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Identification of Critical Areas for Mammal Conservation in the Brazilian Atlantic Forest Biosphere Reserve

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Abstract

Herein we identified the geographic location of protected areas (PAs) critical for strengthening mammalian conservation in the Brazilian Atlantic Forest Biosphere Reserve (RMBA) by assessing sites of particular importance for mammal diversity using different biodiversity criteria (richness, rarity, vulnerability) and a connectivity index. Although 95% of mammal species were represented by PAs, most of them had less than 10% of their distribution range protected by these areas. A total of 94 critical areas for mammal conservation–representing 49.60% of the total PAs were identified. Most of these areas were located at endangered ecoregions. We recommend that conservationists and policy makers should identify critical areas in order to guarantee biodiversity fluxes among landscapes, and enhance the connectivity between PAs to increase biodiversity protection and conservation. Knowledge about the location of critical areas may encourage managers and policy makers to develop specific programs to strengthen mammal biodiversity protection, especially for threatened species.

Key words: Connectivity, Mammals, Protected Areas, Rarity, Species Richness, Vulnerability.

Introduction

Several mammal species will be under risk of extinction in the near future (Cardillo *et al.* 2004). A key solution to avoid this potential scenario is to identify critical areas for conservation (Dobson *et al.* 1997). These areas should be selected to include the maximum number of species within a given region in order to maintain most of its biological diversity, especially that of rare and threatened species (Margules & Pressey 2000). Critical areas for conservation can be identified either within existing protected areas (PAs) or over wider geographical contexts, including areas that do not have legal protection. Whereas the latter generates more useful information for effective conservation planning, the former provides a more realistic picture of where conservation efforts should be prioritized, considering that these areas have already achieved a legal conservation status. PA networks may indeed play an important role in halting biodiversity loss worldwide (Margules & Pressey 2000). However, there is an increasing debate about society's concern about protected areas, with an imminent risk of diminishing financial support (Wilkie *et al.* 2006). In this sense, identifying protected areas that are critical because they harbor the highest species richness and as many endangered species as possible (vulnerability) would help policy makers prioritize actions to improve biological conservation and the effectiveness of management actions.

Biodiversity indices by themselves are however not sufficient if one aims to conserve species populations over wide regions. This is particularly true for species with broad habitat ranges, which is the case of many mammal species. Habitat connectivity must be therefore considered in natural resource planning for maintaining wildlife populations, ecological flows, reducing extinction risk and many other landscape functions (Saura & Pascual-Hortal 2007; Feced *et al.* 2011). Increasing connectivity has been pointed out as an effective strategy to halt biodiversity loss, especially in fragmented

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landscapes (Bailey 2007). Fragmentation often causes a decrease in the area of available habitat and a decrease in connectivity between patches, causing a reduction in the exchange of individuals between isolated patches (Watts & Handley 2010). Well-connected fragments may maintain a high number of species and individuals, allowing individuals to use multiple fragments and reducing the influence of fragment size (Martensen *et al.* 2008).

Here we aimed to identify key PAs for mammal conservation inside the Brazilian Atlantic Forest Biosphere Reserve (RMBA), one of the Conservation International's Biodiversity Hotspots and one of the most devastated and threatened ecosystem of the globe (Galindo-Leal & Câmara 2003; Metzger 2009). Critical PA selection was carried out by quantifying the number of rare, vulnerable and total mammal species in side PAs as well the degree of connectivity between them. Our specific goals were to 1) explore how well mammal species are represented within PAs of the RBMA; 2) investigate the spatial patterns of species richness, rarity, and vulnerability, as well as connectivity, across PAs of the RMBA; and 3) identify the geographic location of existing PAs that are critical for mammal conservation (important mammal sites, IMS) based on the above-mentioned criteria.

Methods

Study area

The RBMA has an area of *ca.* 94.000 km^2, with highly heterogeneous environmental conditions and covers 14 different Brazilian states (Galindo-Leal & Câmara 2003). RBMA is made up of 14 terrestrial ecoregions and it is considered one of the most diverse biomes of the globe (Olson & Dinerstein 1998). Its geographical characteristics include a wide latitudinal range, including tropical and subtropical regions, with its coast receiving over 4000 mm/year of rain (Galindo-Leal & Câmara 2003). Although the RBMA supports one of the highest degrees of species richness and endemisms of the globe, strong deforestation rates have been reported during the last decades and, currently, only *ca.* 11.4-16% of the forest remains, and a large number of endemic and threatened species are found in this area (Ribeiro *et al.* 2009).

Mammal data

Distribution data for mammal species were obtained from NatureServe Digital Distribution Maps of the Mammals of the Western Hemisphere Version 3.0 (Patterson *et al.* 2007). This project covers continental North, Central and South America and associated islands and comprises over 1,737 mammal species distribution maps. After excluding all islands and those species not present in the RBMA, a total of 308 terrestrial mammal species were processed in ArcGIS 9.3. Presence/absence of each mammal species in each of the 541 protected areas (PAs) was obtained by intersecting mammal distribution maps with the RMBA PAs map, which compiles data from the World Database on Protected Areas version 2010 (IUCN & UNEP 2009) and the Brazilian environmental agency (available at http://mapas.mma.gov.br/geonetwork/srv/br/main.home). Kernel density plots were used to investigate the percentage of mammal distribution protected by PAs. The next step was to intersect the terrestrial ecoregions map of the RMBA (WWF 2010) with each mammal distribution map to calculate the number of species in each ecoregion. The WWF Terrestrial Ecoregions map for the RBMA was obtained from the Global 200 Ecoregions dataset. This is provided in ESRI shapefile format and contains 100 polygons representing 13 ecoregions (see Appendix A1 in the Additional Supporting Information, at www.abecol.org.br).

Criteria for measuring connectivity between protected areas

We measured connectivity between protected areas using the Integral index of connectivity (IIC) using CONEFOR Sensinode 2.2 (Pascual-Hortal & Saura 2006).The IIC requires the selection of certain distance threshold values that are useful for reducing computational GIS processing time. This is recommended when processing data covering large geographical scales. Therefore, twelve connectivity maps were obtained using different threshold values: 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 10000, 15000 and 20000 m. In almost all cases, the spatial distribution of the most connected areas was quite similar, with the most connected PAs located at São Paulo and Rio de Janeiro, specifically at Serra do Mar coastal forest and Alto Paraná Atlantic forest ecoregions (see Appendix A2 in the Additional Supporting Information, at www.abecol.org.br). We calculated a mean connectivity index (IICm) by averaging all IIC at different threshold values.

Criteria for identifying critical PAs for mammal conservation (IMS)

We proposed a new index, the Conservation Importance Index (CII), which incorporates the combined biodiversity index (*sensu* Rey Benayas & de la Montaña 2003) and the mean connectivity index (IICm). Highest CII values reflect the most relevant IMS. The CII was calculated as follows (Equation 1):

$$\sum_{i=1}^{s} (1 / n_{ri}) / V_{ri} * (IICm) \qquad (1)$$

where: the parameter $(1/n_{ri})$ represents the rarity of species; n_{ri} represents the number of PAs where species (i) was present. V_{ri} represents the vulnerability score of the species present in each PA. The vulnerability of species was calculated using six categories defined by the International Union for Nature Conservation (IUCN, 2001), namely: endangered (En), vulnerable (Vu), rare (R), undetermined (U), data deficient (DD), and near-threatened (NT). Then, we assigned a score related to its degree of vulnerability to each species, ranking from one for non-threatened, two for data defficient, three for rare, four for vulnerable and undetermined and five for endangered species. Finally, the IICm represents the mean connectivity index.

We then used the CII to identify critical PAs for mammal conservation by means of the G* spatial statistic (Getis & Ord 1992). The G* statistic allows the identification of hotspots, higher or lower in magnitude that one might expect to find by chance (Getis & Ord 1992). This method incorporates not only the absolute value of CII in the identification of hotspots, but also compares the value for a given observation with locations in the neighborhood, thus providing a more explicit consideration of space (Nelson & Boots 2008). G* spatial statistics were calculated using the hotspot analysis tool from ArcGIS version 9.3. This tool also provides information about whether these values are statistically significant. We then selected those significant positive PAs (hotspots) as critical areas for mammal conservation.

Results

In general, mammal diversity is well represented in PAs within the RBMA. From a total of 308 species, 14 were not found inside any PA. From these, five were considered critically endangered (CR) - *Phyllomys unicolor*, endangered (EN) - *Phyllomys brasiliensis*, *Trinomys eliasi*, vulnerable (VU) - *Monodelphis umbristriata*, or near threatened (NT) - *Rhagomys rufescens* and three others were considered data deficient (DD) - *Brucepattersonius paradisus, Micronycteris brosseti, Molossops neglectus* (see Appendix A3 in the Additional Supporting Information at www.abecol.org.br). A kernel density plot of the percentage of mammal distribution protected by PAs indicated that over 75% of the mammal species considered had less than 10% of their distribution range protected by PAs (Figure 1).

The overall geographic pattern of PAs within RMBA shows that mammal richness increased southwards – from the states of Paraiba to São Paulo, decreasing sharply in the state of Rio Grande do Sul PA (southernmost Brazil) (Figure 2a). High richness areas were observed in PAs of north Paraná (160 species) located at the Alto Paraná Atlantic forest (APAf) ecoregion followed by São Paulo (156) and Rio de Janeiro (154) PAs, both located within the Serra do Mar coastal forests (SMcf) ecoregion, whereas the least richness was found in South Rio Grande do Sul PA (20) at the Uruguayan savanna ecoregion. The spatial patterns of rarity and vulnerability (Figure 2b-c) were similar, with highest values observed in the southwest of RMBA (Paraná state) included in the Alto Paraná Atlantic forest ecoregion. The most connected PAs were found in São Paulo and Rio de Janeiro (Figure 2d) at Serra do Mar coastal forest and Alto Paraná Atlantic forest ecoregions.

The spatial patterns of the Conservation Importance Index show that the highest CII areas were located mainly in the southwest and northwest of the RMBA (Figure 2e). A total of 94 critical areas for conservation – representing 49.6% of the total protected areas were identified by G* statistics analysis. They are especially distributed along the Brazilian coast (Figure 2f). Most of these hotspot areas are located at the Alto Paraná Atlantic Forest (43.53%) and the Bahia Coastal Forest (24.6%) ecoregions, whereas less hotspots were found in Cerrado (0.17%) and Atlantic Coast restingas (0.003%) ecoregions (Table 1).

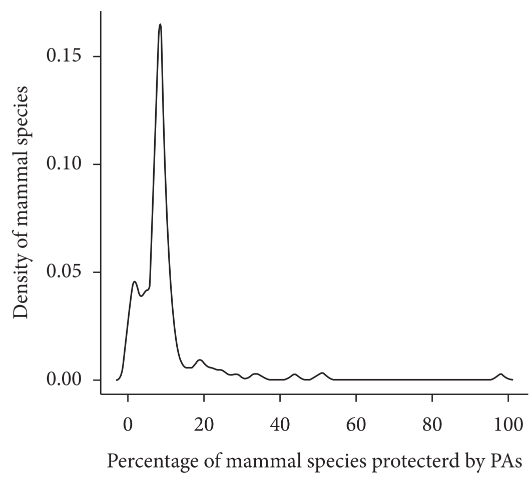

Figure 1. Density plot of the percentage of mammal species distributions included in protected areas (PAs) across the Brazilian Atlantic Forest Biosphere Reserve.

Table 1. Percentage of critical areas for mammal conservation in different ecoregions of the Brazilian Atlantic Forest Biosphere Reserve. The total protected area (PA) is given in km^2.

Ecoregion	PA area	Percentage
Alto Paraná Atlantic forests	23,135.716	43.530
Bahia coastal forests	13,075.551	24.602
Southern Atlantic mangroves	12,006.682	22.590
Caatinga	2,248.125	4.230
Bahia interior forests	1,470.292	2.766
Campos Rupestres montane savanna	768.282	1.446
Pernambuco interior forests	177.815	0.335
Serra do Mar coastal forests	173.222	0.326
Cerrado	91.872	0.173
Atlantic Coast restingas	1.757	0.003
Total	53,149.31	100.00

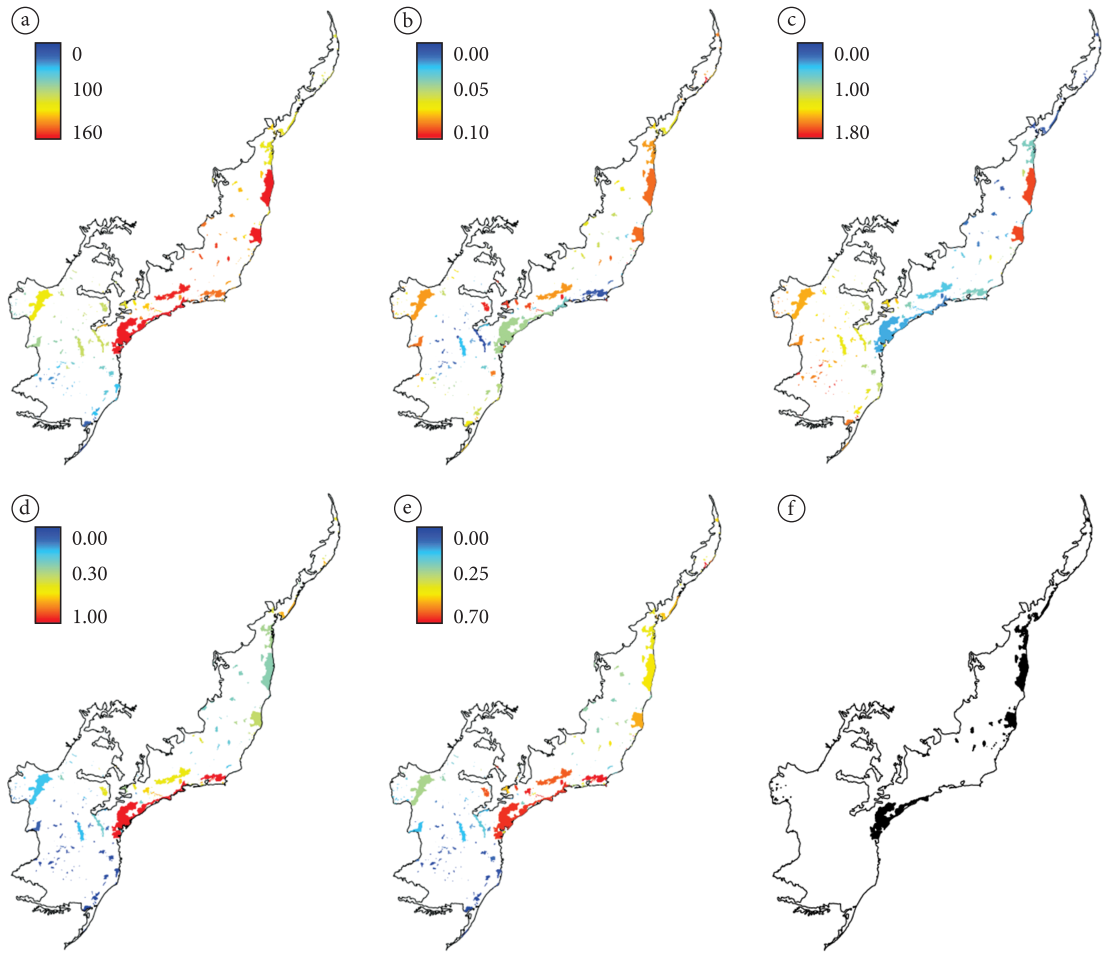

Figure 2. Biogeographic patterns of mammal species richness (a); rarity (b); vulnerability (c); connectivity (d); conservation importance index (e); and mammal hotpots (f) in protected areas of the Brazilian Atlantic Forest Biosphere Reserve.

Discussion

In general, results show that mammal diversity is well represented in the RBMA PAs network. However, results should be analyzed with care, since almost 5% of the total RMBA mammal diversity is not included within any PA. This includes critically endangered (*Phyllomys mantiqueirensis*) and endangered (*i.e. Phyllomys unicolor, Trinomys eliasi*) species. Leite & Patterson (2008) and Brito *et al.* (2008) support that habitat destruction and degradation are major threats for these species. They highlight that there is a need for policy actions in order to safeguard them. A great number of species underrepresented by PAs were considered of Least Concern, according to IUCN criteria (IUCN 2010). However, strong population declines have also been reported for species classified as of least concern in different parts of the world (del Hoyo *et al.* 2003; Kumara *et al.* 2010). In this sense, policy makers should also take into account these species when designing PA networks to ensure that their distribution and population flows are maintained across the RBMA.

The highest mammal richness was found in PAs of Alto Paraná Atlantic forest and Serra do Mar coastal forest ecoregions. These ecoregions represent the largest portion of the Brazilian Atlantic moist forest region and are also an important habitat for several endemic and threatened mammal species (*i.e. Brachyteles arachnoides, Leopardus pardalis)* (São Paulo 1998; Mendes 1999). This agrees with previous studies supporting that these ecoregions are the most diverse and threatened of the RBMA (Mendes 1999; WWF 2008). The high richness observed in these ecoregions may be associated with the protection policy developed in these PAs. Although the surface area of Alto Paraná Atlantic forest and Serra do Mar coastal forests has been reduced by *ca.* 50% (WWF 2008), both ecoregions are considered the largest and best-protected regions of the RMBA (Leitão Filho 1992; Fundação SOS Mata Atlântica 1998). Our data also indicated that PAs localized in both ecoregions are crucial to maintain mammal fluxes within the RMBA, since these PAs sustain the highest mammal diversity and connectivity, suggesting that these areas may act as corridors for several species. This agrees with previous studies supporting that Alto Paraná Atlantic forest and Serra do Mar coastal forests ecoregions play a key role as corridors, connecting the moist and semi-deciduous forests, as well as between Atlantic forest and Cerrado (Mantovani 1993).

The lowest species richness and connectivity found in PAs of the Urugayuan Savanna ecoregion, in the southern part of Rio Grande do Sul, may also may be associated with the greatest landscape alteration promoted by human action (*i.e.* agriculture and cattle ranching) (WWF 2008). The disruption of forest connectivity has negative consequences (*i.e.* local extinctions) for fauna conservation in tropical rainforests, especially in the Brazilian Atlantic Coastal Forest (Dixo *et al.* 2009).

The largest number of critical PAs for mammal conservation in the RMBA was found at Alto Paraná Atlantic forests followed by Bahia coastal forest and Southern Atlantic mangroves. Although a high percentage of these PAs are located at the Alto Paraná Atlantic forests ecoregion, the highest percentage of critical areas are found at two of the most endangered areas of the RMBA. The Brazilian coastal forest ecoregion suffered a reduction of *ca.* 95% of its original cover and only 0.4 percent of the original forest remains (Fundação SOS Mata Atlântica 1998; WWF 2008), whereas mangrove forest areas are declining significantly worldwide (Polidoro *et al.* 2010). In general, the major threat for these ecoregions is human action (*i.e.* clearance process for timber production, aquaculture and fuel production) (Araujo *et al.* 1998; Polidoro *et al.* 2010). A fundamental issue to mitigate these threats at critical PAs and therefore safeguard mammal diversity is to establish Areas of Important Ecological Relevance. These areas have strict policy rules that aim to halt biodiversity loss by forbidden developing any activity that endanger ecosystem conservation, species protection and landscape harmony (Brasil 2008).

We recommend that conservationists and policy makers should identify critical areas to maintain biodiversity fluxes between landscapes, enhance the connectivity among PAs to increase biodiversity protection and conservation, and use a legal protection figure to regulate human actions in these areas and thus halt mammal loss. Knowledge about the location of critical areas may guide managers and policy makers to develop specific programs that strengthen mammal biodiversity protection, especially for threatened species.

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