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Environmental conditions of the Suape estuarine-port complex area (Pernambuco, Brazil): phytoplankton biomass and hydrological parameters

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The Suape coastal zone has suffered since the 1980s the effects of anthropogenic action due to the construction of the industrial complex of Suape. This work aimed to evaluate the environmental conditions and possible eutrophication processes of the area. Six campaigns were carried out, three in the dry season (November 2015, January and April 2016) and three in the rainy season (July 2015, July and August 2016). Water samples were collected at the surface during low tide and high tide, in neap tides. Salinity ranged from 19.75 to 37.20, the dissolved oxygen rate ranged from 61.75 to 125.90% and chlorophyll-a from 0.02 to 3.48 mg m^{-3}*. Water transparency, temperature, nitrate and silicate presented significant seasonal variation, the concentrations of nutrients being higher in the rainy season and the others in the dry season. Water transparency, salinity, dissolved oxygen saturation and chl-a* $<$*20 μm showed significant differences for tide, being higher at high tide, and at low tide for chl-a of* $<$*20 μm. The low content of dissolved inorganic nutrient salts and chl-a were indicative of an area still free of eutrophication. Anthropogenic changes in the environment have led to greater marine interference and consequently to a reduction of the productive capacity of the system.*

Keywords: Chlorophyll-a, estuary, hydrology, port area, seasonality

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INTRODUCTION

The Suape coastal zone is located 40 km south of Recife, capital of the state of Pernambuco, Brazil, and has suffered since the 1980s the effect of anthropogenic action through the development of a port complex, thermoelectric plant, dredging, reef dynamiting, landfills on the reef line, heavy traffic of boats and ships, and suppression of mangrove and native vegetation (Neumann *et al.*, 1998; Muniz *et al.*, 2005; Pessoa *et al.*, 2009). In addition, there were major changes in the geomorphological conditions and hydrodynamic patterns in the area (Paiva & Araújo, 2010). These processes have led to an excessive dispersion of suspended matter that affects the distribution and composition of organisms that inhabit mainly the water column such as phytoplankton and the hydrological conditions of the adjacent area (Pessoa *et al.*, 2009).

Phytoplankton represents the basis of the food web and modifications in its structure results in changes throughout the trophic web. In addition, it absorbs excess CO_2 (biological pump), limiting the processes of marine acidification, and is an effective water quality bioindicator (Cordeiro *et al.*, 2014).

Therefore, the understanding of factors that regulate phytoplankton biomass is essential for the understanding of changes in the environment in its temporal and spatial variations. This is fundamental in studies aimed at minimizing or even preventing negative impacts on the aquatic environment (Anjos *et al.*, 2012).

In the Suape estuarine-port complex (EPC), some studies on plankton have already been carried out (Eskinazi-Leça & Koening, 1985/86; Koening, 1997; Neumann-Leitão *et al.*, 1999; Koening *et al.*, 2003; Bezerra Júnior *et al.*, 2011; Borges, 2011). This work aimed to continue the environmental monitoring due to constant anthropogenic changes in the area.

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MATERIALS AND METHODS

Study area

Suape Port is located on the southern coast of Pernambuco (08°23′45″S 34°58′04″W) (Figure 1), between the municipalities of Cabo de Santo Agostinho and Ipojuca, occupying an area of ~13,500 ha, of which 323,258 ha correspond to the area of the Organized Port. The environments found in the surroundings include mangroves, sandy beaches, reefs and banks of algae, among others.

The tides recorded in the region are semidiurnal, being classified in terms of amplitude as mesotidal, with amplitude of ~3.0 m (Suape, 2015).

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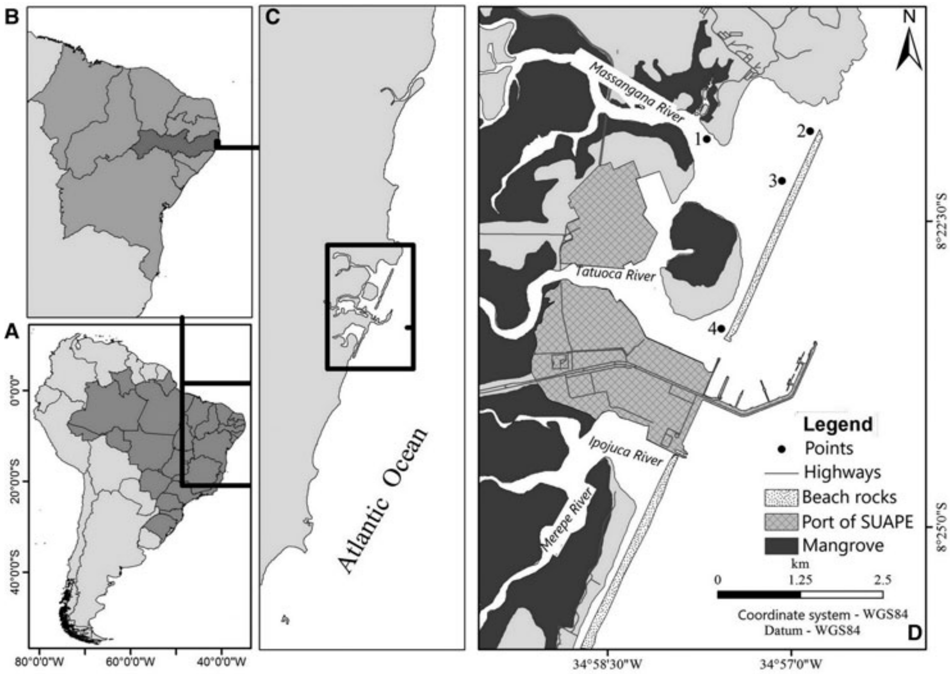

Fig. 1. Location of the Estuary Port Complex of Suape, PE, Brazil and location of sampling points.

According to Köppen, the climate of the Pernambuco coast is of As' type, characterized by two distinct periods in the pluviometric regime: a dry season and a rainy season. The area has average annual rainfall of 2.272 mm, air temperature of 25.6 °C and relative humidity of 90% (Aragão, 2000; Torres & Machado, 2011).

Before the construction of the port complex, four rivers (Massangana, Tatuoca, Ipojuca and Merepe) converged on Suape Bay, an estuary partially isolated from the ocean by an extensive sandstone line. Today, only the Massangana and Tatuoca Rivers converge to Suape Bay. Ipojuca and Merepe Rivers had their communication with the bay interrupted by intensive earthworks to build the port complex. As a result of restricted access to the sea, the backflow of these rivers flooded the surrounding fields causing damage to agriculture. The government solution was a partial break of the baseline. As a result, a large amount of suspended material now passes through the opening of the drag line that is installed inside the port, with high-cost dredging. In the Suape area, more than 600 hectares of mangroves were destroyed (Neumann *et al.*, 1998).

Data preparation

Collections were performed in six months including the rainy period (July 2015, July and August 2016) and dry period (November 2015, and January and April 2016) at four fixed points on the high tide and low tide, in the inner port region (Figure 1).

The following hydrological parameters were determined: water transparency (Secchi); temperature and salinity by CTD; depth by an echo sounder; dissolved oxygen concentration by the modified Winkler method and described by Strickland & Parsons (1972); saturation rate by the UNESCO Table (1973); dissolved nutrients nitrite, nitrate by Strickland & Parsons (1972), ammonia, phosphate and silicate by Grasshoff *et al.* (1983) and suspended particulate matter by the gravimetric method of Baumgarten *et al.* (1996).

Samples to obtain phytoplankton biomass were collected in 5 l Niskin bottles.

For fractionation, a PVC pipe with 20 μm mesh was used. The biomass was subsequently calculated; 3 l of samples were vacuum filtered in Whatman GF/F glass fibre filters of 47 mm in diameter and 0.7 μm porosity, with 1.5 l for total biomass and 1.5 for fractionated biomass quantified by the chlorophyll-a (chl-a) content by the spectrophotometric method of UNESCO (1966). In order to perform calculations, the equation of Parsons & Strickland (1963) was used, and the results were expressed in mg m^{-3}.

Statistical analysis

For statistical analysis, data normality and homogeneity were tested through the Shapiro Wilk and Levene tests, respectively. Subsequently, the non-parametric Kruskal–Wallis test was used to verify spatial, seasonal and tidal differences among samples.

PERMANOVA was performed to verify tidal, seasonal and spatial differences of environmental variables. For all tests, values of $P < 0.05$ were considered significant.

RESULTS

Climatic and hydrological variables

Rainfall precipitation had annual total of 1913.20 mm in 2015 and 1705 mm in 2016, with maximum monthly value of 478 mm in May 2016, and a minimum of 13.70 mm in October 2016, with median of 83.2 mm (Figure 2). In 2015 and 2016, most pluviometric data were below the historical

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average of 31 years, with significant seasonal differences (Table 1) ($P = 0.02$).

Samples were always collected in spring tide, with minimum of 0.0 m at low tide and maximum of 2.5 m in high tide, both in April 2016, with amplitude of 2.5 m.

The minimum depth was 1.3 m and the maximum was 15 m, both at point 3 and in the low tide (April and January 2016, respectively), with median of 6.5 m. There was a significant spatial variation among the different collection points ($P = 0.00$), where point 4 was different from points 1 and 3 (Table 1).

The water transparency was lower at point 1 in July 2016 with 0.50 m and higher at point 4 in the high tide in November 2015 with 5.2 m, with median of 1.7 m.

The water transparency showed significant seasonal differences ($P = 0.00$) and between tides ($P = 0.04$), being more transparent in the dry season and in the high tide (Table 1).

The temperature varied from 25.9 to 31.13°C, both at point 1 and in the high tide, with minimum in July 2015 and maximum in April 2016, with median of 28.03 °C. It presented significant variation with higher temperatures in the dry season ($P = 0.00$) (Table 1).

Salinity presented its lowest and highest levels at point 1, in the lowest tide, varying from 19.75 in July 2015 to 37.20 in April 2016, with median of 36.37 (Figure 3). There was significant seasonal and tidal variation ($P = 0.01$ and $P = 0.00$, respectively), with higher salinities in the dry season and in the high tide (Table 1).

The dissolved oxygen content (DO) presented minimum concentration of 2.60 ml l^{-1} at point 1 at low tide in January 2016 and maximum of 5.13 ml l^{-1} at point 1 in August 2016, with median of 4.47 ml l^{-1}. The DO saturation rate ranged from 61.75 to 125.90%, with median of 105.80% (Figure 4). There was significant variation between tides, exclusively for the dissolved oxygen saturation rate ($P = 0.00$), with higher levels in the high tide (Table 1).

The suspended particulate matter (SPM) showed minimum concentration of 1.6 mg l^{-1} at point 1 in April 2016 and maximum of 50.56 mg l^{-1} at point 3 in November 2015, with median of 35.56 mg l^{-1}, showing no significant differences (Table 1).

Nitrite presented value of 0.01 μmol l^{-1} in several points and months sampled, and maximum of 1.34 μmol l^{-1} at point 3 in the high tide in April 2016, with median of 0.01 μmol l^{-1}, showing no significant variations (Table 1).

Nitrate values ranged from 0.01 μmol l^{-1} at point 3 in the high tide in April 2016 and at point 4 at low tide in August 2016 to 4.48 μmol l^{-1} at point 3 in the low tide on July 2015, with median of 1.07 μmol l^{-1} (Figure 5) showing significant seasonal variation ($P = 0.00$), with higher values in the rainy season (Table 1).

Ammonia levels ranged from 0.01 μmol l^{-1} at several points and months sampled to maximum concentration of 0.84 μmol l^{-1} at point 1 on January 2016 at low tide, with median of 0.10 μmol l^{-1}, with no significant variations (Table 1).

Phosphate levels ranged from 0.02 μmol l^{-1} in the low tide at point 1 on August 2016 to 0.45 μmol l^{-1} at point 2 on July 2015 in the high tide, with median of 0.12 μmol l^{-1}, with a significant difference for tide, with higher levels at low tide ($P = 0.03$) (Table 1).

Silicate showed minimum concentration of 0.57 μmol l^{-1} at point 2 in the high tide in April 2016 and maximum of 51.73 μmol l^{-1} at point 3 in the low tide in July 2015, with median of 7.38 μmol l^{-1} (Figure 6), with significant seasonal variation, with higher levels in the rainy season (Table 1).

Chlorophyll-a

Chlorophyll-a content ranged from 0.04 mg m^{-3} at point 3 in the high tide in August 2016 to 3.48 mg m^{-3} at point 1 in the high tide in July 2015 (Figure 7), with median of 0.50 mg m^{-3}, without significant tidal, seasonal and spatial variations (Table 1).

Chlorophyll-a <20 μm content ranged from 0.02 mg m^{-3} at point 1 in the low tide in July 2015 and in the high tide in August 2016, at point 2 in January 2016 and August 2016, at Point 3 in January 2016 in the high tide and in April 2016 and August 2016 in the low tide and at point 4 in January 2016 in the high tide and in April 2016 in the high tide and in the low tide. It obtained maximum value of 2.73 mg m^{-3} at point 1 in the low tide in July 2015, with median of 0.21 mg m^{-3} (Figure 8), with significant variation only according to tide, with higher concentrations in the low tide ($P = 0.01$) (Table 1).

PERMANOVA

In relation to the group of hydrological variables with the three factors (tide, collection points and climatic period), there were significant variations only for tide and climatic period ($P = 0.00$ and $P = 0.00$, respectively).

Chlorophyll-a showed a significant interaction between climatic period and tide ($P = 0.04$). After the pairwise tests of

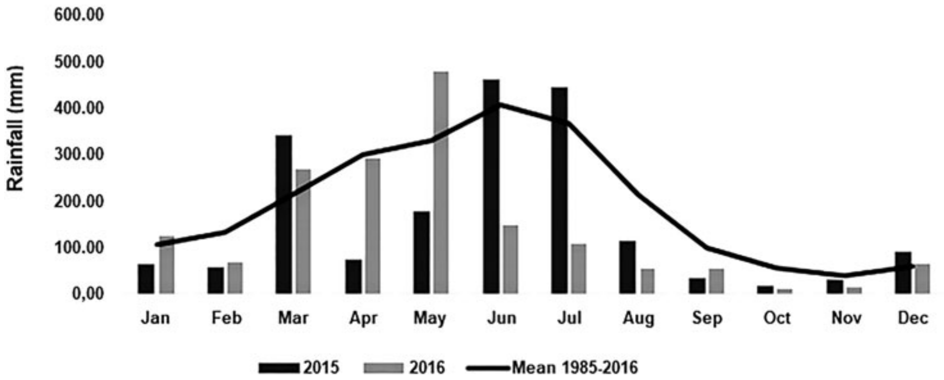

Fig. 2. Rainfall data from the Experimental Station of Curado-PE in 2015 and 2016 and the average historical monthly values (1985–2016). Source: INMET.

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Table 1. Biological and abiotic variables in dry and rainy seasons (Min = minimum, Max = maximum, Med = Median), Kruskal–Wallis test, with *P*-values for the various treatments (seasonal, spatial and tidal) (Chl-a, Chlorophyll-a; D.O., Dissolved Oxygen; D.O.S., Dissolved Oxygen Saturation; S.P.M., Suspended particulate matter).

	Rainy		Dry		Kruskal–Wallis (*P*)		
Parameters	**Min/Máx**	**Med**	**Min/Máx**	**Med**	**Seasonal**	**Tidal**	**Spatial**
Rainfall (mm)	57.50/478.90	223.8	13.70/126.00	223.80	0.02*	–	–
Chl-a (mg m^{-3})	0.03/3.47	0.43	0.18/2.45	0.68	0.05	0.66	0.03*
Chl-a < 20 µm (mg m^{-3})	0.02/2.73	0.26	0.02/2.17	0.2	0.48	0.01*	0.76
Depth (m)	2.8/14.3	6.9	1.30/15.00	6.15	0.75	0.14	0.00*
Transparency (m)	0.5/4.4	1.4	0.90/5.2	2.31	0.00*	0.04*	0.09
Dissolved oxygen (ml l^{-1})	3.43/5.12	4.58	2.60/4.88	4.23	0.07	0.00*	0.16
Dissolved oxygen saturation (%)	62.48/125/9	108.08	61.75/120/29	103/72	0.77	0.00*	0.44
Nitrite (µmol l^{-1})	0.01/0.28	0.05	0.01/1.34	ND	0.17	0.96	0.79
Nitrate (µmol l^{-1})	0.01/4.47	1.65	0.01/2.03	0.63	0.00*	0.12	0.85
Ammonia (µmol l^{-1})	0.01/0.62	0.09	0.01/0.8	0.13	0.09	0.77	0.96
Phosphate (µmol l^{-1})	0.02/0.44	0.12	0.04/0.23	0.11	0.52	0.05	0.06*
Silicate (µmol l^{-1})	5.1/51.72	10.79	0.56/14.20	5	0.00*	0.12	0.86
Suspended particulate matter (µmol l^{-1})	7.4/47	38.4	1.60/50.56	34.68	0.30	0.36	0.95
Temperature (°C)	25.9/27.8	26.7	28.27/31.313	28.75	0.00*	0.54	0.92
Salinity	19.75/37.2	36.05	29.23/37.04	36.66	0.05	0.01*	0.74

the period × tide interaction, there was a significant seasonal difference for the dry season ($P = 0.01$) (Table 2).

DISCUSSION

Rainfall was below the historical average during the entire study period due to the El Niño atmospheric-oceanic phenomenon characterized by abnormal warming of surface waters, with reduced rainfall and changes in wind patterns, which had as consequences climate changes at regional and global levels (Oliveira, 2001).

Particularly, rainfall in the Suape estuarine-port complex was enough to cause variations in some environmental parameters analysed, as confirmed by PERMANOVA. In the rainy season, there was elevation in silicate and nitrate contents and reduction of temperature and water transparency.

In the port area of Santos-SP, Masuda *et al.* (2011) observed that higher rainfall caused lower depth of the euphotic zone and higher salinity variation and consequently higher haline stratification in the system. The increase in rainfall increased continental drainage and consequently the eutrophication degree in the system.

On the other hand, tide was also a determining factor in the alterations of some parameters, according to PERMANOVA, such as water transparency, dissolved oxygen and its saturation, salinity and chl-a fractions. This can be explained due to the fact that the region under study has a semidiurnal

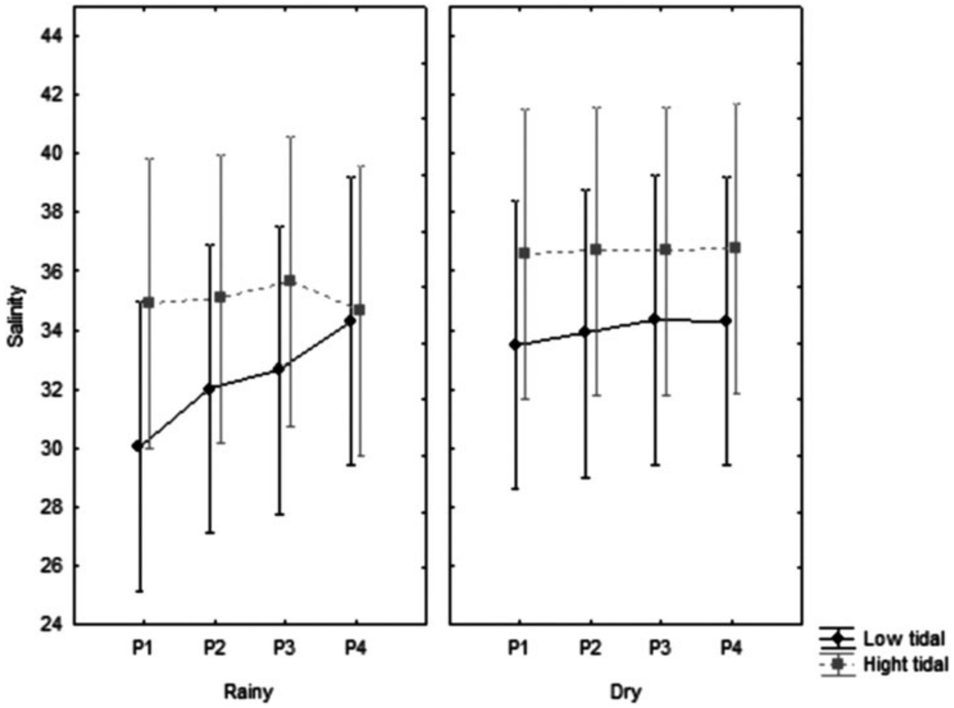

Fig. 3. Distribution of salinity, at the four fixed collection points collected, at low tide and high tide, with the median and interquartile range.

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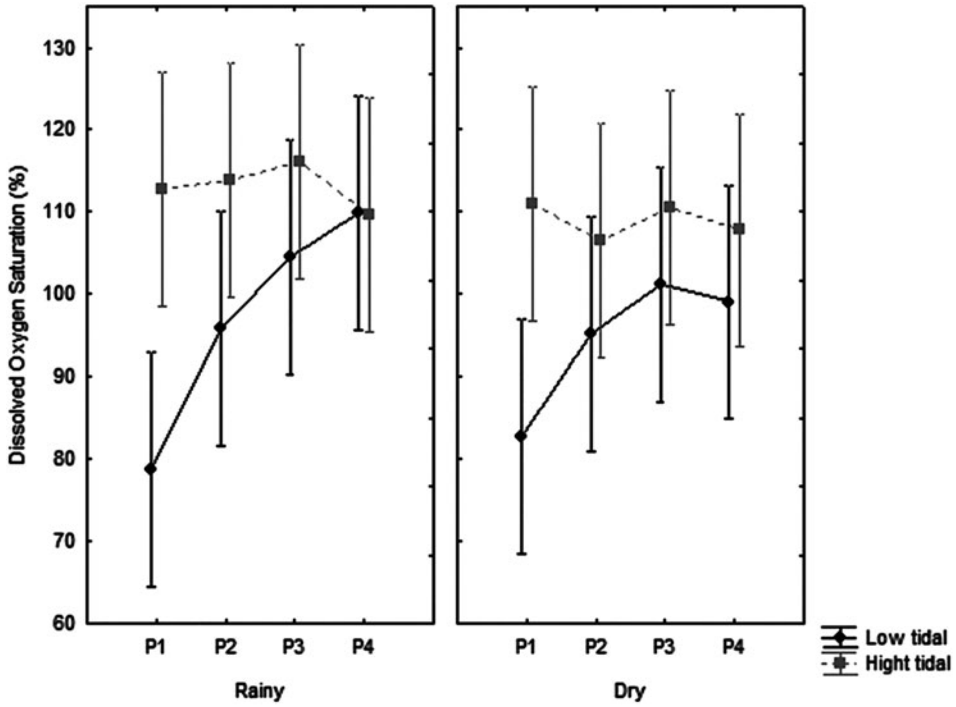

Fig. 4. Distribution of dissolved oxygen saturation, at the four fixed collection points, at low tide and high tide, with the median and interquartile range.

type tide, with amplitude of 3 m, becoming able to cause significant changes in the environment. In the 'Golfão Maranhense' region, Azevedo *et al.* (2008), observed that physical forces such as wind, tide and high turbidity were the main causes for reductions of the euphotic zone and consequently of phytoplankton biomass.

Water transparency varies according to rainfall and terrestrial drainage, and light may become a limiting factor for phytoplankton in the months of higher rainfall, effectively limiting phytoplankton biomass (Passavante & Koening, 1984; Sassi, 1991).

In Suape, transparency was within the expected standard for an estuarine area, with more transparent waters during the dry season in the high tide period. This water transparency pattern as a function of tide and seasonality is commonly reported for other Pernambuco estuaries such as the Ilhetas and Mamucaba Rivers (Losada *et al.*, 2003), Formoso estuary (Honorato da Silva *et al.*, 2004) and Ariquindá River

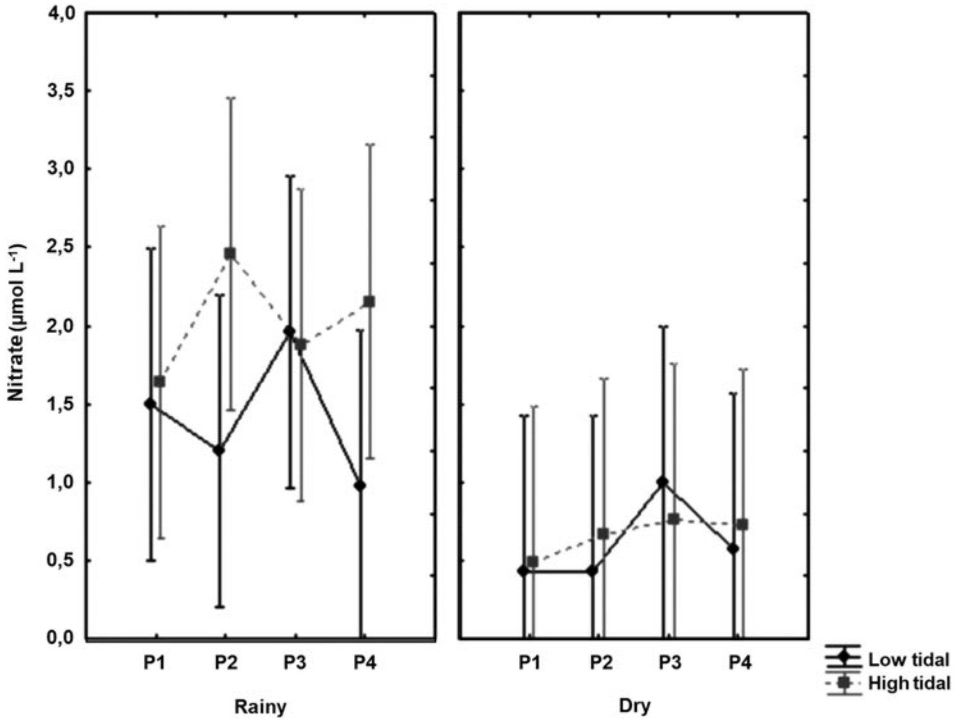

Fig. 5. Distribution of nitrate, at the four fixed collection points, at low tide and high tide, with the median and interquartile range.

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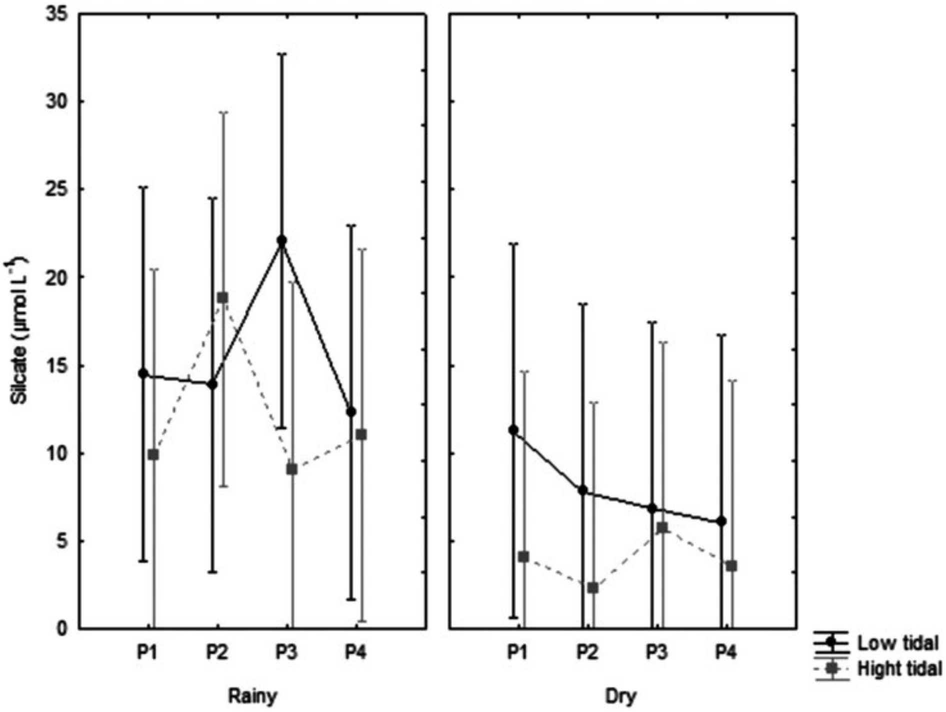

Fig. 6. Distribution of silicate, at the four fixed collection points, at low tide and high tide, with the median and interquartile range.

(Grego *et al.*, 2009). In relation to current data compared with those of CONDEPE (1983), it was verified that the euphotic zone practically did not change.

As for depth, the main feature of port areas is being deep due to the mooring of large boats, continuous traffic and dredging activities. Suape Port, being located by a river, needs to undergo periodical dredging activities, increasing the local depth, and therefore, point 4 has been highlighted among the others as the deepest, because it is close to the navigation channel of large boats.

Dredging can cause great alterations in the environment, as a consequence of the resuspension of sedimented material, a fact corroborated by Forte Neto *et al.* (2014), who evaluated the Aratu Port – Bahia and observed that there was a strong disturbance during the dredging stage, with a decrease in the density of fish eggs and larvae, increase in turbidity and in the

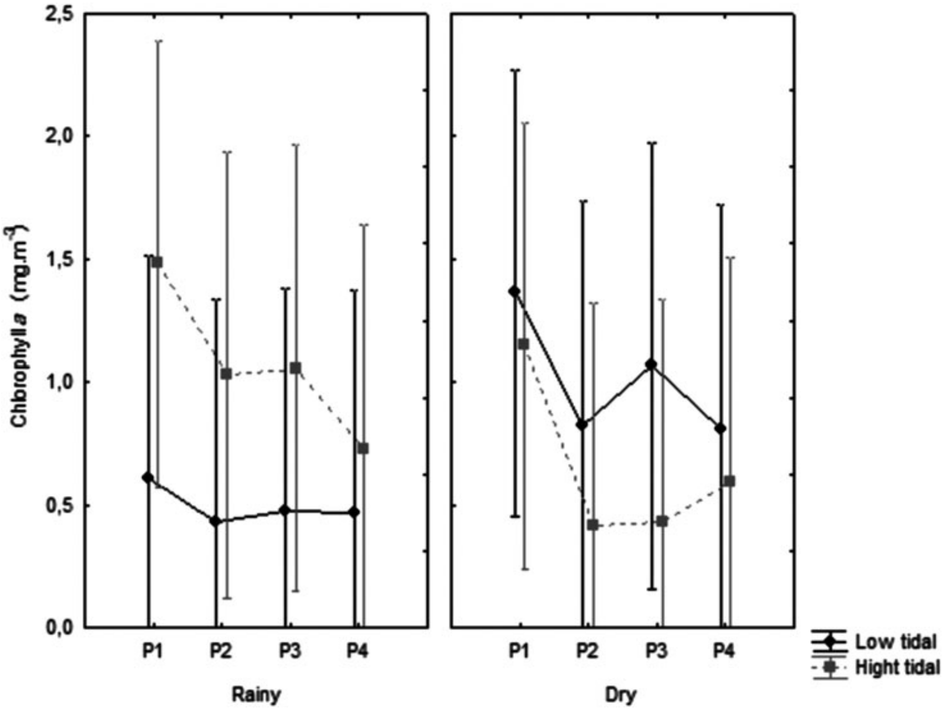

Fig. 7. Distribution of chlorophyll-a, at the four fixed collection points, at low tide and high tide, with the median and interquartile range.

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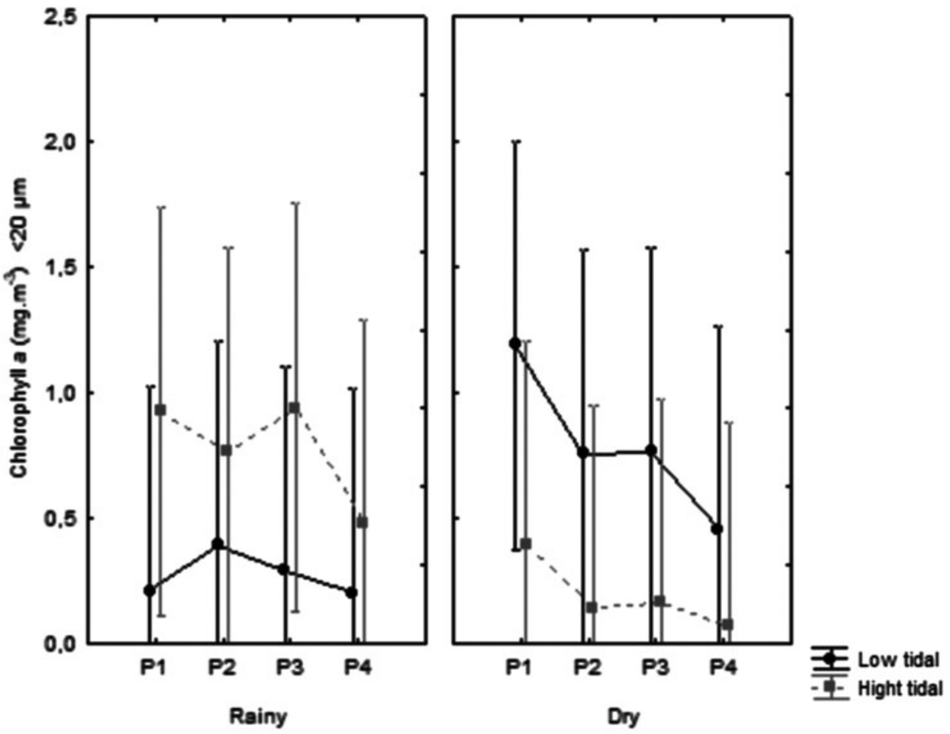

Fig. 8. Distribution of chlorophyll-a <20 μm, at the four fixed collection points, at low tide and high tide, with the median and interquartile range.

density of the microphytoplankton and mesozooplankton, stimulated by the increase in the concentration of phosphorus and ammonia and that after dredging, the environment returned to its stable condition.

In the Ipojuca River estuary, Pernambuco, Koening *et al.* (2002) observed that the phytoplankton community presented qualitative and quantitative changes after the development of Suape Port, with coastal marine species predominating due to the shallow depth and high hydrodynamism in the area and a decrease of 70% in cell density, contrary to what occurred prior to the construction of the port, when higher occurrence of planktonic marine species and higher number of cells per litre were detected.

Table 2. PERMANOVA test of chlorophyll-a and hydrological variables in dry and rainy season in the low tidal and high tidal, with *P*-values of the treatment.

PERMANOVA – P (perm)		
	Group of variables	
Factors	**Hydrological variables**	**Chlorophyll-a**
Seasonal	0.00	0.87
Tidal	0.00	0.62
Spatial	0.22	0.40
Seasonal × Spatial	0.99	0.82
Tidal × Spatial	0.99	0.99
Seasonal × Tidal	0.07	0.04
Spatial × Seasonal × Tidal	1.00	0.98
Pairwise tests Seasonal × Tidal – Chl-a		
Rainy × dry	Low tide	High tide
	0.05	0.20
Low tide × High tide	Rainy	Dry
	0.23	0.04

In the inner portion of Suape Port, Bezerra Júnior *et al.* (2011) found high concentrations of fish larvae; despite the port having a high impact on natural conditions, it is still an important nursery area for fish of ecological and economic and commercial interest (Scombridae, Engraulidae, Clupeidae and Bothidae).

For the present study in the Suape Bay, this type of disturbance by the dredging process was not seen, since parameters such as chl-a and dissolved inorganic nutrients did not show significant changes in their patterns. This can be explained by the fact that the environment is influenced by strong hydrodynamism and with the opening of the reefs, there was greater penetration of coastal waters, causing greater water renewal.

Regarding temperature variations, it was observed that they occurred according to patterns expected for the area, which although tropical (where the amplitude is relatively small), showed a significant difference between climatic periods (dry and rainy seasons). However, the effects of these thermal variations on the planktonic community are not obvious because the variation occurs gradually (Passavante & Feitosa, 2004).

In the Todos os Santos Bay, Mafalda *et al.* (2003) observed larger amplitude possibly due to the fact that the environment has a more limited circulation. Cordeiro *et al.* (2014), in the Port of Recife, Santos *et al.* (2008) in the waters of the Amazon River platform, Ferreira (2011) in the Aratú Port area and Bastos *et al.* (2011) in the estuary of the Ipojuca river – PE also observed seasonal differences.

In general, low temperatures are related to low salinities because in the rainy period, the flow of fresh water increases due to rain and cloud cover. In the dry season, the increase in temperature coincides with higher salinities, explained by the lower flow of fresh water from rain and rivers (Macêdo & Costa, 1990).

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In addition, salinity is an important parameter in the estuarine zone delimitation, influencing the distribution of organisms. In EPC, higher salinities with regimens ranging from polyhaline to euhaline were observed. It is noteworthy, however, that in data from CONDEPE (1983) previous to the anthropic action, the environment varied from limnetic to euhaline due to the discharges of the Ipojuca, Tatuoca and Massangana Rivers. Therefore, after the construction of the port, there was a radical change in the local dynamics, favouring a greater marine intrusion with consequences of increased salinity, dissolved oxygen concentration and reduction of dissolved inorganic nutrients, SPM and chl-a.

Salinity showed significant tidal variation, as observed in other areas of the coast of Pernambuco, in the Recife port basin (Borges *et al.*, 2012; Cordeiro *et al.*, 2014) and in Porto de Galinhas (Machado *et al.*, 2017). Taking into account the pattern of circulation of the estuary area of Bay of Suape, it was verified that the environment is homogeneous, with no thermohaline stratification, as reported in previous data from CONDEPE (1983).

The importance of determining dissolved oxygen is due to the fact that it is an essential gas for life and an indicator of environmental conditions. Its aquatic cycle is governed by several biotic and abiotic processes that produce or consume dissolved oxygen, such as respiration, photosynthesis, oxidation of organic matter and chemical compounds and cellular metabolic processes (Flores-Montes, 1996; Gardner *et al.*, 2006). In EPC, well oxygenated waters were found due to the great input of marine waters and low input of organic matter from river discharges. Prior to the construction of Suape Port, dissolved oxygen concentrations in the Suape Bay were similar to those found currently, except for the Ipojuca River, where concentrations below 2.0 ml l^{-1} were registered, being indicative of organic pollution.

Taking into account the classification of Macêdo & Costa (1978), the oxygen saturation rate ranged from saturated to supersaturated, being indicative of an environment free of excess organic matter, which is compatible with results observed in Maracajaú – Rio Grande do Norte by Feitosa & Bastos (2007), in the São Francisco River, by Melo-Magalhães *et al.* (2011), in the Aratú Port area – Bahia, by Ferreira (2011) and Porto de Galinhas – Pernambuco by Machado *et al.* (2017).

The amount of suspended particulate matter in the Suape Port area was lower than expected for an estuarine environment, possibly due to anthropogenic action, which provided less continental influence and greater marine influence. However, current SPM levels are higher than those observed by Jales *et al.* (2012), in Serrambi – Pernambuco and Masuda *et al.* (2011), in Santos Port – São Paulo and compatible with those reported by Grego *et al.* (2009), in the Ariquindá – Pernambuco estuary and Cordeiro *et al.* (2014) in the Recife Port region.

Coastal waters tend to receive significant amounts of nutrients such as phosphate and nitrate due to the influence of adjacent continents, not presenting total nutrient depletion, even in the tropics (Lourenço & Marques, 2009). According to Macêdo *et al.* (2004), nutrients have high importance in the aquatic environment, because their concentrations, together with light, are the main limiting factors for phytoplankton production, thus affecting the entire trophic web.

In relation to the estuarine region of Suape Bay, nitrogenous nutrients were mostly found at low concentrations, such as nitrite, for example, indicating that there is no contamination by organic matter in the area. The nitrite levels were low, as observed in other environments with good environmental quality, such as Machado *et al.* (2007) in Porto de Galinhas and Jales *et al.* (2012) in Serrambi (0.12–5.23 and 0.00–0.13 µmol l^{-1}, respectively). Nitrite is an intermediate and unstable nutrient from denitrification and nitrification reactions, and can be rapidly converted into nitrate, so in general, it is common that its concentrations in water are relatively lower than those of other forms of dissolved nitrogen (Noriega *et al.*, 2005).

Nitrate, in turn, also presented low concentrations possibly because it is the nitrogen form most needed by the phytoplankton community after ammonia. Nitrate and ammonia presented seasonal variations, with relatively higher values in the rainy period for nitrate and in the dry season for ammonia. Bastos *et al.* (2011), in Maracaípe and Machado (2007) in Porto de Galinhas observed similar results (0.00–3.29 and 0.12–5.23 µmol l^{-1}, respectively) different from those observed by Jales *et al.* (2012) in Serrambi – PE (0.13–2.10 µmol l^{-1}), where even lower values were found and by Koening *et al.* (2002) in the Ipojuca River estuary – PE, (0.02–699.0 µmol l^{-1}) with higher values.

In Suape Bay, Batista (2014) observed high concentrations of phosphate, and reported that this fact was associated with the remobilization of sedimented phosphorus to the water column through oxidation-reduction processes, microbial activity and the equilibrium potential of phosphorus concentrations (Reddy *et al.*, 1999; Zhou *et al.*, 2000; Foy *et al.*, 2003). However, as with nitrogenous nutrients, phosphate also showed low levels, with concentrations similar to those observed by Ferreira *et al.* (2015) in the reef zone of São José da Coroa Grande and by Azevedo *et al.* (2008) in Golfão Maranhense (0.04–0.27 and 0.13–0.58 µmol l^{-1}, respectively).

Silicate was the most concentrated nutrient in the region inside Suape Port, probably explaining the predominance of the diatom phytoplankton group, the most representative community in coastal ecosystems, silicate being an essential element for its development (Grego *et al.*, 2009; Borges, 2011).

In addition, the Massangana River has suffered several anthropogenic impacts, such as landfills, constructions and deforestation along its banks, increasing the contribution of clayed sediments in the environment (which are sources of silicate), due to the leaching of soil by rainfall, and points 1 and 2 located near its mouth presented high concentrations. In addition, silicate showed seasonal variation, with higher levels in the rainy season, as expected for the area. Rosevel da Silva *et al.* (2005), in the Tamandaré Bay – Pernambuco and Borges (2011), in the estuary of the Massangana River – Pernambuco, reported concentrations similar to those of the EPC area (3.72–53.03 and 2.19–65.80 µmol l^{-1}, respectively). Grego *et al.* (2009), in the estuary of the Arinquidá River – Pernambuco and Otsuka *et al.* (2016), in the coastal region of Barra de Jangadas – Pernambuco observed higher values (6.05–106.02, and 3.10–221.12 µmol l^{-1}, respectively).

Phytoplankton biomass in the ocean is a difficult factor to measure accurately. This is in part due to the discontinuous and relatively irregular distribution of phytoplankton populations in the environment. The most common method of measuring phytoplankton biomass is based on the measurement of a component common to all photosynthetic planktonic organisms, i.e. the chl-a content (Lourenço & Marques, 2009).

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According to Vollenweider (1974), it is the most indicated method because chl-a is the most abundant and important pigment of living matter.

Since all photosynthetic organisms have this pigment and use it to perform photosynthesis, the total chl-a of a given volume of seawater should provide a measure of all photosynthetic organisms present (Lourenço & Marques, 2009).

Total chl-a presented slightly higher levels in the high tide, contrary to what is observed for most estuaries. Coincidentally, there was also an increase in nitrite and nitrate contents. The environment showed low chl-a concentrations, different from what was expected and compatible with those obtained by Borges (2011) in the estuary of the Massangana River at the most downstream point and by Batista (2014) in Suape Bay (0.54–6.46 and 0.00–4.0 mg m^{-3}, respectively). Possibly, the anthropogenic actions affecting the estuary dynamics also caused this type of pattern, and the plume of the Ipojuca River is even able to influence Suape Bay during the period of tide flood. Another possibility is the presence of large boats, which may be contributing with releases of organic matter.

In other port areas of the Brazilian coast, the amount of phytoplankton biomass varied, such as those reported by Paiva *et al.* (2006) in the Guajará Bay – Pará, from 1.49–23.33 mg m^{-3}; Masuda *et al.* (2011) in Santos – São Paulo, concentrations from 0.9–11.6 mg m^{-3}, and Cordeiro *et al.* (2014) in the Recife Port, from 0.24–19.29 mg m^{-3}.

Along the coastline of Pernambuco, a number of authors have observed low chl-a levels in areas considered not impacted, such as Tamandaré Bay (Silva, 2016), Porto de Galinhas (Machado *et al.*, 2017), São José da Coroa Grande (Ferreira *et al.*, 2015) and Serrambi (Jales *et al.*, 2012), presenting values lower than 9 mg m^{-3}. In contrast, there are also other highly eutrophic environments, such as the Pina Basin (Santos *et al.*, 2009) with contents up to 211.15 mg m^{-3}, Barra das Jangadas (Otsuka *et al.*, 2016; Branco *et al.*, 2002) with 34.71 and 49.84 mg m^{-3} respectively, and Candeias beach (Santos *et al.*, 2007) with 158.99 mg.m^{-3}.

Taking into account the classification for the coastal zone of Vollenweider & Kerekes (1982), the Suape estuarine complex ranged from oligotrophic to mesotrophic, with a strong tendency to oligotrophy.

The phytoplankton community is composed of organisms of different sizes. According to Takahashi & Biefang (1983), the size distribution of the phytoplankton community may play a major role in the dynamics of the food web, in the biological structure and ecological efficiency.

A higher contribution of fraction $<$20 μm, corresponding to pico- and nanophytoplankton, will be due to a low concentration of nutrients in aquatic environments, considering that larger phytoplankton species in these environments are in disadvantageous conditions (Tada *et al.*, 2003; Jales *et al.*, 2012).

This limits the development of the largest fraction, which has a surface × volume ratio smaller than the $<$20 μm phytoplankton. However, Charpy & Blanchot (1999) suggest that biotic factors may also affect the structure of the phytoplankton community, such as herbivory. In addition, Tada *et al.* (2003) reported that the domain of this fraction may also be associated with environmental factors, with high temperatures in the water column becoming a limiting factor for the phytoplankton cell growth of the largest fraction in relation to the smallest one.

In Suape Port, the fraction $<$20 μm predominated with an average of 60.75% in the environment, becoming the main contributor. This fraction had higher concentrations at low tide, during the dry season, and these factors were considered determinants, as confirmed by PERMANOVA. According to Moran *et al.* (2010), this fraction may become more significant for the environment with increasing temperature in the two regions of the Atlantic. Similar situations have also been observed in some coastal regions of the world, such as by Costa (2007), in Todos os Santos Bay, by Tada *et al.* (2003) in Sesoko Island in Okinawa – JP and by Charpy & Blanchot (1999) in Fiji.

Along the coastline of Pernambuco, other authors have observed low chl-a levels, such as Silva (2016) in Tamandaré Bay, Ferreira *et al.* (2015) in São José da Coroa Grande, and Jales *et al.* (2012) in Serrambi (0.14–2.25, 0.00–5.70 and 0.35–3.35 mg m^{-3}, respectively).

In view of the above, it could be concluded that rainfall and tide were the physical forces that most affected the environmental variables. The environment presented a circulation pattern of the homogeneous type, with strong marine intrusion.

The low levels of nutrients and chl-a were indicative of an environment free of eutrophication processes, with nitrogen being the limiting biomass element.

Anthropogenic changes in the environment have led to greater marine interference and consequently to a reduction in the productive capacity of the system.

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REFERENCES

Anjos D.L., Passavante J.Z.O., Silva-Cunha M.G.G. and Honorato da Silva M. (2012) Biomassa fitoplanctônica correlacionada aos fatores hidrológicos no estuário dorio Capibaribe (Recife, Pernambuco, Brasil). *Tropical Oceanography* 40, 167–184.

Aragão J.O.R. (2000) *Fundamentos de meteorologia e relação oceano-atmosfera*. Recife: Secretaria de Recursos Hídricos de Pernambuco.

Azevedo A.C.G., Feitosa F.A.N. and Koening M.L. (2008) Distribuição espacial e temporal da biomassa fitoplânctonica e variáveis ambientais no Golfão Maranhense, Brasil. *Acta Botânica Brasílica* 22, 870–877.

Bastos R.B., Feitosa F.A.N., Koening M.L., Machado R.C.A. and Muniz K. (2011) Caracterização de uma zona costeira tropical (Ipojuca – Pernambuco-Brasil): produtividade fitoplanctônica e outras variáveis ambientais. *Brazilian Journal of Aquatic Science and Technology* 15, 1–10.

https://doi.org/10.1017/S0025315418000176 Published online by Cambridge University Press

Batista T.N.F. (2014) *Estado trófico das águas estuarinas do Complexo Industrial Portuário de Suape-PE.* MSc dissertation. Universidade Federal de Pernambuco, Recife, Brasil.

Baumgarten M.G.Z., Rocha J.M.B. and Niencheski L.F.H. (1996) *Manual de análises em oceanografia química.* Rio Grande: FURG.

Bezerra Júnior J.L., Diaz X.G. and Neumann-Leitão S. (2011) Diversidade de larvas de peixes das áreas internas e externas do porto de Suape (Pernambuco, Brasil). *Tropical Oceanography* 39, 1–13.

Borges G.C.P. (2011) *Comunidade fitoplanctônica do estuário do rio Massangana (Pernambuco-Brasil).* MSc dissertation. Universidade Federal de Pernambuco, Recife, Brasil.

Borges G.C.P., Silva-Cunha M.G.G., Santiago M.F. and Lima J.C. (2012) Comunidade fitoplanctônica e variáveis ambientais em área portuária, nordeste do Brasil. *Tropical Oceanography* 40, 308–317.

Branco E.S., Feitosa F.A.N. and Flores Montes M.J. (2002) Variação Sazonal e Espacial da Biomassa Fitoplanctônica Relacionada com Parâmetros Hidrológicos no Estuário de Barra das Jangadas (Jaboatão dos Guararapes – Pernambuco – Brasil). *Tropical Oceanography* 30, 79–96.

Charpy L. and Blanchot J. (1999) Picophytoplankton biomass, community structure and productivity in the Great Astrolabe Lagoon, Fiji. *Coral Reefs* 18, 255–262.

CONDEPE (1983) Caracterização do complexo estuarino-lagunar da área de Suape (Pernambuco-Brasil): síntese ecológica, Recife, v. 1.

Cordeiro I.A., Feitosa F.A.N., Flores Montes M.J. and Honorato da Silva M. (2014) Distribuição sazonal e espacial da clorofila a e variáveis ambientais na Plataforma Continental de Pernambuco (Porto do Recife), Brasil. *Tropical Oceanography* 42, 60–76.

Costa O.S. Jr (2007) Anthropogenic nutrient pollution of coral reefs in Southern Bahia, Brazil. *Brazilian Journal of Oceanography* 55, 265–279.

Eskinazi-Leça E. and Koening M.L. (1985/86) Distribuição das diatomáceas (Bacillariophyceae) na área de Suape (Pernambuco-Brasil). *Trabalhos Oceanográficos da Universidade Federal de Pernambuco* 19, 73–100.

Feitosa F.A.N. and Bastos R.B. (2007) Produtividade fitoplanctônica e hidrologia do ecossistema costeiro de Maracajaú – RN. *Arquivos de Ciências do Mar* 40, 26–36.

Ferreira A.N. (2011) Avaliação do impacto da dragagem sobre a associação fitoplanctônica do porto de Aratu, Baía de Todos os Santos, Bahia. Salvador. MSc dissertation. Universidade Federal da Bahia, Salvador, Brasil.

Ferreira L.C., Silva Cunha M.G.G., Aquino E.P.Borges G.C.P., Feitosa F.A.N., Eskinazi-Leça E. and Lima J.C. (2015) Temporal and spatial variation of phytoplankton in a tropical reef area of Brazil. *Tropical Ecology* 56, 367–382.

Flores-Montes M.J. (1996) *Variação nictemeral do fitoplâncton e parâmetros hidrológicos no canal de Santa Cruz, Itamaracá, PE.* MSc dissertation. Universidade Federal de Pernambuco, Recife, Brasil.

Forte Neto J.B., Beretta M., Ferreira A.N., Souza C.S. and Mafalda P.O. Jr. (2014) A Variabilidade da biomassa planctônica sob influência da sazonalidade e da dragagem do Porto de Aratú, baía de Todos os Santos, Brasil. *Tropical Oceanography* 42, 230–242.

Foy R.H., Lennox S.D. and Gibson C.E. (2003) Agriculture or urban? Changing perspectives on the importance of urban phosphorus inputs as the cause of enrichment of Lough Neagh. *Science of the Total Environment* 310, 87–99.

Gardner L.R., Kjerve B. and Petrecca D.M. (2006) Tidal fluxes of dissolved oxygen at the North Inlet-Winyah Bay National Estuarine Research Reserve. *Estuarine Coastal and Shelf Science* 67, 450–460.

Grasshoff K., Ehrhardt M. and Kremling K. (1983) *Methods of seawater analysis*, 2nd edition. Deerfield Beach, FL: Verlag Chemie.

Grego C.K.S., Feitosa F.A.N., Silva M.H., Cunha M.G.G.S. and Nascimento-Filho G. A. (2009) Fitoplâncton do ecossistema estuarino do Rio Ariquindá (Tamandaré, Pernambuco, Brasil): variáveis ambientais, biomassa e produtividade primária. *Atlântica* 31, 183–198.

Honorato da Silva M., Passavante J.Z.O., Silva-Cunha M.G.G., Nascimento Vieira D.A., Grego C.K.S. and Muniz K. (2004) Distribuição espacial e sazonal da biomassa fitoplanctônica e dos parâmetros hidrológicos do estuário do rio Formoso (Rio Formoso, Pernambuco, Brasil). *Tropical Oceanography* 32, 89–106.

Jales M. C., Feitosa F. A. N., Koening M. L., Bastos R. B. and Machado R. C. A. (2012) O Ecossistema recifal de Serrambi (nordeste do Brasil): biomassa fitoplanctônica e parâmetros hidrológicos. *Atlântica* 34, 87–102.

Koening M.L. (1997) *Ecologia e dinâmica do fitoplâncton no estuário do rio Ipojuca, após a implantação do porto de Suape (PE-Brasil).* PhD thesis. Universidade Federal Rural de Pernambuco, Recife, Brasil.

Koening M.L., Eskinazi-Leça E., Neumann-Leitão S. and Macêdo S.J. (2002) Impactos da construção do Porto de Suape sobre a comunidade fitoplanctônica no estuário do rio Ipojuca (Pernambuco – Brasil). *Acta Botânica Brasílica* 16, 407–420.

Koening M.L., Eskinazi-Leça E., Neumann-Leitão S. and Macêdo S.J. (2003) Impacts of the construction of the Porto of Suape on phytoplankton in the Ipojuca River Estuary (Pernambuco-Brazil). *Brazilian Archives of Biology and Technology* 46, 73–81.

Losada A.P.M., Feitosa F.A.N. and Lins I.C. (2003) Variação sazonal e espacial da biomassa fitoplanctônica nos estuários dos rios Ilhetas e Mamucaba (Tamandaré – PE) relacionada com parâmetros hidrológicos. *Tropical Oceanography* 31, 1–29.

Lourenço S.O. and Marques N. A. Jr (2009) Produção primária marinha. In Pereira R.C. and Soares-Gomes A. (eds) *Biologia marinha*, 2nd edition. Rio de Janeiro: Interciência, pp. 111–154.

Macêdo S.J. and Costa K.M.P. (1978) Estudo ecológico da região de Itamaracá Pernambuco–Brasil, condições hidrológicas do estuário do rio Botafogo. *Ciência e Cultura* 30, 368.

Macêdo S.J. and Costa K.M.P. (1990) Condições hidrológicas do estuário do rio Igaraçu – Itamaracá – Pernambuco. *Trabalhos Oceanográficos* 2, 7–32.

Macêdo S.J., Muniz K. and Flores Montes M.J. (2004) Hidrologia da região costeira e plataforma continental do Estado de Pernambuco. In Eskinazi-Leça E., Neumann-Leitão S. and Costa M.F. (eds) *Oceanografia: um cenário tropical.* Recife: Bagaço, pp. 255–286.

Machado R.C.A. (2007) Dinâmica da biomassa fitoplanctônica e parâmetros hidrológicos no ecossistema recifal e Porto de Galinhas, Pernambuco, Brasil. *Boletim Técnico Cientifico do CEPENE* 15, 17–29.

Machado R.C.A., Feitosa F.A.N., Koening M.L. and Flores Montes M.J. (2017) Spatial and seasonal variation of the phytoplankton community structure in a reef ecosystem in north-eastern Brazil. *Journal of the Marine Biological Association of the United Kingdom.* doi: 10.1017/S0025315416001600.

Mafalda P.O. Jr, Sousa P.M.M. and Silva E.M. (2003) Estrutura hidroquímica e biomassa planctônica no norte da Baía de Todos os Santos, Bahia, Brasil. *Tropical Oceanography* 31, 31–51.

Masuda L.S.M., Moser G.A.O. and Barrera-Alba J.J. (2011) Variação temporal do fitoplâncton no canal estuarino de Santos (SP). *Brazilian Journal of Aquatic Science and Technology* 15, 79–93.

https://doi.org/10.1017/S0025315418000176 Published online by Cambridge University Press

Melo-Magalhães E.M., Moura A.N., Medeiros P.R.P., Lima E.L.R. and Koening M.L. (2011) Phytoplankton of the São Francisco river estuarine region (Northeastern Brazil): a study of its diversity. *Brazilian Journal of Aquatic Science and Technology* 15, 95–105.

Moran X.A.G., Lopez-Urrutia A., Calvo-Díaz A. and Li W.K.W. (2010) Increasing importance of small phytoplankton in a warmer ocean. *Global Change Biology* 16, 1137–1144.

Muniz K.; Neto B.B.; Macêdo S.J. and Pinheiro Filho W.C. (2005) Hydrological impact of the port complex of Suape on the Ipojuca River (Pernambuco – Brazil). *Journal of Coastal Research* 21, 909–914.

Neumann-Leitão S., Koening M.L., Macêdo S.J., Medeiros C., Muniz K. and Feitosa F.A.N. (1999) Plankton disturbance at Suape estuarine area – Pernambuco – Brazil after a port complex implantation. *Transactions on Ecology and the Environment* 27, 47–56.

Neumann-Leitão V.H., Medeiros C., Parente L., Neumann-Leitão S. and Koening M.L. (1998) Hydrodynamism sedimentology, geomorphology and plankton changes at Suape Area (Pernambuco – Brazil) after a port complex implantation. *Anais da Academia Brasileira de Ciências* 70, 313–323.

Noriega C.D., Costa K.M.P., Feitosa F.A., Flores Montes M.J., Grego C.K.S., Soarea G.S.S. and Silva H.P. (2005) Distribuição espacial da biomassa fitoplanctônica e sua relação com os sais nutrientes, no sistema estuarino de Barra das Jangadas (Pernambuco-Brasil). *Arquivos de Ciência do Mar* 38, 5–18.

Oliveira G. S. (2001) *O El Niño e você: o fenômeno climático*. São Paulo: Transtec.

Otsuka A.Y., Feitosa F.A.N., Flores Montes M.J. and Silva A. (2016) Dynamics of chlorophyll *a* and oceanographic parameters in the coastal zone: Barra das Jangadas – Pernambuco, Brazil. *Journal of Coastal Research* 32, 490–499.

Paiva A.C.G. and Araújo M.E. (2010) Environmental characterization and spatial distribution of fish fauna in estuaries in the State of Pernambuco, Brazil. *Tropical Oceanography* 38, 1–46.

Paiva R.S., Eskinazi-Leça E., Passavante J.Z.O., Silva-Cunha M.G.G. and Melo N.F.A.C. (2006) Considerações ecológicas sobre o fitoplâncton da baía do Guajará efoz do rio Guamá (Pará-Brasil). *Boletim do Museu Paraense Emílio Goeldi* 1, 133–146.

Parsons T.R. and Strickland J.D.H. (1963) Discussion of spectrophometric determination of marine-plant pigments, with revised equations for ascertaining chlorophyll *a* and carotenoids. *Journal of Marine Research* 21, 155–163.

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

Passavante J.Z.O. and Koening M.L. (1984) Estudo ecológico da região de Itamaracá (Pernambuco – Brasil). XXVI Clorofila *a* e material em suspensão no estuário do rio Botafogo. *Trabalhos Oceanográficos da Universidade Federal de Pernambuco* 18, 207–230.

Pessoa V.T., Neumann-Leitão S., Gusmão L.M.O., Silva A.P. and Porto-Neto F.F. (2009) Comunidade zooplanctônica na Baía de Suape e nos estuários dos rios Tatuoca e Massangana, PE (Brasil). *Revista Brasileira de Engenharia de Pesca* 4, 80–94.

Reddy K.R., Kadlec R.H., Flaig E. and Gale P.M. (1999) Phosphorus retention in streams and wetlands: a review. *Critical Reviews in Environmental Science and Technology* 29, 83–146.

Rosevel da Silva M., Silva Cunha M.G.G., Feitosa F.A.N. and Muniz K. (2005) Estrutura da comunidade fitoplanctônica na baía de Tamandaré (Pernambuco, Nordeste do Brasil). *Tropical Oceanography* 33, 163–181.

Santos D.H.C., Passavante J.Z.O. and Barros D.C.P. (2007) Biomassa fitoplanctônica na praia de Candeias, Pernambuco (Brasil): a construção de um quebra mar como agente transformador. *Boletim Técnico Científico* 15, 21–29.

Santos M.L.S., Medeiros C., Muniz K., Feitosa F.A.N., Schwamborn R. and Macedo S.J. (2008) Influence of the Amazon and Pará rivers on water composition and phytoplankton biomass on the adjacent shelf. *Journal of Coastal Research* 24, 585–593.

Santos T.G., Bezerra Júnior J.L., Costa K.M.P. and Feitosa F.A.N. (2009) Dinâmica da biomassa fitoplanctônica e variáveis ambientais em um estuário tropical (Bacia do Pina, Recife). *Revista Brasileira de Engenharia de Pesca* 4, 95–109.

Sassi R. (1991) Phytoplankton and environmental factors in the Paraiba do Norte river estuary, southeastern Brazil: composition, distribution and quantitative remarks. *Boletim do Instituto Oceanográfico* 39, 93–115.

Silva L.M. (2016) *Condições ambientais do ecossistema recifal de Tamandaré (APA COSTA DOS CORAIS): comunidade fitoplanctônica e variáveis hidrológicas*. MSc dissertation. Universidade Federal de Pernambuco, Recife, Brasil.

Strickland J.D.H. and Parsons T.R. (1972) A practical handbook of seawater analysis. *Bulletin of the Fisheries Research Board of Canada* 167, 207–211.

Suape (2015) Complexo industrial portuário governador Eraldo Guerios – Meio Ambiente. Available at: http://www.suape.pe.gov.br/environment/structure.php (accessed 1 July 2015).

Tada K., Sakai K., Nakano Y., Takemura A. and Monyani S. (2003) Size fractionated phytoplankton biomass in coral reef waters off Sesoko Island, Okinawa, Japan. *Journal of Plankton Research* 25, 991–997.

Takahashi M. and Biefang P.K. (1983) Size structure of phytoplankton biomass and photosynthesis in subtropical Hawaiian waters. *Marine Biology* 76, 203–211.

Torres F.T.P. and Machado P.J.O. (2011) *Introdução à Climatologia*. São Paulo: Cengage Learning.

UNESCO (1966) Report of SCOR/UNESCO Working Group 17 on determination of photosynthetic pigments in seawater. *Monographs on Oceanographic Methodology, Paris* 1, 9–18.

UNESCO (1973) *International oceanographic table*, 2nd edition. Wormley: Institute of Oceanographic Sciences.

Vollenweider R.A. (1974) *A manual on methods for measuring primary production in aquatic environments*, 2nd edition. IBP Handbook No. 12. Oxford: Blackwell Scientific.

Vollenweider R.A. and Kerekes J. (1982) Eutrophication of waters: monitoring, assessment and control. In *Report of the OECD cooperative program on eutrophication.* Paris: Organization for the Economic Development and Cooperation, 156 pp.

and

Zhou Q.X., Gibson C.E. and Foy R.H. (2000) Long-term changes of nitrogen and phosphorus loadings to a large lake in north-west Ireland. *Water Research* 34, 922–926.

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