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Reserve selection, Gap Analysis and Conservation targets for Primates of the Brazilian Atlantic Forest

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Thesis presented to the Programa de Pós-Graduação em Ecologia da Universidade Federal do Rio de Janeiro as a part of the requirements obtaining a master's degree in Ecology.

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“Nowadays people know the price of everything, and the value of nothing.”

Oscar Wilde - *The Picture of Dorian Gray*

“No one could make a greater mistake than he who did nothing because he could do only a little.”

Edmund Burke

Acknowledgments

Contents

Abstract

We are living in a biodiversity crisis, species are becoming extinct at unprecedented rates and many more are threatened by human activity. Several conservation actions are being implemented around the world to try to bring the biodiversity crisis to a halt. Species management, the creation of protected areas, environmental education, reintroductions and restoration are examples of such actions. Protected areas are considered the most efficient *in situ* strategy for biodiversity conservation. The establishment of protected areas is in the global conservation agendas with governments committed to conserve a combined ≥ 17% of terrestrial and ≥ 10% of marine environments with an especial focus on areas of particular importance for biodiversity. The Atlantic Forest is a biodiversity hotspot with around 11.7% of its original extension scattered in small forest fragments and with 9.3% of its remaining extension falling within the boundaries of protected areas. Conservation action in this biome is urgent, it should be based on scientific knowledge and quality data and should be planned for maximum efficiency as resources are scares and conservation is in direct conflict with economic agendas. The main aim of this thesis is to assess the current state of primate conservation in the Atlantic Forest and suggest new areas to complement the existing conservation network. In chapter one we evaluate the quality of range map data from IUCN and NatureServe for Atlantic Forest primates. We quantified the amount of omission errors present IUCN and NatureServe range maps for 19 Atlantic Forest primates and found that roughly 19% of all localities points correspond to omission errors in both databases. Although IUCN performed slightly better. However, omission errors were much greater for threatened species totaling 37.50% for IUCN and 43.18% for NatureServe. In chapter two, we determine conservation targets, perform a gap-analysis, prioritize areas for conservation and suggest a refined distribution dataset based on remaining fragments (“Remaining Habitat”) for 17 endemic Atlantic Forest primates. Conservation targets were on average 33% of species’ extents of occurrence for IUCN and NatureServe datasets and around 91% for Remaining Habitat. Only one species was considered adequately protected by the current reserve network in all three datasets while 11 were gap-species in all dataset. We found that a minimum of 49 697 km^2 is necessary to protect

all 17 species endemic primates which is four times the amount of reserves that currently exist.

This thesis: i) sheds light on the quality of online range databases, ii) evaluates the state of conservation of Atlantic Forest primates, iii) provides support for conservation planning and decision making on Atlantic Forest conservation.

Resumo

Estamos vivendo uma crise da biodiversidade, com taxas de extinção de espécies sem precedentes e muitas outras espécies ameaçadas por atividades humanas. Diversas ações de conservação estão sendo implementadas ao redor do mundo com o objetivo de diminuir a crise de biodiversidade. O manejo de espécies, a criação de áreas protegidas, educação ambiental, reintroduções e restauração são alguns exemplos dessas ações. O estabelecimento de áreas protegidas é considerado a estratégia *in situ* mais eficiente de conservação da biodiversidade. A criação de áreas protegidas está na agenda de conservação global com governos comprometidos a conservar um total combinado de ≥ 17% de ambientes terrestres e ≥ 10% de ambientes marinhos com um foco especial em áreas de grande importância para a biodiversidade. A Mata Atlântica é um *hotspot* de biodiversidade com 11,7% da sua extensão original dispersa em pequenos fragmentos de floresta e 9,3% da sua extensão remanescente protegida por Unidades de Conservação. Ações de conservação nesse bioma são urgentes e devem ser baseadas em conhecimento científico e dados de qualidade, e ainda serem planejadas para máxima eficiência já que recursos são escassos e a conservação está em conflito direto com agendas econômicas. O objetivo principal dessa dissertação é avaliar o estado atual da conservação de primatas na Mata Atlântica e sugerir novas áreas de proteção para complementar a rede de reservas existente. No capitulo um, nós avaliamos a qualidade dos mapas de distribuição da IUCN e da NatureServe para primatas da Mata Atlântica. Nós quantificamos a quantidade de erros de omissão para 19 primatas da Mata Atlântica. Erros de omissão foram por volta de 19% de todos os pontos de localidade em ambas as bases de dados. Porém, IUCN teve um desempenho um pouco melhor que NatureServe. Porém, erros de omissão foram muito maiores para espécies ameaçadas: 35,70% para IUCN e 43,18% para NatureServe. No capítulo dois nós determinamos alvos de conservação, realizamos uma análise de lacunas, priorizamos áreas para conservação e sugerimos uma base de dados refinada de distribuição das espécies baseada em fragmentos remanescentes (“Remaining Habitat”) de floresta para 17 primatas endêmicos da Mata Atlântica. Alvos de conservação foram em média 33% da extensão de ocorrência das espécies tanto para IUCN quanto para NautureServe e em torno de 91% para *Remaining Habitat.* Apenas

uma espécie foi considerada adequadamente protegida pela atual rede de reservas em todas as três bases de dados enquanto 11 espécies foram consideradas espécies lacuna em todas as bases de dados. Nós encontramos que um mínimo de 49 697 km^2 são necessários para proteger todas as 17 espécies de primates endêmicos. Esse valor corresponde a quatro vezes a quantidade de reservas existente atualmente.

Essa dissertação: i) determina a qualidade dos mapas de extensão da IUCN e da NatureServe, ii) avalia o estado de conservação de primatas da Mata Atlântica, iii) fornece apoio para o planejamento de conservação e tomadas de decisão envolvendo a Mata Atlântica.

Overall Introduction

We are living in a biodiversity crisis, with extinction rates comparable only to few mass extinctions documented in the geological records (Grelle & Alves, 2008; Pimm *et al.*, 1995). Habitat loss, pollution, climate change as well as other anthropogenic disruptions of natural environments have led species to extinction and threaten many more. Many initiatives are in motion to try to stop the biodiversity crisis from deepening and restore natural environments. Protected areas in particular serve as sources of individuals for surrounding areas, maintain ecosystem function, and protect populations and genetic variability. As such, it is a consensus between conservation biologists that establishing protected areas is the best *in situ* strategy for protecting biodiversity from human impact.

Setting aside protected areas is not a novel concept. People have been doing so for millennia either for religious reasons, to protect areas of scenic beauty, as hunting grounds or to limit exploitation and preserve biodiversity (e.g. Chandrashekara & Sankar, 1998); it has always been a part of human culture. According to the 2014 United Nations List of Protected Areas, there are currently 209,429 protected areas around the globe, in comprising 15.4% of the world surface. However, to this day, most protected areas are selected opportunistically seldom considering the contribution the new area will make to whole picture (Pressey *et al.*, 1993). Studies have shown that such ad-hoc selected conservation areas are also markedly cost-inefficient (Pressey *et al.* 1994; Pressey & Crowling 2001). Considering that resources destined to conservation will always be limited as conservation is often in direct conflict with economic pressures, it is highly desirable to optimize conservation efforts. Reserves have two major roles: representing the variety of biodiversity elements and ensuring their persistence (Margules & Pressey, 2000). However, they will be more likely to fulfill such roles if they are selected systematically with clear targets and based in strong science and complementarity (Margules & Sarkar, 2007).

Systematic Conservation Planning aims to resolve such issues by using specific and replicable protocols (Margules & Pressey, 2000). It consists in six steps process (Box 1): compiling and reviewing data of conservation significances, identifying conservation goals, reviewing the existent reserve network, selecting additional reserves, implementing conservation action and finally managing and monitoring protected areas (Margules & Pressey, 2000).

Biodiversity is expressed in several levels of organization – from molecules to

Box 1

Stages in systematic conservation planning

Systematic conservation planning can be separated into six stages, and some examples of tasks and decisions in each are presented below[25]. Note that the process is not unidirectional; there will be many feedbacks and reasons for altering decisions (see text for examples).

1. Compile data on the biodiversity of the planning region
- Review existing data and decide on which data sets are sufficiently consistent to serve as surrogates for biodiversity across the planning region.
- If time allows, collect new data to augment or replace some existing data sets.
- Collect information on the localities of species considered to be rare and/or threatened in the region (these are likely to be missed or under-represented in conservation areas selected only on the basis of land classes such as vegetation types).

2. Identify conservation goals for the planning region
- Set quantitative conservation targets for species, vegetation types or other features (for example, at least three occurrences of each species, 1,500 ha of each vegetation type, or specific targets tailored to the conservation needs of individual features). Despite inevitable subjectivity in their formulation, the value of such goals is their explicitness.
- Set quantitative targets for minimum size, connectivity or other design criteria.
- Identify qualitative targets or preferences (for example, as far as possible, new conservation areas should have minimal previous disturbance from grazing or logging).

3. Review existing conservation areas
- Measure the extent to which quantitative targets for representation and design have been achieved by existing conservation areas.
- Identify the imminence of threat to under-represented features such as species or vegetation types, and the threats posed to areas that will be important in securing satisfactory design targets.

4. Select additional conservation areas
- Regard established conservation areas as 'constraints' or focal points for the design of an expanded system.
- Identify preliminary sets of new conservation areas for consideration as additions to established areas. Options for doing this include reserve selection algorithms or decision-support software to allow stakeholders to design expanded systems that achieve regional conservation goals subject to constraints such as existing reserves, acquisition budgets, or limits on feasible opportunity costs for other land uses.

5. Implement conservation actions
- Decide on the most appropriate or feasible form of management to be applied to individual areas (some management approaches will be fallbacks from the preferred option).
- If one or more selected areas prove to be unexpectedly degraded or difficult to protect, return to stage 4 and look for alternatives.
- Decide on the relative timing of conservation management when resources are insufficient to implement the whole system in the short term (usually).

6. Maintain the required values of conservation areas
- Set conservation goals at the level of individual conservation areas (for example, maintain seral habitats for one or more species for which the area is important). Ideally, these goals will acknowledge the particular values of the area in the context of the whole system.
- Implement management actions and zonings in and around each area to achieve the goals.
- Monitor key indicators that will reflect the success of management actions or zonings in achieving goals. Modify management as required.

Box 1 From "Systematic Conservation Planning" by C.R. Margules & R. L. Pressey, 2000, *Nature*, 405, p.245.

ecosystems, being hard to quantify. It is also ill sampled across the globe; biological data is biased and incomplete for most taxa and environments. As such, the compilation of strong data and the selection of appropriate biodiversity surrogates is the first step in performing *Systematic Conservation Planning*. Reserves have two major roles: representing the variety of biodiversity elements and ensuring their persistence (Margules & Pressey, 2000). The latter means that reserves must protect biodiversity elements from anthropic pressure and ensure its long-term persistence. To do such, appropriate targets for the representation of the biodiversity elements must me calculated and clearly stated to allow

Step 4 of Systematic Conservation Planning (Box 1) is selecting additional areas for conservation. This is accomplished by finding the most cost-efficient areas that complement regional biodiversity through spatial algorithms (Margules & Sarkar, 2007). Systematic Conservation Planning is an valuable tool for conservation decision making as it is a stepwise, iterative process, that should be recalculated and reassessed every time something changes (e.g. social and political conflicts emerge, areas become unavailable, more data becomes available).

Study Area

The Atlantic Forest was one of the largest rainforest of the American continent with an original extension of around 150 million ha (Ribeiro *et al.*, 2009). The Brazilian Atlantic Forest is one of the five most important biodiversity *hotspots* (Myers *et al.*, 2000) presenting high levels of endemism and threat. It is a highly heterogeneous biome as it ranges 29 degrees in latitude, from tropical to subtropical producing several different forest formations. However, it has been severally exploited with 11.7% of its original extent remaining today, scatter in about 245,000, mostly small (> 50 ha), forest fragments. According to the last assessment (Ribeiro *et al.*, 2009) only 9.3% of the remaining habitat is currently protected by reserves. The Atlantic Forest is habitat for 24 primates species, of which 19 are endemic (Paglia *et al.,* 2012). Primates are especially susceptible to forest fragmentation as they are strictly arboreal, as a consequence, the Order Primates is the most threatened of the Atlantic Forest mammals (Grelle *et al.*, 2006). As such, they serve as good surrogates for highly fragmented landscapes such as the Atlantic Forest.

Objective

The objective of this thesis is to evaluate the conservation status and plan conservation actions for the conservation of primates of the Brazilian Atlantic Forest. This will be accomplished by performing all stages of *Systematic Conservation Planning* that take place prior to the implementation and monitoring of conservation action (Box 1, 1-4). Nineteen species, representing four families, will be used for this study (Table 1), all of which are endemic to the Atlantic Forest with the exception of *Cebus flavius,* which also occurs in the "Caatinga" biome (Paglia *et al.*, 2012). In *Chapter One* data on the focal species will be gather and its quality for conservation planning will be assessed and discussed. In *Chapter Two* conservation targets will be selected, existing reserves will be reviewed and new priority areas for the establishment of reserves will be selected.

Table 1 Primate species and families used in the study.

Family	Species
Atelidae	*Alouatta guariba*
	Brachyteles arachnoides
	Brachyteles hypoxanthus
Callitrichidae	*Callithrix aurita*
	Callithrix flaviceps
	Callithrix geoffroyi
	Callithrix kuhlli
	Leontopithecus caissara
	Leontopithecus chrysomelas
	Leontopithecus chrysopygus
	Leontopithecus rosalia
Cebidae	*Cebus flavius*
	Cebus nigritus
	Cebus robustus
	Cebus xanthosternos
Pitheciidae	*Callicebus coimbrai*
	Callicebus melanochir
	Callicebus nigrifons
	Callicebus personatus

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Chapter 1: How representable are range map data of species' distributions?

Abstract

Range maps are widely used in ecological assessment and conservation planning. They are promptly available and inexpensive, providing great advantage over survey data for large-scale studies. However, they often fail to acknowledge heterogeneity within species' distributions potentially originating misleading results, and being inadequate for conservation planning. The present study aimed test range map accuracy for 19 Atlantic Forest primates. A total of 745 presence data were collected from museum record and scientific literature, and contrasted to range maps from IUCN and NatureServe online databases. A total of 18.26% of points fell range map borders for IUCN (N=745) and 19.21% for NatureServe (N=713) constituting omission errors. Omission errors were grater for critically threatened species in both databases, 37.50% for IUCN and 43.18% for NatureServe. The present study sheds light on the quality of range map data concluding that such datasets can be inadequate for regional conservation planning, especially concerning endangered species and heterogenic and fragmented landscapes.

Introduction

Species range maps are commonly used in ecological and conservation studies as they are readily accessible and inexpensive compared to survey data. Their use ranges from inferring ecological patterns to prioritizing areas for conservation and assessing species' conservation status (IUCN, 2008). Range polygons are widely used to determine areas of conservation concern (e.g. Balmford *et al.,* 2001; Ceballos *et al.*, 2005; Jetz *et al.*, 2007) even though their quality for conservation planning is questionable (Palminteri *et al.*, 2011).

Extent-of-occurrence maps are the most common type of range map, they describe the minimum convex polygon that comprises all know, inferred or projected sites were a species occur by linking together extreme sites (IUCN, 2001). Range maps are drawn based on presence data gathered by experts, and they assume that species are present inside polygons and absent outside. Range maps are used as if species distributions were even throughout the polygons' extension not accounting for habitat variability and constraints to species dispersion (Gaston, 2003). Range polygons can potentially contain two types of error: commission and omission errors. Commission errors occur when a species is considered to be present where it is actually absent. Wherefore, omission error occur when the species is consider to be absent where it is actually present. Due to the nature of range maps and how they are drawn, commission errors are thought to be the most common (Gaston, 2003; Brown *et al.*, 1996).

Although it is widely recognized that range maps portray a false homogeneity to species distribution (Gaston, 2003; Brown *et al.,* 1996) they are still largely used in broad-scale conservation planning (e.g. Rodrigues *et al.,* 2004; Hernandez *et al.*, 2008). However, the quality of conservation planning and action is strongly related to the data on which it is based. Regardless of the quality of conservation algorithms or ecological models, results obtained will be unreliable if based on poor quality data. Conservation actions based on poor quality data may lead to misallocating valuable resources and promoting a false sense of security that a certain outcome is being achieved. Analyzing the quality of primate range maps will help understand the strengths and limitations of studies based on this type of data as well as indicate areas were more information is needed and guide future surveys.

This study aims to determine range map robustness for two published range polygons IUCN (2008) and NatureServe (Patterson *et al.,* 2007) and its accuracy for conservation planning for primates of Brazilian Atlantic Forest. More specifically, we will test how range polygons perform when compared to point locality (presence) data. Primates are a relatively well study taxon for which significant data is available in the scientific literature and museums. They are also charismatic and potentially good flagship species as they are able to draw positive attention to conservation efforts (Dietz *et al.,* 1994; Cunha & Grelle, 2008), as well as possibly indicator taxa (Sebastião

& Grelle, 2009). To assess IUCN and NatureServe range map robustness, we have compared primate range maps to presence data obtained from museum records and scientific literature.

Methods

Presence data were obtained from museum records from “Museu Nacional da UFRJ” and “Museu de Zoologia da USP” and scientific literature for 19 primates, all of which are endemic to the Brazilian Atlantic forest, with the exception of *Cebus flavius*. This same dataset was already used in others studies (Pinto & Grelle 2009, Figueiredo & Grelle 2009). Point locality data were overlaid with range map data from IUCN Redlist (IUCN, 2008) and NatureServe (Patterson *et al.*, 2007) using ArcGIS 10.2. The correspondence between the two data sets was calculated by measuring the proportion of locality points found inside and outside the range maps borders, as well as the closest distances from the outer points and range map border for each species.

To determine if vulnerability was related to range map errors, species were group by the IUCN Redlist Criteria and the proportion of points inside and outside rage map border were quantified for each group as well as the mean distances from the outer points to the closest range map border.

Results

A total of 745 presence data was collected for the 19 primate species (Table 1.1) varying from three to 174 point for a given species. The IUCN database had range maps available for all 19 species. NatureServe did not possess range maps for *Cebus flavius* nor *Cebus robustus*, thus, for this database the study was carried out for the remaining 17 species. On average, 18.26% of points fell outside range map borders for IUCN (Figure 1.1) and 19.21% for NatureServe (Figure 1.2) (see maps in Supplemental material). The outer points distanced themselves from range map border 39.85 km in average for IUCN and 34.53 km for NatureServe (Table 1.2). All species had omission errors associated to their range maps for both databases except for one *Callicebus* *coimbrai,* which had no omission errors for the IUCN range map. For *Leontopithecus caissara* omission errors represented 100% of the presence data for both databases (Figure 1.1 and 1.2). However, both results may be due to small sample size (*n*=3 for the former and *n*=4 for the latter, Table 1.1). For the remaining species, omission errors varied from 7% to 59% from IUCN and 5% to 71% for NatureServe (Figure 1.1 and 1.2).

Table 1.1 Presence data collected for each species of Brazilian Atlantic Forest primates.

Species	*n*
Alouatta guariba	106
Brachyteles arachnoides	28
Brachyteles hypoxanthus	25
Callicebus coimbrai	3
Callicebus melanochir	14
Callicebus nigrifons	20
Callicebus personatus	19
Callithrix aurita	61
Callithrix flaviceps	22
Callithrix geoffroyi	61
Callithrix kuhlli	23
Cebus flavius	4
Cebus nigritus	174
Cebus robustus	28
Cebus xanthosternos	15
Leontopithecus caissara	4
Leontopithecus chrysomelas	115
Leontopithecus chrysopygus	6
Leontopithecus rosalia	17
Total	**745**

Table 1.2 Mean distance and standard deviation from points (localities) falling outside range map boarders to the closest border of 19 Brazilian Atlantic Forest primates.

IUCN	NatureServe
39.85 km ± 54.16	34.53 km ± 49.94

Figure 1.1 Percentage of points falling within species ranges and outside ranges for IUCN range maps. Dark grey bars represent the percentage of points falling inside ranges and light grey bars the percentage falling outside ranges.

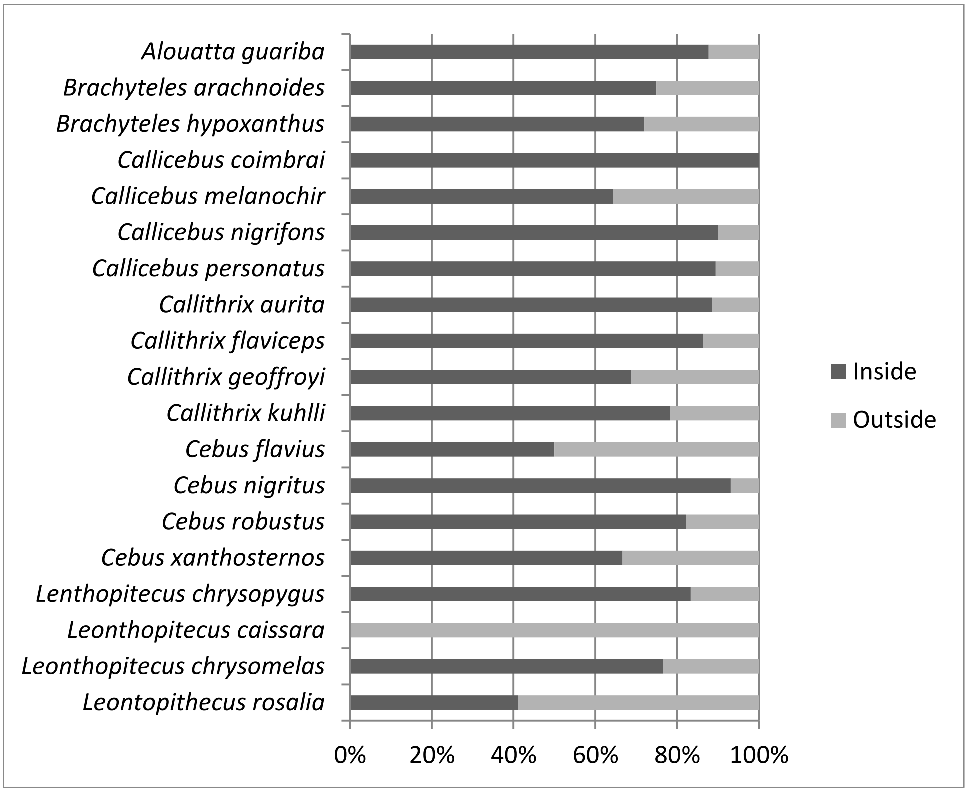
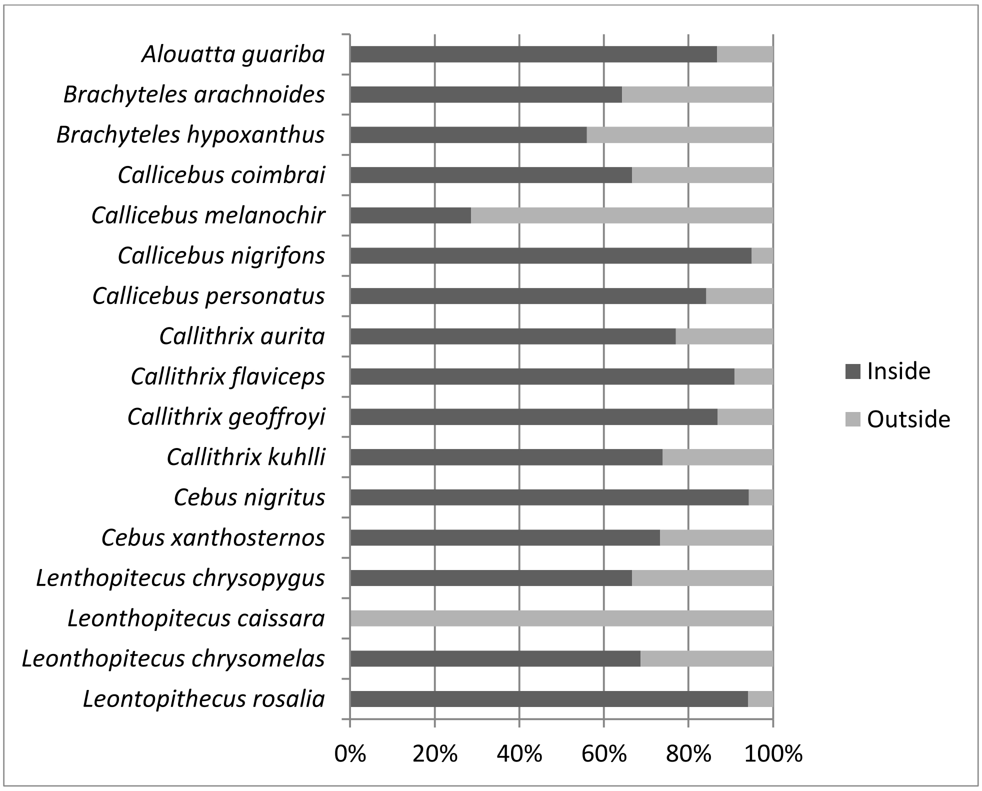


Figure 1.2 Percentage of points falling within species ranges and outside ranges for NatureServe range maps. Dark grey bars represent the percentage of points falling inside ranges and light grey bars the percentage falling outside ranges.



When data was grouped together based on IUCN Redlist Criteria, endangered species had more errors associated to their maps than near threatened and least concern species for both data bases (Figures 1.3 and 1.4). For critically endangered species 37.50% of all presence data fell outside range boundaries for IUCN and 43.15% for NatureServe, compared to 8.76% and 7.83% respectively for near threatened species. For NatureServe, distances from outer points to range map border were also greater for critically endangered species than other categories (Table 1.3), although variation was high in all categories for both datasets.

Figure 1.3 Percentage of points falling within species ranges and outside ranges for IUCN range maps for species pooled together according to their to IUCN Redlist criteria. Dark grey bars represent the percentage of points falling inside ranges and light grey bars the percentage falling outside ranges.

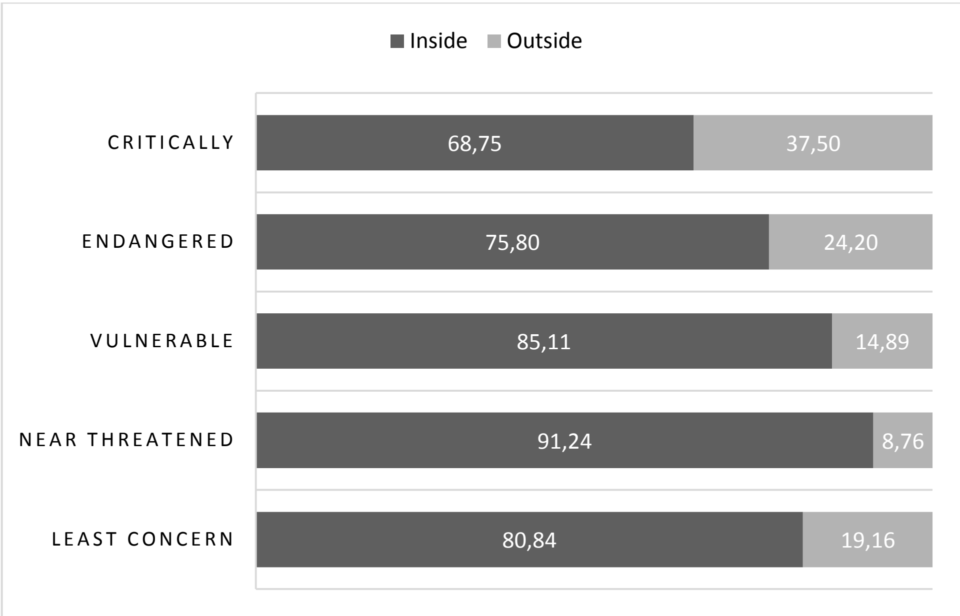


Figure 1.4 Percentage of points falling within species ranges and outside ranges for NatureServe range maps for species pooled together according to their IUCN Redlist criteria. Dark grey bars represent the percentage of points falling inside ranges and light grey bars the percentage falling outside ranges.

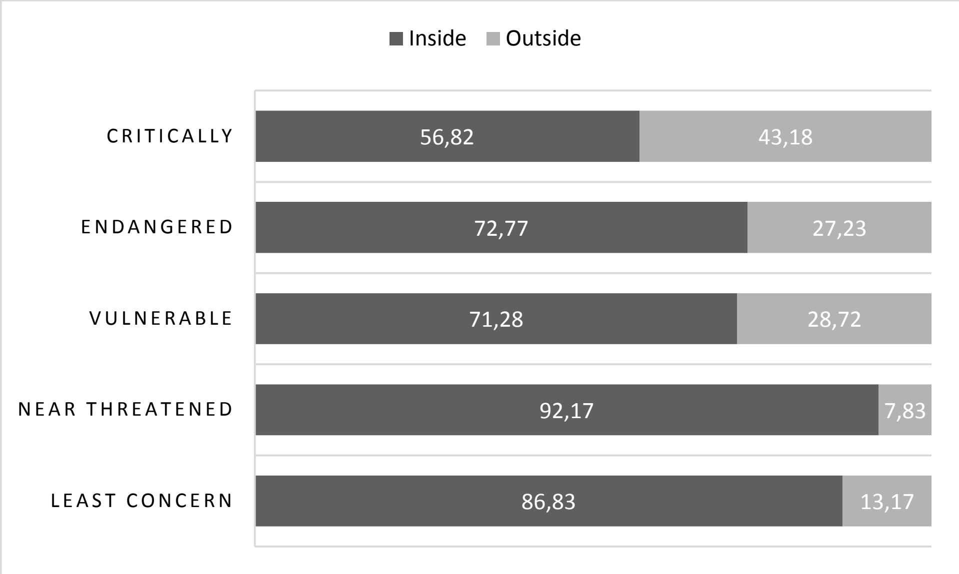


Table 1.3 Mean distance and standard deviation from points falling outside range map boarders to the closest border for species pooled together according to their IUCN Redlist Criteria.

IUCN Redlist Criteria	**IUCN**		**NatureServe**	
	Mean (km)	SD	Mean (km)	SD
Critically Endangered	41.96	59.93	59.92	69.47
Endangered	31.92	40.15	21.46	24.20
Vulnerable	60.15	64.06	43.11	51.70
Near Threatened	39.44	80.52	50.44	84.32
Least concern	43.16	48.04	20.66	18.95

Discussion

Our study provide important information on the quality and accuracy of range map databases that can be useful for future studies that wish to use such information as baseline data. Omission errors were around 19% of the presence data collected for both databases, showing that range maps fail to accurately represent current knowledge on species distribution. This number is high considering primates are diurnal and charismatic, being a relatively well know taxonomic group. Other taxa are likely to have worse results. Ficetola *et al.* (2013) analyzed IUCN range map robustness for 4507 amphibian species worldwide and found that between 22.8% and 11% of presence record fell outside range map borders. However, results were much worse when considering less studied regions such as South America and Asia (see Ficetola *et al.,* 2013). Palminteri *et al.* (2011) also found omission errors for four of the 10 primate species evaluated in Peru when comparing locality points to IUCN and NatureServe maps, as well Pinto *et al.* (2014) in a reserve selection study comparing locality points with IUCN maps.

The proportion of omission errors worsened with threat levels (IUCN Redlist criteria) (Figures 1.3 and 1.4). Omission errors represented 37.50% of the data for IUCN and 43.18% for NatureServe for critically endangered species, and 8.76% and 7.83% respectively for near threatened species pooled together. Omission errors were also higher for endangered species for IUCN range maps and for endangered and vulnerable species for NatureServe (Figures 1.3 and 1.4). Although the present study only evaluated omission errors, this is an indication that critically endangered species have the worst quality range maps for both databases. Showing that the most vulnerable species have the most unreliable data.

Distribution is known to have shifting borders (Gaston, 2003; Brown *et al.,* 1996) as occupation changes over time, thus, distances found between outer points and border (39.85 km ± 54.16 for IUCN and 34.53 km ± 49.94 for NatureServe) (Table 1.2) could be explained either by the dynamic nature of distribution borders or due to true omission errors.

Omission errors could have resulted from the way maps are drawn or due to the lack of access to primary records at the time maps were drawn (Ficetola *et al.*, 2013). Although the present studied aimed at evaluating range map accuracy, it only accounted for omission errors, as commission (areas were the species is believed to be present but is not) errors could not be assess with the available data. Actually, we believe that commission errors are extensive for primates in the Atlantic Forest due to its highly fragmented landscape. For example, few populations of *B. hypoxanthus* still exist inside its original geographical range (Figueiredo & Grelle 2009). In addition, much of the area inside range maps are probably of inadequate habitat for primates. A refined representation of primate's distributions, which takes into account such heterogeneity, would be much more useful for conservation. For conservation purposes, commission errors are more dangerous that omission errors, as protecting a given area were a species is falsely believed to occur will produce a false sense of security that conservation is being achieved and could mean the waste of valuable resources or the misallocation of conservation effort. However, ignoring the existence of populations outside range boundaries could be critical for threatened species as populations could be becoming extinct unnoticeably.

The present study shows the need for greater investment and continuous update of range map databases. We also advocate that primary data should be shared amongst researchers in online databases, as they could be used to improve the quality of distribution data. Consequently improving the amount and reliability of information available for conservation purposes. Our conclusions are similar to those of Jetz *et al.* (2008) and Hurlbert and White (2007) for birds, Ficetola *et al.* (2013) for amphibians and Palminteri *et al.* (2011) for Peruvian primates. Although any biological data has inherent inaccuracies, range maps may be to coarse for regional conservation planning especially when considering endangered species and highly fragmentation and heterogenic ecosystems such as the Brazilian Atlantic Forest.

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Supplemental Material

Figure 1.5 IUCN and NatureServe range maps and presence data for *Alouatta guariba.*

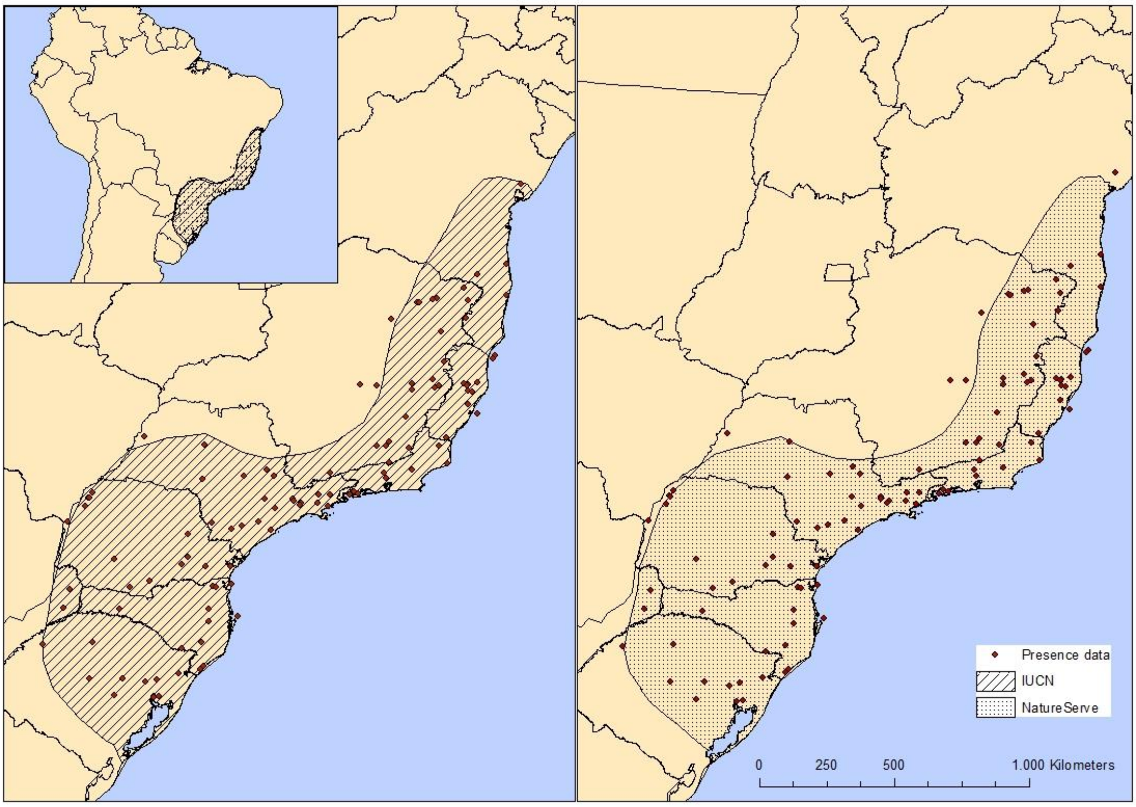


Figure 1.6 IUCN and NatureServe range maps and presence data for *Brachyteles arachnoides.*

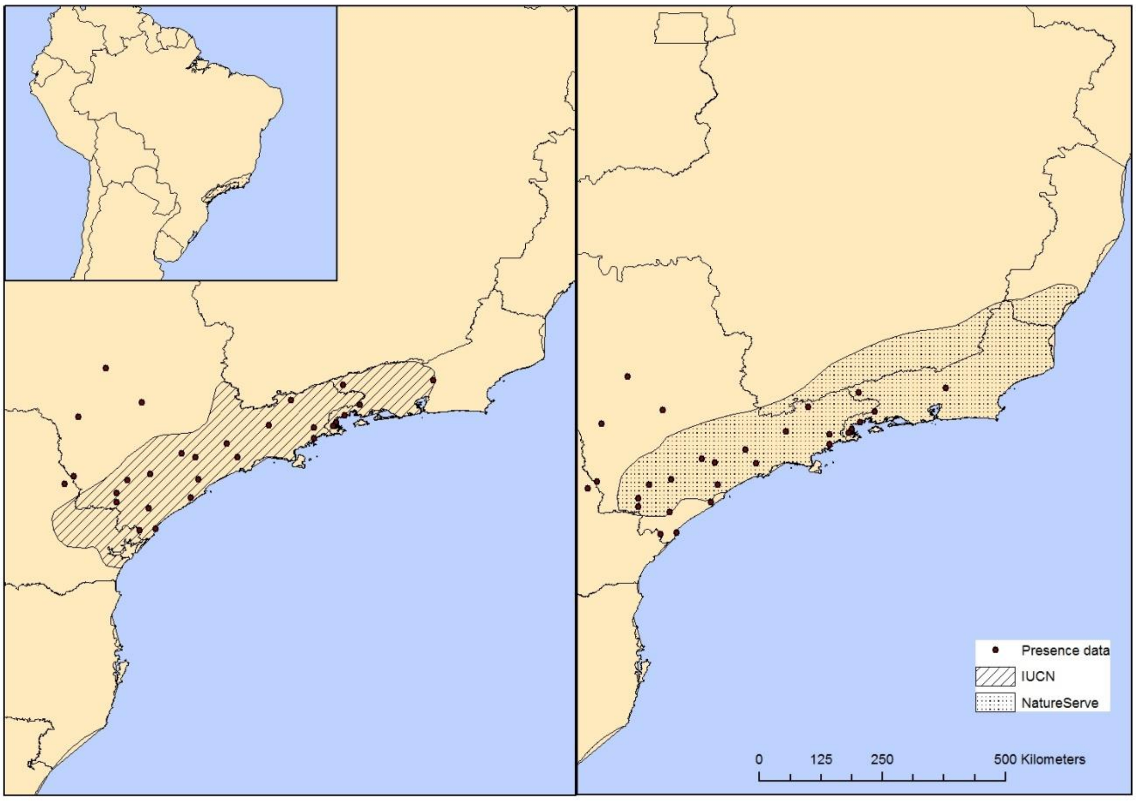


Figure 1.7 IUCN and NatureServe range maps and presence data for *Brachyteles hypoxanthus.*

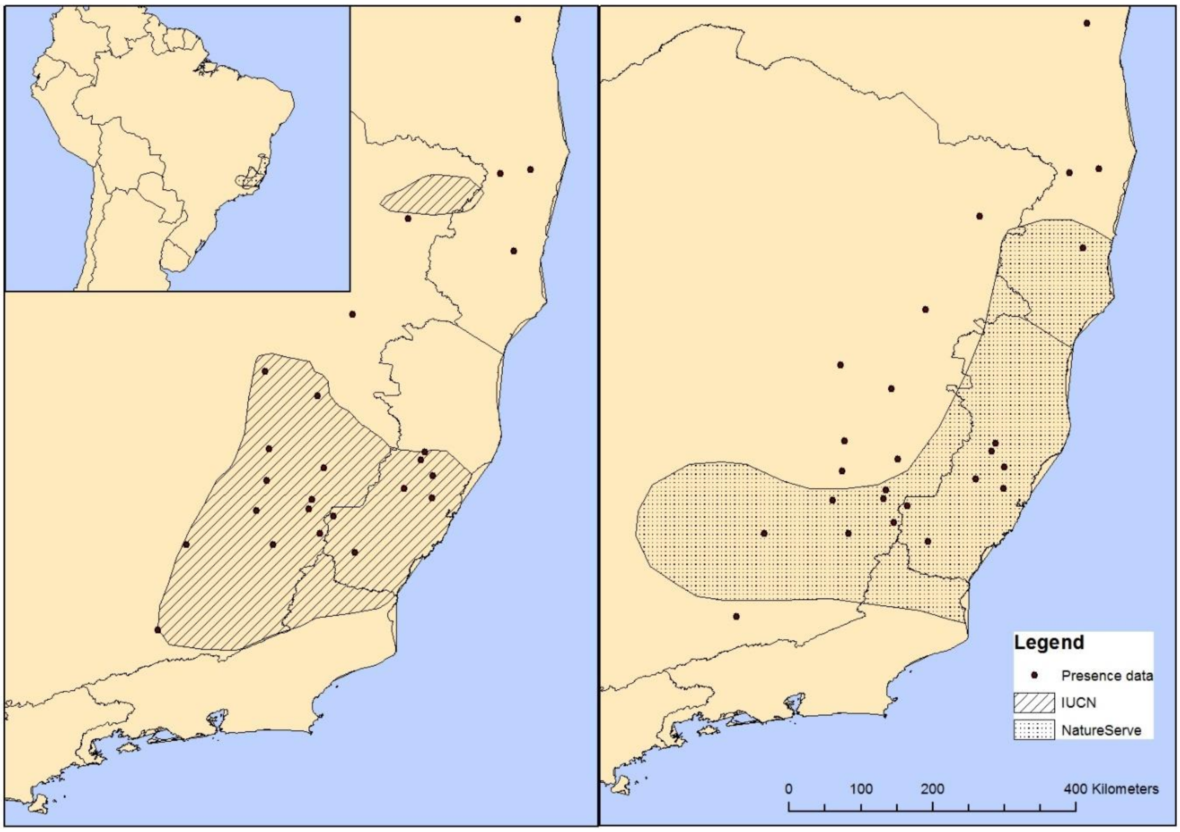


Figure 1.8 IUCN and NatureServe range maps and presence data for *Callicebus coimbrai.*

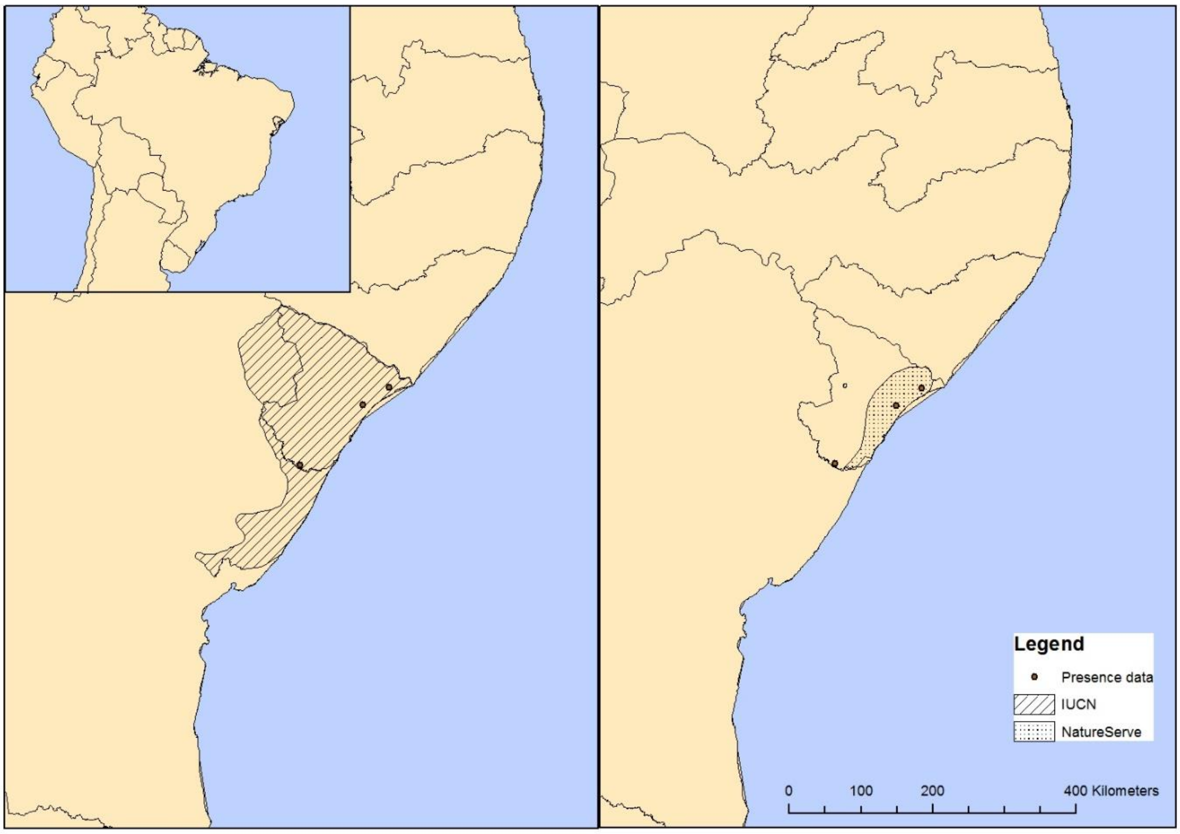


Figure 1.9 IUCN and NatureServe range maps and presence data for *Callicebus melanochir*.

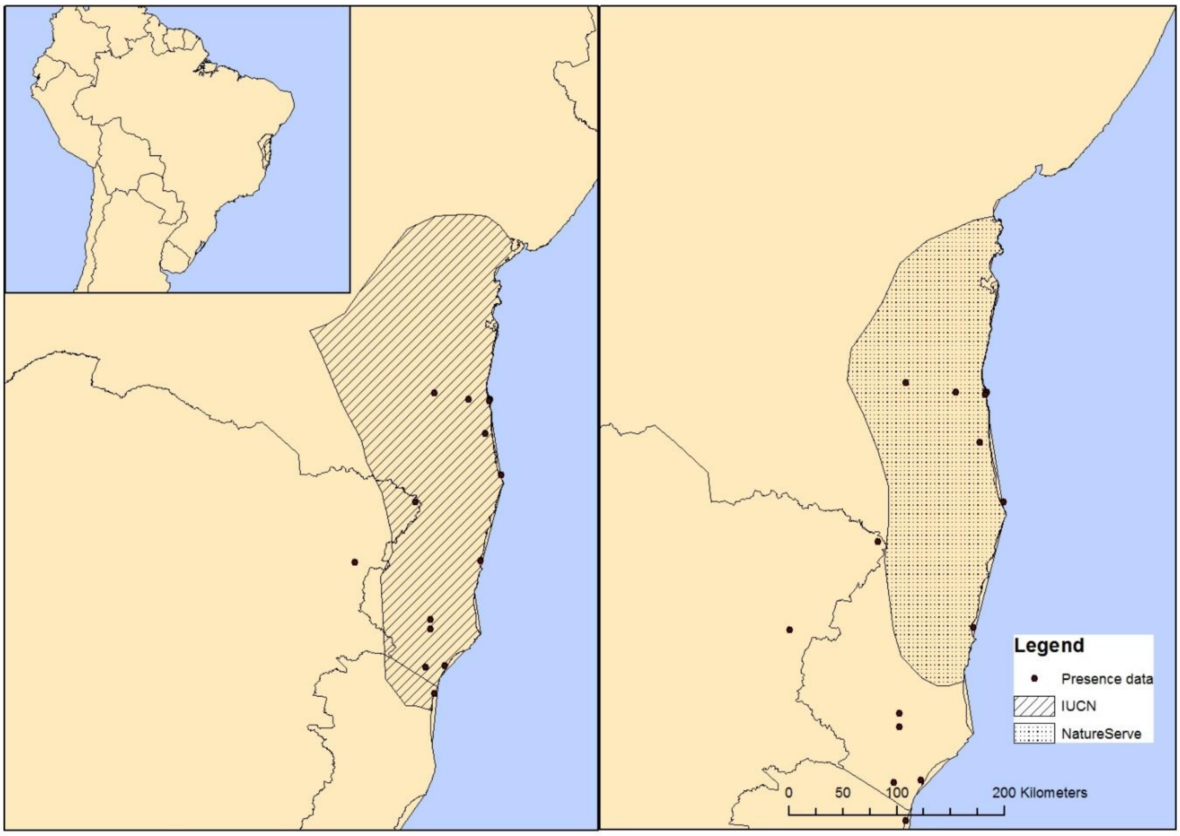


Figure 1.10 IUCN and NatureServe range maps and presence data for *Callicebus nigrifrons*.

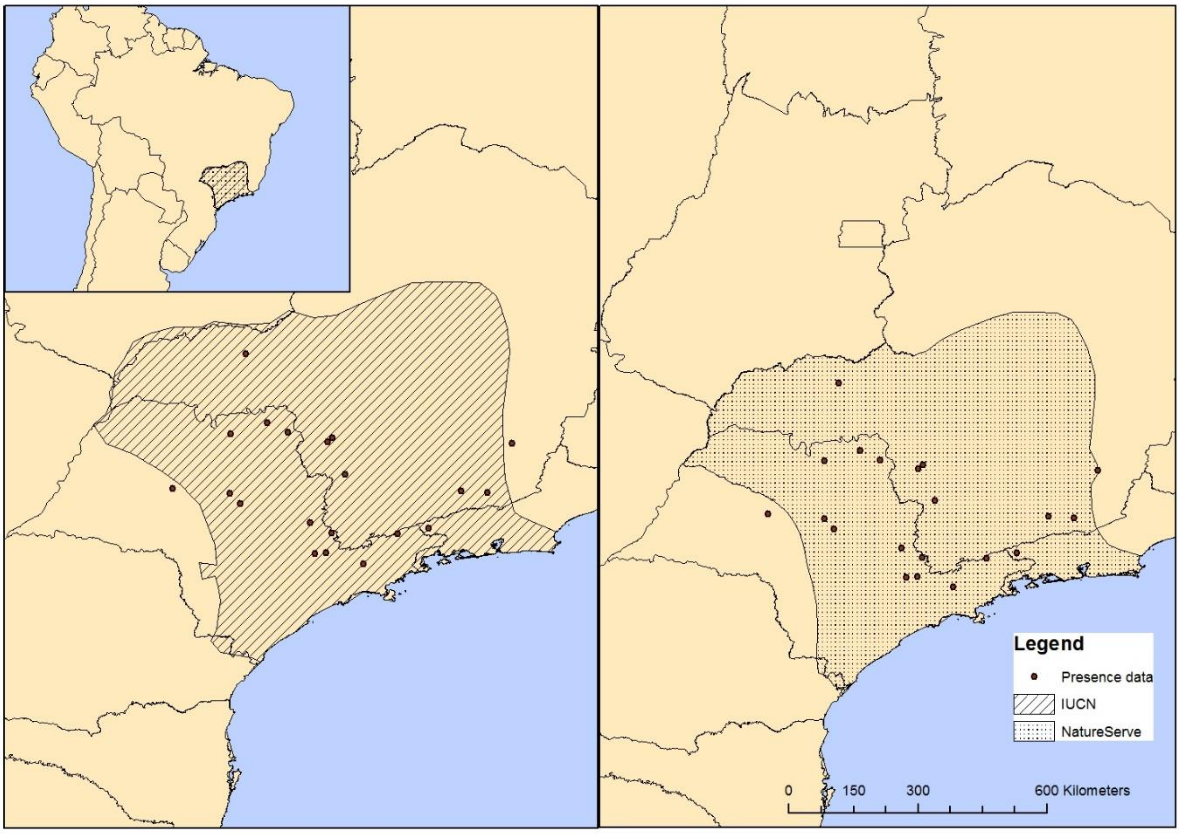


Figure 1.11 IUCN and NatureServe range maps and presence data for *Callicebus personatus.*

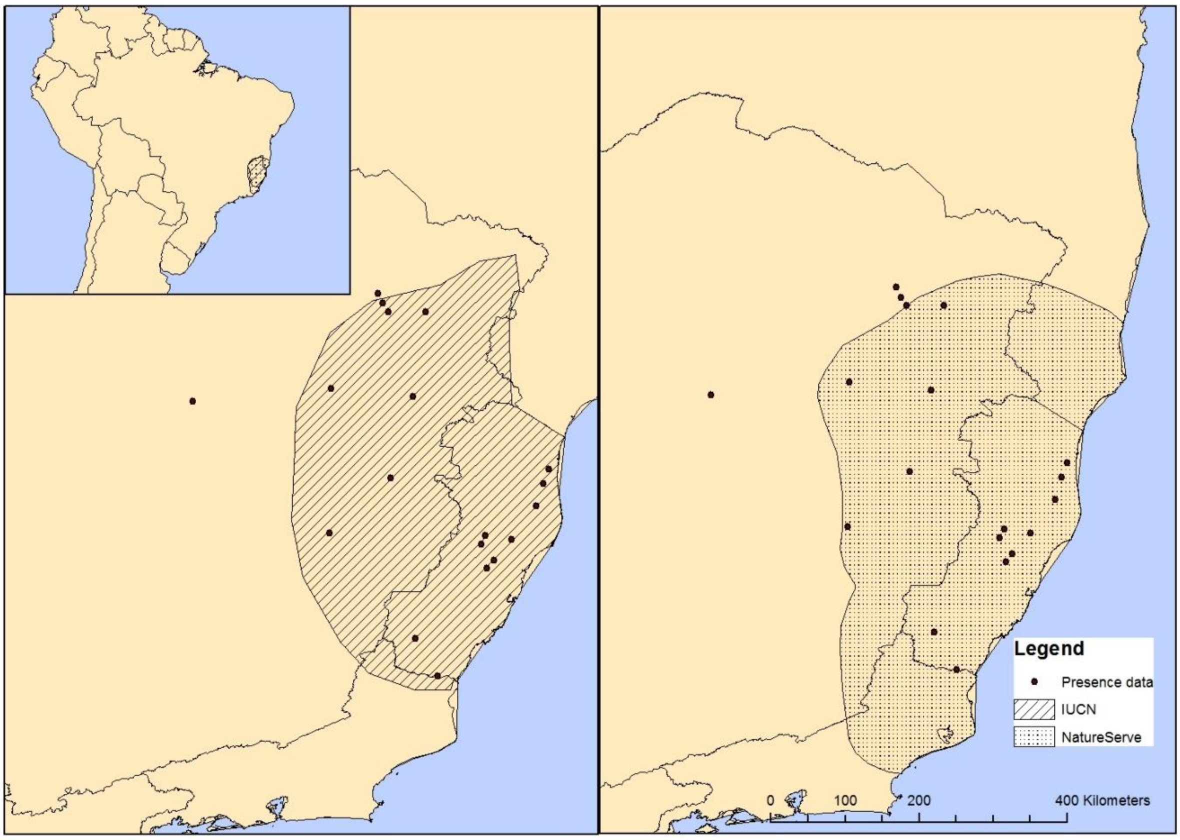


Figure 1.12 IUCN and NatureServe range maps and presence data for *Callithrix aurita.*

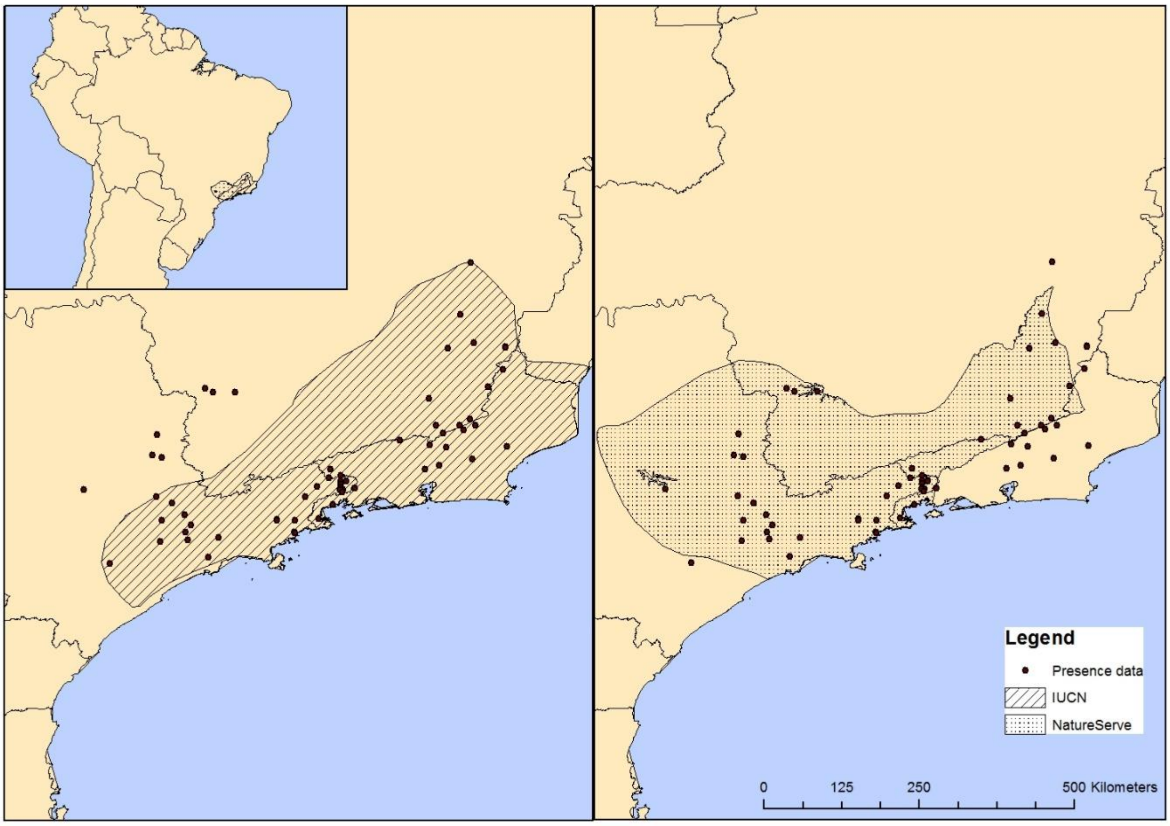


Figure 1.13 IUCN and NatureServe range maps and presence data for *Callithrix flaviceps.*

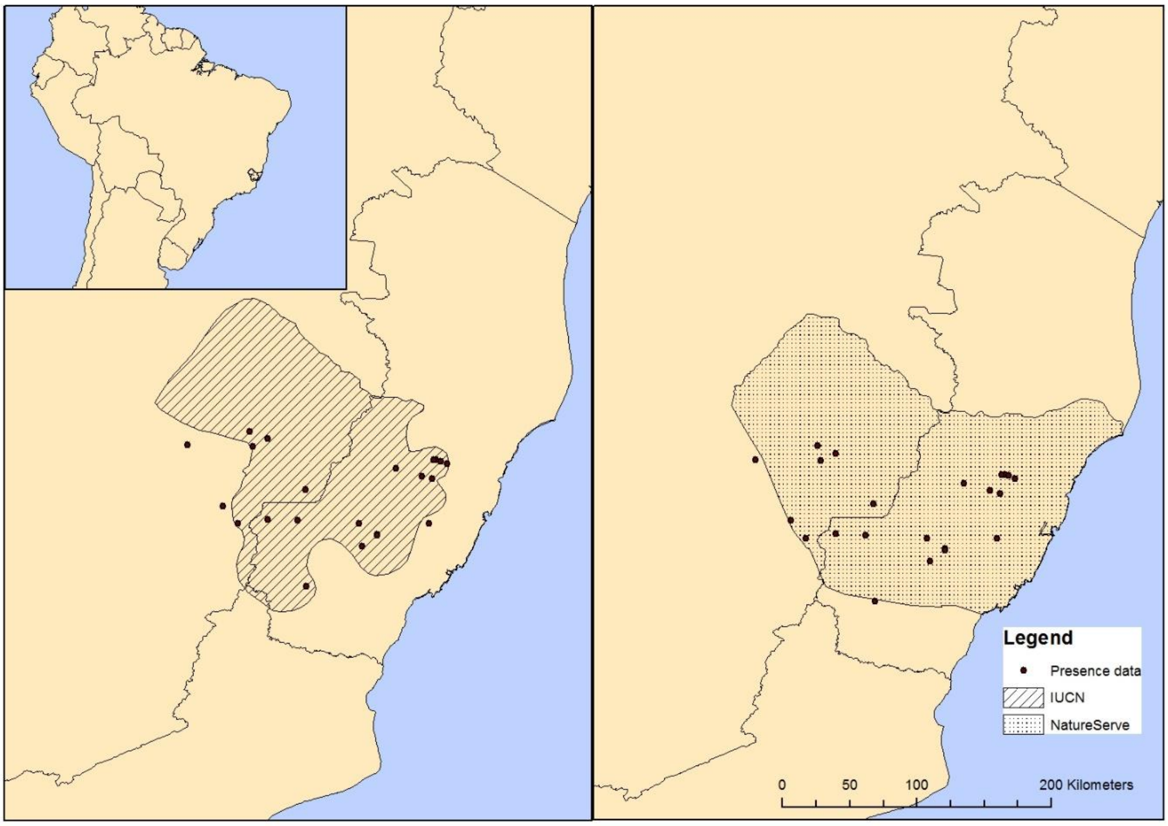


Figure 1.14 IUCN and NatureServe range maps and presence data for *Callithrix geoffroyi.*

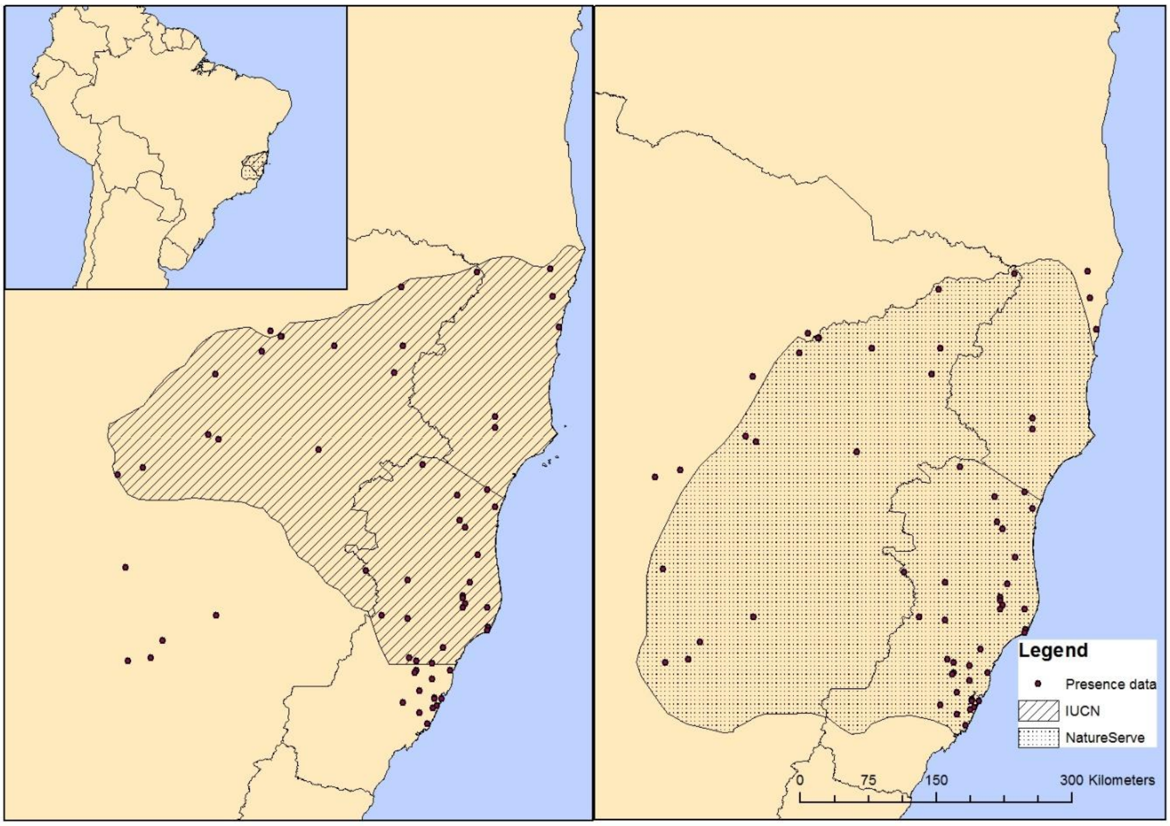


Figure 1.15 IUCN and NatureServe range maps and presence data for *Callithrix kuhlii.*

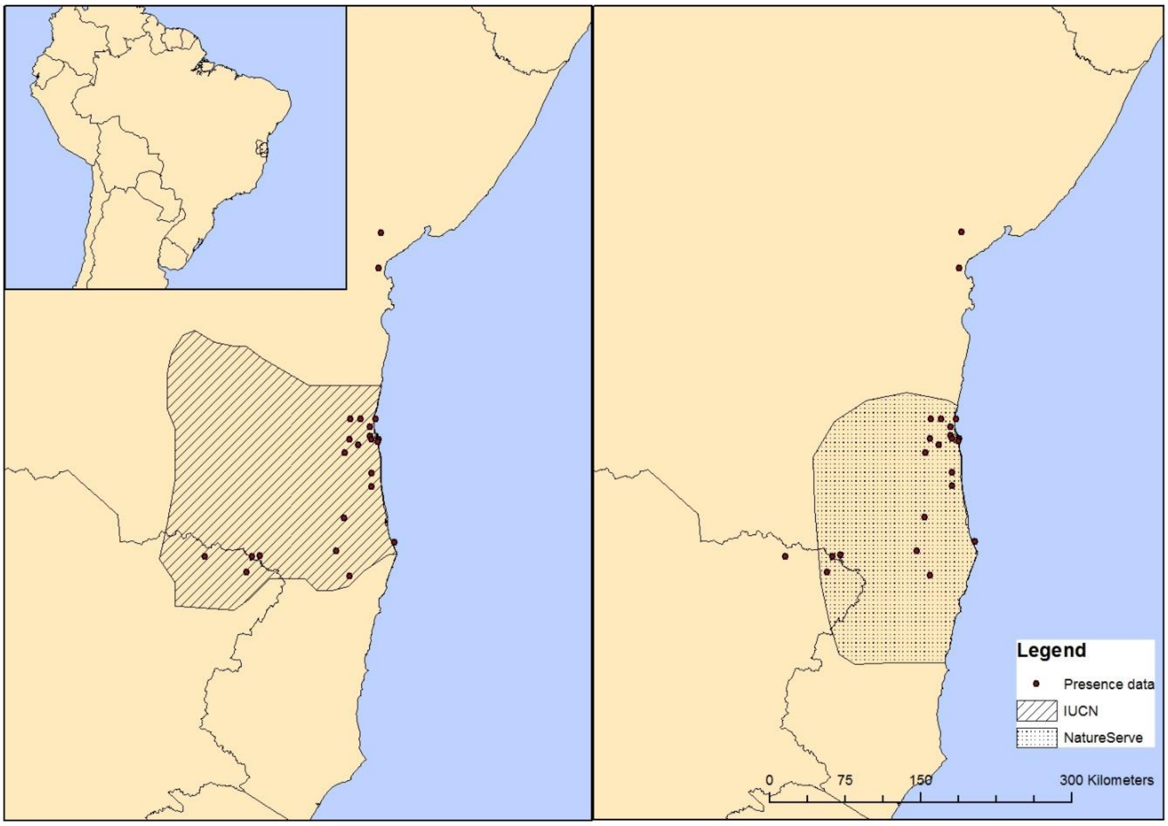


Figure 1.16 IUCN range map and presence data for *Cebus flavius.*

Figure 1.17 IUCN and NatureServe range maps and presence data for *Cebus nigritus.*

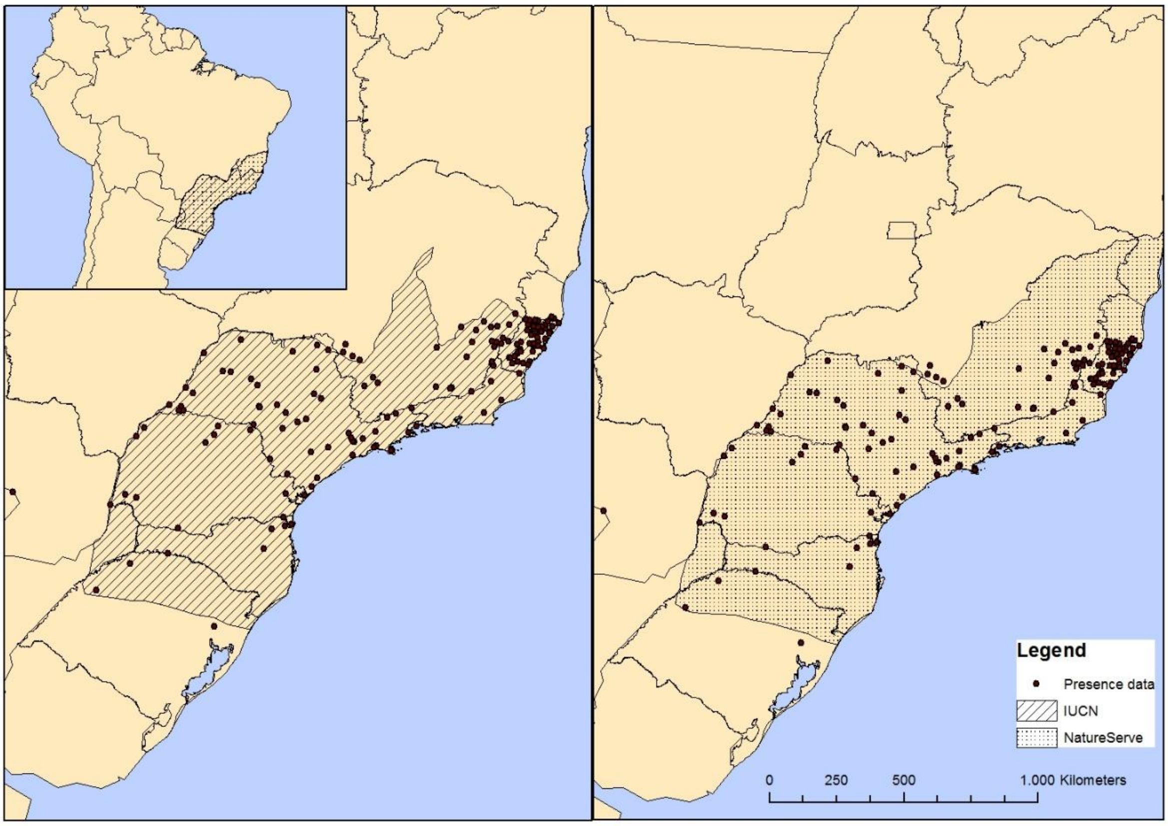


Figure 1.18 IUCN range map and presence data for *Cebus robustus.*

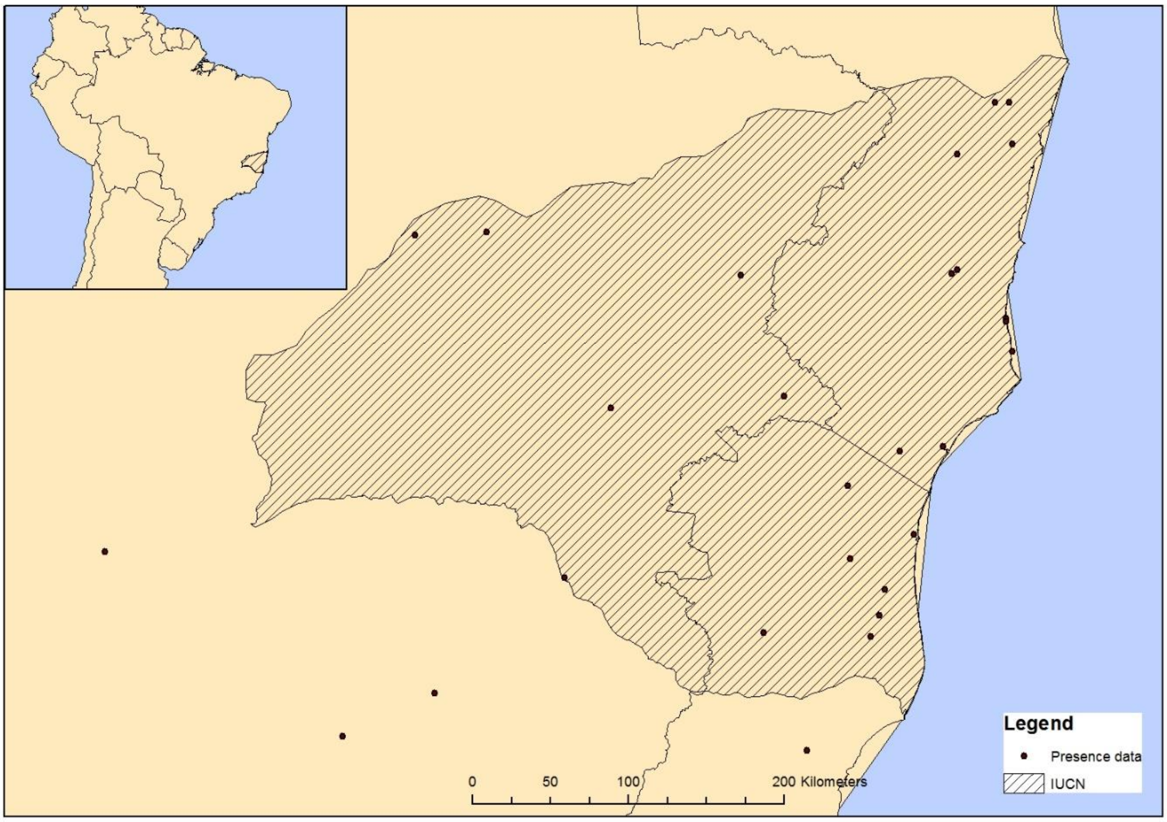


Figure 1.19 IUCN and NatureServe range maps and presence data for *Cebus xanthosternos.*

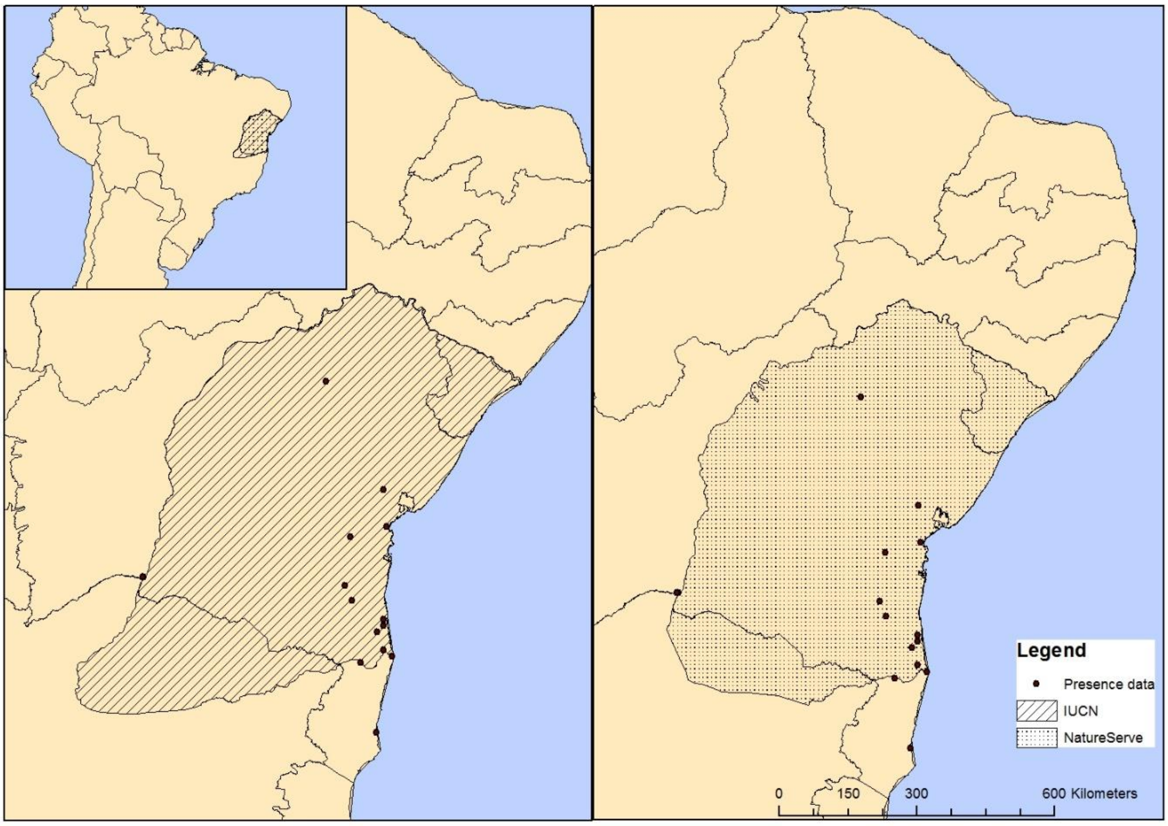


Figure 1.20 IUCN and NatureServe range maps and presence data for *Leontopithecus caissara.*

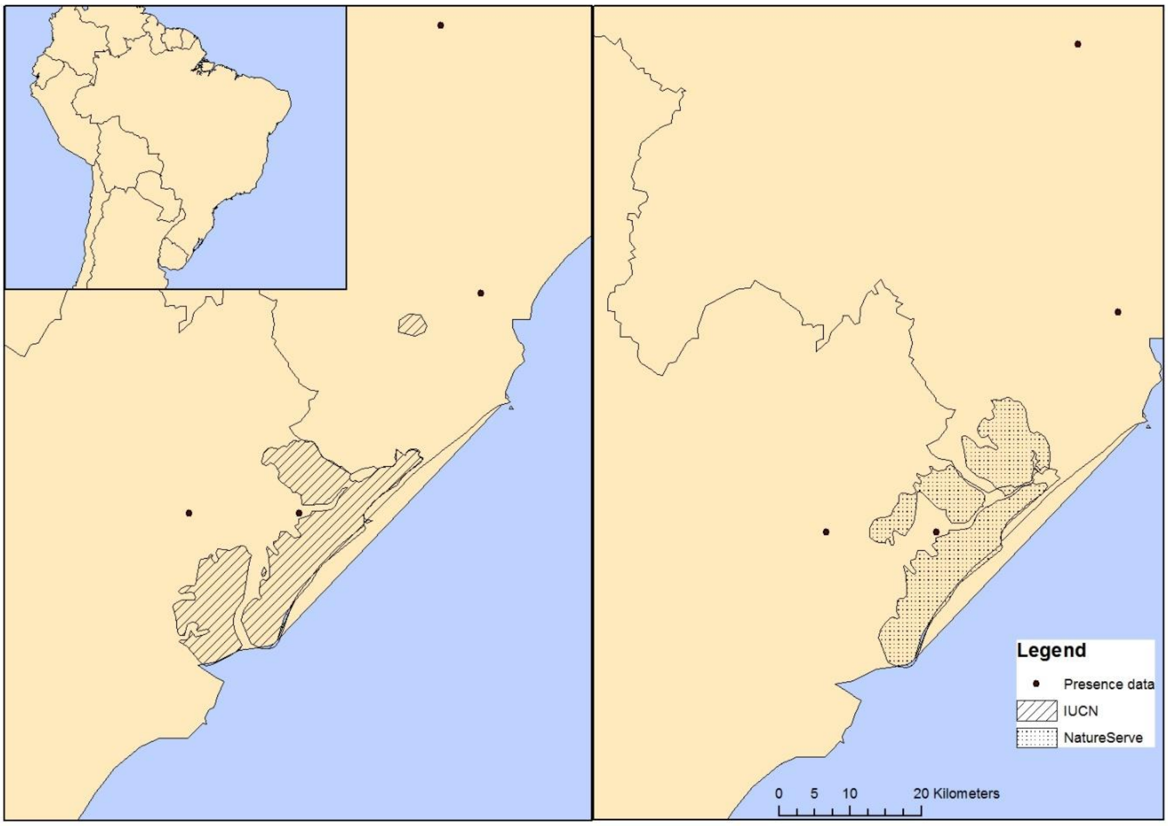


Figure 1.21 IUCN and NatureServe range maps and presence data for *Leontopithecus chrysomelas.*

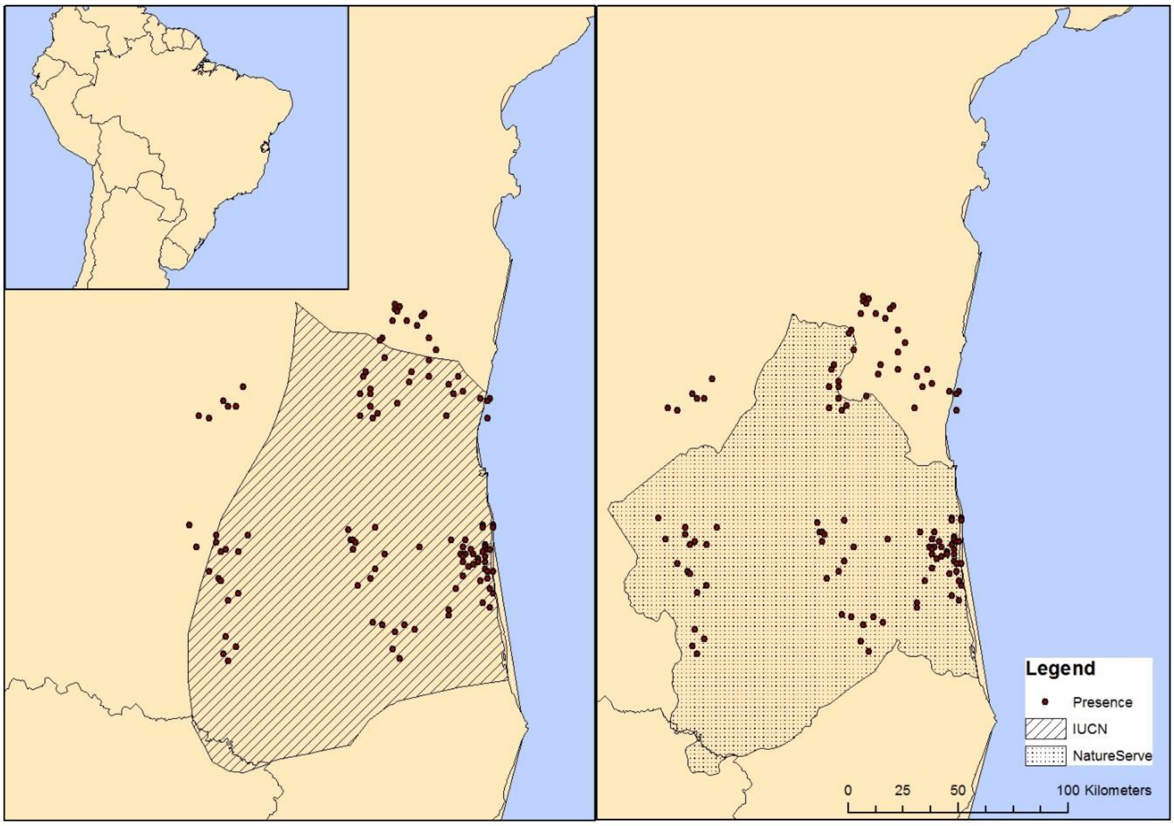


Figure 1.22 IUCN and NatureServe range maps and presence data for *Leontopithecus chrysopygus.*

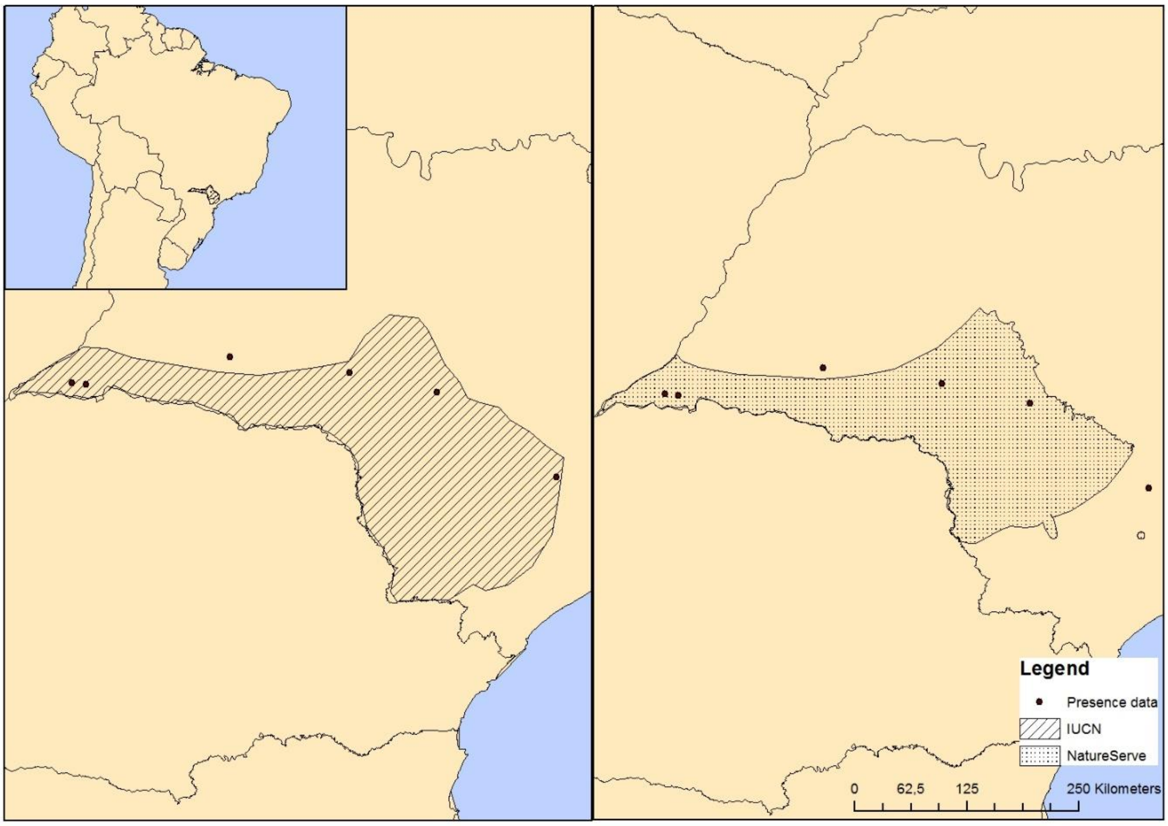


Figure 1.23 IUCN and NatureServe range maps and presence data for *Leontopithecus rosalia.*

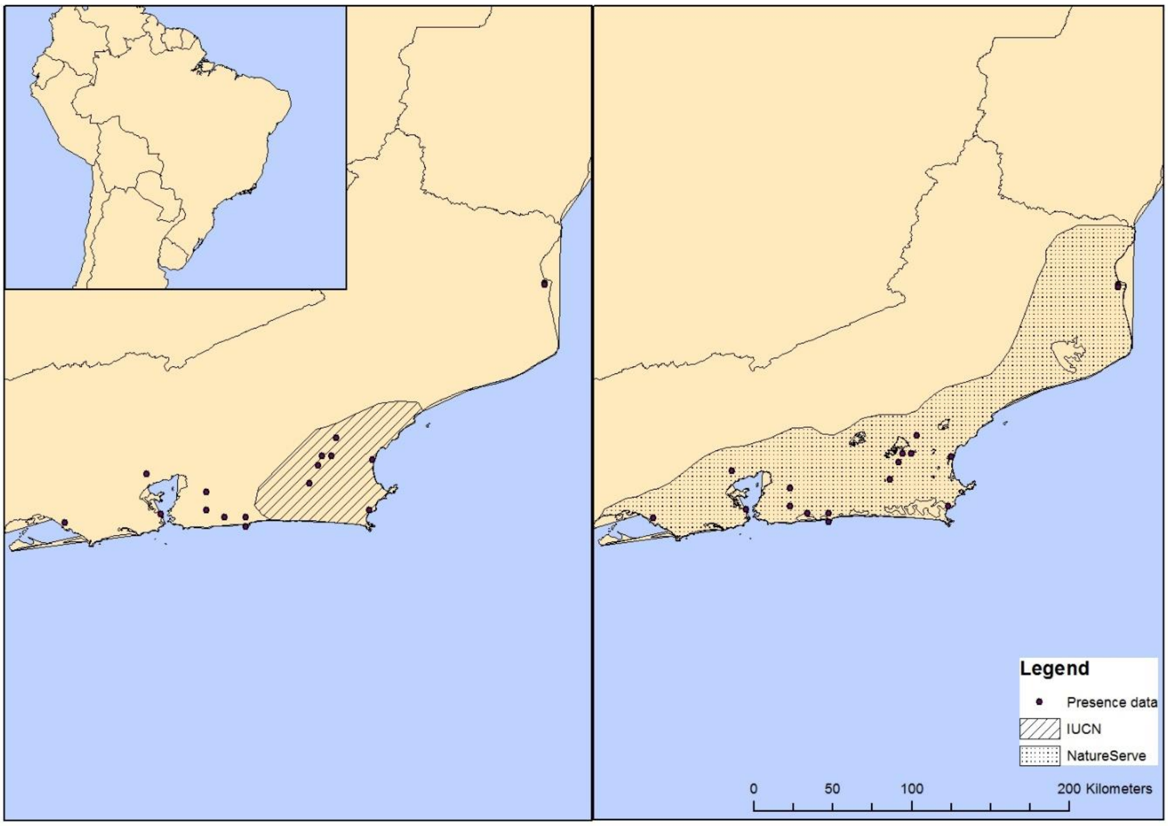


Table 1.5 Species according to their IUCN Redlist Criteria and the number of presence data gather (*n)* after species were pooled together.

Critically Endangered (*n*=48)	*Brachyteles hypoxanthus* *Cebus flavius* *Cebus xanthosternos* *Leontopithecus caissara*
Endangered (*n*=219)	*Brachyteles arachnoides* *Callicebus coimbrai* *Callithrix flaviceps* *Cebus robustus* *Leontopithecus chrysomelas* *Leontopithecus chrysopygus* *Leontopithecus rosalia*
Vulnerable (*n*=94)	*Callicebus melanochir* *Callicebus personatus* *Callithrix aurita*
Near Threatened (*n*=217)	*Callicebus nigrifrons* *Callithrix kuhlii* *Cebus nigritus*
Least Concern (*n*=167)	*Alouatta Guariba* *Callithrix geoffroyi*

Chapter Two: Reserve selection, Gap Analysis and Conservation targets for Primates of the Brazilian Atlantic Forest

Abstract

Reserves are the best tool for *in situ* conservation and have been a human practice for millennia. However, the process of selecting areas destined to become reserves has been done opportunistically and not much taught is given to the contribution that the new area brings to the whole picture. In order to tackle the biodiversity crisis, conservation has to become more systematic and efficient. We calculated biodiversity targets, performed a gap-analysis and selected complementary areas for the establishment of reserves for 17 endemic primates. To achieve this goal, we used three different dataset, IUCN and NatureServe range map databases, and a refined dataset based on remaining habitat. Conservation targets varied from 10% to 100% depending on the dataset and on the species. They were on average 33% of species' extents of occurrence for IUCN and NatureServe datasets and around 91% for Remaining Habitat. Only *Brachyteles arachnoides* was considered adequately protected by the current reserve network throughout all datasets and only six species were considered protected in at least one dataset. A hexagonal grid (10km side length) was used to prioritize areas to complement the existing network and meet conservation targets by selecting the minimum area necessary to protect Atlantic Forest primates. A minimum of 49 697 km^2 (191 hexagons) is necessary to achieve the conservation targets for all 17 species of endemic primates which is four times the amount of reserves that currently exist.

Introduction

Setting aside areas for their preservation is an ancient human practice. Historically they were meant to protect areas of religious importance, natural resources, beautifully sceneries or areas of cultural significance (e.g. Chandrashekara & Sankar, 1998). In modern times the focus shifted towards the conservation of nature and biodiversity. With the strengthening of the biodiversity crisis caused by the increasing pressure of human activities in natural systems (Pimm *et al.,* 1995), they have become key in the attempt to slow down and cease the extinction process.

However, reserves are known to be established opportunistically and usually little thought is given to their contribution to the overall representation of biodiversity, turning them at times inefficient and ineffective (Pressey *et al*., 1993; Margules & Pressey, 2000). Reserves are therefore more likely to fulfill their role in biodiversity conservation if it is taking in to account how will a new reserve complements the existing reserve network, and contribute to the conservation goal of the region. From this notion derived the idea for a systematic approach to conservation planning (Margules & Pressey, 2000).

Systematic Conservation Planning, as it is called, begins with the premise that resources destined to conservation are scarce and thus must be optimized and is based on three rules: complementarity, flexibility and irreplaceability (Margules & Pressey, 2000; Pressey *et al.*, 1993, Margules LIVRO). Systematic Conservation Planning is a six-steps process: compiling and reviewing data of conservation significances, identifying conservation goals, reviewing the existent reserve network, selecting additional reserves, implementing conservation action and finally managing and monitoring protected areas (Margules & Pressey, 2000).

To perform a systematic selection of reserves, it is required to explicitly state the representation target (or conservation goals) for the region (Pressey, 1993). Most studies set fixed targets for all species being considered. However, such strategy favors wide-spread species over restricted ones, thus, targets should be species specific. This information can be used to determine rather or not the current network of reserves is effective (Gap-Analysis). Subsequently, areas can be selected to complement the existing network, maximizing conservation while minimizing costs to achieve conservation targets.

Conservation planning is only as good as the data on which it is based. Most broad-scale studies are based in range map data available in online databases such as IUCN Redlist (IUCN, 2008) and NatureServe (Patterson *et al.* 2007). However, such maps posses important errors and can be consider inadequate for conservation purposes (ref.). Here we suggest a refine dataset based on remaining habitat that is more reliable for conservation planning, especially in highly fragmented and heterogenic landscapes.

This study aims to compare the use of different types of datasets in prioritizing areas for conservation and their effects on the conservation output derived from them. Exploring three phases of Systematic Conservation Planning (Margules & Pressey, 2000) – Identifying conservation goals, reviewing existing conservation areas and selecting additional conservation areas.

Methods

From all the 24 species of primates know to occur in the Brazilian Atlantic Forest (Paglia *et al.*, 2012), 17 species of Atlantic Forest primates were selected for this study. We selected all the species for which range map data was available in the IUCN and NatureServe online databases as well as point locality data. The latter were gather from scientific literature, and the museum collections from Museu Nacional da UFRJ and Museu de Zoologia da USP.

For each of the 17 species, distribution maps based on the Remaining Habitat method (Bechara, 2012) were drawn and a conservation targets were calculated for each of the three distribution data – IUCN, NatureServe and Remaining Habitat.

Subsequently a Gap-Analysis was performed and priority areas for the conservation of the 15 species were selected in order to reach their respective conservation targets.

Remaining Habitat

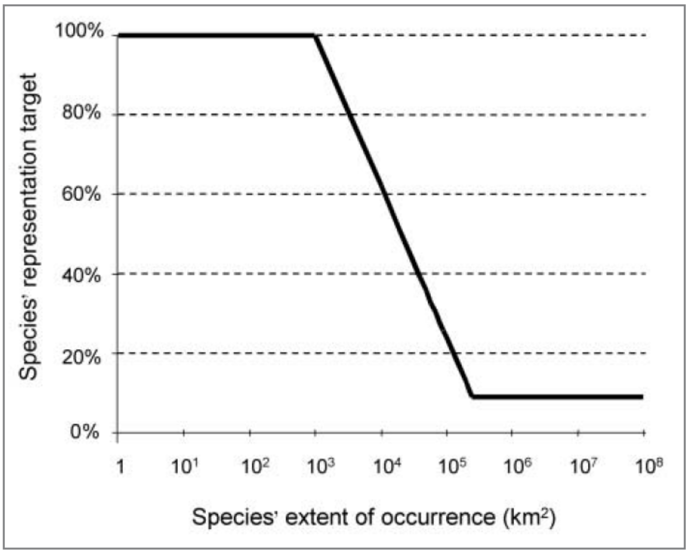
To create the remaining habitat maps we adapted the protocol established by Bechara (2012). The dataset of SOS Mata Atlântica & INPE 2011 for the remaining forest patches for the Atlantic Forest was crossed with point locality data for each species. All forest patches within a buffer the size of each species home ranges were selected to create the remaining habitat map (supplemental material). When the home range for the species was not found, we used the same value found for other species of the same genus. Such buffer were used to account for potential movements across the matrix.

Identifying conservation targets

In this study, the guidelines from the International Union for Conservation of Nature (IUCN) were followed (Figure 2.1) to determine conservation goals for the endemic primates of the Atlantic Forest for each range map data.

Where species with small extent sizes (<1,000 km^2) should have the hole of their extent protected by reserves in order to be considered protected and species with large extent sizes (≥ 250,000 km^2) should have at least 10% of their extents' protected by reserves. Any species with intermediate extent size will have a target that ranges between 10%-100% determined by the graph. Restricted species have more strict conservation targets than widespread species. Although this method is still arbitrary, such discrepancy is intended to avoid biases towards widespread species. As fixed target of 15%, for instance, represents a large area for widespread species it could be insufficient for maintaining populations of more restricted species. In addition, restricted species are usually also less abundant than widespread species resulting in a "double jeopardy" for the narrow range species (Lawton, 1993). This means that narrow range and rare species would have disproportionally fewer individuals protected by fixed targets in comparison to widespread species (Rodrigues *et al.* 2004).

Figure 2.1 Curve describing the relationship between extent of occurrence and conservation target. From Rodrigues *et al.* (2004).



Reviewing existing conservation areas or Gap Analysis

In order to review the existing reserve network IUCN, NatureServe and remaining habitat range maps were overlapped with the Brazilian reserve network map provide by "Ministério do Meio Ambiente", using ArcGIS 10.2. The proportion of each range that fell within reserve boundaries was calculated and compared to the conservation targets. Species that did not meet the targets constituted a gap-species.

Selecting additional conservation areas

Priority areas for conservation were selected for the three types of range data. A hexagonal grid was used to create planning units over the range maps with 10km side length hexagons (approximately 260 km^2). Tables and shapefiles were prepared using ArcGIS 10.2 and planning units were selected using Marxan and Zonae Cogito. Marxan algorithm ran with 1000 repetitions, 1000000 iterations and no boundary length modifier. As the goal was to select the smallest area necessary to represent all species, all planning units received a cost value of "1". The best solution for each range map type was consider that which met the conservation targets for all species at the same time selecting the smallest number of planning units.

As Marxan software has a hard time prioritizing species with narrow ranges, for the remaining habitat maps, only the hexagons overlapping with the distributions were used for the prioritization Also, all hexagons that overlapped with species who's targets were 100% were manually given status value of "2" to insure that they would be selected by the software. The remaining species – those with targets different from 100% - were used to prioritize the remaining hexagons.

Results

Extension of occurrence and Remaining Habitat

Using the remaining habitat method, distributions were extremely reduced for all species. Species' distribution range from losing all of its distribution, which was the case for *Leontopithecus caissara*, and to *Cebus nigritus* for an extension of around 15700 km^2 (Table 2.1). Mean distribution extents were similar between IUCN and NatureServe maps, 224 773 km^2 and 228 823 km^2 respectively. When Remaining Habitat was calculated, mean extension dropped to 2 660 km^2, two degrees of magnitude smaller that IUCN and NatureServe's mean extensions of occurrence (Table 2.1 and Figure 2.2 for an example with *Brachyteles arachnoides*).

Figure 2.2 Extension of occurrence maps for IUCN, NatureServe and Remaining habitat datasets for *Brachyteles arachnoides.*

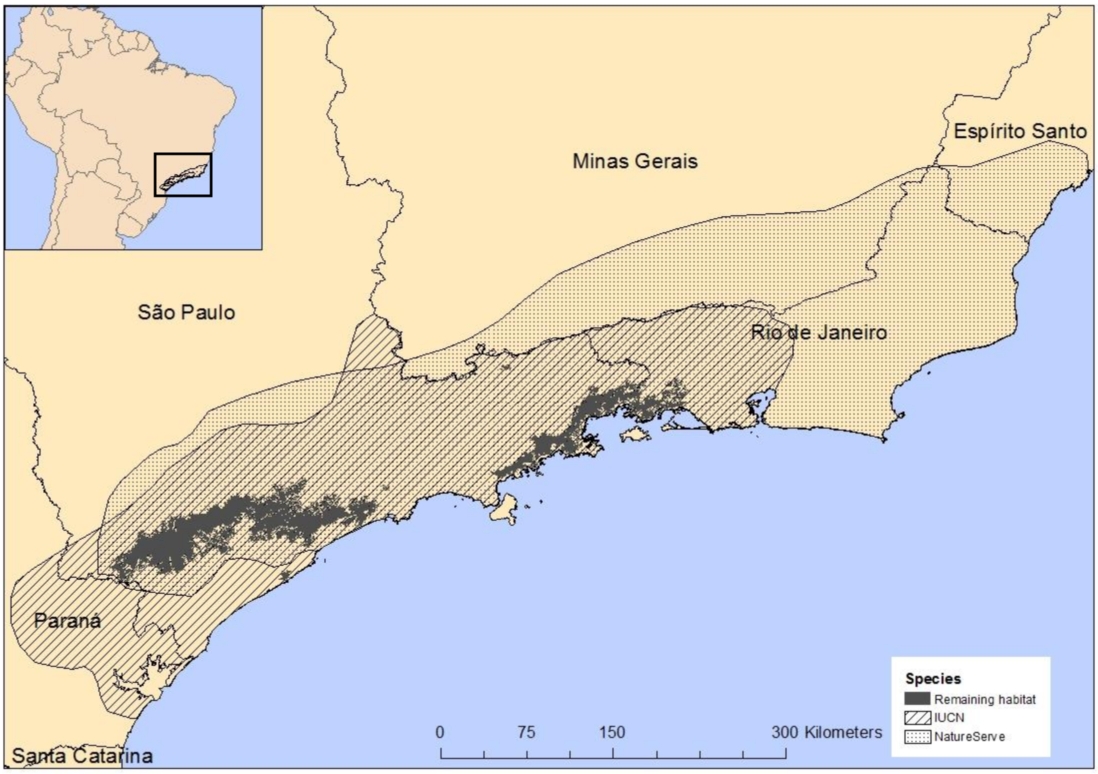


Table 2.1 Extent of occurrence in km^2 according to IUCN, NatureServe and Remaining habitat datasets of Brazilian Atlantic Forest primates. *Remaining habitat dataset was build based on habitat remnants and locality points.

Species	IUCN	NatureServe	Remaining Habitat
Alouatta guariba	1076604	1013440	12428
Brachyteles arachnoides	86274	133514	9408
Brachyteles hypoxanthus	96657	133769	478
Callicebus coimbrai	38585	5959	4
Callicebus melanochir	99866	39641	127
Callicebus nigrifrons	490586	479008	1
Callicebus personatus	142974	167394	193
Callithrix aurita	159613	152057	2987
Callithrix flaviceps	24732	34509	28
Callithrix geoffroyi	124967	172465	254
Callithrix kuhlii	45701	34390	154
Cebus nigritus	879800	1013200	15689
Cebus xanthosternos	466596	425386	229
Leontopithecus caissara	335	308	-
Leontopithecus chrysomelas	20190	19074	368
Leontopithecus chrysopygus	63671	49806	196
Leontopithecus rosalia	3991	16073	17

Identifying conservation goals and reviewing existing conservation network

Reviewing the existing conservation network we found 13 gap species using the IUCN maps, 15 for NatureServe and 14 for Remaining Habitat maps (Tabel 2.2). Only one species, *Brachyteles arachnoides,* was adequately protected in all three scenarios. Due to marked loss in the extent of distribution in the Remaining Habitat method, conservation targets increased with 12 species requiring 100% of its' distribution to be found within protected areas in order to be considered adequately protected. Mean conservation targets were similar for IUCN and NatureServe maps, around 33%, but were nearly triple for Remaining Habitat as distributions narrowed (Table 2.2).

Selecting additional conservation areas

A total of 7 052 hexagons were created over an area of 1 834 879 km^2. Using IUCN range maps, Marxan best solution selected 722 hexagons equal to 187 859 km^2 (Figure 2.3). Of the 722 hexagons, 404 were selected all 1 000 times (Figure 2.6), signifying 105 118 Km^2 that are irreplaceable for the protection of all 17 species of primates. For the NatureServe dataset 686 hexagons were selected totaling 178 492 km^2 (Figure 2.4) and, as for IUCN, 404 (105 118 km^2) were selected as irreplaceable (Figure 2.7). For the remaining habitat data set, 191 hexagons were selected (49 697 km^2) (Figure 2.5) all of which were selected as irreplaceable (Figure 2.8). The 404 irreplaceable hexagons were the same for IUCN and NatureServe (Figure 2.9) and 110 hexagons were irreplaceable in all three datasets (Figure 2.10).

Table 2.2 Conservation targets and gap-analysis (percentage of extent protected by reserves) from three datasets, IUCN, NatureServe and Remaining Habitat. In bold are the datasets in which the amount protected surpassed the established conservation target for the species. The gap-analysis was not performed for *Leontopithecus caissara* and neither was a conservation target calculated as the species lost all of its extension in the Remaining habitat dataset.

Species	IUCN		NatureServe		Remaining Habitat	
	Protected (%)	Conservation Target (%)	Protected (%)	Conservation Target (%)	Protected (%)	Conservation Target (%)
Alouatta guariba	6,91	10,00	7,19	10,00	**61,92**	**58,93**
Brachyteles arachnoides	**35,95**	**27,35**	**24,38**	**20,23**	**80,29**	**63,46**
Brachyteles hypoxanthus	2,13	25,49	2,16	20,20	88,74	100,00
Callicebus coimbrai	0,88	40,46	1,82	70,91	0,00	100,00
Callicebus melanochir	6,67	24,96	13,65	40,02	95,47	100,00
Callicebus nigrifrons	**10,56**	**10,00**	**10,84**	**10,00**	65,30	100,00
Callicebus personatus	3,96	19,11	4,27	16,54	3,46	100,00
Callithrix aurita	**19,19**	**17,32**	18,05	18,11	74,00	82,16
Callithrix flaviceps	2,31	47,71	2,34	42,28	0,18	100,00
Callithrix geoffroyi	5,19	21,31	4,45	16,06	10,11	100,00
Callithrix kuhlii	7,35	37,70	9,73	42,34	86,51	100,00
Cebus nigritus	7,29	10,00	7,13	10,00	**75,78**	**55,13**
Cebus xanthosternos	4,59	10,00	4,16	10,00	58,29	100,00
Leontopithecus caissara	**100,00**	**100,00**	94,15	100,00	-	-
Leontopithecus chrysomelas	11,86	51,02	7,93	51,95	54,98	100,00
Leontopithecus chrysopygus	15,34	32,30	13,14	36,30	93,46	100,00
Leontopithecus rosalia	33,51	77,44	22,70	54,74	0,00	100,00
Mean	16,10	33,07	14,59	33,51	53,03	91,23

Figure 2.3 Priority areas for the conservation of 17 Atlantic Forest primates. Best solution for IUCN dataset.

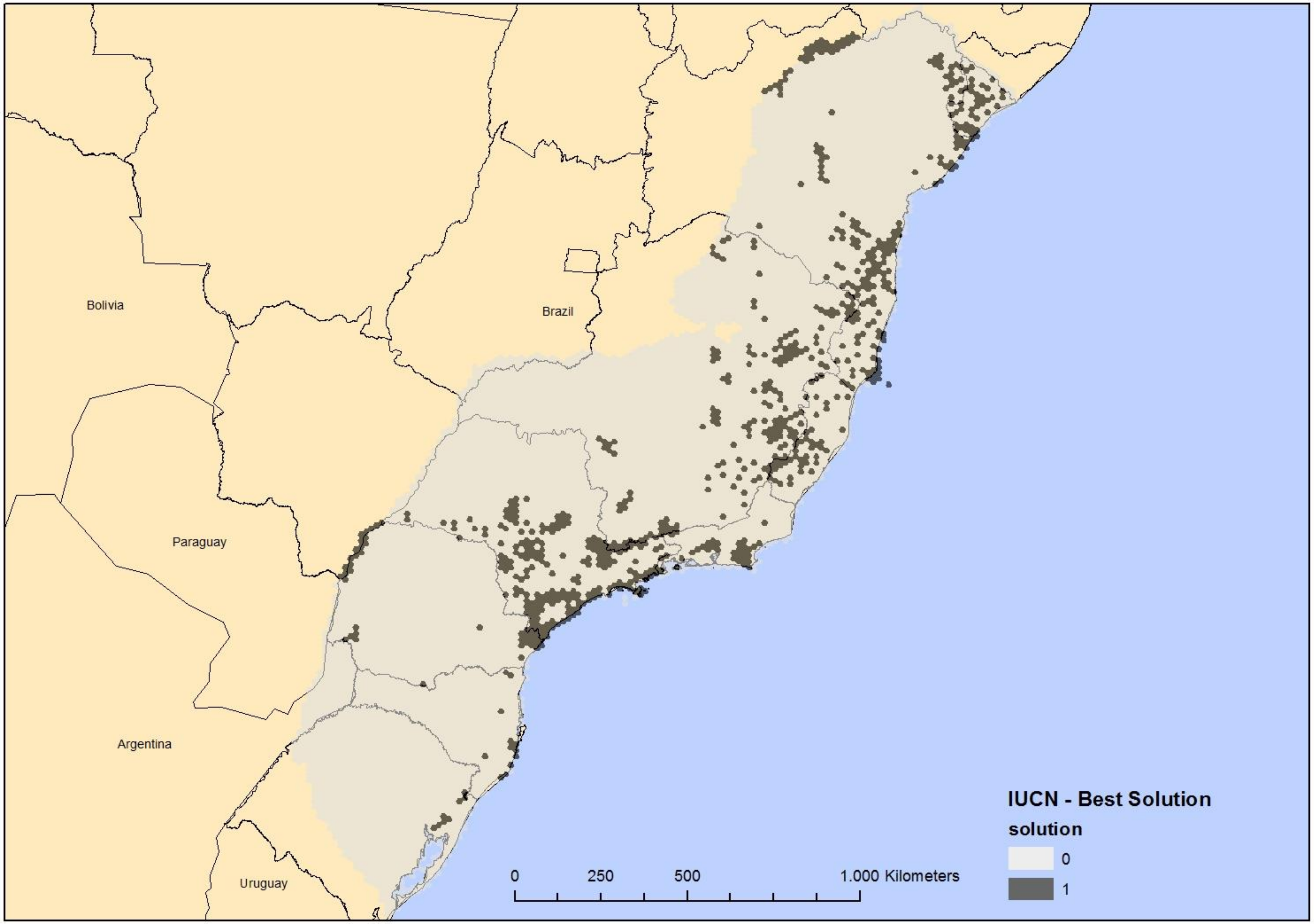


Figure 2.4 Priority areas for the conservation of 17 Atlantic Forest primates. Best solution for NatureServe dataset.

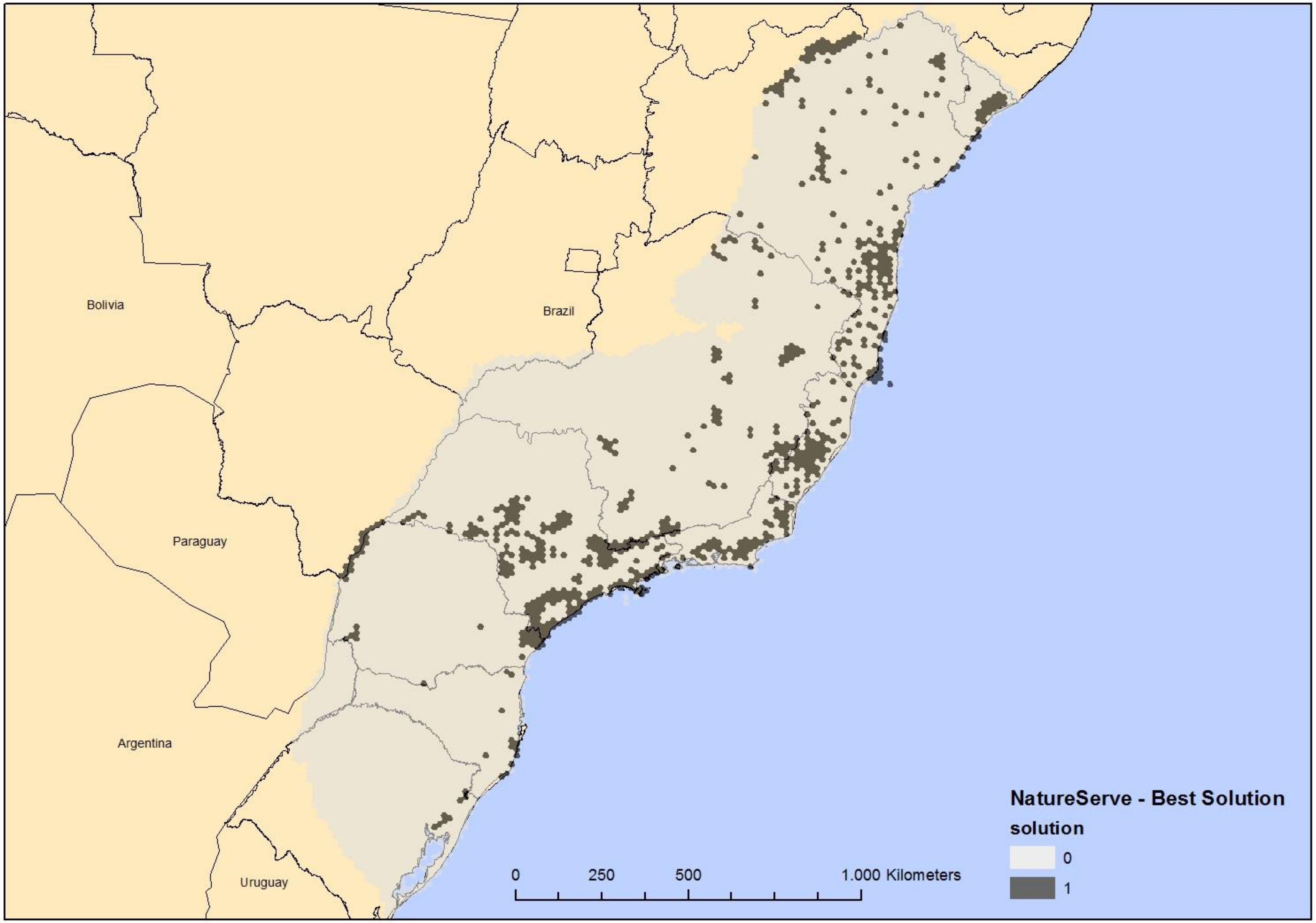


Figure 2.5 Priority areas for the conservation of 16 Atlantic Forest primates. Best solution for Remaining Habitat dataset.

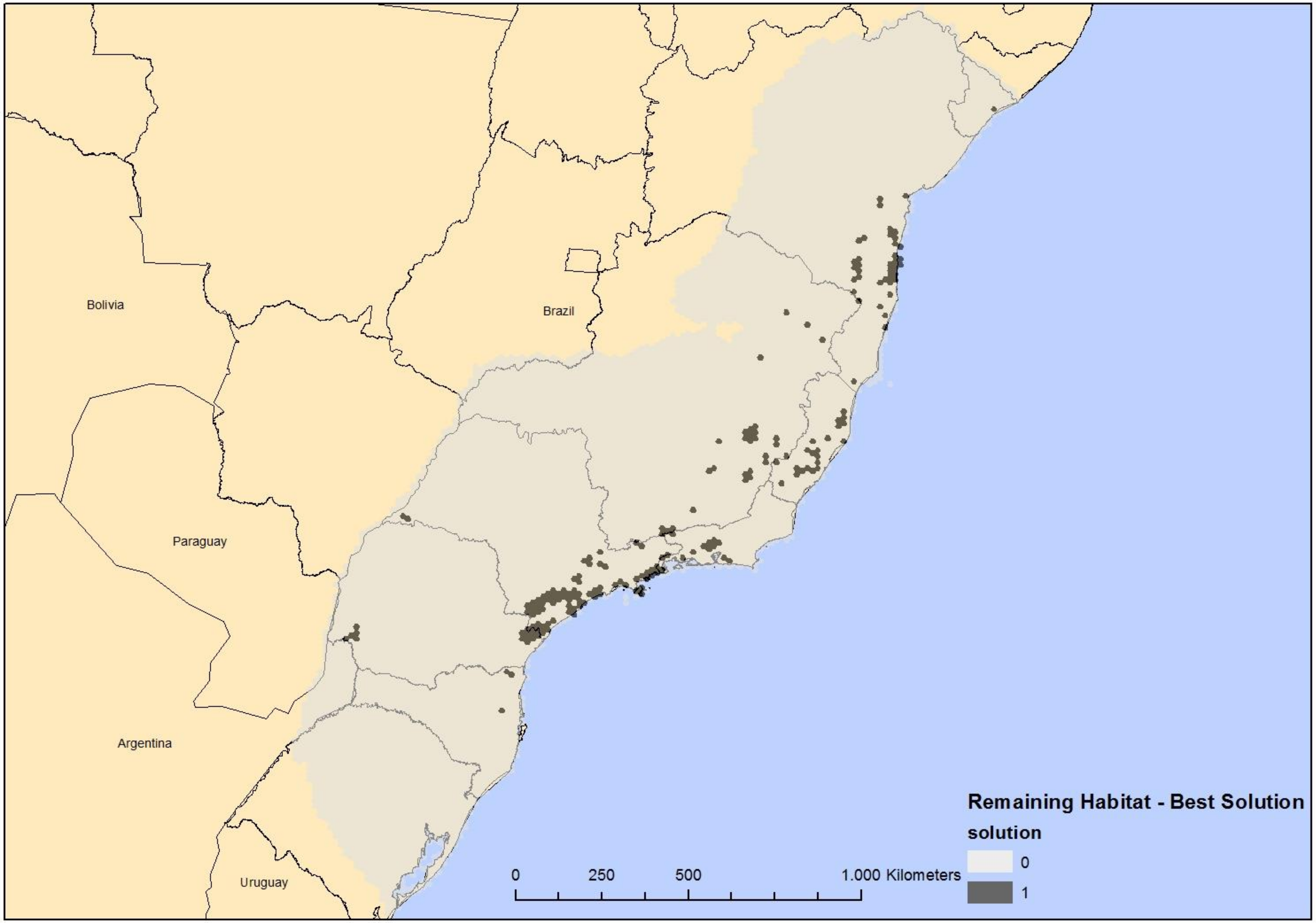


Figure 2.6 Priority areas for the conservation of 17 Atlantic Forest primates. Frequency of selection for each hexagons for the IUCN dataset

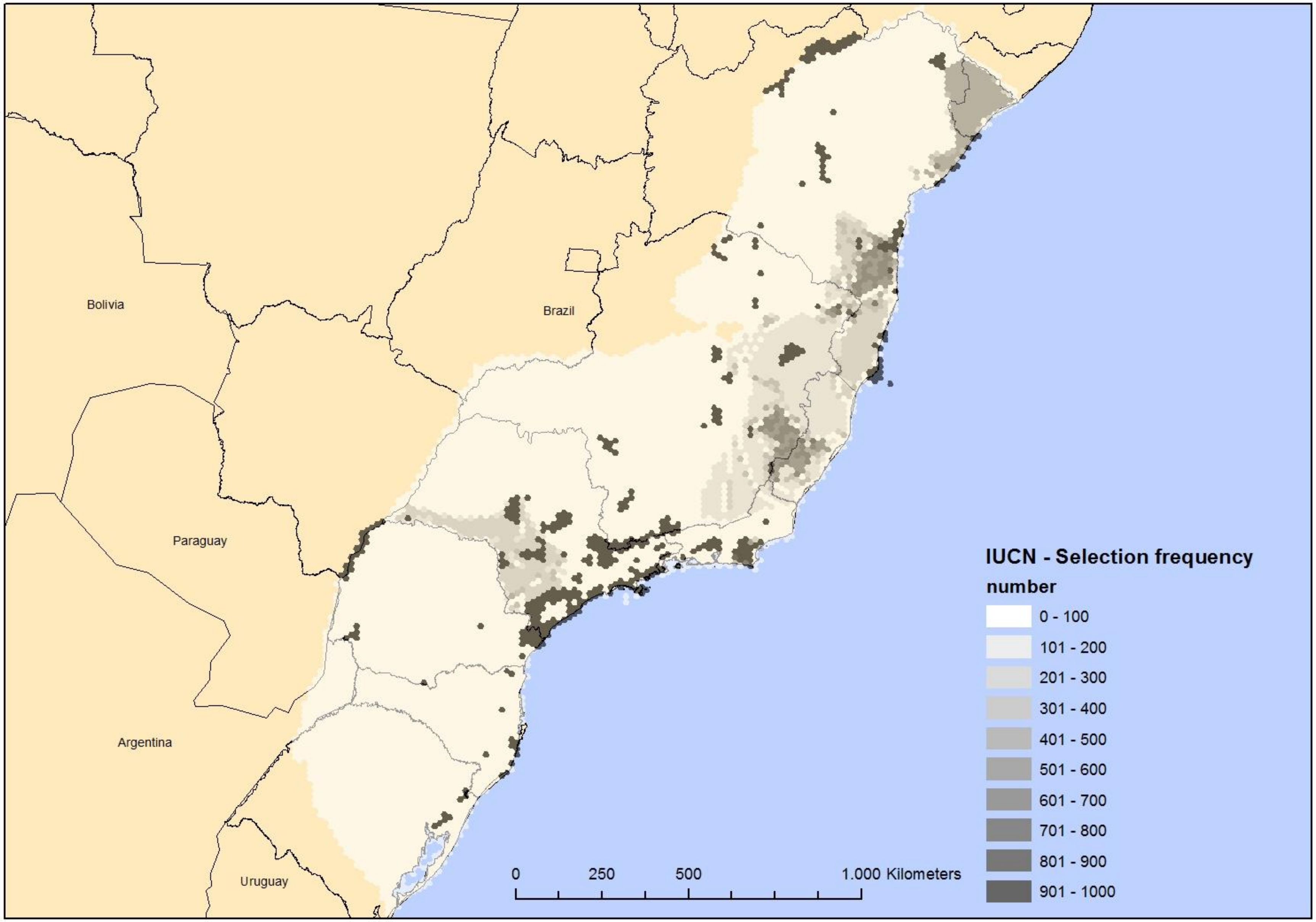


Figure 2.7 Priority areas for the conservation of 17 Atlantic Forest primates. Frequency of selection for each hexagons for the NatureServe dataset.

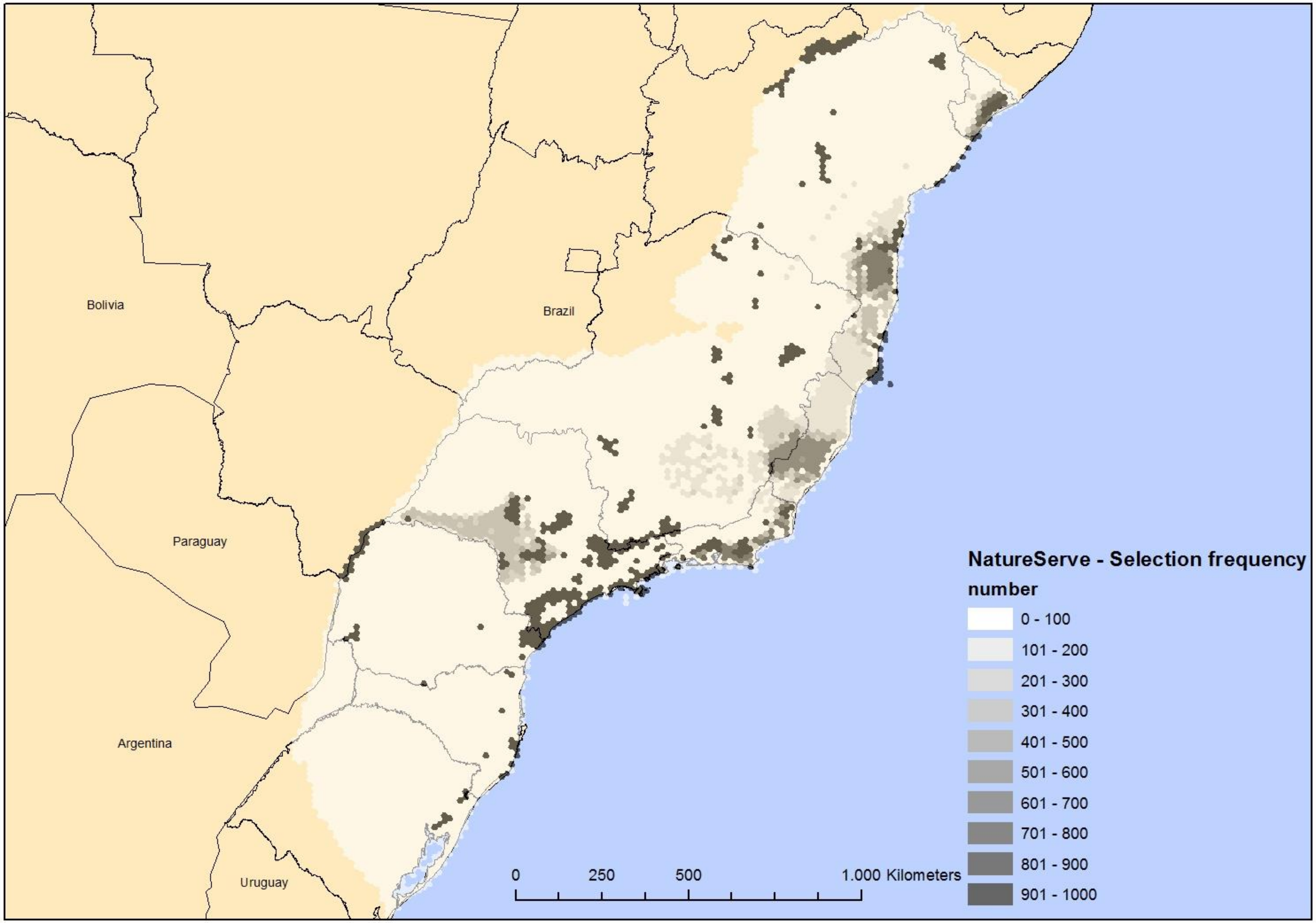


Figure 2.8 Priority areas for the conservation of 16 Atlantic Forest primates. Frequency of selection for each hexagons for the Remaining Habitat dataset.

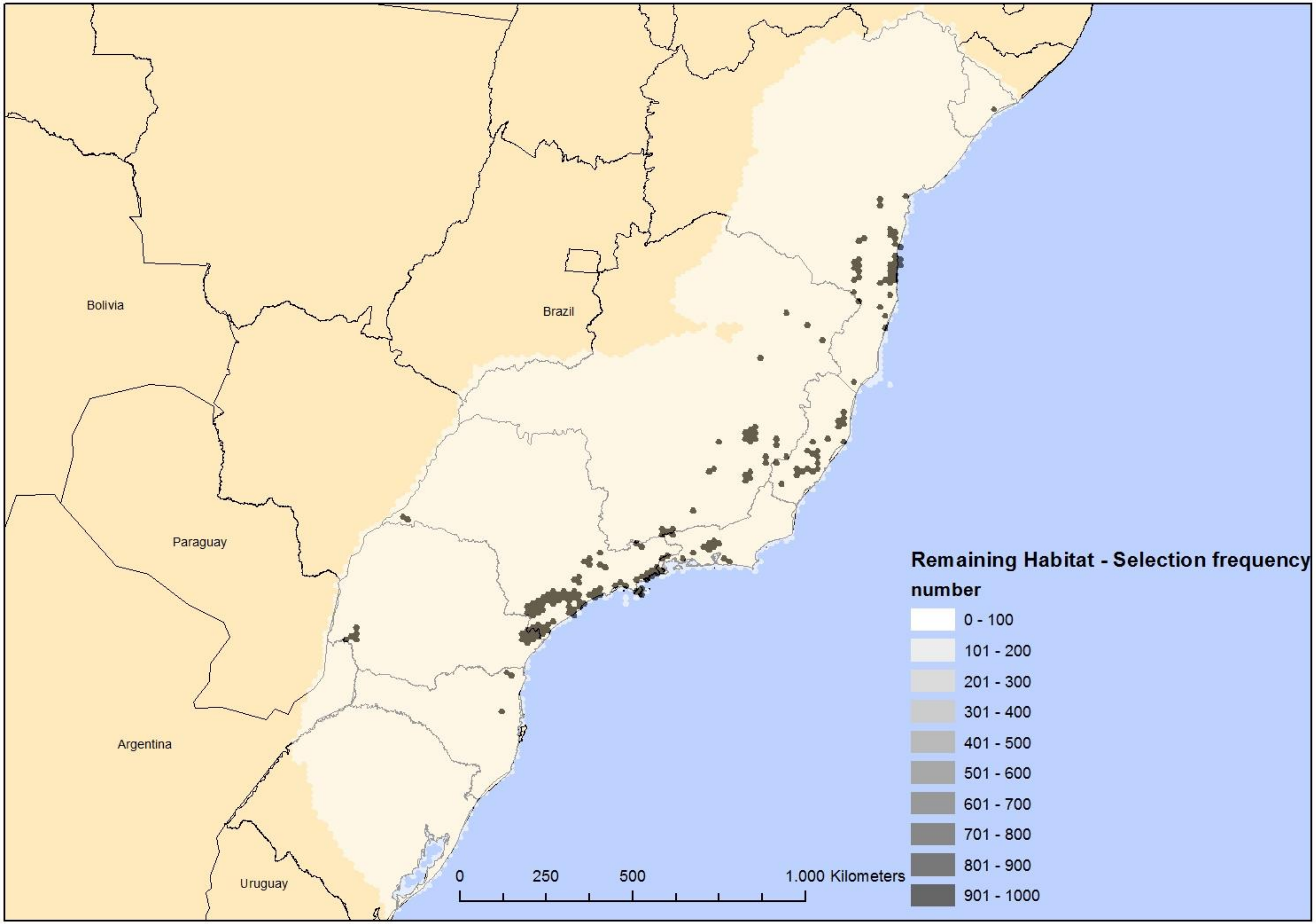


Figure 2.9 Priority areas for the conservation of 17 Atlantic Forest primates. Irreplaceable areas (areas which were selected 1000 times) for IUCN and NatureServe datasets.

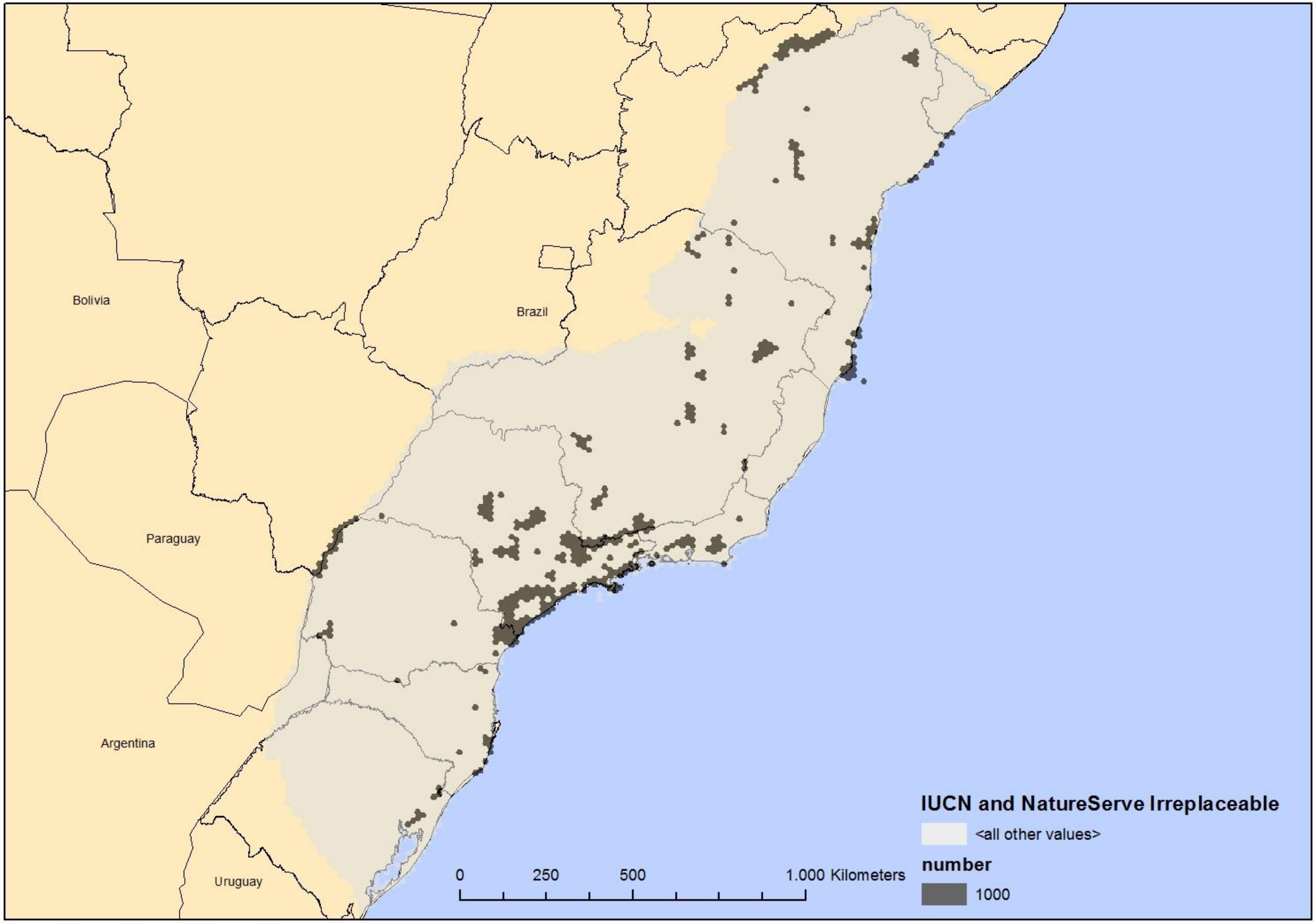
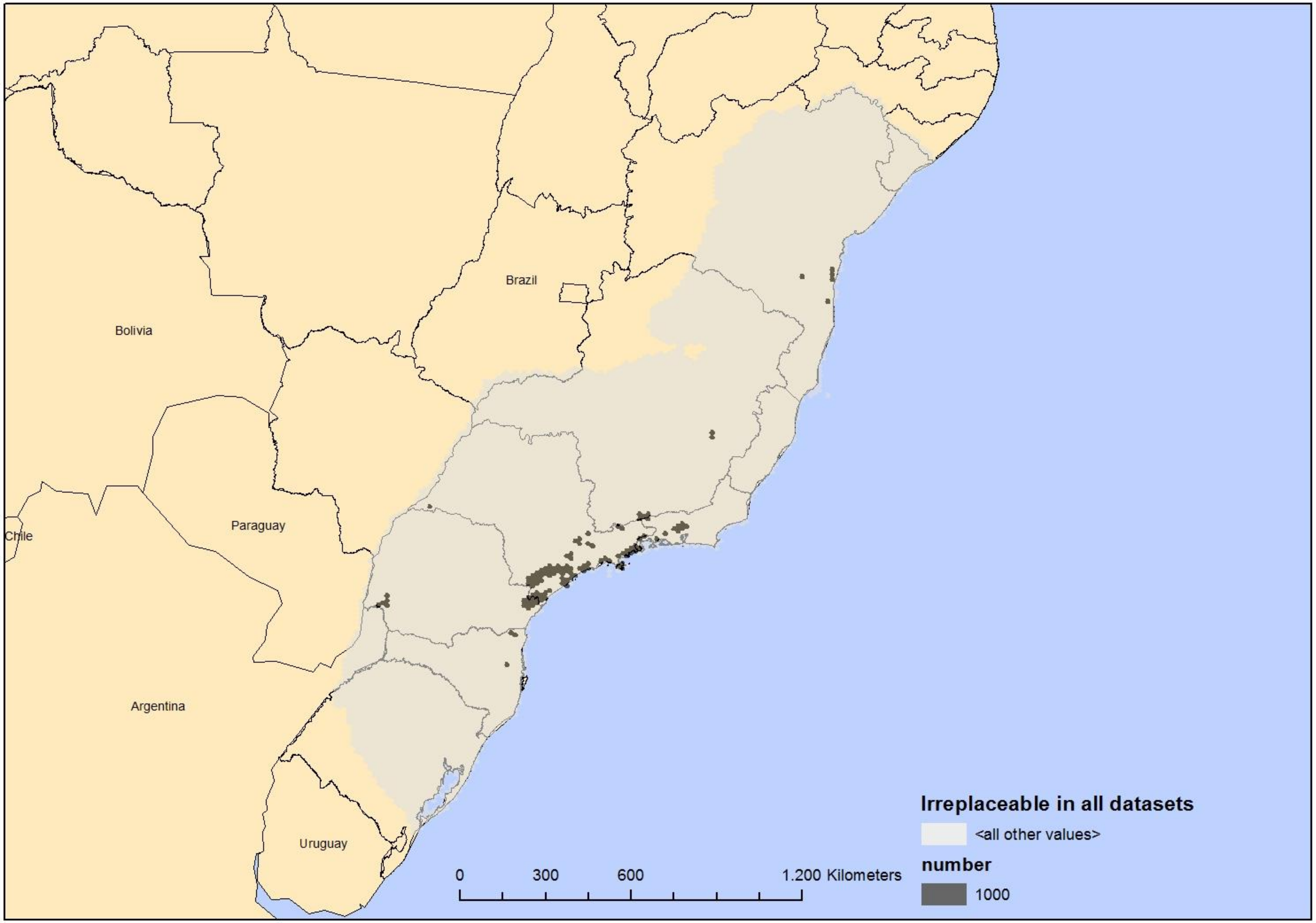


Figure 2.10 Priority areas for the conservation of 17 Atlantic Forest primates. Irreplaceable areas (areas which were selected 1000 times) for all three datasets: IUCN, NatureServe and Remaining Habitat



Discussion

Identifying conservation goals and reviewing existing conservation network

Conservation targets varied from 10-100% for IUCN and NatureServe, which are the respectively lower and higher limits (Figure 2.1). The mean target was around 33% for both databases as extension varied little. For remaining habitat, targets varied from 55-100% with a mean of 91% as extensions became very restricted, shifting the target for most species to 100% (Table 2.2).

Only six species were considered adequately protected in at least one dataset. All other 11 species were classified as gap species for all datasets. Only *Brachyteles arachnoides* was considered adequately protected in all datasets. Four species were considered protected for IUCN maps, and two for NatureServe and three for Remaining Habitat. Even though NatureServe extensions of occurrence were much higher, and targets lower, it perform worse than remaining habitat with a total of 15 gap species having the worse performance out of all three datasets. The number of gap species found here is much higher than that found in similar studies. Pinto & Grelle (2009) found only six gap species (30%) in a group of 19 Atlantic Forest primates (which comprised the species used in this study). Alburquerque *et al.* (2011) found that 14 out of 308 mammal species (4,5%) were gap species in the Atlantic Forest. Although both studies were conducted in the Atlantic Forest, and targeting some of the same species this discrepancy can be explained by the target setting. Pinto & Grelle (2009) and Albuquerque *et al.* (2011) considered a species represented by the current reserve network if any amount of their extension overlapped with reserves. This is problematic as the extension protected by reserve boundaries may be insufficient for species' long-term persistence. Rodrigues *et al.* (2004), using the same protocol to determine conservation targets, found that globally 74% of 11 633 vertebrate species are gap species. We found that for the 17 primate species considered in this study 76%, 88% and 81% were gap species for IUCN, NatureServe and Remaining Habitat respectively.

Hence, Atlantic Forest primates seem to be on average less represented in protected areas than other taxa in other areas.

Selecting additional conservation areas

The number of selected hexagons were much higher for IUCN and NatureServe when compared to remaining habitat due to large extents of distribution for the species in those datasets. Results were also more flexible, with less irreplaceable hexagons. However, range maps possess large amounts of commission and omission error (Gaston *et al.*, 2003; Brown *et al.* 1996; Palminteri, *et al.,* 2009; Pinto *et al.,* 2014; *Chapter One*) and species might not be present in the selected hexagons. Even though all hexagons selected by Marxan's best run for Remaining Habitat were irreplaceable, this dataset shows the most promise, as cost are lower due to smaller extents of occurrence and data is more conservative, meaning we are more confident that the species will be present in the selected areas. However, *Leontopithecus caissara* was left out of the remaining habitat prioritization as it lost all of its extension of distribution as none of the point locality data overlapped with forest remains due to its limited extent of occurrence (the smallest between all 17 species) and small sample size *(n=4)*

Today, 14 636 km^2 of the remaining Atlantic Forest is under protection (Ribeiro *et al.,* 2009) in order to protect the 17 primates described in this study, the number would have to at nearly quadruple as at least 49 697 km^2 would have to be protected according to the Remaining Habitat approach. This means that about 1/3 of the existing forest (157 056 km^2) (Ribeiro *et al.*, 2009) would need to be converted to reserves just in order to adequately protect 17 primate species. Both results given by IUCN and NatureServe approaches surpass the existing amount of remaining forest, as they do not take into account habitat availability – demonstrating that conservation planning based on data that ignores habitat availability yield unrealistic results.

Further, this results show a more dramatic future for persistence of Brazilian Atlantic forest primate species than showed before (Pinto & Grelle, 2009).

In this study we made no distinction between large and small fragments. Large fragments are useful to maintain large populations (e.g. Brito et al 2008) and serve as source for smaller neighboring fragments. However, considering the extreme degradation exhibited by the Atlantic Forest, small fragments can play a crucial role in maintaining connectivity throughout the landscape (Ribeiro *et al.*, 2009; Crouzeilles *et al*., 2011). Although this is a general expectation, there is a lack evidence of dispersal movements of primates between fragments in the Brazilian Atlantic forest. However, a point can be made that every single forest remain is crucial for the conservation of the Atlantic Forest specially when considering that a 1/3 of all the remaining forest is necessary to protect as few as 17 primate species.

This study did not consider population viability analysis and many forest fragments may be too small and to isolated to sustain populations. However, we argue that due to the server state of degradation of the Atlantic Forest all forest remains should be managed to some extent. Though this does not render prioritization futile, as areas are continually being destroyed and converted and resources are limited, making prioritization critical to decide which areas are irreplaceable and in need of more urgent attention. Although our results based on the more conservative data suggest that adequate primate conservation could be achieved in the Atlantic Forest, it is possible that not enough forest is left to protect other taxa. As such, we suggest that alongside the establishment of new reserves, restoration efforts are key for the conservation of the Atlantic Forest biodiversity.

This study is by no means a set result for prioritizing areas for the conservation of the Atlantic Forest nor its' primates. Rather, it should be consider a conservation planning exercise as several other important factors were left out. In addition, systematic conservation planning is a stepwise, iterative process, that should be recalculated and reassessed every time scenarios change (e.g. areas are unavailable for conservation; more data on target species becomes available).

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Supplemental Material

Figure 2.9 Remaining habitat maps for *Brachyteles arachnoides*.

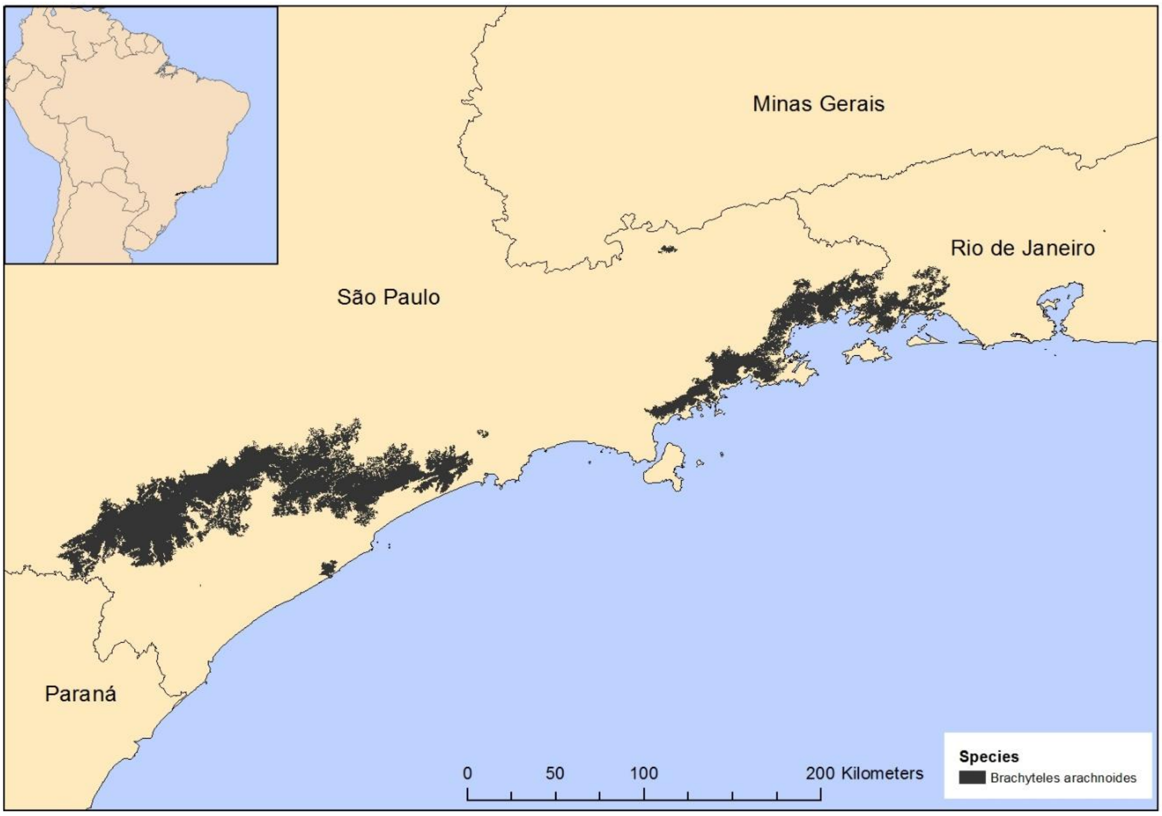

Figure 2.10 Remaining habitat maps for *Brachyteles hypoxanthus*.

Figure 2.11 Remaining habitat maps for *Callicebus coimbrai*.

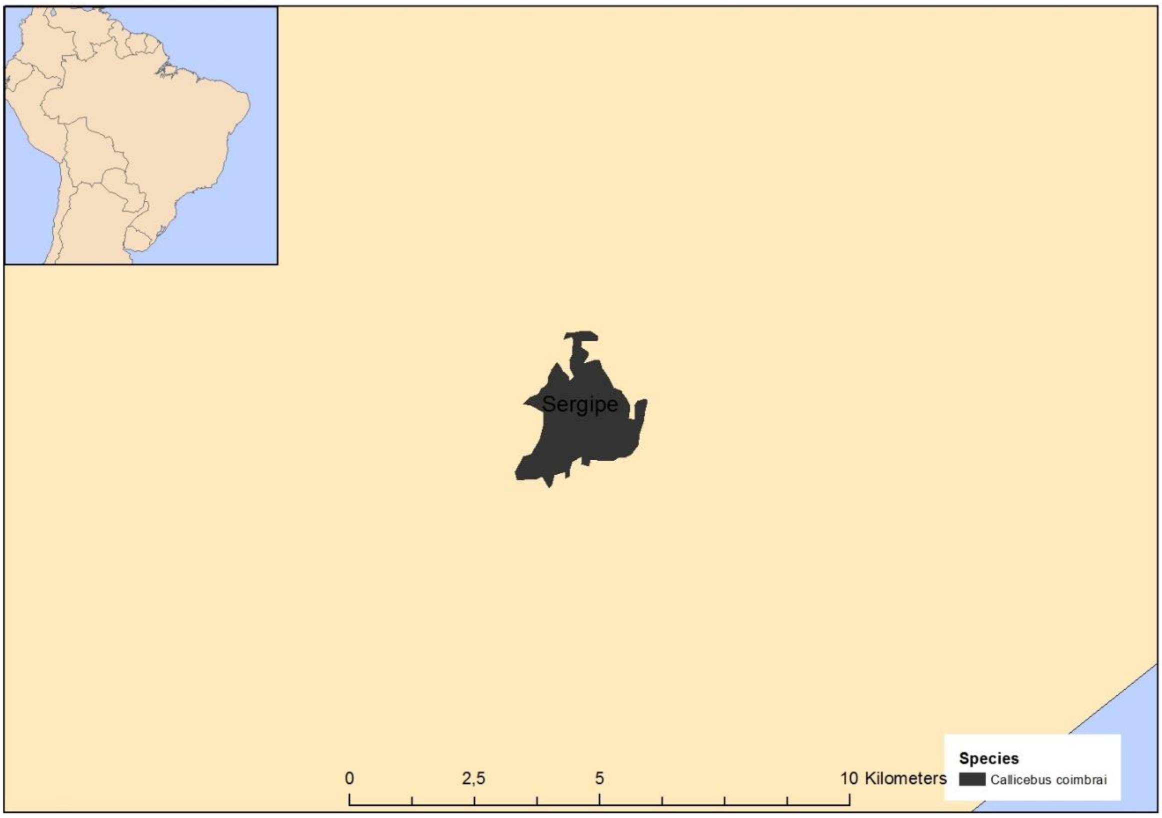

Figure 2.12 Remaining habitat maps for *Callicebus melanochir*.

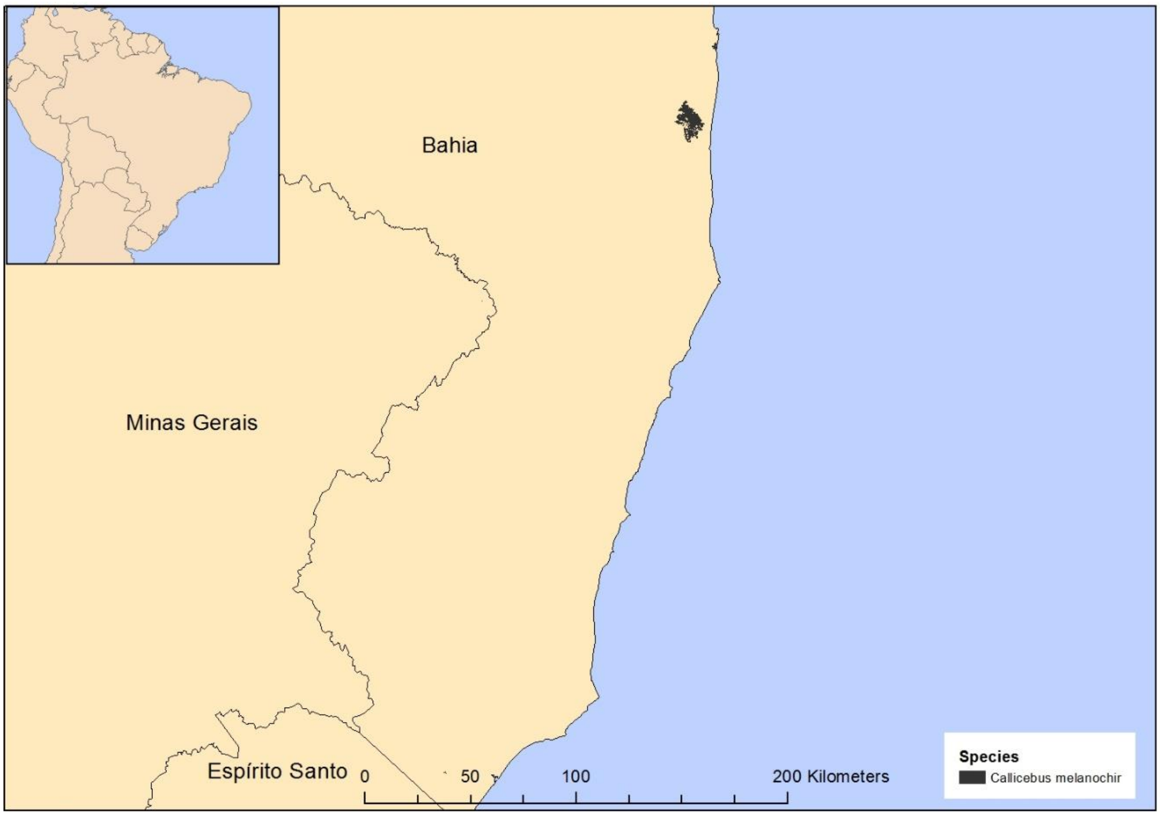

Figure 2.13 Remaining habitat maps for *Callicebus nigrifrons.*

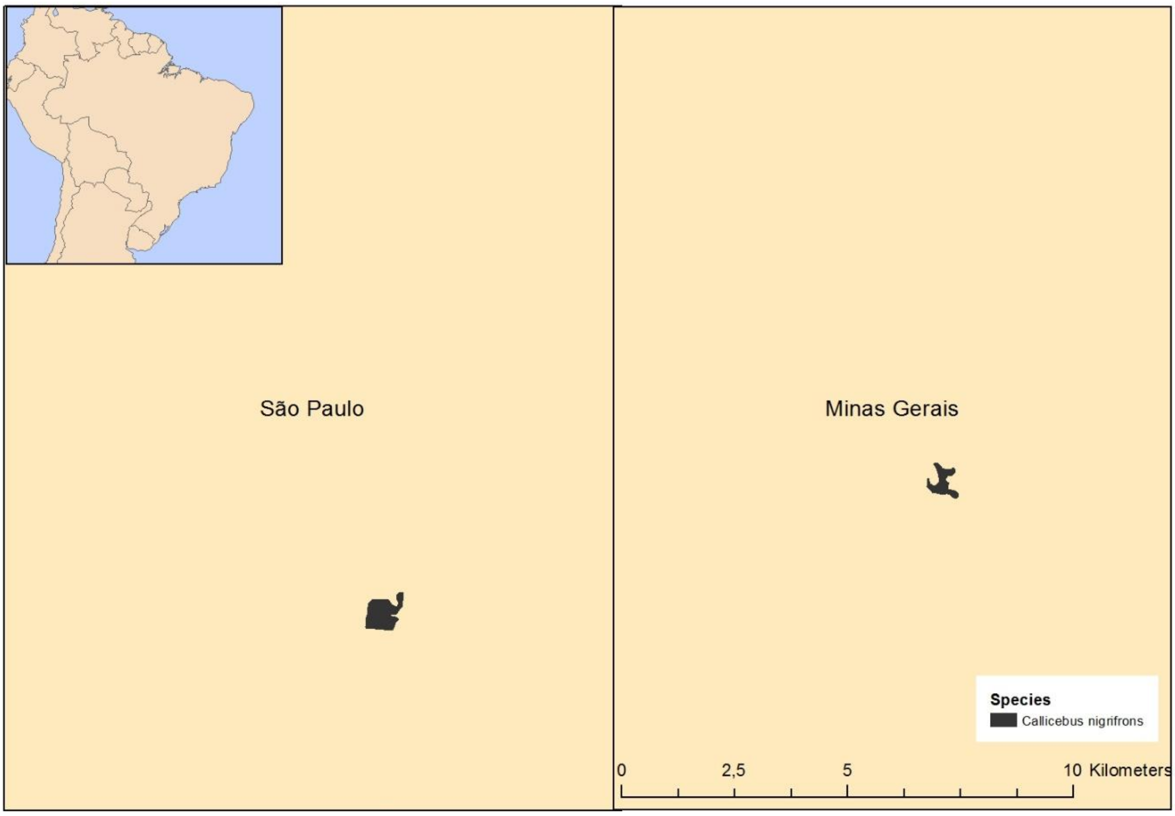

Figure 2.14 Remaining habitat maps for *Callithrix aurita*.

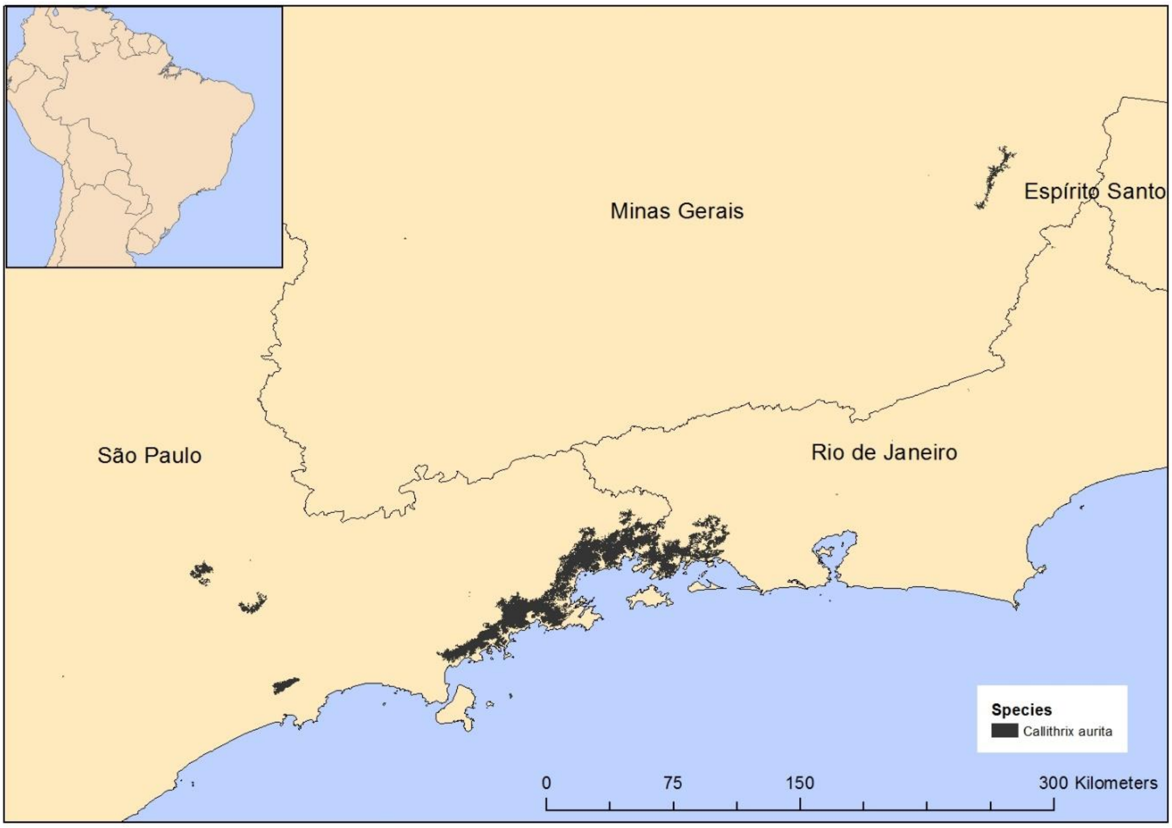

Figure 2.15 Remaining habitat maps for *Callithrix flaviceps*.

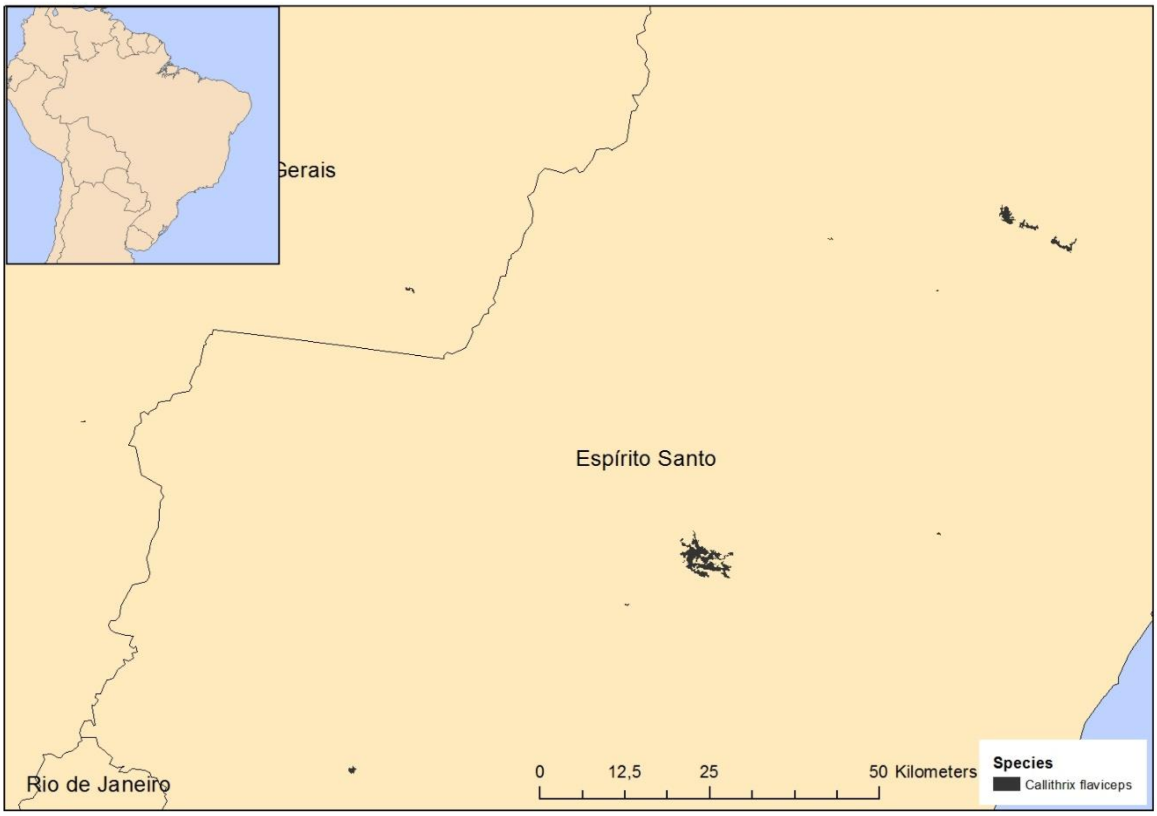

Figure 2.16 Remaining habitat maps for *Callithrix geoffroyi*

Figure 2.17 Remaining habitat maps for *Callithrix kuhlii*.

Figure 2.18 Remaining habitat maps for *Cebus nigritus*.

Figure 2.19 Remaining habitat maps for *Cebus xanthosternos.*

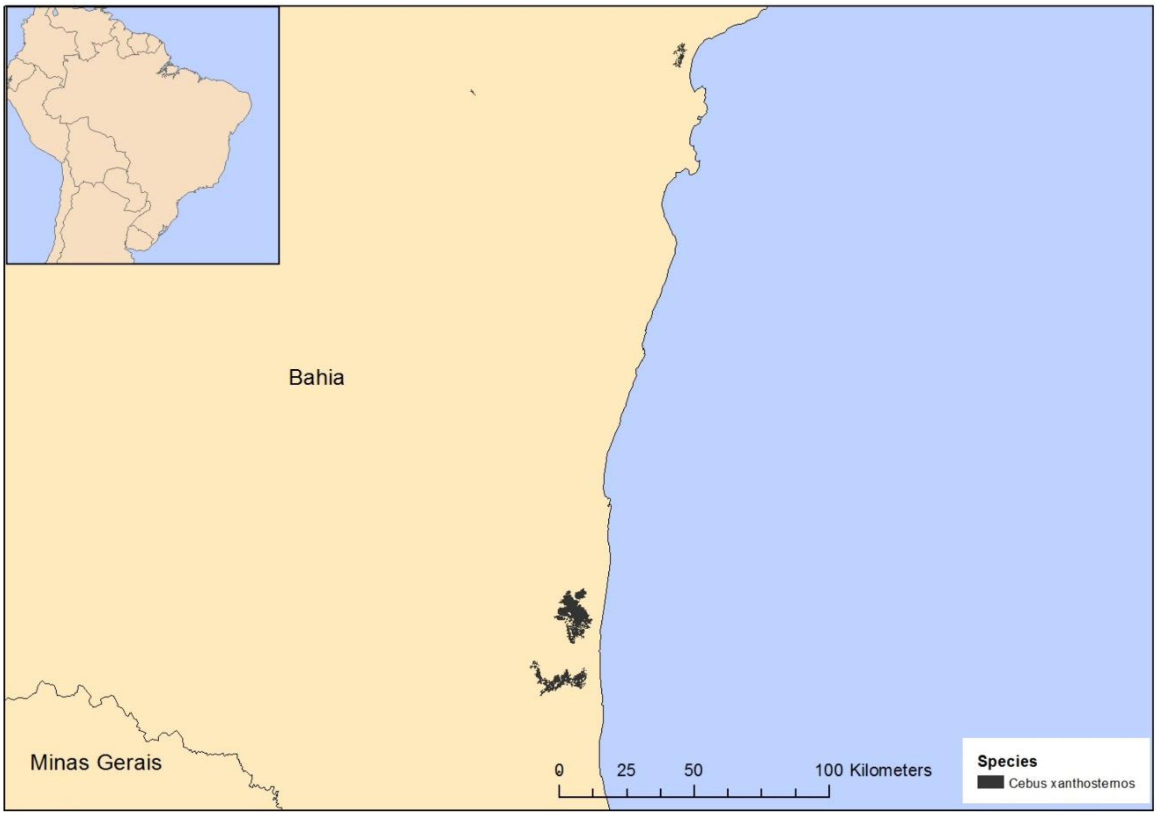

Figure 2.20 Remaining habitat maps for *Leontopithecus chrysomelas*.

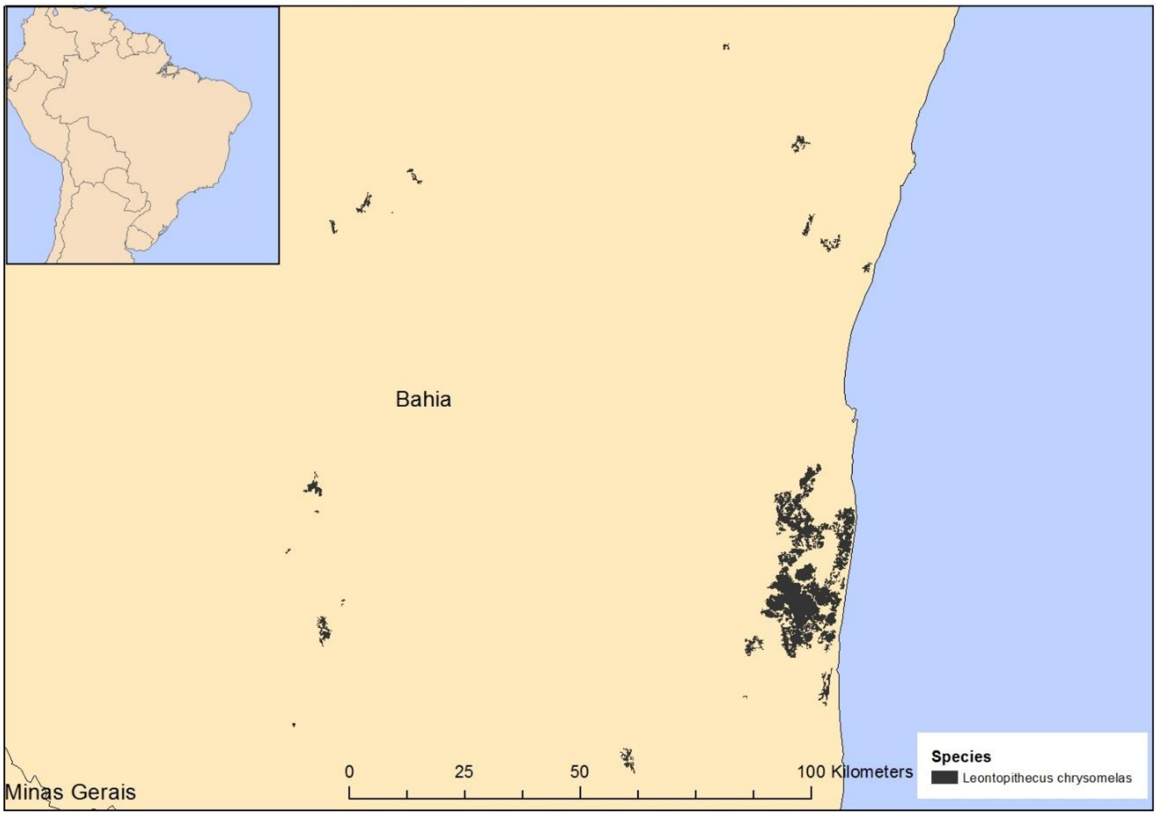

Figure 2.21 Remaining habitat maps for *Leontopithecus chrysopygus*.

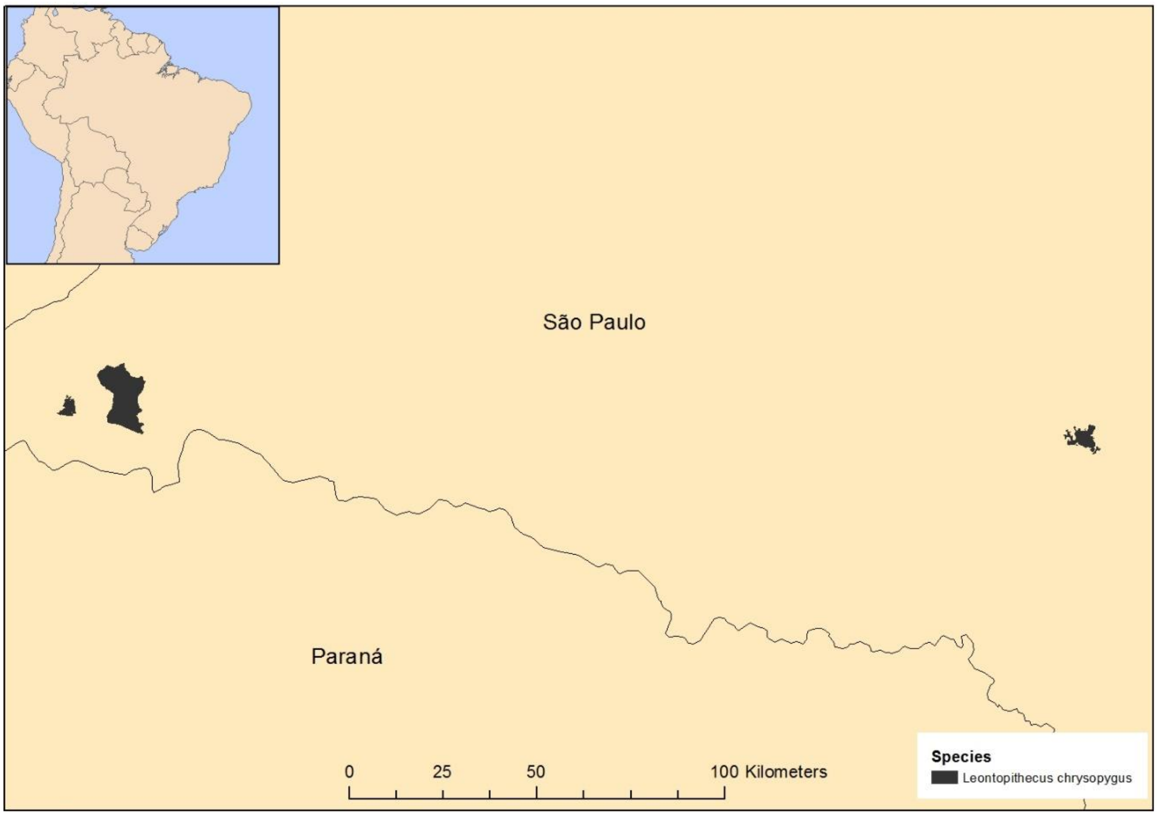

Figure 2.22 Remaining habitat maps for *Leontopithecus rosalia*.