MICROPHYTOPLANKTON DYNAMICS IN CURUPERÉ ESTUARY AT THE AMAZONIAN MANGROVE ECOSYSTEM*

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 CURUPERÊ EM UM ECOSISTEMA DE MANGUEZAL AMAZÔNICO

RESUMO

O objetivo deste estudo foi avaliar a dinâmica microfitoplânctônica e os parâmetros ambientais no estuário do rio Curuperê, 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 outubro, 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 microfitoplânctônica. 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 ao 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 intense 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 (Nitrrouer 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 km² and are characterized by irregular geomorphology, with 23 estuaries and 30 catchment areas, draining 330,000 km² (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 (Souza 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), Sodrê 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 km² 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 ºC (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).

Sampling 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
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 nanoplanckton 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 variables 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 Odébrecht (2010) for dinoflagellates and Desikacharya (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-α (Figure 3c) (p<0.05), as tested by Kruskall-Wallis. The pH values showed significant differences between the sampling months (Table 2).

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     | 16.17±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-α (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-α; (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 Curupé 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 first 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 longicurvis* 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 higher than February and November. We observed a significant difference between the specific diversity of source and mouth of Curupé 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) Rafís, *C. concinnus* W. Smith, *T. nitzschioides* (Grunow) Mereschkowsky and *Thalassionema frauenfeldii* (Grunow) Tempère & Peragallo.
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. longicuris, 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 (Campylopeis grevillea, Diploneis bombus, D. littoralis and D. crabro). There is the presence of a branched filamentous cyanobacteria (Scytonema sp.).

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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 heterocyes (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., Thalassiosira longissima and Pseudo-nitzschia delicatissima).

Finally, association 5 has predominantly estuarine-neritic habitats, composed mostly of diatoms (Aulacoseira granulata, Fragilaria acus, Polymyxus coronalis and Pseudo-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 = Campyloheis grevilleu; Skesp = Skeletonema sp.; Dipbomb = Diploneis bombus; Cosrad = Coscinodiscus radiatus; Thaecc = Thalassiosira eccentrica; Dplitt = Diploneis littoralis; Cycmen = Cyclotella meneghiniana; Melnum = Melosira nummuloides; Dipcr = Diplococcus crabro; Scytsp = Scytonema sp.; Association 3: Cyclost = Cylindrotheca closterium; Nitsigma = Nitzschia sigma; Yonael = Yoneaella sp.; Phocor = Phormidium cf. corium; Navare = Navicula arenaria; Navgre = Navicula gregaria; Nitsigmo = Nitzschia sigmoidea; Association 4: Bacpax = Bacillaria paxillifera; Thalong = Thalassiosira 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 = Pseudo-nitzschia seriata.
Table 3. Significant indicator species (IndVal). mar = marine; ner = neritic; oce = oceanic; eur = eurihaline; mhb = mesohalobic; olig = oligohaline; s = brackish water, but at unspecified salt concentrations; I = indifferent, tolerates small amounts of salt; plc = planktonic; tcp = ticooplanktonic; 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 |
| Yonedaela sp.                     | 1              | 69.6       | 22.6  | 7.59      | 0.0001   | s; mar; per; epf; tcp |
| Navicula gregaria                 | 1              | 66.7       | 21.5  | 9.8       | 0.0009   | olig, s; per; epl |
| Nitzschia recta                   | 1              | 54.7       | 15.5  | 7.56      | 0.001    | s; per; tcp    |
| Nitzschia arenaria                | 1              | 54.2       | 26.5  | 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   | olig; 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 sergera              | 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; 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; 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; plc  |
| Pleurosigma marinus               | 1              | 31.3       | 13.6  | 7.19      | 0.0316   | mar; s; ner; plc |
| Nitzschia palea                   | 1              | 30         | 11.5  | 7.24      | 0.03     | olig; per; plc |
| Chaetoceros decipiens             | 1              | 30         | 11.3  | 7.37      | 0.0308   | mar; s; 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. graviga         | 2              | 43.1       | 25.8  | 4.52      | 0.0014   | mar; ner; plc |
| Campyloneis grevilei              | 2              | 40         | 28.2  | 6.16      | 0.0478   | mar; eur; plc |
| Pseudo-nitzschia delicatissima    | 2              | 35.3       | 22.4  | 5.8       | 0.0335   | mar; s; plc   |
| Cyclotella steforum               | 2              | 33.7       | 17.6  | 6.62      | 0.0269   | mar; ner; tcp |
| Coscinodiscus concinnus           | 3              | 70.1       | 32.4  | 6         | 0.0001   | mar; eur; 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; 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; plc |
| Odontella longicornis             | 4              | 64.9       | 26     | 6.52      | 0.0001   | mar; eur; plc |
| Zygoceros ehrenbergii             | 4              | 58.9       | 25.1  | 6.08      | 0.0001   | mar; eur; epf; tcp |
| Campylostriga cymbelliformis      | 4              | 54.2       | 25.1  | 5.99      | 0.0005   | mar; eur; per; plc |
| Trybliionella 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; epf; 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; 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; eur; plc |
| Actinoptychus senarius            | 4              | 32.1       | 14.7  | 7.54      | 0.0231   | mar; eur; plc |
| Trybliionella 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; plc |
| Trieres mobiliensis               | 5              | 45.5       | 22.7  | 5.99      | 0.0033   | mar; 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. fusu* 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 *Bellerococha 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

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**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*; Cyestr = *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 mobilensis*; Tri fusus = *Tripos fusus*; Treg = *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 \textit{N. sigma}, \textit{Yondaella} sp., \textit{C. closterium}, \textit{N. gregaria} and \textit{Phormidium cf. corium}, while in the dry period were \textit{Pseudo-nitzschia delicatissima} and \textit{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 \textit{C. belgica} and \textit{Dimmeregramma 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 \textit{T. fusus}, \textit{Thalassiosira cf. gravida} and \textit{C. concinnum} showed higher correlations to the rainfall parameter, while \textit{T. mobiliensis}, \textit{O. longicirris}, and \textit{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-\textit{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-\textit{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 \textit{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 Curupé 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 Curupé 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 Curupé River, probably due the influence of marine water and their buffer pH system.

Diatoms were the dominant taxa recorded in Curupé 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 (Omor and Ikeda, 1984). The increase in dominance was mainly due to the increase in the abundance of the species \textit{C. belgica} and \textit{D. minor}, interfering in the establishment of other species. Dominance of \textit{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 Curupé 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 Ipójuca 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 euhaline, 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. longicurulis, 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. longicurulis, belonging to the diatomaceous group, has an eurialine pattern and occurs along the entire Brazilian coast (Eskininza-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 periphytic. In a mangrove ecosystem in the State of Pernambuco, northeastern Brazil, the cited authors found this cyanobacteirum 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-α 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-α (≈ 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 mentioned 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 (≈ 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 tico-plankton 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.

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