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Phytosociology and litterfall in the mangrove estuary of the Itabapoana river, Southeast Brazil

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Abstract. The vegetation structure and litterfall were analyzed in the mangrove estuary of the Itabapoana River, Southeast Brazil. We selected two study sites for structural characterization. Plots were demarcated at 5 (Zone A), 45 (Zone B) and 85 m (Zone C) from the margin of the river in two study sites. The species recorded were *Avicennia germinans* (L.) Stearn., *Laguncularia racemosa* (L.) Gaertn. f. and *Rhizophora mangle* L. The average height varied from 4.1 to 9.2 m, the average diameter at breast height from 6.7 to 13.9 cm, the basal area from 14.3 to 25.3 $m^2.ha^{-1}$ and density from 1,800 to 4,400 $trunks.ha^{-1}$. The forests showed a dominance of *A. germinans*. The daily litter production ranged from 1.3 to 12.1 $g.m^{-2}$ and annual litter production was 9.0 $t.ha^{-1}$. Leaves corresponded to the main component of litterfall. Litter production showed seasonality and variation in the contribution of each species. The total litterfall exhibited a peak in the dry season or rainy season, while fruits showed higher production during the rainy season. Vegetation structure and litterfall did not differ between zones. This result can be attributed to constant flooding of the sediment in both zones.

Key words: productivity, vegetation structure, zonation

Resumo. Fitossociologia e produção de serapilheira em florestas de mangue do estuáiro do rio Itabapoana, Sudeste do Brasil. A estrutura da vegetação e a produção de serapilheira foram analisadas no manguezal do estuário do rio Itabapoana, Sudeste do Brasil. Parcelas foram demarcadas a 5 (Zona A), 45 (Zona B) e 85 m (Zona C) da margem do rio em dois sítios de estudo. As espécies registradas foram *Avicennia germinans* (L.) Stearn., *Laguncularia racemosa* (L.) Gaertn. f. e *Rhizophora mangle* L. A altura média variou de 4,1 a 9,2 m, o diâmetro à altura do peito de 6,7 a 13,9 cm, a área basal de 14,3 a 25,3 $m^2.ha^{-1}$ e a densidade de 1.800 a 4.400 $troncos.ha^{-1}$. As florestas mostraram dominância de *A. germinans*. A produção diária de serapilheira variou de 1,3 a 12,1 $g.m^{-2}$ e a produção anual de serapilheira foi de 9,0 $t.ha^{-1}$. As folhas corresponderam ao principal componente da serapilheira. A produção de serapilheira mostrou sazonalidade e variação na contribuição das espécies. A produção total de serapilheira exibiu pico no período seco e no período chuvoso, enquanto os frutos mostraram maior produção durante o período chuvoso. A estrutura da vegetação e a produção de serapilheira não difeririam entre as zonas. Este resultado pode ser atribuído à constante inundação do sedimento em ambas as zonas.

Palavras chave: produtividade, estrutura da vegetação, zonação

Introduction

Mangrove forests play a key role between land and sea, where they are the only woody plants that grow and thrive along most tropical and subtropical coasts (Alongi 2011). They provide a range of environmental services, such as serving as a habitat for many economically important species (Mumby 2006), stabilizing and protecting shorelines (Barbier 2006), and improving the water quality of creeks and coastal waters (Adame *et al.* 2010). Mangroves are among the most carbon-rich forests in the tropics, containing on average of 1023 Mg carbon per hectare (Donato *et al*. 2011), and the high productivity is likely to subsidize coastal production as mangroves export particulate and dissolved carbon and litter to coastal waters (Adame & Lovelock 2011). The export level of dissolved and particulate materials from the litter depends on geomorphology and tidal amplitude (Twilley & Day 1999, Woodroffe 1992).

Litterfall and biomass in mangroves have been measured across a wide geographical range, and the results have demonstrated a high litter production at low latitudes and a decrease its production with high latitudes (Saenger & Snedaker 1993, Twilley *et al*. 1992). Variations in the structure and function of mangroves can be found within a single estuary, representing a continuum of stand types in relation to changes in hydrological, chemical, and geomorphologic setting; less clear is whether or not structural changes in forests translate into changes in functional characteristics such as photosynthetic rate and primary productivity (Alongi 2009). At the stand level, there may be significant spatial heterogeneity in the structure and litterfall of the mangrove, because many factors operate to control the ecosystem. These factors include salinity, hydrodynamics, flooding frequency, sediment grain size and chemistry, nutrient and oxygen availability in pore water, physiological tolerances, predation, and competition (Day *et al*. 1996, Smith 1992).

In mangroves of Espírito Santo and Rio de Janeiro States, Southeast Brazil, investigations of the structure of vegetation are more abundant (Bernini & Rezende 2004, Bernini & Rezende 2010a, 2011, Calegario *et al*. in press, Carmo *et al*. 1995, Pereira *et al*. 2009, Petri *et al*. 2011, Silva *et al*. 2005, Soares 1999) than of litter production (Almeida 2001, Bernini & Rezende 2010b). In the mangrove estuary of the Itabapoana River, Southeast Brazil, Bernini and Rezende (2010a) evaluated the distribution of mangrove species along the estuary, but there is no information about the distribution of species along the flooding gradient and litter production. On the right bank, the mangrove forests have suffered direct impacts (clear-cutting, embankments) since the nineteenth century. There are plans for the construction of a deepwater port terminal near the estuary, which could compromise the health of the mangrove.

Accordingly, the aim of this study was to characterize the phytosociology and to quantify litter production in different zones in the mangrove estuary of the Itabapoana River. The information may be helpful in the development of conservation projects and recovery of degraded areas in the study area.

Study Area

The study was conducted in the mangrove estuary of the Itabapoana River, located between the cities of Presidente Kennedy, Espírito Santo State, and São Francisco de Itabapoana, Rio de Janeiro State (Fig. 1). The climate is hot and humid, with average temperatures between 18°C and 24°C and total annual rainfall around 1320 mm (ANA 2001).

During the study period (April 2010 to March 2011), the lowest air temperatures were recorded between June and August, while the highest values were recorded from December to February (Figure 2). In general, rainfall was higher from October to March (Fig. 2). Regarding the winds, the highest speed was recorded in September and October (2.6 and 2.0 $m.s^{-1}$, respectively). The climatic data were obtained from a station located 60 km from the estuary of the Itabapoana River (National Institute of Meteorology – INMET). The estuary is under a microtidal regime with semidiurnal tides. Based on data from the Ponta do Ubu Terminal in Espírito Santo (20° 44'S, 40° 32'W), between 2010 and 2011, the average tide was 0.8 m (DHN 2011).

The mangrove forest is composed of three tree species *Avicennia germinans* (L.) Stearn. (Acanthaceae), *Laguncularia racemosa* (L.) Gaertn. f. (Combretaceae) and *Rhizophora mangle* L. (Rhizophoraceae). Other associated species such as *Acrostichum aureum* L. (Pteridaceae) and *Hibiscus pernambucensis* Arruda (Malvaceae) were also recorded (Bernini & Rezende 2010a).

Methods

Vegetation structure

Plots were used to characterize vegetation structure, according to the method proposed by Cintrón and Schaeffer-Novelli (1984). The study consisted of a sample during the months of January and February 2010. We selected two study sites (Fig. 1). The definition of the sites was based on field observations, in order to depict the general appearance of the mangrove forest. The Site 1 consists of riverine forest (located east), appears more conserved, while Site 2 also consists of riverine forest (located west) is under high human influence (presence of trash, clear-cutting, sewage dumping, pig breeding).

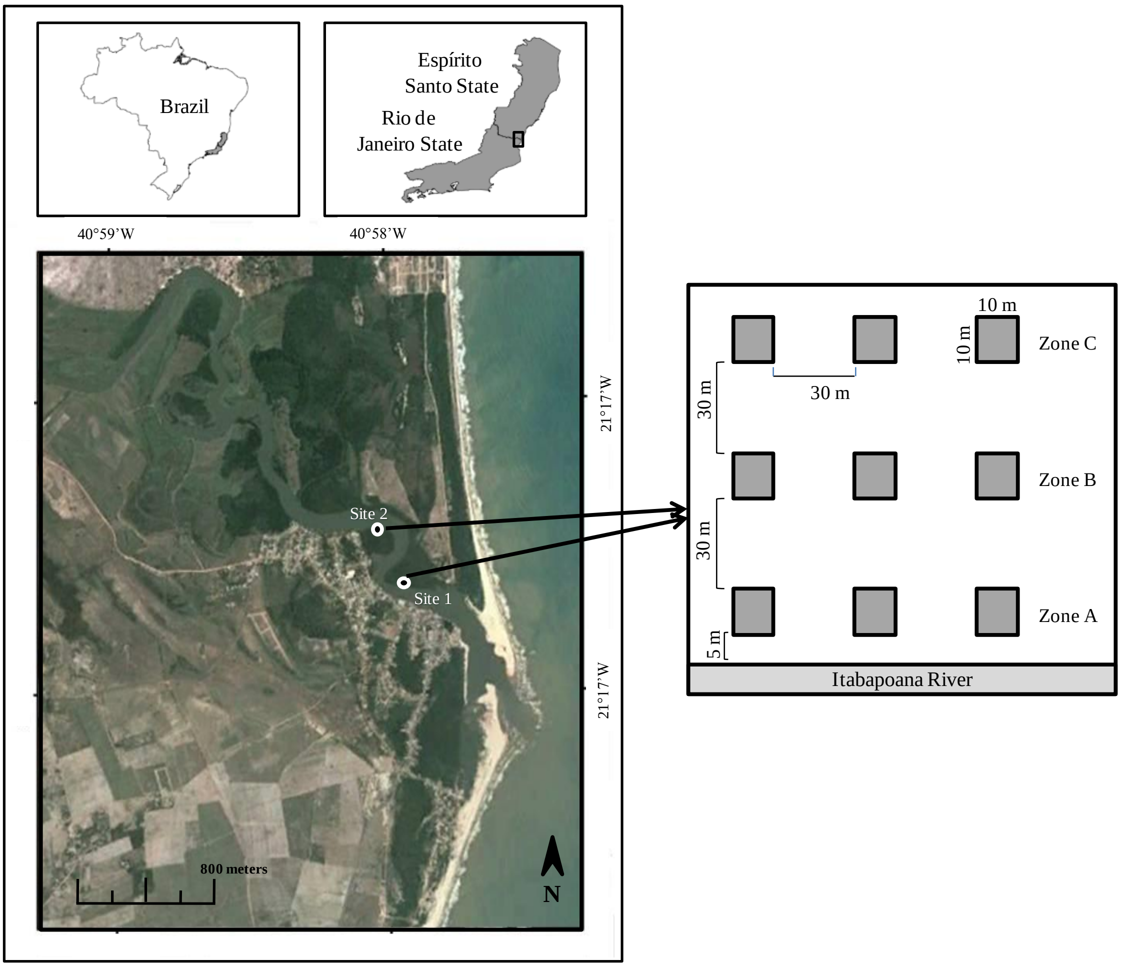

Figure 1. Location of the study sites and arrangement of the plots at each site in the estuary of the Itabapoana River, Southeast Brazil. Source: Google Earth.

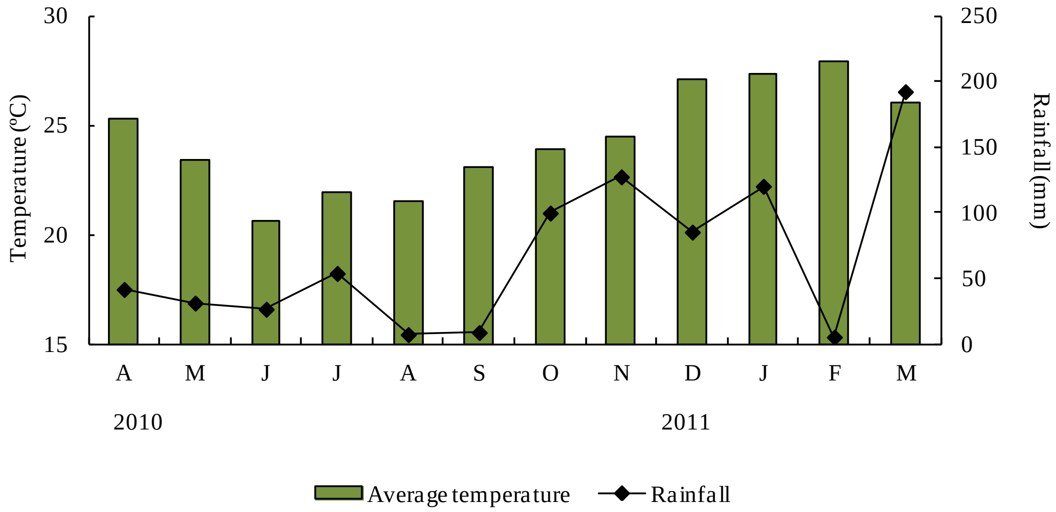

Figure 2. Monthly average temperatures and monthly total rainfall from April 2010 to March 2011 for Campos dos Goytacazes City, Rio de Janeiro State, located approximately 60 km away from the estuary of the Itapaboana River (Data source: National Institute of Meteorology - INMET).

Nine plots were demarcated at each study site, three at 5 (Zone A), 45 (Zone B) and 85 m (Zone C) from the margin of the river, spaced at 30 m (Figure 1). In each plot, we measured diameter at breast height (DBH, 1.3 m above substrate) and the height of all living individuals $\geq$1 m tall. To measure DBH, a measuring tape graduated in units of π (3.14159) was used. The height measurements of the living trees were obtained with a graduated rod. The diameters of trunks and dead trees still standing were also included in the sample. Afterwards, the structural parameters of average height, average DBH, basal area, density, dominance and relative density were calculated following Cintrón and Schaeffer-Novelli (1984). Two-way ANOVA and Tukey's test for later evaluation were performed to compare data between zones and study sites.

Litter production

At Site 1, Zone A and Zone B were selected to quantify litter production. These plots were chosen because they have less human influence. In Zone C, the forest is also composed of patches of *Acrostichum aureum* and *Hibiscus pernambucensis* and we deliberately avoided areas with high contribution of species associated with mangroves.

In each plot, three baskets of 70x70 cm (0.49 m^2) were randomly placed and were separated from each other by at least 3 m. The baskets consisted of a wood frame and 2 mm nylon mesh, 50 cm deep, and they were suspended in the trees about 1.3 m above the ground. From April 2010 to March 2011, trap contents were collected monthly during which time there was no decomposition observed. The material collected was oven dried until constant weight (60ºC/72 h) and then weighed and sorted into the following components: leaves, branches, flowers, fruits and miscellaneous (all plant material <2 mm and occasional structures of other species).

Dry weight per trap was converted to $g.m^{-2}.day^{-1}$ and to tons per hectare ($t.ha^{-1}$) for comparison with other studies. The Friedman test was used to assess differences in litterfall between collection intervals (12 samples). Variations between zones (A and B) were analyzed with the Mann-Whitney test. Variations between species were analyzed with the Kruskal-Wallis and Dunn tests (Zar 1996). Multiple regression analysis was used to determine the relationships between monthly litter production and climatic parameters (mean air temperature, rainfall and wind speed). Pearson correlation was performed to assess the relationship between total litterfall and the structural parameters.

Abiotic factors

Three sediment samples (15 cm deep) were collected from each plot described above during low tide on July 2010. In the laboratory, the sediment was lyophilized and coarse fragments (over 2.0 mm) removed. Grain size distribution was determined in a particle analyzer (Laser Diffraction, Sald 3101 Shimadzu). For the analysis of organic matter, aliquots of sediment (2 g) were weighed and incinerated in a muffle furnace (550°C/1 h). The percentage of organic matter was obtained by the difference between the initial and final dry weights. Porewater salinity was determined with a refractometer after centrifugation of 15 g of sediment (2500 rpm/5 min).

Results

The species recorded at the sites analyzed were *Avicennia germinans*, *Laguncularia racemosa* and *Rhizophora mangle*. Associated species included *Acrostichum aureum* and *Hibiscus pernambucensis*.

Structural parameters are shown in Table I. The average height varied from 4.1 to 9.2 m, average DBH from 6.7 to 13.9 cm, basal area from 14.3 to 25.3 $m^2.ha^{-1}$ and density from 1,800 to 4,400 $trunks.ha^{-1}$. There was no significant difference in the structural parameters between Zones A, B and C. Besides the percentage of cut trunks being significantly higher at Site 2, there were no significant differences in the structural parameters between the study sites. The main contribution of the basal area corresponded to the $\geq$ 10.0 cm diameter class (Fig. 3); however, the values in this class were higher at Site 2. Site 2 showed higher contribution in $\geq$ 2.5 cm diameter class in relation to Site 1.

The dominance and relative density of species varied between plots, with no apparent zonation (Figs. 4-5). At Site 1, the order of dominance for living trunks was *Avicennia germinans* > *Rhizophora mangle* > *Laguncularia racemosa* (65.7, 29.6 and 4.7%, respectively; Fig. 4A) and the sequence of relative density was *Rhizophora mangle* > *Avicennia germinans* > *Laguncularia racemosa* (50.0, 25.5 and 24.5%, respectively; Fig. 5A). At Site 2, there was the same sequence, and the values of dominance were 50.4% for *Avicennia germinans* 35.1% for *Rhizophora mangle* and 14.5% for *Laguncularia racemosa* (Fig. 4B). The relative density values were 44.4% for *Rhizophora mangle*, 28.3% for *Avicennia germinans* and 27.3% for *Laguncularia racemosa* (Fig. 5B).

Table I. Structural parameters (mean ± standard deviation, n = 3) of the vegetation in the mangrove estuary of the Itabapoana River. DBH = diameter at breast height. In the columns, uppercase compare each parameter between sites and lowercase compare each parameter between the different zones. Different letters indicate significant difference ($p \leq 0.05$). Plots were demarcated at 5 (Zone A), 45 (Zone B) and 85 m (Zone C) from the margin of the river.

	Height (m)	DBH (cm)	Basal area alive ($m^2.ha^{-1}$)	Basal area dead ($m^2.ha^{-1}$)	Density alive ($trunks.ha^{-1}$)	Density dead ($trunks.ha^{-1}$)	Cut trunks (%)
Site 1							
Zone A	8.3±4.5 a	13.9±5.5 a	19.9±3.2 a	2.57±1.43 a	1,800±1,473 a	367±153 a	2.2±3.9 a
Zone B	5.3±1.8 a	10.6±1.6 a	25.3±9.2 a	0.24±0.21 a	2,767±321 a	300±265 a	0 a
Zone C	4.1±0.8 a	6.7±0.6 a	14.3±2.8 a	1.21±1.31 a	4,233±1,343 a	367±153 a	0 a
General	**5.9±3.1 A**	**10.4±4.3 A**	**19.8±6.9 A**	**1.48±1.44 A**	**2,933±1,465 A**	**356±188 A**	**0.7±2.2 A**
Site 2							
Zone A	5.8±0.6 a	7.0±1.6 a	16.8±5.9 a	0.60±0.40 a	4,400±900 a	567±321 a	19.1±17.4 a
Zone B	6.8±1.2 a	7.6±2.9 a	15.5±9.0 a	0.85±0.56 a	3,333±586 a	600±520 a	12.6±15.5 a
Zone C	9.2±0.5 a	10.7±1.0 a	21.3±4.8 a	0.80±0.71 a	2,467±961 a	433±306 a	18.4±16.5 a
General	**7.3±1.7 A**	**8.4±2.5 A**	**17.9±6.4 A**	**0.70±0.49 A**	**3,400±1,106 A**	**533±350 A**	**16.7±14.6 B**

The daily litter production ranged from 1.3 to 12.1 $g.m^{-2}$ and annual litter production was 9.0 $t.ha^{-1}$ of dry weight. The annual values obtained in the Zone A and Zone B were 8.7 and 9.3 $t.ha^{-1}$, respectively. In Zone A, the values of leaf, fruit, flower, branch and miscellaneous litter production were 52, 18, 15, 13 and 2% of total litter production, respectively, while in Zone B, the values of leaf, fruit, branch, flower and miscellaneous litter production components accounted for 50, 33, 9, 6 and 2% of the total litter production, respectively.

Components and total litter production, showed no significant difference between Zones A and B (Tables II). There was a higher production of leaves and flowers of *Avicennia germinans* and *Rhizophora mangle* in relation to *Laguncularia racemosa* in both A and B zones (Table II). This result was also observed for fruit production in the Zone A (Table II). In the Zone B there was a higher fruit production to *Rhizophora mangle* in relation to *Laguncularia racemosa*, an intermediate value for *Avicennia germinans* (Table II).

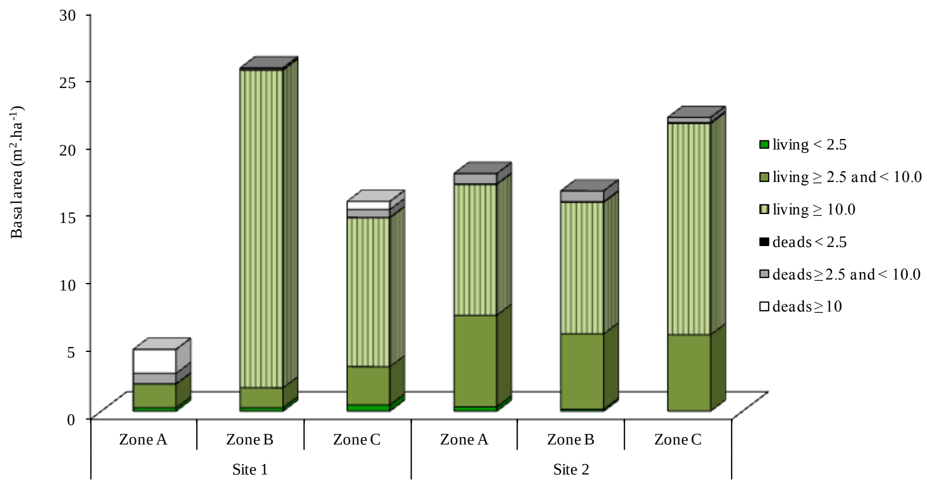

Figure 3. Basal area of live and dead trunks, by diameter class (cm) in the mangrove estuary of the Itabapoana River, Southeast Brazil.

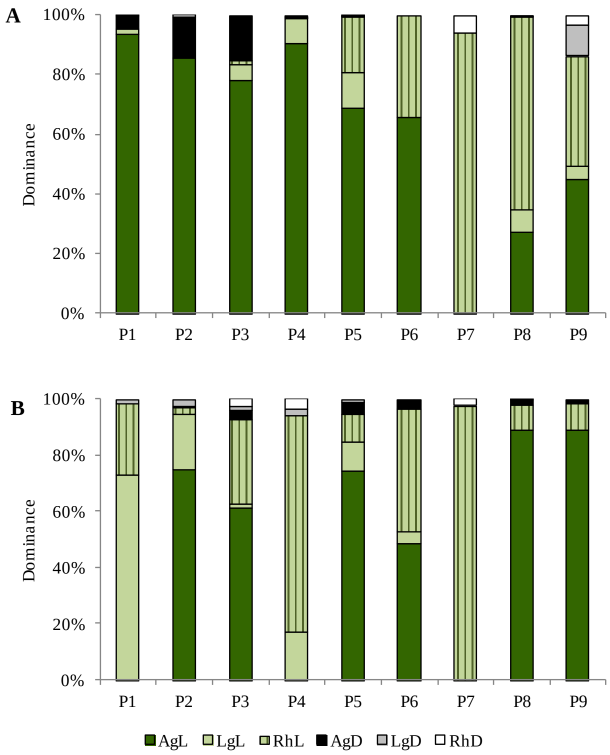

Figure 4. Dominance of live and dead trunks in the plots analyzed at sites 1 (A) and 2 (B) in the mangrove estuary of the Itabapoana River, Southeast Brazil. AgL: *Avicennia germinans* live; LgL: *Laguncularia racemosa* live; RhL: *Rhizophora mangle* live; AgD: *Avicennia germinans* dead; LgD: *Laguncularia racemosa* dead; RhD: *Rhizophora mangle* dead. Plots 1 a 3: Zone A; Plots 4 a 6: Zone B; and plots 7 a 9: Zone C.

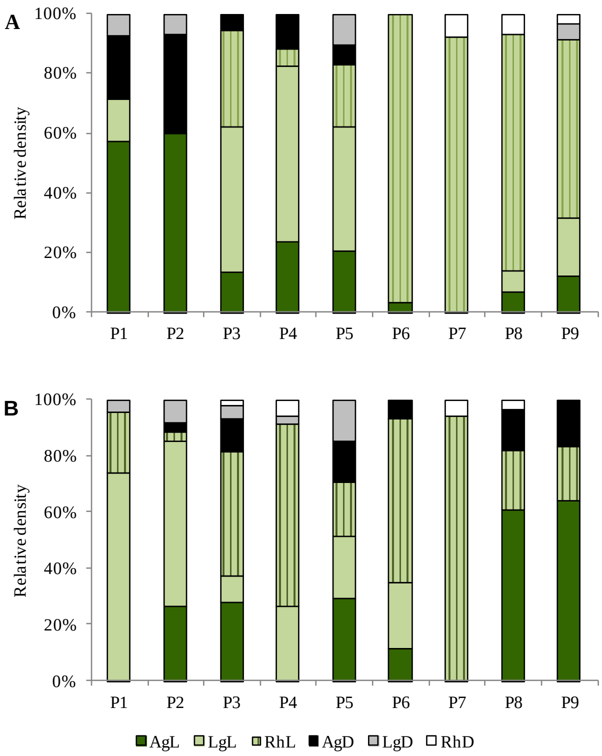

Figure 5. Relative density of live and dead trunks in the plots analyzed at sites 1 (A) and 2 (B) in the mangrove estuary of the Itabapoana River, Southeast Brazil. AgL: *Avicennia germinans* live; LgL: *Laguncularia racemosa* live; RhL: *Rhizophora mangle* live; AgD: *Avicennia germinans* dead; LgD: *Laguncularia racemosa* dead; RhD: *Rhizophora mangle* dead. Plots 1 a 3: Zone A; Plots 4 a 6: Zone B; and plots 7 a 9: Zone C.

Table II. Production of leaves, flowers, fruits, branches, miscellaneous and total litter ($g.m^{-2}.dia^{-1}$) in the mangrove estuary of the Itabapoana River, Southeast Brazil. The values did not differ significantly between outer and inner forests ($p > 0.05$). In the lines, lowercase letters compare each component among species. Different letters indicate significant difference ($p \leq 0.05$) (n = 12). Ag: *Avicennia germinans*, Lg: *Laguncularia racemosa* e Rh: *Rhizophora mangle*. SD = standard deviation.

		Zone A	Zone B
Ag leaves	Mean ± SD	1.130 ± 0.852 a	0.990 ± 0.650 a
	Median	0.781	0.870
	Minimum - Maximum	0.401 - 3.329	2.394 - 0.247
Lg leaves	Mean ± SD	0.004 ± 0.012 b	0.003 ± 0.008 b
	Median	0	0
	Minimum - Maximum	0 - 0.0417	0 - 0.0293
Rh leaves	Mean ± SD	1.047 ± 0.820 a	1.135± 0.522 a
	Median	0.876	1.070
	Minimum - Maximum	0.308 - 3.294	0.453 - 2.050
Ag flowers	Mean ± SD	0.074 ± 0.094 a	0.061 ± 0.095 a
	Median	0.030	0.020
	Minimum - Maximum	0.001 - 0.287	0.001 - 0.308
Lg flowers	Mean ± SD	0.001 ± 0.003 b	0.001 ± 0.001 b
	Median	0	0
	Minimum - Maximum	0 - 0.0116	0 - 0.0006
Rh flowers	Mean ± SD	0.041 ± 0.026 a	0.058 ± 0.038 a
	Median	0.041	0.056
	Minimum - Maximum	0.005 - 0.075	0.008 - 0.140
Ag fruits	Mean ± SD	0.350 ± 0.701 a	0.381 ± 0.778 ab
	Median	0.020	0.024
	Minimum and Maximum	0 - 1.850	0 - 2.290
Lg fruits	Mean ± SD	0.016 ± 0.053 b	0.006 ± 0.018 b
	Median	0	0
	Minimum - Maximum	0 - 0.185	0 - 0.061
Rh fruits	Mean ± SD	0.327 ± 0.625 a	0.944 ± 1.661 a
	Median	0.110	0.225
	Minimum - Maximum	0 - 2.184	0.079 - 4.656
Branches	Mean ± SD	0.052 ± 0.600	0.401 ± 0.644
	Median	0.230	0.135
	Minimum - Maximum	0.025 - 2.169	0.025 - 2.169
Miscellaneous	Mean ± SD	0.083 ± 0.066	0.083 ± 0.079
	Median	0.057	0.067
	Minimum - Maximum	0.049 - 0.285	0.042 - 0.327
Total	Mean ± SD	3.3 ± 2.1	3.9 ± 3.4
	Median	2.4	2.5
	Minimum - Maximum	1.3 - 7.4	1.7 - 12.1

Significantly seasonal variations were found in all litter production, including total, leaves, branches, flowers, fruits and miscellaneous of both zones of forests (Friedman, $p \leq 0.05$; Figs. 6-7). The Zona A and Zone B showed a similar pattern seasonal to the components and total litter (Figs. 6-7). The *Avicennia germinans* leaves exhibited higher production on August and September (Figs. 6A-6B). *Laguncularia racemosa* leaves showed reduced contribution over the months. *Rhizophora mangle* showed greater leaves production on February and March (Figs. 6A-6B).

Regarding the flowering period, *Avicennia germinans* had high production between October and December (Fig. 6C-6D); *Laguncularia racemosa* reached higher values on March, while *Rhizophora mangle* exhibited higher production on September and October. The monthly production of fruits was similar to *Rhizophora mangle* and *Avicennia germinans*, with highest values on February and March (Figs. 6E-6F). The highest fruit production for *Laguncularia racemosa* was observed on March (Figs. 6E-6F). The production of branches was higher on September, October and March (Fig. 7A). Miscellaneous litterfall category showed production peak on March (Fig. 6B). The total litter production was higher on June, September, February and March (Fig. 7C).

In general multiple regression analysis indicated no significant relationship between litter production and the variables average air temperature, rainfall and wind speeds (Table III). There was no significant correlation between total litter production and the structural parameters (Table IV).

Sediment abiotic factors are shown in Table V. Porewater salinity showed low values in relation to seawater, while the percentage of organic matter showed high values at both study sites. The sediment had a higher percentage of silt, with fine granulometry in all areas analyzed.

Table III. Results of multiple linear regression performed for the data of litter production and mean air temperature (X_1), rainfall (X_2), and wind speed (X_3) in the mangrove estuary of the Itabapoana River, Southeast Brazil. *Values statistically significant to $p \leq 0.05$.

	Equação	R^2	F	p
Avicennia germinans leaves	$Y = 3.41 – 0.53 (X_1) – 0.15 (X_2) + 0.64 (X_3)$	0.50	4.69	0.036*
Laguncularia racemosa leaves	$Y = -0.06 + 0.58 (X_1) – 0.30 (X_2) + 0.60 (X_3)$	0.22	2.06	0.072
Rhizophora mangle leaves	$Y = -2.93 + 0.54 (X_1) + 0.27 (X_2) + 0.16 (X_3)$	0.21	2.00	0.193
Avicennia germinans flowers	$Y = -0.05 – 0.06 (X_1) + 0.62 (X_2) + 0.27 (X_3)$	-0.01	0.95	0.462
Laguncularia racemosa flowers	$Y = -0.001 + 0.41 (X_1) + 0.49 (X_2) + 0.45 (X_3)$	0.33	2.78	0.111
Rhizophora mangle flowers	$Y = 0.20 – 0.46 (X_1) + 0.01 (X_2) + 0.44 (X_3)$	0.01	1.05	0.422
Avicennia germinans fruits	$Y = -4.17 + 0.62 (X_1) – 0.03 (X_2) – 0.39 (X_3)$	0.16	1.68	0.248
Laguncularia racemosa fruits	$Y = -0.02 + 0.31 (X_1) + 0.17 (X_2) – 0.50 (X_3)$	0.15	1.66	0.251
Rhizophora mangle fruits	$Y = -9.80 + 0.67 (X_1) – 0.17 (X_2) – 0.37 (X_3)$	0.15	1.66	0.251
Branches	$Y = -0.16 + 0.02 (X_1) + 0.36 (X_2) + 0.05 (X_3)$	-0.22	0.34	0.793
Miscellaneous	$Y = -0.09 + 0.25 (X_1) + 0.36 (X_2) – 0.26 (X_3)$	0.09	1.37	0.320
Total litterfall	$Y = -13.69 + 0.48 (X_1) + 0.001 (X_2) – 0.17 (X_3)$	-0.08	0.72	0.567

Discussion

The species of mangroves and mangrove associates recorded in this study were similar to those described by Bernini and Rezende (2010a) who analyzed the structure of mangrove forests along the Itabapoana River estuary. The richness observed is also consistent with the record for the mangrove estuary of the Paraiba do Sul River, Rio de Janeiro State, located about 33 km away (Bernini & Rezende 2011).

The forests analyzed showed a high structural development, characterized by greater basal area in the class diameter above 10.0 cm. According to the classification of Cintrón *et al.* (1985), the forests studied are the physiographic type riverine, which runs along rivers and tidal channels and displays better structural development when compared to the fringe and basin physiographic types. The structural parameters are within the range reported for other mangroves in Espírito Santo and Rio de Janeiro States (Bernini & Rezende 2011, Calegario *et al.* in press, Carmo *et al.* 1995, Petri *et al.* 2011, Silva *et al.* 2005, Soares 1999). The trunk density described here is less than that previously recorded, since Bernini and Rezende (2010a) analyzed forests of different ages, including areas with recent deposition of sediments near the mouth and areas subject to high anthropogenic influence.

Forests showed no significant differences in structural parameters between zones. This result may be due to the high flooding frequency along the forest substrate, which promotes similar abiotic conditions as those observed in the sediment variables. Similar results were reported for the mangrove of Babitonga Bay, Santa Catarina State (Cunha *et al.* 2004).

At Site 2, mangrove forests had a higher percentage of cut trunks due to high human influence in the area, and at Site 1, the same pattern was observed in the outer forest due to the ease of access. The values reported here are lower than those found in the mangrove estuary of the

Guaxindiba River, Rio de Janeiro State, located about 25 km away, where the values of cut trunks ranged 2-43% (Chagas 2011). Some authors have reported higher percentages of deforestation, such as for mangroves in the Philippines (Walters 2005) and East Timor (Alongi & Carvalho 2008), with values of 30-50% and 13-72%, respectively. Selective logging may result in changes in structure and abundance, since some species may be affected more than others by cutting (Eusebio *et al.* 1986, Pinzon *et al.* 2003) and may disrupt some functional features such as below- and above-ground production. Accordingly, human influence can be one of the factors that explain the higher contribution of the basal area on diameter class over 10.0 cm at Site 1 compared to Site 2, because selective logging reduces the basal area of the forest at Site 2.

Table IV. Results of Pearson correlation between total litterfall and the structural parameters analyzed in the mangrove estuary of the Itabapoana River, Southeast Brazil. The correlations were not significant ($p > 0.05$). DBH = diameter at breast height.

	Total litterfall
Heigh	0.54
DBH	0.24
Basal area alive	0.38
Basal area dead	-0.22
Density alive (trunks)	-0.44
Density dead (trunks)	-0.20

The dominance and relative density of species varied in the different mangrove zones analyzed, and we could not define any zonation. Similar results were reported for the mangrove estuary of the Paraíba do Sul River (Bernini & Rezende 2004, 2011). In the mangrove estuary of the Itabapoana River the lower porewater salinity, a stable fresh water input and flooding have a negligible effect on plant physiology. In this case, other factors such as competition may be more important in determining the distribution of the species (Fromard *et al*. 1998, Tomlinson 1986). This inundation regime was observed for the mangrove at Paraíba do Sul River (Bernini & Rezende 2004, 2011) and can be considered a remarkable process for riverine mangroves in microtidal regions.

Table V. Abiotic factors of the sediment (mean ± standard desviation, n = 3) analyzed in the mangrove estuary of the Itabapoana River, Southeast Brazil.

	Porewater salinity	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)
Site 1					
Zone A	2.0±0.0	18.8±4.7	25.5±7.8	60.4±6.0	14.1±1.7
Zone B	2.7±1.2	11.3±5.4	21.6±0.5	63.3±0.2	15.1±0.3
Zone C	2.3±0.5	27.6±2.5	14.7±1.2	69.4±0.3	16.0±1.0
Site 2					
Zone A	2.0±0.0	14.3±1.3	32.3±1.8	54.6±1.6	13.0±0.6
Zone B	2.0±0.0	14.6±8.0	20.8±6.1	64.6±3.9	14.6±2.2
Zone C	2.0±0.0	18.4±4.5	19.1±3.1	64.9±1.6	16.0±1.6

The dominance of *A. germinans* shows that the mangrove studied is similar to the mangrove estuary of the Paraíba River, where the dominance of *A. germinans* reaches 53% (Bernini & Rezende 2011). Meanwhile, other studies conducted in Espírio Santo and Rio de Janeiro States have indicated the dominance of *Avicennia schaueriana*, *R. mangle* and/or *L. racemosa* (Calegario *et al*. in press, Pellegrini *et al*. 2000, Petri *et al*. 2011, Silva *et al*. 2005, Soares 1999). However, those mangroves are not recorded for the occurrence of *A. germinans*, or this species is restricted to the upper river estuary, where porewater salinity is less than 10. *Avicennia germinans* typically occurs in less elevated areas and may also be present in places where flooding is less frequent. The species is found in clay, silt or sandy substrates, with the best development observed in riverine forests (Jimenez & Lugo 1985), such as the mangrove estuary of the Itabapoana River.

The results indicated no relationship between the vegetation structure and the litter production, corroborating observations made in other mangrove forests (Lopez-Portilho & Ezcurra 1985, Twilley & Day 1999, Bernini & Rezende 2010). The higher values of dominance and relative density of *A. germinans* and *R. mangle* reflected their greater contributions to the litterfall components at Site 1. The amount of litter production obtained in this study (9.0 $t.ha^{-1}.year^{-1}$) is higher than that reported by Farias *et al.* (2006), Fernandes *et al.* (2007), Gonçalves *et al.* (2006) in mangroves comprising the same species in Pará State (3.4 to 7.8 $t.ha^{-1}.year^{-1}$), located near the equator. However, the values are below those of the mangrove estuary of the Paraíba do Sul River (13.2 $t.ha^{-1}.year^{-1}$; Bernini & Rezende 2010b), near our study area. The litterfall in the mangrove estuary of the Itabapoana River is within the mid-range compared with global mangrove litterfall (1.3 - 18.7 $t.ha^{-1}.year^{-1}$; Saenger & Snedaker 1993). The largest litter production in the mangrove estuary of the Itabapoana River regarding mangroves located at low latitudes indicates optimal habitat for the mangrove, particularly with regard to low porewater salinity.

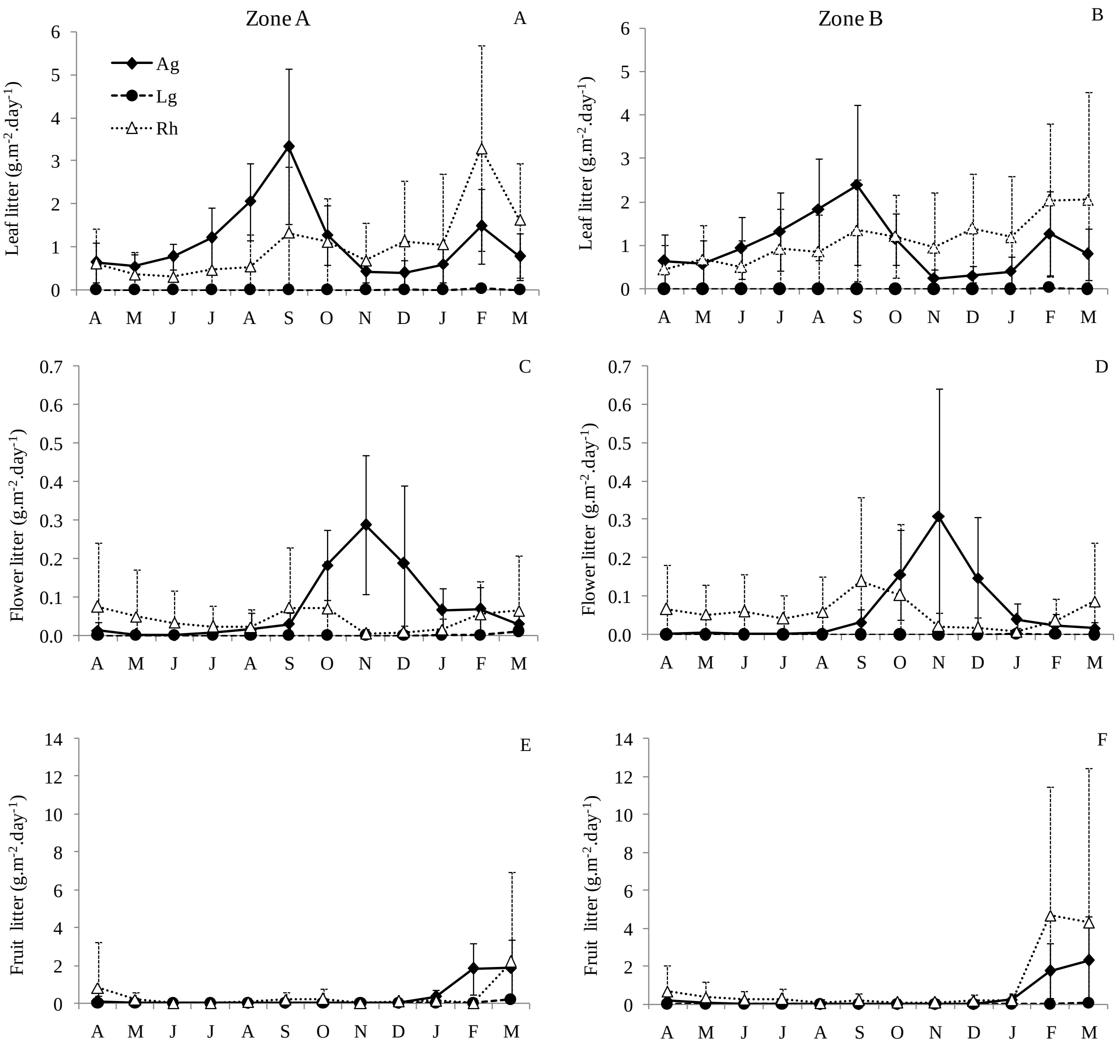

Figure 6. Litter production of the mangrove forests from April 2010 to March 2011, in the estuary of the Itabapoana River, Southeast Brazil (mean ± standard desviation).

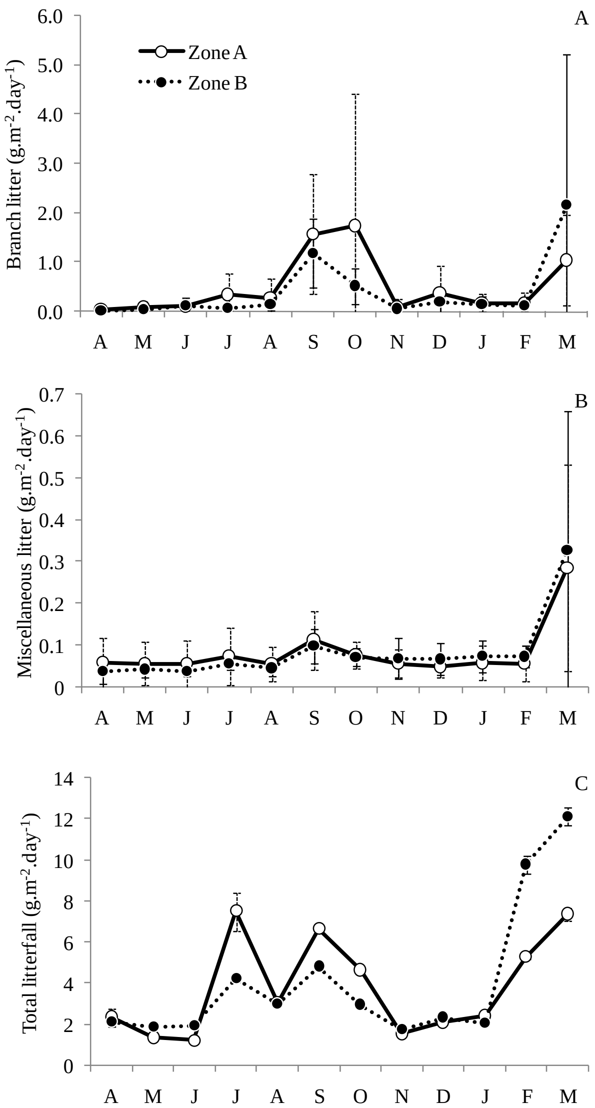

Figure 7. Litter production of the mangrove forests from April 2010 to March 2011, in the estuary of the Itabapoana River, Southeast Brazil (mean ± standard desviation).

Like the structural parameters, litter production did not differ between Zones A and B, reflecting similar abiotic conditions. Aké–Castillo *et al.* (2006) estimated the litterfall in fringe and basin forests in the southern Gulf of Mexico and also found no differences, although the forests were subjected to different flooding frequencies.

Leaves represented the largest biomass input of litterfall. These results are consistent with data reported in other studies, which indicated that leaves rarely contribute less than 50% to total litter production (Adame *et al.* 2013, Cunha *et al.* 2004, Fernandes *et al.* 2007, Kamruzzaman *et al.* 2012, Querales *et al.* 2011, Sherman *et al.* 2003; Ye *et al.* 2013).

Litterfall at our study site changed as well over time, supporting previous findings on seasonality of mangrove litterfall (Adame *et al.* 2013, Aké-Castillo *et al.* 2006, Arreola-Lizárraga *et al.*, 2004, Cunha *et al.* 2004, Fernandes *et al.* 2007, Kamruzzaman *et al.* 2012, Sánchez-Andrés *et al.* 2010, Ye *et al.* 2013). Leaves were present every month, with higher values in the dry season for *A. germinans* and rainy season for *R. mangle*. The higher production of leaves during the rainy season is common for *R. mangle* (Arreola-Lizárraga *et al.* 2004, Sherman *el al.* 2003, Querales *et al.* 2011) and other species in the same genus (*R. apiculata*, *R. lamarckii* and *R. stylosa*) (Williams *et al.*, 1981). Seasonal pattern is less clear for *A. germinans* leaves (Bernini & Rezende 2010b, Clough *et al.* 2000).

Species showed a production peak for flowers in the rainy season or the transition dry/rainy season. Fruit production for all species occurred synchronously with the rainy season, ensuring the dispersal of diaspores of mangrove species by hydrochory. Mangrove species that develop in tropical regions usually have one reproductive peak per year (Bernini & Rezende 2010b, Farias *et al.* 2006, Fernandes *et al.* 2007, Kamruzzaman *et al.* 2012, Ocheing & Erftemeijer 2002).

Branch production exhibited a peak during the dry period and a peak during the rainy season. The mechanical effect of the winds may have contributed to greater falling in the months that showed the maximum speeds (September and October), which coincided with the dry season. Miscellaneous showed a peak in the rainy season, probably, reflecting a greater contribution of waste from reproductive structures.

Total litterfall exhibited a peak in the dry season and another peak in the rainy season. Therefore, there was no significant relationship between total litterfall and rainfall, mean air temperature or wind speed. Studies suggest that high temperatures, increased day length, higher rainfall rates and fresh water flow are probably the factors responsible for the largest litter fall during the rainy season (López-Portilho & Ezcurra 1985, Sherman *et al.* 2003, Arreola-Lizárraga *et al.* 2004, Aké-Castillo *et al*. 2006). Litter production along the months can be influenced by other factors such as nutrient availability (Twilley 1995), position along the flooding gradient and particular geomorphologic setting where the species occur (Lopez-Portilho & Ezcurra 1985). Other studies have also reported little or no relationship between these variables (Bernini & Rezende 2010b, Lopez-Portilho & Ezcurra 1985, Ramos e Silva *et al*. 2006).

In summary, structural parameters and litter production did not differ along the zones analyzed. These results can be attributed to constant flooding of sediment. Forests showed a dominance of *A. germinans*, with high structural development and absence of zonation in the analyzed sites. Litter production showed seasonality, with higher contribution of leaves and variation in the contribution of each species. There were a higher percentage of cut trunks at the Site 2, indicating the need to develop conservation projects. The results of this study may be helpful in the development of recovery of degraded areas in the study area.

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