

Frog species richness, composition and β -diversity in coastal Brazilian restinga habitats

Rocha, CFD. *, Hatano, FH., Vrcibradic, D. and Van Sluys, M.

Departamento de Ecologia, Instituto de Biologia Roberto Alcântara Gomes – IBRAG, Universidade do Estado do Rio de Janeiro – UERJ, Rua São Francisco Xavier 524, Maracanã, CEP 20550-019, Rio de Janeiro, RJ, Brazil

*e-mail: cfdrocha@uerj.br

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(With 3 figures)

Abstract

We studied the species richness and composition of frogs in 10 restinga habitats (sand dune environments dominated by herbaceous and shrubby vegetation) along approximately 1500 km of coastal areas of three Brazilian States: Rio de Janeiro (Grumari, Maricá, Massambaba, Jurubatiba and Grussaí), Espírito Santo (Praia das Neves and Setiba) and Bahia (Prado and Trancoso). We estimated β -diversity and similarity among areas and related these parameters to geographic distance between areas. All areas were surveyed with a similar sampling procedure. We found 28 frog species belonging to the families Hylidae, Microhylidae, Leptodactylidae and Bufonidae. Frogs in restingas were in general nocturnal with no strictly diurnal species. The richest restinga was Praia das Neves (13 species), followed by Grussaí and Trancoso (eight species in each). The commonest species in the restingas was *Scinax alter* (found in eight restingas), followed by *Aparasphenodon brunoi* (seven areas). Our data shows that richness and composition of frog communities vary consistently along the eastern Brazilian coast and, in part, the rate of species turnover is affected by the distance among areas. Geographic distance explained approximately 12% of species turnover in restingas and about 9.5% of similarity among frog assemblages. Although geographic distance somewhat affects frog assemblages, other factors (e.g. historical factors, disturbances) seem to be also involved in explaining present frog assemblage composition in each area and species turnover among areas. The frog fauna along restinga habitats was significantly nested (matrix community temperature = 26.13°; $p = 0.007$). Our data also showed that the most hospitable restinga was Praia das Neves and indicated that this area should be protected as a conservation unit. Frog assemblage of each area seems to partially represent a nested subset of the original assemblage, although we should not ignore the importance of historical factors. This nestedness pattern, in part, probably results from the intensive fragmentation of restinga habitats. Possibly, many frog species may have been lost in some studied areas as a result of the extensive habitat degradation to which restinga habitats are presently exposed.

Keywords: Restinga habitats, Atlantic forest, frog richness, frog assemblages, faunal similarity.

Riqueza de espécies, composição e diversidade de anfíbios anuros em ambientes de restingas costeiras no Brasil

Resumo

Estudamos a riqueza de espécies e a composição de anuros em 10 habitats de restinga (ambientes de dunas e praias arenosas dominadas por vegetação herbácea e arbustiva), ao longo de aproximadamente 1500 km da costa de três estados brasileiros: Rio de Janeiro (Grumari, Maricá, Massambaba, Jurubatiba e Grussaí), Espírito Santo (Praia das Neves e Setiba) e Bahia (Prado e Trancoso). Estimamos a diversidade beta (β) e a similaridade entre as áreas e relacionamos estes parâmetros com a distância geográfica entre áreas. Todas as áreas foram estudadas com um esforço de amostragem similar. Nas restingas, encontramos um total de 28 espécies de anuros pertencentes às famílias Hylidae, Microhylidae, Leptodactylidae e Bufonidae. Os anuros nas restingas foram de forma geral noturnos não tendo sido encontradas espécies estritamente diurnas. A restinga com maior riqueza de anuros foi a da Praia das Neves (13 espécies), seguida das de Grussaí e de Trancoso (8). A espécie mais comum nas restingas foi *Scinax alter* (encontrada em 8 restingas), seguida por *Aparasphenodon brunoi* (7). Os dados mostram que a riqueza e a composição das assembléias de anuros variam consistentemente ao longo das restingas da costa leste do Brasil e que a taxa mudança na composição de espécies foi afetada, em parte, pela distância geográfica entre as áreas. A distância geográfica explicou aproximadamente 12% da mudança de espécies nas restingas e cerca de 9,5% da similaridade entre assembléias de anuros, mas outros fatores (e.g. fatores históricos, distúrbios) parecem estar também envolvidos para explicar a assembléia de anuros em cada área e a taxa de substituição entre as áreas. A fauna de anuros ao longo das restingas mostrou-se significativamente hierarquizada

(temperatura da matriz da comunidade = 26,13°; $p = 0,007$). A área de restinga mais hospitaleira entre as estudadas foi a da Praia das Neves, indicando que essa área deveria ser protegida como uma Unidade de Conservação. A fauna de anuros em cada área parece representar parcialmente um subconjunto hierárquico da assembléia original, embora não se possa ignorar a importância dos fatores históricos. Esse padrão hierarquizado provavelmente resulta da intensa fragmentação dos habitats de restinga. Provavelmente, muitas espécies de anuros podem ter sido perdidas em algumas das áreas estudadas, como resultado do extenso processo de degradação a que as restingas se encontram submetidas.

Palavras-chave: Restingas, Mata Atlântica, riqueza de anuros, assembléias de anuros, similaridade de fauna.

1. Introduction

The area along the coast of Brazil has been intensively occupied and modified by man in the last five centuries and today it is the most densely occupied region of the country (Rocha et al., 2003; 2005). Coastal areas are dominated by sand dune habitats covered with herbaceous and shrubby vegetation, known as “restingas”. These habitats belong to the Atlantic Rainforest biome, which is considered one of the so-called “hotspots” of the world (Myers et al., 2000). As a result of a set of disturbances continuously imposed on these habitats, most of their original area has been degraded and a large portion of it was lost (Rocha et al., 2003; 2005). The present coastal region is composed of many fragments of restinga habitats separated by anthropically altered landscapes.

The fauna of amphibians in Brazilian restinga habitats is relatively poorly known and only in the case of the restingas of Barra de Maricá and Jurubatiba, in Rio de Janeiro State, are there introductory lists of anuran species (Britto-Pereira et al., 1988a, b; Van Sluys et al., 2004). The relative lack of information on restinga anurans prevents a better understanding of the ecological processes affecting these organisms and even of species composition, species richness and endemisms along these habitats, which are important for the conservation actions in an environment under such an intense degradation rate.

In general, species composition in assemblages represents a subset of the species available in the landscape. Assemblages are nested when species present at species-poor sites are non-random subsets of the species present in species-rich areas (Atmar and Patterson, 1993; Fischer and Lindenmayer, 2005a, b; Maron et al., 2004). The analysis of community nestedness has been widely used for different organisms, including amphibians (Cutler, 1991; Ficetola and De Bernardi, 2004; Fischer and Lindenmayer, 2005a, b). It has also been argued that this analysis may be used for biodiversity management and conservation (Atmar and Patterson, 1993; Maron et al., 2004). Different factors including extinction, colonization, and habitat and niche structure may create these nested patterns, and some degree of nestedness appears to be the rule in nature (Wright et al., 1998).

In this study we analyzed the species composition, species richness and similarity of the frog fauna of restinga habitats along approximately 1500 km of the coast of Brazil and presented data on the occurrence of endemic anurans in some areas. We also evaluated to what

extent the loss of frog species may occur as a result of habitat loss in a nested pattern and not at random.

2. Study Sites and Methodology

We studied the species richness and composition of frogs in 10 areas of restinga habitat along approximately 1500 km of Brazilian coast (Figure 1). Two localities were situated in Bahia state: Trancoso (16° 39' S and 39° 05' W) and Prado (17° 18' S and 39° 13' W). Three other areas were localized in Espírito Santo state: Guriri (18° 41' S and 39° 45' W), Setiba (20° 35' S and 40° 27' W) and Praia das Neves (21° 15' S and 40° 58' W). The remaining five study areas were situated in Rio de Janeiro state: Grussaí (21° 44' S and 41° 02' W), Jurubatiba (22° 17' S and 41° 41' W), Massambaba (22° 56' S and 42° 12' W), Barra de Maricá (22° 57' S and 42° 50' W) and Grumari (23° 03' S and 43° 32' W). Restingas are Quaternary habitats characterized by sandy soils with high salt concentration and covered by predominantly herbaceous and shrubby xerophilous vegetation (Franco et al., 1984; Suguio and Tessler, 1984). These habitats may vary floristically and structurally along the coast (Araujo et al., 1998) and are part of the Atlantic Forest biome (Eiten, 1992). In general, the climate of the study areas is seasonal with a rainy season from November to March and a dry season from May to September (Nimer,

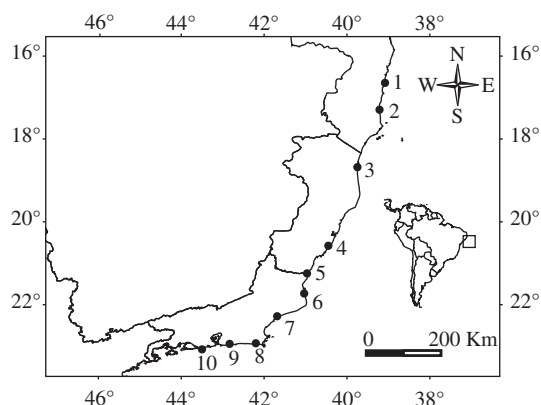


Figure 1. Map showing the 10 restinga habitats where frogs were surveyed along the Brazilian coast in the states of Bahia (1: Trancoso, 2: Prado), Espírito Santo (3: Guriri, 4: Setiba, 5: Praia das Neves) and Rio de Janeiro (6: Grussaí, 7: Jurubatiba, 8: Massambaba, 9: Barra de Maricá and 10: Grumari). After Kiefer et al. (2005).

1979). Mean annual temperature varies little among areas, usually averaging 23 °C and the mean annual rainfall ranges from 1000 to 1350 mm (Nimer, 1979).

All areas were surveyed under similar sampling effort during the wet season (between November 1999 and March 2000), in order to eliminate differences among areas due to seasonal effects. At each area, the survey involved a total of 80 hour of search (20 hour/man) using the complete species inventory method (Heyer et al., 1994). In each area we intensively searched for frogs among the different microhabitats available (i.e. at the border and inside bushes, on branches and trunks of trees/shrubs, on the leaf litter, on bromeliads) following Rocha et al. (2004). This method leads to the best sampling of anurans in restinga habitats (Rocha et al., 2004). Transects were diurnal and nocturnal. Additionally, in each area we dissected 200 tank-bromeliads. The bromeliads were taken at random and carefully checked (leaf by leaf) for the presence of frogs. All frogs found were collected for posterior identification.

To assess frog species turnover among restinga areas we used β -diversity estimates. The β -diversity measures the variation in the frog diversity among restingas, being an estimate of how different the areas are in terms of the number of species they maintain. The variation in frog diversity among restingas (W^{β}) was calculated for each pair of restingas (each restinga area was compared to each of the other nine) using the formula of Whittaker (1970): $W^{\beta} = S/\beta - 1$, in which S is the total number of frog species found in the two restinga areas and β represents the average frog richness among pairs of compared restingas (Magurran, 1988). To evaluate the relationship between the distance (in km) among pairs of restinga areas and their respective values of β -diversity, we used simple regression analysis. Distances among restingas were measured in the field using a Garmin III-plus GPS. The Mantel test of aleatorization (Zar, 1999) was used in order to avoid the pseudoreplication of data and to factor out the effect of such replications, since each restinga area is included more than once in the analysis. Our null hypothesis was absence of correlation between β -diversity and distance among areas. To estimate the similarity among restinga habitats in terms of frog assemblage composition we used the Jaccard index of similarity (Zar, 1999): $C_j = j / a + b - j$, in which “j” is the number of species common to the areas being compared, “a” is the number of species in the “A” environment and “b” is the number of species in the “B” environment). The value of similarity in the index varies from zero (no similarity among areas) to 1 (areas have identical assemblages). The distances between areas in terms of frog species were estimated by Cluster analysis, using the Euclidean distance and the average linkage method. The relationship between the distance (in km) among pairs of restinga areas and their respective values of similarity, were estimated using simple regression analysis. As done for the β -diversity comparisons, we used the Mantel test of aleatorization to avoid the pseu-

doreplication of data and to factor out the effect of such replications in the analysis. Our null hypothesis was lack of relationship between the distance among areas and the similarity in frog faunas.

Several metrics exist for measuring assemblage nestedness (Wright et al., 1998). We used the “Nestedness Temperature Calculator” of Atmar and Patterson (1993, 1995) to analyze the species distribution pattern among the studied restingas. This method analyzes the matrix of presences and absences of frog species and calculates its temperature, which indicates the level of order or disorder of the matrix. The lower the matrix temperature (level of nestedness of the system), the lower the disorder and the less stochastic is the distribution of the species in the assemblage. We also evaluated the capacity that each particular restinga area has to maintain frog species (“hospitality”), and potential areas to be preserved (Atmar and Patterson, 1993; 1995). For this analysis we used 1000 randomizations.

3. Results

We found 28 frog species belonging to the families Hylidae, Microhylidae, Leptodactylidae and Bufonidae (Table 1) in the restingas studied. The richest restinga was Praia das Neves, where we found 13 frog species, followed by Grussaí and Trancoso (8 species each). Overall, Hylidae was the most speciose anuran Family (Table 1).

The most frequent species was *Scinax alter* (B. Lutz, 1973) (recorded in 8 areas), followed by *Aparasphenodon bruno*i Miranda-Ribeiro, 1920 (7 areas), and *Leptodactylus ocellatus* (Linnaeus, 1758) and *Phyllodytes luteolus* (Wied-Neuwied, 1824) (5 areas). The relationship between the distances among restinga areas and the corresponding values of β -diversity was positive and significant ($F_{1,43} = 6.055$, $R = 0.351$, $p = 0.018$; Figure 2a) and the aleatorization test indicated that this effect was not random (Mantell Test, $F = 6.06$, $p = 0.023$). The most similar frog assemblages were those of Maricá and Massambaba, and Setiba, Grumari and Guriri (Figure 3). The relationship between the distances among restinga areas and the corresponding values of frog similarity was negative and significant ($F_{1,43} = 4.499$, $R = -0.308$, $p = 0.040$; Figure 2b). The aleatorization test indicated that the variation in frog similarity varies according to the distance among pairs of restinga areas (Mantell test, $F = 4.50$, $p = 0.032$).

The anuran fauna in the restingas studied was significantly nested (matrix community temperature = 26.13°, $p = 0.007$, 1000 randomizations). This analysis showed Neves, Grussaí, and Trancoso, in decreasing order, to be the most hospitable for frogs.

4. Discussion

According to our results, the species richness and composition of frog communities varied consistently among restingas along the eastern Brazilian coast. Hylidae was the most representative family in the rest-

Table 1. Frog species and frog richness found in 10 restinga areas along the coasts of Rio de Janeiro, Espírito Santo and Bahia states, in eastern Brazil. B = Bufonidae; H = Hylidae; L = Leptodactylidae; M = Microhylidae.

| Frog Species | Grumari | Maricá | Massambaba | Jurubatiba | Grussaí | Neves | Setiba | Guriri | Prado | Trancoso | Occurrences |
|---|---------|--------|------------|------------|---------|-------|--------|--------|-------|----------|-------------|
| <i>Aparasphenodon brunoi</i> Miranda-Ribeiro, 1920 (H) | x | x | x | x | - | x | x | - | - | x | 7 |
| <i>Arcovomer passarelli</i> Carvalho, 1954 (M) | - | - | x | - | - | x | - | - | - | - | 2 |
| <i>Dendropsophus bipunctatus</i> (Spix, 1824) (H) | - | - | - | - | - | x | - | - | - | - | 1 |
| <i>Dendropsophus decipiens</i> (A. Lutz, 1925) (H) | - | - | x | - | - | x | - | - | - | - | 2 |
| <i>Dendropsophus meridianus</i> (B. Lutz, 1954) (H) | - | - | - | x | - | - | - | - | - | - | 1 |
| <i>Dendropsophus pseudomeridianus</i> (Cruz, Caramaschi and Dias, 2000) (H) | - | - | - | - | - | x | - | - | - | - | 1 |
| <i>Hypsiboas albomarginatus</i> (Spix, 1824) (H) | - | - | - | x | - | x | x | - | - | - | 3 |
| <i>Hypsiboas semilineatus</i> (Spix, 1824) (H) | - | - | - | x | - | - | - | - | x | - | 2 |
| <i>Itapotihyla langsdorffii</i> (Duméril and Bibron, 1841) (H) | - | - | - | - | - | - | - | - | - | x | 1 |
| <i>Leptodactylus fuscus</i> (Schneider, 1799) (L) | - | x | - | - | - | - | - | - | - | - | 1 |
| <i>Leptodactylus mystacinus</i> (Burmeister, 1861) (L) | - | - | - | - | x | - | - | - | - | - | 1 |
| <i>Leptodactylus ocellatus</i> (Linnaeus, 1758) (L) | x | - | - | - | x | x | x | - | - | x | 5 |
| <i>Phyllodytes luteolus</i> (Wied-Neuwied, 1824) (H) | - | - | - | - | x | - | x | x | x | x | 5 |
| <i>Physalaemus marmoratus</i> (Reinhardt and Lütken, 1862) (L) | - | - | - | - | x | - | - | - | x | - | 2 |
| <i>Physalaemus signifer</i> (Girard, 1853) (L) | - | - | - | - | - | - | - | - | - | x | 1 |
| <i>Pseudopaludicola</i> sp. (L) | - | - | - | - | x | x | - | - | - | - | 1 |
| <i>Rhinella crucifer</i> (Wied-Neuwied, 1821) (B) | - | - | - | - | - | - | - | - | - | x | 1 |
| <i>Rhinella icterica</i> Spix, 1824 (B) | - | - | - | - | - | - | - | - | x | - | 1 |
| <i>Rhinella pygmaea</i> Myers and Carvalho, 1952 (B) | - | - | - | x | x | - | - | - | - | - | 2 |
| <i>Scinax agilis</i> (Cruz and Peixoto, 1983) (H) | - | - | - | - | - | - | - | - | - | x | 1 |
| <i>Scinax alter</i> (B. Lutz, 1973) (H) | - | x | x | x | x | x | x | x | - | x | 8 |
| <i>Scinax cuspidatus</i> (A. Lutz, 1925) (H) | - | x | - | x | - | x | x | - | - | - | 4 |
| <i>Scinax similis</i> (Cochran, 1952) (H) | - | - | - | - | x | - | - | - | - | - | 1 |
| <i>Scinax x-signatus</i> (Spix, 1824) (H) | - | - | - | - | - | - | x | - | x | - | 2 |
| <i>Scinax</i> sp. (aff. <i>x-signatus</i>) (H) | - | - | - | - | - | x | - | - | - | - | 1 |
| <i>Stereocyclops incrassatus</i> Cope, 1870 (M) | - | - | - | - | - | x | - | - | - | - | 1 |
| <i>Trachycephalus nigromaculatus</i> Tschudi, 1838 (H) | - | - | - | - | - | x | - | - | - | - | 1 |
| <i>Xenohyla truncata</i> (Izecksohn, 1959) (H) | - | x | x | - | - | - | - | - | - | - | 2 |
| Total of frog species | 2 | 5 | 5 | 7 | 8 | 13 | 7 | 2 | 5 | 8 | - |

inga habitats, as reported in other studies (Britto-Pereira et al. 1988a; Carvalho-e-Silva et al., 2000; Van Sluys et al., 2004). Carvalho-e-Silva et al. (2000) listed 52 amphibian species occurring in restingas from southern to northeastern Brazil (Santa Catarina state to Bahia state). In the present study, encompassing only the region between the states of Rio de Janeiro and southern Bahia (and thus, not including the coastal areas of Santa Catarina, Paraná and São Paulo states), we found 28 frog species, which is a little more than half the number of species reported by Carvalho-e-Silva et al. (2000). Of these 28 species, 23 have already been reported as occurring in restingas by Carvalho-e-Silva et al. (2000), whereas four (*Dendropsophus pseudomeridianus*, *Physalaemus*

marmoratus, *Scinax x-signatus* and *Stereocyclops incrassatus*) represent new records for restinga habitats of eastern Brazil.

Our data shows that the frog assemblages in restinga habitats tend to change somewhat along the coast and, in part, the rate of species turnover is affected by the distance among areas. Geographic distance explained approximately 12% of species turnover. Accordingly, distance among restinga areas explained about 9.5% of similarity among frog assemblages. Although geographic distance affects frog assemblages, other factors (e.g. historical factors, disturbances) are also probably involved in differences in species composition and species turnover among areas.

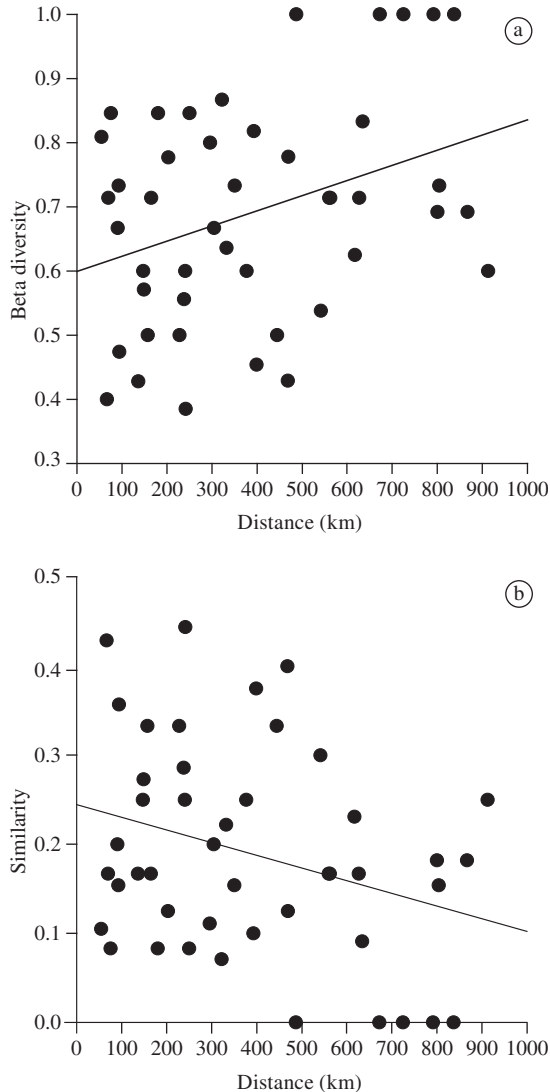


Figure 2. Relationship between the distances among restinga areas and the corresponding values of β -diversity of frogs a) and between the distances among restinga areas and b) the corresponding values of frog assemblage similarity.

Frog assemblages along the restingas studied were significantly nested. The relatively low matrix community temperature calculated indicates a considerable level of ordination of frog assemblages in restinga habitats. This trend may, in part, result from the degradation and fragmentation of restingas along the coast (Rocha et al., 2003). The fragmentation of restingas potentially led each extant remnant to maintain a distinct subset of the original frog fauna, probably depending on their size. The fragmentation process is well-known to negatively affect the species living in the remnants of the ecosystem, posing an effective threat to their existence. Because the negative effects of habitat fragmentation may differentially affect the species in the community under habitat reduction, the loss of species may not occur at random but

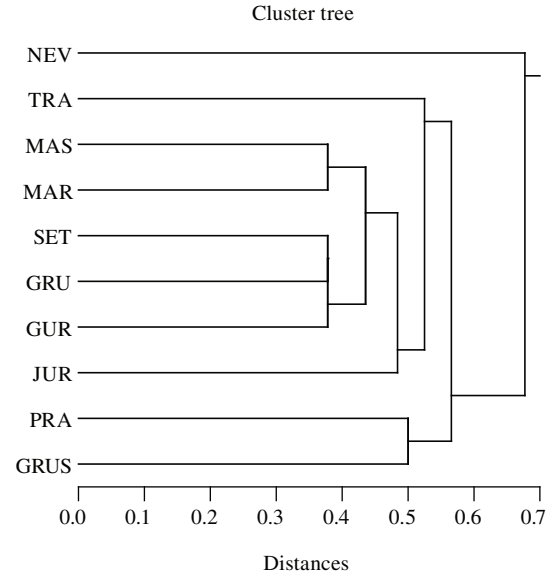


Figure 3. Cluster tree of similarities among 10 restinga habitats studied along the coast of the states of Rio de Janeiro, Espírito Santo and Bahia, in terms of frog assemblages.

in a nested pattern (Atmar and Patterson, 1995; Patterson and Atmar, 2000). It has been shown that nestedness appears most prevalent and evident in fragmented systems (Atmar and Patterson, 1995; Patterson and Atmar, 2000). Fragmented systems tend to exhibit distinctive patterns of species richness and species composition (Atmar and Patterson, 1995; Patterson and Atmar, 2000) and this was the tendency we found. However, we need to consider that such differences are also due to the distinct histories of the restinga areas. Historical and biogeographical factors such as the age and processes of origin and formation of a given restinga and the patterns of colonization and extinction of individual species in the past were fundamental in determining the present faunas of restinga areas (e.g. Porto and Teixeira, 1984; Cerqueira, 2000; Reis and Gonzaga, 2000; Rocha, 2000). However, the evaluation of such factors for the studied areas is too complex and beyond the scope of the present study.

Our data indicated that Praia das Neves, Grussaí and Trancoso were the most hospitable restingas for frogs, suggesting that these areas have a considerable capacity to maintain a rich anuran fauna. This makes them eligible as potential areas to preserve frogs and thus these remnants of restinga habitats should be protected in the near future as conservation units in order to keep their biodiversity.

There are five frog species which are known to be endemic to the restinga environments of eastern Brazil: the bufonid *Rhinella pygmaea*, the hylids *Scinax agilis*, *Scinax littoreus* (Peixoto, 1988) and *Xenohyla truncata*, and the leptodactylid *Leptodactylus marambaiae* Izecksohn, 1976 (Carvalho-e-Silva et al., 2000; Rocha et al., 2005). Some of these endemics have a very restricted geographic distribution, such as *Leptodactylus*

marambaiae in the restinga da Marambaia, and *Scinax littoreus* in the region of Ponta Negra, both in the state of Rio de Janeiro (Carvalho-e-Silva et al., 2000; Izecksohn and Carvalho-e-Silva, 2001). *Rhinella pygmaea* and *Xenohyla truncata* have a comparatively wider distribution across the restingas, but also seem to be restricted to the state of Rio de Janeiro (Carvalho-e-Silva et al., 2000; Narvaes, 2003). *Scinax agilis* was until recently known only for the states of Espírito Santo and Bahia, but it was recently recorded in a restinga habitat in the state of Alagoas, which extended its known distribution substantially (Toledo, 2005). Three of the five aforementioned endemic species were sampled during our study in some restingas surveyed (i.e. *X. truncata* in Massambaba and Maricá, *Rhinella pygmaea* in Jurubatiba and Grussaí, and *S. agilis* in Trancoso) and their occurrence represents an additional conservation value for those areas.

We conclude that some restinga remnants may be particularly valuable for conserving anurans due to the occurrence of endemic frog species and/or a comparatively high richness of frogs. Also, frog faunas in restinga areas occur in a nested pattern in which the current frog assemblage of each area seems to partially represent a nested subset of the original assemblage, although we should not ignore the importance of historical factors. This nestedness pattern probably results, in part, from the intensive fragmentation of restingas. Amphibians are very sensitive to environmental alterations and disturbances and, as a result, are considered good biological indicators (e.g. Vitt et al., 1990; Young et al., 2004). Probably, many frog species may have been lost in some studied areas as a result of the extensive habitat degradation to which the restinga habitats are exposed.

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