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Phosphorus concentrations in sediments from the equatorial Amazon estuary, Furo of Muriá, Pará State, Brazil

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ABSTRACT. We characterized the spatial and seasonal distributions of different phosphorus fractions in surface sediments from the Furo of Muriá estuary by chemical fractionation. Five phosphorus species were successfully separated: phosphorus bound to Fe/Al oxyhydroxides (non-apatite inorganic phosphorus (NAIP) ranging from 164.54 to 280.32 μg g^{-1}), phosphorus bound to calcium (apatite phosphorus (AP) ranging from 63.02 to 102.80 μg g^{-1}), inorganic phosphorus (IP, ranging from 227.21 to 378.61 μg g^{-1}), organic phosphorus (OP, ranging from 30.33 to 135.88 μg g^{-1}) and total phosphorus (TP, ranging from 257.54 to 507.73 μg g^{-1}), in which 88% of TP is constituted by IP. Statistical results showed that seasonality was not a major factor influencing phosphorus concentrations. Considering the classification of estuarine sediment conditions, we can conclude that the TP concentrations found in Furo of Muriá do not yet indicate the risk of environmental deterioration.

Keywords: chemical fractionation; Curuçá River; phosphorus speciation.

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Introduction

Phosphorus is considered a fundamental nutrient in aquatic ecosystems because it plays a part in the metabolism of phytoplankton (Wang, Ye, Li, Zou, & Zhou, 2013) and is an essential element for plant growth and productivity (Malhotra, Vandana, Sharma, & Pandey, 2018). In continental and coastal waters, phosphorus was originally released from rocks through weathering and natural erosion, as well as from anthropogenic sources. Transport of phosphorus to aquatic environments occurs through rainwater infiltration and leaching (Esteves, 2011). Generally, rivers are considered the main route for the transport of P to the marine environment (Fang & Wang, 2020).

When transported to aquatic environments, phosphorus can remain in the water or be deposited in sediments, in different forms. These forms will elucidate, in an integrated manner, the anthropogenic processes that influence the hydrographic basin and the natural processes that characterize the local hydrogeochemistry as it interferes with the predominant biogeochemical processes in the sedimentation materials (Marins, Paula Filho, & Rocha, 2007).

However, if the phosphorus load in water is reduced, sediments that otherwise would absorb it tend to release it; thus, aquatic environments act as a phosphorus source to the medium (Cao et al., 2017; Cotovicz Junior, Machado, Brandini, Zem, and Knoppers, 2014; Meng et al., 2014). According to Fisher, Carlson, and Barber (1982), approximately 28-35% of phosphorus from sediment is needed for primary productivity in coastal sea areas.

The potential of sediments to store or release phosphorus in the environment is reflected in the trophic status of waters and, consequently, their productivity. Therefore, the observation of phosphorus dynamics in the sediment is a key factor in understanding the phosphorus cycle in rivers, lakes, and estuaries (Wang et al., 2013).

Accordingly, the identification and quantification of various geochemical forms and characteristics of the P fractionation in sediments are essential to elucidate the P cycle in coastal ecosystems (Yang, Cao, Liu, & Zang, 2015).

The northern region of Brazil is known for its diverse water bodies, which are a part of the life of the local community. These water bodies are called “Furo,” which consist of a canal or hydrographic accident that connects

lakes, rivers (off the alluvial plain), or a river to a lake (Pimentel, Oliveira, & Rodrigues, 2012). This is the case for the Furo of Muriá, south of Mutucal Island, which connects the Curuçá and Mocajuba rivers to Curuçá Bay.

The Furo of Muriá is located 8 km from Curuçá and 136 km from Belém (Pará State, Brazil) and connects the Curuçá River estuary, which is close to the Beira Mar and Recreio communities, to the Mocajuba River estuary. The new law No. 9.064 of May 25, 2020 (SEMAS, 2020) fits the research area in Sector 4—Fluvium-Maritime in the Pará Coastal Zone—for the State Policy for Coastal Management.

Many residential areas can be observed in the vicinity of the Furo of Muriá, such as the Beira Mar and Recreio communities. The economy of these communities, as well as the rest of the city, are mainly based on agricultural activities and artisanal fishing, as well as commerce that meets the needs of the residents and tourists in the area, and some other industries. The Furo of Muriá also plays a fundamental role in connecting the population in nearby islands via the use of small boats. The main sources of pollution observed in the study area are strongly linked to the lack of sanitation infrastructure and the disposal of domestic sewage in the open air or through open burning, in which irregular disposal of solid waste and traces of oil leaks can sometimes be observed from vessels in the area (Figure 1).

Figure 1. (a), (b), (c), and (d) Vessels used for locomotion of the local population; (e) and (f) burnt solid waste; (g) leak of oil into estuary waters and (h) open air bathroom.

The region has an Amazonian equatorial climate, with an average temperature of 27°C, small temperature variation, and abundant rainfall exceeding 2,000 mm per year (Carvalho, Martinelli-Lemos, Nevis, & Isaac, 2016). The high and low rainfall periods are from January to June and July to December, respectively (Bittencourt et al., 2014). The region tides have a maximum height of 4 m and may be higher during equinoctial spring tides. The streams have strong currents and reach speeds between 0.97 and 1.08 m s^{-1} and are mostly responsible for the existence of several sandbars that are distributed perpendicularly to the coast. The coastal plain of Curuçá has dynamic transitional environments due to the meteorological and oceanographic conditions in the region (Leite, Pereira, & Costa, 2009).

In relation to other coastal areas around the world, information on the P fractions in the sediments of the Furo of Muriá estuary is extremely limited. To fill this knowledge gap and provide a comprehensive review of the geochemistry of P in the study area, we employed the Williams, Jaquet, and Thomas (1976) method, as modified by Burrus, Thomas, Dominik, and Vernet (1990) and described by Pardo, Rauret, and López-Sánches (2004). The objectives of this study were to quantify the main species of P on the sediment surface and explore the factors that influence the distribution and geochemical behaviors of P fractions in sediments. This information provides a better understanding of the biogeochemical cycling of P in estuarine equatorial areas.

Material and methods

Sampling and analyses

In 2015, sediment samples were collected at fourteen points in the Furo of Muriá area (Figure 2) in March, June, September, and December, with a total of 56 sediment samples. All points were georeferenced with a global positioning system (Magellan GPS, NAV 5000 PROTM model). Salinity measurements were instantaneously conducted during sample collection using a Hanna HI9828 multiparameter probe.

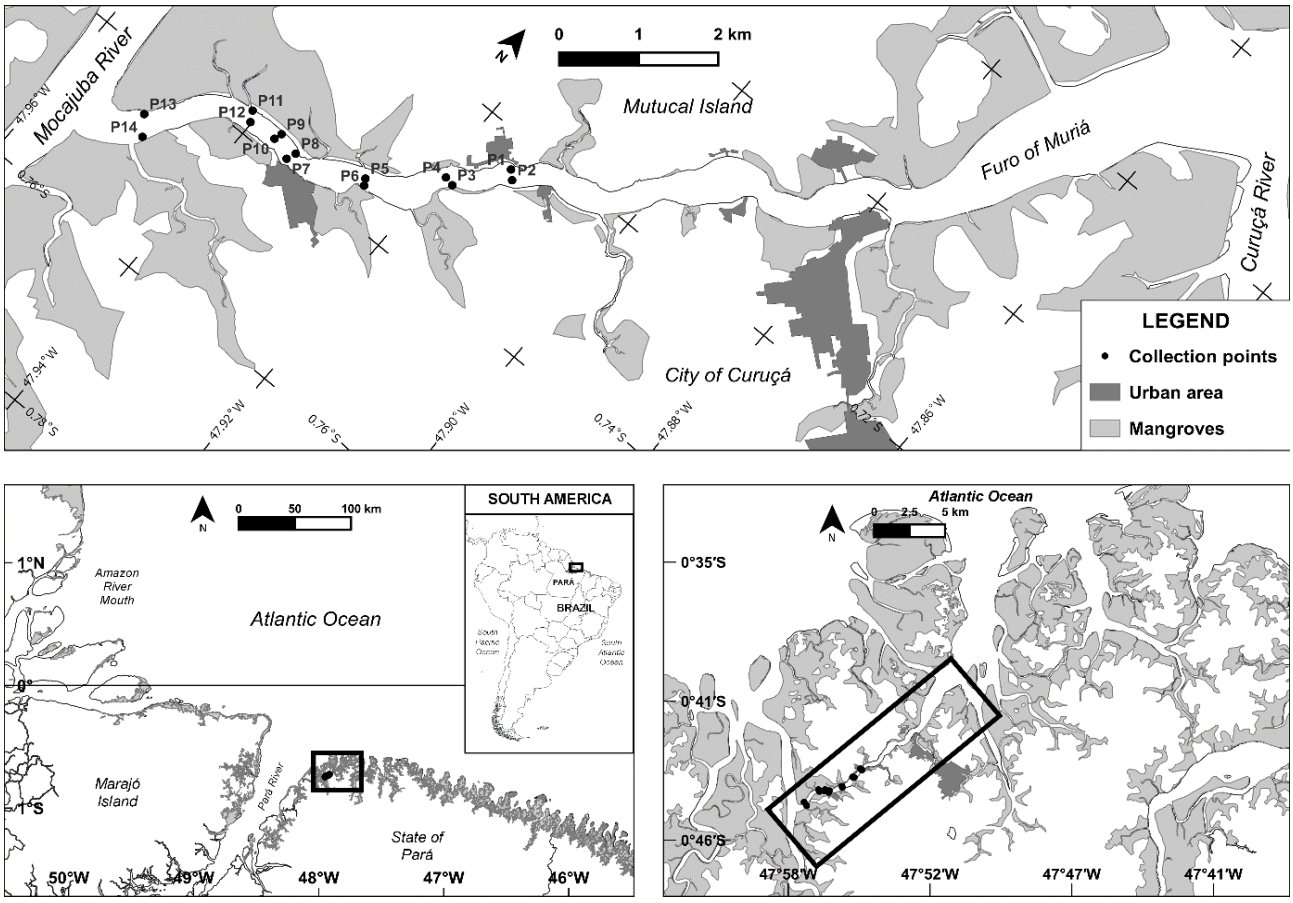

Figure 2. Sampling stations for surface in the Furo of Muriá.

The sediment samples were then taken on board a small vessel equipped with an Ekman–Birge type bottom sampler. After opening the dredger, representative samples of the different sampled points were collected. The most oxidized and recent fractions of the sediment were collected only in the Furo of Muriá's bank (intertidal zone), as fine sediments were not observed in the central section of the Furo. Subsequently, the samples were placed in clean plastic bags and properly sealed and labeled for storage in a cooler with ice before being transported to the Environmental Chemistry Laboratory of the Federal Rural University of Amazonia, where chemical phosphorus speciation was performed. The samples were also sent to the Laboratory of Marine and Coastal Studies Group of the Federal University of Pará, where the analysis of organic matter (OM) was carried out. All analyses were performed in triplicate.

Sediment analysis

OM in the sediment was gravimetrically determined by following the methodology developed by Kralik (1999). From each sampled point, 1 g of crude sediment was weighed, without washing, in porcelain crucibles after being dried in an oven at 100°C for 24h to remove moisture. Next, the samples were subjected to calcination in a muffle furnace for 2h at 360°C, followed by cooling in a desiccator. The difference between the final (calcined sediment) and initial (dry sediment) weights was the total amount of OM.

All analyses of the phosphorus fractions were performed in triplicates. Extractions for organic phosphorus (OP), non-apatite inorganic phosphorus (NAIP), and calcium-bound phosphorus (apatite phosphorus (AP)) were determined by the method developed by Williams et al. (1976), modified by Burrus et al. (1990), described by Pardo et al. (2004), and used by the Standards, Measurements and Testing Programme of the European Commission. All extracted phosphates were determined by the colorimetric molybdenum blue method, as described in APHA (2017).

To determine the NAIP, 0.50 g of the washed, dried, and macerated sediments were weighed. Next, 20 mL of 1 mol L^{-1} NaOH was added to the sediment sample and the mixture was stirred for 16 h. The samples were then centrifuged for 5 min at 3000 rpm. Subsequently, 10 mL of the extract was removed and transferred to a test tube filled with 4 mL of 3.5 mol L^{-1} HCl, allowing it to decant for 16 h for the precipitation of OM and further analyses using a spectrophotometer.

The determination of AP was carried out using the solid phase that was obtained from the determination of NAIP. To prepare the sample for the AP determination, 12 mL of 1 mol L^{-1} NaCl was added to the solid phase and the resulting mixture was stirred for 5 min. The samples were then centrifuged for 5 min at 3000 rpm and the supernatant obtained was discarded. Next, 20 mL of 1 mol L^{-1} HCl was added to the residue, and the mixture was subsequently stirred for 16 h. The samples were centrifuged again for an equal period of rotation and temperature to obtain the extract, which was later analyzed on a spectrophotometer.

Inorganic phosphorus (IP) was obtained by adding NAIP to AP.

OP was determined by adding 10.0 mL of 1 mol L^{-1} HCl to 0.5 g of sediment sample, and the mixture was stirred for 16h. The samples were then centrifuged for 5 min. at 3,000 rpm. Next, 6.0 mL of distilled water was added to the residue, and the mixture was stirred for 5 min. and subsequently centrifuged for an equal amount of time and rotation. The samples were transferred to porcelain crucibles, placed in an oven at a temperature of 105°C, and calcined at 550°C for 1h in a muffle furnace. Subsequently, 10.0 mL of 1 mol L^{-1} HCl was added to the residue. The samples were then transferred to test tubes, subjected to agitation for 16h, centrifuged for 5 min. at 3,000 rpm, and later analyzed on a spectrophotometer.

Total phosphorus (TP) was obtained by adding OP to IP.

Statistical analysis

The statistical data obtained were organized in tables using the Past 3.14 statistical software. Descriptive statistics were also applied (minimum, maximum, mean, and standard deviation), as well as a correlation matrix (Pearson), in which the correlations were considered weak, moderate, and strong when $p < 0.3$, $0.3 < p < 0.4$, and $p > 0.4$, respectively. To check whether there were significant seasonal and spatial differences between the phosphorus concentrations and OM, the Shapiro–Wilk normality test, with a significance level adopted at $p < 0.05$, followed by a one-way ANOVA (critical value of $p < 0.05$) were performed.

Results and discussion

The minimum and maximum values of salinity (13–35), which demonstrate the influence of seasonality on the distribution of phosphorus (Figure 3), were determined during periods of high and low rainfalls, respectively. In the Furo of Muriá, no exact variation in salinity was observed during the low tide periods; however, the lowest and highest values were detected near the Mocajuba and Curuçá estuaries, respectively.

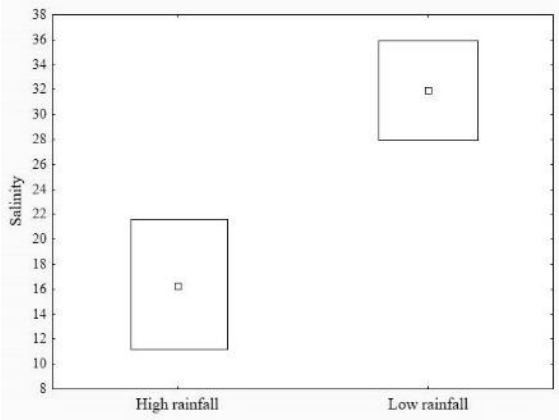

Figure 3. Box plot with values found for the salinity in both seasonal periods.

Salinity values in the Furo of Muriá were also previously reported by Carvalho et al. (2016), with minimum and maximum values of 6.1 and 40.8, respectively. Lima et al. (2014) reported salinity values ranging from 15.49 to 30.42 for the Curuçá river estuary, while Barbosa, Muller, Alves, Berrêdo, and Souza-Filho (2015) reported a salinity value of 35 for the Bragantino estuary during the low rainfall periods. These salinity values are due to the proximity of these regions to the ocean and strong oceanic influence, especially in periods of low rainfall.

According to Gaspar et al. (2013), salinity values are usually higher in estuaries, which induces an exchange between phosphate bound to Fe/Al oxyhydroxides and salts of calcium, increasing the AP contribution to the estuary. This phenomenon was observed in our study because the concentration of AP was directly proportional to the salinity levels.

The granulometric composition of surface sediments in the Furo of Muriá mostly consists of fine sediments (silt and clay) with small percentages of sand. For textural classification, the Shepard diagrams (Figure 4a and b) show that most of the samples remained between silty sand and sandy silt. Pejrup's triangular diagram shows that the sediment samples from the Furo of Muriá are concentrated in sections III C and IV C, indicating high (Figure 4c) and very high (Figure 4d) hydrodynamic conditions, respectively (Mendes et al., 2019).

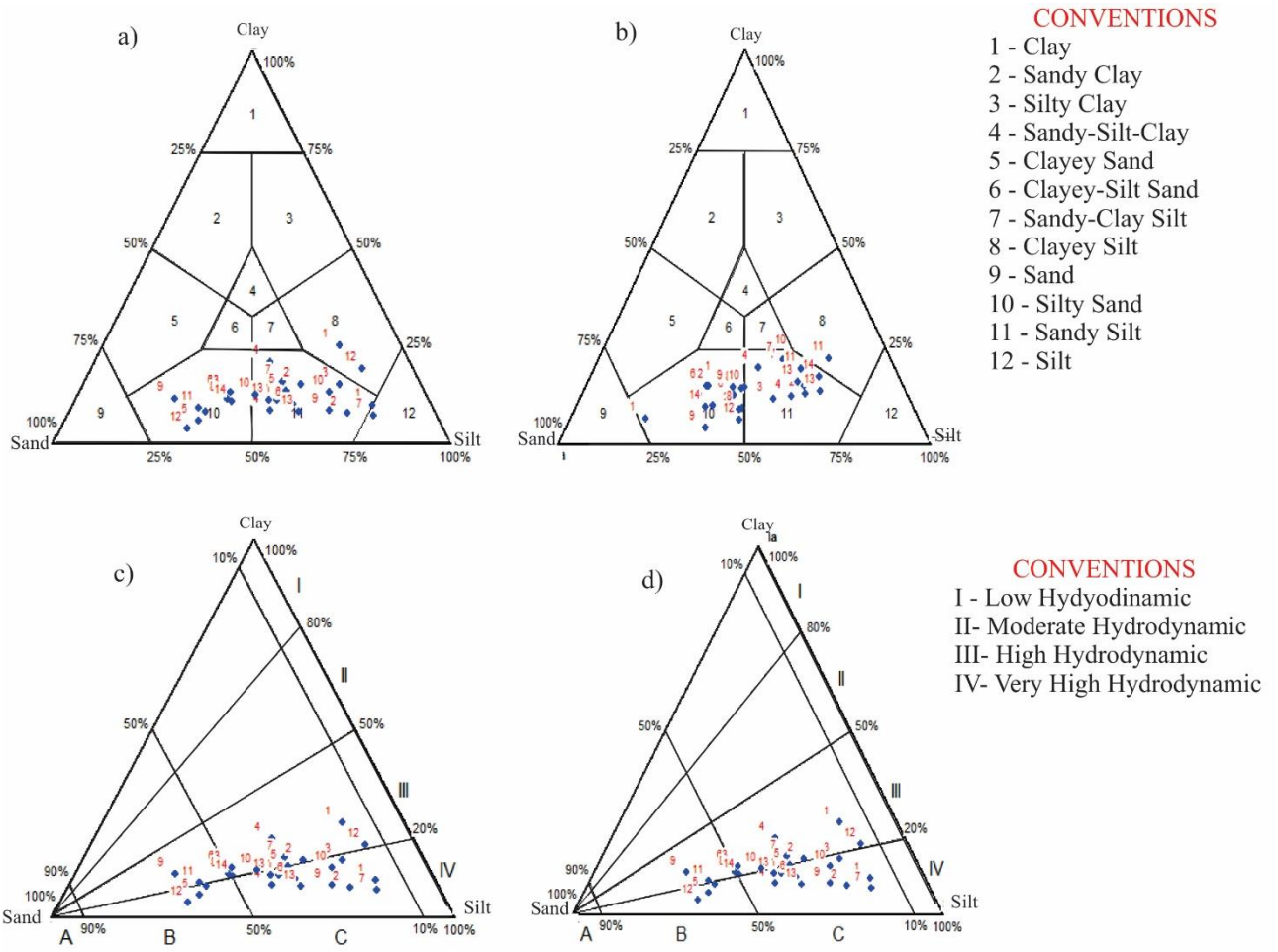

Figure 4. Shepard and Pejrup diagrams corresponding high rainfall and low rainfall periods. (a) Shepard diagram for high rainfall period; (b) Shepard diagram for low rainfall period; (c) Pejrup diagram for high rainfall period; and (d) Pejrup diagram for low rainfall period (Mendes et al., 2019).

The particle size difference of the samples was evaluated by comparing the distribution of fine sediments. The ANOVA results ($p = 0.940$) showed no significant difference in the particle size composition of the sediments between the sampled points. The opposite trend was observed for OM ($p = 0.0027$), indicating that there was no significant spatial variation in this parameter.

The OM showed high concentration values because the study area has characteristics of a confined and mangrove environment, which commonly has high OM concentrations (Pereira et al., 2015). The lowest rate of OM was observed upstream of the Furo of Muriá, where there was a greater influence from the Curuçá River estuary, with the lowest average rate of 3.53%. In contrast, the highest average rate of 11.55% was observed downstream of the Furo of Muriá, which is influenced by the waters from the Mocajuba River estuary (Figure 5).

The reception of OM in the Furo of Muriá sediments is primarily related to the natural conditions of production and deposition of OM in the mangrove forest, which are mainly vegetal in nature. Aguiar Neto, Gomes, and Freire (2012) pointed out that estuarine sediments, as well as other coastal system sediments, are the global reservoirs of OM. OM is preserved in sediments and consists primarily of humic substances formed by both chemical and enzymatic degradations of plants and animals, as well as by the synthesis of organisms. Barbosa et al. (2015) also revealed that high OM levels in sediments suggest high ripeness of vegetation and indirect tides can promote OM retention and assimilation in surface sediments.

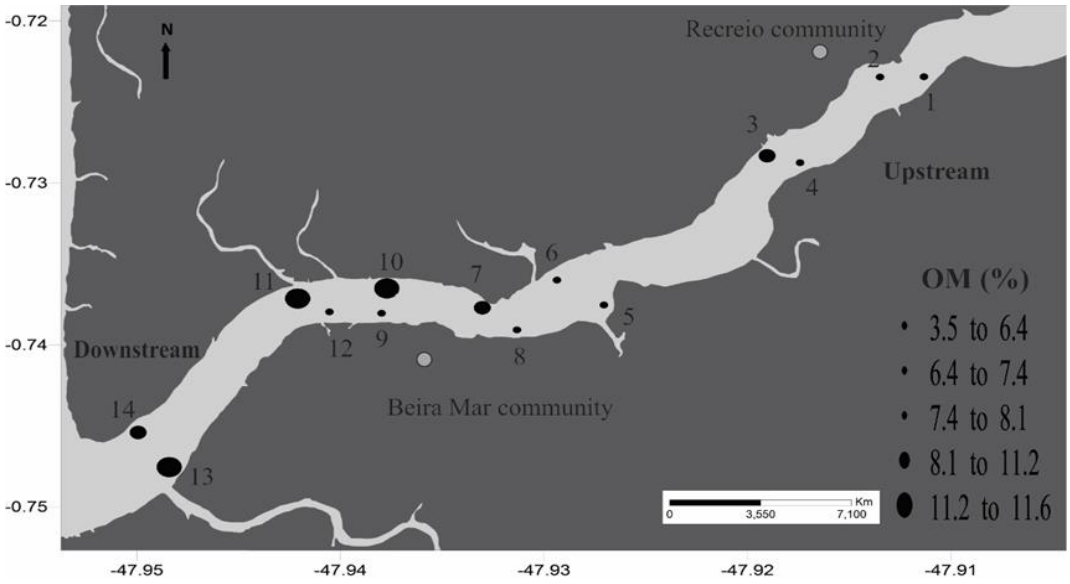

Figure 5. Distribution of organic matter (%) in the sediments of the Furo of Muriá.

In addition to natural sources, the Furo of Muriá also receives anthropogenic contributions of OM that originate mainly from untreated sewage and agricultural activities in the region. This anthropogenic influence modifies the composition and natural concentrations of OM in the environment and may affect local biota (Costa, Souza, Zucchi, Azevedo, & Argollo, 2016).

According to the Esteves (2011) definition, the sediments in the Furo of Muriá can be classified as typically organic, as values over 10% of OM have been found in this region.

Similar to the present study, high OM percentages were detected by Santos et al. (2015), with 24.61% of OM in the surface sediments collected from a mangrove area of the São Francisco River estuarine region. They also classified the sediments as typically organic. Yang et al. (2015) found sediments with high OM values, ranging from 18-22% of OM, in the Yangtze River estuary, China.

The spatial distributions of the concentrations of the three phosphorus forms were similar along the estuary, with the highest concentrations of IP and NAIP observed near the Mocajuba River estuary. In contrast, the AP and OP species had heterogeneous concentration distributions over the Furo of Muriá, without possible influences from the Curuçá or Mocajuba estuaries (Figure 6). The phosphorus species that showed significant variation along the study area were OP ($p = 0.03246$) and TP ($p = 0.01821$). The other species showed no significant spatial variation.

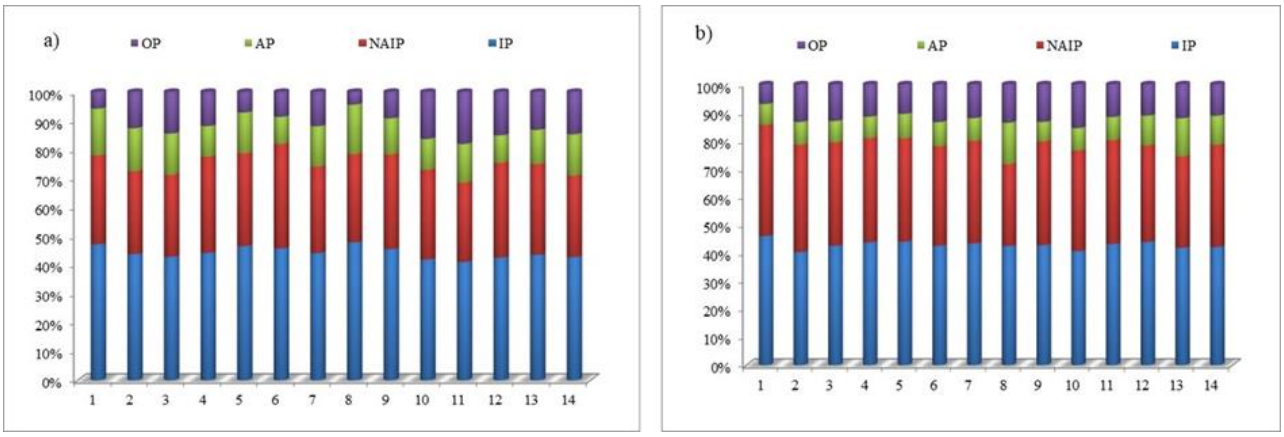

Figure 6. Percentagens of the P forms (OP, AP, NAIP, IP) in surface sediment at each station, a) Low Rainfall and b) High Rainfall, in the Furo of Muriá.

To evaluate the seasonality of the studied parameters (Figure 7), the ANOVA results showed variation only for NAIP ($p = 0.0004$). This phosphorus fraction contributed > 50% of the total sum of IP, indicating that under favorable environmental conditions, the bioavailable fraction would have the greatest contribution to the phosphorus released in water columns.

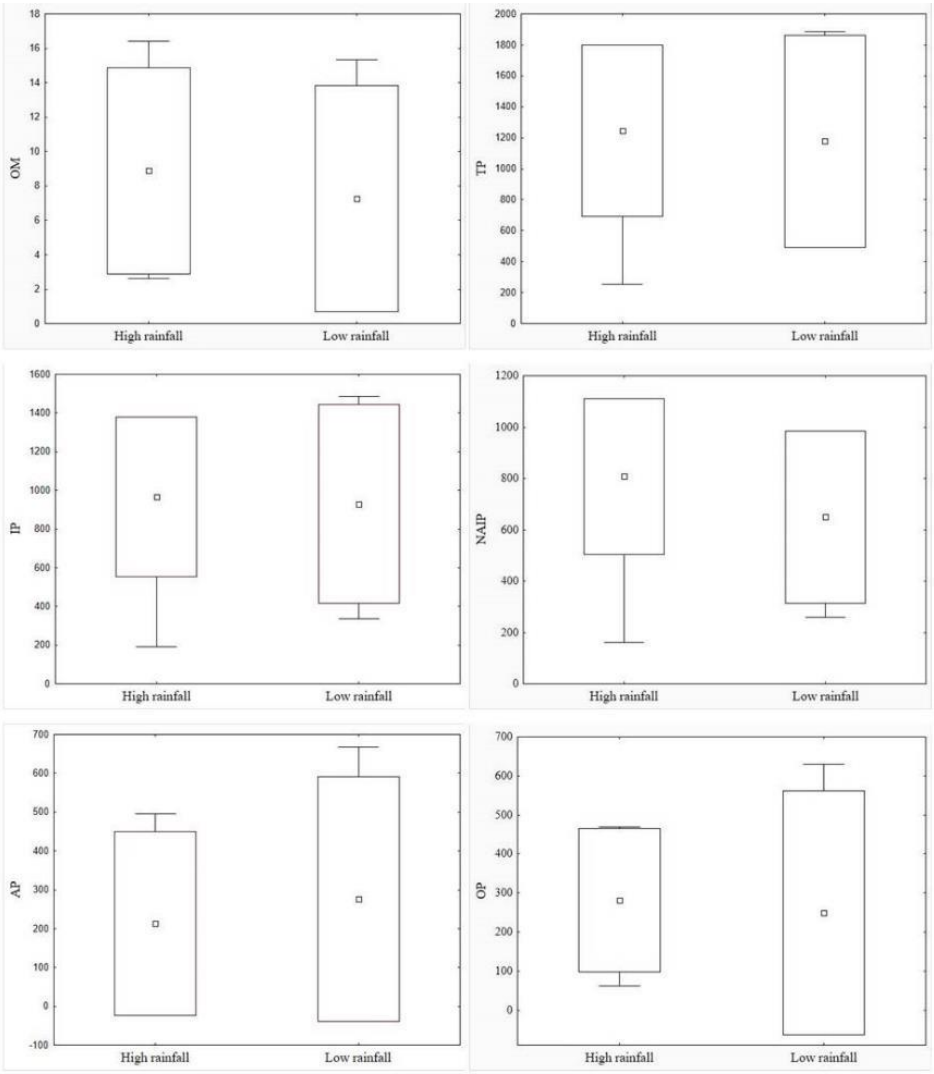

Figure 7. Distribution of OM and P forms in sediment of the Furo of Muriá, according to seasonality.

High amounts of AP were found in the Furo of Muriá, where the maximum values were observed at points 8, 10, and 11 (Table 1), indicating the presence of large amounts of calcium-bound phosphorus in this region. As for OP, IP, and TP, the highest average values were observed at points 8 (135.88 μg g^{-1}), 10 (378.61 μg g^{-1}), and 11 (507.73 μg g^{-1}), respectively.

Table 1. Descriptive statistics of the analyzed variables.

			Salinity	NAIP (μg g^{-1})	AP (μg g^{-1})	IP (μg g^{-1})	OP (μg g^{-1})	TP (μg g^{-1})	OM (%)
[1]Min.	March	High rainfall	13.17	52.78	17.21	62.45	20.37	82.82	3.55
[2]Max.			14.14	314.79	102.65	392.72	128.07	520.78	12.77
Mean			13.70	260.12	84.83	308.85	100.72	409.57	8.29
[3]SD			0.24	62.81	20.48	57.93	25.09	102.04	2.81
[1]Min.	June		17.88	213.41	9.89	227.17	27.01	274.59	2.60
[2]Max.			20.35	309.00	161.63	445.14	153.26	564.32	16.43
Mean			18.79	267.44	54.15	322.13	82.61	404.74	8.70
[3]SD			0.71	33.26	46.67	57.93	32.48	80.47	3.40
[1]Min.	September	Low rainfall	29.11	117.66	51.13	224.74	29.82	278.42	3.43
[2]Max.			31.21	290.32	217.68	485.25	159.80	577.37	15.32
Mean			30.06	213.71	109.73	323.98	69.98	393.96	8.70
[3]SD			0.63	51.92	50.45	77.29	45.01	94.72	3.40
[1]Min.	December		33.10	84.71	16.04	109.45	35.76	166.90	2.46
[2]Max.			35.00	300.35	144.54	410.71	205.38	616.90	10.68
Mean			33.90	210.34	71.14	282.02	92.73	374.75	5.83
[3]SD			0.59	59.92	46.22	87.55	55.83	129.15	2.56

[1]Min. = Minimum, [2]Max. = Maximum,[3]SD = ±Standard deviation.

A phosphorus species had a strong positive correlation with similar phosphorus species and with OM (Table 2). This is because OM is directly connected to the adsorption and desorption processes of phosphorus in the sediments. However, only a weak correlation was observed between OM and AP, as this phosphorus species is linked to the crystal structure of apatite and, therefore, is limited to the environment.

Table 2. Correlation matrix of the analized variables in the Furo of Muriá.

	NAIP	AP	IP	OP	TP	OM (%)	SAND (%)	SILT (%)	CLAY (%)
NAIP	1.0000								
AP	0.1307	1.0000							
IP	0.7662*	0.6865*	1.0000						
OP	0.5273*	0.1369	0.4411*	1.0000					
TP	0.7898*	0.5690*	0.9287*	0.7425*	1.0000				
OM%	0.5246*	0.2302	0.5099*	0.4927*	0.5843*	1.0000			
SAND	-0.0562*	-0.0105	-0.0483	-0.0979	-0.0765	-0.4536*	1.0000		
SILT	0.0139	-0.0475	-0.0380	0.0583	-0.0042	0.4375*	-0.9477*	1.0000	
CLAY	0.1343	0.1564	0.2463	0.1442	0.2434	0.2297	-0.5496*	0.2542	1.0000

Statistical results showed that seasonality was not a major factor influencing phosphorus concentrations in the Furo of Muriá. Seasonal changes in phosphorus concentrations in sediments are most evident in temperate regions, where temperatures vary greatly between winter and summer. The increase in temperature leads to large microbial activity and subsequent decomposition of OM, which increases the availability of dissolved phosphorus in estuaries and lakes in temperate regions (Gaspar et al., 2013).

In aquatic environments, phosphorus flow dynamics between the sediment and surrounding water are essential for the phosphorus cycle. Various chemical, physical, and biological factors, such as pH, organic and carbonate compounds, redox conditions, sulfides, and concentrations of iron and aluminum ions (Esteves, 2011), are involved in the precipitation (immobilization) and release of phosphate ions.

In this study, the values obtained for phosphorus species were close to those reported in other estuaries in Brazil and worldwide (Table 3).

Table 3. Phosphorus species concentrations ($\mu g.g^{-1}$) in another study areas.

StudyArea	TP	IP	OP	NAIP	AP	Authors
Jaguaribe River Estuary (Brazil)	77.5 - 157.1	43.0 - 124.8	10.4 - 58.1	11.2 - 77.2	8.5- 42.8	Marins et al., 2007
Estuaries of Botafogo and Carrapicho Rivers (Brazil)	52 - 1124.4	51.4 - 915.2*	0.6 - 209.2	29.7- 398.1	21.72 - 558.8	Gaspar et al., 2013
Zhujiang River Estuary (China)	648.9 - 1064	422.5 - 643.9	125 - 300	98 - 495	202 - 309	Wang et al., 2013
Changjiang Estuary and adjacent East China Sea inner shelf (China)	465 - 663.4	439.6 - 531 *	25.4 - 132.4	11.5 - 20.15	16.7 - 46.5	Meng et al., 2014
Guaratuba BayEstuary (Brazil)	114.9-330	91.3-234.8	23.6- 95.2	-	-	Cotovicz Junior et al., 2014
Laizhou Bay and the coastal waters of the Zhangzi Island (China)	315.9 - 582.7	272.5 - 491.8	4.8 - 90.9	1.2 - 68.4	3.1 - 100.3	Zhuang et al., 2014
Santos–São Vicente Estuarine System (Brazil)	117.8 - 2297.4	106.3 - 1971.9*	11.4 - 325.5	33.79 - 1168	11.2 - 329.8	Berbel, Favaro, and Braga, 2015
Yangtze River Estuary and adjacent sea (China)	300.7 - 674.25	259 - 590.5	23.6 - 176.08	-	-	Yang et al., 2015
Guapimirim Estuary (Brazil)	-	98.6 - 221	-	24.5 - 53	21 - 59.2	Vicente et al., 2016
Furo of Muriá (Brazil)	257.54- 507.73	227.21-378.61	30.33- 135.88	164.54-280.32	63.02 -102.80	

*Obtained by subtraction of TP and OP.

IP was the main phosphorus species in the TP of the study area. According to Cotovicz Junior et al. (2014), the pervasiveness of IP in several estuaries in Brazil and worldwide is the main feature that differentiates estuary soil sediments, which are predominantly composed of OP. Phosphorus of anthropogenic origin is found mainly in inorganic forms due to the indiscriminate use of chemical fertilizers in the soil or emissions of effluents (Marins et al., 2007).

The biogeochemical cycling of phosphorus in surface sediments involves various phosphorus species, which can be found bound to oxy/hydroxides of iron, aluminum, or calcium, and may be adsorbed onto the surface of inorganic or organic compounds (Singh, Chauhan, Ranjan, Prasad, & Ramanathan, 2015).

The NAIP phosphorus species is commonly known as the most predominant fraction in mangrove sediments and represents the mobile fraction that is sensitive to redox potential in coastal sediments (Singh et al., 2015). Phosphorus bound to iron and aluminum mostly represents anthropogenic orthophosphate ions that are adsorbed onto the surface of iron and aluminum hydroxides, forming complexes (Gachter, Meyer, & Mares, 1998).

As for AP, these are the orthophosphates included in the crystal structure of apatite and only a few are available to the environment. This phosphorus species, along with the organic fraction, corresponded to the smaller parcel of TP in the entire studied area of the Furo of Muriá compared with the other species.

The OP concentrations in sediments indicate the influence of mangrove vegetation roots and OM load in the effluent discharge and biogeochemical conditions. Based on the results, the OP had considerable concentrations in sediments, which indicates high retention and OM cycling in mangroves, adsorbing P in the organic matrix, releasing phosphorus through microbial degradation to the water column, and influencing the dissolved phosphorus dynamics (Singh et al., 2015).

By comparing the phosphorus species investigated in the Furo of Muriá with other estuaries in Brazil and worldwide, we found that the P concentrations in the sediments are below the reported range for contaminated environments.

Robertson and Stevens (2013) proposed a "classification of conditions" of sediments in the New River estuary in New Zealand based on the TP values. We used this categorization to classify sediments in the Furo of Muriá and found that the sediments from this region were mostly considered "good" (Table 4).

Table 4. Classification of surface sediments conditions considering total phosphorus concentrations, proposed by Robertson and Stevens (2013).

Concentrations (μg g^{-1})	< 200 μg g^{-1}	200 – 500 μg g^{-1}	500 – 1000 μg g^{-1}	> 1000 μg g^{-1}
Sediment quality in relation to Ptotal	Very good	Good	Fair	Poor
Stations (this study) High Rainfall	1	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	-	-
Stations (this study) Low Rainfall	-	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14	11	-

Conclusion

The salinity values reflected the seasonality of the region, which showed no influence on the Furo of Muriá surface sediments. However, the water coming from the Mocajuba River affected the distribution of OM and phosphorus, especially for TP and IP. Considering the classification of the conditions of the Furo of Muriá sediments, we can conclude that the TP concentration does not present a risk of environmental deterioration. As for the IP composition, the most prominent chemical species was the NAIP, which is the form that can become bioavailable in the event of changes in estuary environmental conditions.

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