Composition and community structure of mangroves distributed on the east coast of Marajó Island, Brazil

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Received: 22 December 2021 / Accepted: 17 November 2022 / Published online: 27 November 2022
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Abstract The present study aimed to determine the composition and structure of the fringe and inland mangroves near the mouth of the Amazon River in Marajó Island. We established five study sites and, in each site, we established a fringe zone and an inland zone. In each zone, we delimited five 400-m² plots, and we selected arboreal individuals with a minimum height of 1 m. The individuals were grouped into diameter and height classes and basal area, and we analyzed five phytosociological parameters. The composition, richness, density, diversity and dendrogram analysis used were compared between the sampled fringe and inland zones. In our exploration, 344 individuals were recorded, distributed in 10 species, suggesting that Marajó Island has one of the most diverse mangrove forests ever recorded in the world. We also recorded three typical species of mangrove, namely, Rhizophora racemosa, Avicennia germinans, and Laguncularia racemosa. We also observed that the Marajó mangroves have species that occur in other ecosystems (e.g., várzea and igapós), such as Paeonia officinalis, Phalaris aquatica, and Virola surinamensis. We observed that no significant variation between zones was found in terms of richness and density. The NMDS explained variance of 95.3% but no clear pattern of dissimilarity was observed between fringe and inland. In cluster analysis, four groups were statistically well supported, with an explanation of 85% on the dendrogram. These characteristics are important for conservation policies and specific management plans for the mangroves in Salvaterra, since, just as the vegetation is unique in this region.

Keywords Mangrove · Forest fragments · Species composition · Species richness · Amazon · Phytosociology

Introduction

Mangroves are coastal ecosystems with high productivity and biological diversity (Soria-Barreto et al. 2021), anaerobic soils with low oxygen, high salinity, and high hydrogen sulfide levels, formed in transitional zones between the terrestrial and marine environment, common in regions with tropical and subtropical climates, and subject to the tidal regime (Schaeffer-Novelli et al. 2004; Schaeffer-Novelli et al. 2015). Mangroves provide a number of environmental services important to nature maintenance, including...
nutrient regulation, water supply, and coastal protection from the effects of erosion, flooding, and storms (Alongi 2002; Barbier et al. 2011; Himes-cornell et al. 2018).

The global mangrove extent gives an estimated total area of 137,600 km², and they are distributed along 11,072 km² of the Brazilian coast, which represents 8.1% of the global area (Bunting et al. 2018). A recent survey showed the expansion of the existing mapped area of mangroves in the Amazon River mouth with a potential addition of 180 km² of forests (~20%), increasing estimates in Brazil with an updated area of 11,252 km² of mangroves (Bernardino et al. 2022). Along the Brazilian coast, mangrove ecosystems extend from the extreme North in the state of Amapá to its Southern limit in Santa Catarina (Soares et al. 2012), occurring along coastal fringes periodically inundated by macrotidal regimes and under brackish to marine salinities (Bernardino et al. 2022), with the formation of mangrove forests that differ both in floristic and in structural development (Souza and Sampaio 2001; Bernardi and Rezende 2004; Sales et al. 2009; Martins et al. 2011; Londe et al. 2013).

The mangroves are ecosystems composed of typical woody species (Schaeffer-Novelli 1995), for example, some species of the genus *Avicennia*, *Laguncularia*, and *Rhizophora* (Sales et al. 2009; Cerón-Souza et al. 2014; Carvalho and Jardim 2017; Bernardino et al. 2022). However, the mangroves have low floristic diversity compared to terrestrial tropical forests (Schaeffer-Novelli et al. 2004). This is mainly due to the abiotic conditions of mangroves (Mehlig et al. 2010; Tomlinson 2016), since the patterns of spatial and temporal processes of species diversity in ecosystems are mainly conditioned by ecological and environmental processes (Whittaker and Levin 1975; Huston 1979, 1994).

Depending on the distance from the waterline and the effects of tidal inundation, different environmental conditions that act at a local scale can influence the growth (Fry et al. 2000) and structure (Joshi and Ghose 2003) of the vegetation. In special, salinity acts as a limiting factor in the distribution of mangrove species along the estuary (Costa et al. 2014). Variations in the tidal inundation gradient are factors that may reflect on the species distribution patterns, both in areas closer to the sea and those located more inland (Soares 1999; Silva et al. 2005; Bernini and Rezende 2010; Londe et al. 2013).

In the Amazon, it is possible to find diverse and complex wetland ecosystems, which are subject to variable hydrology, soil biogeochemistry and vegetation cover (Junk et al. 2011). This major hydrological distinction of Amazon can also influence the structural characteristics of mangroves, including those located at the mouth of the Amazon River, which are also under the influence of the mouth of the Tocantins River (Lima et al. 2001). These rivers discharge a large volume of sediment, carrying biological material and chemical components (e.g., whitewater and blackwater rivers), dispersed through the vast hydrological network that makes up the territory of the Marajó Island (Martins and Mendes 2011).

Broader environmental factors can also influence the structural characteristics of mangroves, including those located at the mouth of the Amazon River, which are also under the influence of the mouth of the Tocantins River (Lima et al. 2001). Furthermore, a recent study that sampled eleven mangrove forests from Amazon River mouth to the northern coast of Amapá state the suggested that over 1713 km² (15.2%) of Brazilian mangroves are directly influenced by the Amazon River plume within the Amazon Delta (Bernardino et al. 2022).

The Marajó Island is home to a mosaic of ecosystems formed by sandbanks, white-water flooded (várzea) forests, savannas, floodplains, and mangroves (Lisboa 2012). The mangroves of the Marajó Island are surrounded by a complex hydrological network of rivers, rich in fine suspended sediments with a high tidal range, added to high rainfall (França et al. 2007). In addition, the significant discharge of fresh water from the Amazon River on the Marajó Island resulted in areas with low regional salinity when compared to rivers on the southeastern coast of the state of Pará (Kjerfve et al. 2002). During the characterization of the natural and anthropic environments of the Marajó Island, Lisboa (2012) reported differences in the structure and floristic composition of three mangroves and explained them as resulting from the influence of age, form of exploitation of resources, and the mouths of rivers. The present study aimed to determine the composition and structure of the fringe and inland mangroves near the mouth of the Amazon River in Marajó Island.
Methods

Study area

The research was carried out in discontinuously distributed mangrove ecosystems over an extension of 53.23 km on the east coast of Marajó Island. The complex hydrological network that makes up the territory of Marajó Island constantly receives a large volume of sediments from the Amazon River and the Tocantins River, transporting biological material and variable chemical components (Martins and Mendes 2011). The freshwater non-tidal wetlands of the Amazon Basin also influence mangroves, mainly due to their different origins, chemistry and water color. For example, várzea (area flooded by Andean sediment-rich whitewater rivers) and igapós (area flooded by organic-rich blackwater rivers) (Bernardino et al. 2022).

Five study sites were established on the east coast of the municipality of Salvaterra, Ilha de Marajó, Pará (Fig. 1): (1) Caldeirão village, (2) São Veríssimo village/Guajará warehouse, (3) Mata do Bacurizal Ecological Reserve, (4) Jubim village, and (5) Camará village (Table 1). These sites are bordered by várzea, non-flooded (terra firme) forests, and floodplains in site 1; the Camará and Paracauari rivers, within the limits set by the PA 154 km highway and adjacent environments such as várzea and savanna ecosystems in the case of sites 2 and 4; várzea, savanna and non-flooded forests in site 3; and várzea and terra firme forests in site 5. The climate is humid equatorial with average annual temperature of 28 °C and precipitation all the year round. The months with less precipitation in the year studied were July through December (average of 654 mm) and the ones with more precipitation were January through June (average of 724 mm). This information was obtained from the database of the National Institute of Meteorology (https://portal.inmet.gov.br/).

Sampling method

For allocation of plots, we used the coastal ecosystem monitoring protocol by Schaeffer-Novelli et al. (2015), with adaptations. Thus, in each site, we analyzed the mangroves close to the influence of the Marajó Bay and the ones located more inland, considering two physiogeographic zones along a discontinuous flood profile, approximately 1 km apart from each other: the fringe zone (Fr), located 30 m from the river bank; and the inland zone (In), close to transition areas between mangrove and other ecosystems.

In each physiogeographic zone, we delimited five 400-m² plots and measured the following variables of the arboreal individuals with a minimum height of 1 m: height and CBH (circumference at breast height, 1.30 m from the ground), later transformed into diameter at breast height (DBH). Diameter values were grouped into diameter classes < 2.5 cm; ≥ 2.5 to < 10 cm; and ≥ 10 cm and height into classes according to Spiegel (1977). For individuals of the genus Rhizophora L. we measured the circumference from the last stem branching (rhizophores) supporting the trees (Schaeffer-Novelli and Cintron 1986).

Data analysis

To assess the sampling effort of the study, we used the species accumulation curve that was based on an occurrence data matrix and was generated from the iNEXT package (Hsieh and Chao 2016). We calculate the accumulation curve with 95% confidence intervals (Chao et al. 2014) and we estimate the species richness (q = 0) and Shannon diversity (q = 1).

Species richness, density, Shannon–Wiener index (Magurran 1988), and Pielou’s evenness (Pielou 1977) were measured to compare the diversity status of mangrove community in each zone, using Kruskal–Wallis test and post-hoc using the Dunn test.

Non-metric multidimensional scaling (NMDS) was applied to analyze the species composition, using the metaMDS function of the Vegan package, from a ranked distance matrix of species composition, by the Bray Curtis method (Zar 2010), and compared using a MANOVA. In recluster package, we performed a robust cluster analysis (multiscale bootstrap analysis) using the UPGMA method with the Jaccard index and a consensus tree with a 50% rule (Dapporto et al. 2013).

The variables (DBH, height, and basal area) were compared between fringe and inland zones using the Student’s t test, using the Vegan package (Oksanen et al. 2020). For the phytosociological parameters, the variables used were: Relative Frequency (RF), Relative Density (RD), Relative Dominance (RDo), Importance Value Index (IVI), and Coverage Value.
Results

Species accumulation curve

The species accumulation curve showed stabilization for both the fringe and the inland zone of the mangroves and for the diversity order q, indicating that the sampling effort used in the study was sufficient to represent the tree community in the studied mangroves (Fig. 2). The estimated species richness was 9.16 for the Fringe zone and 8.0 for the Inland Zone, while Shannon’s diversity estimate was 1.57 and 1.04, respectively (Table 2). A total of 344 individuals distributed in 10 species and seven families were registered (Table 3). Of the sampled species, seven were shared between the two zones, while L. racemosa, S. globulifera, and A. grandiflora occurred exclusively in either one of the study zones.

Floristic composition

We found three typical species of mangrove ecosystems, namely, R. racemosa, A. germinans, and L. racemosa. Among the other species, V. surinamensis, S. globulifera, and P. aquatica are predominant in other ecosystems such as black-water (igapó) flooded forest, várzea forest, and terra firme forest. In addition to the mentioned species, we observed in our excursions the occurrence of a plant community formed by Açaí (Euterpe oleracea), bamboos, lianas, aningas and bryophytes. These species were not included in the analysis of this study, but they occur in codominance with the arboreal flora of the mangroves on the east coast of Marajó Island.

Among the sampled families, Fabaceae stood out both in terms of richness (4 spp.) and abundance (175 individuals, representing 50.87% of the individuals analyzed). Each of the other families was represented by a single species and totaled 169 (49.13%) individuals. The two zones analyzed had similar richness: the fringe with nine and the inland with eight species.

In the fringe zone, 107 individuals were registered. A higher abundance was found in the inland zone: 237 individuals. However, no significant variation between zones was found in terms of richness (H = 0.011; p-value = 0.915) (Fig. 3A) and density (H = 1.843; p-value = 0.174) (Fig. 3B). In fringe zone, Shannon diversity index (H') calculated the highest species diversity in area Fr5 (H' = 1.584) and the lowest in area Fr2 (H' = 0.223). In inland zone, area In1 had the highest Shannon index (H' = 1.174) followed by area In5 (H' = 1.092). Between the areas of the inland zone, we observed the record of only one species (Rhizophora racemosa) with 28 individuals in the In3 area, resulting in a diversity index (H') equal to zero. In fringe zone, Pielou’s Evenness indicated that area Fr4 was more evenly distributed (J' = 0.932), while that the inland zone was in area In5 (J' = 0.994). We found no significant variation in Shannon index between zones (H = 0.06; p-value = 0.8065) (Fig. 3C), as well as for the Pielou’s Evenness (H = 0.06; p-value = 0.8065) (Fig. 3D).

The NMDS (Fig. 4) presented a stress value of 4.7%, which corresponds to an explained variance of 95.3%, indicating that the diagram is suitable for interpretation. No clear pattern of dissimilarity was observed based on the abundance and composition of species between fringe and inland plots, which was in agreement with the MANOVA (Pseudo F = 1.35; p-value = 0.25).

In the multiscale bootstrap analysis of the dendrogram (Fig. 5), four groups were statistically well supported, with an explanation of 85% on the dendrogram. Well supported nodes are represented by numbers in black and poorly supported nodes, in red based on the “Partitioning Around Medoids” method. The greatest similarity observed in group I (Fr2 and Fr3) may be related to the vegetation surrounding these areas: both had savanna and várzea formations. Várzea forest was also the shared environment between groups II (In5 and Fr4) and III (Fr5 and In2). Group IV (Fr1 and In1) was the one with lower similarity, sharing várzea forest, terra firme forest, and floodplain environments.
Vegetation structure

In the fringe zone, the vertical structure of most individuals was in the height class from 10.1 to 15 m (35.5%) and in the diameter class > 10 cm (32.4%). The highest individual height, diameter and basal area values in the fringe environment were recorded for the species A. germinans, followed by R. racemosa. The species A. germinans had only two individuals in the 25–28 m height class, while R. racemosa had the highest number (30%) of individuals in the 10–20 m height classes (Fig. 6).

In inland mangroves, the vertical structure of the community was characterized by the predominance of individuals in the height classes 5.1–10 m (60%) and in the intermediate class of DBH ≥ 2.5 and ≤ 10 (59%), with a reverse-J pattern. P. officinalis was the most abundant species with 149 records, accounting for more than 54% of the individuals sampled in the first height and diameter class. We did not observe significant differences in the structural parameters.
of height (t = 1.27; p-value = 0.23), CBH (t = 1.57; p-value = 0.15), DBH (t = 1.57; p-value = 0.15), and basal area (t = 1.14; p-value = 0.28) between the fringe and inland zones.

Phytosociological analysis

Regarding the phytosociological parameters, *R. racemosa* and *P. officinalis* were the species that presented higher IVI when compared to the others, corresponding to a total of 67.6% in the fringe and 78% in the inland.

On the fringe zone, *R. racemosa* stood out with a CVI of 55.70%, IVI of 46.39%, density of 51.4%, dominance of 59%, and it was present in all plots. Then, following *R. racemosa*, *P. officinalis* and *A. germinans* had similar phytosociological values, except for frequency. In addition to these species, *P. aquatica* and *S. globulifera* obtained a frequency of 11.1% each in the fringe zone and the other four species had a total frequency of 22.4%. *S. globulifera* and *A. grandiflora* were exclusive to the fringe zone.

In inland mangroves, *R. racemosa* and *P. officinalis* also presented the highest values of IVI (41.86% and 36.63%) and CVI (47.16% and 42.44%). *A. germinans* and *P. aquatica* presented IVI equal to 5.55% and 5.30%, respectively. The other species showed importance values below 5%. *Z. latifolia* and *L. racemosa* were the species with the lowest values of IVI (both 2.27%). In relation to the RD, *P. officinalis* recorded a high density of 62.8% compared to other species. *Laguncularia racemosa* was exclusive to this zone (Table 4).

**Discussion**

Floristic composition

Mangroves with a floristic composition similar to the mangroves on the east coast of Marajó Island were also recorded in the Amazon Delta. The researchers observed a unique mangrove ecosystem thriving in soils with porewater salinity from 0 to 11 PSU and soil pH varying from 4.65 to 7.25, with a species

| Family/Species             | Fringe zone | Inland zone |
|----------------------------|-------------|-------------|
|                           | I | II | III | IV | V | Total | I | II | III | IV | V | Total |
| Acanthaceae               |   |   |     |    |   | 15 | 15 | 4  | 4  |    |       |
| Avicennia germinans (L.) L. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Combretaceae              |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Laguncularia racemosa (L.) C.F.Gaertn. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Clusiaceae                |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Symphonia globulifera L.f. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Fabaceae                  |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Alexa grandiflora Ducke.  |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Pterocarpus officinalis Jacq. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Macrolobium bifolium (Aubl.) Pers. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Zygia latifolia (L.) Fawc. & Rendle |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Rhizophoraceae            |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Rhizophora racemosa G. Mey. |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Malvaceae                 |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Pachira aquatica Aubl.   |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Myristicaceae             |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Virola surinamensis (Rol. ex Rottb.) Warb |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Richness                  |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
| Abundance                 |   |   |     |    |   | 1  | 1  | 1  |   |    |       |
composition typical of mangrove (Rhizophora and Avicennia) and co-dominance with woody species typical of freshwater wetlands such as Mauritia flexuosa, Euterpe oleracea, Pterocarpus sp., Guadua glomerata, Rhabdadenia biflora, Montrichardia sp. and etc. (Bernardino et al. 2022). Amazon delta mangrove soils have oligohaline and acidic soils, unlike Brazilian mangroves which have saline soils with
porewater salinity > 15 PSU and higher pH (> 6) (Ferreira et al. 2022). Bernardino et al. (2022) observed that porewater salinities only increased to values 5–10 in the farthest sites 100 km to the north, suggesting that these mangrove ecosystems are thriving under the direct influence of the Amazon River plume, a large freshwater volume transported along the coast in a Northwest direction.

The predominance of Fabaceae in the study area is mainly due to its dominance in different phytogeographic units of the Amazon (Ferreira and Prance 1998; Oliveira 2000; Funk et al. 2007). In an analysis of several surveys on the geographic distribution of Fabaceae on the Marajó Island, Silva et al. (2013) showed that due to its phytophysiognomic heterogeneity, the island has about 30% of the species of this family reported for the state of Pará.

The record of species from várzea forests in the studied mangroves, such as *V. surinamensis*, *S. globulifera*, *P. aquatica*, and *A. grandiflora* can be due to the inflow of fresh and brackish water from the Pará River and low salinity, conditions in which the establishment of propagules of species from other ecosystems is observed (Almeida 1996). According to Muehe (1998), the large volume of fresh water in the Amazon River discharges a low salinity surface plume into the mouth that can reach large distances.

Among the species recorded in this study, *P. aquatica* has mechanisms that allow it to grow in sites with fluctuating salinity, rainfall, tides, and other environmental conditions. Some of these mechanisms are the form of germination by viviparity (Cardoso 2004), the development of radicles while dispersed by water (Mata and Moreno-casasola 2005), and tolerance to a wide range of salinity, up to 25% of seawater (Infante-mata and Moreno-casasola 2014), similar to typical mangrove species.

Colonization strategies are crucial factors for the survival of these individuals, where the ability to float is one of the fundamental mechanisms for dispersal, since it is through water that the seed can reach greater distances (Wittmann et al. 2007). Thus, species such as *M. bifolium*, which has hydrochoric dispersion, can be found in mangroves due to constant tidal movements that promote the transport of seeds to other ecosystems.

The plots with the greatest diversity and similarity were those located in Caldeirão village (Fr-I and In-I), which is influenced by the waters of the Paracauari River. Through its currents, this river may be carrying propagules from one environment to another and, according to Oliveira and Tognella (2014), mangroves usually have a plant community with a specific composition and physiological uniformity. Another aspect is the presence of terra firme forests close to these plots.

The Paracauari River is part of the vast drainage network of the eastern portion of the Marajó Island.
and has remarkable characteristics, with drainage patterns including localized and long meanders and the presence of continuous and branched lakes (Souza and Rossetti 2011). These characteristics provide a connection between the ecosystems of the Marajó Island, that is, the transport of materials through the hydrological system allows the linking between various environments.

A study on Marajó Island showed that the physicochemical composition of the Paracauari River is directly influenced by seasonal periods, with average water temperature values between 28 and 58 °C, pH from acid (5.80) to alkaline (7.86) and salinity between 0.06 and 7.56 (Monteiro et al. 2015). The authors reported that the salinity variation was mainly due to the action of continental waters, less saline, during the rainy and intermediate season, and the

![Fig. 6 Distribution of the number of individuals in height (m) and diameter (cm) classes sampled in fringe and inland environments: a Height classes in the fringe and inland zones, and b Diameter classes in the fringe and inland zones.](image)

![Table 4 Physiologic parameters of the species sampled in the mangroves of Salvaterra, in Marajó Island, Pará, Brazil](table)

| Species                  | Fringe zone | Inland zone | RF | RD | RDo | IVI | CVI |
|--------------------------|-------------|-------------|----|----|-----|-----|-----|
| Rhizophora racemosa      | 55          | 107         | 23.78 | 51.4 | 46.39 | 55.70 | 66 | 31.25 |
| Pterocarpus officinalis  | 14          | 149         | 22.22 | 13.08 | 10.44 | 15.25 | 4  | 6.25 |
| Avicennia germinans      | 15          | 4          | 5.56  | 14.02 | 16.64 | 12.07 | 15.33 | 4  | 6.25 |
| Pachira aquatica         | 10          | 6          | 11.11 | 9.35  | 7.82  | 9.43  | 8.59 | 6  | 12.5 |
| Symphonia globulifera    | 2           | 4          | 11.11 | 1.87  | 0.81  | 4.60  | 1.34 | 1  | 6.25 |
| Virola surinamensis      | 6           | 4          | 5.56  | 5.61  | 4.33  | 3.86  | 1  | 6.25 |
| Macrolobium bifolium     | 2           | 3          | 5.56  | 1.87  | 0.60  | 2.67  | 1.24 | 3  | 6.25 |
| Zygia latifolia          | 1           | 4          | 5.56  | 1.87  | 0.60  | 2.67  | 1.24 | 3  | 6.25 |
| Laguncularia racemosa    | 1           | 4          | 5.56  | 1.87  | 0.60  | 2.67  | 1.24 | 3  | 6.25 |
| Total                    | 107         | 237         | 107 |

N number of individuals; RF relative frequency (%); RD relative density (%); RDo relative dominance; IVI importance value index; CVI coverage value index.
coastal waters of Marajó Bay, more saline, in the dry season.

The predominance of *R. racemosa* in the estuaries of Marajó Island is due to the low salinity of this environment, since this is a typical species of mangrove, adapted to grow at low levels of salinity. According to Almeida (1996), low salinity occurs due to the supply of fresh water from rivers that are part of the hydrological system of Marajó Island, in addition to the flow from the Pará River. In this sense, the author reinforces this analysis when he registered a high occurrence of this species in the municipalities of Marituba and Mosqueiro Island, both in the state of Pará.

Vegetation structure

The presence of individuals of *A. germinans* and *R. racemosa* with greatest height and diameter values in the fringe zone shows that these forests can be mature, that is, more developed in structural terms than the more inland forests. In a study of the mangroves of Marapanim, state of Pará, Sales et al. (2009) recorded *A. germinans* occurring with lower abundance but high structural values, indicating that these individuals had settled for a long time in the analyzed site. In the Legal Amazon, mangroves found in mesohaline and polyhaline environments under salinities of 17–23 PSU (practical salinity units) are largely dominated by three well-developed tree species between 17 and 28 m in height, that area *R. manglar*, *A. germinans* and *L. racemosa* (Kauffman et al. 2018).

In inland mangroves, individuals were concentrated in the DBH class of 2.5–10 cm, with individuals presenting low height and small diameters. This result was also found by Seixas et al. (2006), where 50% of the individuals had DBH belonging to the 3.9–9 cm class, which the authors assume to be evidence of a high regeneration of these woods and/or low degree of conservation.

Although the structure of the fringe and inland zones did not vary statistically, it was possible to observe anthropic interventions in the inland forests of Salvaterra, especially in the mangroves located in Jubim village. In these mangroves, we observed the exclusive occurrence of *L. racemosa*, with record only in areas with clearings and degraded areas, being pointed out by Soares (1999) as an indicator species of anthropic interference. In these areas, we observed the presence of solid waste, felled trees, and deteriorated soil, possibly due to proximity to the urban center. In addition, this mangrove area had a significant loss of habitat with the construction of the 154 km PA highway that cuts through this ecosystem. Thus, all these anthropic processes have caused changes in the landscape of this mangrove.

Phytosociological analysis

*Rhizophora racemosa* was the species with the highest relative frequency, relative density, and relative dominance in both studied zones. In the mangroves of the Soure Marine Extractive Reserve (Resex), located on the east coast of Marajó Island, Carvalho and Jardim (2017) observed that *R. Racemosa* stood out with the highest relative density (59.09%), relative dominance (77.59%), coverage (68.34%), and importance (59.85%) values. Both the mangroves studied here and the mangroves in the municipality of Soure are bathed by a hydrological network of rivers that makes these ecosystems less saline and creates environmental conditions within the niche of *R. racemosa*. According to Cerón-Souza et al. (2014), *R. racemosa* usually occurs in areas with significant fresh water inflow. In the mangroves of Marituba and Mosqueiro Island, both in the state of Pará, Almeida (1996) recorded a high density of *R. racemosa* and suggested the existence of the influence of an environmental gradient in the mangroves promoted by the discharge of fresh water from the Amazon River, which can make the environment more susceptible to the colonization of this species.

In the fringe zone, it was observed that *A. germinans* presented high density and dominance, but low frequency, always occurring together with other species in lower density. *A. germinans* is a species that tolerates environmental conditions with high salinity, low content of organic matter, and anthropogenic changes. It also has a low frequency in mangroves with high fresh water input (Tomlinson 2016), as is the case of the mangroves of Salvaterra.

*Paeonia officinalis* is a common species of várzea forests, an environment with low salt content in the water. Thus, the predominance of *P. officinalis* in the mangroves studied may be related to the discharge of fresh water from the Pará and Amazonas rivers, which reduces the concentration of salt in the mangroves,
allowing the colonization of species from várzea forests and other environments. The co-occurrence of *P. officinalis* with other species has also been recorded in the mangroves of the municipality of Marituba and Mosqueiro Island (Almeida 1996), and in the central Pacific coast of Colombia (Riascos et al. 2018).

**Conclusion**

The results of this study suggest that the vegetation of the mangroves on the east coast of the Marajó Island is strongly influenced by a fluvial-marine system of the great rivers of the Amazon associated with a diversity of ecosystems that, together, generate a greater floristic richness when compared to mangroves in other regions. Our research is reinforced by the most recent study carried out in the Amazon Delta, which is relatively close to Marajó Island. This study showed that the mangroves in this region have soils with low salinity due to the large volume of water from the plume of the Amazon River. Thus, it is possible to observe arboreal species that present a versatile behavior before environmental conditions, with high abundance in várzea and igapó forests as well as in mangroves. In our research, it was possible to verify that the Salvaterra mangroves have species that occur in freshwater wetlands, such as *P. officinalis*, *P. aquatica* and *V. surinamensis*.

The fringe and inland zones were very similar in composition and structure. We believed that this was so because the Marajó Island has a flat relief to the east of the Island, and because of the influence of rivers and adjacent ecosystems. Furthermore, it was possible to observe areas under the influence of human activities that can modify the vegetation structure, especially in the inland zone. These characteristics are important for conservation policies and specific management plans for the mangroves in Salvaterra, since, just as the vegetation is unique in this region, the way in which resources are used is also most likely different from other regions of Brazil.

**Funding** This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

**Data availability** Occurrence records of plant species used for floristic composition and community structure analysis are available at: https://doi.org/10.6084/m9.figshare.17125592

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