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Minimizing conservation conflict for endemic primate species in Atlantic forest and uncovering knowledge bias

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SUMMARY

Human population is a predictor of mammal extinction risk, an indicator of conservation conflict and habitat conversion, and is thus associated with the threats to primate species. Priority areas that represent endemic primates in Atlantic Forest were identified where all counties had the same cost or where the costs of counties varied according to human population size (HPS); networks for both approaches consisted of nine counties. In the networks without human constraint, the average HPS was not higher than expected by chance alone. In the approach with human population constraint, HPS was not lower than the average of the null distribution. Although it is possible to minimize human conservation conflict, available occurrence data of endemic primates seems to be related to highly populated areas. The sum of HPS is greater in counties with some occurrence data than expected by chance. Conservation conflicts in the Atlantic Forest will continue to exist once this is the Brazilian most populous region, and data availability is directly related to counties' HPS. Field surveys are necessary to minimize Wallacean shortfall and efforts must be made to maintain the few natural areas remaining in this biome to promote the conservation of endemic primates and other biodiversity elements.

Keywords: Atlantic forest, complementarity, conservation conflicts, endemic primates, human population size, knowledge bias, randomization test, reserve selection, simulated annealing, Wallacean shortfall

INTRODUCTION

From 1995 to 2000, human population growth occurred in virtually all global hotspots and, although human disturbance can occur in the absence of human settlements, thus it is likely that habitats will continue to be converted and species will continue to become threatened or extinct (Cincotta *et al*. 2000). The Atlantic Forest biome is a global biodiversity hotspot, with high conversion rates and high plant endemism (Myers *et al*. 2000), and home to approximately 70% of Brazil's 169 million people (Jacobsen 2003). Species extinction is likely to be high in this geographically restricted region with high species endemism, heavy habitat loss and a rapidly increasing human population (Laurance 2006, 2009). For the Atlantic forest region, there are some studies related to conservation planning, such as population viability analysis of mammals (for example, marsupials: Brito & Grelle 2004; and primates: Brito & Grelle 2006; Oliveira *et al*. 2010), and a spatial conservation prioritization with all species of a mammal group (Pinto & Grelle 2009). There are also other major conservation initiatives by non-governmental organizations (NGOs) and governmental agencies (Tabarelli *et al*. 2005). This biome urgently requires further investigation of current conservation methods and the establishment of priority areas for conservation.

The use of human population density in reserve selection procedures is based on the assumption that an increase in density represents a threat to conservation (Luck 2007). For example, human population is a strong predictor of extinction risk, especially for large-bodied mammals (Cardillo *et al*. 2005). Human population size (HPS) may also be an indicator of conflict between conservation and development (Balmford *et al*. 2001). There are another two implicit and related reasons to include human population in the reserve selection approach: habitat conversion is directly related to HPS (Laurance *et al*. 2002), and this variable is also a surrogate for monetary costs (Luck *et al*. 2004; Rangel *et al*. 2007). Highly populated areas generally have no or very few habitat remnants. The opposite is not necessarily true. It is likely that there is some remaining habitat for conservation in counties with low human populations, but habitat conversion caused by humans can also occur in areas of low human density (Cincotta *et al*. 2000), for example in large estates used for farming or cattle raising. Correlations between human population and species richness are almost always positive (Balmford *et al*. 2001; Chown *et al*. 2003; Luck *et al*. 2004; Vázquez & Gaston 2006), but this does not mean that conservation conflicts will necessarily exist; there may be biological reasons for this correlation (for example Luck *et al*. 2010) or it may be an artefact of sampling bias. Several researchers tried to identify networks of priority areas with low human population using

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the principle of complementarity in Africa (Balmford *et al.* 2001), the Cerrado of Brazil (Diniz-Filho *et al.* 2006; Pinto *et al.* 2007), Europe (Araújo *et al.* 2002) and Australia and North America (Luck *et al.* 2004). As well as species richness, the beta biodiversity pattern is strictly linked to complementarity.

The order Primates is the mammal group with the highest number of globally threatened species (Grelle *et al.* 2006) and, in Brazil, not all species are represented in reserves of strict protection (Pinto & Grelle 2009). Selecting priority conservation areas with lower human population densities is possible and desirable because the majority of the factors associated with primate species threat in Atlantic forest are related to human population, such as habitat loss, hunting for food, sport or pets, mining, illegal palm-harvesting, roads, power lines, predation from domestic pets and exotic species (see for example Machado *et al.* 2008; IUCN 2010).

Prioritization exercises are often done using grids organized in hexagons or squares (see Reyers 2004; Pinto *et al.* 2008; Tognelli *et al.* 2008), but geopolitical units may also be relevant, since this is the scale at which administrative decisions relevant to conservation are made in practice (Hunter & Hutchinson 1994; Ando *et al.* 1998). Indeed, Hunter and Hutchinson (1994) referred to the extent of study, but in Brazil, using counties as spatial units to separate grains in reserve selection procedures is pertinent since this is the smallest geopolitical unit at which this kind of administrative, and consequently conservation, decision is generally made.

In this study, we evaluate the possibility of minimizing conservation conflicts as function of HPS by applying a systematic conservation approach (Margules & Sarkar 2007) to identify priority areas that represent endemic primate species in the Atlantic forest biome. We used the Brazilian counties as units of analysis within this biome, as these are the smallest administrative units where the political decisions are taken and HPS is estimated. Using the results we obtained and other findings of knowledge bias (Dennis & Thomas 2000; Dennis *et al.* 1999), we also investigated the hypothesis that HPS in the set of counties with available data is greater than expected by chance alone.

Figure 1 Distribution of the Atlantic forest biome among the Brazilian states. CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, SE = Sergipe, PI = Piauí, BA = Bahia, GO = Goiás, MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, MS = Mato Grosso do Sul, SP = São Paulo, PR = Paraná, SC = Santa Catarina and RS = Rio Grande do Sul.

METHODS

We obtained the map for the Brazilian counties from the Brazilian Agency of Geography and Statistics (IBGE; http://www.ibge.gov.br) and superimposed it onto the Atlantic forest biome (Fundação SOS Mata Atlântica 2009; Fig. 1). If a county's area of Atlantic forest biome was < 25% of its total area, it was excluded from the set. The remaining 3130 counties with Atlantic forest coverage ≥ 25% of their total area were considered the units of analysis in our study. We organized the presence/absence data for the 19 primate species endemic to the Atlantic Forest biome (see Pinto & Grelle 2009) per county in a binary matrix. Species richness was calculated by summing the species present in each county.

Human population data were obtained from the IBGE population census for the year 2007, and these were associated with the county map. We log-transformed these data to normalize distribution. We analysed the linear correlation between HPS and species richness. Autocorrelation in data may inflate Type I errors (see Legendre *et al.* 2002; Diniz-Filho *et al.* 2003); we therefore used the corrected degrees of freedom using the Dutilleul (1993) method in the test of significance for correlation, implemented through SAM software (Rangel *et al.* 2006, 2010).

Optimization routines were used to select networks to represent each species at least once with a minimum total number of sites. These routines use a total cost function that should be minimized (Ball *et al.* 2009); it increases if any species is not represented and if additional counties are selected. The total cost function also increases as more populated counties are selected (an individual cost related to HPS was given to each county in the second approach; see below). For this purpose we used the simulated annealing algorithm (Andelman *et al.* 1999; Possingham *et al.* 2000, 2006), which starts with a random set of reserves and, at each iteration, randomly swaps sites in and out of that set, measuring the change in the total cost function. Only changes that diminished cost were retained. In the cost function, the non representation of any species increased the cost, as well as the inclusion of any site.

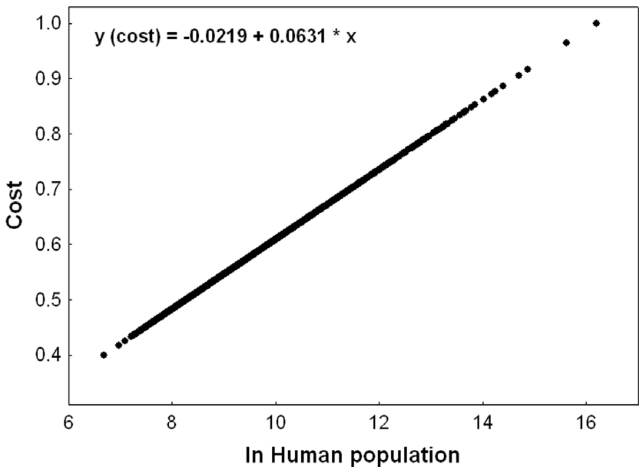

Figure 2 Values attributed as costs to the counties obtained as a linear function of ln-human population size. We provide a detailed explanation of cost in the Methods section.

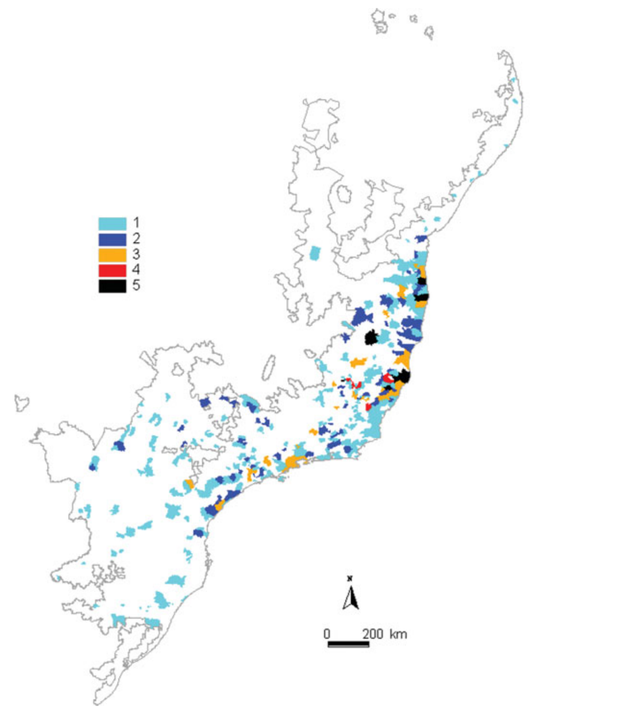

Figure 3 Spatial pattern of endemic primate richness per county in the Atlantic forest biome, in number of species (for state names, see Fig. 1).

Two approaches were used to select reserve networks. In the first (referred to as 'without human constraint' hereafter), all the counties were considered to have the same cost. In the conflict minimization approach ('human constraint' hereafter), the cost of counties varied according to the HPS. The counties' costs needed to be rescaled to values between 0 and 1, to values comparable to the cost 1 of not representing any species, once these were used in the same total cost function. A linear function was then adjusted such that the smallest ln-human population value (6.69) was 0.4, and the largest ln-human population value (16.20) was 1. To obtain the other counties' cost values we used the function obtained (Fig. 2):

$$\text{Countycost} = -0.0219 + (0.0631 \times \ln\text{HPS}) \quad (1)$$

We could not attribute a zero value to the smallest ln-HPS because the county would then have had no cost, and would enter a network more easily.

We used the software MARXAN (Ball & Possingham 2000; Possingham *et al.* 2000, 2006; Game & Grantham 2008), which incorporates the simulated annealing algorithm, in the reserve selection procedures. We ran it 300 times with 10 000 000 iterations for each approach. In the approach without human constraint and with no costs attributed to the counties, most of the solutions represented all primate species with the minimum number of counties, but some did not; therefore we used the first 100 networks that did represent all the primate species with the minimum number of counties to map the irreplaceability of the counties. The frequency of each county in the various optimized networks indicates its relative importance for complementarity solutions, a simple measure of irreplaceability of that county (Meir *et al.* 2004; see also Ferrier *et al.* 2000 for a more complex approach). The highest degree of irreplaceability is when a county occurs in each of the 100 representation solutions.

The HPS in all the networks for both approaches was calculated by summing the human population of the counties within each network. These values were compared using a null distribution composed of the HPS in 100 000 random networks with the same number of counties of the networks obtained with the simulated annealing algorithm. We used RRS (Randomization Reserve Selection) software (Rangel *et al.* 2004) to select the random networks and calculate the HPS in these networks. The area of forest remnants in the counties that composed the network minimizing HPS was obtained from Fundação SOS Mata Atlântica (2009). The results obtained led us to investigate whether the counties which had some presence data had a total HPS greater than expected by chance alone. In order to test this using a null model, we selected 332 random counties from the 3130 counties in 10 000 simulations.

RESULTS

Occurrences of the primate species endemic to the Atlantic forest were distributed along 332 counties from the 3130 counties with an area of Atlantic forest biome composing $\geq$ 25 of their total area (Fig. 3). The five counties that had the highest number of species were: Belmonte and Una (Bahia state) in the most north-easterly coast region, Linhares and Santa Teresa (Espírito Santo state) in the east,

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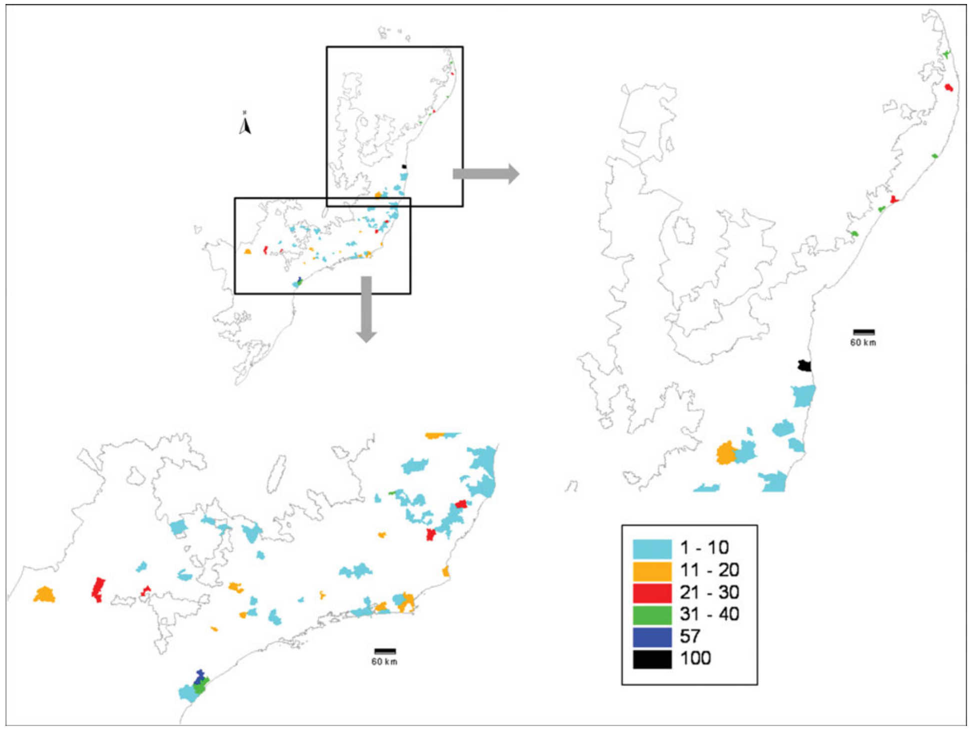

Figure 4 Irreplaceability pattern obtained using the frequency of occurrence of the counties in the 100 best networks with nine counties from the first approach; all the counties have the same cost (for state names, see Fig. 1).

and Teófilo Otoni and Timóteo (Minas Gerais state) in the interior. The species with the greatest number of occurrences was *Cebus nigritus* (114 counties). Three species occurred in only three counties, namely *Callicebus coimbrai*, *Cebus flavius* and *Leontopithecus caissara*. *C. coimbrai* is endangered, and *C. flavius* and *L. caissara* are critically endangered (IUCN 2010). Other species are also endangered, but had greater numbers of occurrences.

There was a positive correlation between HPS and primate species richness in Atlantic forest ($r = 0.239$, $p < 0.001$, corrected degrees of freedom = 843.1), indicating possible conservation conflicts. The 100 best networks selected to represent the primate species without human constraint where all counties had the same cost contained nine counties. Only one county, Una (Bahia), occurred in all networks and it contained five primate species (Fig. 4). The other counties can be replaced by one another in different networks.

In the 'with human constraint' approach, one minimal network with nine counties representing all primate species was obtained and this contained the minimum possible human population (Fig. 5). The other networks had more counties or a higher total human population. The counties selected were Passo de Camaragibe, Santo Amaro das Brotas, Una, Machacalis, Monte Belo, Santa Teresa, Silva Jardim, Cananéia and Gália (Table 1).

HPS was greater in counties selected in the 'without human constraint' approach, as compared to the 'with human constraint' approach. The networks selected without human constraint (Fig. 4) had an average ln-HPS = 13.26 (SD = 0.79; maximum = 15.71; minimum = 12.09), and this was not greater than expected by chance alone ($p = 0.11$). The ln-HPS in the network selected with human constraint was 11.78, which was not smaller than the average of the null distribution ($p = 0.27$). The average ln-human population in 100 000 random networks was 12.30 (SD = 0.79; maximum = 16.91; minimum = 10.12). A network devised using human population constraint had fewer people compared to the networks selected without human constraint constraint (Fig. 6).

The total ln-HPS in the 332 counties that had some kind of endemic primate species occurrence data was 17.54. Only one of the 10 000 sets of 332 random counties ($p < 0.01$) had a ln-HPS as high as 17.54.

DISCUSSION

Several studies have defined priority areas for conservation in South America for different groups of organisms (Fjeldså 2000; Cavieres *et al.* 2002; Thiollay 2002; Arzamendia & Giraudo 2004; Diniz-Filho *et al.* 2004, 2006, 2007; Tognelli 2005; O´Dea *et al.* 2006; Pinto *et al.* 2007, 2008) and identified conservation priorities in the entire Neotropical region (Wege & Long 1995; Loyola *et al.* 2008*a*, *b*, 2009) or part of it (Galván & Vázquez 2008). Only one study has used point locality data for primates evaluating the efficiency of the reserve network in 0.25° × 0.25° grid cells (Pinto & Grelle 2009). Our study is the first to use counties as the unit of analysis including human population in the reserve selection process in South America, although counties have been the focus of studies elsewhere (Abbitt *et al.* 2000).

About 74% of the species in this study are considered threatened (IUCN 2010). Two of the nine counties selected had <15% vegetation cover, and neither of these contained any strict reserve (Table 1). Of the other counties, five had

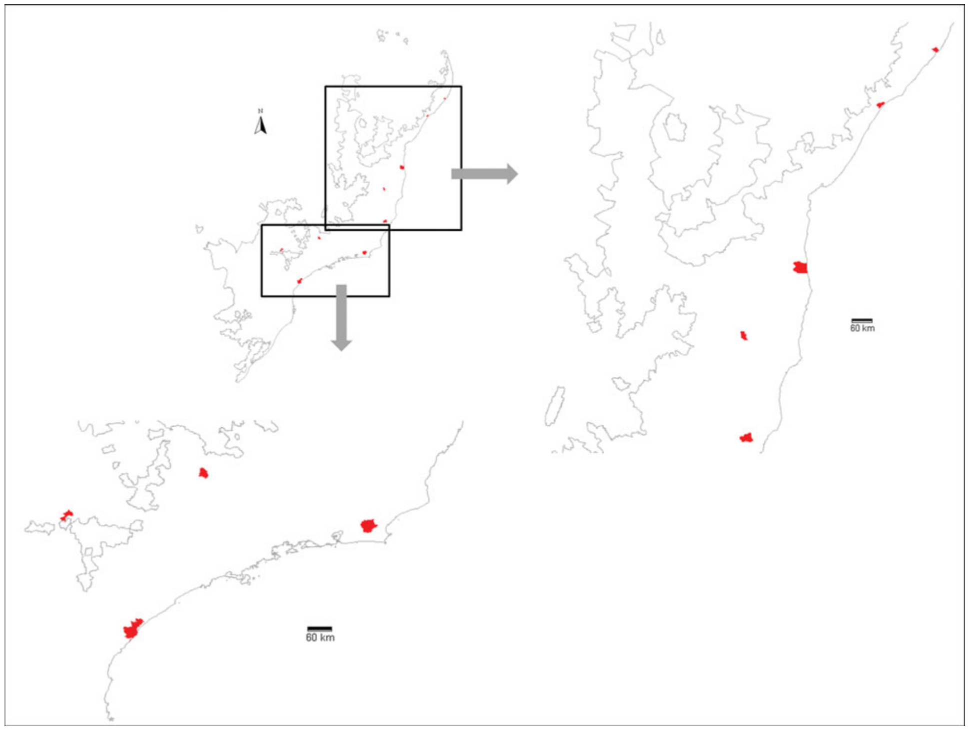

Figure 5 Single network with nine counties selected in the 'with human constraint' approach, each county has a cost directly related to its human population size (for state names, see Fig. 1).

partial strict use reserve protection. The local knowledge to guarantee that the selected areas have available native areas to be conserved is not available, but the areas most converted and that have the greatest potential for conservation conflict have not entered the reserve networks we identified. Point locality occurrence data are considered a conservative approach because they minimize commission errors when compared to studies that use geographical distributions (O´Dea *et al.* 2006; Rondinini *et al.* 2006; Pinto & Grelle 2009).

The average HPS in networks found using reserve selection without human constraint was high but no greater than in random networks with the same number of counties. Minimum networks that represented all the endemic primate species had large HPS. The present results also show that it is possible to minimize human conservation conflict in the Atlantic forest. Human population in the single network with human constraint (with costs) was lower than that in the networks selected without constraints, albeit not lower than those in random networks. This also corroborates that the occurrence data that are available derive from highly populated areas. Although there are less densely populated counties, insufficient occurrence data exist for these. Of the 3130 counties in the Atlantic forest, 332 had some kind of endemic primate species occurrence data, and there were more people in the counties for which there were data than expected by chance alone. Surveys may thus be directly related to areas with more people or factors associated with this, such as taxonomists' home ranges or study areas, proximities to

Table 1 Name, state, human population size, vegetation cover and strict use reserves in the nine counties selected in the human constraint approach. PN = Parque Nacional (National Park); RB = Reserva Biológica (Biological Reserve); PE = Parque Estadual (State Park); EE = Estação Ecológica (Ecological Station); RVS = Refúgio de Vida Silvestre (Wildlife Refuge). AL = Alagoas; SE = Sergipe; BA = Bahia; MG = Minas Gerais; ES = Espírito Santo; RJ = Rio de Janeiro; SP = São Paulo.

County	*State*	*Human population size (n)*	*Vegetation cover (%)*	*Strict use reserves*
Passo de Camaragibe	AL	14302	17	
Santo Amaro das Brotas	SE	11652	19	
Una	BA	24938	37	PN da Serra das Lontras; RB de Una; RVS do Una
Machacalis	MG	6869	5	
Monte Belo	MG	12573	6	
Santa Teresa	ES	19953	21	RB de Augusto Ruschi
Silva Jardim	RJ	21362	33	PE dos Três picos; RB de Poço das Antas
Cananéia	SP	12039	82	PE do Lagamar de Cananéia; PE Ilha do Cardoso
Gália	SP	6870	15	EE dos Caetetus

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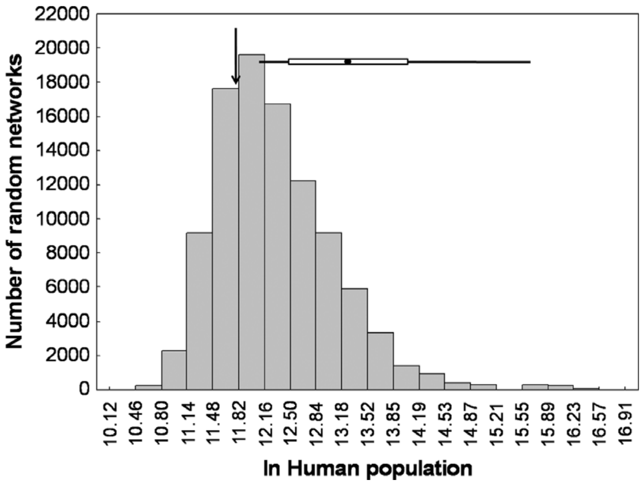

Figure 6 ln-human population in 100 000 random networks with nine counties. ln-human population in the 100 networks selected to conserve primates (the point represents the mean, the right and left limits of the box show the standard deviation, and the right and left limits of the line represent the minimum and maximum). The vertical arrow shows the ln-human population in the network selected to conserve primates while minimizing the human population.

work centres and roads (Dennis *et al*. 1999; Dennis & Thomas 2000, Kadmon *et al*. 2004). There is insufficient research data for areas with low human populations.

The size of the species' range may also have influenced the results (Pinto *et al*. 2007). There is no way to avoid conservation conflicts for species with very small geographic ranges if these ranges are restricted to areas with high human population density, although this may not be a problem in this study because we used occurrence point data instead of species geographic distributions. Species are artificially restricted when occurrence data are used, but such data assure the species will be represented in the networks selected.

Field surveys are essential to minimize the Wallacean shortfall, a concept associated with low knowledge of species' distributions (Lomolino 2004; Whittaker *et al*. 2005), but conservation planning is an urgent need that cannot wait for the solution. The prioritization of areas for species conservation needs to be implemented using information already available, even if the selection is biased for some taxonomic groups and incomplete. For example, in the present study, the fact that data were biased did not mean they were wrong; rather that primate occurrence points were more frequent in those areas for which the data were biased. These data should be used for conservation planning, but this does not eliminate the need for additional inventories. Updating of strategies must follow the data actualization. Improvements can also be made in reserve selection procedures, including other variables such as vegetation cover and current land costs.

The present study shows that it is possible to minimize the HPS in the reserve selection procedure, but conservation conflicts in the Atlantic Forest will continue given this is the Brazil's most populous region and data availability seems linked to high human population. Our study is an initial exploration of this issue at a broad scale following the framework of conservation biogeography (Whittaker *et al*. 2005) in the Atlantic Forest biome. Such broad-scale approaches can provide overall guidelines for downscaled conservation strategies. Furthermore the maintenance of the few natural areas remaining in this biome is needful.

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