PANAMJAS
Pan-American Journal of Aquatic Sciences

Microphytoplankton community and environmental variables in an urban eutrophic estuary (Capibaribe River, Northeast Brazil).

EVELINE P. AQUINO, GISLAYNE C. P. BORGES, MARCOS HONORATO-DA-SILVA, JOSÉ Z. O. PASSAVANTE, MARIA G. G. S. CUNHA

Federal University of Pernambuco. Professor Moraes Rego Avenue, 123, Cidade Universitaria, Recife City, Pernambuco, 50670-901. Email: eveline_aquino@yahoo.com.br

Abstract. Estuaries are dynamic ecosystems with high spatial heterogeneity greatly and are influenced by seasonal and tidal cycles. This study investigated the effects of spatial, seasonal, and tidal variations on the physical, chemical, and biological characteristics of water and the consequences for the structure and distribution of the microphytoplankton community in the Capibaribe River estuary (Northeast Brazil). We identified 127 microphytoplanktonic taxa, dominated by diatoms (phylum Ochrophyta), which formed 54% of the total, followed by the phyla Cyanobacteria (18%), Chlorophyta (13%), Myzozoa (7%), Euglenozoa (5%), and Charophyta (3%). We observed a significant relationship between abiotic and biotic variables. Both spatial and tidal changes affected the distribution of species and chlorophyll *a* because of salinity variations. The microphytoplankton species had low relative abundance. The cyanobacterium *Planktothrix agardhii* (G.) Anagnostidis & Komárek and diatom *Cyclotella* sp. were dominant during the rainy and dry seasons, respectively. Based on the seasonal distribution of the phytoplankton in our study, we suggest periodic monitoring of this area to identify the long-term effects of environmental variables on the phytoplankton. This approach is important for understanding the dynamics of *P. agardhii* due to its potential toxicity.

Keywords: diatoms, cyanobacteria, salinity, estuarine dynamics.

Resumo. Comunidade fitoplanctônica e variáveis ambientais em um estuário eutrófico urbano (rio Capibaribe, nordeste do Brasil). Os estuários são ecossistemas dinâmicos, de elevada heterogeneidade espacial e influenciados pelo regime de marés e sazonalidade. Esse trabalho objetivou investigar o efeito da espacialidade, sazonalidade e ação das marés sobre as características físicas, químicas e biológicas da água e suas consequências para a estrutura e distribuição da comunidade fitoplanctônica do estuário do rio Capibaribe (Nordeste do Brasil). Identificamos 127 táxons fitoplanctônicos, dentre os quais, as diatomáceas (filo Ochrophyta) estiveram melhor representadas (54% do total), seguido dos filos Cyanobacteria (18%), Chlorophyta (13%), Myzozoa (7%), Euglenozoa (5%) e Charophyta (3%). Observamos uma relação significativa entre as variáveis bióticas e abióticas. Espacialidade e ação das marés afetaram na distribuição das espécies e da clorofila *a*, como consequência da variação da salinidade. As espécies apresentaram baixa abundância relativa. A cianobactéria *Planktohtrix agardhii* (G.) Anagnostidis & Komárek e a diatomácea *Cyclotella* sp. dominaram durante os períodos chuvoso e de estiagem, respectivamente. Com base na distribuição sazonal do fitoplâncton no presente estudo, sugerimos o monitoramento periódico da área, para constatar o efeito das variáveis ambientais sobre o fitoplâncton a longo prazo, bem como, para o conhecimento da dinâmica de *P. agardhii*, devido ao potencial tóxico para a espécie.

Palavras-chave: diatomáceas, cianobactérias, salinidade, dinâmica estuarina.

Introduction

The majority of coastal ecosystems are highly affected by anthropic actions. This is the case for the estuary of the Capibaribe River, in Northeast Brazil (Macedo *et al.* 2007, Santiago *et al.* 2010, Flores-Montes *et al.* 2011), a highly urbanized area.

It is characterised as strongly eutrophicated (Flores-Montes *et al.* 2011) due to the intense discharge of domestic and industrial effluents. Although anthropised, data have shown that it has considerable biological diversity because of water renewal from the high dynamism of the tides (Srh 2010).

Estuarine ecosystems are generally strongly affected by tidal action, which, together with the river flow, provides large spatial heterogeneity. In addition, tropical estuaries are subject to short term changes due to climatic periods in the region. Thus, the biotic and abiotic parameters of water change according to the effects of tidal dynamics and spatial and seasonal variations (Paerl & Justic 2013).

Considering that phytoplankton provide rapid responses to environmental changes, studies with these organisms are necessary to identify the bioindicators and to clarify which abiotic variables may influence its distribution and dynamics. Thus, we aimed to evaluate the microphytoplankton species as indicators of environmental quality in a tropical estuary (the Capibaribe River) in Northeast Brazil. Before this, we intended to answer the follow question: "How are environmental variables (physical, chemical, and biological) distributed across seasonal, spatial, and tidal variations, and how do they influence the composition, structure, and distribution of the microphytoplankton community?" Since it is an estuarine ecosystem, we expect that diatoms well be represented. This is usually observed for other estuaries (Lacerda *et al.* 2004, Perez *et al.* 2009) due to the euryhaline characteristics of diatoms (Reynolds 2006).

Material and methods

The Capibaribe River estuary is located in the downtown of Recife City, Northeast Brazil (Fig. 1). The river cross 42 cities in its basin, and its main effluents are water reservoirs such as Tapacurá, Jucazinho, Carpina, Goitá, and Poço Fundo. The area has a high degree of urbanization, leading to different, sometimes conflicting, uses of water, such as intensive fishing, tourism, discharge of domestic and industrial effluents, transport of products through the Port of Recife, mangrove deforestation, and coastal erosion. In all units of its basin, the Capibaribe River is considered polluted and eutrophic, as confirmed by high concentrations of nutrients, thermotolerant coliforms, and undetectable levels of dissolved oxygen (Flores-Montes *et al.* 2011, Brayner *et al.* 2003). This is a consequence of the intense and inadequate discharge of domestic and industrial effluents.

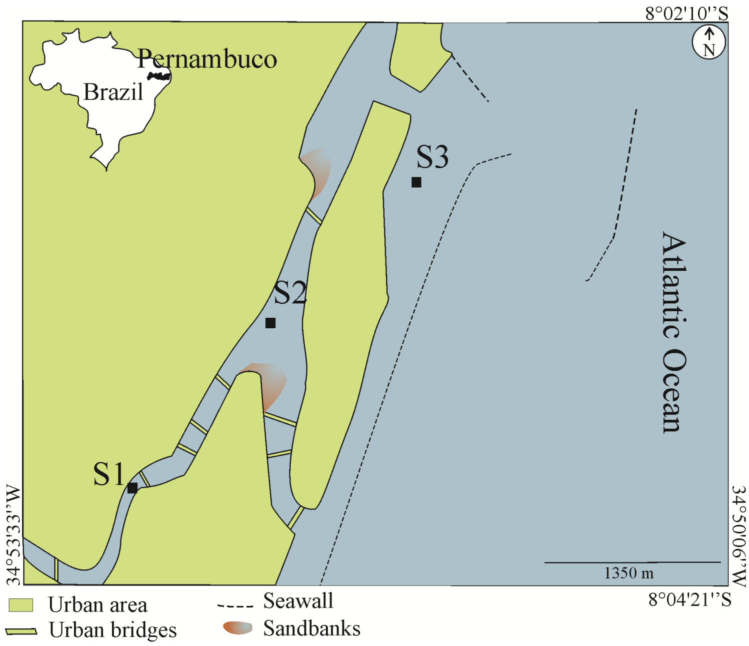

Figure 1. Capibaribe River estuary (Pernambuco State, Northeast of Brazil), where is located the sampling stations S1, S2, and S3.

Despite its being strongly affected by anthropic activities, Lins *et al.* (2007) have demonstrated that the Capibaribe River has considerable biological diversity compared to other coastal rivers in Brazil. These authors demonstrated an increased abundance of ichthyofauna downstream in the Capibaribe River, as a result of improved water quality from marine waters. In general, the Capibaribe River estuary is dominated by species that indicate impacted environments, such as rotifers and cladocerans, zooplankton (Eskinazi-Sant'Anna & Tundisi 1996, Paranaguá *et al.* 2005), and the fish *Poecilia vivipara* Bloch & Schneider (Lins *et al.* 2007). The local Secretary of Hydric Resources (Srh 2010) emphasizes the importance of research on autotrophic organisms that occur in this river (phytoplankton and macrophyta), since they contribute to maintaining other biological communities. In the estuarine area, there are mangrove tracks downtown from the establishment of embankments for the development of the city decades ago. Such tracks resulted from replanting are slowly increasing, and mainly comprise *Laguncularia racemosa* (L.) C. F. Gaertn and *Avicennia* spp. (Srh 2010).

Sampling and data analysis

The samples were collected for the analysis of chemical, physical, and biological variables, at three sampling stations along the Capibaribe River estuary. The sampling occurred during three months encompassing both the dry (October to December 2010) and rainy (May to July 2011) periods, and during the low and high tide, at the spring tide.

Environmental variables

The tide height was obtained from the National Oceanographic Database of the Hydrography and Navigation Board of the Brazilian Navy (Dhn 2010), referring the Port of Recife (Pernambuco State, Northeast of Brazil). The rainfall data was obtained from the long-term monitoring station from the Pernambuco Institute of Technology.

During each sampling event, the local depth was measured by using a depth gauge. The water transparency was verified with a Secchi disk. The water surface was sampled with a Kitahara bottle (1 L) and was measured the values of temperature and salinity, using a digital thermometer and refractometer, respectively. To verify the presence of thermic and/or saline stratification, the water was sampled in the surface and in maximal local depth. The water was filtered for evaluate the Chlorophyll *a*, corresponding to the phytoplankton biomass ($mg.m^{-3}$), with pigment extraction. For this, was used Millipore HA filters (0.47 µm of diameter and 0.45 µm of porosity), and acetone 90% followed by spectrophotometer analysis (Unesco 1966, Strickland & Parsons 1972).

To verify normality of data was applied the Shapiro-Wilk test (Zar 1996) within all data has a normal distribution. The data were evaluated as a function of seasonal (dry and rainy periods), spatial (S1, S2, and S3 sites locations), and tides (low and high tides) changes by the One-Way ANOVA test, using the Statistica 7.0 software (Statsoft 2004).

Species composition

The microphytoplankton was sampled (n = 36) through sub-superficial horizontal hauls with a plankton net of 64 mm mesh size for approximately three minutes at each sampling station. The choice of mesh size was based on previous studies and because during the low spring tide Northeast Brazilian estuaries have high levels of suspended particulate matter that rapidly saturate the plankton net (Grego *et al.* 2009; Borges *et al.* 2012). The samples were fixed with 4 % neutralized formaldehyde (Newell & Newell 1963).

The species were identified based on specific references, books, thesis, dissertations, and articles. When necessary, the chloroplasts were observed using a contrast phase system, and to better identification of the diatom frustule ornamentations was referenced Carr *et al.* (1986). For the taxonomical classification was used the system of Guiry & Guiry (2012).

The values of relative abundance were calculated, as recommended by Lobo & Leighton (1986), with a dominant species defined as accounting for over 50% of the total number of organisms in the sample, and abundant species in which the occurrence is higher than the medium value of individuals in the sample. Based on their frequency of occurrence (Mateucci & Colma 1982), the species was classified into four categories: very frequent (with values greater than 70% of occurrence), frequent (between 69 and 40%), infrequent (between 39 and 10%), and sporadic (less than 10%). Subsequently, Shannon-Weiner index was calculated (Shannon 1948), with the data reported in $bits.cel^{-1}$, where 1 bit is equal to a unit, and evenness was calculated following Pielou (1967) using Bioestat 5.0 software (Ayres *et al.* 2007).

To verify the normality of the microphytoplankton data (abundance, frequency, diversity, and uniformity), was applied the Shapiro-Wilk test (Zar 1996) with transformation and standardization of values in log10, when necessary, for non-normal distribution. The differences in data was evaluated in function of seasonal (dry and rainy periods), spatial (S1, S2, and S3 sites locations), and tides (low and high tides) changes by the Anova One-Way test, using Statistica 7.0 software (Statsoft 2004). The relationship between environmental variables and the dominant species was verified with the Correspondence Canonic Analysis (CCA), using Canoco 4.5 software (Braak & Smilauer 2002). The significance of the correlation was evaluated using the Monte Carlo permutation procedure, with 999 unrestricted permutations, on the first two CCA axes.

Results

Environmental variables: Climatic periods and intertidal periods

The rainy season was characterized by 518.5 mm of median rainfall and greater local depths. On the other hand, the dry season was characterized by 48.56 mm of median rainfall, warmer superficial waters ($F_{(1.34)} = 20.86$; $p < 0.01$), and higher salinity ($F_{(1.34)} = 16.88$; $p < 0.01$; Fig. 2).

Regarding to the intertidal periods, during high tide, there was higher superficial salinity ($F_{(1.34)} = 8.17$; $p < 0.01$). The low tide had greater chlorophyll *a* ($F_{(1.34)} = 7.88$; $p < 0.01$; Fig. 2).

Spatial changes

There were significant differences among the sampling stations in water depth ($F_{(2.33)} = 235.8$; $p < 0.01$); the intermediate station (S2) was shallower, with a median depth of 1.5 ± 0.1 m, whereas the downstream station (S3) was the deepest, with a median depth of 15.8 ± 0.4 m (Fig. 2). There were significant differences in water transparency ($F_{(2.33)} = 14.59$; $p < 0.01$), with increasing values further downstream, and median values oscillating from 30 ± 0.1 cm to 1.40 ± 0.2 m.

There were no significant differences between the surface and deep layers in temperature or salinity ($F_{(1)} = 0.3$; $p = 0.57$ and $F_{(1)} = 13.5$; $p = 0.24$; respectively), and the column of water had no thermic or saline stratification. In the surface layer there were no significant spatial differences for either variable ($F_{(2.33)} = 1.42$; $p = 0.25$ for temperature and $F_{(2.33)} = 4.51$; $p = 0.02$ for salinity). The water temperature decreased going downstream, with a low median of 27 ± 1.0°C and a high median of 29.5 ± 0.8°C (Fig. 2). On the other hand, salinity increased going downstream, with medians from 0 to 30 ± 2.0.

There was no significant spatial variation in the chlorophyll *a* ($F_{(2.33)} = 2.40$; $p = 0.11$). This values decreasing downstream, from 2.9 ± 2.4 mg/m³ up to 34.4 ± 20.8 mg/m³ (Fig. 2). Therefore, the downstream portion (S3) was deepest and was characterized by low levels of chlorophyll *a* and high light penetration. We verified the opposite for the upstream portion (S1).

Species composition

We identified a total of 127 taxa, overwhelmingly dominated by diatoms (Phylum Ochrophyta), which formed 54% of the total, followed by Phylum Cyanobacteria (18%), Chlorophyta (13%), Myzozoa (7%), Euglenozoa (5%), and Charophyta (3%). There were no significant differences in species diversity or uniformity with seasonal ($F_{(1)} = 0.27$; $p = 0.61$), spatial ($F_{(2.33)} = 11.54$; $= 0.32$), or tidal ($F_{(1)} = 0.12$; $p = 0.72$) differences. The diversity values varied from 1.96 bits.cel^{-1} (at low tide at S2 in the dry season) to 5.0 bits.cel^{-1} (at high tide at S2 in the rainy season), with uniformity values from 0.88 to 0.99.

For the three parameters (seasonal, spatial, and tidal changes), we considered that the relative abundance of species was low, and most species were classified as abundant, low abundant, or rare, except for the cyanobacterium *Planktothrix agardhii* (G.) Anagnostidis & Komárek and the diatom *Cyclotella* sp. (Fig. 3), which were more abundant for a great number of samples in the rainy and dry seasons, respectively.

Climatic periods

There were significant seasonal differences in the relative abundance of the cyanobacterium *P. agardhii* ($F_{(1.34)} = 40.87$; $p < 0.01$), with higher values during the rainy season. This species was found with the diatoms *Aulacoseira granulata* (E.) Simonsen and *Cylindrotheca closterium* (E.) Reimann & Lewin, with maxima abundances of 52.05 and 74.53%, respectively. On the other hand, during the dry season the dominant cyanobacterium was *Oscillatoria* sp. (83.0%), which was found with diatoms from Order Centrales, *Cyclotella* sp., *Cyclotella glomerata* Bachmann, *Helicotheca tamesis* (S.) Ricard, and *Skeletonema costatum* (G.) Cleve, with abundances between 50 and 85%. Of those, the abundance of *Cyclotella* sp. had a significant seasonal difference ($F_{(1.34)} = 13.22$; $p < 0.01$; Fig. 3).

There was a significant seasonal difference in the frequency of occurrence ($F_{(1)} = 302.1$; $p < 0.01$). During the dry season, no highly frequent species were found. On the other hand, during the rainy season, the cyanobacterium *P. agardhii* and the diatom *Coscinodiscus centralis* Ehrenberg were highly frequent species. The frequent species for both climatic periods included the diatom *Gyrosigma balticum* (E.) Rabenhorst and small pennate diatoms (identified to the level of Order Pennales). Most species were infrequent and sporadic.

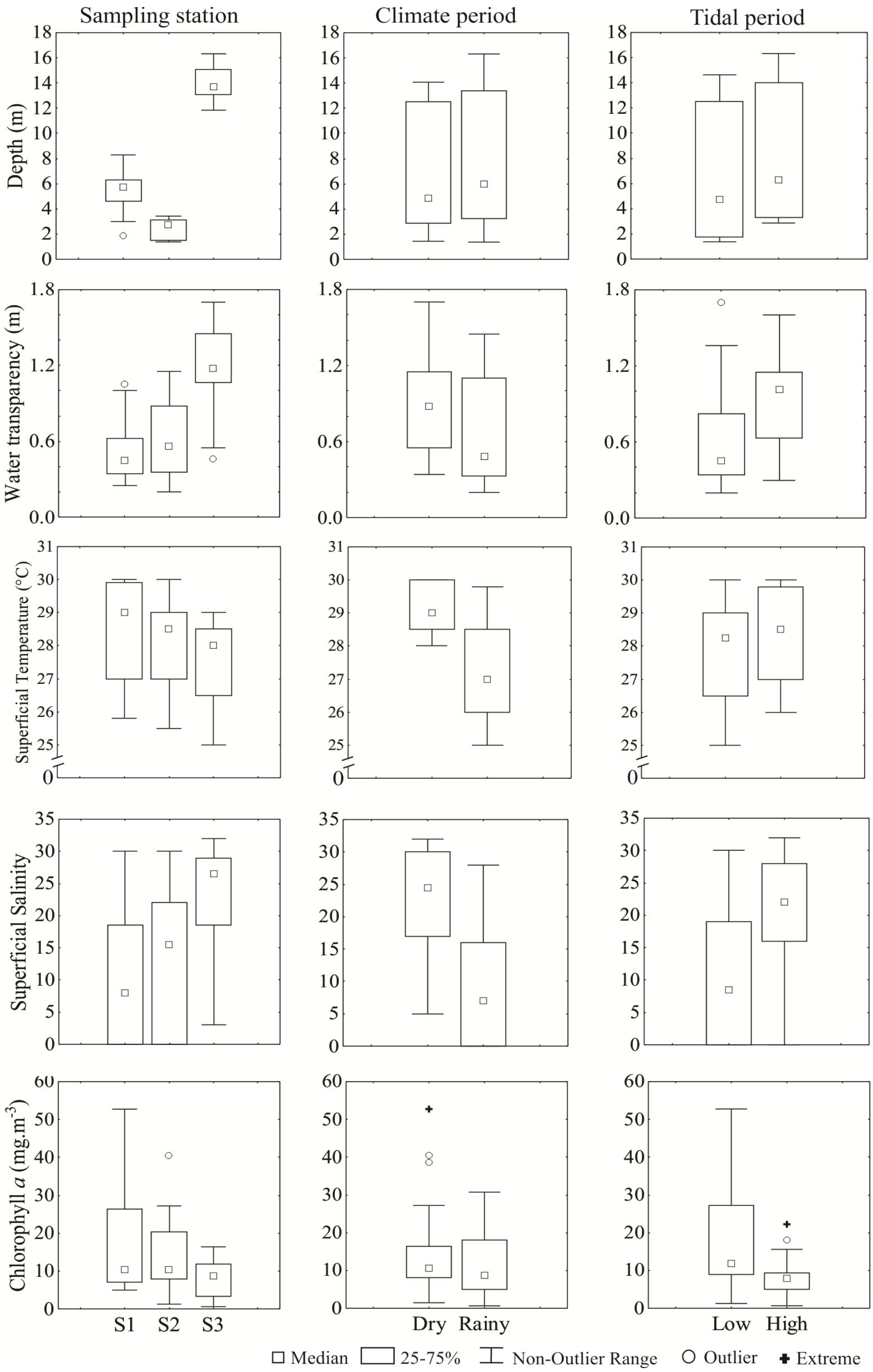

Figure 2. Environmental variables analyzed in the sampling stations S1, S2, and S3 in the Capibaribe River estuary, during intertidal (low and high tide) and climatic periods (rainy and dry).

Intertidal periods

The diatoms *C. closterium*, *A. granulata*, *C. glomerata*, *H. tamesis*, and *S. costatum* were dominant at high tide, while small centric diatoms (identified to the level of Order Centrales) and *Cyclotella* sp. dominated at low tide. The cyanobacteria *P. agardhii* and *Oscillatoria* sp2 were common at both high and low tide.

There was no significant difference in the frequency of occurrence between tides ($F_{(1)} = 0.11$; $p = 0.74$). Neither tide had highly frequent species. On the other hand, the cyanobacterium *P. agardhii* and the diatoms *C. centralis, C. closterium*, Pennales, and *G. balticum* were frequent at both tides (between 40 and 70% occurrence).

Spatial changes

In all three stations, the cyanobacterium *P. agardhii* was dominant. This species was found with others co-dominant species, as following: the species *Oscillatoria* sp2, *C. closterium* and *Cyclotella* sp. were dominant in the S1 station; the diatoms *A. granulata*, *Cyclotella* sp., *C. glomerata*, and Centrales were dominant in the S2 station; the species *Oscillatoria* sp2, *C. glomerata*, *H. tamesis*, and *S. costatum* were dominant in the S3 station (Fig. 3).

There was no significant difference spatially in the frequency of occurrence ($F_{(2)} = 68.8$; $p = 0.03$). The diatom *G. balticum* was highly frequent in the S1 and S2 stations, but did not occur in the S3 station. Among all three stations, the frequent species were *P. agardhii*, *C. centralis*, *Coscinodiscus* sp., *C. closterium*, Centrales, Pennales, and *Pediastrum duplex* Meyen.

Interaction between species and environmental variables

The CCA indicated an association between the dominant species and the environmental variables ($p < 0.01$). Axes 1 and 2 accounted for 36.4% of the variance of species along the environmental gradient. The correlation between species and environmental variables accounted for 36.8% of the CCA analysis on the first two axes (Table I).

Along axis 1, the species *P. agardhii*, *C. closterium*, and *A. granulata* were directly correlated with rainfall and depth and inversely correlated with chlorophyll *a*, temperature, tide, salinity, and water transparency. Along axis 2, the species *Cyclotella* sp., *C. closterium*, and *P. agardhii* were directly correlated with temperature, chlorophyll *a*, and rainfall and inversely correlated with tide, salinity, water transparency, and depth (Fig. 4).

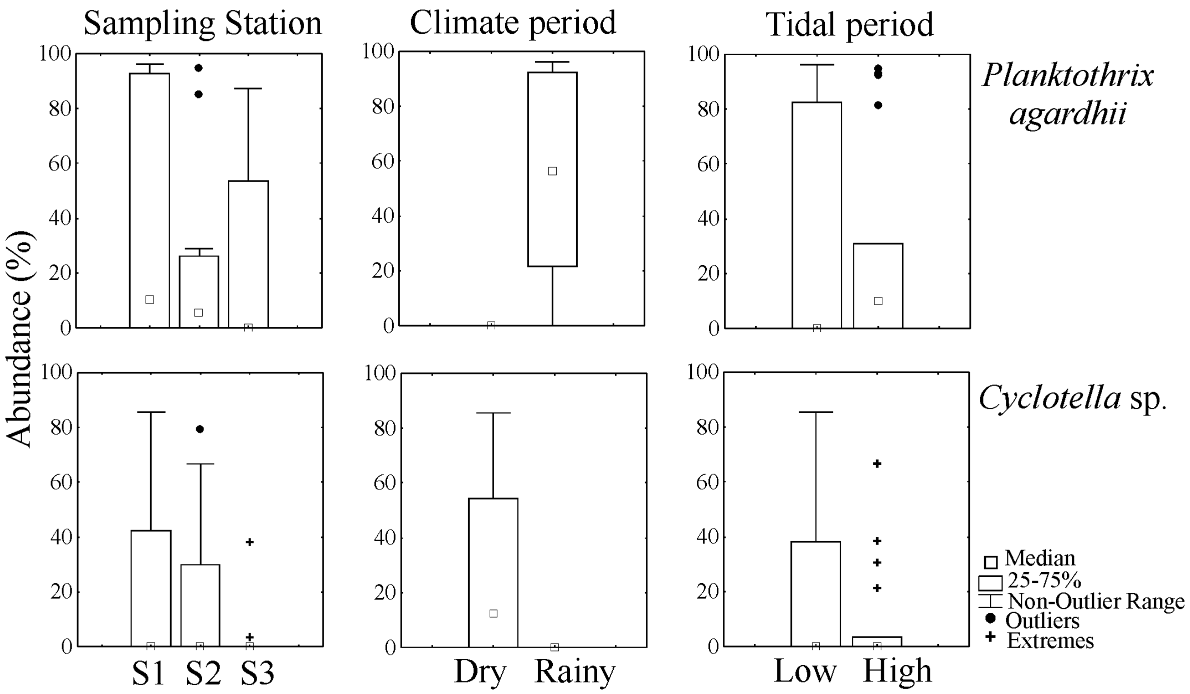

Figure 3. Relative abundance (%) of the cyanobacterium *Planktohtrix agardhii* (G.) Anagnostidis & Komárek and the diatom *Cyclotella* sp. during dry and rainy seasons, during both tides (low and high tide), and at site stations (S1, S2, and S3) along the Capibaribe River estuary.

Table I. Statistical resume and correlation coefficients between phytoplankton species and environmental variables for the first two axes of the CCA.

	Axis 1	**Axis 2**
Eigenvalues	0,506	0,398
Variation of the biotic data (%)	20,4	16,0
Variation of the species-environment relation (%)	20,6	16,2
Species-environment correlation	0,995	0,998
Monte-Carlo test:		
Significance of the first canonic axis – *p*	0,001	
Significance of all canonic axes – *p*	0,001	
Canonic coeficiente		
Rain	-0,8563	0,1722
Tide	0,0528	0,1741
Depth	-0,0264	0,0919
Water transparency	0,4186	-0,0334
Temperature	0,3488	-0,1774
Salinity	0,5476	0,0753
Chlorophyll *a*	0,2436	-0,1065

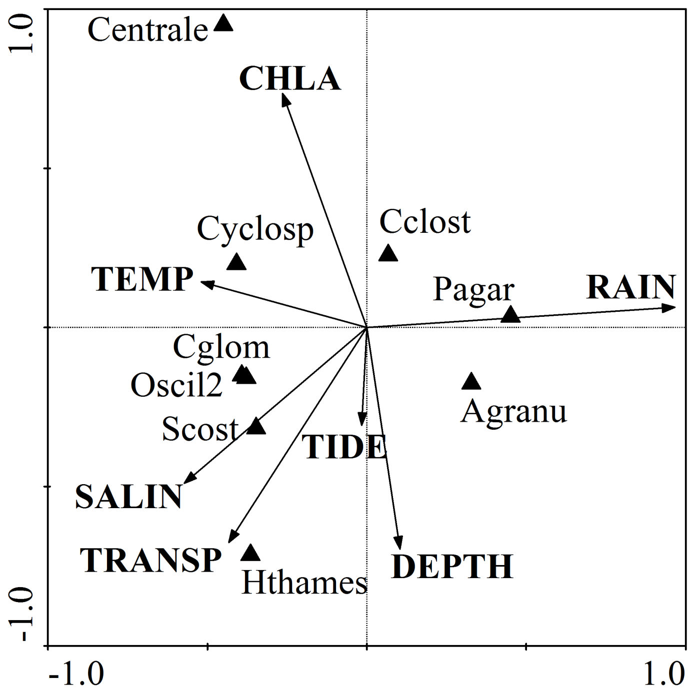

Figure 4. CCA ordination for the species and environmental variables in the Capibaribe River estuary. Codes: Agranu = *Aulacoseira granulata*; Centrale = Centrales; Cyclosp = *Cyclotella* sp.; Cclost = *Cylindrotheca closterium*; Cglom = *Cyclotella glomerata*; Hthames = *Helicotheca tamesis*; Oscil2= *Oscillatoria* sp2; Pagar = *Planktothrix agardhii*; Scost = *Skeletonema costatum;* CHLA = chlorophyll *a*; TEMP = superficial temperature; SALIN = superficial salinity; TRANSP = water transparency.

Discussion

Environmental variables

We observed low chlorophyll *a* in the Capibaribe River estuary in the deepest zones and during the rainy period, at high tide, and in the downstream zone. The increase in salinity due to the influence of marine waters (during high tides and downstream) and the increase in the flow of the river during rainy months (Araújo *et al.* 2013) are variables that might contribute to the decrease in chlorophyll *a* (Passavante & Feitosa 2004).

We verified that the S2 station is a transitory zone between the downstream and upstream portions. At this transitory zone, the environmental data (water transparency, temperature, salinity, and chlorophyll a) had intermediate values. Since the chlorophyll a was better represented in the S1 station, we verified the spatial influence on the distribution of chlorophyll a, mainly dependent on salinity changes along the estuary, during this study period. Similar results have been observed in other estuaries, such as in Belgium and the Netherlands (Muyleart et al. 2009), and in Brazil (Grego et al. 2009). Therefore, salinity was an important variable for determining the tidal and spatial effects on chlorophyll a distribution.

Species composition

Previous studies in the Capibaribe River estuary indicated the effect of seasonality for the structure of the phytoplankton community. The highest species richness have been record during the rainy season (Borges *et al.* 2012). Similarly, the cyanobacteria species appear as dominant during the rainy season and diatoms dominates in the dry seasons (Santiago *et al.* 2005). In our study, in general, species had low relative abundance in both climatic periods, except for *P. agardhii* and *Cyclotella* sp., which dominated the rainy and dry seasons, respectively. Their dominance (>80%) indicates that the limits of their coverage determine the limits of many other species (Cloern & Dufford 2005). In the last decades, the chlorophycean *Botryococcus* sp. has disappeared from estuarine areas of South Brazil (Torgan *et al.* 2001), a phenomenon that might be associated with the discharge of domestic and agricultural residues (Medeanic & Dillenburg 2005) and which can also induce a rapid increase in the population of cyanobacteria (Paerl & Paul 2012). In addition, cyanobacteria are important in this environment due to factors such as their high capacity to capture nitrogen from the atmosphere, tolerance of high concentrations of phosphorus, and regulation of their position in the water column based on light availability. In this context, cyanobacteria species were dominant in the estuary of Patos Lagoon (Southern Brazil), resulting in high levels of chlorophyll *a* (Odebrecht *et al.* 2005). The phenomenon of the replacement of species and dominance of cyanobacteria over other species might be observed in other parts of the world as a consequence of global climatic changes (Hays *et al.* 2005, Paerl & Paul 2012). Some research on ecologic succession and long temporal series in aquatic ecosystems indicates that the phenomenon of global climatic changes is one of the main reasons for the replacement of diatoms by cyanobacteria or the coexistence of these two competing taxa (Paerl & Paul 2012), with the possible emergence of toxic species (Moore *et al.* 2008). Therefore, the seasonal distribution of phytoplankton in the Capibaribe River estuary showed the replacement of the dominance of *Cyclotella* sp. by the cyanobacterium *P. agardhii.* This cyanobacterium was found living in co-dominance with other diatoms (*A. granulata* and *C. closterium*). This is important since retrospective studies during the 1980's in the Capibaribe River estuary showed that diatoms, such as *C. closterium* and *Coscinodiscus* spp., were the main component of the phytoplankton (Travassos 1991).

Thus, we recommend periodic monitoring of the area to verify the effect of climatic changes on the phytoplankton community. We also highlight the importance of studies of the dynamics of the cyanobacterium *P. agardhii*, since many studies have reported its capacity to produce toxins. Such toxins are bioaccumulated in higher trophic levels, with drastic effects to living organisms (Reviers 2006).

According to Trigueiros & Orive (2000), phytoplankton are better distributed during low tide. However, in the present study we observed that tidal oscillations had a minor influence on species variation. We believe that *Cyclotella* sp. and *P. agardhii* were more dominant during low tide because of the corresponding low salinity, as shown in the CCA (Fig. 4).

We observed that spatial heterogeneity in the Capibaribe River estuary has a strong effect on the dominance of species, mainly due to salinity changes along the estuary, which work like an ecologic barrier for the distribution of organisms (Muyleart *et al.* 2009) such as specific dinoflagellates (Caric *et al.* 2011).

Most species of cyanobacteria occur in continental waters (Reviers 2006), explaining why the species identified in this study, such as *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju, *Microcystis aeruginosa* (Kützing) Kützing, and *Aphanizomenon* sp., were rare and sporadic in the downstream station (S3). The exception was *P. agardhii*, thus, we proposed that this species is tolerant of salinity, since it is found all over the world not only in continental waters (Dantas *et al.* 2012), but also in estuarine, saline, and brackish waters (Perez *et al.* 2009). In addition, for some nitrogen-fixing cyanobacteria species, Paerl & Justic (2013) have stated that salinity is not a barrier for their expansion. This is the case for the cyanobacterium *P. agardhii*, which was well represented at the three stations in our study, with high values of frequency and abundance. Thus, we highlight the need for experiments determining its physiologic characteristics to confirm its euryhaline ability. At the upstream station (S1), *P. agardhii* was almost 100% abundant, indicating good development in low salinity waters, and also shallow deep and with no effect to the water transparency. Similarly, other species of *Planktothrix* have been found in estuaries in Belgium and the Netherlands, and are more abundant upstream in other estuarine areas (Muyleart *et al.* 2009). Nevertheless, since *P. agardhii* was found at the station furthest downstream the Capibaribe River estuary (S3; although at a lower proportion than at S1), we conclude that the river flow transports species to the river mouth. In other words, the presence of this and other species of cyanobacteria in the estuarine portion might be explained, mainly, by the influence of waters and continental effluents. Dantas *et al.* (2012) registered the presence of *P. agardhii*, *C. raciborskii*, *M. aeruginosa*, and other species in reservoirs that supply the Capibaribe River.

Salinity was an important factor in the limited occurrence of the diatom *Cyclotella* sp. at the downstream station (S3). Thus, this diatom is not tolerant of high levels of salinity, like many other species in the genus, which are characterized as continental in habit (Eskinazi-Leça *et al.* 2012, Guiry & Guriy 2012). As found in the CCA, the restriction to its distribution is inversely proportional to water transparency and depth. Therefore, luminosity is not a limiting factor for its development, and we suggest that this species could be a component of the phytobenthos because of its presence in shallow waters and availability in the water column and resuspension of sediment found in the floor.

Through the CCA, we found that the high abundance of *Cyclotella* sp. was related to high values of chlorophyll *a* (during dry months, low tide, and upstream), as well as the dominance of Centrales diatoms. Thus, we suggest that these organisms are the main components of phytoplankton biomass in the Capibaribe River estuary. Both diatom groups consist of small-sized life forms, so it was not possible to identify lower taxonomic levels.

In conclusion, the microphytoplankton data presented here showed only limited variation between tides. However, there were large seasonal and spatial changes, with the rainy and dry seasons represented by cyanobacteria and diatom species, respectively. Downstream and upstream locations had differences in microphytoplankton, with an intermediate zone transitional between the extremes. We highlight the need of other investigations of ecologic succession due to climatic changes, focusing on the dominant species of diatoms and cyanobacteria and during a longer period. In addition, our data suggest concern for the intense fishing performed in the area, mainly in the rainy months, along the different estuarine portions in both tide periods, due to the abundance of the cyanobacterium *P. agardhii*. Therefore, we recommend further monitoring of the area and other experimental research on salinity as a limiting factor for this species, because of its potential toxins and their effects on human beings and the environment.

References

Araujo, M.; Noriega, C.; Veleda, D.; Lefèvre, N. 2013. Nutrient Input and CO2 Flux of a Tropical Coastal Fluvial System with High Population Density in the Northeast Region of Brazil. **Journal of Water Resource and Protection**, 5: 362-375.

Ayres, M. M., Ayres, J. R., Ayres, D. L. & Santos, A. S. 2007. **BioEstat 5.0: aplicações estatísticas nas áreas de ciências biológicas e médicas.** Instituto de Desenvolvimento Mamiruá, Belém.

Borges, G. C. P., Silva-Cunha, M. G. G., Santiago, M. F. & Lima, J. C. 2012. Comunidade fitoplanctônica e variáveis ambientais em área portuária, nordeste do Brasil. **Tropical Oceanography**, 40(2): 309-318.

Braak, C. J. F. & Smilauer, P. 2002. **Canoco Reference Manual and CanoDraw for Windows User‟s guide: Software for Canonical Community Ordination (version 4.5).** Microcomputer Power, Ithaca, New York.

Brayner, F. M. M., Barbosa, F. M. M., Silva, H. K. P. & Melo, L. V. 2003. Behaviour of heavy metals in the estuarine area of the Capibaribe River in the Northeast of Brazil. **Journal de Physique**, 107(4): 221-225.

Caric, M., Jasprica, N., Calić, M. & Batistić, M. 2011. Phytoplankton response to high salinity and nutrient limitation in the eastern Adriatic marine lakes. **Scientia Marina**, 75(3): 493-505.

Carr, J. M., Hergenrader, G. L. & Troelstrup, N. H. 1986. A simple inexpensive method for cleaning diatoms. **Transanctions of American Microsccopical Society,** 105: 152-157.

Cloern J. E. & Dufford R. 2005. Phytoplankton community ecology: principles applied in San Francisco Bay. **Marine Ecology Progress Series,** 285: 11–28.

Dantas, E. W.; Bittencourt-Oliveira, M. C. & Moura, A. N. 2012. Dynamics of phytoplankton associations in three reservoirs in northeastern Brazil assessed using Reynolds' theory. **Limnologica**. 42(1): 72–80.

Dhn. 2010. **Previsões de mares (Hydrography and Navigation Board)** – World Wide Web electronic publication, accessible at http://www.mar.mil.br/dhn/chm/tabuas. (Accessed 04/11/2010).

Eskinazi-Leça, E., Koening, M. L. & Silva-Cunha, M. G. G. 2004. Estrutura e dinâmica da comunidade fitoplanctônica. Pp. 353-373. *In:* Eskinazi-Leça, E., Newmann-Leitão, S. & Costa, M. F. (Eds). **Oceanografia: um cenário tropical**. Recife: Edições Bagaço.

Eskinazi-Leça, E., Cunha, M. G. G. S., Santiago, M. F., Borges, G. C. P., Lima, J. C., Silva, M. H., Menezes M., Ferreira, L. C. & Aquino, E. P. 2012. **Bacillariophyceae in Lista de Espécies da Flora do Brasil** – World Wide Web electronic publication, accessible at http://floradobrasil.jbrj.gov.br/2011/FB097964. (Accessed 10/21/2012).

Eskinazi-Sant'anna, E. M. & Tundisi, J. G., 1996. Zooplâncton do estuário do Pina (Recife, Pernambuco, Brasil): composição e distribuição temporal. **Revista Brasileira de Oceanografia, 44(1):** 23-33.

Flores-Montes, M. J., Paulo, J.G.; Nascimento-Filho, G. A., Gaspar, F. L., Feitosa, F. A., Santos-Júnior, A. C., Batista, T. N. F., Travassos, R. K. & Pitanga, M. E. 2011. The trophic status of an urban estuarine complex in Northeast Brazil. **Journal of Coastal Research**, 64: 408-411.

Fujita, C. C. & Odebrecht, C. 2007. Short term variability of chlorophyll *a* and phytoplankton composition in a shallow area of the Patos Lagoon estuary (Southern Brazil). **Atlântica**, 29(2): 93-106.

Grego, C. K. S., Feitosa, F. A. N., Honorato-Da-Silva, M., Silva-Cunha, M. G. G. & Filho, G. A. N. 2009. Fitoplâncton do ecossistema estuarino do rio Ariquindá (Tamandaré, Pernambuco, Brasil): variáveis ambientais, biomassa e produtividade primária. **Atlântica,** 31(2): 183-198.

Guiry, M. D. & Guiry, G. M. 2011. **AlgaeBase –** World Wide Web electronic publication, accessible at http://www.algaebase.org. (Accessed 11/02/2011).

Hays, G. C., Richardson, A. J. & Robinson, C. 2005. Climate change and marine plankton. **Trends in Ecology and Evolution,** 20(6): 337-344.

Hillebrand, H., Bennett, D. M. & Cadotte, M. W. 2008. Consequences of dominance: a review of evenness effects on local and regional ecosystem processes. **Ecology,** 89(6): 1510-1520.

Lacerda, S. R., Koening, M. L., Neumann-Leitão, S. & Flores-Montes, M. J. 2004. Phytoplankton nyctemeral variation at a tropical river estuary (Itamaracá – Pernambuco – Brazil). **Brazilian Journal of Biology,** 64(1): 81-94.

Lins, M. L. A.; Campos, S. S. & Teixeira, S. F. 2007. A ictiofauna da margem do baixo rio Capibaribe, Recife, Pernambuco. **8th Symposium of Ecologia of the Brasil**, Caxambu, Minas Gerais, Brasil.

Lobo, E. & Leighton, G. 1986. Estructuras comunitarias de las fitocenosis planctonicas de los sistemas de desembocaduras de rios y esteros de la zona central de Chile**.** **Revista Biologia Marina,** 22:1-29.

Macedo, S. J., Philippini-da-Silva, H. K., Brayner, F. M. M., Duarte, M. M. M. B. & Barbosa, A. M. F. 2007. Heavy metal concentrations in sediments of the Capibaribe river estuary in the Metropolitan Region of Recife, Pernambuco-Brazil. **WIT Transactions on Ecology and the Environment**, 102: 357-365.

Mateucci, S. D. & A. Colma. 1982. La metodologia para el estudo de la vegetacion. **Collection de Monografías Científicas,** 22: 1-168.

Medeanic S. & Dillenburg S. R. 2005. Palynology and 210Pb datings: first integrated approach to estimating anthropogenic impact on the environment of the Tramandaí Lagoon and adjacent areas during the last century. **Journal of Coastal Research,** 42: 271-276.

Moore, S. K., Trainer, V. L., Mantua, N. J., Parker, M. S., Laws, E. A., Backer, L. C. & Fleming, L. E. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. **Environmental Health,** 7(2): 1-12.

Muylaert, K., Sabbe, K. & Vyverman, W. 2009. Changes in phytoplankton diversity and community composition along the salinity gradient of the Schelde estuary (Belgium/ The Netherlands). **Estuarine, Coastal and Shelf Science**, 82: 335–340.

Newell, G. H. & Newell, R. 1963. **Marine Plankton: a practical guide.** Hutchinson Educat, London.

Odebrecht, C., Abreu P. C., Möller, O. O., Niencheski, L. F., Proença, L. A. & Torgan L. C. 2005. Drought effects on pelagic properties in the shallow and turbid Patos Lagoon, Brazil. **Estuaries,** 28(5): 675-685.

Ottmann, F. & Ottmann, J. M. 1959. La maree de Salinite Dans le Capibaribe Recife-Bresil. **Trabalhos do Instituto de Biologia Marítima e Oceanografia da Universidade do Recife**. 1(1): 39-49

Paerl, H. W. & Justic, D. 2013. Estuarine phytoplankton. In.: Day-Jr. (Eds). **Estuarine ecology**. Wiley, Blackwell. p. 85-110

Paerl, H. W. & Paul, V. J. 2012. Climate change: Links to global expansion of harmful cyanobacteria. **Water Research,** 46: 1349-1363.

Paranaguá, M. N., Neumann-Leitão, S., Nogueira-Paranhos, J. D., Silva, T. A. & Matsumura-Tundisi, T. 2005. Cladocerans (Branchiopoda) of a tropical estuary in Brazil. **Brazilian Journal of Biology**, 65(1): 107-115.

Passavante, J. Z. O. & Feitosa, F. A. N. 2004. Dinâmica da produtividade fitoplanctônica na zona costeira marinha. Pp. 425-440. *In:* Eskinazi-Leça, E., Newmann-Leitão, S. & Costa, M. F. (Eds.). **Oceanografia: um cenário tropical.** Bagaço, Recife.

Perez, M. C., Maidana, N. I. & Comas, A. 2009. Phytoplankton composition of the Ebro River estuary, Spain. **Acta Botanica Croatica,** 68(1): 11–27.

Pielou, E. C. 1967. **Mathematical Ecology.** Wiley, New York.

Reviers, B. 2006. **Biologia e filogenia das algas**. Artmed, Porto Alegre, 280 p.

Santiago, M. F., Silva-Cunha, M. G. G., Neumann-Leitão, S., Costa, K. M. P., Borges, G. C. P., Porto-Neto, F. F. & Nunes, F. S. 2010. Phytoplankton dynamics in a highly eutrophic estuary in Tropical Brazil. **Brazilian Journal of Oceanography,** 58(3): 189-205.

Shannon, C. E. 1948. A mathematical theory of communication. **Bulletin of System Technology Journal,** 27: 379-423.

Shr. 2010. **Plano hidroambiental da bacia hidrográfica do rio Capibaribe: Resumo executivo/ Projetos técnicos**. Recife, Secretaria de recursos hídricos do estado de Pernambuco, 98 p.

Statsoft. 2004. **Statistica: data analysis software system, version 7.**

Strickland, J. D. H. & Parsons, T. R. 1972. A practical handbook of seawater analysis. **Bulletin Fisheries Research Board of Canada**, 167: 1-211.

Torgan, L. C., Barreda, K. A. & Fortes, D. F. 2001. Catálogo das algas Clorophyta de águas continentais e marinhas do Rio Grande do Sul. **Iheringia-Série Botânica**, 56: 147-182.

Travassos, P. E. P. F. 1991. Hidrologia e biomassa primária do fitoplâncton no estuário do rio Capibaribe, Recife – Pernambuco. **Phd. Thesis.** Federal University of Pernambuco, Recife, Brasil, 287 p.

Trigueros, J. M. & Orive, E. 2000. Tidally driven distribution of phytoplankton blooms in a shallow, macrotidal estuary. **Journal of Plankton Research**, 22(5): 969–986.

Unesco. 1966. Determination of photosynthetic pigments in seawaters. **Monographys on Oceanology Methodology,** 69-88.

Zar, J. H. 1996. **Biostatistical analysis**. Prentice Hall, New Jersey

Received July 2014
Accepted December 2014
Published online December 2014