), temperature (Figure 3a) and salinity (Figure 3b) ($p<0.01$), rainfall ($p<0.001$), and chlorophyll-*a* (Figure 3c) ($p<0.05$), as tested by Kruskall-Wallis. The pH values showed significant differences

Table 2. Mean values (± standard deviation) of the environmental variables in the four sampling months in 2015 and the respective averages in the rainy and dry periods in Curuperé Estuary.

	February	May	August	November	Rainy period	Dry period
Temperature (C°)	27.8±1.39	26.1±1.19	27.6±0.69	28±0.94	26.95±1.53	27.8±0.83
Salinity	21.89±8.51	6.17±2.60	29.65±5.86	35.7±6.83	14.02±10.12	32.67±6.93
pH	7.55±0.14	7.58±0.10	8.18±0.11	8.12±0.22	7.57±0.12	8.15±0.17
Chlorophyll-*a* (mg m^{-3})	22.34±10.07	34.25±27.91	31.52±6.93	25.18±10.32	28.29±21.32	28.35±9.15
Turbidity (FAU)	16.2±10.86	13.1±8.00	20.5±9.32	11.9±17.27	14.65±9.41	16.2±14.2

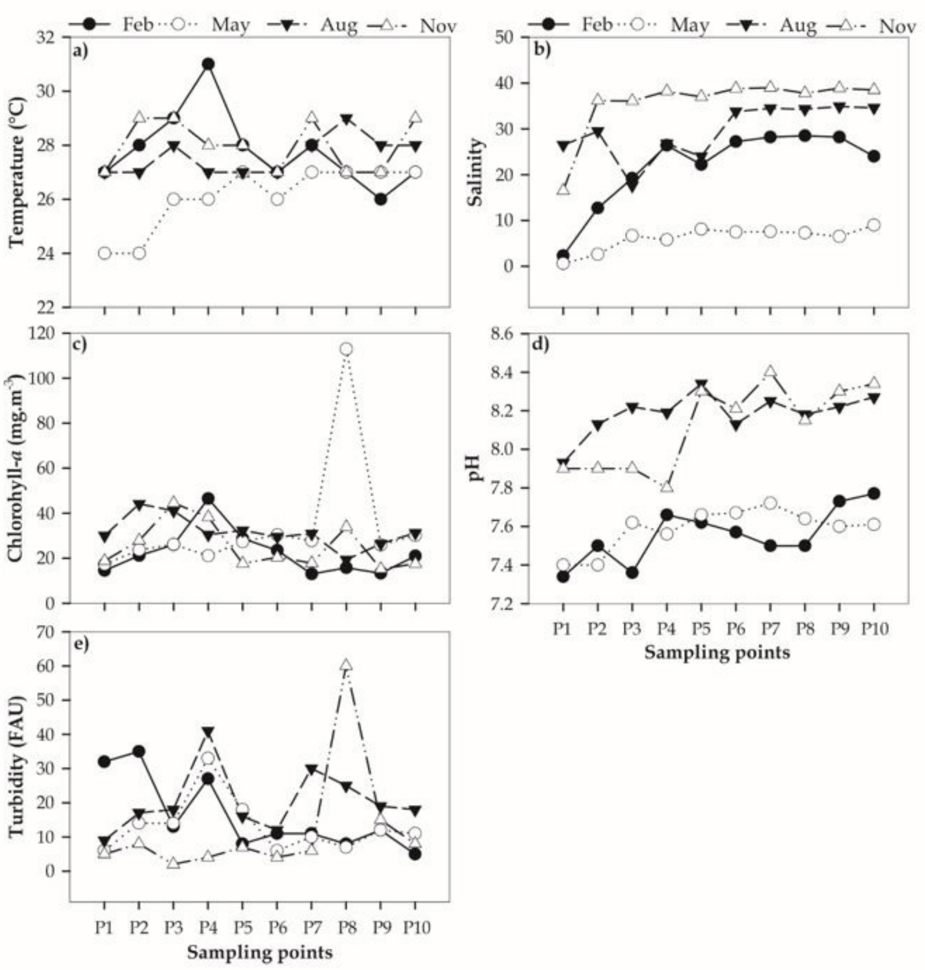

Figure 3. Spatiotemporal variation of the variables evaluated. (a) temperature; (b) salinity; (c) chlorophyll-*a*; (d) pH; (e) turbidity, measured at the ten sampling points in Curuperé Estuary in the four sampling months.

among all months, but it was possible to notice that pH values of August and November (dry) were significantly higher than the rainy season months. Salinity and conductivity showed a pattern similar to pH; however, the two variables decreased significantly from February to May and increased from May onwards. Temperature also presented a similar pattern to the previously mentioned variables, however, only May was significantly different from the other months. Regarding chlorophyll-*a*, were observed significant difference only between February and August. Finally, rainfall presented an inverse pattern to the other variables, with the highest values occurring in February and May, and only between these two months there were no significant differences.

Specific composition, density and structure of microphytoplankton community

This study identified 212 taxa, belonging to the phyla Bacillariophyta (149 taxa), Euglenophyta (5 taxa), Charophyta (4 taxa) and Chlorophyta (4 taxa), beyond Myzozoa (29 taxa) and Cyanobacteria (21 taxa). In general, Bacillariophyta presented the highest richness throughout the sampled period, tending to increase in dry season, followed by Myzozoa, whose the richness decreased during dry period.

Furthermore, 164 phytoplankton species were identified, ranging in density from 7,700 ind L^{-1} found in point 1 in May, to 343,800 ind L^{-1} in point 4, in August. This last month was the one that presented the highest densities and greater variations between the sampling points. In general, density of phytoplankton in ind L^{-1} tends to increase from source to intermediate portion of the river and decrease towards the estuarine mouth.

Seasonal periods revealed no difference in phytoplankton abundance values between rainy and dry periods ($p>0.05$), but there were differences in abundance between February and May and between May and August ($p<0.05$).

In February, *Cymatosira belgica* was the most abundant species in nine sampling sites, while *Dimeregramma minor* was the second most abundant species in eight sites, being these two species the responsible for the peak of density in point 6 (38,600 and 25,800 ind L^{-1}, respectively). These species presented very similar patterns of spatial distribution along the river. The diatom *Cylindrotheca closterium* was the most abundant species at point 1 (7,600 ind L^{-1}) and the second most abundant at point 2 (5,400 ind L^{-1}), both points located closer to river source. This species density decreased along Curuperé River in February.

In May, *Coscinodiscus concinnus* was the most abundant at points 4, 5, 8 and 10 (9,650.00 ± 3,767.84 ind L^{-1}), while *D. minor* was more abundant at points 1, 7 and 9 (9,933.33 ± 8,295.38 ind L^{-1}). The diatom *Navicula gregaria* was responsible for higher values of phytoplankton density at points 2 and 3 (6,050.00 ± 3,889.08 ind L^{-1}) and, *C. belgica* had higher density of individuals at point 6 (11,000 ind L^{-1}). The peak density of phytoplankton at point 7 was mainly caused by *D. minor* (17,000 ind L^{-1}), *C. concinnus* (15,800 ind L^{-1}) and *C. belgica* (13,800 ind L^{-1}) densities.

In August, *C. belgica* and *D. minor* were respectively the first and second most abundant species at all points sampled, being the most responsible for the peak density of individuals at point 4 (180,600 ind L^{-1} and 120,400 ind L^{-1}, respectively) and 7 (140,200 and 37,000 ind L^{-1}, respectively). Thirdly, the diatom *Odontella longicruris* also obtained a high density of individuals from point 3 onwards (10,475.00 ± 4,108.44 ind L^{-1}), except for point 8, where the third most abundant species was *Thalassionema nitzschioides* (8,000 ind L^{-1}). This month showed higher phytoplankton density when compared to other months.

Moreover, in November, *C. belgica* was the most abundant in almost all the sampling sites, except for point 7, in which the most abundant species was the cyanobacteria *Phormidium* cf. *nigroviride* (48,000 ind L^{-1}). In point 3, the diatoms *Skeletonema* sp. and *T. nitzschioides* were the most abundant along with *C. belgica* (1,600 ind L^{-1} each).

Shannon diversity index varied from 1.26 in August to 3.61 nats ind^{-1} in February with monthly averages being 2.82 ± 0.67 nats ind^{-1} in February; 2.44 ± 0.38 nats ind^{-1} in May; 1.84 ± 0.63 nats ind^{-1} in August; and 2.70 ± 0.56 nats ind^{-1} in November (Figure 4a). There was no significant difference between rainy and dry periods for diversity indexes ($p<0.05$), but there were differences between months of February and August and August and November ($p<0.01$). August was significantly lower than February and November. We observed a significant difference between the specific diversity of source and mouth of Curuperé River in all months ($p<0.001$).

Pielou equitability varied from 0.36 in August to 0.92 in May and November, and varied, on average, 0.73 ± 0.14 in February; 0.71 ± 0.09 in May; 0.48 ± 0.13 in August; and 0.74 ± 0.14 in November (Figure 4b). A difference was showed between the equitability of the species of the rainy and dry periods, and that of the dry period was significantly lower than that of the rainy season ($p<0.05$). There was also difference between monthly equitability values, and it was possible to observe that the August equitability was significantly lower than that February ($p<0.001$), May ($p<0.01$) and November ($p<0.001$). Equitability also diverged significantly between river source and mouth in the four months of sampling ($p<0.001$).

Finally, Berger-Parker index of dominance ranged from 0.10 in May to 0.71 in August, and its averages were 0.27 ± 0.15 in February; 0.26 ± 0.07 in May; 0.53 ± 0.15 in August; and 0.25 ± 0.12 in November (Figure 4c). Between rainy and dry periods, were detected difference between their respective average values of Berger-Parker index, evidencing that in dry period the dominance index was higher than in rainy season ($p<0.05$). There was also a difference between the values of monthly dominance index, with significant differences between August and other months ($p<0.001$), showing that species dominance in August was higher. There were also significant differences between indexes of dominance of source and mouth in the four campaigns carried out in 2015 ($p<0.001$).

Among the identified species, those with a frequency equal or greater than to 95% were the diatoms *C. belgica* Grunow, *D. minor* (Gregory) Ralfs, *C. concinnus* W. Smith, *T. nitzschioides* (Grunow) Mereschkowsky and *Thalassionema frauenfeldii* (Grunow) Tempère & Peragallo.

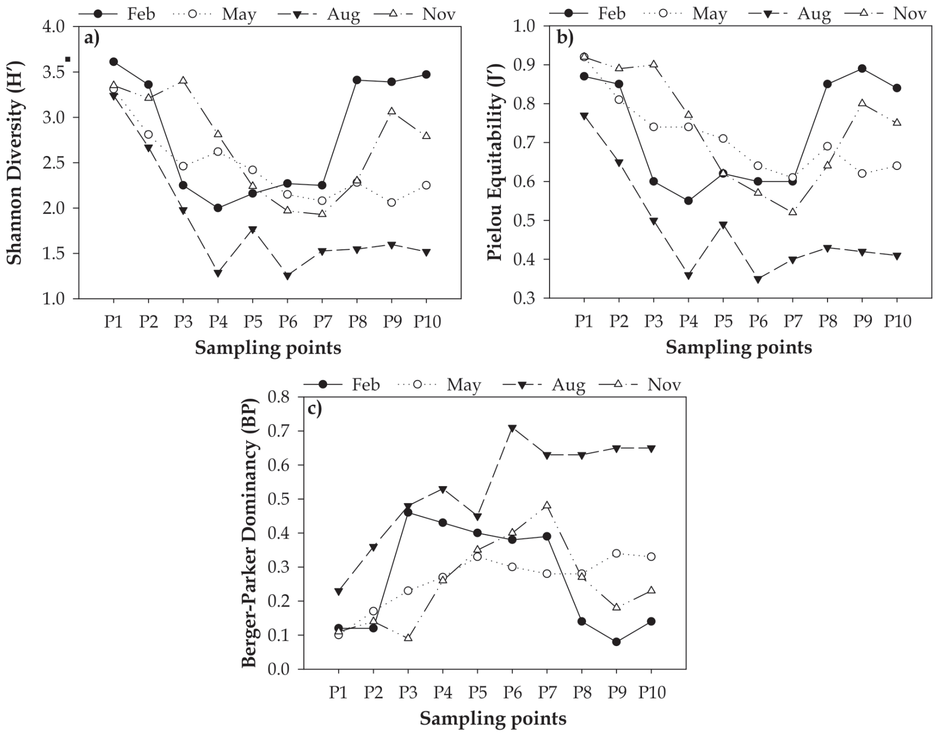

Figure 4. Spatiotemporal variation of the ecological indexes (a) Shannon diversity, (b) Pielou equitability and (c) Berger-Parker dominancy at the ten sampling points in Curuperé Estuary in the four sampling months.

The R mode cluster analysis showed the formation of five species associations. In addition, these associations were related to both temporal (groups defined for each sampling month) and spatial patterns (groups that were related to areas near source, intermediate areas and river mouth) and therefore, in Q mode, it's formed also five samples groups (Figure 5).

Association 1 was composed by neritic and oceanic species, with presence of centric (*Odontella aurita*, *O. longicruris*, *Trieres mobiliensis*, *T. sinensis*, *Lauderia annulata*, *Zygoceros ehrenbergii*), and pennate diatoms (*Campylosira cymbelliformis* and *Pleurosigma elongatum*) and simple filamentous cyanobacteria (*Phormidium* cf. *nigroviride*).

Association 2, indicates the predominance of estuarine species, some with an optimal development in freshwater (*Cyclotella meneghiniana* and *Fragilaria capucina*) and, to a lesser extent, neritic species. It is composed mostly of diatoms, with a greater number of centric diatoms (*Coscinodiscus radiatus*, *Cyclotella striata*, *Melosira nummuloides*, *Paralia sulcata*, *Skeletonema* sp., *Thalassiosira eccentrica*, *T. gravida* and pennate (*Campyloneis grevillea*, *Diploneis bombus*, *D. littoralis* and *D. crabro*). There is the presence of a branched filamentous cyanobacteria (*Scytonema* sp.).

Association 3 is composed of majority of estuarine, oligohaline and mesohalobic species and cosmopolitan neritic species. Most are represented by pennate diatoms (*C. closterium*, *Nitzschia sigma*, *Navicula arenaria*, *N. gregaria* and *Nitzschia sigmoidea*). There are two species of cyanobacteria, one filamentous composed of heterocytes (*Yonedaella* sp.) and another simple filamentous (*Phormidium* cf. *corium*).

Association 4 is composed of nerito-oceanic species, represented in their totality by diatoms, centric (*Chaetoceros compressus*, *Ditylum brightwellii*, *Rhizosolenia setigera* and *Skeletonema costatum*) and pennate (*Bacillaria paxillifera, Navicula* sp., *Thalassiotrix longissima* and *Pseudo-nitzschia delicatissima*).

Finally, association 5 has predominantly estuarine-neritic habitats, composed mostly of diatoms (*Aulacoseira granulata*, *Fragilaria acus*, *Polymyxus coronalis* and *Pseuso-nitzschia seriata*), but with the presence of two dinoflagellates species (*Peridinium* sp. and *Tripos fusus*).

The nodal analysis (Figure 5) revealed that the highest phytoplankton densities occurred in species associations 3, 5 and 2. In addition, these associations were related, respectively, to groups of samples G1, G2 and G3. It is also possible to identify that certain species associations are absent or with very low densities in certain groups of samples.

According to PERMANOVA results, the variation of species selected for this grouping was significant both in relation to seasonal pattern (F = 4.91) and spatial pattern (F = 2.72) (p = 0.0001 for both the patterns), but there was no significant difference in interaction between them (F = -0.78, p = 0.0584).

Indicator species based on groups of samples formed can be identified in Table 3. Among the species analyzed in IndVal, 54 were significant as environmental indicator species.

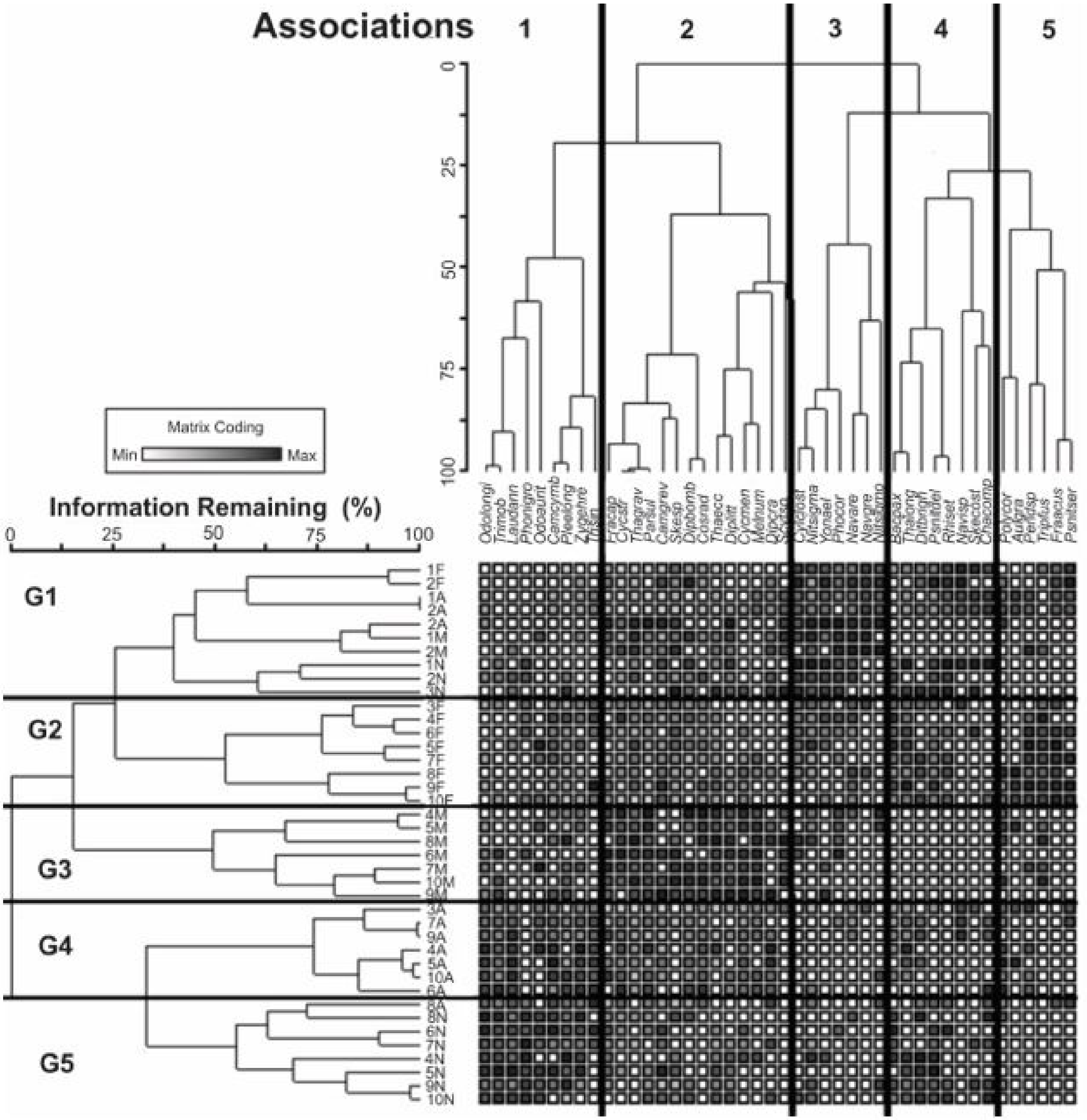

Figure 5. Nodal analysis of the abundance data of 44 phytoplankton species at 10 points and 4 sampling months in course of Curuperé River. Cladograms generated by WARD grouping method based on Hellinger distance. Legends 1 through 5 represent species associations. Legends from G1 to G5 represent groups of samples formed. F = February; M = May; A = August; N = November. Association 1: Odolongi = *Odontella longicruris*; Trimob = *Trieres mobiliensis*; Laudann = *Lauderia annulata*; Phonigro = *Phormidium* cf. *nigroviride*; Odoaurit = *Odontella aurita*; Camcymb = *Campylosira cymbelliformis*; Pleelong = *Pleurosigma elongatum;* Zygehre = *Zygoceros ehrenbergii*; Trisin = *Trieres sinensis*; Association 2: Fracap = *Fragilaria capucina*; Cycstr = *Cyclotella striata*; Thagrav = *Thalassiosira* cf. *gravida*; Parsul = *Paralia sulcata*; Camgrev = *Campyloneis grevillea;* Skesp = *Skeletonema* sp.; Dipbomb = *Diploneis bombus*; Cosrad = *Coscinodiscus radiatus*; Thaecc = *Thalassiosira eccentrica*; Diplitt = *Diploneis littoralis*; Cycmen = *Cyclotella meneghiniana*; Melnum = *Melosira nummuloides*; Dipcra = *Diploneis crabro*; Scytsp = *Scytonema* sp.; Association 3: Cyclost = *Cylindrotheca closterium*; Nitsigma = *Nitzschia sigma*; Yonael = *Yonedaella* sp .; Phocor = *Phormidium* cf. *corium*; Navare = *Navicula arenaria*; Navgre = *Navicula gregaria*; Nitsigmo = *Nitzschia sigmoidea*; Association 4: Bacpax = *Bacillaria paxillifera*; Thalong = *Thalassiotrix longissima*; Ditbrigh = *Ditylum brightwellii*; Psnitdel = *Pseudo-nitzschia delicatissima*; Rhiset = *Rhizosolenia setigera*; Navisp = *Navicula* sp.; Skecost = *Skeletonema costatum*; Chacomp = *Chaetoceros compressus*; Association 5: Polycor = *Polymyxus coronalis*; Aulgra = *Aulacoseira granulata*; Peridsp = *Peridinium* sp.; Tripfus = *Tripos fusus*; Fraacus = *Fragilaria acus*; Psnitser = *Pseuso-nitzschia seriata*.

Table 3. Significant indicator species (IndVal). mar = marine; ner = neritic; oce = oceanic; eur = eurihaline; mhb = mesohalobic; olg = oligohaline; s = brackish water, but at unspecified salt concentrations; I = indifferent, tolerates small amounts of salt; plc = planktonic; tcp = ticoplanktonic; per = periphytic; eps = epipsamic; epf = epiphytic.

Species	Samples Groups	IndVal (%)	Mean	Deviation	*p*-value	Habitat
Cylindrotheca closterium	1	77.9	25.3	8.96	0.0001	ner; mhb; plc
Yonedaella sp.	1	69.6	22.3	7.59	0.0001	s; mar; per; epf, tcp
Navicula gregaria	1	66.7	21.5	9.8	0.0009	olg, s; per; epl
Nitzschia recta	1	54.7	15.5	7.56	0.001	s; per; tcp
Navicula arenaria	1	54.2	26.2	8.27	0.004	mar; ner; tcp
Nitzschia sigma	1	54	25.9	6.58	0.0012	s; mhb; plh; per; tcp
Nitzschia sigmoidea	1	50.4	26.5	11	0.0296	olg; per; tcp
Entomoneis alata	1	46.6	17.6	8.01	0.0063	s; per; tcp
Surirella splendida	1	45.6	16.6	7.84	0.0066	s; per; plc; tcp
Phormidium cf. *corium*	1	44.1	20.7	6.1	0.0029	s; per; tcp
Guinardia striata	1	40	12.6	7.09	0.005	mar; eur; ner; oce; plc
Rhizosolenia setigera	1	39.9	19.5	6.65	0.0134	mar; ner; oce; plc
Nitzschia subtilis	1	39.6	17.3	7.37	0.0129	s; per; tcp
Hemiaulus sinensis	1	37.3	17.5	7.07	0.0182	mar; eur; ner; plc
Scytonema sp.	1	36.5	18.4	7.22	0.0264	s; per; tcp
Navicula sp.	1	35	18.1	8.28	0.0469	s; per; tcp
Skeletonema costatum	1	34.2	17.2	7.75	0.0402	mar; eur; ner; plc
Chaetoceros subtilis	1	33.1	13.4	6.94	0.014	mar; s; ner; plc
Guinardia flaccida	1	32	14.4	7.21	0.0302	mar; eur; ner; plc
Pleurosigma marinum	1	31.3	13.6	7.19	0.0316	mar; s; ner; plc
Nitzschia palea	1	30	11.5	7.24	0.03	olg; per; plc
Chaetoceros decipiens	1	30	11.3	7.37	0.0308	mar; ner; plc
Tripos fusus	2	89.5	20.1	7.44	0.0001	mar; ner; s; plc
Tripos furca	2	77.3	17.9	7.79	0.0001	mar; ner; s; plc
Fragilaria acus	2	71	18.6	7.38	0.0001	I; per; epf; plc
Bacillaria paxillifera	2	53.2	22.8	5.65	0.0001	mar; eur; per; plc
Thalassiothrix longissima	2	50.5	23.7	6.25	0.0014	mar; ner; s; plc
Peridinium sp.	2	50.2	19.9	6.79	0.0019	s; plc
Thalassiosira cf. *gravida*	2	43.1	25.8	4.52	0.0014	mar; ner; plc
Campyloneis grevileii	2	40	28.2	6.16	0.0478	mar; eur; plc
Pseudo-nitzschia delicatissima	2	35.3	22.4	5.8	0.0335	mar; ner; s; plc
Cyclotella stylorum	2	33.7	17.6	6.62	0.0269	mar; ner; tcp
Coscinodiscus concinnus	3	70.1	32.4	6	0.0001	mar; eur; ner; oce; plc
Melosira nummuloides	3	59	20.6	6.62	0.0002	mar; s; per; plc
Bellerochea malleus	4	85.7	14.4	7.24	0.0001	mar; eur; ner; plc
Lauderia annulata	4	72.5	22.9	7.3	0.0001	mar; ner; plc
Cymatosira belgica	4	65.2	32.6	5.45	0.0001	mar; eur; eps; tcp
Odontella longicruris	4	64.9	26	6.52	0.0001	mar; eur; ner; plc
Zygoceros ehrenbergii	4	58.9	25.1	6.08	0.0001	mar; eur; ner; epf; tcp
Campylosira cymbelliformis	4	54.2	25.1	5.99	0.0005	mar; eur; per; plc
Tryblionella coarctata	4	53.3	15.4	7.04	0.0005	s; ner; per; tcp
Dimeregramma minor	4	52.9	35.1	4.68	0.0003	mar; eur; ner; eps; tcp
Diploneis crabro	4	48.6	23.4	7.16	0.0052	mar; eur; per; tcp
Paralia sulcata	4	43	27.2	4.98	0.0051	plh; eur; ner; per; plc
Cyclotella striata	4	42.0	26.7	4.39	0.0023	mar; eur; per; plc
Psamodiscus nitidus	4	33.2	12.4	7.02	0.0237	mar; ner; plc
Actinoptychus senarius	4	32.1	14.7	7.54	0.0231	mar; eur; ner; plc
Tryblionella granulata	4	29.8	14.1	7.05	0.0265	mar; s; per; tcp
Chaetoceros costatus	4	25.6	12.3	7.22	0.0448	mar; s; ner; plc
Phormidium cf. *nigroviride*	5	94.6	36.1	12.9	0.0002	mar; eur; per; tcp
Trieres regia	5	51.6	16.4	6.67	0.0004	mar; eur; ner; plc
Trieres mobiliensis	5	45.5	22.7	5.99	0.0033	mar; ner; eur; plc
Lithodesmium sp.	5	37.7	13.4	6.86	0.0114	mar; ner; plc
Thalassiosira subtilis	5	32.4	14.6	7.03	0.0299	mar; eur; oce; plc; tcp

The first group of samples (G1), which grouped points closest to river source in each month, presented 22 indicative species, especially the diatoms *C. closterium* and *N. gregaria*, and cyanobacteria *Yonedaella* sp., with IndVal higher than 60%.

Ten species were indicative in the second group of samples (G2), which grouped intermediate points and river mouth points, in February (rainy). Dinoflagellates *T. fusus* and *T. furca* and the diatom *F. acus* showed values above 70%.

For the third group of samples (G3), which grouped points considered intermediate and mouth of May (rainy season), two species were indicative, mainly the diatom *C. concinnus* (70.1%).

Fifteen species were indicative for the fourth group of samples (G4), which grouped intermediate points and river mouth points of August (dry), especially the diatoms *Bellerochea malleus*, *L. annulata*, *C. belgica* and *O. longicruris*, with IndVal higher than 60%.

In the fifth group of samples (G5), which consisted mostly of intermediate and mouth points of November (dry), except for one point near the mouth of August, five species were indicative. Cyanobacterium *Phormidium* cf. *nigroviride* was the species with the highest indicator value, not only in group 5 (94.6%), but also in relation to all other values.

Redundancy analysis (RDA), based on indicator species, showed that the first two axes of the ordination analysis explained 24.3% of the total variance of the species. Among analyzed variables, pH, rainfall and salinity explained a significant proportion ($p < 0.05$) of the phytoplankton species variance.

The ordination diagram (Figure 6) indicated that in axis 1 (13.7%) there was a tendency to group samples closer to the source of the

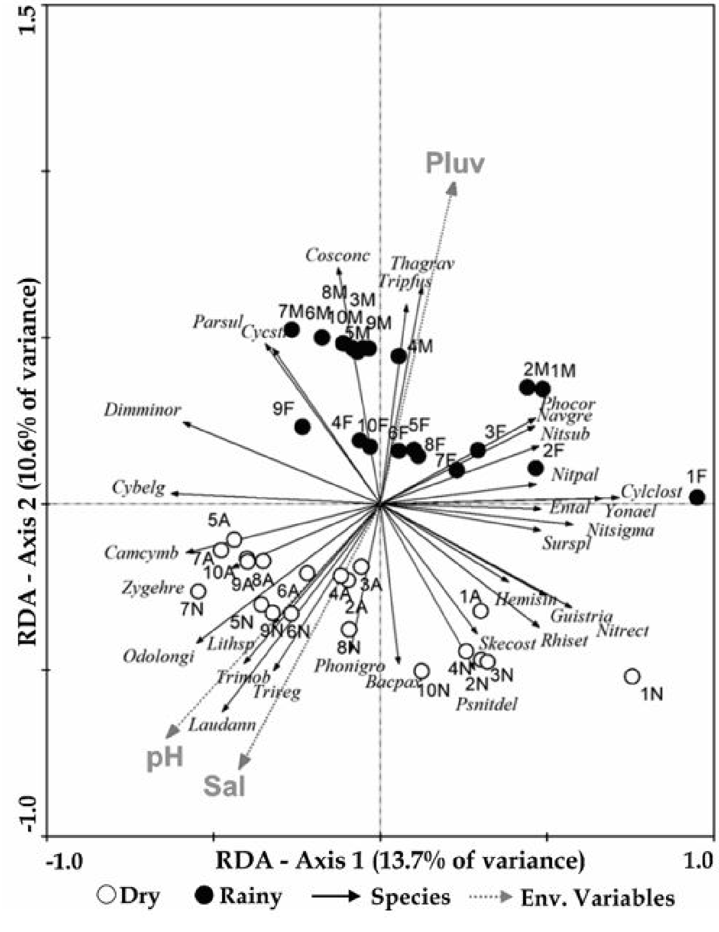

Figure 6. RDA ordering diagram showing relationships among species data and significant environmental variables ($p<0.005$). Bacpax = *Bacillaria paxillifera*; Camcymb = *Campylosira cymbelliformis*; Cosconc = *Coscinodiscus concinnus*; Cybelg = *Cymatosira belgica*; Cyclost = *Cylindrotheca closterium*; Cycstr = *Cyclotella striata*; Dimminor = *Dimeregramma minor*; Ental = *Entomoneis alata*; Guistria = *Guinardia striata*; Hemisin = *Hemiaulus sinensis*; Laudann = *Lauderia annulata*; Lithsp = *Lithodesmium* sp .; Navgre = *Navicula gregaria*; Nitpal = *Nitzschia palea*; Nitrect = *Nitzschia recta*; Nitsigma = *Nitzschia sigma*; Nitsub = *Nitzschia subtilis*; Odolongi = *Odontella longicruris*; Parsul = *Paralia sulcata*; Phocor = *Phormidium* cf. *corium*; Phonigro = *Phormidium* cf. *nigroviride*; Psnitdel = *Pseudo-nitzschia delicatissima*; Rhiset = *Rhizosolenia setigera*; Skecost = *Skeletonema costatum*; Surspl = *Surirella splendida*; Thagrav = *Thalassiosira* cf. *gravida*; Trimob = *Trieres mobiliensis*; Tripfus = *Tripos fusus*; Trireg = *Trieres regia*; Yonael = *Yonedaella* sp .; Zygehre = *Zygoceros ehrenbergii*; Pluv = Rainfall; Sal = salinity; F = February; M = May; A = August; N = November.

river in the right quadrants. The species most related to the springs in the rainy season were *N. sigma*, *Yonedaella* sp., *C. closterium*, *N. gregaria* and *Phormidium* cf. *corium*, while in the dry period were *Pseudo-nitzschia delicatissima* and *R. setigera*. In contrast, the species most related to the mouth were mostly grouped in the left quadrants, and during the rainy season, the species were more related to the rainfall vector, whereas in the dry period, predominant species of these portions were related more to the pH vector. It should be emphasized that the position of the vectors of the species *C. belgica* and *Dimmeregrama minor* indicate that these tend to occur more in samples located in the intermediate course and at the mouth of the river. Based on these data, it can be demonstrated that the gradient explained by axis 1 is related to the spatial pattern while that of axis 2 is related to a seasonal pattern.

In axis 2 (10.6%) the environmental variables pH, salinity and conductivity were more correlated to their negative portion (r = -0.66, -0.75, and -0.75, respectively), while the variable rainfall was correlated to the positive portion of this axis (r = 0.91). Thus, in the upper quadrants of the graph, the samples for the months of February and May (rainy season) were grouped, while on the left the samples of the months of August and November (dry period) were grouped. The species *T. fusus*, *Thalassiosira* cf. *gravida* and *C. concinnus* showed higher correlations to the rainfall parameter, while *T. mobiliensis*, *O. longicruris*, and *L. annulata* correlated with higher values of pH, conductivity and salinity. It is necessary to remember that these data corroborate the spatial and seasonal gradients tested in PERMANOVA, the groups formed in the Cluster Analysis and the strong seasonal gradient in the nonparametric correlation of Spearman.

DISCUSSION

This study showed that the environmental parameters evaluated had a considerable seasonal variation during the year 2015, evidenced by statistical tests and by nonparametric correlation of Spearman, mainly with respect to pH, salinity and rainfall.

Among sampled months, pH, salinity, temperature, rainfall and chlorophyll-*a*, were significantly different. In the dry period, pH values were higher, mainly due to the greater entrance of seawater into the estuary. This phenomenon may also explain the significant higher chlorophyll-*a* concentrations in August when compared to February, and may be associated with transport of sandy sediment to the estuary, introducing a larger number of individuals of epipsamic species, in particular *C. belgica.* In May, the amount of rainfall was higher when compared to the other months of sampling. Rainfall was recorded at the same time of sampling in the rainy season months, with May rainfall being more intense than February one. On the other hand, in the month of November, values of salinity were registered above the average salinity of the surface seawater (35). This is due to the fact that Curuperé River is a shallow environment, where the residence time of the water in the channel was higher in period of lower rainfall, in which an increase in the evaporation process is possible and, consequently, an increase of the concentration of dissolved salts per liter of river water. In this period, it is also possible to observe the presence of marine species in the local plankton community, as was emphasized in the relation between the grouping of samples and associations of species.

Taking into account the adjacent areas similar to Curuperé River, Monteiro et al. (2015) evaluated spatial and seasonal distribution of abiotic parameters in an Amazonian Estuary located on Marajó Island, northern Amazonian coast. The authors detected pH and salinity increase near the river mouth, as well as determined for Curuperé River, probably due the influence of marine water and their buffer pH system.

Diatoms were the dominant taxa recorded in Curuperé River. This pattern is due to their euryhaline nature (Procopiak et al., 2006) and the silica availability (essential element of diatom valve architecture) in estuaries (major source from continental weathering) (Riley 1967). A similar pattern can be observed in the adjacent estuarine regions of Guajará Bay and mouth of Guamá River (Paiva et al., 2006), on a segment of Guamá River (Monteiro et al., 2009), in Caeté River (Matos et al., 2011), Paracauari, Arari and Guajará rivers (Sodré et al., 2011) and Arienga River (Sena et al., 2015).

Ecological indexes also had significant variations, both seasonally and spatially. It was observed that upstream samples always had the diversity and equitability indexes greater than intermediate samples ones and, in some cases, even larger than in the samples close to river mouth. Due to the natural continental contribution in this area and the lower water circulation, the permanence of several species of freshwater, estuarine and neritic habits can be favored. These species take advantage of nutritional resources that probably accumulate in the place and consequently distribute more uniform in the environment. The decrease in diversity and, hence, equitability, can be commonly observed in estuaries or in eutrophic environments (Llebot et al., 2011), due to the unstable equilibrium of these systems. In general, low to intermediate diversity indexes (classification according to Margalef, 1978) were recorded in phytoplankton communities of Igarassu Estuary (Leão et al., 2008), Formoso Estuary (Silva et al., 2009) and estuaries of Ceará, Cocó, Pacoti and Pirangi rivers (Barroso et al., 2016), all on Brazilian northeast coast, and in Arari, Paracauari and Guajará Bay estuaries (Sodré et al., 2011), located on the northern coast of Brazil.

On the other hand, dominance increased in intermediate samples, mainly in August. We observe that when one or a few species dominate the community, diversity decreases (Omori and Ikeda, 1984). The increase in dominance was mainly due to the increase in the abundance of the species *C. belgica* and *D. minor*, interfering in the establishment of other species. Dominance of *D. minor* has already been observed in surf zone of an Amazonian beach (Sousa et al., 2009).

We verified that specific diversity is directly related to the ecosystem complexity and maturity. Thus, in intermediate degrees of water mixing, as observed in source of Curuperé River, we found the maximum diversity of the species, with a reduction of the dominance of a few precursor species and tending to the uniformity in the number of taxa. However, the high degree of water mixing in the intermediate and mouth samples allowed the occurrence of one or a few species resistant to this disturbance until its dominance (Belgrano and Brown, 2002; Leão et al., 2008).

Among the most significant species represented in RDA ordination analysis and with IndVal above 50%, characteristics of source, we can mention, in descending order of indicator value: *C. closterium*, cyanobacteria *Yonedaella* sp., *N. gregaria* and *N. sigma.* Koening et al. (2002), in an evaluation of phytoplankton community in estuary of Ipojuca River, found *C. closterium* associated with brackish water.

Yonedaella is a marine genus, with a habit primarily as periphytic, but its occurrence characterized the region near the source of Curuperé River, in February, being this month with greater salinity in the rainy season. Branco et al. (2003) identified this genus in the mangrove of Pernambuco State, northeastern Brazil, and stated that it can be found in both brackish and marine waters.

N. gregaria is characteristic of oligohaline habitats with higher nutrient intakes and was recorded in continental environments, in regions with more tropical characteristics (Day et al., 1995 and Montoya-Moreno et al., 2013). In Brazil, it was recorded in the inventories made in the marine and estuarine areas of southern Brazil (Moreira Filho et al., 1990) and in the north and northeast of Brazil (Moreira Filho et al., 1999).

N. sigma occurs in brackish waters and was identified by Silva et al. (2009) in the Formoso River Estuary, northeast of Brazil, being associated with periods of higher rainfall and higher concentrations of inorganic nitrogen compounds. This species was also found in Guajará Bay and the mouth of the Guamá River, both oligohaline ecosystems and with tidal influence, being part of the Amazonian estuary (Paiva et al., 2006).

T. fusus was the most significant in the intermediate and mouth group of samples of Curuperé River for February. This species has an optimum development between temperatures ranging from 14 to 28 °C and between salinities ranging from 20 to 34 (Baek et al., 2007), and is also able to grow under conditions of low nutrient concentration, although higher amounts of N and P in the environment favor higher rates of growth and increased abundance (Baek et al., 2008). In February, similar temperature and salinity conditions favored the occurrence of *T. fusus* in the estuary of the Curuperé River. This species is distributed along the north, northeast, southeast and south coast of Brazil (Odebrecht, 2010). The source of Curuperé River, where this species was shown to be indicative, is in a more restricted area, where marine water circulation is less prominent, which may favor the accumulation of nutrients and other organic substances.

In May, we can observe the occurrence of *C. concinnus*, the most significant species of the month. This species can be classified as eurihalin, r-strategist and commonly found in eutrophic environments (Reynolds, 2006). In Amazon region, *C. concinnus* is distributed through an extensive salinity gradient in estuaries, and also in sandy beaches (Paiva et al., 2006; Sousa et al., 2008; Monteiro et al., 2009; Sodré et al., 2011; Matos et al., 2012; Sena et al., 2015; Matos et al., 2016).

There was a differentiation in terms of indicator species for August and November. The most significant species related to August were *L. annulata, C. belgica* and *O. longicruris*, while the species *Phormidium* cf. *nigroviride* was the best indicator of November.

August was characterized by the higher syzygy tidal amplitude, when compared to the other months of sampling, because of the greater incursion of marine water into the estuary. In this context, *L. annulata* is very common and well distributed in oceanic phytoplankton (Round et al., 1990). This species has an occurrence along the northern coast of Brazil (Sousa et al., 2008; Santana et al., 2010), and in an estuary associated with a mangrove ecosystem in India (Biswas et al., 2010). *O. longicruris,* belonging to the diatomaceous group, has an eurialine pattern and occurs along the entire Brazilian coast (Eskinazi-Leça et al., 2010).

August was also the month with the highest values of turbidity. In this month, *C. belgica* and *D. minor* occurred in all samples. These species have a periphytic life habit, associated with sandy sediment (Round et al., 1990) and with ticoplankton habit (Vos and de Wolf, 1993). According to the observations made in the area, it was possible to notice that the studied environment showed a gradual sedimentation with sandy sediment coming from the coast and, the occurrence of these species corroborates the existence of this oceanographic phenomenon. The transport of sandy sediments into estuaries located in coastal zone of Pará State was discussed by Mácola and El-Robrini (2004) and El-Robrini et al. (2006). On the Guarás Island, located in Curuçá City, in Pará State, distant approximately 13 km from Curuperé River, the presence of an elongated submarine sandy crest was identified in one of its estuarine channels, which presents a preferential direction, the same of the tidal currents.

Finally, in November, the cyanobacteria *Phormidium* cf. *nigroviride* was the most indicative species, at the sampling point closest to the mouth of the Curuperé River. According to Branco et al. (2003), *P. nigroviride* is a marine species and has a habit mainly perithytic. In a mangrove ecosystem in the State of Pernambuco, northeastern Brazil, the cited authors found this cyanobacterium as a mass of individuals growing on the soil. In the estuary of the Curuperé River, we visualize, during the low tide, extensive periphytic biofilm adhered to muddy sediment of the estuary channel borders, mainly in the outer parts. Based on these characteristics, the occurrence of *P. nigroviride* in the plankton was probably due to water circulation that may have resuspended individuals. This last process was explained by Torgan (1989), in addition to the decrease of the turbidity, which causes greater penetration of solar radiation in the water column (Tundisi, 1970), conditions observed during the month of November. These may have been important factors for the abundance of the species, as well as conditions of eutrophication of the environment may be favoring the higher species abundance and higher chlorophyll-*a* concentrations since, in the vicinity of the study area, there are shrimp farms whose effluents may have been carried to the mouth of the Curuperé River by the estuarine currents of the Curuçá River (Paula et al., 2006; Brabo et al., 2016).

This behavior was verified by Palheta et al. (2012) in a marine shrimp farm, whose effluents, with high concentrations of total phosphorus (≈ 1.8 mg L^{-1}), caused an increase of this element and of chlorophyll-*a* (≈ 280 mg m^{-3}) in the adjacent estuary, become a hypereutrophic environment, probably because of the effluent disposal of the shrimp farm at the shrimp harvest. It should be stressed that during this same study, the chlorophyll-*a* and total phosphorus concentrations were lower and constant (<15 mg m^{-3} and <0.4 mg L^{-1}, respectively) in the estuary during the majority of cultivation period, while in the shrimp pond, these concentrations gradually increased, showing maximum peaks in the shrimp harvest. This last pattern was also observed by Silva et al. (2018) at shrimp pond in the Curuçá River, with the chlorophyll-*a* concentrations reaching maximum peak (471.34 mg m^{-3}). Therefore, in the Curuperé River, the higher chlorophyll-*a* concentration (>100 mg m^{-3}) observed in the sampling point next to the mouth (8), during the May, it could be probably caused by shrimp culture effluent, associated with the lower turbidity value (7 FAU). In the other hand, the average chlorophyll-*a* concentrations of both seasonal periods ($\approx$ 28 mg m^{-3}), indicates probably a nutrient enrichment when compared concentrations observed by Palheta et al. (2012), and thus, evidencing anthropic eutrophication process.

CONCLUSION

This study showed the presence of differences in the microphytoplankton community along the Curuperé estuarine axis, related to abiotic conditions which varies seasonally.

We observed a greater amount of freshwater and estuarine species in the rainy season months, while more species of marine habitat occurred in the dry season, where we observed a greater incursion of seawater into the estuary. This phenomenon was accompanied by transport of more intense sandy sediment, which carried a greater density of marine ticoplankton species, which indicate a gradual transformation of the environment in relation to estuarine hydrodynamic.

The diversity of species of the Curuperé River was directly related to the different degrees of water mixing, where near the source of the river, it was possible to find the maximum values of diversity and equitability indices, while the high degree of water mixing in the intermediate and in the mouth allowed the domination of a few species.

The most strongly indicative species of the environment, suggesting a process of eutrophication caused by possible shrimp farming effluents, inducing a great increase in chlorophyll - *a* concentrations. To confirm this fact, it is necessary to improve the knowledge about the biogeochemical dynamics of Curuperé River.

Knowledge of the ecology of phytoplankton organisms in this environment is of vital importance, and will serve as a subsidy for new studies in estuarine and coastal Amazonian areas and, mainly, to contribute to the conservation of biodiversity and local productivity.

REFERENCES

ANA – Agência Nacional de Águas. 2016. Hidroweb v3.1.1. Brasília: ANA. (Séries Históricas). Available from: <http://www.snirh.gov.br/hidroweb/apresentacao> Access on: 20 nov. 2016.

Anderson, M.J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology, 26(1): 32-46. http://dx.doi.org/**10.1111/j.1442-9993.2001.01070.pp.x**.

Azeria, E.T.; Fortin, D.; Hébert, C.; Peres-Neto, P.; Pothier, D.; Ruel, J.C. 2009. Using null model analysis of species co-occurrences to deconstruct biodiversity patterns and select indicator species. Diversity & Distributions, 15(6): 958-971. http://dx.doi.org/**10.1111/j.1472-4642.2009.00613.x**.

Baek, S.H.; Shimode, S.; Han, M.; Kikuchi, T. 2008. Growth of dinoflagellates, *Ceratium furca* and *Ceratium fusus* in Sagami Bay, Japan: The role of nutrients. Harmful Algae, 7(6): 729-739. http://dx.doi.org/**10.1016/j.hal.2008.02.007**.

Baek, S.H.; Shimode, S.; Kikuchi, T. 2007. Reproductive ecology of the dominant dinoflagellate, *Ceratium fusus*, in coastal area of Sagami Bay, Japan. Journal of Oceanography, 63(1): 35-45. http://dx.doi.org/**10.1007/s10872-007-0004-y**.

Barroso, H.S.; Becker, H.; Melo, V.M.M. 2016. Influence of river discharge on phytoplankton structure and nutrient concentrations in four tropical semiarid estuaries. Brazilian Journal of Oceanography, 64(1): 37-48. http://dx.doi.org/**10.1590/S1679-87592016101406401**.

Belgrano, A.; Brown, J.H. 2002. Oceans under the macroscope. Nature, 419(6903): 128-129. http://dx.doi.org/**10.1038/419128a**.

Berger, W.H.; Parker, F.L. 1970. Diversity of planktonic foraminifera in Deep-Sea sediments. Science, 168(3927): 1345-1347. http://dx.doi.org/**10.1126/science.168.3937.1345**.

Biswas, H.; Dey, M.; Ganguly, D.; De, T.K.; Ghosh, S.; Jana, T.K. 2010. Comparative analysis of phytoplankton composition and abundance over a two-decade period at the Land–Ocean Boundary of a Tropical Mangrove Ecosystem. Estuaries and Coasts, 33(2): 384-394. http://dx.doi.org/**10.1007/s12237-009-9193-5**.

Boynton, W.R.; Kemp, W.M.; Keefe, C.W. 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. In: Kennedy, V.S. Estuarine comparisons. New York: Academic Press. p. 69-90.

Brabo, M.F.; Ferreira, L.A.; Veras, G.C. 2016. Aspectos históricos do desenvolvimento da piscicultura no nordeste paraense: trajetória do protagonismo à estagnação. Revista em Agronegócio e Meio Ambiente, 9(2): 595-615. http://dx.doi.org/**10.17765/2176-9168.2016v9n3p595-615**.

Branco, L.H.Z.; Moura, A.N.; Silva, A.C.; Bittencourt-Oliveira, M.C. 2003. Biodiversidade e considerações biogeográficas das Cyanobacteria de uma área de manguezal do estado de Pernambuco, Brasil. Acta Botanica Brasílica, 17(4): 585-596. http://dx.doi.org/**10.1590/S0102-33062003000400010**.

Cloern, J.E. 1987. Turbidity as a control on phytoplankton biomass and productivity in estuaries. Continental Shelf Research, 7(11-12): 1367-1381. http://dx.doi.org/**10.1016/0278-4343(87)90042-2**.

Cloern, J.E.; Foster, S.Q.; Kleckner, A.E. 2014. Phytoplankton primary production in the world's estuarine-coastal ecosystems. Biogeosciences, 11(9): 2477-2501. http://dx.doi.org/**10.5194/bg-11-2477-2014**.

Costa, B.O. 2010. Variação nictemeral do microfitoplâncton em um estuário do nordeste paraense brasil. Belém, Brasil. Belém. 102f. (Dissertação de Mestrado. Programa de Pós-graduação em Ecologia Aquática e Pesca, UFPA). Available from: <http://repositorio.ufpa.br/jspui/handle/2011/3506> Access on: 25 aug. 2018.

Costa, R.M.; Leite, N.R.; Pereira, L.C.C. 2009. Mesozooplankton of the Curuçá Estuary (Amazon Coast, Brazil). Journal of Coastal Research, 56(1): 400-404. Available from: <https://www.jstor.org/stable/pdf/25737606.pdf?seq=1> Access on: 6 jun. 2017.

Day, S.A.; Wickham, R.P.; Entwisle, T.J.; Tyler, P.A. 1995. Bibliographic checklist of non-marine algae in Australia. England: Australian Biological Resources Study. v. 4, 276p. (Flora of Australia, Supplementary Series).

Desikachary, T.S. 1959. Cyanophyta. New Delhi: Council of Agricultural Research. 686p.

DHN – Diretoria de hidrografia e navegação. 2015. Previsões de marés. Available from: <https://www.marinha.mil.br/chm/tabuas-de-mare>. Access on: 15 jan. 2015.

Dominguez, J.M.L. 2009. The coastal zone of Brazil. In: Dillenburg, S.R.; Hesp, P.A. Geology and geomorphology of holocene coastal barriers of Brazil. Berlin: Springer. p. 17-51. http://dx.doi.org/**10.1007/978-3-540-44771-9_2**.

Dufrêne, M.; Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs, 67(3): 345-366. http://dx.doi.org/**10.1890/0012-9615(1997)067[0345:saaist]2.0.co;2**.

El-Robrini, M.; Alves, M.A.M.S.; Souza Filho, P.W.M.; El-Robrini, M.H.S.; Silva Júnior, O.G.; França, C.F. 2006. Atlas de erosão e progradação da zona costeira do estado do Pará – região amazônica: áreas oceânica e estuarina. In: Muehe, D. Atlas de erosão e progradação da zona costeira brasileira. São Paulo: MMA. p. 1-34.

Eskinazi-Leça, E.; Cunha, M.G.G.S.; Santiago, M.F.; Borges, G.C.P.; Lima, J.M.C.; Silva, M.H.; Lima, J.P.; Menezes, M. 2010. Bacillariophyceae. In: Forzza, R.C. Catálogo de plantas e fungos do Brasil. Rio de Janeiro: Andrea Jakobsson Estúdio, Instituto de Pesquisas, Jardim Botânico do Rio de Janeiro. v. 1, p. 262-309. http://doi.org/**10.7476/9788560035083**.

Giarrizzo, T.; Krumme, U. 2009. Temporal patterns in the occurrence of selected tropical fishes in mangrove creeks: implications for the fisheries management in North Brazil. Brazilian Archives of Biology and Technology, 52(3): 679-688. http://dx.doi.org/**10.1590/S1516-89132009000300020**.

Guiry, M.D.; Guiry, G.M. 2017. AlgaeBase is a global algal database of taxonomic, nomenclatural and distributional information. Galway: National University of Ireland. Available from: <http://www.algaebase.org> Access on: 6 jun. 2017.

Hammer, Ø.; Harper, D.A.T.; Ryan, P.D. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1): 1-9. Available from: <http://palaeo-electronica.org/2001_1/past/issue1_01.htm> Access on: 6 jun. 2017.

Koening, M.L.; Eskinazi-Leça, E.; Neumann-Leitão, S.; Macedo, S.J. 2002. Impactos da construção do porto de Suape sobre a comunidade fitoplanctônica no estuário do rio Ipojuca (Pernambuco-Brasil). Acta Botanica Brasílica, 16(4): 407-420. http://dx.doi.org/**10.1590/S0102-33062002000400004**.

Leão, B.M.; Passavante, J.C.O.; Silva-Cunha, M.G.G.; Santiago, M.F. 2008. Ecologia do microfitoplâncton do estuário do rio Igarassu, PE, Brasil. Acta Botanica Brasílica, 22(3): 711-722. http://dx.doi.org/**10.1590/S0102-33062008000300009**.

Llebot, C.; Sole, J.; Delgado, M.; Fernandez-Tejedor, M.; Camp, J.; Estrada, M. 2011. Hydrographical forcing and phytoplankton variability in two semi-enclosed estuarine bays. Journal of Marine Systems, 86(3-4): 69-86. http://dx.doi.org/**10.1016/j.jmarsys.2011.01.004**.

Mácola, G.; El-Robrini, M. 2004. Ilha dos Guarás (Mariteua). Município de Curuçá (NE do Pará): aspectos físicos, meteorológicos e oceanográficos. Belém: DNPM/CPRM. 35p. Relatório final.

Margalef, R. 1978. Les types biologiques de phytoplankton consideres comme des alternatives de survie dans um millieu instable. Oceanologica Acta, 4(1): 493-509.

Matos, J.B.; Cardoso, E.H.N.; Pereira, L.C.C.; Costa, R.M. 2013. Diatomáceas cêntricas da zona de arrebentação de uma ilha amazônica. Tropical Oceanography, 41(1-2): 54-66. http://dx.doi.org/**10.5914/tropocean.v41i1-2.5414**.

Matos, J.B.; Oliveira, S.M.O.; Pereira, L.C.C.; Costa, R.M. 2016. Structure and temporal variation of the phytoplankton of a macrotidal beach from the Amazon coastal zone. Anais da Academia Brasileira de Ciências, 88(3): 1325-1339. http://dx.doi.org/**10.1590/0001-3765201620150688**.

Matos, J.B.; Silva, N.I.S.; Pereira, L.C.C.; Costa, R.M. 2012. Caracterização quali-quantitativa do fitoplâncton da zona de arrebentação de uma praia amazônica. Acta Botanica Brasílica, 26(4): 979-990. http://dx.doi.org/**10.1590/S0102-33062012000400028**.

Matos, J.B.; Sodré, D.K.L.; Costa, K.G.; Pereira, L.C.C.; Costa, R.M. 2011. Spatial and temporal variation in the composition and biomass of phytoplankton in an Amazonian estuary. Journal of Coastal Research, 64: 1525-1529. Available from: <https://www.jstor.org/stable/26482430?seq=1> Access on: 6 jun. 2017.

McCune, B.; Mefford, M.J. 2011. PC-ORD. Multivariate Analysis of Ecological Data. version 6. Gleneden Beach, Oregon: MjM Software.

Monteiro, M.D.R.; Melo, N.F.A.C.; Alves, M.A.M.S.; Paiva, R.S. 2009. Composição e distribuição do microfitoplâncton do rio Guamá no trecho entre Belém e São Miguel do Guamá, Pará, Brasil. Boletim do Museu Paraense Emílio Goeldi. Ciências Naturais, 4(3): 341-351. Available from: <http://scielo.iec.gov.br/pdf/bmpegcn/v4n3/v4n3a05.pdf> Access on: 6 jun. 2017.

Monteiro, S.M.; El-Robrini, M.; Alves, I.C.C. 2015. Dinâmica sazonal de nutrientes em estuário amazônico. Mercator (Fortaleza), 14(1): 151-162. http://dx.doi.org/**10.4215/RM2015.1401.0010**.

Montoya-Moreno, Y.; Sala, S.; Vouilloud, A.; Aguirre, N.; Plata-Diaz, Y. 2013. Lista de las diatomeas de ambientes continentales de Colombia. Biota Colombiana, 14(2): 13-78. http://dx.doi.org/**10.21068/bc.v14i2.282**.

Moraes, B.C.; Costa, J.M.N.; Costa, A.C.L. 2005. Variação espacial e temporal da precipitação no estado do Pará. Acta Amazonica, 35(2): 207-214. http://dx.doi.org/**10.1590/S0044-59672005000200010**.

Moreira-Filho, H.; Eskinazi-Leça, E.; Valenti-Moreira, I.M.; Cunha, J.A. 1999. Avaliação taxonômica e ecológica das diatomáceas (Chrysophyta, Bacillariophyceae) marinhas e estuarinas nos estados de Pernambuco, Paraíba, Rio Grande do Norte, Ceará, Piauí, Maranhão, Pará e Amapá. Tropical Oceanography, 27(1): 55-90. http://dx.doi.org/**10.5914/tropocean.v27i1.2773**.

Moreira-Filho, H.; Valente-Moreira, I.M.; Souza-Mosimann, R.M.; Cunha, J.A. 1990. Avaliação florística e ecológica das diatomáceas (Chrysophyta-Bacillariophyceae) marinhas e estuarinas nos estados do Paraná, Santa Catarina e Rio Grande do Sul. Estudos de Biologia, 25: 5-48.

Moro, R.S.; Fürstenberger, C.B. 1997. Catálogo dos principais parâmetros ecológicos de diatomáceas não-marinhas. Ponta Grossa: Ed. UEPG. 282p.

Nittrouer, C.A.; Brunskill, G.J.; Figueiredo, A.G. 1995. Importance of tropical coastal environments. Geo-Marine Letters, 15(3-4): 121-126. http://dx.doi.org/**10.1007/bf01204452**.

Odebrecht, C. 2010. Dinophyceae. In: Forzza, R.C. Catálogo de plantas e fungos do Brasil. Rio de Janeiro: Andrea Jakobsson Estúdio, Instituto de Pesquisas, Jardim Botânico do Rio de Janeiro. v. 1, p. 366-383. http://doi.org/**10.7476/9788560035083**.

Omori, M.; Ikeda, T. 1984. Methods in marine zooplankton ecology. New York: Wiley Interscience Publication. 332p.

Paiva, R.S.; Eskinazi-Leça, E.; Passavante, J.Z.O.; Silva-Cunha, M.G.G.; Melo, N.F.A.C. 2006. Considerações ecológicas sobre o fitoplâncton da baía do Guajará e foz do rio Guamá (Pará, Brasil). Boletim do Museu Paraense Emílio Goeldi. Ciências Naturais, 1(2): 133-146. Available from: <http://scielo.iec.gov.br/pdf/bmpegcn/v1n2/v1n2a10.pdf>. Access on: 6 jun. 2017.

Palheta, G.D.A.; Takata, R.; Palheta, H.G.A.; Melo, N.F.A.C.; Rocha, R.M.R.; Santos, M.L.S. 2012. Índices de qualidade da água como ferramenta no monitoramento da carcinicultura paraense. Boletim Técnico-Científico do CEPNOR, 12(1): 9-15. http://dx.doi.org/**10.17080/1676-5664/btcc.v12n1p9-15**.

Paula, J.H.C.; Rosa Filho, J.S.; Souza, A.L.B.; Aviz, D.E. 2006. A meiofauna como indicadora de impactos da carcinicultura no estuário de Curuçá (PA). Boletim do Labohidro, 19: 61-72. <http://www.periodicoseletronicos.ufma.br/index.php/blabohidro/article/view/2105/262> Access on: 6 jun. 2017.

Pielou, E.C. 1969. An introduction to mathematical ecology. New York: Wiley. 286p.

Poos, M.S.; Jackson, D.A. 2012. Addressing the removal of rare species in multivariate bioassessments: The impact of methodological choices. Ecological Indicators, 18: 82-90. http://dx.doi.org/**10.1016/j.ecolind.2011.10.008**.

Procopiak, L.K.; Fernandes, L.F.; Moreira-Filho, H. 2006. Diatomáceas (Bacillariophyta) marinhas e estuarinas do Paraná, Sul do Brasil: lista de espécies com ênfase em espécies nocivas. Biota Neotropica, 6(3): 1-28. http://dx.doi.org/**10.1590/S1676-06032006000300013**.

Reynolds, C. Ecology of phytoplankton. Cambridge: Cambridge University Press, 2006. p. 535.

Riley, G.A. 1967. The plankton of estuaries. In: Lauff, G. H. (Ed.). Estuaries. Washington: American Association for the Advancement of Science Publication. v. 83, p. 316-326.

Round, F.E.; Crawford, R.M.; Mann, D.G. 1990. The diatoms, biology e morphology of the Genera. Cambridge: Cambridge University. 747p.

Santana, D.S.; Paiva, R.S.; Pereira, L.C.C.; Costa, R.M. 2010. Microphytoplankton of the Marapanim estuary (Pará, northern Brazil). Tropical Oceanography, 38(2): 153-164. http://dx.doi.org/**10.5914/tropocean.v38i2.5168**.

Schwendenmann, L.; Riecke, R.; Lara, R. 2006. Solute dynamics in a North Brazilian mangrove: the influence of sediment permeability and freshwater input. Wetlands Ecology and Management, 14(5): 463-475. http://dx.doi.org/**10.1007/s11273-006-0008-1**.

Sena, B.A.; Costa, V.B.; Nakayama, L.; Rocha, R.M. 2015. Composition of microphytoplankton of an estuarine Amazon River, Pará, Brazil. Biota Amazônia, 5(2): 1-9. http://dx.doi.org/**10.18561/2179-5746/biotaamazonia.v5n2p1-9**.

Shannon, C.E. 1948. A mathematical theory of communication. The Bell System Technical Journal, 27: 379-423. http://dx.doi.org/**10.1002/j.1538-7305.1948.tb01338.x**.

Silva, M.H.; Silva-Cunha, M.G.G.; Passavante, J.Z.O.; Grego, C.K.S.; Muniz, K. 2009. Seasonal and spatial structure of microphytoplankton in the tropical estuary of Formoso River, Pernambuco State, Brazil. Acta Botanica Brasílica, 23(2): 355-368. http://dx.doi.org/**10.1590/S0102-33062009000200007**.

Silva, R.S.; Souza, A.S.L.; Palheta, G.D.A.; Costa, M.S.M.; Melo, N.F.A.C. 2018. Diversidade e biomassa fitoplanctônica em viveiro de carcinicultura marinha no estado do Pará. Veterinária e Zootecnia, 25(2): 142-155. http://dx.doi.org/**10.35172/rvz.2018.v25.19**.

Sodré, D.K.L.; Matos, J.B.; Costa, K.G.; Pereira, L.C.C.; Costa, R.M. 2011. Tide-induced Changes in the Phytoplankton Communities of three Amazon Estuaries (Pará – Northern Brazil). Journal of Coastal Research, SI 64:1574-1578.

Sousa, E.B.; Costa, V.B.; Pereira, L.C.C.; Costa, R.M. 2008. Microphytoplankton of Amazon coastal waters: Canela Island (Bragança, Pará State, Brazil). Acta Botanica Brasílica, 22(3): 626-636. http://dx.doi.org/**10.1590/S0102-33062008000300004**.

Sousa, E.B.; Costa, V.B.; Pereira, L.C.C.; Costa, R.M. 2009. Variação temporal do fitoplâncton e dos parâmetros hidrológicos da zona de arrebentação da Ilha Canela (Bragança, Pará, Brasil). Acta Botanica Brasílica, 23(4): 1084-1095. http://dx.doi.org/**10.1590/S0102-33062009000400018**.

Sousa, J.A.; Cunha, K.N.; Nunes, Z.M.P. 2013. Influence of seasonal factors on the quality of the water of a tidal creek on the Amazon Coast of Brazil. Journal of Coastal Research, 65: 129-134. http://dx.doi.org/**10.2112/SI65-023.1**.

Souza, M.F.L.; Eça, G.F.; Silva, M.A.M.; Amorim, F.A.C.; Lôbo, I.P. 2009. Distribuição de nutrientes dissolvidos e clorofila-a no estuário do rio Cachoeira, nordeste do Brasil. Atlântica, 31(1): 107-121. http://dx.doi.org/**10.5088/atlântica.v31i1.1537**.

Souza-Filho, P.W.M. 2005. Costa de manguezais de macromaré da Amazônia: cenários morfológicos, mapeamento e quantificação de áreas usando dados de sensores remotos. Revista Brasileira de Geofísica, 23(4): 427-435. http://dx.doi.org/**10.1590/S0102-261X2005000400006**.

Steidinger, K.A.; Tangen, K. 1997. Chapter 3 - Dinoflagellates. In: Tomas, C.R. Identifying marine phytoplankton. Florida: Academic Press. p. 387-584. http://doi.org/**10.1016/B978-012693018-4/50005-7**.

Strickland, J.D.H.; Parsons, T.R. 1972. A practical handbook of sea water analysis. Ottawa: Fisheries Research Board of Canadá. Bulletin 167. 328p.

Ter Braak, C.J.F.; Milauer, P.S. 2002. CANOCO - reference manual and CanoDraw for windows user's guide: software for canonical community ordination (version 4.5). Ithaca: CANOCO.

Torgan, L.C. 1989. Floração de algas: composição, causas e consequências. Insula (Madrid), 19: 15-34. Available from: <https://periodicos.ufsc.br/index.php/insula/article/view/22299/20259> Access on: 6 jun. 2017.

Tundisi, J.G. 1970. O plâncton estuarino. Contribuições avulsas do Instituto Oceanográfico da Universidade de São Paulo. Série Oceanografia Biológica, 19: 1-22.

Utermöhl, H. 1958. Zur Vervollkommnung der quantitativen phytoplankton-methodik. Mitteilungen Internationale Vereiningung fur Teoretische und Angewandle Limnologie, 9: 1-38.

Valentin, J.L. 2012. Ecologia Numérica: uma introdução à análise multivariada de dados ecológicos. Rio de Janeiro: Interciência. 154p.

Vos, P.C.; de Wolf, H. 1993. Diatoms as a tool for reconstructing sedimentary environments in coastal wetlands; methodological aspects. Hydrobiologia, 269(1): 285-296. http://dx.doi.org/**10.1007/bf00028027**.

Zar, J.H. 1999. Biostatistical analysis. Upper Saddle River, New Jersey: Prentice Hall. 944p.