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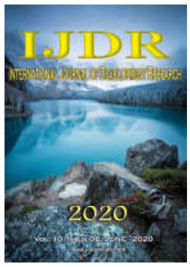

RESEARCH ARTICLE OPEN ACCESS

PHYTOSOCYOLOGIC CHARACTERIZATION AND ASSOCIATED SEDIMENT IN A MANGROVE AREA WITH IMPACTS OF OIL SPILL, TODOS OS SANTOS BAY, BAHIA, BRAZIL

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ABSTRACT

This article presents the phytosociological characteristics of the São Paulo River estuary, northeastern part of Todosos Santos Bay, a mangrove area with impacts of oil spill as well as the physical-chemical composition of the plant of individuals associated with sediments. For qualitative, phytosociological research, the multiple plot method was applied, with a total of five 20x25 m^2 plots. All living species present, *Laguncularіaracemosa*, *Avicenniaschaueriana* and *Rhizophorae mangle* identified with a breast height circumference (HBC) less than 15 cm were marked and their height and circumference values sampled. The results indicated that the mangrove ecosystem of the São Paulo estuary has a fringe face with intermediate size, indicating the species of *A. schaueriana* as dominant species. The granulate had a predominantly silty texture and low levels of the elements Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn that are within the range of variation of this type of environment. Geochemical analysis of sediments reveals significant differences between plots. Diagnostic reasons pointed to a predominantly pyrogenic origin. Therefore, they consider mixed sources of polycyclic aromatic hydrocarbons (PAHs) contaminating this location as a result of the incomplete burning of fossil fuels and the presence of domestic effluents.

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INTRODUCTION

The mangrove is a coastal ecosystem subject to tidal actions, of fundamental importance for the cycling of nutrients. Its structure allows the maintenance of several habitats suitable for protection against predators, reproduction, spawning and growth of various marine or freshwater species, as well as numerous terrestrial species in the vegetation. It extends along the tropical and subtropical areas of the world (SCHAEFFER-NOVELLI, 2002).Mangroves occupy a significant extension of the Brazilian coast, having 92% of coastline coverage (MAIA *et al*., 2005). Four species occur on the coast of Bahia: *Rhizophorae mangle* (red mangrove), *Avicenniagerminans* (siriúba mangrove), *Avicenniaschaueriana* (black mangrove), and *Laguncularia racemosa* (white mangrove) (RAMOS, 2002). Because it is located in coastal areas, the mangrove ecosystem may be occupied by industrial and / or port facilities, and consequently land, deforestation, eutrophication and, consequently, entry of foreign elements (contaminants) into the system, as well as impacts of other natures (MACINTOSH and ASHTON, 2005). The phytosociological survey is an important tool for studies on the responses of this system to existing environmental conditions (SOARES, 1999). Mangroves in the state of Bahia - Brazil, are relatively little studied, especially their ecology, and therefore many basic processes, including responses to disturbances, disturbances and restoration are not fully understood (Schaeffer-Novelli *et al*., 2000). Recent contributions on the chemical composition of sediment(BAHIA, 2004; QUEIROZ and CELINO, 2008; OLIVEIRA *et al*., 2008; MOREIRA, *et al*., 2010) and plant populations (SCHAEFFER – NOVELLI, 1986; SILVA *et al*., 1990; FREITAS, 2002; MOREIRA, 2010; ZHU, 2015), new insights on the subject.

Accidents with oil spills have strongly affected mangroves (MOREIRA *et al*., 2015; CARDOSO *et al*., 2017). For this reason, phytoremediation has been one of the main remediation technologies applied to mangrove sediments (MOREIRA *et al*., 2011). However, the choice of plant species to be used is not so simple and depends on background data for the correct application of biotechnology in the affected mangrove areas (MOREIRA *et al*., 2013; MOREIRA *et al*., 2016 and CARDOSO *et al*., 2020). This research will present a study model conducted in a mangrove to choose the plant species to be applied in phytoremediation. The main objectives of this study were to determine the phytosociological characteristics of the estuary of the São Paulo River, identifying whether the possible effects of the petroleum industry on the communities of mangrove plants are determined or not for diagnostic reasons Phenanthrene / Anthracene, Anthracene / (Anthracene + Phenanthrene) and the sum of the high molecular weight / molecular weight PAHs of the low molecular weight polycyclic aromatic hydrocarbons - PAHs besides possibly subsidizing studies with phytoremediation proposals of the area.

MATERIALS AND METHODS

Sampling in the São Paulo estuary was done in the northeast portion of Bay of All Saints (figure 1) for sediment. The collection was performed between April and May 2015 and the collection of phytosociological data occurred between October 2015 and December 2016, using the multiple plots method (DAUBENMIRE, 1968; SCHAAF, 2001; SCHORN, 2005; BMA, 2005). This method was applied with a total of five (5) sample plots of 20x25m², with codes A, B, C, D and E representing plots 1, 2, 3, 4 and 5, respectively, each with three (3) sediment collection points, resulting in a total of 15 samples. In order to mark the plots and collect the samples, it was necessary to prepare the work team as well as the equipment used, since in addition to the collected samples, a survey of the area, including social aspects and the marking of points with the aid of GPS, frame 1.

FRAME 1: All trees in each plot were counted with labels listed, having the purpose to prevent recounting. Data collected from each plot the number of individual trees, its species, breast height length (BHL), diameter at breast height (DBH) and total height (Ht).

The relative density (RD), relative dominance (RDo), relative frequency (RF), importance value index (IVI) and coverage value index (CVI) were calculated based on the work of Oliveira and Amaral (2004), Employing calculations no Excel software, version 2010 and later, confirmed with the help of software MATA NATIVA, version 4.0. Concentrations of Ba, Co, Cr, Cu, Mn, Ni, Pb, V and Zn in the sediment were determined using Inductively Coupled Plasma Optical Emission Spectrometer - ICP OES (model 720 series, brand Agilent Technologies) and P was determined Spectrophotometrically. Three diagnostic reasons were used to indicate the possible sources of polycyclic aromatic hydrocarbons - PAHs found in sediments of the São Paulo estuary (frame 2): Phenanthrene / Anthracene (Fen/Ant), Anthracene / (Anthracene + Phenanthrene) (Ant/(Ant+Fen)) and the sum of the high molecular weight / molecular weight PAHs of the low molecular weight PAHs (ΣLMW/ΣHMW) (TOBISZEWSKI *et al*., 2012; MENICONI, 2007). In an attempt to identify how the variables studied could influence the response and if it is possible to observe the formation of groups, the main component analysis (PCA) was used with the aid of Statistica for Windows, version 13.0 of Statsoft Inc. The data were standardized and a Cluster analysis was performed based on Gower's general similarity coefficient (GOWER, 1971).

RESULTS AND DISCUSSION

Considering the average height of the three species of the five plots, the São Paulo estuary is predominantly a low / medium profile mangrove area, with maximum heights of about 10,45m (plot 5), 10,25m (plot 1) and 8.75m (plot 5), *R. mangle*, *A. schaueriana*and *L. racemosa*, respectively (table 1). Plots 4 and 5 present larger basal areas (both with approximately 14.6m² ha^{-1}). The estimates of the phytosociological parameters, such as DR, FR, and IVI for the three species confirmed that *A. schaueriana* predominated, that *L. racemosa* was the least prevalent in the São Paulo estuary. Among mangrove species, *A. schaueriana* predominated in most plots except for plot 3, where *R. mangle* was the most abundant (table 2). These data confirm the results of Moreira (2010), where the researcher carried out a pilot study on a laboratory scale, identifying that the *A. schaueriana* species was the one that best adapted to the known oil dosages in the monitored sediment. Table 2 shows the maximum density of individuals for *A. schaueriana* (68,18) in plot 4, and minimum for *R. mangle* (2.5%) in plot 2. The largest number of individuals with CAP>15.0 centimeters was recorded for *A. schaueriana* (111 individuals), followed by *L. racemosa* (62 individuals), and *R. mangle* (46 individuals). The granulometric analysis of sediment samples from the five study plots (table 3) revealed that the sediments are predominantly silty. The silt fraction ranged from 14.71 to 60.65% and remained above 30% in most of the profiles. Trace metal concentrations in the sediment of the São Paulo estuary (table 4) and of physical-chemical parameters (table 7) varied among the sampling sites. Nevertheless, all this values for the five (5) plots are in the preservation range in relation to Guidance Values for Soils and Groundwater, according to Sharma *et al*. (2020), Cetesb (2014) and CONAMA Resolution n° 344/2004. When comparing tables 3 and 4, it is possible to identify that the adsorption of trace metals increased with the increase in the proportion of PAHs and decrease in the size of the sediment particles.

Frame 1. Geographic coordinates of the sediment collection points in the São Paulo estuary, Todos os Santos Bay, Bahia, Brazil

Sampling Points and Parameters	Plots	Coordenates UTM Datum SAD 69	
		X	Y
Sediment – P1	Portion 1	548987	8594201
Sediment – P2		548996	8594206
Sediment – P3		549003	8594208
Sediment – P4		549039	8594190
Sediment – P5	Portion 2	549046	8594193
Sediment – P6		549054	8594193
Sediment – P7		549434	8594199
Sediment – P8	Portion 3	549429	8594192
Sediment – P9		549421	8594186
Sediment – P10		549153	8594634
Sediment – P11	Portion 4	549152	8594643
Sediment – P12		549152	8594650
Sediment – P13		548843	8594808
Sediment – P14	Portion 5	548837	8594809
Sediment – P15		548829	8594812

Elaboration: the author, 2020.

Frame 2. Diagnostic reasons used to determine the source of PAHs

Reasons	Borderline	Classification of origin	References
Fen/Ant	>10	Petrogens	Soclo, 1986.
	<10	Pyrolytic	
Ant/(Ant+Fen)	<0,1	Petrogens	Yunker et al., 2002.
	>0,1	Pyrolytic	
∑LMW/∑HMW	>1	Petrogens	Zhang et al., 2008.
	<1	Pyrolytic	

Source: Adapted from Tobiszewski et al., 2012 and Meniconi,2007.

Table 1. Estimates of structural parameters of mangrove communities in the São Paulo estuary, Todosos Santos Bay, Bahia, Brazil

Portion	Species	Number of individuals	Average diameter at breast height (cm)	Average height (m)	Maximum height (m)	Mean basal area ($m^2 ha^{-1}$)
Portion 1	*L. racemosa*	21	12,65	6,17	8,25	12,48
	A. schaueriana	34	17,95	7,71	10,25	
Portion 2	*L. racemosa*	13	21,4	6,11	7,9	13,46
	A. schaueriana	26	18,37	6,86	9,05	
	R.mangle	1	10,19	4,9	4,9	
Portion 3	*L. racemosa*	12	15,29	5,88	6,95	12,12
	A. schaueriana	4	19,5	6,46	6,93	
	R.mangle	31	18,1	7,1	8,12	
Portion 4	*L. racemosa*	9	15,75	6,14	8,25	14,6
	A. schaueriana	30	20,26	7,8	9,75	
	R.mangle	5	19,12	8,59	9,75	
Portion 5	*L. racemosa*	7	20	6,6	8,75	14,63
	A. schaueriana	17	20,61	7,74	10,2	
	R.mangle	10	20,31	9,17	10,45	

Elaboration: the author, 2020.

Table 2. Abstract of the phytosociological indexes of mangrove communities in the São Paulo estuary, Todos os Santos Bay, Bahia, Brazil

Portion	Species	Relative Density (RD)	Relative Frequency (RF)	Relative Dominance (RDo)	Value of Importance Index (IVI)
Portion 1	*L. racemosa*	38,18	50,00	22,36	110,55
	A. schaueriana	61,82	50,00	77,64	189,45
Portion 2	*L. racemosa*	32,50	33,33	41,90	107,73
	A. schaueriana	65,00	33,33	57,50	155,83
	R.mangle	2,50	33,33	0,60	36,43
Portion 3	*L. racemosa*	25,53	33,33	19,31	78,17
	A. schaueriana	8,51	33,33	10,87	52,71
	R.mangle	65,96	33,33	69,83	169,11
Portion 4	*L. racemosa*	20,45	33,33	12,97	66,75
	A. schaueriana	68,18	33,33	77,05	178,56
	R.mangle	11,36	33,33	9,98	54,676
Portion 5	*L. racemosa*	20,59	33,33	17,98	71,897
	A. schaueriana	50,00	33,33	43,41	126,74
	R.mangle	29,41	33,33	38,62	101,36

Elaboration: the author, 2020.

Table 3. Percentages of grain size fractions and texture of mangrove sediments under tree communities in the São Paulo estuary, Todos os Santos Bay, Bahia, Brazil

Portion	Collection points	Coarse sand (%)	Middle Sand (%)	Thin sand (%)	Very Fine Sand (%)	Silte (%)	Clay (%)
Portion 1	A1	18,24	10,12	9,27	14,85	44,89	2,63
	A2	21,03	0,00	2,75	14,09	59,59	2,55
	A3	28,09	13,79	15,53	13,75	27,04	1,81
Portion 2	B1	12,21	0,00	3,62	20,94	60,65	2,58
	B2	30,16	5,87	5,56	12,97	43,33	2,11
	B3	27,21	0,00	2,29	14,37	53,39	2,73
Portion 3	C1	29,97	9,75	10,04	16,47	30,85	2,93
	C2	44,81	9,05	15,60	14,85	14,71	0,98
	C3	27,14	11,67	10,90	15,91	32,12	2,25
Portion 4	D1	9,08	7,59	20,40	28,56	32,25	2,11
	D2	16,41	9,10	17,14	18,26	36,60	2,49
	D3	16,28	5,92	18,08	28,30	29,31	2,12
Portion 5	E1	38,72	0,18	8,54	18,49	31,07	3,00
	E2	13,45	9,16	18,44	22,66	32,97	3,31
	E3	30,87	0,00	3,29	16,00	45,87	3,97

Elaboration: the author, 2020.

Table 4 - Concentrations of trace metals in (mg Kg^{-1}) in the sediment adjacent to the root system of the shallow mangrove trees of the São Paulo estuary

Portion	Samples	Ba	Co	Cr	Cu	Mn	Ni	Pb	V	Zn
	A1	56,00	4,80	23,60	12,50	47,50	12,90	7,40	29,70	23,90
Portion 1	A2	53,10	4,99	26,78	16,96	45,32	14,36	5,79	37,48	26,55
	A3	39,50	3,15	21,12	9,70	29,58	10,58	10,83	27,61	17,58
	B1	101,00	4,12	18,88	11,34	58,59	9,18	0,05	23,18	19,71
Portion 2	B2	80,10	4,91	24,76	13,64	73,33	12,58	0,05	30,10	24,73
	B3	86,30	4,36	20,97	10,83	55,46	10,49	0,05	26,68	20,37
	C1	86,50	6,40	36,90	33,10	12,60	14,40	16,00	48,60	54,40
Portion 3	C2	44,10	31,16	21,96	12,50	78,51	37,33	8,64	30,07	29,14
	C3	61,30	5,47	31,74	21,71	99,43	13,08	12,24	42,61	45,76
	D1	824,60	4,71	51,99	16,82	68,61	11,29	14,57	41,23	37,46
Portion 4	D2	636,10	4,34	30,04	19,06	77,10	10,53	11,49	39,15	38,38
	D3	448,50	5,92	38,24	17,18	104,89	12,34	14,15	43,77	44,40
	E1	158,90	7,79	56,51	37,24	81,20	20,29	24,68	75,26	65,78
Portion 5	E2	140,80	6,50	45,00	29,70	107,30	17,40	17,20	60,30	55,60
	E3	170,60	6,58	44,42	28,05	99,84	16,31	15,29	61,95	50,53

Elaboration: the author, 2020.

Table 5 - Results of the diagnostic parameters of PAHs origin in the São Paulo estuary

Portion	Collection points	Fen/Ant	Ant/(Ant + Fen)	ΣLMW / ΣHMW
Portion 1	A1	0,22	0,82	0,14
	A2	0,29	0,77	0,10
	A3	1,00	0,50	0,20
Portion 2	B1	1,00	0,50	0,08
	B2	15,54	0,06	0,10
	B3	3,66	0,21	0,05
Portion 3	C1	5,40	0,16	0,21
	C2	1,21	0,45	0,11
	C3	1,29	0,44	0,10
Portion 4	D1	0,31	0,76	0,16
	D2	0,52	0,66	0,12
	D3	0,40	0,71	0,13
Portion 5	E1	0,27	0,79	0,20
	E2	0,48	0,68	0,16
	E3	0,60	0,62	0,15

Elaboration: the author, 2020.

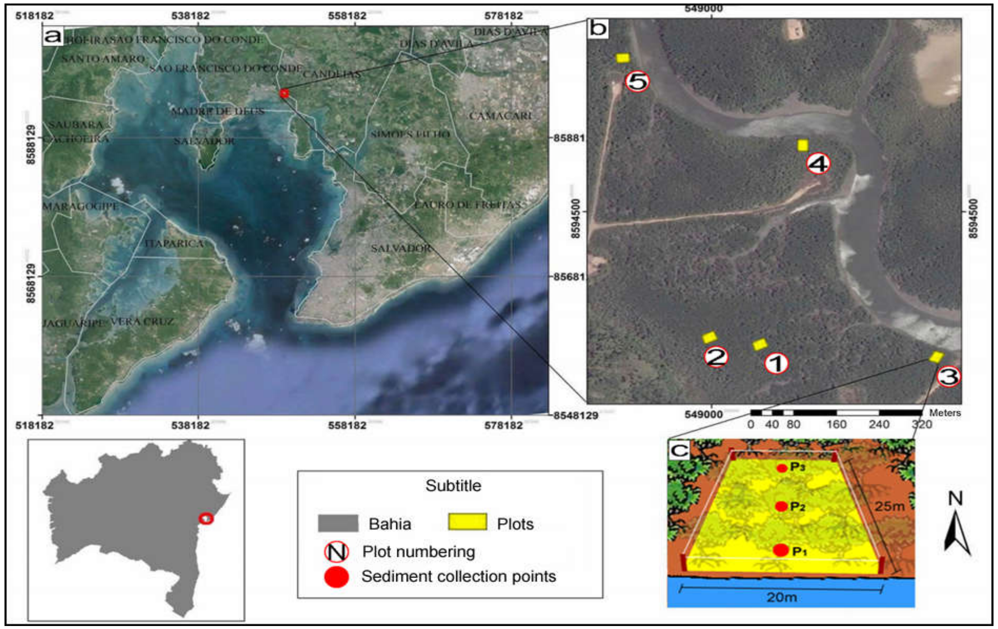
These data confirm the results of Ngugi (2013), where the researcher investigated the adsorption of copper in aqueous solutions using mangrove biomass from the Kenyan coast. According to frame 2, the limits for the geochemical indices used in this work can be identified for possible verification of the origin of the oil determined in the studied sediment. The Fen / Ant ratio higher than ten has its contamination resulting mainly from petrogenic sources, and values below 10 indicate contamination of pyrogenic origin (BUDZINSKI *et al*., 1997). The results of the geochemical parameter Antracene / (Antracene + Phenanthrene) (An/(An + Fen)) greater than 0,1 indicate pyrogenic sources and less than 0.1 petrogenic sources (YUNKER *et al*., 2002), while the values obtained from the ratio ΣLMW / ΣHMW less than 1 indicates pyrogenic contamination, a value greater than 1 indicates petrogenic source (SOCLO *et al*., 2000).

FRAME 2: The sample data presented in table 6 contributed to the study of the diagnostic reasons Phen / Ant, Ant / (Ant + Phen) and ΣLMW / ΣHMW listed in table 5. The results reveal a pyrogenic origin for most points in the São Paulo estuary.

Table 6 - Concentrations of PAHs in the sediment (ng.g-[1]) of the São Paulo estuary

Portion	Samples	Naf	AcNf	AcN	Fl	FEN	An	FLU	Pir	BaA	Cri	BbFlA	BkFlA	BaP	IP	DBahA	BghiP
	A1	0,53	0,38	0,12	1,61	0,27	1,22	0,46	0,46	2,47	2,47	0,02	20,87	2,40	0,54	0,59	0,27
Portion 1	A2	0,61	0,23	0,01	3,06	0,59	2,00	1,66	1,66	5,64	5,64	0,10	41,99	7,40	2,17	1,90	1,27
	A3	0,15	0,05	0,05	0,14	0,05	0,05	0,05	0,05	0,14	0,14	0,05	1,26	0,21	0,05	0,05	0,05
	B1	0,05	0,05	0,05	0,05	0,05	0,05	0,52	0,52	0,50	0,50	0,26	0,41	1,20	0,25	0,29	0,05
Portion 2	B2	0,30	0,05	0,05	0,61	0,78	0,05	2,31	2,31	2,70	2,70	0,41	2,25	5,68	1,25	4,53	0,05
	B3	0,12	0,05	0,05	0,14	1,04	0,29	3,38	3,38	5,18	5,18	1,15	5,05	9,85	2,48	8,08	0,05
	C1	0,10	1,08	0,36	0,73	17,31	3,21	26,90	26,90	19,65	19,65	1,98	13,83	24,05	7,64	16,35	0,05
Portion 3	C2	0,05	0,10	0,05	0,05	0,23	0,19	0,90	0,90	0,92	0,92	0,34	0,44	2,38	0,55	0,42	0,05
	C3	0,05	0,18	0,05	0,05	0,38	0,30	1,54	1,54	1,48	1,48	0,67	0,80	3,47	1,10	0,96	0,05
	D1	0,18	1,68	0,03	0,21	1,16	3,78	2,49	2,49	12,31	12,31	2,57	2,71	10,20	2,99	10,33	0,05
Portion 4	D2	0,11	0,43	0,05	0,15	0,45	0,87	1,44	1,44	2,38	2,38	1,89	0,93	4,82	1,35	3,80	0,05
	D3	0,20	1,65	0,05	0,42	1,40	3,48	2,93	2,93	14,47	14,47	0,68	5,50	14,74	3,65	12,76	0,05
	E1	0,05	2,23	0,05	0,34	0,86	3,23	3,23	3,23	3,98	3,98	0,26	1,95	10,52	2,66	2,73	3,55
Portion 5	E2	0,18	2,10	0,11	0,60	1,79	3,71	6,20	6,20	7,18	7,18	2,70	3,18	15,50	4,62	3,76	4,18
	E3	0,05	0,25	0,05	0,13	0,29	0,49	0,89	0,89	1,10	1,10	1,35	0,61	2,05	0,49	0,53	0,62

Subtitle:Naf = Naphthalene, Act = Acenaphthylene, Acn = Acenaphthene, Fl = Fluorene, Fen = Phenanthrene, Ant = Anthracene, FLU = Fluoranthene, Pir = Pyrene, Ba = Benzo (a) anthracene, Cri = Criseno, BbFLA = Benzo (b) fluoranthene, BkFLA = Benzo (k) fluoranthene, BaP = Benzo (a) pyrene, IP = Indene (123cd) pyrene, Dib = Dibenzo (ah) anthracene, Bep = Benzo (ghi) perylene.



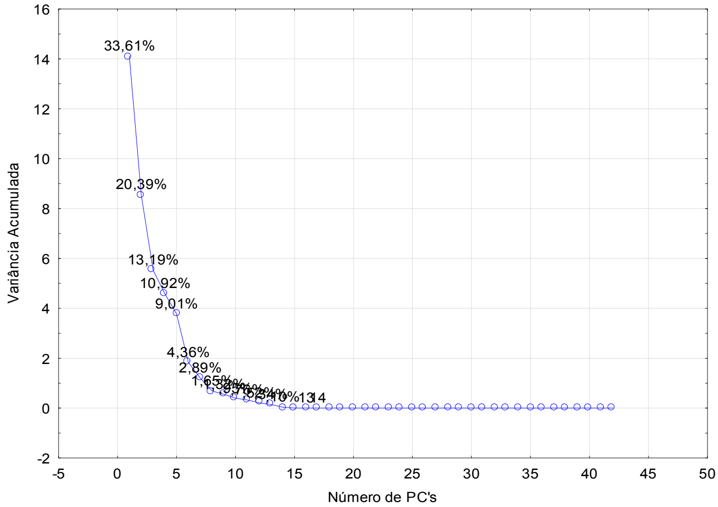
Elaboration: the author, 2020.

Figure 1. Location Map of the Study Area A) Location Map of Todos os Santos Bay. B) Aerial photograph of the sediment collection area to be studied

Table 7. Physical-chemical parameters of the São Paulo river estuary sediment, BTS

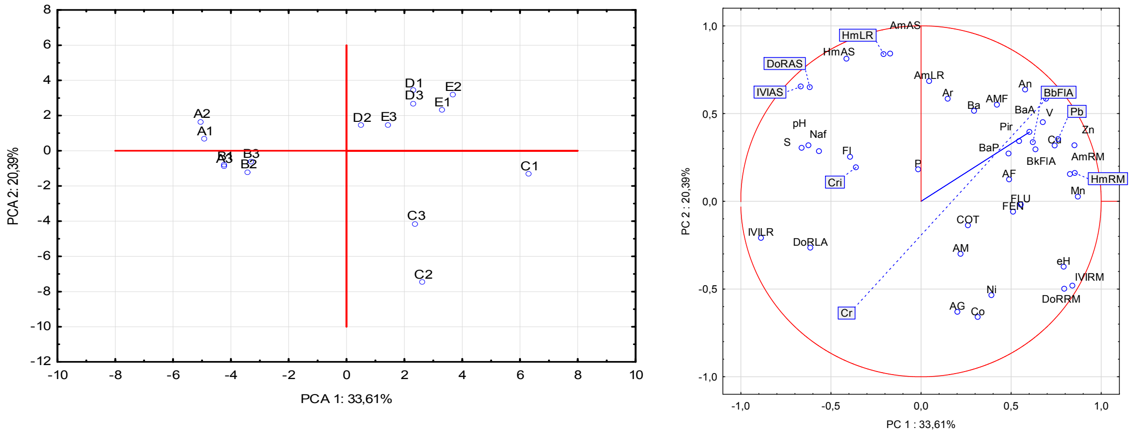
Portion	Samples	P (mg kg-1).	COT (%)	N (%)	pH	Eh
	A1	57,00	5,53	0,13	7,36	-27
Portion 1	A2	51,00	4,58	0,16	7,14	-14
	A3	38,00	7,23	0,22	6,96	-8
	B1	230,00	1,96	0,05	7,02	-12
Portion 2	B2	235,50	1,86	0,05	7,14	-19
	B3	193,00	1,96	0,05	7,17	-20
	C1	138,50	5,69	0,22	6,84	81
Portion 3	C2	77,00	4,99	0,15	3,91	155
	C3	5,00	5,87	0,24	5,29	79
	D1	81,50	3,51	0,11	5,32	78
Portion 4	D2	92,50	3,08	0,05	5,45	70
	D3	86,50	4,41	0,14	5,5	70
	E1	209,00	4,08	0,21	6,09	33
Portion 5	E2	160,00	5,06	0,24	6,17	33
	E3	152,00	5,60	0,28	6,1	37

Elaboration: the author, 2020.



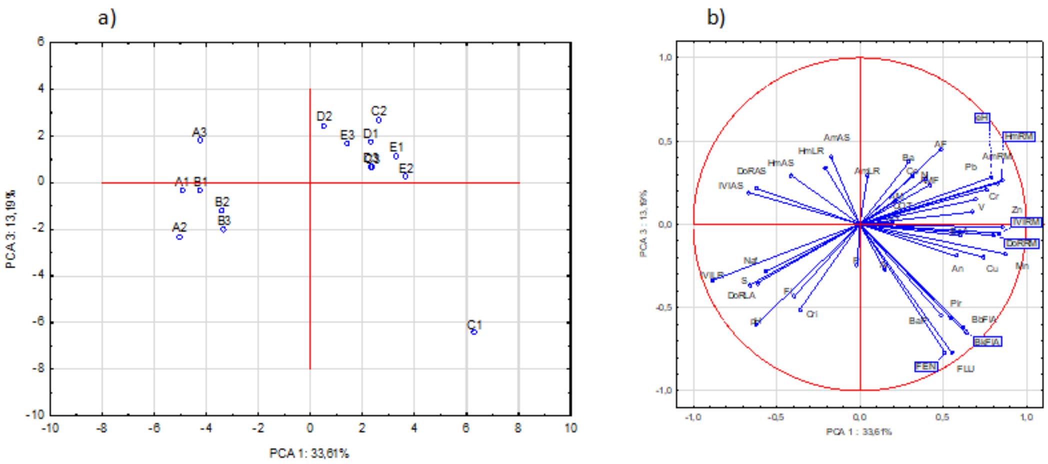
Elaboration: the author, 2020.

Figure 2. Graph of cumulative variance in each Main Component



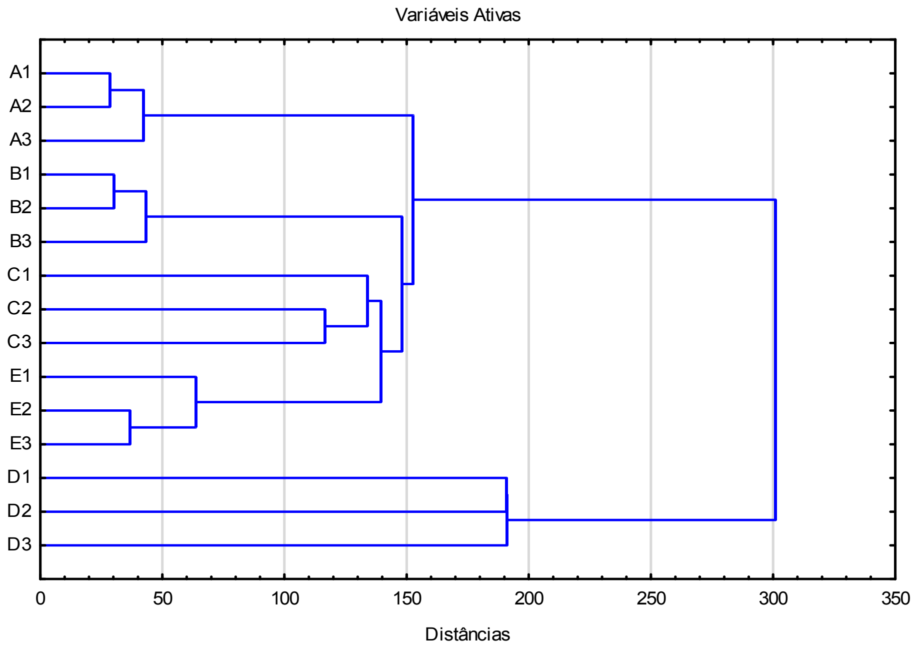
Elaboration: the author, 2020.

Figure 3. Graph of scores PC1 x PC2 (a) and graph of weights (b)



Elaboration: the author, 2020.

Figure 4. Graph of scores PC1 x PC3 (a) and graph of weights (b)



Elaboration: the author, 2020.

Figure 5. Dendogram of the sediment samples from the 15 sediment samples and phytosociological data from the São Paulo estuary

Therefore, mixed sources of PAH_S in this location are considered: pyrogenic, resulting from the incomplete combustion of the presence of domestic and industrial effluents present throughout the mangrove. According to the results found for the diagnostic reasons Fen / Ant and AN / (Fen + AN), the only point that indicates petrogenic origin is B2 (central point of plot 2). These results are confirmed by Santana *et al.* (2010) in the BTS, which obtained predominance of compounds of pyrogenic origin in the sediment matrix. In the estuary of the São Paulo river, a spatial distribution of species was identified, where *Lagunculariaracemosa* was identified as located more in the interior of the continent, *Avicenniaschaueriana* was more common in upper and supramarineintermarine zones, and *Rhizophora mangle* dominating the Areas of low and to intermarry. The results presented here resemble those of some regions of the country. Cintrón and Schaeffer-Novelli (1983) stated that in the South and Southeast regions of Brazil, the size of the trees varies from 4.1 to 12.1 m. These authors cite, for example, heights of 15 m for the *Avicennia* species.

Multivariate Analysis of Results

Fifteen (15) samples of five (5) plots located in the São Paulo estuary, in the northeast portion of Todosos Santos Bay, Bahia, Brazil, were prepared and analyzed. This statistical analysis was composed by PAHs (table 6) concentration values, physicochemical parameters (table 7), phytosociological indicators (table 8), as well as granulometry (table 3) and trace metals data (table 4). The results of the 42 analytes concentrations in the 15 analyzed samples were evaluated using the PCA chemometric tools, with the software Statistica 13.0. A data matrix (42 x 15) was constructed for performing the pre-processing of the data. In this matrix the 42 elements were represented in columns and the 15 samples arranged in lines. The data were previously treated according to the self-scaling technique, due to the difference between the analyte concentration units (micro and macro scales). After self-scaling, all variables have the same degree of importance.
The data were modeled considering the first three main components PC1, PC2 and PC3, which together account for

67.19% of the total information, meeting the minimum explanability limit of 60% of the variance (LEPS *et al*., 1998). The graph of cumulative total variance is shown in figure 2. The first major component (PC1) is governed by phytosociological indices, trace-metal contents (except Ni, Co, and Ba), major granulometric fractions identified in the sediment (silt, fine and very fine sand) and concentrations of most PAHs, pH and Eh, where they represent 33.61% of the total variance. All these elements contributed to the variability in the samples and are positively correlated. The second main component (PC2) accounts for 20.39% of the total variance, governed by the height data of the plant species and grain size data of the sediment (coarse sand and very fine sand). The third major component (PC3) is governed by pH, fine sand and PAHs, accounting for 13.19% of the total variance. The remaining components were considered an integral part of the residual matrix. The scoring chart in figure 3 (PC1 x PC2) shows in PC1 three groups represented by plots 1 and 2 (samples A1, A2, A3, B1, B2 and B3), in plots 4 and 5 (samples D1, D2, D3, E1, E2 and E3) and plot 3 (samples C1, C2 and C3), the first two with similar random behavior in gradient formation.

In relation to the first and second major components (PC1 and PC2), it can be stated that: in the group of plots 1 and 2, the parameters that most influence are the importance value index, relative dominance, mean height and maximum height of species *A. schaueriana*, besides the maximum height of the species *L. racemosa*, pH and silt; (Cu, V, Zn and Mn), some PAHs (Na, BaA, BkFLA and Pir), mean and maximum heights of the *R. mangle* and very fine sand species ; And for the third group (plot 3), the trace elements Ni and Co, coarse sand, eH, and phytosociological indices such as relative dominance and importance value index of the *R. mangle* species are the ones that most explain the formation of this group. The scoring chart in figure 4 (PC1 x PC3) shows in PC1 two groups represented by plots 1 and 2 (samples A1, A2, A3, B1, B2 and B3), in plots 3, 4 and 5 (samples C2, C3, D1, D2, D3, E1, E2 and E3).In the analysis of the third main component (PC3), the group of plots 1 and 2, the parameters that influence the most are fine sand, pH and some PAHs (anthrene, fluorene, pyrene, chrysene, benzo (b) fluoranthene, benzo (k) fluoranthene and Benzo (a) pyrene).The data of the 15 sediment samples and phytosociological data of the five plots were also evaluated by PCA. The Euclidean distance method was used to calculate the distances between the points (samples) and similar groups. Although the mangrove ecosystem is complex and the sources of contamination in the estuary of the São Paulo River are diverse, by the analysis of Cluster it is possible to identify 5 groups (representing the plots) at a distance of 150 in the dendogram obtained (Figure 5).

Conclusion

Although the petroleum complex is located in the north / northeast portion of Todos os Santos Bay, the activities of the petrochemical industry, in particular the operation of oil exploration wells in the mangrove, were not considered as the main sources of PAHs determined in estuary sediments of the São Paulo river. The results indicated that the mangrove communities of the São Paulo estuary in Todos os Santos Bayhave a low rolling fringe physiognomy and that *Avicenniaschaueriana* was the predominant species, while *Rhizophora mangle* had the lowest number of individuals per hectare. Among the sampled plots, the São Paulo estuary presented representative numbers of individuals and, consequently, a considerable basal area (m^2 ha^{-1}). Being in the development phase, the estuary presented higher relative density of *Avicenniaschaueriana*, as well as higher values for the cover value index.Since in the multivariate analysis the phytosociological indexes for this species were those of greater weight in the formation of groups of the first main component (PC1).The results of this study may, besides serving as a model and reference for future research, subsidize a phytoremediation plan of the area pointing to *Avicenniaschaueriana* as a promising species for this purpose. The results of the present study showed that the PAHs identified in the São Paulo estuary are of high molecular weight and of pyrogenic origin. Regarding the physicochemical variables, the plots showed predominantly silt-based sediments with pH values close to neutrality, and trace amounts of trace metals when compared to the limit values proposed by Cetesb in 2014.

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