Biodivers Conserv
DOI 10.1007/s10531-010-9906-x

ORIGINAL PAPER

Fine-scale sites of global conservation importance in the Atlantic forest of Brazil

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Received: 12 January 2010 / Accepted: 22 July 2010

Abstract The Brazilian Atlantic Forest is a highly threatened biodiversity hotspot that has been the subject of several complementary conservation assessments and priority-setting initiatives in the last 30 years. Results of these initiatives have relied on distinct types of distribution data for biodiversity features and differ in the objectivity and repeatability of their methodologies. Here we refine earlier priority-setting exercises using the key biodiversity areas (KBA) approach. We evaluate how well these KBAs are represented in the existing protected areas system, prioritize among them, and analyze critical aspects of the KBA methodology in the Brazilian Atlantic Forest context, such as its ability to guide specific conservation strategies. Building upon an extensive database with 1,636 species records and 122 previously identified Important Bird Areas, we demonstrate that conservation assessments in highly fragmented landscapes may be benefited by high resolution species data as is required by the KBA process. We identify 538 KBAs for 141 globally threatened vertebrate species. Prioritizing among these KBA, we highlight the 24 most irreplaceable sites for terrestrial vertebrate species conservation in the Atlantic Forest, based on existing data.

Keywords Atlantic forest · Brazil · Conservation assessment · Conservation priority-setting · Key biodiversity areas · Important bird areas

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Published online: 03 August 2010

Introduction

The Brazilian Atlantic Forest has been the subject of several complementary conservation assessments and priority-setting initiatives for almost 30 years, as a reflection of the level of human activity affecting the biome, the growing involvement of academic, governmental and non-profit conservation organizations and the quality and quantity of the data that have become available. At the global level, the Atlantic Forest has been identified as one of the world's biodiversity hotspots, based on a quantification of threats, associated to estimated numbers of endemic plant species (Myers et al. 2000). Within the Atlantic Forest hotspot, coarse-scale conservation priorities have been identified based on centers of endemism for various taxa (Kinzey 1982; Silva et al. 2004) and the definition of biodiversity corridors (Ayres et al. 2005). Finer-scale priority areas for conservation and restoration have been identified for a number of Brazilian biomes (CI-Brasil et al. 2000; MMA 2007) and several states (Tabarelli and Silva 2002; Drummond et al. 2005; Rodrigues et al. 2008) in a series of expert-based workshops, which have utilized databases on a wide range of taxonomic groups, ecological, and socio-economic variables. In the absence of comprehensive data on species distributions, some conservation assessments have focused on single taxonomic groups (Harris et al. 2005; Bencke et al. 2006) or on detailed descriptions of the remaining forest spatial patterns (Ribeiro et al. 2009).

Results of the above conservation assessments have guided species inventories, the creation of protected areas (Timmers 2006, Ministry of Environment Act No. 126 of May 27th 2004), and have directly influenced public policies regulating the suppression of native vegetation and land cover change (São Paulo, RESOLUÇÃO SMA-15 of March 13th 2008). However, they are rarely utilized without further local biodiversity investigations, due to the coarse scale at which they are presented.

Here, we advocate that in biologically rich and highly fragmented landscapes, conservation planning and implementation may benefit from high resolution biodiversity data, which may minimize commission errors—the probability of indicating a site where there is no actual evidence of the biodiversity features (e.g. species assemblages, populations, vegetation types) to be conserved (Rondinini et al. 2006). Commission errors in conservation planning data may lead to species' extinction (Brooks et al. 2004), and to the misdirection of conservation resources and efforts to places where the biodiversity features do not actually occur. Most of the previous initiatives in the Atlantic Forest do not inform the precise locations for public or private protected areas creation or forest restoration projects, requiring further investigation before any conservation action is taken.

The key biodiversity areas (KBA) methodology has been developed to identify globally important sites for biodiversity conservation, using quantitative and transparent criteria and thresholds. KBA are sites of global significance for biodiversity conservation that are large enough or sufficiently interconnected to support populations of the globally threatened species for which they are important (Eken et al. 2004). By requiring the documented presence of a target species at a particular site to trigger KBA status, (species distribution data at high spatial resolution) this approach minimizes commission errors in conservation planning. The KBA approach builds on the Important Bird Areas framework (Birdlife International 2004, 2006) and is being implemented in many countries to date. The KBA criteria and thresholds need to be tested in different biomes (terrestrial and aquatic) and in regions having varying degrees of habitat fragmentation and land management (Eken et al. 2004, Langhammer et al. 2007).

We have three objectives. First, we apply the key biodiversity area methodology (Eken et al. 2004; Langhammer et al. 2007) for identifying fine-scale sites of global conservation importance for terrestrial vertebrate species in the biologically rich and highly fragmented Atlantic Forest of Brazil. Second, we evaluate how identified KBAs are represented in the existing protected areas system and, prioritize among the KBAs for conservation action. Finally, we evaluate the utility of the KBA methodology, including its effectiveness in guiding conservation priorities in the region.

Materials and methods

Our study area is the original extent of the Atlantic Forest, as it is defined in the Brazilian legislation (Federal Decree No. 750/93 and Atlantic Forest law No. 11428, of December 22, 2006). Within the borders of Brazil, the original extent of the Atlantic Forest approximated 13.5 million ha (Hirota 2003) distributed across 27° of latitude and 17 Brazilian states.

A long history of intensive land use (Hirota 2003) combined with a heterogeneous physical geography has affected the distribution of the remaining biodiversity in the Atlantic Forest (Tabarelli et al. 2005; Rodrigues et al. 2009). Today, the remaining native vegetation covers from 11.4 to 16% of its original extent, with 80% of forest fragments not greater than 50 ha (Ribeiro et al. 2009). The largest forest patches are located in the states of Santa Catarina, Paraná, São Paulo and Rio de Janeiro, in the mountain region of Serra do Mar (Galindo-Leal and Câmara 2003; Ribeiro et al. 2009).

The key biodiversity areas methodology

Identification

KBA are identified using globally standard criteria and thresholds to species and sites vulnerability and irreplaceability (Margules and Pressey 2000). KBA are identified based on the confirmed presence of (1) globally threatened species, (2) restricted-range species, (3) congregations of species that concentrate at particular sites during some stage in their life cycle, and (4) biome-restricted species assemblages (Eken et al. 2004). The first of these four criteria, the confirmed presence of globally threatened species, addresses vulnerability (conservation options in time), while the latter three cover different components of irreplaceability (conservation options in space) (Margules and Pressey 2000).

This work is an initial assessment that tests the application of the vulnerability criterion (the confirmed presence of globally threatened species) to KBA identification. This criterion is likely to capture most KBAs in the Atlantic Forest and is the most urgent to address due to the elevated numbers of globally threatened species in the region—at least 187 animal taxa, representing 52 percent of all threatened fauna in Brazil, listed by IUCN (2008).

Thresholds for KBA identification were defined based on the confirmed presence of at least one globally threatened species, according to the IUCN Red List. Although a threshold of 10 pairs or 30 individuals is suggested when applying the first KBA criteria for species classified as 'vulnerable' (Langhammer et al. 2007), due to the lack of information on species abundance, we considered the confirmed occurrence of a species in any category as sufficient to trigger KBA identification.

The IUCN Red List is one of the most important information sources about the conservation status of the world's fauna and flora worldwide, and is used as a planning tool for national and international conservation and research strategies (Gärdenfors et al. 2001; Butchart 2003; Lamoreux et al. 2003; Miller et al. 2006).

The KBA methodology was developed to support the Programme of Work on Protected Areas of the Convention on Biological Diversity (CDB) fulfill its mandate of a global gap analysis on the existing protected areas system, so it utilizes the IUCN Red List as a standard tool. Since it was our intention to contribute to this global evaluation process, we have adopted the IUCN Red List as a tool for KBA identification in the Atlantic Forest. However, planning for the expansion and reinforcement of the existing protected system in Brazil and further refinements of the KBA process in the Atlantic Forest may benefit from the consideration of the National Red List of Threatened Species. The inclusion of the Brazilian List of Threatened Species may increase local stakeholders participation over the KBA identification process and ensure that species that are regionally secure but locally threatened are not excluded from the prioritization process.

Species data

We employed an extensive database on species distribution, with 1,636 species records at various spatial resolutions, which comprised of point data for 141 globally threatened terrestrial vertebrates: 20 amphibians, 14 reptiles, 69 birds, 38 mammals, representing all critically endangered (CR) ($n = 27$), endangered (EN) ($n = 36$) and vulnerable (VU) ($n = 78$) terrestrial vertebrate species, occurring in the Atlantic Forest, according to the IUCN Red List (IUCN 2007) (Fig. 1).

Species occurrence data were compiled from primary literature, scientific reports and museum records. Points were reviewed by specialists, in order to update historical records to the species current extents. Birds occurrence data were obtained from Silva et al. (2002), Cordeiro (2003), Roda (2004), Bencke et al. (2006). Primates data were obtained from BDGEOPRIM database (Hirsch 2003), reviewed by specialists, Marcelino and Marini-Filho (2003), Jerusalinsky et al. (2006). Polygons for other mammal species were obtained from Pedro and Aguiar (1998), Pinheiro et al. (2004). Amphibians extent of occurrences

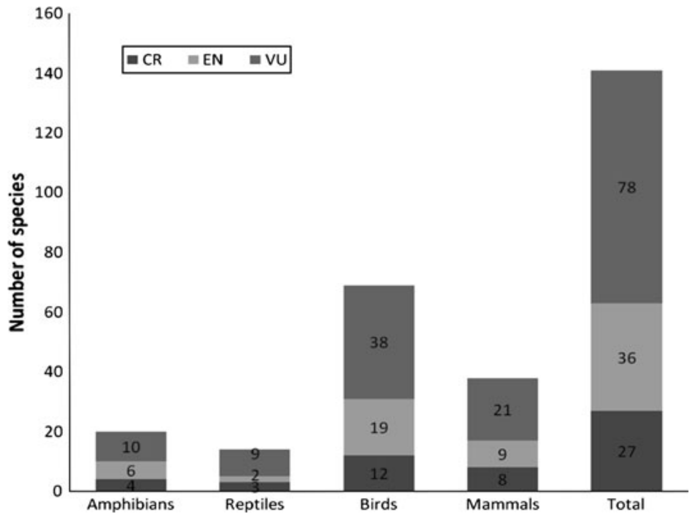

Fig. 1 Number of species employed in KBA identification, their threatened status (IUCN 2006) and taxonomic groups

were estimated using point data by Silvano and Pimenta (non published data), Verdade and Rodrigues (2003). Reptiles extents of occurrences were obtained the same way, based on point records for these species were compiled by Rocha and Sluys (non published data), Rocha (1999), Drummond (2002).

Municipality heads represented 21% of the geographic coordinates in the database. They were filtered and excluded from the analysis using a map of estimated urban areas of Brazilian cities (IBGE 2003; Miranda et al. 2005). Point localities that represented historical data were reviewed by specialists to update the records to their current locations.

Delineation

Delineation is an important step of the KBA process as it provides quantitative measures of the areas where conservation actions may be implemented and facilitates communication with stakeholders and donors. KBA delineation is still unresolved in many regions due to the application of globally standardized criteria to landscapes where habitat patters manifest in very different spatial scales. In the Atlantic Forest, a great number of species is dependent on habitat configuration and landscape connectivity due to the fine scale of habitat fragmentation. Planning for these species persistence would require that spatial scale and habitat connectivity issues, such as the identification of a constellation of functionally connected habitat fragments, were considered in the KBA delineation process.

In a first step towards this goal we have focused on the identification of continuous habitat patches where the species had been recorded, based on a number of contextual layers and following expert's knowledge and descriptions of the species current distributions. The most important data layers used in this refinement process were vegetation cover (Fundação SOS Mata Atlântica and Instituto Nacional de Pesquisas Espaciais 2002; Landau et al. 2002; Probio 2007), protected areas, topographic and elevation maps (CI-Brasil et al. 2000). This initiative represents per se, a refinement to previous conservation assessments in the region and may be complemented with data on ecology and behavior of the taxa considered in the KBA identification process, as they become available.

Prioritization

Once identified, KBA were prioritized, based on a combination of three criteria: irreplaceability, vulnerability, and species-based vulnerability. Irreplaceability reflects the spatial options for conserving the species occurring in that KBA (Pressey et al. 1993; Carwardine et al. 2007, Langhammer et al. 2007). In the prioritization framework, KBA irreplaceability was ranked as: "extreme" if at least one trigger species is restricted to the site; "high", if at least one species triggering a KBA occur in two to four other sites; and low, if all species present in the site were also present in more than four other sites. Site vulnerability was considered either low if a site is completely within a strictly protected area, or high if it is not currently protected as a strictly protected area. A species-based vulnerability score was assigned to a key biodiversity area based on the global threat status of trigger species, following the IUCN Red List. Species-based vulnerability was assigned as high if a site holds at least one critically endangered (CR) or endangered species (EN) species, and low if it is home of vulnerable (VU) species. The classification of a site as vulnerable due to the presence of a threatened species intends to reflect the reduced temporal options for conserving the species occurring in that site.

Results

We identified 538 key biodiversity areas in the Atlantic Forest by applying the vulnerability criteria (occurrence of globally threatened species). With regards to the number of species triggering KBA, the great majority of KBA (407 or 75.65%) were identified for a single species. 128 (23.79%) KBA were triggered by two or more species and three by more than 20 species (Fig. 2).

479 KBAs were classified as with low irreplaceability, meaning that more than four spatial options are available for conserving all the species occurring in these sites. The majority of KBAs with low irreplaceability (66%) were triggered by an endangered or critically endangered species (Fig. 3a). 57 KBAs were classified as highly irreplaceable, meaning that at least one species occurring in these sites also occur in two to four other sites. The great majority of highly irreplaceable KBAs (82%) are highly vulnerable due to the presence of an endangered or critically endangered species (Fig. 3b).

A particularly important result of the KBA process in the Atlantic Forest was the identification of 24 KBAs that hold the only record of a globally threatened species (Table 1). These sites, with irreplaceability ranked as extreme, represent the only spatial option for preventing the imminent global extinction of 35 terrestrial vertebrate species (Fig. 3c). 87.5% of the KBA ranked as extremely irreplaceable were triggered by one endangered or critically endangered species.

By overlaying the identified KBAs with strictly protected areas boundaries we were able to determine that only 98 KBAs are currently protected and 440 KBA are not covered by the current strictly protected areas system. The majority of KBAs classified as highly irreplaceable ($n = 42$) are also not protected. Of the 24 extremely irreplaceable KBAs, 14 (4%) are not completely within any strictly protected area's boundaries, leaving 14 globally threatened species and the last spatial option for conserving them under great threat.

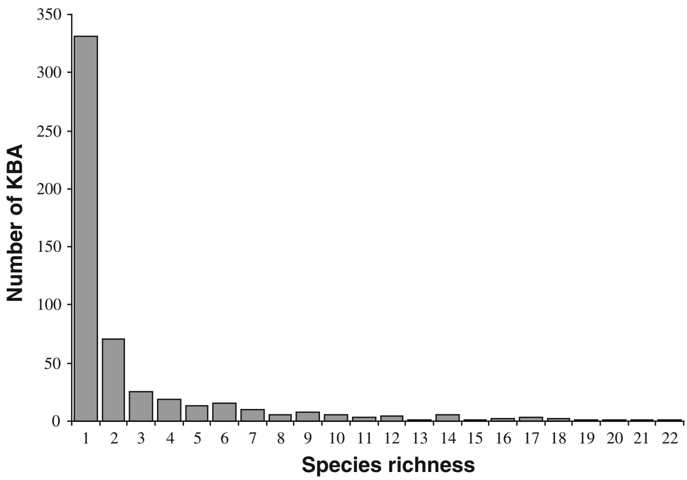

Fig. 2 Distribution frequency of number of species in KBA

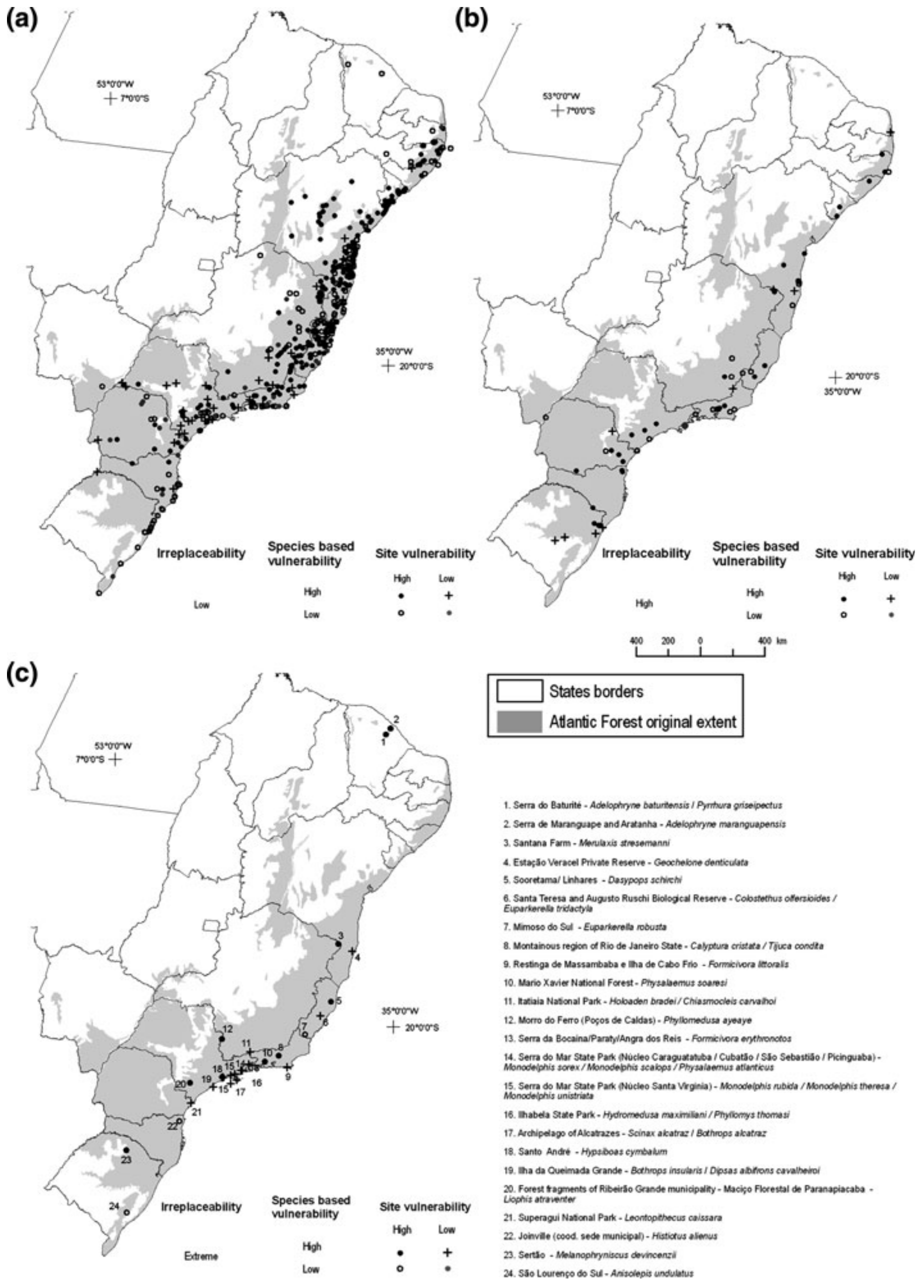

Fig. 3 KBAs classification according to site irreplaceability, site vulnerability, and species based vulnerability. KBA with irreplaceability ranked as: **a** low, **b** high, and **c** extreme

Table 1 Species triggering KBA with irreplaceability ranked as extreme

KBA	Site number (Fig. 3c)	Trigger species	Taxonomic group	Threat status (IUCN 2007)	Site vulnerability
Serra do Baturité	1	*Adelophryne baturitensis/Pyrrhura griseipectus*	Amphibian/bird	VU/CR	Not protected
Serra de Maranguape and Aratanha	2	*Adelophryne maranguapensis*	Amphibian	EN	Not protected
Santana Farm	3	*Merulaxis stresemanni*	Bird	CR	Not protected
Estação Veracel Private Reserve	4	*Geochelone denticulata*	Reptile	VU	Protected
Sooretama/Linhares	5	*Dasypops schirchi*	Amphibian	VU	Protected
Santa Teresa Augusto Ruschi Biological Reserve	6	*Colostethus olfersoides/Euparkerella tridactyla*	Amphibian	VU	Protected
Mimoso do Sul	7	*Euparkerella robusta*	Amphibian	VU	Not protected
Montainous region of Rio de Janeiro State	8	*Calyptura cristata/Tijuca condita*	Bird	CR/VU	Not protected
Restinga s at Massambaba and Ilha de Cabo Frio	9	*Formicivora littoralis*	Bird	CR	Not protected
Mario Xavier National Forest	10	*Physalaemus soaresi*	Amphibian	EN	Protected
Itatiaia National Park	11	*Holoaden bradei/Chiasmocleis carvalhoi*	Amphibian/amphibian	CR/EN	Protected
Morro do Ferro (Poços de Caldas)	12	*Phyllomedusa ayeaye*	Amphibian	CR	Not protected
Serra da Bocaina/Paraty/Angra dos Reis	13	*Formicivora erythronotos*	Bird	EN	Not protected
Serra do Mar State Park (Caraguatatuba/Cubatão/São Sebastião/Picinguaba)	14	*Monodelphis sorex/Monodelphis scalops/Physalaemus atlanticus*	Mammal/mammal/amphibian	VU/VU/VU	Protected
Serra do Mar State Park (Santa Virgínia)	15	*Monodelphis rubida/Monodelphis theresa/Monodelphis unistriata*	Mammal/mammal/mammal/	VU/VU/VU	Protected
Ilhabela State Park	16	*Phyllomys thomasi/Hydromedusa maximiliani*	Mammal/reptile	VU/VU	Protected
Archipelago of Alcatrazes	17	*Scinax alcatraz/Bothrops alcatraz*	Amphibian/reptile	CR/CR	Not protected
Santo André	18	*Hypsiboas cymbalum*	Amphibian	CR	Not protected
Ilha da Queimada Grande	19	*Bothrops insularis/Dipsas albifrons cavalheiroi*	Reptile	CR	Not protected

Table 1 continued

KBA	Site number (Fig. 3c)	Trigger species	Taxonomic group	Threat status (IUCN 2007)	Site vulnerability
Forest fragments of Ribeirão Grande municipality/Maciço Florestal de Paranapiacaba	20	*Liophis atraventer*	Reptile	VU	Not protected
Superagui National Park and surrounding area	21	*Leontopithecus caissara*	Mammal	CR	Protected
Joinville	22	*Histiotus alienus*	Mammal	VU	Not protected
Sertão	23	*Melanophryniscus devincenzii*	Amphibian	EN	Not protected
São Lourenço do Sul	24	*Anisolepis undulatus*	Reptile	VU	Not protected

Discussion and conclusions

Previous conservation assessments and priority setting initiatives in the Atlantic Forest have relied on different types of distribution data for biodiversity features, such as coarse scale species (Kinzey 1982; Silva et al. 2004) or vegetation maps (Rodrigues et al. 2008). Others have largely relied on non-published biodiversity data, leading to results that cannot be easily replicated (CI-Brasil et al. 2000; Tabarelli and Silva 2002; Drummond et al. 2005). Some works have considered species richness alone as a criterion to prioritizing among sites (Harris et al. 2005), and most of them, exceptionally Paglia et al. (2004) and MMA (2007), have not considered species representation in protected areas that already exist or the spatial or temporal options for biodiversity conservation (Margules and Pressey 2000).

We refine earlier priority setting initiatives in the Atlantic Forest by providing transparent, replicable measures for the application of conservation resources. The aim of our analysis was to test the KBA criteria and thresholds for highly fragmented biodiversity hotspot where an approach that minimizes commission errors is highly desirable. Results of individual species or taxonomic groups surveys illustrate the extreme threat to the Atlantic Forest biodiversity. Jerusalinsky et al. (2006) described the occurrence of an endangered species (*Callicebus coimbrai*) in forest fragments as small as 3 ha in Bahia and Sergipe states; Roda (2004) found 20 globally threatened bird species in forest fragments as small as 8.5 ha in the Brazilian Northeast; and Pinto and Bede (2006), reported the occurrence of 20 globally threatened species in a single forest fragment (<1,000 ha) in private property in Northeastern Minas Gerais state. Building on these individual works on single species or taxonomic groups and distributional data compiled from primary literature, scientific reports and museum records we have compiled a comprehensive database that systematically depicts the vulnerability and irreplaceability of KBA in the Atlantic Forest.

The Atlantic Forest holds an overwhelmingly high number of KBA ($n = 538$), most of them triggered by an endangered or critically endangered species. Although the great majority of identified KBA ($n = 407$) are triggered by only one globally threatened species, we have also found forest fragments with species numbers as high as 24 species (Sooretama Biological Reserve and adjacent forest fragments in Linhares, Espírito Santo). This skewed distribution of species in KBA reveals spatial and temporal sampling biases, which in turn indicates omission errors in KBA identification. Sampling biases have been observed in other species databases in Brazil, and result from the fact that the available data were not primarily collected with the objective of informing conservation planning (Rodrigues et al. 2008).

Recent efforts to compile large databases on species distribution are now taking place in the Atlantic Forest. A plants database with approximately 50,000 records for 3,000 species of bromeliads and vascular plants is currently being built (e.g. Stehmann et al. 2008). In hotspots with fewer remaining habitat patches, such as the Eastern Arcs and Coastal Forests of East Africa, as other taxonomic groups were included in the KBA identification process, the total number of KBA ($n = 160$) quickly stabilized as most remaining forest patches are identified for KBA (Conservation International and International Centre of Insect Physiology and Ecology 2003). In the Atlantic Forest, due to the immense number of forest patches, we foresee overall an increase in KBA numbers as databases continue to be built, as species inventories progress, as national and states threatened species lists and other criteria are incorporated into KBA identification process. As a result of incorporating this database into the KBA process, omission errors may be reduced and small forest fragments that are not usually the focus of vertebrate species inventories may be highlighted as conservation priorities.

The application of criteria two, three and four into the KBA identification process, the inclusion of restricted ranges, congregatory species and biome-restricted assemblages, may result in a better representation of these taxonomic groups. While the vulnerability criteria is mostly based on published data on species distribution, the inclusion of restricted ranges and congregatory species may require a broader review of specialists.

Despite the high number of protected areas in the region, most KBAs identified in this work are not strictly protected. A closer look at strictly protected areas in the Atlantic Forest reveals that ~60% are not fully implemented due to a lack of financial resources, management plans, problems related to land tenure documentation (Fonseca et al. 1997; Rylands et al. 2004). Strictly PAs cover from 17.7 (calculated here) to 7.7% of the remaining native vegetation total area (Schmitt et al. 2009). A more realistic approach to assessing site vulnerability in KBA prioritization, which could be explored in future work, would also consider these aspects of protected area management effectiveness and implementation.

The indication of the 24 most irreplaceable sites for terrestrial vertebrate species conservation is an important result of KBA prioritization. Fourteen of the most irreplaceable sites for conservation in the Atlantic Forest are not currently protected. Urgent protection of these sites will require the joint effort of land owners, local stakeholders and government. The 'Brazilian Alliance for Zero Extinction—BAZE' is an initiative to identify, delineate and protect the most irreplaceable sites where globally and/or nationally threatened species occurring in Brazil and may benefit from the data generated in this work. BAZE builds from the baseline laid by the global Alliance for Zero Extinction (AZE) (www.zeroextinction.org), which is an alliance of over 60 organizations that attempt to identify the last remaining sites for EN or CR species.

So far, results of KBAs analysis have helped locate sites for protected areas creation in the Atlantic Forest of Southern Bahia State, Brazil (Timmers 2006), demonstrating that the utilization of transparent and quantitative criteria conservation priority areas identification may facilitate the engagement of local stakeholders in different steps of the implementation processes as suggested by Pressey and Botrill (2008); Lovejoy (2009) and Knight et al. (2008).

While the very detailed results of this work represent a valuable and consistent contribution to conservation actions in the Atlantic Forest, larger scale conservation planning and implementation are needed to ensure long-term persistence of these species in the region (Knight et al. 2007). The KBA approach provides transparent data for the precise application of conservation resources orienting private reserves, public protected areas creation and fine scale forest restoration initiatives. A complementary landscape scale approach (Didier et al. 2009) would benefit a broader array of generalists and widespread species while taking into account landscape connectivity issues, landscape change, socio-environmental drivers of land use change and conservation opportunity costs.

As useful first step to more integrated conservation planning the aim of our analysis was to test the KBA criteria and thresholds for highly fragmented biodiversity hotspot where an approach that minimizes commission errors is highly desirable. Outcomes of this study could be useful for leveraging funds, drawing attention and focusing efforts to the most urgent and irreplaceable sites for conservation while providing a base line for future biodiversity monitoring in the Atlantic Forest.

Acknowledgments We thank F. Melo for reviewing mammal species records, P. Develey from Birdlife—Save Brasil for reviewing birds point records and for revising a previous version of this manuscript. The authors also thank the Conservation Leadership Program for partially providing financial support, K. Didier and P. Langhammer for critically reviewing this work.

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