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

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Abstract

Mangroves in the Amazon are influenced by several environmental conditions that determine the composition and structural development of the arboreal flora, which results in different distribution patterns. In this study, we sought to answer two questions: (1) what is the composition and structure of the mangroves near the mouth of the Amazon River in Marajó Island? (2) Are the fringe and inland mangroves more similar or dissimilar in terms of floristic composition? For this, we delimited a fringe zone and an inland zone about 1 km apart from each other. In each zone, we distributed five 400-m^2 plots. The individuals were grouped into diameter and height classes and structural and phytosociological parameters were calculated. Ten species were recorded in the mangroves, of which seven are typical of white-water (várzea) and black-water (igapó) flooded forest ecosystems. We believed the adjacent ecosystems and the hydrological network are inducing the establishment of such species. The composition and structure of mangroves did not differ statistically between zones, and the degree of similarity may be a result of similar environmental factors in these zones such as low relief and high frequency of macrotides. We conclude that the vegetation of the studied mangroves has a major influence of the fluvial-marine system of the great rivers of the Amazon associated with a diversity of ecosystems that, together, generate greater floristic richness when compared to mangroves in other regions.

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).

Mangroves cover about 170,600 km^2 of tropical and subtropical coasts around the world (Lacerda 2002), and they are distributed along approximately 14,000 km^2 of the Brazilian coast. According to the National Environmental Monitoring and Information Center (Cenima/IBAMA), around 80% of mangroves in the Brazilian territory are concentrated in the Amazon biome (https://www.gov.br/ibama/pt-br/composicao/quem -and-who/centers/cenima#cenima), which is the Brazilian terrestrial biome with the greatest coverage of protected areas (MMA 2019). Thus, Brazil became the country with the largest continuous portion of mangroves under legal protection in the world, with 12,114 km^2 (87%) of mangroves found within a total of 120 conservation units, with 1,998 km^2 distributed in areas of strict protection (17%) and 10,115 km^2 in areas of sustainable use (83%). This situation, in theory, increases the effective conservation of this ecosystem, reinforcing its legal status as a permanent preservation area (Brazil 2012).

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) with the formation of mangrove forests that differ both in floristic and in structural development (Souza and Sampaio 2001; Bernini and Rezende 2004; Sales et al. 2009; Martins et al. 2011; Londe et al. 2013). These ecosystems are composed of typical woody species (Schaeffer-Novelli 1995) and 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 especial, salinity acts as a limiting factor in the distribution of mangrove species along the estuary (Costa 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).

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). These rivers discharge a large volume of sediment, carrying biological material and chemical components, dispersed through the vast hydrological network that makes up the territory of the Marajó Island (Martins and Mendes 2011).

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). 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.

In this study, we sought to answer two questions: (1) what is the composition and structure of the mangroves near the mouth of the Amazon River in Marajó Island? (2) Are the fringe and inland mangroves more similar or dissimilar in terms of floristic composition?

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 the municipality of Salvaterra, Marajó Island, state of Pará. Five study sites were established: (1) Vila de Jubim (00°47’54” S and 48°32’06” W); (2) Vila de São Veríssimo/Porto do Guajará (00°43’33” S and 48°32’09” W); (3) Mata do Bacurizal Ecological Reserve (00°46’40” S and 48°31’11” W); (4) Vila do Caldeirão (00°42’20” S and 48°33’12” W); and (5) Vila de Camará (00°56’30” S; 48°35’25” W). These sites are bordered by 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 1 and 2; várzea, savanna and non-flooded forests in site 3; várzea, non-flooded (terra firme) forests, and floodplains in site 4; 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-m^2 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 Cítron 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 et al. 2016). To assess species diversity, the Shannon (H’) Magurran (1988) and Pielou's evenness (J’) indices were calculated (Pielou 1977).

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 addition to the NMDS, we performed a robust cluster analysis using the UPGMA method with the Jaccard index from the *recluster.dist* function in the *recluster* package. We used the *recluster.cons* function to create a consensus tree with a 50% rule; we designed the *recluster.multi* function to perform multiscale bootstrap analysis (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 Index (CVI) (Brower et al. 1997). All analyses were performed using R 4.1.0 software (R Core Team 2021).

Results

Species accumulation curve

The species accumulation curve showed stabilization for both the fringe and the inland zone of the mangroves. Of the sampled species, seven were shared between the two zones, while *Laguncularia racemosa* C. F. Gaertn., *Symphonia globulifera* L. f., and *Alexa grandiflora* Ducke. occurred exclusively in either one of the study zones (Fig. 1).

Floristic composition

A total of 344 individuals distributed in 10 species and seven families were registered. We found three typical species of mangrove ecosystems, namely, *Rhizophora racemosa* G. Mey., *Avicennia germinans* (L.) L., and *L. racemosa*. Among the other species, *Virola surinamensis* (Rol. ex Rottb.) Warb, *S. globulifera*, and *Pachira aquatica* Aubl. are predominant in other ecosystems such as black-water (igapó) flooded forest, várzea forest, and terra firme forest (Table 1). The H’ and J’ indices for the fringe zone were 1.57 and of 0.97, respectively, and for the inland zone, 1.43 and 0.89, respectively.

Among the sampled families, Fabaceae stood out both in terms of richness (four spp.) and abundance (177 individuals, representing 52% of the individuals analyzed). Each of the other families was represented by a single species and totaled 167 (48%) 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 ($t = 0.33$; $p = 0.74$) or abundance ($t = 1.49$; $p = 0.7$).

The NMDS (Fig. 2) 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 $F = 1.35$; $p = 0.25$).

In the multiscale bootstrap analysis of the dendrogram (Fig. 3), 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 Fr1) and III (Fr5 and In2). Group IV (Fr4 and In4) 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 to 15 meters (35.5%) and in the diameter class ≥ 2.5 and ≤ 10 cm (40%). 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 to 28 m height class, while *R. racemosa* had the highest number (30%) of individuals in the 10 to 20 m height classes (Fig. 4).

Inside the mangroves, the vertical structure of the community was characterized by the predominance of individuals in the height classes 5.1 to 10 m (60%) and in the intermediate class of DBH ≥ 2.5 and ≤ 10 (59%), with a reverse-J pattern. *Pterocarpus officinalis* Jacq. was the most abundant species with 130 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 ($t = 1.27$; $p = 0.23$), CBH ($t = 1.57$; $p = 0.15$), DBH ($t = 1.57$; $p = 0.15$), and basal area ($t = 1.14$; $p = 0.28$) 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%. *Symphonia 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 and CVI, corresponding to 78% and 89%, respectively. *P. officinalis* recorded a high density of 62% compared to other species. The other species showed importance values below 5%. *Laguncularia racemosa* was exclusive to this zone (Table 2).

Discussion

Species accumulation curve

The stabilization of the accumulation curve indicates that the sampling effort used in the study was sufficient to represent the tree community in the studied mangroves. The abiotic conditions of the mangroves may have also contributed to the stabilization of the accumulation curves, since few species are able to grow in these ecosystems, and mangroves usually have a plant community with a specific composition and physiological uniformity (Oliveira and Tognella 2014) .

Floristic composition

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. aquatic*, 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 et al. 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 *Macrolobium bifolium* (Aubl.) Pers., 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 Vila de Caldeirão (F4 and I4), which is influenced by the waters of the Paracauari River. Through its currents, this river may be carrying propagules from one environment to another. 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.

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.

Species diversity values in the studied mangroves varied around 1.43 in the inland zone and 1.57 in the fringe zone. Although this type of index is not normally used in mangroves, studies conducted in tropical forests revealed that values can reach 3.83 to 5.85 due to the high diversity of species (Knight 1975). The Pielou (J) evenness value of 0.97 in the fringe and 0.89 in the inland zone indicates that more than 80% of the maximum theoretical diversity was captured through the sampling performed.

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 interior of the mangroves, individuals were concentrated in the DBH class of 2.5 to 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 to 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 those located in Vila de Jubim. In these areas, we observed the presence of solid waste, felled trees, and deteriorated soil, possibly due to proximity to the urban center, as the PA 154 km highway is causing changes in the mangrove landscape.

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 (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. *Avicennia 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.

Pterocarpus 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

This study demonstrated 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. In these sites, 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 of the Marajó Island, such as *P. officinalis*, *P. aquatic*, and *V. surinamensis*. In this research, it was possible to verify that the mangroves of Salvaterra have species that occur in other ecosystems in the proximities.

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 also 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.

Declarations

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Tables

Table 1 Floristic composition and respective abundances of mangrove species in the fringe and inland zones in the municipality of Salvaterra, Marajó Island, Pará, Brazil.

Family/Species	Fringe	Inland
Acanthaceae		
Avicennia germinans (L.) L.	15	4
Combretaceae		
Laguncularia racemosa (L.) C.F.Gaertn.	0	4
Clusiaceae		
Symphonia globulifera L.f.	2	0
Fabaceae		
Alexa grandiflora Ducke.	2	0
Pterocarpus officinalis Jacq.	14	149
Macrolobium bifolium (Aubl.) Pers.	2	3
Zygia latifolia (L.) Fawc. & Rendle	1	4
Rhizophoraceae		
Rhizophora racemosa G. Mey.	55	66
Malvaceae		
Pachira aquatica Aubl.	10	6
Myristicaceae		
Virola surinamensis (Rol. ex Rottb.) Warb	6	1
Total	107	237

Table 2 Phytosociological parameters of the species sampled in the mangroves of Salvaterra, in Marajó Island, Pará, Brazil. N: number of individuals; RF: Relative Frequency (%); RD: Relative Density (%); RDo: Relative Dominance; IVI: Importance value index; CVI: Coverage value index.

Species	Fringe						Inland					
	N	RF	RD	RDo	IVI	CVI	N	RF	RD	RDo	IVI	CVI
Rhizophora racemosa G.Mey.	55	27.78	51.4	59.99	46.39	55.70	66	31.25	27.85	66.47	41.86	47.16
Pterocarpus officinalis Jacq.	14	22.22	13.08	10.44	15.25	11.76	149	25	62.87	22.01	36.63	42.44
Avicennia germinans (L.) L.	15	5.56	14.02	16.64	12.07	15.33	4	6.25	1.69	8.72	5.55	5.21
Pachira aquatica Aubl.	10	11.11	9.35	7.82	9.43	8.59	6	12.5	2.53	0.87	5.30	1.70
Symphonia globulifera L.f.	2	11.11	1.87	0.81	4.60	1.34						
Virola surinamensis (Rol. ex Rottb.) Warb	6	5.56	5.61	2.11	4.43	3.86	1	6.25	0.42	0.20	2.29	0.31
Macrolobium bifolium (Aubl.) Pers.	2	5.56	1.87	1.36	2.93	1.62	3	6.25	1.27	1.11	2.87	1.19
Alexa grandiflora Ducke.	2	5.56	1.87	0.60	2.67	1.24						
Zygia latifolia (L.) Fawc. & Rendle	1	5.56	0.93	0.22	2.24	0.58	4	6.25	1.69	0.30	2.27	1
Laguncularia racemosa (L.) C.F.Gaertn							4	6.25	1.69	0.32	2.27	1.01
Total	107						237					

Figures

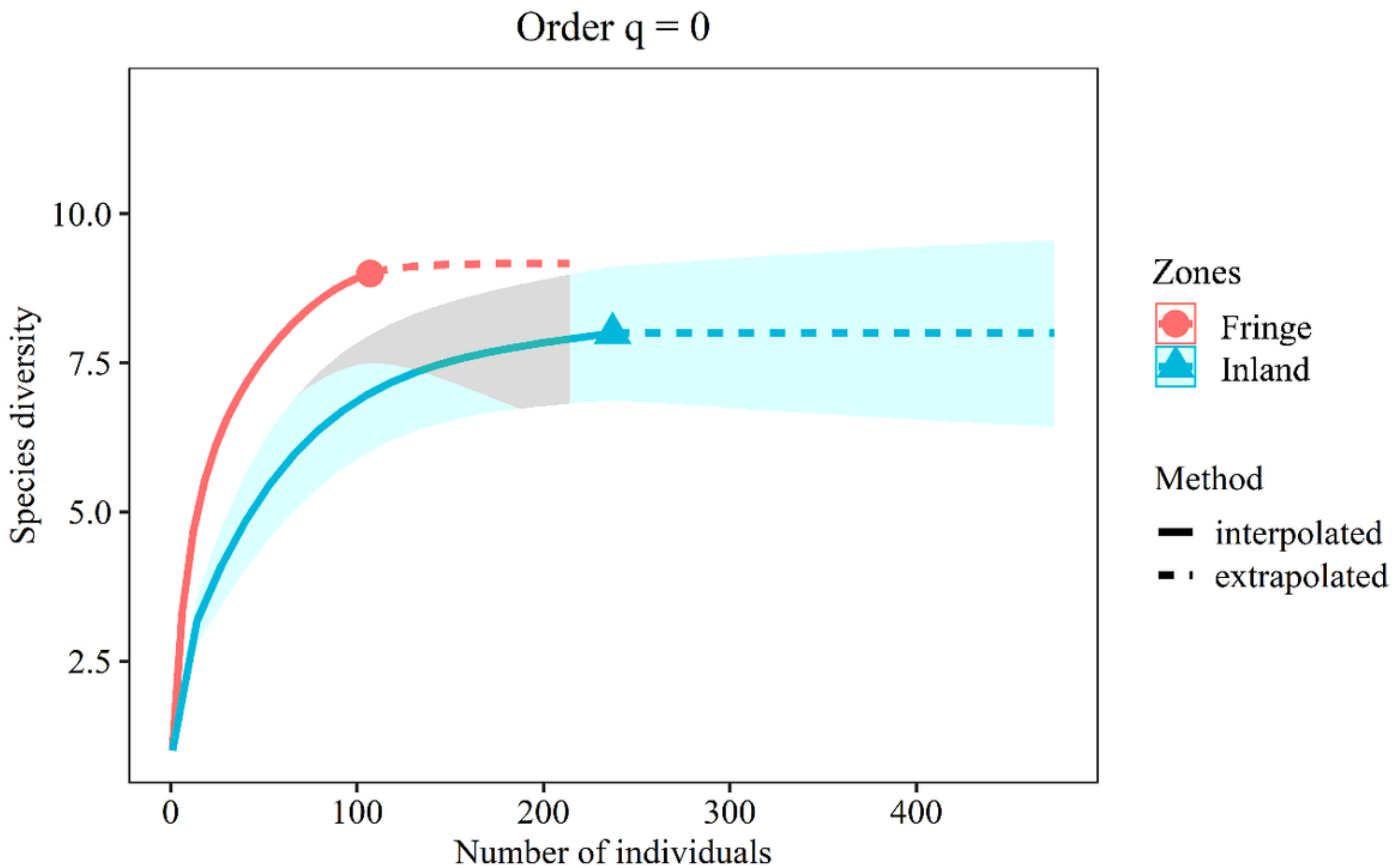

Figure 1

Accumulation curve based on the abundance of individuals in the fringe and inland zones of the mangroves of Salvaterra, Pará, Brazil.

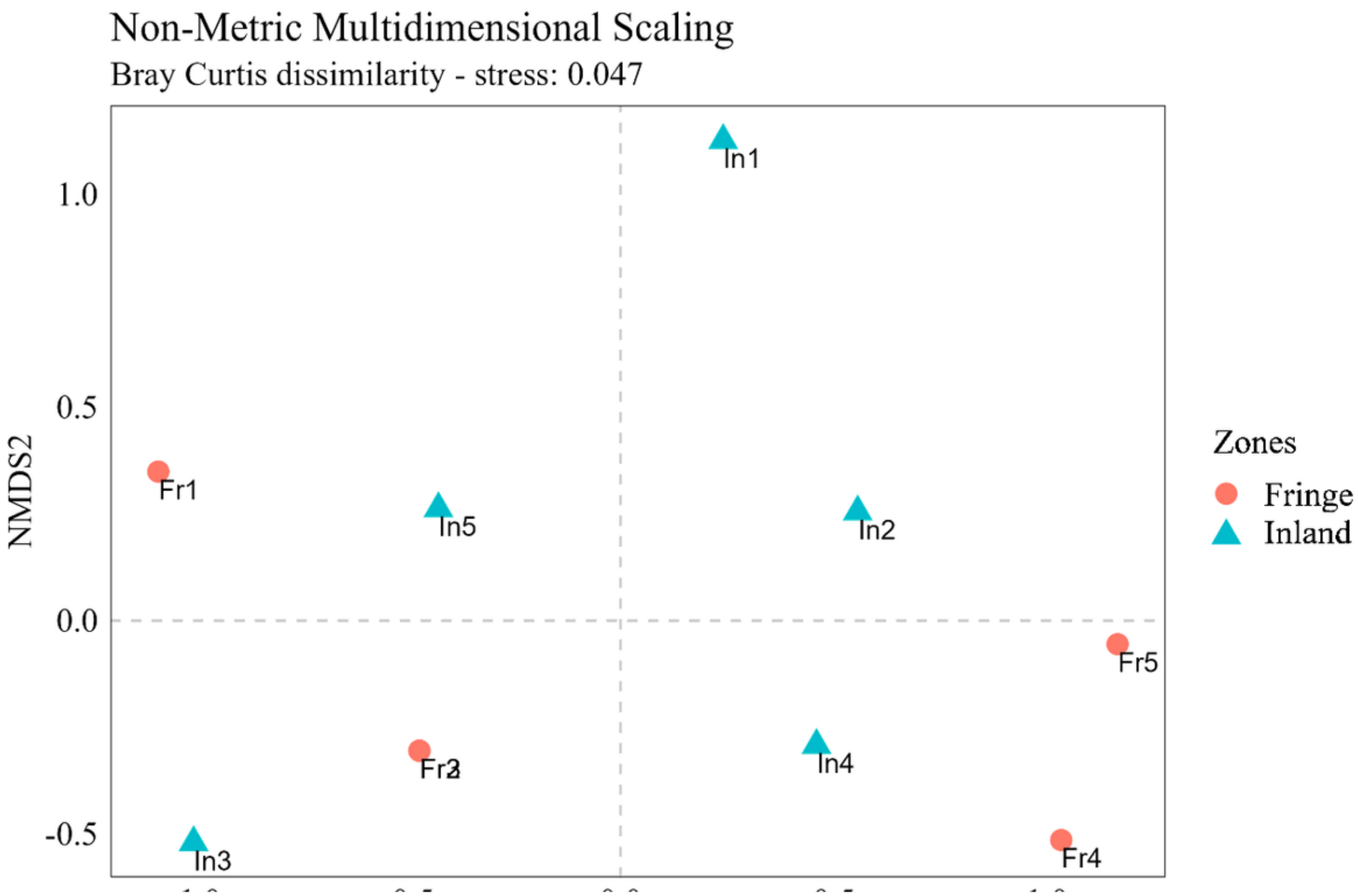

Figure 2

Non-metric multidimensional scaling (NMDS) of the Mangroves of Marajó Island, Pará, Brazil.

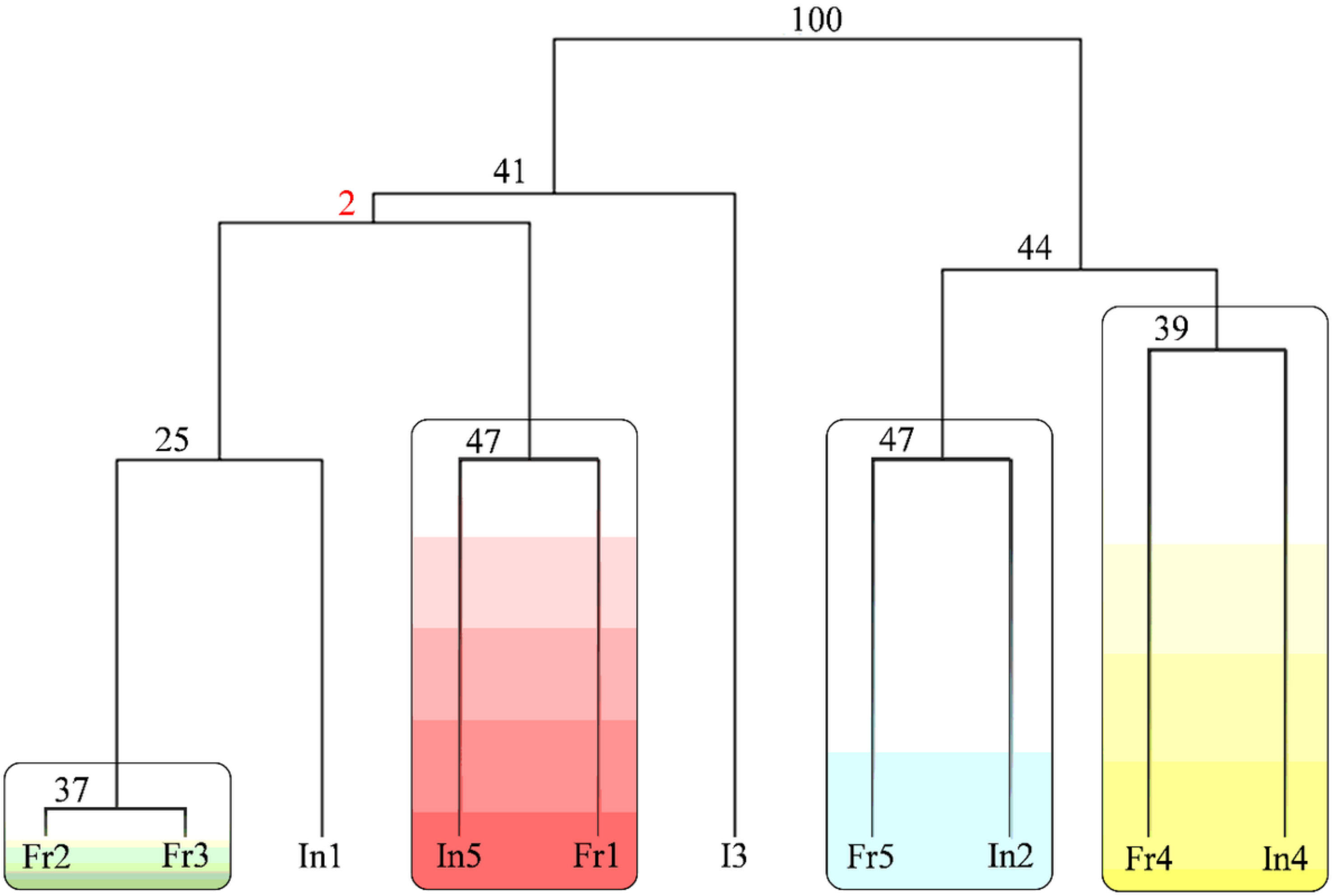

Figure 3

Bootstrap cluster analysis of the Mangroves of Marajó Island, Pará, Brazil.

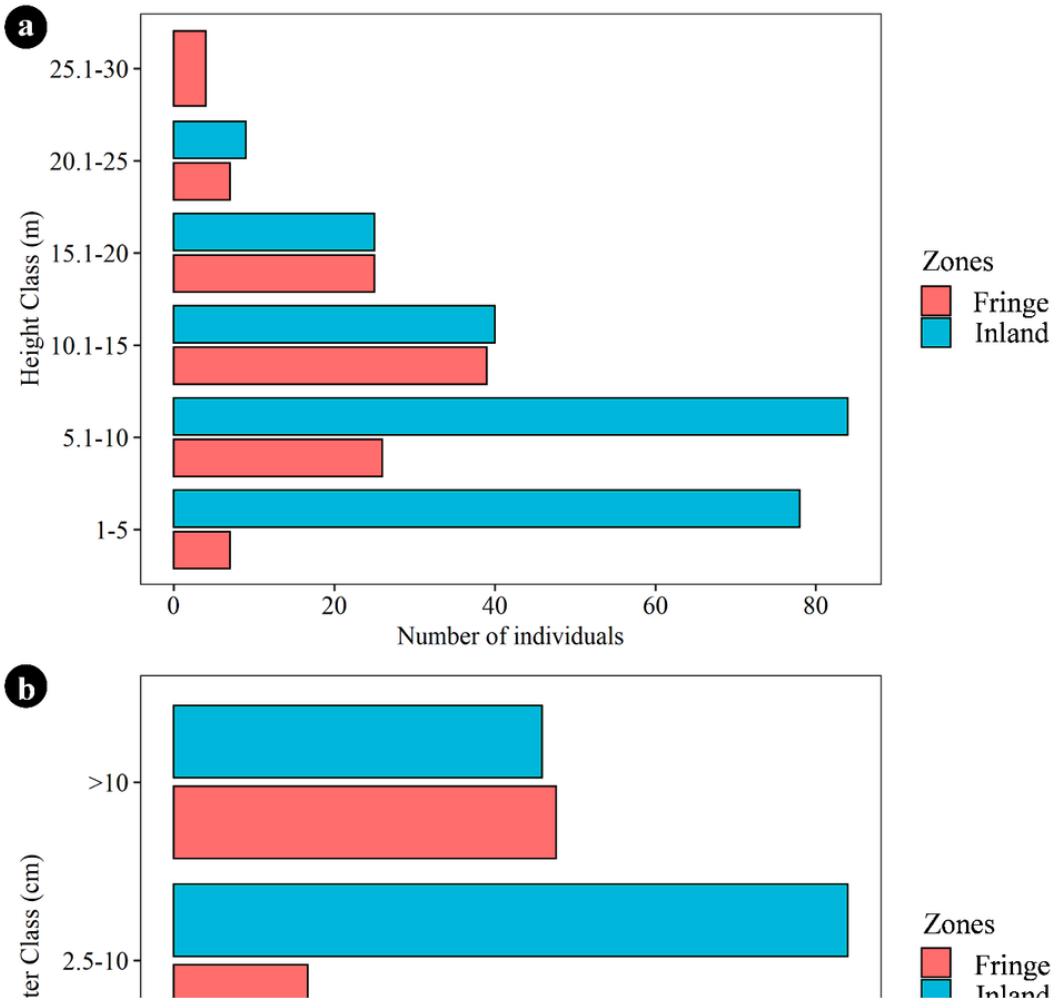

Figure 4

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; b) Diameter classes in the fringe and inland zones.