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Evaluating Mangrove Conservation through the Analysis of Forest Structure Data

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ABSTRACT

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In Brazil, the National System of Conservation Units addresses the commitments arising from the country's signature and ratification of the Convention on Biological Diversity. This study evaluates the effectiveness of two protected areas (Conservation Units) in Brazil through the analysis of mangrove forest structure data. Structural and functional characteristics of mangrove forests are primarily governed by the interaction of environmental characteristics that act in global, regional and local scales. However, in areas submitted to strong influence of human activities disturbance should be considered seriously. Structural measurements were taken in 43 plots at the Guapimirim Environmental Protection Area and the Guanabara Ecological Station. The main structural characteristics of these forests are: mean diameter at breast height ($\overline{DBH}$): from 3.6 to 12.3 cm; mean height: from 2.7 to 11.6 m; maximum height: from 6.5 to 16.7 m; live basal area: from 8.5 to 24.8 $m^2.ha^{-1}$ and higher than 15 $m^2.ha^{-1}$ at 26 plots; relative basal area of trunks with DBH higher than 10 cm: above 50% at 28 plots and above 40% at 37 plots. The forests studied presented higher structural development than the mangrove areas outside these protected areas reflecting a lower anthropogenic influence. On the other hand, when compared with other mangrove forests from the same segment of the Brazilian coast we noted that this development was not the optimum. The maintenance of these protected areas associated with better management strategies is very relevant to prevent the extinction of the remaining mangrove forests of the Guanabara Bay.

ADITIONAL INDEX WORDS: *Disturbance, Protected Areas, Brazil, Guanabara Bay*

INTRODUCTION

The mangrove species found in a given region interact, according to their physiological requirements and environmental tolerance, to form forests that can be either monospecific or mixed. The prevalent environmental conditions contribute to determine both the domination of a given species by another (SAENGER, 2003) and the degree of structural development of mangrove forests according to the concept of "energy signature" (LUGO and SNEDAKER, 1974; SCHAEFFER-NOVELLI *et al.*, 1990). Nevertheless, in areas under the strong influence of human activity, the effects of disturbances must be seriously taken into consideration. Therefore in these areas the structural and functional characteristics of mangroves will be a result of the interaction between environmental characteristics and man-induced stressors (LUGO and SNEDAKER, 1974).

SOARES *et al.* (2003) point out that this scenario becomes even more complex when dealing with systems submitted to several stressors, as is the case of the Guanabara Bay (Rio de Janeiro, Brazil), where we must consider, besides the individual characteristics of each stressor (including its variability in space-time and intensity), the possibility of synergism.

In this context, the present study evaluates the effectiveness of the implementation of protected areas for the conservation of mangrove forests located under strong anthropogenic pressure (Guanabara Bay, Rio de Janeiro, Brazil), through the analysis of forest structure data.

METHODS

Study Area

The Guanabara Bay is located in the central part of the coast of the state of Rio de Janeiro (Southeastern Brazil) (Figure 1). According to AMADOR (1996), the Guanabara Bay basin measures approximately 4600 km^2, encompassing, besides the water body, regions belonging to 14 municipalities. This region is located in the segment described by SILVEIRA (1964) as a "Coast of crystalline cliffs", which is characterized by the presence of a crystalline basis that approaches or moves away from the shoreline alternately, allowing the formation of extensive quaternary coastal plains such as those in the Guanabara Bay region. According to the classification proposed by SCHAEFFER-NOVELLI *et al.* (1990) for the Brazilian coast, the mangroves of the Guanabara Bay are located in segment VII, which is basically characterized by the geomorphologic attributes described by SILVEIRA (1964), associated with a humid climate and a mean tidal range less than 2 meters. According to CHAVES (2007), the Guanabara Bay region has an average annual precipitation of 1142.9 mm and the annual mean temperature is 23.70°C. The dry period takes place between June and August, with precipitation values below 80 mm, and the rainy period occurs between December and April, with monthly averages above 100 mm.

The Guanabara Bay comprises the second largest Brazilian industrial region, the second largest port, two refineries, oil storage and distribution companies, naval services, dockyards and intense maritime and terrestrial transportation activities.

According to KJERFVE and LACERDA (1993), 40% of the Guanabara Bay mangroves were decimated as the coast underwent a process of intense urbanization. Thus, we have observed that the Guanabara Bay mangroves were gradually destroyed and modified. We can identify as the main processes responsible for the degradation of the Guanabara Bay and associated mangroves: deforestation for different purposes, different types of landfills, slum occupation and urban expansion, rectification, course alteration and canalization of rivers and canals, discharge of domestic sewage and industrial effluents, refineries and port activity, predatory fishing, predatory crab harvesting, garbage from many different sources and urban garbage deposition.

In an attempt to limit the progress of the degradation of the Guanabara Bay mangroves, the Guapimirim Environmental Protection Area (APA Guapimirim), encompassing the main remainders of the Bay's mangroves, was created in 1985. Recently (2006), part of the APA Guapimirim was transformed into the Guanabara Ecological Station (ESEC Guanabara), a category of protected area with more restrictive characteristics regarding its use (Figure 1).

Although the Guanabara Bay mangroves are associated with Brazil's second largest urban center and the largest urban/industrial center in the Brazilian coast, the available studies related to the structure and function of the Bay's mangrove forests are quite scarce. Recently, SOARES (2002) e SOARES *et al.* (2003) developed quantitative studies on the Guanabara Bay mangroves. However, all these studies were limited to the forests located in the west side of the Guanabara Bay and within the northern and southern limits of the APA Guapimirim, where the anthropogenic pressures on the mangrove forests are felt more intensely. The present study favored data collection specifically in the innermost region of the APA Guapimirim and in the ESEC Guanabara (Figure 1).

Forest Structure

The methodology adopted for the characterization of the forest structure of mangroves is presented by CINTRON & SCHAEFFER-NOVELLI (1984).

Forty-three sampling stations were established in the innermost area of the APA Guapimirim and in the ESEC Guanabara (Figure 1), in which plots of 112 m^2 to 324 m^2 were delimited according to forest density, so as to display a representative number of individuals as well as their homogeneity in terms of structural characteristics (species composition and structural development of individuals). All individuals (height > 1m) had their heights and diameter at breast height (DBH) of each trunk measured. Individuals were identified according to their species and condition of their trunks (alive or dead).

Once the field data was available, for each sampling station the mean forest height (m), maximum height (m), mean diameter at breast height $\overline{DBH}$ (cm), basal area ($m^2.ha^{-1}$), density of trunks ($tr.ha^{-1}$), relative density (%) of each species, contribution in basal area (%) of living trunks with DBH higher than 10.0 cm and contribution in basal area (%) of dead trunks were calculated.

Analysis of the Conservation of Mangrove Forests

The analysis of the state of conservation of the mangroves in protected areas was based on the comparison between the structural data obtained in this work and studies developed in the Guanabara Bay (GB) outside the protected areas, especially those by SOARES (2002) and SOARES *et al.* (2003), and in other mangroves in the state of Rio de Janeiro belonging to segment VII (see Methods). SOARES *et al.* (2003) studied 30 forests distributed among the Duque de Caxias, Suruí, São Gonçalo, New Orleans and Piedade regions. Although these three latter regions are located within the northern and southern limits of the APA, they were considered representative of mangroves outside protected areas on account of the anthropogenic pressures observed (Figure 1).

Comparison with Guanabara Bay Forests

The following variables were selected for the comparison with the data obtained by SOARES (2002) and SOARES *et al* (2003) in mangrove forests of the Guanabara Bay (30 plots), outside the APA/ESEC area: $\overline{DBH}$ (cm), mean height (m), live basal area ($m^2.ha^{-1}$), contribution of live basal area of trunks with DBH higher than 10 cm (%) and contribution of dead basal area (%).

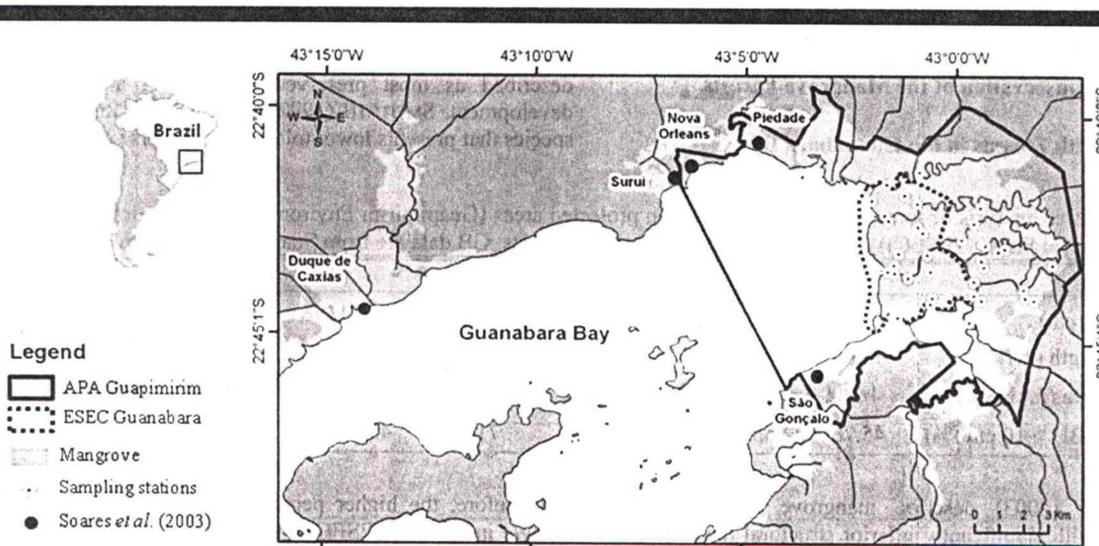

Figure 1. Map of Guanabara Bay indicating the location of sampling stations at Guapimirim Environmental Protection Area (APA) and Guanabara Ecological Station (ESEC). The sites studied by Soares *et al.* (2003) are also marked.

Student's t test ($p<0.01$) was used to compare the mean between groups. For not normally distributed variables (dead basal area %) we used the Mann-Whitney U test ($p<0.01$) (ZAR, 1996).

Finally, an exercise of simulation of theoretical scenarios and a comparison with the obtained data for the Guanabara Bay forests were conducted. With this objective, the following relation between density (trunks.0.1ha^{-1}) and $\overline{DBH}$ (cm), proposed by JIMENEZ *et al.* (1985), on the basis of a study of 114 mangrove forests in the Americas, was used:

$$\ln(density) = 8.92212 - 1.4934 \times \ln(\overline{DBH}) \qquad (1)$$

The APA/ESEC forests were also compared with the other Guanabara Bay forests regarding species composition. Relative density, as conducted by SOARES *et al.* (2003), was used to define the dominant species in each plot. The species whose trunk density (alive and dead) was higher than 50% was considered dominant. When the dominant species was not identified the forest was considered mixed.

Comparison with Mangrove Forests in Segment VII of the Brazilian Coast

According to SCHAEFFER-NOVELLI *et al.* (1990), the mangrove forests that develop in each segment of the Brazilian coast are subjected to similar environmental conditions in a regional scale. Thus, considering the variability of local factors intrinsic to the studies conducted, the comparison among forests of different systems in the state of Rio de Janeiro gives us an idea of the potential structural development of the segment. In this work only the parameters $\overline{DBH}$, mean height, and live basal area were used for comparison with other forests in the state of Rio de Janeiro, belonging to this Segment VII.

RESULTS AND DISCUSSION

Forest Structure

The main structural characteristics of the mangrove forests in the APA/ESEC are: (1) $\overline{DBH}$ from 3.6 to 12.3 cm; (2) mean height from 2.7 to 11.6 m; (3) maximum height from 6.5 to 16.7 m; (4) live basal area from 8.5 to 24.8 m^2.ha^{-1}, being higher than 15 m^2.ha^{-1} at 26 sites; (5) contribution in basal area of trunks with DBH higher than 10 cm, above 50% in 28 plots and above 40% in 37 plots.

Analysis of the Conservation of the Mangrove Forests

Comparison with Forests in the Guanabara Bay

When analyzing the contribution in basal area of dead trunks (Figure 2) we notice that the forests of the Guanabara Bay present a greater ($p<0.01$) contribution of dead trunks, a fact that itself can be an indicator of higher anthropogenic pressures (JIMENEZ *et al.* 1985). According to JIMENEZ *et al.* (1985), the density and dead basal area in a forest are extremely variable, depending on several factors such as: rate of tree growth, intensity and frequency of stress periods, geomorphologic stability, decaying rate of dead wood, and initial diameter of tree. Therefore, it is very difficult to establish a reference for such values. However, the analysis of the data obtained by these authors shows a domain of forests with contribution of dead basal area lower than 20% when free of anthropogenic influence, a situation observed inside the studied protected areas.

When we compare the $\overline{DBH}$ and the density data obtained in this work and by SOARES *et al.* (2003) with the model proposed by JIMEMEZ *et al.* (1985) (Figure 3), we notice that the lower structural development of the forests located outside the APA/ESEC is accompanied by more cases where the density values (trunks.ha^{-1}) distance themselves from the expected curve, to a certain $\overline{DBH}$. According to JIMEMEZ *et al.* (1985), density varies in accordance with the forest's age and maturity. As it matures, a forest tends to become dominated by an ever smaller number of individuals of larger size, on account of the competition for space and of the development of the roots system.

Thus the pattern found, of a wider distribution of values observed for the forests located outside the protected areas than that expected for the model, can represent degraded forests or forests in a process of regeneration (secondary succession). When the trunks density is much lower than that expected for a given $\overline{DBH}$, it is assumed that the available space is not being occupied by mangrove species, a fact that can indicate altered areas.

Regarding the dominant species in the forests of the APA/ESEC, the highest structural development observed is associated with the domain of *Rhizophora mangle* (Table 2). SOARES (2002) and SOARES *et al.* (2003) also describe the higher contribution of *R. mangle* in forests located in less degraded regions. The occurrence of this species is a strong indicator of better preserved forests, since, according to DANSEREAU (1947), OLIVEIRA (1947) and ARAÚJO and MACIEL (1979), the same species once dominated the fringes of mangroves in the Guanabara Bay. Analyzing the results presented by SOUZA and SAMPAIO (2001) for the mangroves of Suape (northeast Brazil) we notice that basically the stations dominated by *R. mangle* are those described as most preserved and having a higher structural development. SMITH III (1992) also mentions that *R. mangle* is a species that presents lower tolerance to adverse conditions.

Table 1: Comparative analysis of forest structure data between protected areas (Guapimirim Environmental Protection Area (APA) and Guanabara Ecological Station (ESEC)) and other Guanabara Bay (GB) forests. GB data are from Soares (2002) and Soares *et al.* (2003).

	APA/ESEC	GB	df	t	p
$\overline{DBH}$ (cm)	8.38 ± 1.96	5.07 ± 1.53	71	7.751398	< 0.01
Mean heigth (m)	7.46 ± 1.96	4.86 ± 1.38	71	6.238943	< 0.01
Live basal area (m^2.ha^{-1})	16.04 ± 3.92	13.20 ± 4.87	71	2.750430	< 0.01
Live basal area DBH > 10 cm (%)	45.76 ± 22.55	21.70 ± 20.73	71	4.634716	< 0.01

SOARES *et al.* (2003) describe mangrove forests in the Guanabara Bay with significantly inferior structural development to those obtained in the APA/ESEC, as expressed in the analysis presented in Table1.

Therefore, the higher percentage of forests dominated by *R. mangle* in the APA/ESEC in relation to the GB (Table 2) is one more indicator of their better state of conservation. On the other hand, several authors (PARADIS, 1979; TOMLINSON, 1986;

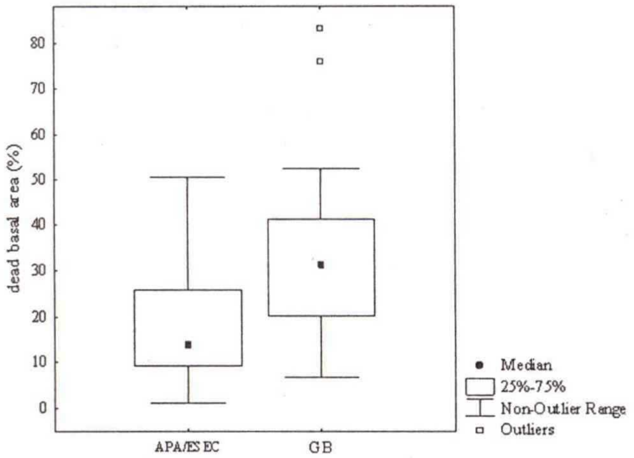

Figure 2. Contribution in basal area (%) of dead trunks in protected areas (Guapimirim Environmental Protection Area (APA) and Guanabara Ecological Station (ESEC)) and in other Guanabara Bay (GB) forests. GB data are from Soares (2002) and Soares *et al.* (2003).

SOARES,1999; Souza and Sampaio, 2001) consider *Laguncularia racemosa* as presenting opportunistic behavior, being typical of regeneration processes in degraded forests.

Comparison with Mangrove Forests in Segment VII of the Brazilian Coast

We can verify the structural change in some mangroves in the Guanabara Bay when we compare the results obtained in this study with data from other mangroves in the state of Rio de Janeiro. PELLEGRINI (2000) and CHAVES (2001) describe forests in a good state of conservation in the Sepetiba Bay having a $\overline{\text{DBH}}$ between 7.37 cm and 15.19 cm and a mean height between 6.76 m

Table 2: Percentage of forests dominated by one species or mixed forests in protected areas (Guapimirim Environmental Protection Area (APA) and Guanabara Ecological Station (ESEC)) and in other Guanabara Bay (GB) forests. GB data are from Soares *et al.*, 2003). n = number of plots.

Dominant species	APA/ESEC (n=43)	GB (n=30)
Avicennia schaueriana	9.3%	30.0%
Laguncularia racemosa	16.3%	33.3%
Rhizophora mangle	65.1%	16.7%
mixed	9.3%	20.0%

and 9.57 m, while SILVA (1988) and SILVA *et al.* (1991) describe a forest with a $\overline{\text{DBH}}$ of 7.8 cm and a mean height of 6.1 m. These values are sufficiently higher than those in the mangrove forests of the Guanabara Bay described by SOARES *et al.* (2003), being compatible with the mangrove forests in the APA Guapimirim and in the ESEC Guanabara. This comparison corroborates the better conservation of the mangroves in the protected areas located in the eastern section of the Guanabara Bay. Likewise, for the Tijuca Lagoon, forests have been described whose structure is possibly similar to that of the original forests (SOARES, 1999). In these sites forests can be found with $\overline{\text{DBH}}$ between 6.83 cm and 16.67 cm and mean height of trees that occupy the upper forest stratum between 7.32 m and 16.13 m.

It is important to consider that although the status of the mangroves located in the eastern region of the Guanabara Bay is much better than those in other areas of the Bay, and although the structural parameters of these forests, such as $\overline{\text{DBH}}$ and mean height, have values more compatible with other mangrove forests in the state of Rio de Janeiro, a detailed analysis demonstrates that the values of live basal area found in the APA Guapimirim and the ESEC Guanabara are in general sufficiently inferior to those observed for other mangrove forests in Rio de Janeiro.

SOARES (1999) presented values between 14.3 and 41.4 $m^2.ha^{-1}$

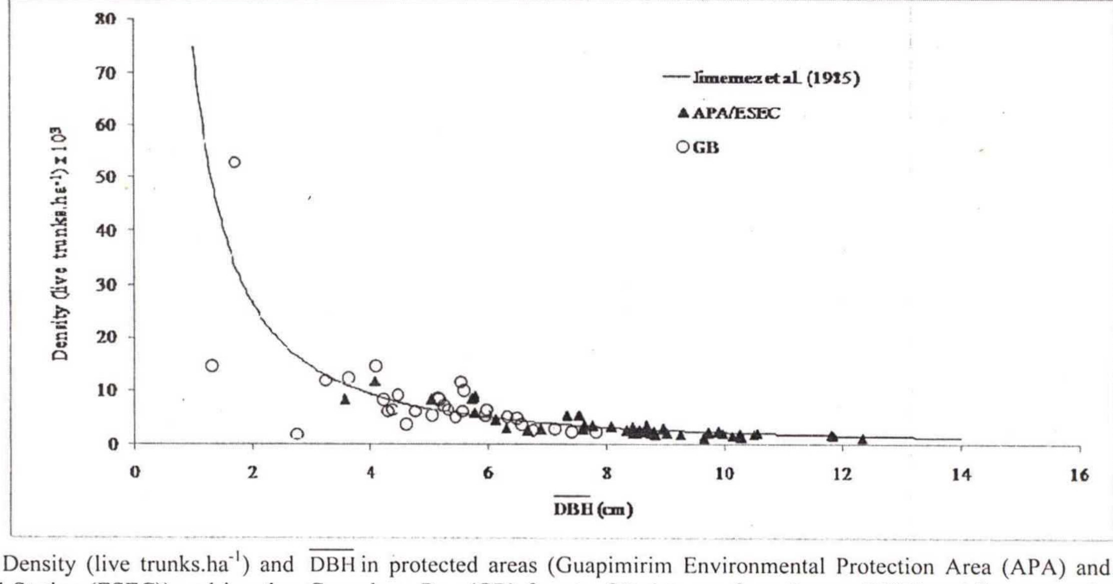

Figure 3. Density (live trunks.ha^{-1}) and $\overline{\text{DBH}}$ in protected areas (Guapimirim Environmental Protection Area (APA) and Guanabara Ecological Station (ESEC)) and in other Guanabara Bay (GB) forests. GB data are from Soares (2002) and Soares *et al.* (2003). The theoric curve represents the relation proposed by Jimenez *et al.* (1985): $y = 74960\ x^{-1,493}$.

for the mangroves in the Tijuca Lagoon, and PELLEGRINI (2000) and CHAVES (2001) presented values between 11.6 and 61.7 $m^2.ha^{-1}$ for mangroves in the Sepetiba Bay. These results, together with the high variability of dead basal area (Figure 2), indicate that although these remainders of mangroves present a better state of conservation in relation to those located in other areas of the Guanabara Bay, they also reflect, in their structure, a strong influence of anthropogenic disturbances, which can eventually jeopardize the integrity of these important preservation areas. This is corroborated by the observation of mangrove forests in the APA Guapimirim and ESEC Guanabara, where we can notice a high physiognomic diversity, with well developed forests, degraded forests, gaps, forests in different states of regeneration and areas occupied by invader species (e.g. *Acrostichum aureum*).

CONCLUSION

The results have shown that the Guanabara Bay mangroves do not present the potential structural development expected for forests located in this segment of the Brazilian coast, being this scenario attributed to the action of several anthropogenic tensors on the system. However, it was observed that forests within the Guanabara Bay differ significantly regarding their main structural parameters, with the most developed ones located within the protected areas (APA Guapimirim and ESEC Guanabara). Associated to this higher development, relations were verified between $\overline{\text{DBH}}$ and density close to what was expected for better preserved forests. A domain of *R. mangle* was also observed in the protected areas, against a domain of *L. racemosa* in the other forests of the bay, pointing to a higher incidence of disturbances in the latter.

Therefore, we can conclude that the creation of protected areas has constituted an important and effective mechanism to limit the action of anthropogenic disturbances. We can also conclude that the adequate maintenance and management of these areas are essential for the preservation of the remaining mangroves of the Guanabara Bay.

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