# Vegetation structure in a mangrove forest in Southeastern Brazil

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**Abstract:** The vegetation structure and spatial distribution pattern of mangrove species was analyzed in 17 study sites using plots in the estuary of the Paraíba do Sul river, located in southeastern Brazil. Only considering individuals $\geq$ 1 m tall, the average height varied from 5.2 to 14.5 m, the average diameter at breast height varied from 2.6 to 23.5 cm, the basal area varied from 15.1 to 46.4 $m^2.ha^{-1}$ and density varying from 732 to 24,060 trunks.$ha^{-1}$. There was a greater contribution of basal area in the diameter class $\geq$10.0 cm (68%), indicating good structural development of forests. *Avicennia germinans* (L.) Stearn. was the dominant species in basal area (53%), followed by *Laguncularia racemosa* (L.) Gaertn.f. (28%) and *Rhizophora mangle* L. (19%). These species were dominant both at the edge and inside the forest and zonation was not observed. The vegetation structure data indicated that interspecific competition may be influencing the spatial distribution of these mangrove species in the studied area.

**Key words**: estuary, Paraíba do Sul river, phytosociology

**Resumo: Estrutura da vegetação em uma floresta de mangue no Sudeste do Brasil.** A estrutura da vegetação e o padrão de distribuição das espécies de mangue foram analisados em 17 sítios de estudo no manguezal do estuário do rio Paraíba do Sul, localizado no Sudeste do Brasil, pelo método de parcelas. Considerando indivíduos $\geq$ 1 m de altura, a altura média variou de 5,2 a 14,5 m, o diâmetro à altura do peito médio de 2,6 a 23,5 cm, a área basal de 15,1 to 46,4 $m^2.ha^{-1}$ e a densidade de 732 to 24.060 troncos.$ha^{-1}$. Houve maior contribuição em área basal na classe de diâmetro > 10,0 cm (68%), indicando o bom desenvolvimento estrutural da floresta. *Avicennia germinans* (L.) Stearn. foi dominante em area basal (53%), seguida por *Laguncularia racemosa* (L.) Gaertn.f. (28%) e *Rhizophora mangle* L. (19%). Estas espécies foram dominantes tanto na borda quando no interior da floresta, não havendo zonação. Os dados indicaram que a competição interespecífica pode estar influenciando a distribuição espacial das espécies de mangue na área estudada.

**Palavras chave**: estuário, rio Paraíba do Sul, fitossociologia

## Introduction

The mangrove is a coastal ecosystem, subject to the tidal regime that contributes significantly with a large input of organic matter to the maintenance of biodiversity and productivity in adjacent coastal waters (Jennerjahn & Ittekkot 2002, Dittmar *et al.* 2006, Rezende *et al.* 2007). The trophic relationships between the mangrove and marine ecosystems can be characterized by the biomass and productivity of mangroves, and these figures are closely related to the structure of mangrove forests (Fromard *et al.* 1998).

On a regional scale, geomorphology is a major factor that explains the different patterns of structural development of mangrove forests (Twilley & Day 1999). Based on geomorphological characteristics, Thom (1984) classified the different environments where mangroves are established in five major categories: 1) river-dominated, 2) tide-dominated, 3) composite - river and wave dominated, 4) wave-dominated barrier lagoon, and 5) drowned bedrock valley. In each type of environment, the architecture of mangrove forests is influenced by different environmental factors that

act on the different scales of time and space and with different intensities and frequency. The environmental forces correspond to the energy subsidiaries (solar energy, rainfall, wind, air temperature, input of fresh water, nutrients, tides and waves), being referred to as "energy signature" (Odum 1967). Twilley and Rivera-Monroy (2005) developed a conceptual model that integrates the different hierarchical levels of regional environmental factors and local biotic interactions, considering that regulatory factors (e.g. salinity), resources (e.g. light) and hydroperiod (e.g. frequency flood and river water supply) would control the structure and function of mangrove forests.

In mangrove ecology, the formation of recognizable bands of vegetation along environmental gradients, known as zonation, that has been one of the most discussed in literature (Davis 1940, Lugo & Snedaker 1974, Smith 1992, Duke *et al*. 1998, Ellison *et al*. 1999). The sequence of occurrence of species typical of mangroves varies among different locations, but in many forests, zonation is not evident. The mechanisms that govern the spatial distribution of the mangrove forests have caused controversy in the scientific community (Snedaker 1982, Smith 1992). The hypotheses proposed to explain the zonation include: (1) succession of plants due to accumulation of sediments, (2) response to geomorphological factors, (3) physiological adaptation along a flooding gradient (4) differential dispersal of seeds, (5) differential predation of seeds, and (6) interspecific competition (Smith 1992). In fact, the varied spatial distribution among the mangroves can be attributed to the different responses of each species to intrinsic biotic and extrinsic abiotic factors that interact and vary widely from one location to another. As species and ecological conditions differ between forests, the expectation is that the factors influencing the spatial distribution of plants also change (Jiménez & Sauter 1991).

In Brazil, where mangroves cover about 1.4 million hectares (Spalding *et al*. 1997), descriptive studies on vegetation structure are numerous, but few studies report data on forests subjected to a strong river influence (Abreu *et al*. 2006, Berger *et al*. 2006). The mangrove estuary of the Paraíba do Sul river, located in southeast Brazil, is one of the largest in the state of Rio de Janeiro and can be considered as a river dominated environment according to Thom's classification (1984).

The objective of this study is to characterize the forest structure and determine the spatial distribution pattern of mangrove plants in the estuary of the Paraíba do Sul river in order to generate information on the structural characteristics of forests subjected to a strong river influenced system.

## Material and Methods
*Study Area*

The Paraíba do Sul river estuary (RPS) is located on the coast of Rio de Janeiro, southeastern Brazil (Fig. 1) has a river mouth denominated as the Main Estuary in São João da Barra, and another one, denominated as the Secondary Estuary in the municipality of São Francisco de Itabapoana. 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 2005 and 2006, the average tide was 0.8 m, with a minimum of 0.2 and maximum of 1.2 m (DHN 2006). Considering the years of 2005 and 2006, the average air temperature was 22.6°C, with higher temperatures from January to March (27.3 to 29.3). The total average rainfall was 1,129 mm (source: Evapotranspirometer Station of the Center for Agricultural Science and Technology in the Northern Fluminense State University, PESAGRO-RIO). From 1995 to 2006, the river flow in the region covering the estuary had an average ranging from 438 to 968 $m^3.s^{-1}$ (Source: Environmental Sciences Laboratory, Northern Fluminense State University).

The estuary has a plain formed by a succession of elongated sandy bars, interspersed with terrazzo covered with superficial clay, where the mangrove ecosystem is developed (Costa 1994). The mangrove estuary of the RPS is an area of 725 ha and is considered the largest in the North of Rio de Janeiro State (Bernini *et al*. 2010). 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 are *Acrostichum aureum* L. (Pteridaceae) and *Hibiscus pernambucensis* Arruda (Malvaceae) were also recorded (Bernini and Rezende 2004). This mangrove forest has been the target of frequent actions of degradation, such as deforestation, conversion for cattle farms, urbanization, dredging, erosion and siltation. According to Bernini *et al*. (2010) this mangrove forest lost 20% of its coverage area between 1986 and 2001 (Fig. 2).

*Vegetation structure*

The study was conducted between the years of 2005 and 2006. The characterization of vegetation structure was done using plots, according to the methodology proposed by Schaeffer-Novelli and Cintron (1986). We selected 17 study sites, one located in the Main Estuary and others in the Secondary Estuary which is the largest mangrove area (Figs. 1 and 2). The definition of the sites was

based on supervised classification performed by Bernini *et al.* (2010) and field observations, in order to depict the general appearance of the mangrove forest. At each site, plots were established along a transect perpendicular to the flooding. The number of plots in each transect varied depending on the width of the mangrove forest. A constant interval of 30 m was maintained between plots. The area of each plot ranged between 25 and 870 m$^2$ and was determined according to tree density (including at least 20 live trees within each plot) (Schaeffer-Novelli & Cintron 1986). A total of 50 plots were

demarcated, corresponding of 1.53 ha.

In each plot, we measured DBH (diameter at breast height, 1.3 m above substrate) and the height of all living individuals taller than 1 m. To measure the DBH a measuring tape graduated in units of π (3.14159) was used. When individuals were less than 1.3 m in height, the DBH was substituted by the diameter of the trunk below the first branch (Soares 1999). The diameters of trunks and dead trees still standing were also included in the sample. The height measurements of the living trees were obtained with a rangefinder or graduated rod.
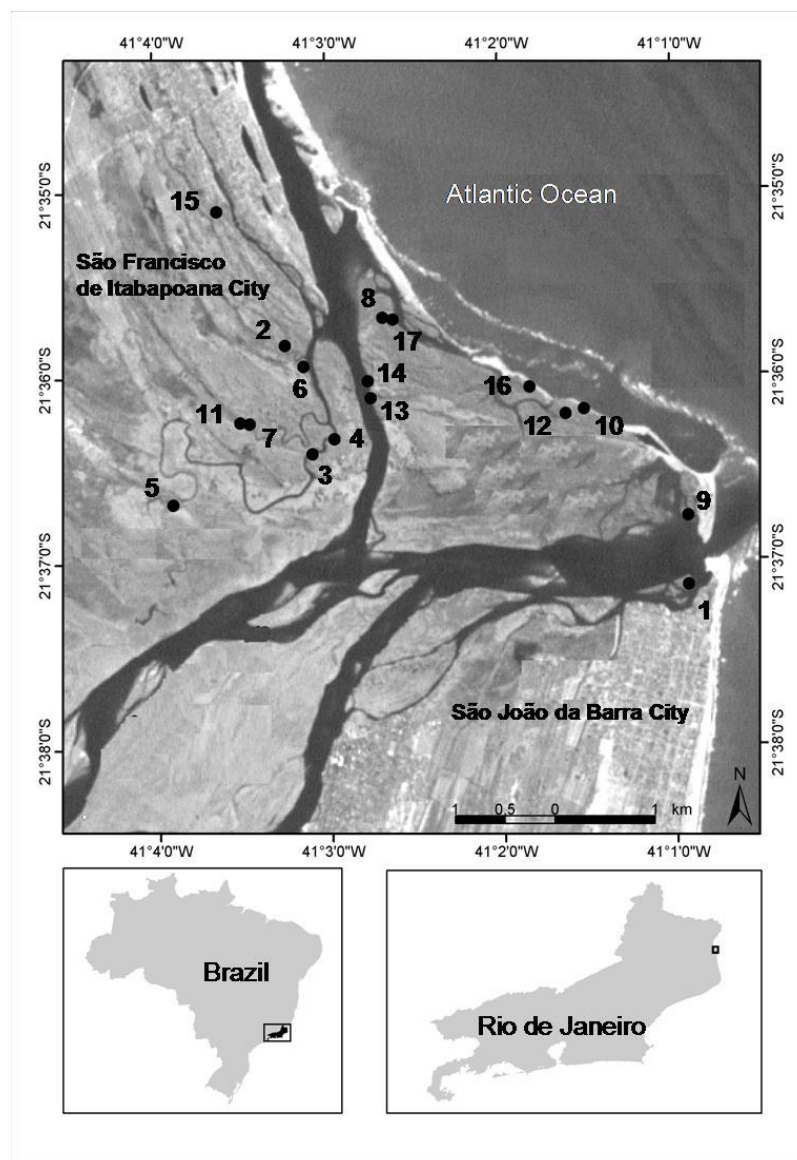


**Figure 1**. Study sites analyzed in the Paraíba do Sul river mangrove estuary.

The data was organized in diameter classes of <2.5 cm, $\geq$ 2.5 cm and $\geq$ 10.0 cm for calculation of the structural parameters of average height, average DBH, basal area, density, dominance and relative density following Schaeffer-Novelli & Cintron (1986). The frequency distribution of range

in diameter of live and dead trunks was prepared for each site. Through the program Statistica 6.0 we carried out a cluster analysis (UPGMA) of the shares, considering the structural parameters: average height, average DBH, basal area of live and dead classes, living basal area, absolute density of

each plot and relative density of each species. The correlation coefficient was calculated for the data of percentage of organic matter and silt+clay sediment fraction with those of average height, basal area and density.

*Abiotic Factors*

From each plot, described above, were collected three sediment samples (15 cm depth) at the end of the rainy season in 2006 during low tide. In the laboratory, the sediment was lyophilized and we removed the coarse fragments with (above of 2,0 mm). Grain size distribution was determined in a particle analyzer (Laser Diffraction, Sald 3101 Shimadzu). Our laboratory is using the reference

material and the results showed repeatability of ~ 95% for certified (Jiss-11 and Glassbeads). The textural classification followed the Sheppard methodology described by Suguio (1973), based on the percentage of sand, silt and clay. 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 and analytical precision determined from 3 replicates (~95%). The salinity of interstitial water was determined with a refractometer after centrifugation of 15 g of sediment (2500 rpm/5 min).
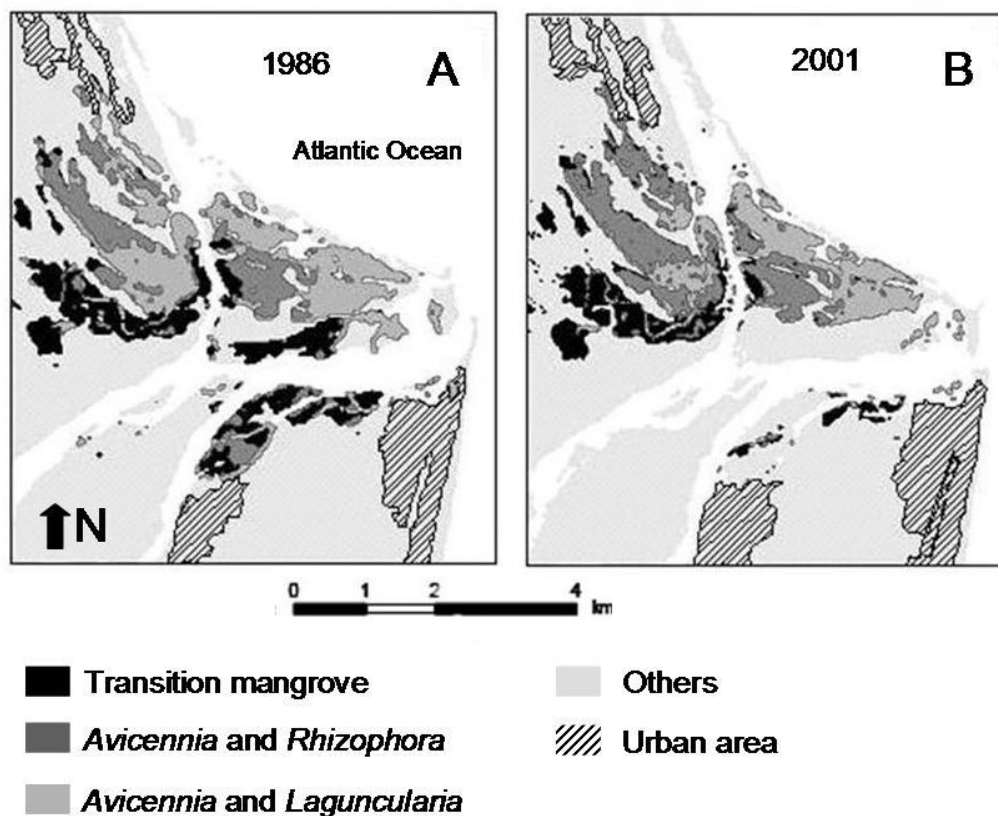


**Figure 2**. A: Spatial distribution of the Paraíba do Sul river mangrove estuary in 1986 (912 ha) and B: in 2001 (725 ha). Modified by Bernini *et al.* (2010).

## Results

*Vegetation structure*

The structural parameters of mangrove forests analyzed in the estuary of the Paraíba do Sul river (RPS) are presented in Table I. The average height of forest varied from 5.2 to 14.5 m. The maximum height was observed for *A. germinans* (25 m), followed by *R. mangle* (19 m) and *L. racemosa* (16 m). The DBH ranged from 2.6 to 23.5 cm and the maximum diameters found for *A. germinans, R.*

*mangle and L. racemosa* were 56.7, 30.2 and 29.9 cm, respectively. The live basal area ranged from 15.1 to 46.4 $m^2$ $ha^{-1}$ and density varied between 732 and 24,060 trunks $ha^{-1}$ totalizing 2,270 of sampled trees. In general, the major contribution of the basal area corresponded to the $\geq 10.0$ cm diameter class (Table II).

Considering all studied sites, *A. germinans* was the dominant species (53%), followed by *L. racemosa* (28%) and *R. mangle* (19%). With respect

to relative density, *L. racemosa* was highest (57%), followed by *A. germinans* (35%) and *R. mangle* (9%).

Avicennia germinans was dominant at sites 1, 3, 5, 6, 7, 13, 14, 15, 16 and 17, while *L. racemosa* was dominant at sites 2, 8, 9, 10 and 12, and *R. mangle* was dominant at site 4 (Table II). At sites with three or more parcels, (Figs. 3 and 4), *R. mangle* exhibited a lower contribution in relation to other species, and within dominant forest sites 11 and 14 (165 and 125 m from the river, respectively). At the other study sites (2, 3, 7, 8, 9, 10, 12, 16 and 17) the dominant species alternated across the flooding gradient, with *A. germinans* and *L. racemosa* dominant both on the fringe (5-45 m from the river), and in the interior of the forests (85-205 m from the river). This alternation was also observed for relative density across the flooding gradient (Figs. 3 and 4; Table II). *Avicennia germinans* and *R. mangle* had a greater contribution to basal area and density of living trunks in the $\geq$ 10.0 cm diameter class and *L. racemosa* in the between 2.5 and 10.0 cm diameter class (Tables II and III).

**Table I**. Structural parameters (mean ± standard deviation) of the vegetation in the mangrove estuary of the Paraíba do Sul river. N = number of plots, DBH = diameter at breast height.

| Site | N | Average height (m) | DBH Average (cm) | Basal live area (m² ha⁻¹) | Basal dead area (m² ha⁻¹) | Density of live trunks (trunks ha⁻¹) | Density of dead trunks (trunks ha⁻¹) |
|------|---|--------------------|-------------------|----------------------------|----------------------------|--------------------------------------|--------------------------------------|
| 1 | 3 | 7.8±1.1 | 10.7±1.4 | 19.9±3.9 | 1.42±0.18 | 2,360±980 | 928±663 |
| 2 | 6 | 6.1±1.1 | 9.0±1.4 | 19.2±2.9 | 4.11±3.17 | 3,931±2,623 | 976±679 |
| 3 | 3 | 9.4±0.9 | 15.0±3.4 | 19.7±7.7 | 1.08±0.45 | 1,139±121 | 247±208 |
| 4 | 2 | 7.7±0.5 | 12.0±1.0 | 24.6±0.3 | 0.39±0.26 | 2,207±387 | 114±66 |
| 5 | 1 | 7.7 | 10.7 | 16.8 | 1.01 | 1,857 | 171 |
| 6 | 1 | 5.2 | 4.9 | 23.5 | 0.80 | 12,300 | 2,200 |
| 7 | 2 | 10.6±1.2 | 14.4±2.8 | 25.3±12.6 | 2.15±2.07 | 1,500±188 | 367±424 |
| 8 | 5 | 6.1±0.9 | 5.7±1.2 | 21.2±4.2 | 1.27±1.09 | 9,200±3,299 | 1,320±1,083 |
| 9 | 4 | 7.0±2.0 | 6.1±1.9 | 23.7±6.9 | 1.16±0.87 | 8,983±3,453 | 2,075±1,112 |
| 10 | 3 | 6.8±2.1 | 7.0±1.5 | 22.1±10.4 | 2.12±1.45 | 5,833±3,275 | 1,073±593 |
| 11 | 6 | 10.9±2.0 | 14.6±2.5 | 21.0±7.1 | 0.91±1.35 | 1,297±551 | 216±192 |
| 12 | 1 | 6.7 | 6.2 | 15.1 | 4.64 | 5,067 | 2,000 |
| 13 | 1 | 14.5 | 23.5 | 46.4 | 0.51 | 1,075 | 225 |
| 14 | 5 | 12.5±1.2 | 16.7±1.6 | 15.9±4.0 | 0.34±0.35 | 732±180 | 117±112 |
| 15 | 3 | 9.7±2.0 | 15.0±2.6 | 18.6±2.0 | 0.92±0.54 | 1,140±334 | 173±64 |
| 16 | 2 | 8.9±2.9 | 10.0±3.7 | 24.4±0.1 | 0.93±0.45 | 3,917±2,805 | 1,617±1,249 |
| 17 | 2 | 5.7±1.3 | 3.7±1.5 | 25.2±6.4 | 3.25±0.45 | 24,060±17,452 | 17,066±17,726 |

For the dead individuals, their basal area ranged from 0.34 to 4.64 m² ha⁻¹ and their density from 114 to 17,066 trunks ha⁻¹ (Table I). In general, *L. racemosa* had a higher contribution of basal area and density of dead trunks, followed by *A. germinans* and *R. mangle*. A higher contribution of these parameters values was observed in the 2.5 and 10 cm class for *A. germinans* and *L. racemosa* and in the $\geq$ 10 cm class for *R. mangle* (Tables II and III).

The distribution of live and dead trunks in diameter classes indicated that 14 sites exhibited an approximately exponential distribution pattern (Fig. 5). This distribution has a higher number of live and dead trunks in lower diameter classes, with progressive decrease in the upper classes. The sites that did not exhibit this type of distribution pattern (4, 7 and 13) showed variation in different diameter classes with a higher contribution of dead trunks in low or intermediate classes (Fig. 5). When we considered species separately we observed that *L. racemosa* and *A. germinans* showed distribution patterns similar to the exponential in 60% and 50%, respectively, of the sites, while *R. mangle* showed the same distribution pattern in only 11% of the sites.

The average height, basal area and density of trunks varied across the flooding gradient at the sites with more than two plots, but did not show a pattern and were not correlated (p > 0.05) with the environmental variables analyzed (percentage of organic matter, silt + clay sediment and interstitial water salinity). Similarly, the values of dominance and relative density of the species were not correlated with environmental variables analyzed (p > 0.05).

**Table II**. Dominance of the basal area (%) of live and dead tree trunks, by diameter class and species in the mangrove estuary of the Paraíba do Sul river Ag: *Avicennia germinans*; Lg: *Laguncularia racemosa*; Rh: *Rhizophora mangle*. * Value <0.04.

| Site | Live trunks | | | | | | | | | Dead trunks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 2,5 cm | | | ≥ 2,5 cm | | | ≥ 10,0 cm | | | < 2,5 cm | | | ≥ 2,5 cm | | | ≥ 10,0 cm | | |
| | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh |
| 1 | 0.2 | 0.1 | - | 13.4 | 4.0 | - | 73.3 | 2.2 | - | 0.2 | - | - | 3.5 | 0.5 | - | 2.6 | - | - |
| 2 | * | 0.5 | - | 0.1 | 32.3 | 2.7 | 18.8 | 15.3 | 14.5 | * | 0.2 | - | 0.1 | 8.6 | - | 0.8 | 6.1 | - |
| 3 | * | * | * | 2.8 | 0.2 | 7.4 | 59.5 | - | 24.8 | * | * | - | 1.3 | 0.5 | - | 1.4 | - | 2.0 |
| 4 | - | - | - | - | - | 16.3 | 12.3 | 0.7 | 69.2 | - | - | - | - | 0.5 | 1.1 | - | - | - |
| 5 | 0.9 | 0.1 | - | 7.3 | 0.1 | - | 82.1 | 3.7 | - | 0.1 | - | - | 0.5 | - | - | - | 5.2 | - |
| 6 | 1.7 | 0.2 | - | 65.7 | 24.1 | - | 5.1 | - | - | 1.3 | 0.1 | - | 1.4 | 0.4 | - | - | - | - |
| 7 | * | * | - | 1.2 | 2.6 | 4.4 | 39.4 | 6.8 | 35.5 | 0.1 | - | - | 1.0 | 2.0 | 0.2 | 2.4 | 3.8 | 0.4 |
| 8 | 0.6 | 2.3 | - | 9.6 | 50.3 | - | 27.9 | 3.8 | - | 0.1 | 0.3 | - | 0.4 | 4.7 | - | - | - | - |
| 9 | 1.6 | 1.4 | - | 14.0 | 41.5 | - | 16.1 | 21.0 | - | 0.2 | 0.7 | - | 0.8 | 2.6 | - | - | - | - |
| 10 | 0.5 | 0.9 | 0.1 | 7.4 | 29.7 | 4.8 | 16.8 | 14.7 | 15.7 | 0.1 | 0.2 | - | 0.6 | 6.1 | 0.1 | - | 2.2 | - |
| 11 | 0.1 | * | - | 1.2 | 1.1 | 6.0 | 41.9 | 7.4 | 36.1 | * | * | - | 0.6 | 1.0 | 0.2 | 0.2 | 4.2 | - |
| 12 | - | 0.8 | - | - | 53.7 | 2.3 | - | 11.4 | 8.3 | - | 0.6 | - | - | 17.1 | - | - | 5.8 | - |
| 13 | * | - | - | 1.4 | - | - | 97.5 | - | - | 0.05 | - | - | 1.0 | - | - | - | - | - |
| 14 | 0.1 | - | - | 2.5 | - | 0.9 | 67.2 | - | 27.1 | * | - | - | 0.7 | - | - | - | - | 1.5 |
| 15 | 0.1 | * | * | 1.9 | 1.1 | 2.7 | 79.0 | 1.2 | 10.0 | * | * | - | 0.7 | 0.1 | - | 3.2 | - | - |
| 16 | 0.3 | 0.2 | 0.2 | 12.5 | 12.3 | 1.0 | 65.1 | 4.1 | 0.6 | 0.5 | 0.4 | - | 1.0 | 1.6 | - | - | - | - |
| 17 | 1.4 | 5.0 | - | 37.9 | 36.6 | - | 7.7 | - | - | 1.9 | 3.9 | - | 0.7 | 5.1 | - | - | - | - |

Cluster analysis showed that among the structural parameters tested, the average height, basal area and relative density living species best separated the plots. Thus, we identified three major groups (Fig. 6). In the first, *R. mangle* is the species with the highest relative density and dominance in most plots, all of which showed basal area in the ≥10 cm diameter class, DBH greater than 11 cm and densities below 2,480 trunks ha$^{-1}$. The second major group consists of plots which, in general, exhibited intermediary structural development in relation to the first and third group. This group showed dominance of *L. racemosa* and *A. germinans*, DBH less than 10 cm and greater contribution of basal area in diameter class between 2.5 and 10.0 cm.

Finally, the third major group, *A. germinans* exhibited greater dominance and relative density, from the contribution of basal area in the ≥10 cm diameter class in most plots.

*Abiotic Factors*

The abiotic factors analyzed in the sediments of the study sites are presented in Table IV. The salinity of interstitial water showed values below 3.0 at most sites. Higher values of this parameter were observed at sites 10, 12 and 16 (5.3 to 17.0). The percentage of organic matter ranged from 0.3 to 46.2%, while the silt fraction was the most abundant in most plots. The sediments were classified as sand, silty sand or sandy silt, with a predominance of the latter.

**Table III.** Relative density (%) of live and dead tree trunks, by diameter class and species in the mangrove estuary of the Paraíba do Sul river Ag: *Avicennia germinans*; Lg: *Laguncularia racemosa*; Rh: *Rhizophora mangle.*

| Site | Live trunks | | | | | | | | | Dead trunks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 2,5 cm | | | ≥ 2,5 cm | | | ≥ 10,0 cm | | | < 2,5 cm | | | ≥ 2,5 cm | | | ≥ 10,0 cm | | |
| | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh | Ag | Lg | Rh |
| 1 | 7.0 | 3.6 | - | 29.7 | 8.0 | - | 24.6 | 1.6 | - | 5.5 | - | - | 15.2 | 2.5 | - | 2.3 | - | - |
| 2 | 0.3 | 7.2 | - | 0.3 | 46.8 | 4.8 | 6.3 | 5.8 | 8.7 | 0.3 | 2.5 | - | 0.9 | 13.6 | - | 0.6 | 1.9 | - |
| 3 | 1.9 | 0.6 | 0.6 | 16.2 | 0.6 | 19.9 | 26.3 | - | 15.9 | 1.9 | 1.2 | - | 8.4 | 4.1 | - | 0.6 | - | 1.8 |
| 4 | - | - | - | - | - | 37.4 | 0.8 | 0.7 | 56.5 | - | - | - | - | 0.7 | 3.9 | - | - | - |
| 5 | 45.7 | 1.4 | - | 22.9 | 1.4 | - | 18.6 | 1.4 | - | 1.4 | - | - | 5.8 | - | - | - | 1.4 | - |
| 6 | 10.9 | 0.7 | - | 54.4 | 18.4 | - | 0.7 | - | - | 10.8 | 0.7 | - | 2.7 | 0.7 | - | - | - | - |
| 7 | 0.8 | 0.8 | - | 5.7 | 8.4 | 18.0 | 11.5 | 5.7 | 30.7 | 2.4 | - | - | 4.1 | 5.7 | 0.8 | 1.8 | 2.4 | 1.0 |
| 8 | 7.0 | 21.5 | - | 7.7 | 46.1 | - | 3.6 | 0.7 | - | 2.0 | 3.8 | - | 0.6 | 7.0 | - | - | - | - |
| 9 | 17.1 | 8.8 | - | 11.4 | 33.9 | - | 3.5 | 5.5 | - | 2.6 | 9.5 | - | 1.6 | 6.1 | - | - | - | - |
| 10 | 7.5 | 14.6 | 1.4 | 11.9 | 28.1 | 7.0 | 4.2 | 5.8 | 3.9 | 2.3 | 3.0 | - | 1.1 | 8.1 | 0.4 | - | 0.7 | - |
| 11 | 3.3 | 2.8 | - | 5.1 | 4.0 | 19.5 | 13.6 | 4.4 | 31.6 | 2.6 | 1.1 | - | 4.0 | 4.2 | 0.6 | 0.4 | 2.8 | - |
| 12 | - | 11.3 | - | - | 52.8 | 2.9 | - | 1.9 | 2.9 | - | 7.5 | - | - | 19.8 | - | - | 0.9 | - |
| 13 | 1.9 | - | - | 13.5 | - | - | 67.3 | - | - | 9.6 | - | - | 7.7 | - | - | - | - | - |
| 14 | 15.3 | - | - | 12.1 | - | 3.3 | 31.5 | - | 26.1 | 5.3 | - | - | 4.4 | - | - | - | - | 2.0 |
| 15 | 8.8 | 4.8 | 1.3 | 11.6 | 7.7 | 8.6 | 33.0 | 1.3 | 9.2 | 4.0 | 0.4 | - | 3.8 | 0.9 | - | 4.6 | - | - |
| 16 | 6.0 | 4.2 | 6.7 | 20.8 | 10.2 | 3.0 | 18.0 | 1.8 | 0.6 | 11.7 | 5.4 | - | 6.8 | 4.8 | - | - | - | - |
| 17 | 6.0 | 10.5 | - | 15.6 | 30.5 | - | 0.9 | - | - | 12.8 | 14.8 | - | 0.8 | 8.1 | - | - | - | - |

## Discussion

Despite the low diversity, the mangrove forest of the RPS estuary exhibited variability in structural development in relation to height, DBH, basal area and trunk density, presenting a spatial mosaic of different structural phases (Smith 1992). Good structural development for the majority of forests, with greater contribution of the basal area in the >10.0 cm diameter class (68%) was emphasized. The structural heterogeneity of forests can be attributed to environmental peculiarities of each site, and especially the processes of accelerated erosion and deposition of sediments that provide a constant formation of new mangrove forests in areas closer to the ocean (Bernini *et al.* 2010).

In recent decades, the natural dynamics of the estuary has been changed due to variations in the RPS water discharge, caused by multiple uses like human supplies, industries and agriculture, environmental disturbances (such as deforestation of the riparian zones and construction of dams upstream of the estuary) and has been accentuated by natural phenomena (e.g. El Niño and La Niña).

When the amount of sediment greatly decreases or stops, due to damming of the river, the materials already deposited become mobilized by coastal processes. Thus, there is a change in the balance between the discharges of sediment and coastal physical processes (tidal, wind, etc.) requiring a new dynamic equilibrium (Marins *et al.* 2003). In the RPS estuary, this phenomenon has promoted siltation, erosion and accelerated deposition in the principal estuary and slow deposition of sediment and change the opening of the fluvial bar in the secondary estuary. These rapid changes have also caused the elimination of mangrove areas and destroyed several blocks of houses on the Atafona beach, representing a serious social and economic problem for the city of São João da Barra.

Higher densities and lower DBH values were found in plots with dominance of *A. germinans* or *L. racemosa* (sites 6, 8, 9 and 17), whose forests showed lower values of height and greater contribution of basal area and density of trunks in the intermediate diameter class (from 2.5 to 10.0 cm). According to Bernini *et al.* (2010)
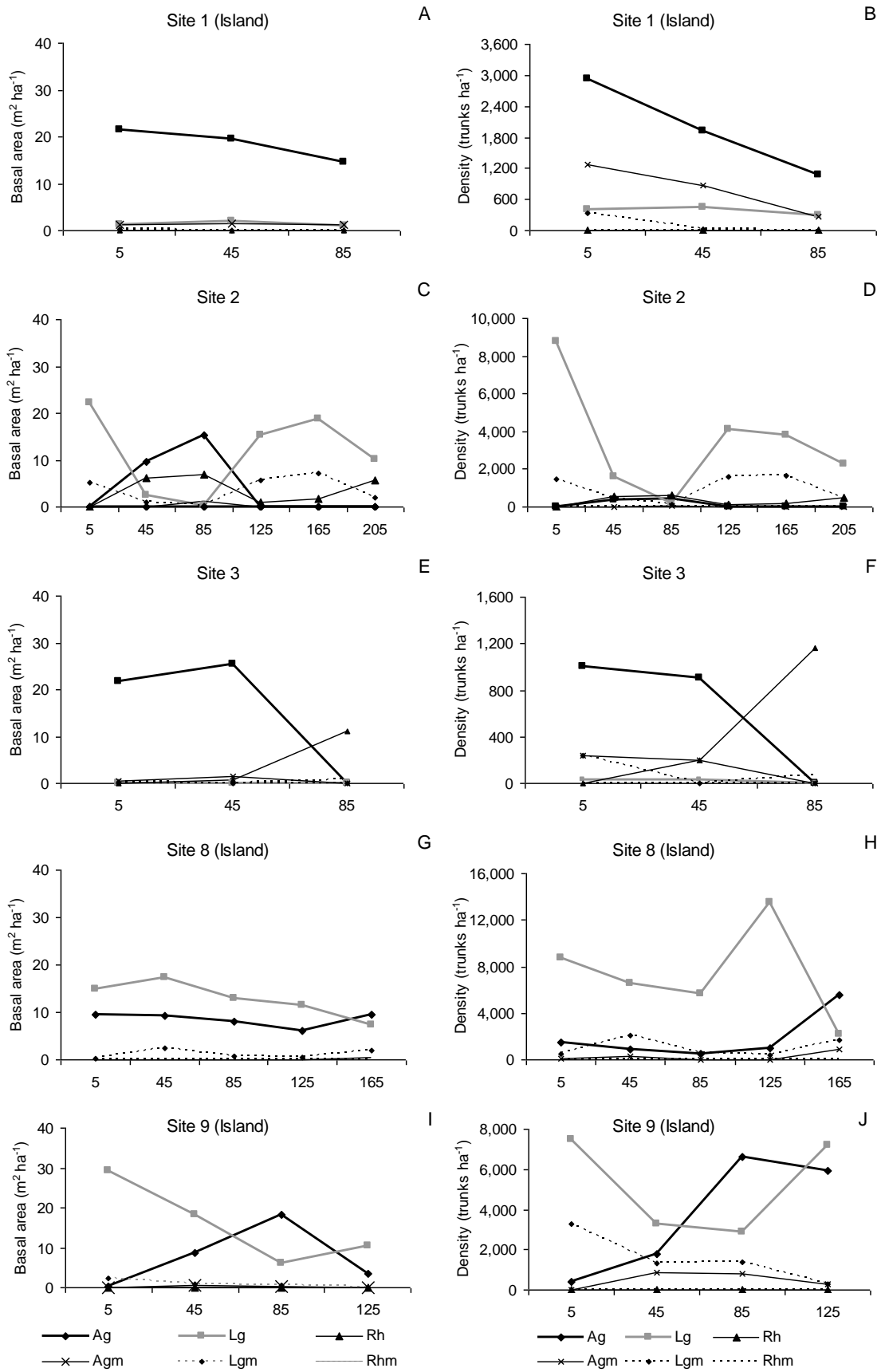
**Figure 3**. Basal area and density of trunks in the plots studied at sites 1, 2, 3, 8 and 9, in the Paraíba do Sul river mangrove estuary. The x-axis represents the distance from the river in meters. Ag: live *Avicennia germinans*; Lg: live *Laguncularia racemosa*; Rh: live *Rhizophora mangle*; Agm: dead *A. germinans*; Lgm: dead *L. racemosa*; Rhm: dead *R. mangle*.
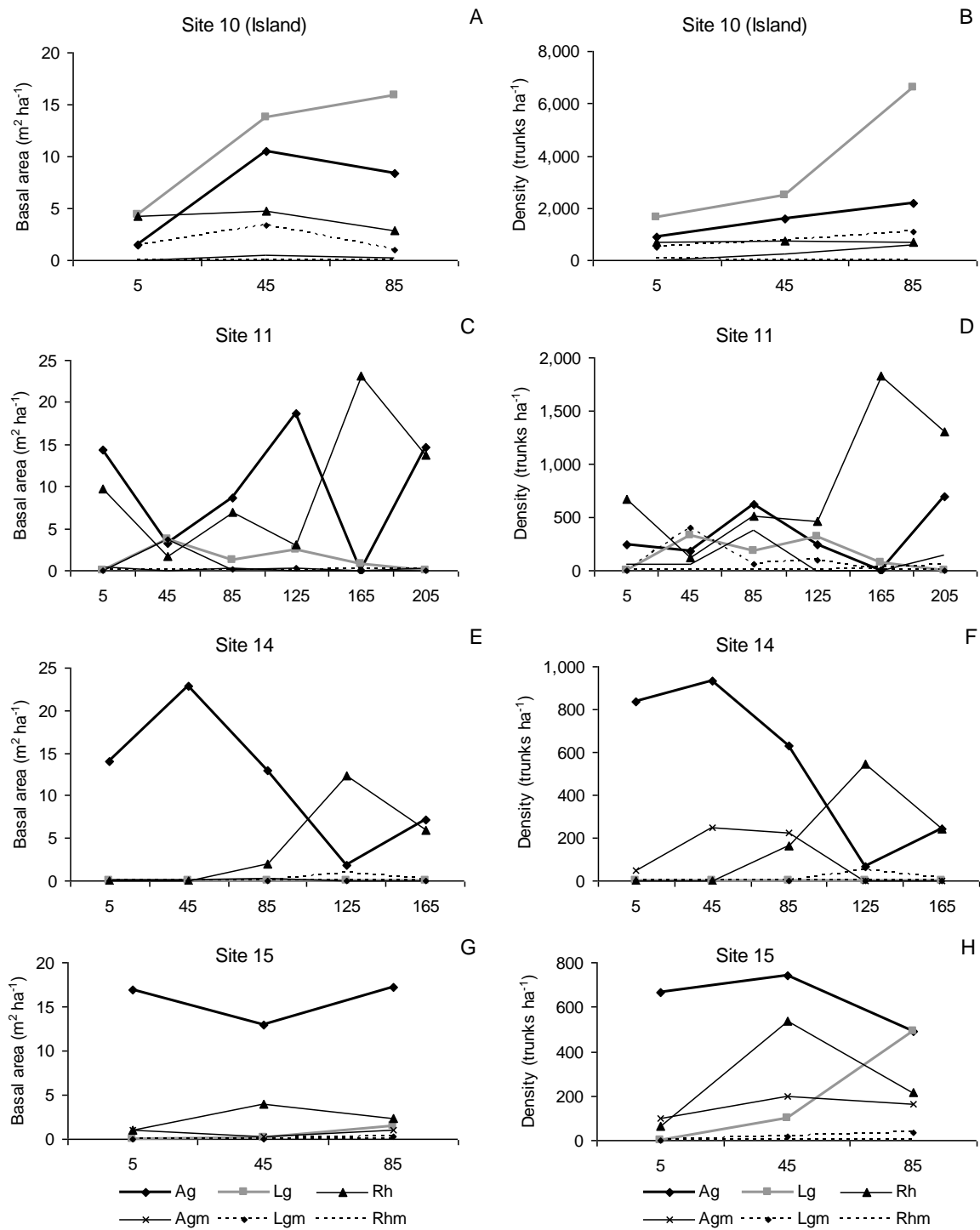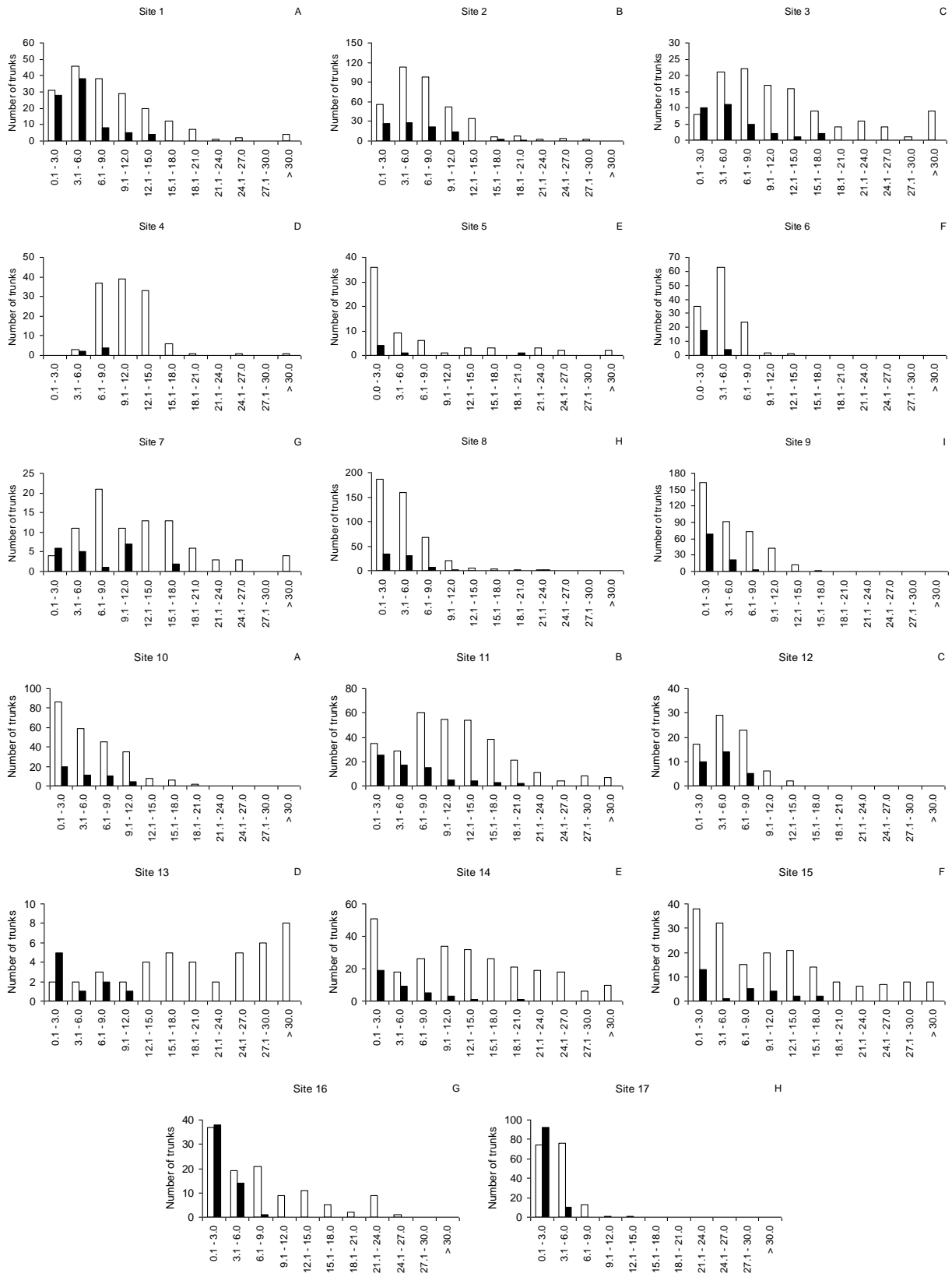
**Figure 4**. Basal area and density of trunks in the plots studied in sites 10, 11, 14 and 15, in the Paraíba do Sul river mangrove estuary. The x-axis represents the distance from the river in meters. Ag: live Av*icennia germinans*; Lg: live *Laguncularia racemosa*; Rh: live *Rhizophora mangle*; Agm dead *A. germinans*; Lgm dead *L. racemosa*; Rhm dead *R. mangle*.

in 1986 there were no forests in sites 8 and 17 of this study (Figs. 1 and 2), while site 9 was situated in an area that had altered patterns of erosion and sediment deposition. These data suggest that these areas are composed of young forests, as evidenced by the structural parameters presented here.

Moreover, near sites 8, 9 and 17 we observed several seedling and sapling banks of *L. racemosa* in areas of local deposition of recent sediments, indicating that this area is conducive to the formation of new forests.

**Figure 5**. Distribution of live and dead trunks by diameter class (x axis), in the Paraíba do Sul river mangrove estuary. □ = Live; ■ = Dead.
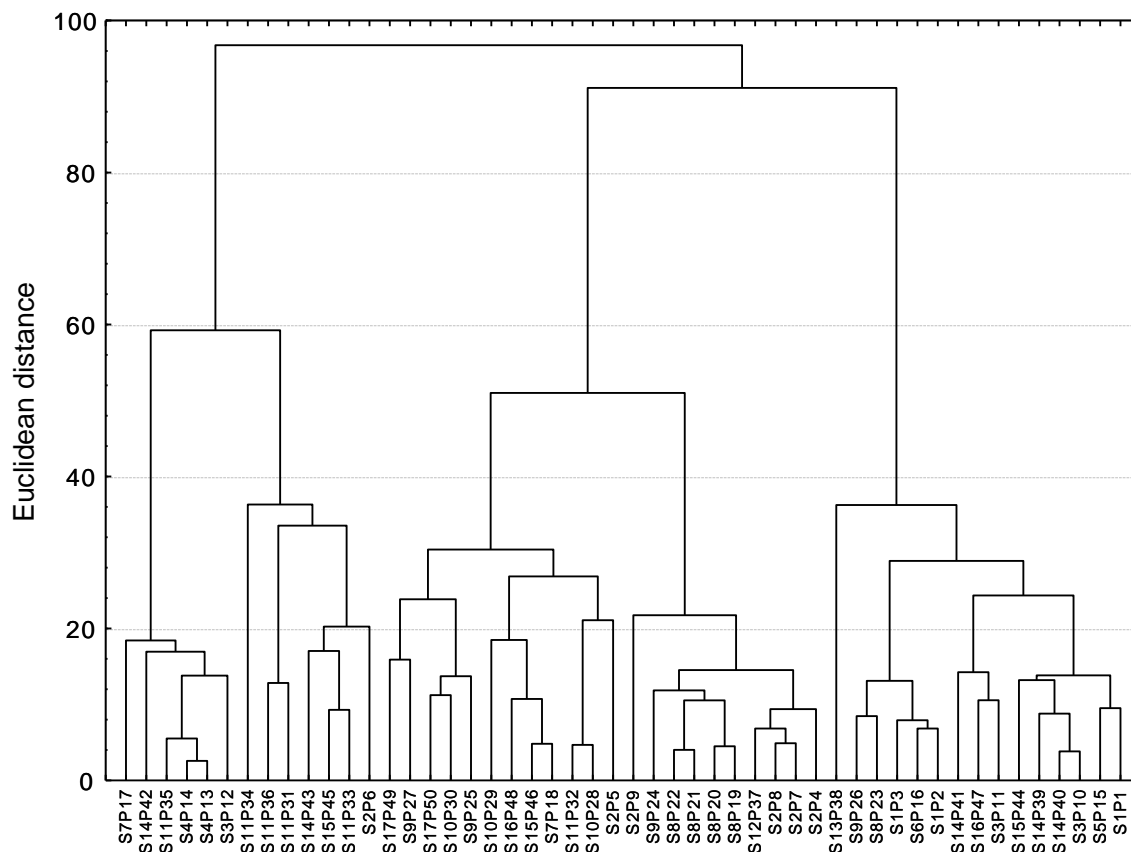
**Figure 6.** Cluster analysis (UPGMA) performed for the data of average height, basal area and relative density living species on the parcels considered in the Paraíba do Sul river mangrove estuary. S: site; P plot.

The majority sites studied in this forest are classified as the riverine type, according to the classification proposed by Lugo & Snedaker (1974), with the exception of sites 10 and 16, which are the fringe type. The forests of these sites receive direct influence of the sea and are receiving rapid deposition of coarse sediments (Table IV). Sedimentation can cause mortality of mangroves, interfering in the recycling of nutrients and exchange of gases due to the covering of the lenticels, promoting apical death (Odum and Johannes 1975). Trees with apical death were recorded in areas close to sites 10 and 16 and were also observed in other regions along the Brazilian coast with the same type of process (Marins *et al.* 2003).

Bernini & Rezende (2004) studied the structure of the RPS mangrove estuary and reported values within the range found in this study. These authors sampled a mangrove area of 0.26 ha and cited *A. germinans* as dominant in basal area (60%), followed by *R. mangle* (25%) and *L. racemosa* (15%). Our study, however, covered an area almost 6 times higher (1.53 ha), confirming the dominance of *A. germinans* (53%), but *L. racemosa* had a

greater contribution (28%) compared to *R. mangle* (19%). This apparent contradiction just show us as difficult is the establishment of a structural profile for mangrove ecosystem in especial where the environmental conditions (ex.: river discharge, sediment transport, deforestation, multiple use in basin drainage) have a continuous changing (ex.: chronic and acute) in a temporal scale.

Jimenez & Lugo (1985) reported that *A. germinans* typically occurs in less elevated areas and may also be present in places where flooding is less frequent. The species is found in sandy substrate, silt or clay, with the best development observed in riverine forests, such as the RPS mangrove estuary, even though this area is located near (about 140 km away) from the southern distribution limit of *A. germinans* in South America (Macaé, RJ; Maciel & Soffiati 1998).

The dominance of *A. germinans*, followed by *L. racemosa* and *R. mangle* shows that the RPS mangrove estuary is similar to the mangrove estuary of Itabapoana, located 33 km from the mouth of the RPS, where a similar result was reported, with *A. germinans* (65%), followed by *L. racemosa* (28%)

**Table IV**. Inorganic fractions (%), textural classification, organic matter (%) and salinity of the intersticial water of the sites evaluated in the mangrove estuary of the Paraíba do Sul river, N = number of plots.

| Plot | N | Coarse Sand | Medium Sand | Fine Sand | Silt | Clay | Textural classification | Organic Matter | Salinity |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | <0.1 - 3.6 | 5.5 - 25.1 | 23.2 - 31.3 | 35.5 - 63.6 | 4.6 - 7.3 | Sand silt – Silt Sandy | 9.3 - 18.4 | 2.3 - 2.7 |
| 2 | 6 | 0.4 - 56.0 | 4.2 - 23.1 | 0.2 - 24.1 | <0.1 - 67.1 | <0.1 - 5.7 | Sand – Sandy Silt Sandy | 8.2 - 26.6 | 2.0 - 2.8 |
| 3 | 3 | <0.1 | 1.4 - 4.9 | 22.7 - 27.3 | 62.5 - 70.1 | 5.2 - 5.9 | Sandy Silt | 17.6 - 22.6 | 2.0 - 2.3 |
| 4 | 2 | 1.7 – 2.2 | 12.0 - 14.9 | 25.0 - 30.6 | 51.0 - 52.0 | 4.2 - 6.4 | Sandy Silt | 12.8 - 13.9 | 2.0 - 2.3 |
| 5 | 1 | 1.2 | 9.6 | 25.3 | 59.2 | 4.8 | Sandy Silt | 46.2 | 2.0 |
| 6 | 1 | 0.8 | 14.7 | 30.1 | 49.6 | 4.8 | Sandy Silt | 13.0 | 2.3 |
| 7 | 2 | <0.1 - 0.3 | 4.8 - 5.8 | 21.4 - 21.9 | 67.6 - 69.9 | 4.0 - 4.4 | Sandy Silt | 19.2 - 33.7 | 2.3 - 2.5 |
| 8 | 5 | 3.2 - 10.2 | 2.0 - 17.3 | 19.2 - 28.6 | 44.1 - 62.6 | 3.2 - 6.7 | Sand silt Sandy | 10.3 - 16.1 | 1.5 - 1.8 |
| 9 | 4 | <0.1 - 0.7 | 0.4 - 7.3 | 14.7 - 26.9 | 63.7 - 76.5 | 5.8 - 8.4 | Sandy silt | 7.9 - 25.3 | 2.0 - 2.2 |
| 10 | 3 | <0.1 - 44.3 | 1.4 - 51.8 | 2.6 - 28.9 | 0.5 - 71.3 | <0.1 - 5.5 | Sand – Sandy Silt | 0.3 -19.7 | 5.3 - 17.0 |
| 11 | 6 | <0.1 - 2.0 | 2.2 - 11.7 | 22.0 - 25.9 | 58.0 - 69.1 | 4.0 - 5.1 | Sandy Silt | 25.0 - 31.2 | 2.0 - 2.3 |
| 12 | 1 | 0.8 | 3.8 | 14.7 | 73.8 | 6.8 | Sandy Silt | 12.1 | 14.8 |
| 13 | 1 | <0.1 | 1.3 | 21.1 | 69.3 | 8.4 | Sandy Silt | 18.7 | 3.0 |
| 14 | 5 | <0.1 - 15.4 | 1.8 - 11.8 | 17.1 - 23.2 | 37.9 - 70.8 | 3.0 - 8.8 | Sandy Silt | 19.2 - 25.0 | 2.8 - 3.4 |
| 15 | 3 | 3.4 - 22.4 | 17.8 - 32.2 | 15.5 - 24.1 | 32.9 - 51.3 | 2.4 - 3.4 | Sand – Sandy Silt Sandy | 17.7 - 37.2 | 2.2 - 2.7 |
| 16 | 2 | 0.7 - 68.7 | 26.0 - 31.2 | <0.1 - 24.1 | <0.1 - 52.4 | <0.1 - 5.5 | Sand – Sandy Silt | 5.3 - 17.0 | 6.9 - 14.0 |
| 17 | 2 | <0.1 - 1.0 | 5.4 - 9.9 | 20.4 - 23.1 | 62.8 - 66.0 | 5.6 - 5.9 | Sandy Silt | 11.0 - 12.97 | 2.2 - 2.3 |

and *R. mangle* (7%) (Bernini & Rezende 2010). However, other studies conducted in the State of Rio de Janeiro highlighted the dominance of *R. mangle* and/or *L. racemosa* (Silva *et al.* 1991, Soares 1999, Pellegrini *et al.* 2000, Soares *et al.* 2003). However, in those mangroves *A. germinans* does not occur and forests have higher levels of salinity of interstitial water (~30) and increased human influence compared to the RPS mangrove estuary.

Thus, the comparison between different areas of mangroves is a difficult task, because the ecosystem is subjected to different environmental conditions and tensors that influence the structural development. Therefore, there is remarkable variation in structural parameters as shown in Table V, which summarizes the structural diversity of vegetation in different mangroves in Brazil.

The average height, basal area and density of trunks of forests differed over the flooding gradient, but there was no zonation present of the tree species. Furthermore, there was no significant correlation between environmental variables and structural parameters. The relationship between grain size and organic matter content of the sediment with the structural development and distribution of species is difficult to investigate in the RPS mangrove estuary due to the intense dynamics in sediment deposition. In general, to explain the evolution of a mangrove community it is necessary to understand the processes that occurred in the past and the present conditions (Thom 1984). In mangrove areas drastic changes can occur in the physical environment on a time scale shorter than the life cycle of plants (Woodroffe 1992), as has been observed in some areas in the RPS mangrove estuary and has intensified after 1980, when there was a transposition of part of the water volume of this river.

The structural development decreases with increasing salinity of the substrate (Cintron *et al.* 1975, Soto & Jimenez 1982, Jimenez & Sauter 1991). In our study, the relationship between spatial distribution of plants and salinity was not observed because of the high river input that prevents the accumulation of salts in the substrate. The low salinity of interstitial water (1.5-17.0) promotes the formation of large patches of transition in which the mangrove plants are intermingled with the typical vegetation of freshwater mangroves and dunes. Among the most common species are *Acrostichum aureum, Hibiscus pernambucensis* and *Dalbergia* sp, which are indicative of low salinity and exhibited a higher abundance inside the forests considered as the oldest (sites 1, 3, 5, 7, 11, 13, 14 and 15; Bernini *et al.* 2010).

Among the 17 sites studied, 14 showed a pattern similar to an exponential distribution of trunks by class diameter. Similar results were reported for most studied mangrove forests in Guanabara Bay, Rio de Janeiro, Brazil (Soares *et al.* 2003), Recife, Pernambuco, Brazil (Souza & Sampaio 2001) and Costa Rica (Jimenez & Sauter 1991). This type of distribution is also common in other forest types such as *cerrado* (Assunção & Felfili 2004), riparian (Battilani *et al.* 2005), riverine forest (Budke *et al.* 2004), coastal sand dune forest (Assis *et al.* 2004), Atlantic forest (Peixoto *et al.* 2005) and semi-deciduous forest (Bianchini *et al.* 2003).

The exponential distribution is observed in communities that have natural mortality (especially in the smaller diameter classes due to increased competition) associated with the forest maturation process, with individuals in varying degrees of development, with major contribution of juveniles that facilitate the maintenance of phytocoenosis (Soares *et al.* 2003). At sites 4, 7 and 13, there was no an exponential type distribution. Smith (1992) argued that mature forests tend to exhibit a more homogeneous pattern of distribution of trunks, which was partly observed in the sites mentioned. At site 5, the different distribution of trunks is attributed to selective logging observed in this area. At this site, human activity is mainly related to the conversion of mangrove areas for livestock production, and the forest currently is present only a small fragment surrounded by pastures and is disturbed, having clumps of *Acrostichum aureum, Hibiscus pernambucensis* and grasses. The high number of trunks less than 3 cm in diameter at this site is due to resprouts originated from *A. germinans* trees hat were cut.

In the RPS mangrove estuary we did not observe zonation, because the species differed in their spatial distribution, being dominant in both at the edge and in the interior of forests. A similar result was reported by Bernini & Rezende (2004). The influence of abiotic factors on the relative competitive ability of species may account for the distribution of mangrove plants in a typical pattern of zonation (Ball 1980, Thom 1982). The combined effect of all abiotic and biotic factors establishes the spatial distribution of vegetation so that multiple species compositions may occur. In some forests, some environmental characteristics may predominate (eg. salinity), promoting zonation. However, in places subject to frequent flooding or input of large quantities of fresh water, the influence of salinity on plant physiology may be negligible. In this case, other factors such as competition may be

more important in determining the distribution of the species (Tomlinson 1986). This seems to be the scenario found in the area examined in this study.

In the forests studied in the RPS estuary the salinity of interstitial water exhibited low values (Table IV) because of high river influence and the constant formation of new mangrove areas generated by coastal dynamics, resulted in forests with different species compositions and no zonation in these mangrove forests. The results for the distribution of live and dead trunks by diameter class and cluster analysis suggested that interspecific competition may be influencing the spatial distribution of mangrove plants in the RPS estuary.

**Table V**. Vegetation structure in different mangroves in Brazil. Limit for inclusion: * individuals with diameter $\geq$ 2.5 cm and ** individuals $\geq$ 1 m.

| Locality | Average DBH (cm) | Average height (m) | Basal area (m² ha⁻¹) | Source |
|---|---|---|---|---|
| Bragança, PA | 8.9 | 16.7 | 9.1 | Abreu *et al.* 2006 |
| São Luís, MA* | 21.2 | 19.8 | 19.4 | Santos 1986 |
| Caravelas, BA* | 5.9-17.8 | 4.6-9.8 | 4.0-38.6 | Schaeffer-Novelli *et al.* 1994 |
| Conceição da Barra, ES* | 8.1-29.6 | 5.5-14.8 | 7.2-30.9 | Silva *et al.* 2005 |
| Vitória, ES* | 4.2-18.9 | 5.3-17.3 | 5.4-29.8 | Carmo *et al.* 1995 |
| Guaratiba, RJ** | 0.8-7.6 | 2.3-9.3 | 13.4-61.7 | Pellegrini *et al.* 2000 |
| Lagoa da Tijuca, RJ** | 1.5-16.1 | 3.4-16.7 | 14.3-41.4 | Soares 1999 |
| Baía de Guanabara, RJ* | 11.0 | - | 34.9 | Araujo & Maciel 1979 |
| Baía de Guanabara, RJ** | 1.3-7.8 | 1.8-7.3 | - | Soares *et al.* 2003 |
| Baía de Sepetiba, RJ* | 7.8 | 6.1 | 21.6 | Silva *et al.* 1991 |
| Estuário do Rio Paraíba, RJ** | 7.4-13.4 | 6.3-9.9 | 14.5-35.3 | Bernini & Rezende 2004 |
| Ilha do Cardoso, SP* | 6.9-12.0 | 5.7-9.8 | 16.2-35.6 | Peria *et al.* 1990 |
| Paranaguá, PR* | - | 3.2-8.6 | 2.2-62.2 | Couto 1996 |
| Estuário do Rio Paraíba, RJ** | 6.3-16.7 | 6.9-11.8 | 15.1-51.7 | This study |

To analyze the successional trajectory of a forest it is necessary to assess the ecological processes in greater detail. The mangrove plants more efficiently adapted to capture photosynthetically active radiation will have a greater advantage to colonize the shaded spaces (Berger *et al.* 2008). Shade tolerance during the seedling and juvenile stages decreases from *R. mangle* and *A. germinans* to *L. racemosa* (Ball 1980). Silva and collaborators (unpublished data) studied the dynamics of seedlings of *A. germinans* and *L. racemosa* in the RPS mangrove estuary and found seedling mortality in areas beneath the canopy due to shade intolerance, while in areas without vegetation or recent sediment deposition had low mortality and the seedlings have developed into juveniles.

Interspecific competition does not manifest itself in the early stages of development, being critical when individuals become larger and require more space, affecting the development of later colonizers (Ball 1980, Jiménez & Sauter 1991, Fromard *et al*. 1998). Although there are well developed individuals of *A. germinans* and *L. racemosa* and the diaspores of these three species can establish under a dense canopy, shading conditions are inhibitory to the development of seedlings of *A. germinans* and *L. racemosa*, but favor the recruitment of young individuals of *R. mangle* (Ball 1980). Thus, the chances of this species to occupy space on this site are much higher. In the RPS mangrove estuary, the ability of *L. racemosa* in maintaining itself in the community is affected by competition with *A. germinans* and/or R. *mangle*, which restricts the species to less flooded sites with higher light intensity, such as in areas of

recent sediment deposition, along narrow bands on the banks of canals, and open spaces or in places of transition to pastures.

In younger forests, there was association of *L. racemosa* and *A. germinans*, generally, with dominance of the first. With the maturing of the forest, the community tends to culminate in forests dominated by *A. germinans* or *R. mangle* (Fig. 2), probably due to competitive interactions (Bernini *et al.* 2010). The results of this study are similar to those described in a mangrove swamp in southern Florida, where Ball (1980) reported the replacement of *L. racemosa* by *R. mangle* in periodically flooded sites that favored the maximum development of both species. A similar effect of competition was reported by Fromard *et al.* (1998) who described the gradual replacement of *L. racemosa* by *A. germinans* in a mangrove forest in French Guiana. Similarly, in a field study, Berger *et al.* (2006) analyzed secondary succession in a mangrove estuary Caeté River (Pará, Brazil) and identified that the sequence started with *L. racemosa* and over time, changed to mixed forests dominated by *A. germinans* or *R. mangle* as observed in the RPS estuary. The species replacement was attributed to shade tolerance and the decrease in nutrient availability that could be responsible for changes in the rates of development of these species.

In conclusion, this study showed that the mangrove studied showed high structural development (contribution of basal area $\geq$10.0 cm of 68%) and the absence of zonation pattern. This result is attributed to high river influence and constant flooding of forests substrate. The vegetation structure data indicated that interspecific competition may be influencing the spatial distribution of these mangrove species in the studied area, since *L. racemosa* forests are being gradually replaced by *A. germinans* and/or *R. mangle*.

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