Habitat disturbance in the Brazilian coastal sand dune vegetation and related richness and diversity of bromeliad species

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Abstract – We analyzed the level of disturbance and related bromeliad richness and diversity in 15 coastal sand dune habitats ("restingas") of the Atlantic Rainforest of Brazil, along 1,500 km, covering the states of Rio de Janeiro, Espírito Santo and Bahia.. The restingas varied greatly in disturbance level, but most fit under at least one type of disturbance. Bromeliad richness and diversity also varied accordingly, with the relationships between bromeliad species richness and disturbance level and between bromeliad diversity and disturbance being both negative. This indicates that bromeliads are strongly affected by human disturbance in restinga habitats. Bromeliads are organisms particularly important for the biodiversity of the ecosystem they live in, due to the increase of available microhabitats within the bromeliad for the establishment of fauna and flora. The increasing degradation of restinga habitats results in a loss of bromeliad species and because bromeliads directly affect many other forms of life, such loss results in a decrease of a large portion of biodiversity in Atlantic Rainforest habitat.

Key words: restinga disturbance, biodiversity decrease, bromeliad richness.

Resumo – Estudamos a relação entre o nível de distúrbio e a riqueza e diversidade de espécies de bromélias em 15 restingas da Mata Atlântica do Brasil, ao longo dos 1.500 km do litoral, incluindo os Estados do Rio de Janeiro, Espírito Santo e Bahia. As restingas estão sob diferentes níveis de distúrbio, mas a maioria se enquadrou em no mínimo um tipo de distúrbio. A riqueza e a diversidade de bromélias também variou entre as restingas, e a relação entre a riqueza de bromélias e o nível de distúrbio foi negativa, assim como a relação entre a diversidade de bromélias e o distúrbio. Isto indica que as bromélias são afetadas pelos distúrbios antrópicos ocorridos nas restingas. Bromélias são organismos particularmente importantes para a biodiversidade do ecossistema no qual estão inseridas, pois promovem o aumento de microhabitats disponíveis na bromélia para o estabelecimento da fauna e da flora. O aumento da degradação das restingas resulta na perda de espécies de bromélias, e a perda destas, por sua vez, ocasionam a diminuição de uma grande porção da biodiversidade deste hábitat da Mata Atlântica, pois as bromélias afetam diretamente muitas outras formas de vida.

Palavras-chave: degradação de restingas, redução da biodiversidade, riqueza de bromélias.

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INTRODUCTION

Most of the Brazilian coast is covered by "restingas," coastal sand dune habitats covered by herbaceous and shrubby vegetation adapted to saline soils (Lacerda *et al*. 1984; Araújo, 1992). Restingas are located in lowland coastal portions and are considered marginal habitats of the Atlantic Rainforest Domain (Scarano, 2000), a biome with high biodiversity considered one of the biodiversity "Hot Spots" of the world (Myers *et al*., 2000). The restinga habitat occupies approximately 5,000 km along the Brazilian coast, from the northern state of Pará to the southern state of Rio Grande do Sul, presenting marked differences in its phyisiognomy, structure and floristic composition (Lacerda *et al*., 1984; Araújo, 2000, Rocha & Bergallo, 1997), as well as considerable species diversity (Rocha *et al*., 2003), especially of plants (Araújo, 2000).

The coastal region is where most of the Brazilian human population has settled and has been explored for the last five centuries. According to recent data (MMA/SBF, 2002), the coastal region has the highest demographic density in Brazil. As a result, degradation of restinga habitats is increasing along a large extent of the Brazilian coast at alarming rates (Rocha & Bergallo, 1997; Araújo & Lacerda, 1987, Rocha *et al*., 2003), supposedly leading to decreasing richness of many groups of organisms.

One of the most representative plant families of restinga habitats is Bromeliaceae (Cogliatti-Carvalho *et al*., 1998; Freitas *et al*., 2000; Araújo, 2000; Cogliatti-Carvalho *et al*., 2000). Bromeliads are organisms particularly important for the biodiversity of the ecosystem they live in, for exhibiting many characteristics that facilitate the life of many organisms: i) they have complex architectures (Oliveira *et al*., 1994; Oliveira & Rocha, 1997; Rocha *et al*; 2004a) which provide microhabitats for many other organisms; ii) many bromeliad species (called tank-bromeliads) store free water, an important element for the complete or partial life cycle of many microscopic and macroscopic organisms (Medina, 1974; Rocha *et al*., 1996; Rocha *et al*., 2000; 2004a); iii) they provide shelter for many vertebrate and invertebrate species (Oliveira *et al*., 1994; Rocha *et al*., 2004a); iv) they provide a germination site for many plant species, what is especially important in arid environments such as restinga habitats (Macedo & Monteiro, 1987; Fialho, 1990; Fialho & Furtado, 1993; Rocha *et al*., 2004a); and v) because of their architecture, decomposing leaves concentrate at their base, providing a richer soil around the rosette (Hay *et al*., 1981). The result of the interaction of these characteristics is that a bromeliad constitutes an important source of life for many organisms (see Rocha *et al*., 2000; 2004a). The increasing degradation of restinga habitats leads to a loss of bromeliad species and because bromeliads directly affect many other forms of life, their loss has a cascading effect on a large portion of biodiversity in this habitat of the Atlantic Rainforest. The idea that disturbance reduces species diversity is expected, but the situation of the bromeliads in Brazilian restingas is a good study case since restingas are very important and fragile habitats in one of the world's most important hot spots.

Because many bromeliad species are particularly sensitive to anthropic habitat change due to change in temperature, light intensity and humidity (Benzing, 1980; Cogliatti-Carvalho *et al*., 1998; Cogliatti-Carvalho *et al*., 2000), the degradation to which most restingas are subjected (Araújo, 1991) may have a negative effect on each local bromeliad community.

In the present study we aimed to evaluate the effect of degradation on restinga habitats along the Brazilian coast, specifically addressing the following questions: i) what are the main sources of habitat degradation in the restingas studied? ii) is there a relationship between degradation level and bromeliad species richness and diversity in the different restinga habitats?; iii) are there differences between protected and non-protected restingas?

MATERIAL AND METHODS

The effect of level of disturbance on present bromeliad richness was analyzed at 15 restinga habitats on approximately 1,500 km of the Brazilian coast. We studied the bromeliad communities of the restingas of Praia do Sul, Grumari, Barra da Tijuca, Barra de Maricá, Massambaba, Jurubatiba and Grussaí ithe state of Rio de Janeiro; Neves, Setiba and Guriri in Espírito Santo, and Prado, Trancoso, Ilhéus, Abaeté and Baixio in Bahia (Table 1).Samples were collected from each restinga at different vegetation zones from the beach area up to 400 m inland. Sampling was limited to sandy soil vegetation zones of the restinga, not including rock shore habitats. To estimate bromeliad richness at each restinga, samples were collected of 100 plots, each measuring 100 m^2 (10 x 10 m), arranged at ran-

RESTINGA	COORDINATES	STATE	LEVEL OF DISTURBANCE	SPECIES RICHNESS	SPECIES DIVERSITY
Praia do Sul[4]	23° 11' S, 44° 12' W	RJ	1	15	0.651
Grumari[4]	23° 02' S, 43° 31' W	RJ	13	14	0.752
Barra/Jacarepaguá	23° 00' S, 43° 24' W	RJ	24	2	0.142
Maricá[4]	22° 57' S, 42° 51' W	RJ	12	7	0.447
Massambaba[4]	22° 56' S, 42° 12' W	RJ	12	8	0.445
Jurubatiba[4]	22° 17' S, 41° 41' W	RJ	4	10	0.806
Grussaí	21° 44' S, 41° 01' W	RJ	10	7	0.259
Neves	21° 15' S, 40° 57' W	ES	7	10	0.713
Setiba[4]	20° 34' S, 40° 26' W	ES	12	14	0.676
Guriri	18° 40' S, 39° 44' W	ES	*8*	6	*0.478*
Prado	17° 18' S, 39° 13' W	BA	20	7	0.330
Trancoso	16° 39' S, 39° 05' W	BA	7	10	0.426
Ilhéus	14° 47' S, 39° 02' W	BA	23	2	*
Abaeté	12° 56' S, 38° 21' W	BA	22	4	0.162
Baixio	11° 53' S, 37° 38' W	BA	8	7	0.378

Table 1 – Location, level of disturbance, species richness and diversity (H') of the restingas located s along the coast of the states of Rio de Janeiro, Espírito Santo and Bahia in eastern Brazil. The level of disturbance is the sum of scores attributed to each of the disturbance categories at each restinga area. (4) indicates that the restinga encompasses Conservation Unit.

(*) At Ilhéus only bromeliad species richness was recorded. The disturbance level at that restinga limited plot sampling.
RJ = Rio de Janeiro; ES = Espírito Santo; BA = Bahia

dom along the restinga. The plots were marked using wooden stakes and string, and the area inside the plot was carefully checked for bromeliads. When a bromeliad species was found, it was identified and the number of individuals per plot was counted [the detailed methodology is described by Nunes-Freitas *et al*. (2000) and Cogliatti-Carvalho *et al*. (2001)]. Species richness (S) was defined as the number of bromeliad species recorded at each restinga. Bromeliad diversity was also estimated for each restinga, using the Shannon diversity index ($H' = - \Sigma p_i \ln p_i$) where p_i is the relative abundance of each bromeliad species in the bromeliad community of the restinga.

To estimate habitat disturbance level in relation to the observed values of bromeliad richness and diversity, we defined a disturbance index based on the 15 commonest human activities causing disturbance as observed in the restinga habitats: 1) removal of vegetation due to construction of coastal roads; 2) removal of vegetation due to construction of sidewalks; 3) destruction of vegetation due to trampling on vegetation to gain access to the beach area; 4) occupation due to urbanization; 5) establishment of housing; 6) traffic of vehicles on sand dune vegetation; 7) removal of vegetation for the establishment of volleyball or football sand courts; 8) removal of vegetation for the establishment of

commercial trailers; 9) evidence of extraction of plant species of gardening/landscaping interest; 10) removal of original vegetation for establishment of plantations (e.g. manioc, sugar cane); 11) evidence of sand removal for building purposes; 12) littering on vegetation; 13) occurrence of multiple trails on vegetation for access to the beach; 14) car parking on vegetation. We identified the occurrence of each of these disturbance categories by visual observation during field work at each sampled area. For each item we attributed the value (0) if the disturbance was not observed at that restinga, (1) if the disturbance occurred but was comparatively low when compared to those at the other restingas, and (2) if the disturbance level relative to that item was comparatively high, locally. We recorded the values for each of the above items at each restinga and used the sum of the values as the disturbance index. We tested for the significance of the relationship between disturbance level and bromeliad species richness and diversity in the restinga areas using linear regression analysis (Zar, 1999).

To evaluate for a possible effect of the conservation level of a particular area as a function of its inclusion in a Conservation Unit, differences were tested at the level of anthropic disturbance, richness and diversity among protected and non-protected areas using the t- test (Zar, 1999).

RESULTS

The restingas varied greatly in level of disturbance (Table 1), but most had at least one type of disturbance. Some restingas found under relatively low disturbance level were conservation units, although the less disturbed restingas were not always necessarily conservation units (Table 1).Species richness and diversity in some conservation units were usually comparatively high, although the higher values of these parameters were not necessarily restricted to restingas in conservation units (Table 1). The most disturbed restingas were those having the lowest bromeliad richness and diversity (Table 1).

The relationship between bromeliad species richness and level of disturbance was negative and significant (R^2 = 0.493; $F_{1,12}$ = 12.618; P = 0.004; figure 1a) similarly to the relationship between disturbance and bromeliad diversity (R^2 = 0.466; $F_{1,12}$ = 10.461; P = 0.007; figure 1b). These results indicate that bromeliads are strongly affected by the level of disturbance in restinga habitats and that approximately 50% of bromeliad richness and 47% of bromeliad species diversity in restingas can be explained by the disturbance level to which they are subjected.

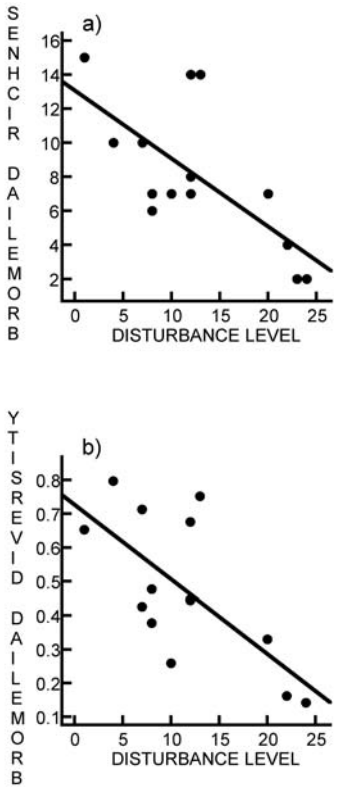

Table 1 – Relationship between (a) level of disturbance and bromeliad species richness (R^2 = 0.493; $F_{1,12}$ = 12.618; P = 0.004) and (b) level of disturbance and bromeliad diversity (R^2 = 0.466; $F_{1,12}$ = 10.461; P = 0.007) at 15 restingas along the Brazilian coast.

There were no differences in anthropic disturbance (t-test, P = 0.083; t = -1.878; df = 13) between protected and non-protected restingas. However, non-protected and protected restingas differed significantly in terms of bromeliad species richness (t-test, p = 0,008; t = 3,131; df = 13) and bromeliad diversity (t-test, p = 0,014; t = 2,882; df = 12), indicating that presently, the protected areas tend to keep a higher number of species of bromeliads compared to non-protected areas.

DISCUSSION

The data indicated that there is a negative effect of the anthropic disturbance on the bromeliad communities of Brazilian costal restingas. The intense soil use and the different forms of degradation caused by humans may result in diversity loss, causing qualitative and quantitative changes in the flora (Kim *et al*., 2002). Lacerda *et al*. (1993) suggest that the restingas have been under anthropic disturbances for many centuries but the highest degradation levels have occurred within the last 50 years. As a result of the restingas being fragile systems (Scarano, 2000), the occurrence of high levels of disturbance may have led to a marked decrease in the diversity of different plant and animal groups (Rocha *et al*., 2003; 2004b), including bromeliads, especially due to their sensitivity to changes in microclimatic environmental conditions (Benzing, 1980; Cogliatti-Carvalho *et al*., 1998; 2000).

The differences between protected and non-protected restinga areas indicate that the establishment of Conservation Units may reduce or inhibit the levels of anthropic interference. In an analysis made by Rocha *et al*. (2003), a similar trend was found for different vertebrate groups, indicating that Conservation Units seem to be an important mechanism of protection of restinga habitats.

Although the restingas of Grumari and Praia do Sul had similar species richness value (14 and 15, respectively), these areas differed consistently in terms of anthropic levels (15 and 1, respectively; Table 1). This may be explained by the differences in extent of time and nature of protection between the two areas. Praia do Sul is an Integral Protection Unit (not opened or allowed for population use) and was established in the 1970s, whereas Grumari was recently established (1986) and is a Sustainable Use Unit (an Environmental Protection Area, where different land uses are allowed). These differences may result from the differences in the protection level of these Conservation Units.

The lack of disturbance levels among protected and non-protected areas may result from differences in the category and level of protection of the Conservation Units (Integral Protection Unit or Sustainable Use Unit). Also, it indicates that the establishment of Conservation Units alone is not sufficient to maintain bromeliad species diversity in different restinga areas, with additional actions being needed, such as increasing the size of protected areas, conducting further studies and sampling as well as elaborating socio-environmental diagnoses.(Rocha *et al*., 2003).

Most Brazilian restingas are subjected to severe human impact, leading to loss of many species (Araújo 1991; Rocha *et al*., 2003). Famous restinga areas such as Copacabana and Ipanema Beaches in the city of Rio de Janeiro were originally extensive sand dune habitats until the early 20th century, and are now urban areas where local vegetation remnants are represented by only a few fragments of a thin strip of beach vegetation, 1 to 4 m wide. Today, no bromeliads are found in these areas (except for the surrounding hills partially covered by the Atlantic Forest), although voucher specimens of some bromeliad species recorded there are deposited in the herbarium of the Museu Nacional do Rio de Janeiro (R). Due to intense human occupation of Brazil's coastal region, the future of many of the restingas investigated in this study may follow the same course Copacabana and Ipanema restingas did, if strong conservation measures are not taken urgently.

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