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Mangrove Forests and Sedimentary Processes on the South Coast of São Paulo State (Brazil)

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ABSTRACT

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Mangrove structure and distribution is conditioned by geomorphic processes. This paper describes the response of mangroves to sedimentary processes at the Cananéia-Iguape Coastal System on the south coast of São Paulo State (Brazil), between latitudes 24°40’S and 25°20’S. Within six study areas 41 plots were established along 14 transects. Plot size varied according to stem density from 2m×2m to 20m×20m. Here mangroves are strongly coupled to sedimentary processes, forming discrete architectural elements within particular depositional environments or topographic settings. These sedimentary structures and progradation environments are colonized by *Laguncularia racemosa*, associated with the smooth cordgrass *Spartina alterniflora*. *Rhizophora mangle* occurs typically near creeklets where tidal flooding is more frequent. Where tidal influence is restricted *Avicennia schaueriana* becomes dominant. Erosive margins are dominated by *A. schaueriana* or *R. mangle*. Single linkage cluster analysis yields three groups (A, B and C), with high levels of similarity, providing support to the classification of the data into two broad landform categories: depositional and erosive. Group A includes plots with the least structural development (nominal stem diameter d_n between 1.05 and 4.61cm). Group B is composed of stems of intermediate diameter ($4.99 \text{ cm} \le d_n \le 5.63\text{cm}$). Group C plots have the largest structural development ($5.50 \text{ cm} \le d_n \le 11.10\text{cm}$). The structure of mangroves (dominance and structural development) reflects responses to geomorphology and habitat change.

ADITIONAL INDEX WORDS: *coastal ecosystem, geomorphology, Cananéia-Iguape Coastal System*

INTRODUCTION

Mangrove ecosystems show close links between geomorphology and vegetation assemblages and can change over time as landforms accrete or erode as a direct response to coastal sedimentary processes (Souza Filho et al., 2006). Mangrove forests develop distinct spatial patterns depending on geomorphological and environmental settings. In sedimentary systems, close relationships exist between propagule transport, tidal hydrodynamics, sediment transport and geomorphology (Bryce et al, 2003; Di Nitto et al., 2008).

According to Lugo and Snedaker (1974) mangrove ecosystems are self-maintaining coastal landscape units that are responsive to long-term geomorphological processes and are open to continuous interactions with contiguous ecosystems at regional scale.

In Brazil, the local variability in mangrove species associations their dominance in a given environment is predominantly determined by the characteristics of the landforms that can be colonized by each species (Schaeffer-Novelli et al., 1990a).

The purpose of this paper is to describe the response of mangroves to sedimentary processes at the Cananéia-Iguape Coastal System on the south coast of São Paulo State (Brazil).

Study Area

The Cananéia-Iguape Coastal System (Figure 1) is located on the southern reach of the coast of São Paulo State, southeastern

Brazil, between latitudes 24°40’S and 25°20’S. This coastal system has three main islands (Cardoso, Cananéia and Comprida), that are separated by meandering channels. These channels show a hydrodynamic pattern influenced by tidal currents and freshwater inputs to the system. Intense erosion occurs on the concave margins and sediment deposition takes place on the convex margins of the Cananéia Channel (Tessler and Mahiques, 1998).

The summers are wet and winters are considerably dry. Maximum precipitation rates occur from January through March (monthly average of 266.9mm) and the minimum rates occur from July to August (monthly average of 95.3mm). The average annual rainfall over a 29-year period has is 2,300mm. The average annual temperature is 23.8°C, the highest monthly average is 27.8°C (February), and the lowest is July (19.8°C). Tides are semidiurnal and mean tidal amplitude is 0.82m.

Six study sites were chosen considering the spectrum of depositional and erosive forms in the Cananéia-Iguape Coastal System: Pai Matos Island, Baguaçu, Nóbrega, Sítio Grande, Cabeçuda Island and Sacová Island (Figure 1).

METHODS

Within six study areas 41 plots were established along 14 transects. Primary transects were located along depositional gradients of sedimentary successions. Where appropriate, one or more secondary transects, with plots located on the extremities, were lied out perpendicular to the primary transects. These plots were in contact with the river or estuary, areas submitted to sedimentary processes. Plot size varied according to stem density from 2m×2m to 20m×20m, according to methodology proposed by Cintrón and Schaeffer-Novelli (1984). We identified transects and plots using a code representing the study site name (PM = Pai Matos, BA = Baguaçu; NO = Nóbrega; SG = Sítio Grande; CA = Cabeçuda Island and SA = Sacová Island), followed by the plot number (P1, P2, P3, etc…). The number of transects and plots per site is given in the results table.

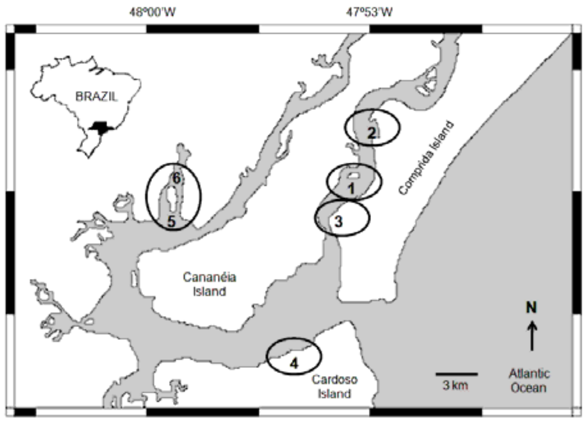

Figure 1. Location of the Cananéia-Iguape Coastal System, on the southern coast of the State of São Paulo, and the study sites: 1. Pai Matos Island; 2. Baguaçu; 3. Nóbrega; 4. Sítio Grande; 5. Cabeçuda Island; and 6. Sacová Island

Once field data had been collected, the average height, d_n (diameter at or close to normal stem form, suggested by Husch et al., 1982), basal area, basal area dominance, and trunk density were assessed. The live basal area ($m^2.ha^{-1}$) was classified according to diameter classes ($d_n<2.5$cm; $2.5 \leq d_n \leq 10$cm; and $d_n \geq 10$cm), proposed by Cintrón and Schaeffer-Novelli (1984). Topography was taken at 1 meter interval along all transects in the mangrove, using a communicating vessels system.

A cluster analysis (UPGMA), using Statistica software, was applied to the data collected. The parameters adopted were d_n and mean height values.

RESULTS

The distribution of species along transects revealed spatial patterns of structural development; d_n and mean height increase and density decrease progressively (Table 1).

Forests with low structural development are characterized by *Laguncularia racemosa* with low d_n (≤2.5cm), low mean height values (1.28±0.16 to 3.32±0.96m, such as plots BAP1 and BAP3, respectively) and high density (67,200 to 38,000 stems.ha^{-1}, such as plots SGP1 and PMP1). We observed a high number of live trunks in low live basal area class (≤2.5cm), such as plots BAP1, BAP2 and NOP1.

Forests with intermediate structural development are dominated by *L. racemosa* and/or *R. mangle* and present intermediate values, such as plots PMP2, PMP5, SGP2, CAP1, CAP2, SAP1, and SAP2 (Table 1).

In contrast, forests with high structural development are characterized by *Rhizophora mangle* and/or *Avicennia schaueriana* with high d_n (≥10.0cm), high mean height values (4.16±2.35 to 5.58±2.91m, such as plots SAP4 and PMP4), and a low density (2,925 to 4,700 stems.ha^{-1}, such as plots PMP4 and PMP6). These plots had high number of living trunks in the high living basal area class (≥10.0cm), such as plots PMP4, PMP6 and SAP4 (Table 1).

Mangroves are strongly coupled to sedimentary processes, forming discrete architectural elements within particular depositional environments or microtopography settings.

Depositional surfaces and progradation environments are colonized by *L. racemosa*, which has a low structural development and is associated with smooth cordgrass (*Spartina alterniflora*) as observed in depositional areas of Pai Matos Island, Baguaçu, Nóbrega and Sítio Grande (PMP1, BAP1, BAP2, NOP1, NOP2, SGP1 and SGP2).

In the eroding sites, as in some areas of Pai Matos Island and Sítio Grande, large *R. mangle* and/or *A. schaueriana* were found, such as plots PMP6 and SGP5 (Table 1 and Figure 3). Landscape positions as well as topography are critical factors influencing establishment patterns and zonation of mangrove species. Within creeklets, *R. mangle* occurs in areas with frequent tidal inundation, such as plots CAP3 and BAP8 (Figure 2). However, where tidal influence is restricted *A. schaueriana* becomes dominant, such as plots PMP4, BAP5, SAP4 (Table 1 and Figure 2).

Table 1: Structural parameters per plot in the mangrove sites studied. d_n = nominal stem diameter; stdev = standard deviation. Species: *R.man*: *Rhizophora mangle*; *L.rac*: *Laguncularia racemosa*; *A.sch*: *Avicennia schaueriana*. Study sites : PM = Pai Matos, BA = Baguaçu; NO = Nóbrega, SG = Sítio Grande, CA = Cabeçuda Island and SA = Sacová Island. --- denotes an absence.

Plot	Mean d_n (cm)	Height ± stdev (m)	Density (stems.ha^{-1})	Basal Area Contribution (%)			Live Basal Area (m^2.ha^{-1})		
				R.man	*L.rac*	*A.sch*	$d_n<2.5$	$2.5\leq d_n\leq 10$	$d_n\geq 10$
PMP1	2.13	2.02±0.62	38,000	---	95.77	4.23	4.65	7.75	---
PMP2	5.47	3.9±2.68	8,300	26.97	71.06	1.97	0.40	5.45	9.66
PMP3	9.33	5.42±2.59	4,000	29.69	28.31	41.99	0.19	5.00	14.86
PMP4	11.10	5.58±.91	2,925	14.30	2.78	82.92	0.20	2.20	23.02
PMP5	5.04	3.54±1.78	23,500	0.74	99.26	---	1.77	14.66	19.48
PMP6	10.41	4.51±2.63	4,700	30.59	25.22	44.19	0.15	6.75	27.98
BAP1	1.05	1.28±0.16	160,000	---	99.10	0.90	13.93	---	---
BAP2	1.42	1.54+-0.48	112,000	8.16	90.32	1.51	15.98	1.70	---
BAP3	2.41	3.32±0.96	67,500	11.34	85.49	3.17	7.65	13.96	---
BAP4	4.61	4.50±1.24	31,200	0.17	81.92	17.91	1.02	34.03	3.60
BAP5	6.35	7.60±2.25	5,733	5.58	19.61	74.80	0.36	6.25	11.54
BAP6	6.39	6.72±1.16	8,400	90.51	---	9.49	0.05	17.30	1.86
BAP7	3.69	4.90±1.06	21,400	86.14	0.52	13.34	0.71	11.33	1.90
BAP8	5.55	6.81±0.81	18,444	100.00	---	---	---	25.23	---
BAP9	4.47	5.01±1.33	18,800	65.83	34.17	---	0.31	16.05	---
BAP10	2.74	3.71±1.31	43,200	71.79	28.21	---	3.57	13.23	---
BAP11	5.50	6.46±0.88	14,200	96.81	3.19	---	0.17	20.75	---
NOP1	1.63	1.91±0.56	85,556	3.90	96.10	---	11.92	4.86	---
NOP2	2.16	2.93±0.93	106,667	31.49	67.60	0.92	8.26	13.70	---
NOP3	4.01	3.93±1.65	26,000	72.14	27.86	---	1.13	22.09	---
NOP4	4.34	4.78±2.21	22,800	42.61	36.46	20.93	0.87	16.73	1.63
NOP5	6.26	3.60±3.37	7,200	84.39	0.24	15.37	0.75	2.05	17.51
SGP1	2.29	2.45±0.75	67,200	44.91	40.37	14.71	8.04	14.77	---
SGP2	3.12	3.37±0.97	72,133	18.82	64.55	16.62	5.68	36.65	---
SGP3	3.76	4.13±1.03	13,281	100.00	---	---	0.58	13.29	---
SGP4	7.63	7.62±2.79	8,200	100.00	---	---	0.07	28.66	4.17
SGP5	8.23	5.77±2.21	6,100	58.87	28.33	12.80	0.31	7.21	20.66
SGP6	6.58	6.31±2.39	10,900	98.04	---	1.96	0.32	25.21	6.77
CAP1	4.99	3.38±1.23	8,733	11.46	74.14	14.40	0.44	8.95	3.66
CAP2	3.92	3.24±1.28	17,200	14.92	85.08	---	1.07	14.36	---
CAP3	8.07	5.43±2.14	4,100	98.36	1.64	---	0.15	5.26	14.53
CAP4	3.44	2.91±0.95	13,611	16.31	83.69	---	1.66	9.97	---
CAP5	3.95	2.83±0.59	13,061	---	100.00	---	0.46	10.30	---
CAP6	2.88	2.28±0.77	27,200	2.77	97.23	---	1.80	13.56	---
CAP7	5.45	3.65±1.66	14,429	0.39	99.61	---	0.71	15.30	7.95
CAP8	5.08	3.44±1.42	12,245	46.53	53.47	---	0.91	12.22	5.45
CAP9	3.65	2.81±1.22	20,204	62.96	37.04	---	2.26	12.81	2.05
SAP1	5.63	4.06±1.42	6,181	100.00	---	---	0.20	10.91	1.16
SAP2	5.63	3.28±2.23	7,156	36.92	63.08	---	0.50	7.45	6.00
SAP3	6.74	5.34±2.54	4,400	100.00	---	---	0.29	5.33	7.24
SAP4	10.96	4.16±2.35	3,778	23.51	---	76.49	0.15	5.20	24.26

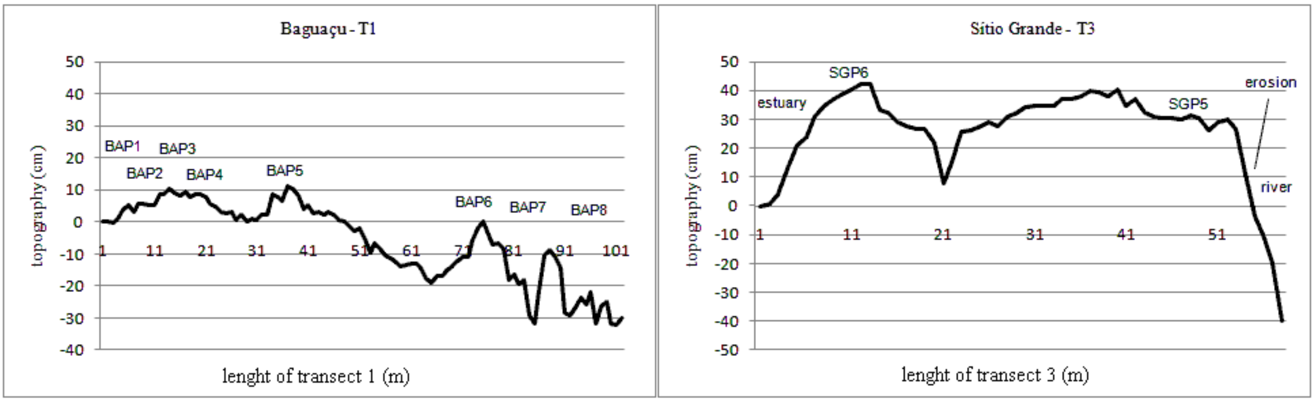

Figure 2. Topography from Baguaçu (transect 1: T1) and Sítio Grande (transect 3: T3) study sites, with location of the plots. We draw the attention to BAP5 (restricted tidal influence, area dominated by *A. schaueriana*), BAP7 and BAP8 (creeklet areas dominated by *R. mangle*) in Baguaçu, and to SGP5 (erosional area dominated by a mixed mangrove forest) in Sítio Grande.

ANALYSIS

Single linkage cluster analysis yields three groups (A, B and C), with high levels of similarity, providing support to the classification of the data into two broad landform categories: depositional and erosive. Group A includes plots with the least structural development (d_n between 1.05 and 4.61cm). Group B is composed of stems of intermediate size (d_n ranging from 4.99 to 5.63cm). Group C plots have the largest structural development (d_n between 5.50 and 11.10cm) (Figure 3 and Table 1).

DISCUSSION

According to Schaeffer-Novelli et al. (1990b), in the Cananéia-Iguape Coastal System, the spatial arrangement of mangroves appear to be a response to underlying topographic and edaphic conditions and constraints imposed by climatic and hydrologic factors. This study highlights that the structural developments of mangrove forests reflects responses to geomorphology as well as habitat change due to the progressive development (maturation) and successional change. Knight et al. (2008) similarly described patterns of tidal flooding within a mangrove forest, in relation with zonation and succession.

The results of the present research indicate that mangrove

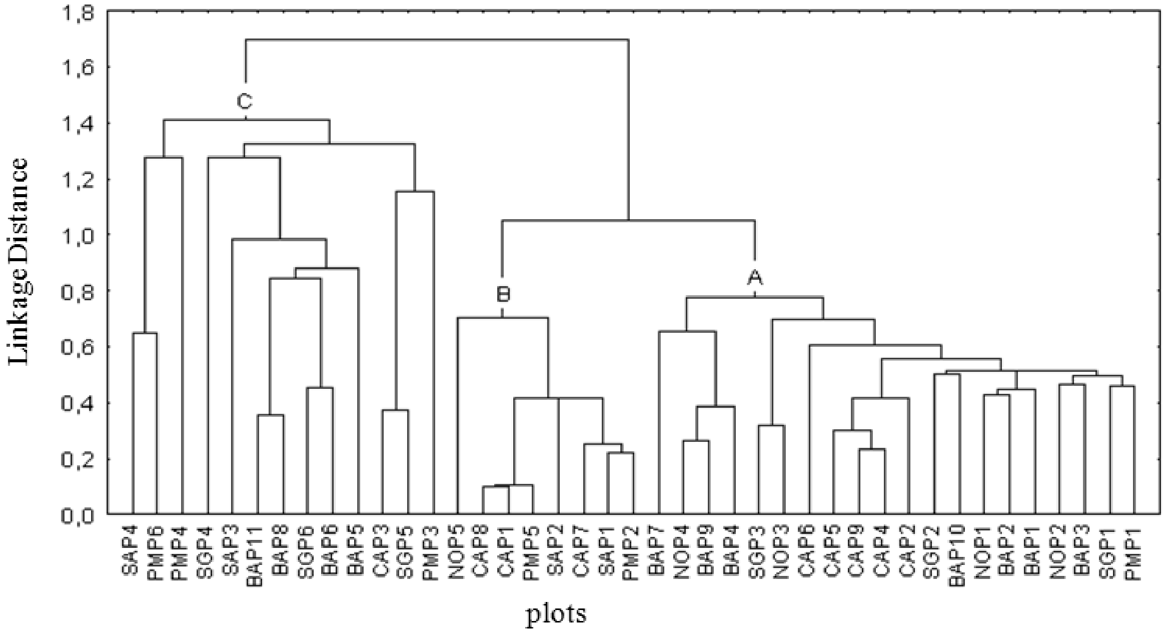

Figure 3. Cluster analysis, considering mean nominal stem diameter (d_n) and mean height values. Clusters A, B and C represent plots with low, intermediate and high structural development, respectively.

forest zonation is a response to depositional and erosive processes and topography, and corroborate the model suggested by Dias-Brito and Zaninetti (1979), in which *L. racemosa* colonizes depositional areas and forms new forest.

In contrast, Lugo (2002) demonstrated that *R. mangle* can be both a pioneer species and a dominant element in a mature forest, as observed by us in the Sítio Grande. The results from our other sites confirm a zonation of mangroves like in French Guiana, with *L. racemosa* in young mangrove areas and *Avicennia* spp. and *Rhizophora* spp. in mature mangrove areas (Fromard et al., 1998).

Our results may prove an invaluable input to simulation models resulting in predictions and in explanations of the processes that control and regulate mangrove forest dynamics (Berger et al., 2008). According to the model developed by Twilley et al. (1999) constraints at higher levels along with mechanisms at lower levels affect bottom-up forest development. Berger et al. (2008) add that such models help mangrove management. Our study indeed implies that sedimentary processes may be site-specific and merit special attention not only in research, but also when conserving and managing mangroves in Brazil and elsewhere.

CONCLUSION

The mangrove forests structure reflects the different development stages of the sedimentary facies in the coastal system, submitted to the distinct subsidiary energies.

In the Cananéia-Iguape Coastal System, *L. racemosa,* with low structural development (low d_n, low height and high density values), dominates in the depositional sites, always associated to the smooth cordgrass *S. alterniflora*. While *R. mangle* and *A. schaueriana*, with high structural development (high d_n, high height and low density values), dominate in erosive sites.

R. mangle occurs, preferentially, in creeklet areas, under important inundation frequency, due to the low level microtopography. *A. schaueriana* colonizes in the high microtopography areas, submitted to a low influence by the tides.

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