Chapter 16
Primate Densities in the Atlantic Forest of Southeast Brazil: The Role of Habitat Quality and Anthropogenic Disturbance

Naiara Pinto, Jesse Lasky, Rafael Bueno, Timothy H. Keitt, and Mauro Galetti

16.1 Introduction

16.1.1 Goals

Studies of variation in abundance within a species' geographic range provide the connection between the disciplines of ecology and biogeography. Empirical studies of various taxonomic groups show that density of a given species is unevenly distributed in space, with few "hotspots" and many "coldspots", where abundance is orders of magnitude lower (Brown et al. 1995). The typical explanation for this pattern is spatial variation in habitat suitability. In other words, variation in density is generated by how closely sites correspond to a species' niche (Brown et al. 1995). Like many ecological patterns, the correspondence between primate density and habitat suitability can be investigated at several spatial scales (Wiens 1989; Levin 1992). For example, coarse-scale studies comparing densities of howler monkeys (*Alouatta* spp.) across the Neotropics have shown that howler density is largely a function of primary productivity (Peres 1997). Fine-scale studies comparing neighboring forest fragments have also reported variation in howler density, but in this case the pattern is frequently attributed to anthropogenic pressure (Hirsh et al. 1994; Cullen et al. 2001; Chiarello 2003; Martins 2005).

In general, human impact on other primates can be direct via hunting, or indirect through habitat disturbance and fragmentation. However, some species thrive in disturbed habitats (Chiarello 1993, 2003; Rylands et al. 1993; Strier et al. 2000). This fact complicates the task of predicting changes in primate density across a gradient in land use. In the present chapter, we investigate the synergistic effects of environmental and anthropogenic factors on the density of five primate genera that inhabit the Atlantic forest of southeast Brazil. Our goal is not to produce distribution maps, but rather to: (i) synthesize available census information for the region; (ii) compare the genera's responses to anthropogenic impact; and (iii) map areas of high

---

N. Pinto (✉)
Jet Propulsion Laboratory, 4800 Oak grove ms 300–325 Pasadena, CA, 91105
e-mail: sardinra@jpl.masa.gov

P.A. Garber et al. (eds.), *South American Primates,* Developments in Primatology: Progress and Prospects, DOI 10.1007/978-0-387-78705-3_16,

predicted densities based on available data. In this section, we introduce the reader to the Brazilian Atlantic forest, present the dataset used in the study, and describe the analytical tools used to study the determinants of primate density.

16.1.2 The Primates at the Brazilian Atlantic Forest

Studies in the Brazilian Atlantic forest provide an ideal opportunity to understand the interaction of anthropogenic factors and habitat quality on primate densities. This ecosystem is a biodiversity hotspot that occupies less than 8% of its original extent (Hirota 2003). Current studies estimate that 40% of the tree and shrub species in this ecosystem are endemic, as well as 22% of their bird and mammal species (Brooks et al. 2000) – and many new species are still being discovered in the region every year (Alves et al. 2006; Donha and Eliasaro 2006; Pontes et al. 2006). Due to its extensive elevational and latitudinal ranges, the Atlantic forest is recognized as a domain that includes several vegetation types (Oliveira-Filho and Fontes 2000). Exploitation of Atlantic forest species did not start recently, as it has been suggested that hunting and forest clearing were already widespread when the first Portuguese arrived in 1500 (Dean 1996). However, the anthropogenic pressure was intensified with the Portuguese colonization, expansion of the agricultural frontier (Dean 1996; Câmara 2003), and later establishment of Brazilian industrial centers in the area, which currently has a population of more than 130 million people (IBGE 2000). As a result of the intense land use in eastern Brazil, the distribution of forest remnants is very distinct from the fishbone pattern observed in the Brazilian Amazon, in which vast forest tracts are interrupted by a network of roads and pipelines. Rather, the Atlantic forest landscape is now an archipelago with small forest fragments embedded in a human-dominated matrix containing pastures, plantations, cities, and roads.

Twenty-three primate species are known to live in the Brazilian Atlantic forest, twenty of which are endemic to this ecosystem (Hirsh et al. 2006). According to the most recent IUCN Mammal Red List (IUCN 2006), three species are vulnerable, four are endangered, and nine are critically endangered (Table 16.1). While some primate populations in the Brazilian Amazon may be sustained via source-sink dynamics (Michalski and Peres 2005), these dynamics have never been documented for the Atlantic forest and are unlikely to be operating due to inter-fragment isolation and inhospitality of the matrix. Also, few fragments are large enough to sustain viable primate populations (Chiarello and Melo 2001; Bernardo and Galetti 2004; *see* also Marsden et al. 2005 for birds), and the extent to which existing conservation units are protecting primate populations against poaching remains unknown.

16.1.3 Census Data for Primate Species in the Brazilian Atlantic Forest

Data on primate abundance were compiled from a variety of sources including graduate theses, primary-literature publications, and grey-literature reports. In all cases,

Table 16.1 Primate species inhabiting the Brazilian Atlantic forest, their conservation (IUCN) status, number of sites that have been censused using the line-transect technique, and number of populations with 500 individuals or more. CE = Critically endangered, E = Endangered, V = Vulnerable

Species	IUCN Status	Census Sites	Viable ($\geq$ 500) populations	Ref.
Alouatta guariba	CE	24	8	3, 4, 7, 8, 9, 10, 1113, 14, 15, 16
Alouatta belzebul	CE	0	–	–
Brachyteles arachnoides	E	9	3	4, 8, 10, 15
Brachyteles hypoxanthus	CE	2	0	6, 7
Callicebus barbarabrownae	CE	0	–	–
Callicebus coimbrai	CE	0	–	–
Callicebus melanochir	V	0	–	–
Callicebus nigrifons	–	3	1	1, 5, 12,
Callicebus personatus	V	8	5	2, 7, 8, 15, 16
Callithrix aurita	V	4	1	1, 8, 10
Callithrix flaviceps	E	2	1	7, 15
Callithrix penicillata	–	2	1	16, 17
Callithrix geoffroji	–	5	2	2
Callithrix jacchus	–	0	–	–
Callithrix kuhlil †	–	0	–	–
Cebus flavius	–	0	–	–
Cebus libidinosus	–	0	–	–
Cebus nigritus	–	25	10	1, 2, 3, 4, 7, 8, 10, 15, 17
Cebus xanthosternos	CE	0	–	–
Leontopithecus caissara	CE	0	–	–
Leontopithecus chrysomelas	E	0	–	–
Leontopithecus chrysopygus	CE	5	1	3
Leontopithecus rosalia	CE	0	–	–

(1) Sao Bernardo and Galetti 2004; (2) Chiarello 2000; (3) Cullen et al. 2001; (4) Martins 2005; (5) Romanini de Oliveira et al. 2003; (6) Strier et al. 2000; (7) Chiarello 2003; (8) Cosenza and Melo 1998; (9) Chiarello and Melo 2001; (10) Galetti et al. unpublished data; (11) Hirsh 1995; (12) Trevelin 2006; (13) Buss 2001; (14) Chiarello 1993; (15) Pinto et al. 1994; (16) Hirsh et al. 1994; (17) Bovendorp and Galetti 2007.

data were collected using the line-transect technique (Buckland et al. 2001). Values of population sizes were often calculated assuming no spatial variation in density within sites. Since this assumption is rarely met, we only show the number of viable populations ($>$500 individuals estimated) instead of attempting to calculate exact population sizes (Table 16.1).

There are a number of limitations inherent in the type of data used in this study. First, line-transect census data are available for only eleven of the twenty-three primate species that inhabit this ecosystem. Second, studies are mostly restricted to the states of São Paulo, Espírito Santo and Minas Gerais (Fig. 16.1). Intensive census studies are lacking for populations inhabiting states such as Paraná, Santa Catarina, Rio de Janerio, and northeast Brazil, where few forest fragments remain and some primate populations are believed to be on the brink of extinction, especially large-bodied species (Pontes et al. 2006).

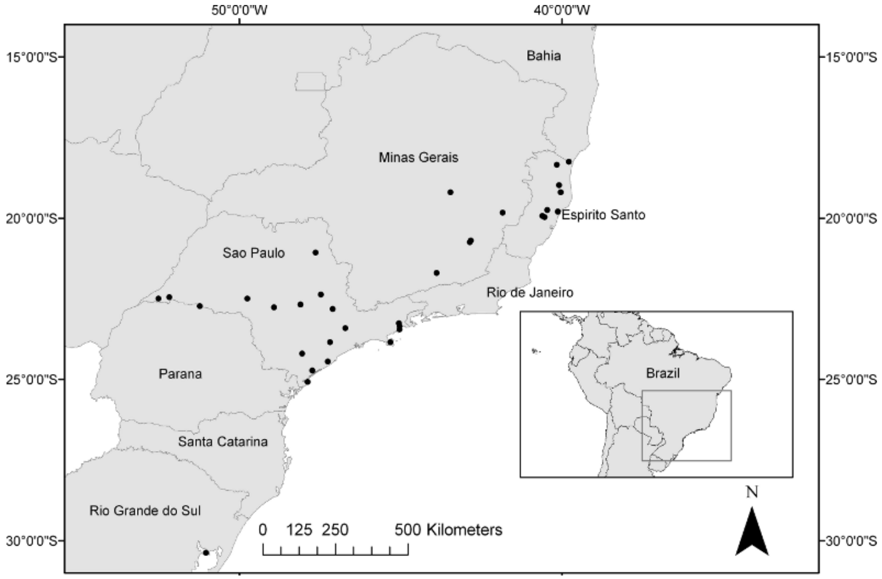


Fig. 16.1 Location of primate census studies carried out in the Brazilian Atlantic forest. The statistical analyses presented here focus on the southeast region, composed of the states of Minas Gerais, São Paulo, Rio de Janeiro, and Espírito Santo

16.1.4 Tools Used in the Present Study

Our task faces two challenges in addition to data scarcity and nonhomogeneous sampling across the ecosystem: first, dealing with nonlinear relationships and correlations between the independent variables, and second, the fact that the influence of a given environmental correlate can manifest itself at unknown spatial scales – for example, it is not possible to determine beforehand the area of influence of a city and therefore its potential impact on neighboring forest fragments. In the present chapter, we will apply tools that can help deal with the difficulties cited above: geographic information systems (GIS) and regression trees.

16.1.4.1 The Use of GIS in Conservation Studies

The use of remote sensing and GIS has recently increased among biologists, because these tools facilitate the analysis of large-scale associations between landscape patterns and biological outcomes. In the present work, three classes of maps are employed to model primate densities. First, maps of climate and elevation are used to differentiate between the evergreen coastal rainforest and the semideciduous forest (Oliveira-Filho and Fontes 2000). This distinction is extremely relevant for folivorous species (Peres 1997), because leaves from perennial trees are expected to be tougher (Coley 1983) and have lower nutritional content (Aerts 1996) than leaves from deciduous trees. Second, we used maps of human accessibility, land use, and social indicators, which can potentially serve as surrogates of anthropogenic disturbance and hunting pressure (Siren et al. 2006; Brashares et al. 2001; Laurance et al. 2005). Third, we used maps of fragment size. Note that climate and elevation maps reflect local habitat quality, whereas the other maps are based on information from the neighboring municipalities and road network that surround study sites.

16.1.4.2 Regression Trees

The statistical analysis of the relationship between environmental factors and population sizes is complicated by the existence of interactions (often nonlinear) among environmental predictors. For example, forest type is known to correlate with temperature, precipitation and elevation (Oliveira-Filho and Fontes 2000). Moreover, the exact shape of these relationships is unknown. Thus, we decided to use a data mining approach that enables us to look for environmental determinants of primate density while accommodating for nonlinear interactions between predictors and which does not require the specification of the relationship between the response and the predictors. Here, we will use Random Forest, a tree regression method (Breiman 2001; Liaw and Wiener 2002). This method recently started being applied in several areas of biology involving data mining, such as bioinformatics (Pang et al. 2006) and niche modeling (Garzon et al. 2006; Prasad et al. 2006). The algorithm works by iteratively splitting the group of data points. Each tree node represents a splitting rule (e.g., "elevation $>$ 1500 m"), and nodes are followed by two branches representing the newly separated data points. More specifically, the splits are performed using the predictor variables to partition the response variable into two groups, so as to maximize the between-groups sum of squares. The output tree contains a series of branches representing the optimized sequence of splitting rules. Random Forest grows hundreds of trees, each one using a subset of the independent variables. The resulting trees are then averaged to obtain the final model, a procedure that reduces overfitting (Breiman 2001). As in other niche model and classification tools, data points are partitioned into a training set, used to construct the model, and a testing set, used to access model accuracy. For a very accessible review of regression tree methods, *see* Berk (2006).

16.2 Methods

16.2.1 Study Area

The study areas comprise four Brazilian states: São Paulo, Rio de Janeiro, Minas Gerais and Espírito Santo (Fig. 16.1). The region spans the two main Atlantic forest domains: the Atlantic rainforest and the Atlantic semideciduous forest. The former comprises areas up to 300 km inland that have high annual precipitation due to oceanic winds and mountain ranges, whereas the latter includes plateau areas with higher elevation and lower annual precipitation. For a detailed description of the forest types, *see* Oliveira-Filho and Fontes (2000).

16.2.2 Target Genera

We focus on five genera: (1) *Brachyteles* (muriqui), the largest species at 12 kg, a frugivore-folivore (Milton 1984; Strier 1991) that is distributed along the Brazilian southern states of São Paulo, Rio de Janeiro, Espírito Santo, and Minas Gerais, and the states of Paraná and Bahia; (2) *Alouatta* (howler monkey), a folivore (Glander 1978; Mendes 1989; Peres 1997) weighing 6.4 kg, distributed in the Brazilian south and all the way to the northeast along the coast; (3) *Cebus* (capuchin monkey), an insectivore-frugivore (Fragaszy et al. 2004) weighing 2.5 kg inhabiting the entire country except the extreme south; (4) *Callicebus* (titi monkey), a folivore-frugivore (Price and Piedade 2001) weighing 1.35 kg and inhabiting the Brazilian southeast, northeast and Amazon; and (5) *Callithrix* (marmoset), the smallest species at 0.30 kg. Neotropical marmosets feed on a large range of plant materials, including gums, fruits, and seeds, as well as animal preys (Correa et al. 2000). They are distributed along the Brazilian southeast, northeast and Amazon.

16.2.3 Compilation of Census Data

We compiled a list of census studies carried out between the years of 1993 and 2005 (Fig. 16.1; Table 16.1). In order to make the data comparable, we selected studies that used the line-transect technique (Buckland et al. 2001). This method basically consists of establishing transects distributed randomly or stratified according to habitat type and counting the number of individuals encountered. Information on straight-line distance to observed individuals is used to calculate the effective strip width (ESW) and estimate local density. Line-transect is considered one of the most precise census techniques and due to its simplicity and cost-effectiveness, it has been applied to census a broad range of animal and plant populations (Buckland et al. 2001). A total of 17 census studies using line-transect technique were found, and 16 were carried out within the Brazilian southeast. Out of those 16 studies, four were excluded: one study reported large within-site variation but did not provide separate density values for those sites (Hirsh et al. 1994); a second study was performed in a field site for which more recent information was available (Pinto et al. 1993); a third dataset (Chiarello 1993) reported extremely high density values for *Alouatta* in an urban park in São Paulo State. Preliminary models using this data point predict that all urban centers will have the highest howler densities. Although it is our intention to predict the impact of urbanization on primate densities, we believe that the conditions leading to the density value observed by Chiarello (1993) are probably tied to historical factors and latent variables that we are presently unable to measure. Last, we excluded data from Anchieta Island (Bovendorp and Galetti 2007) because this island has been a target of “repopulation” initiatives and several vertebrate species have been recently introduced in the area.

Table 16.2 List of GIS layers containing the independent variables used in the tree regression analysis

Variable Name	Units	Original Resolution (m)	Year(s) Data Collected	Ref.
Percent tree cover	%	500	2001	1
Mean annual temperature	Celsius * 10	800	1950–2000	2
Temperature seasonality	SD * 100	800	1950–2000	2
Total annual precipitation	mm	800	1950–2000	2
Precipitation seasonality	Coefficient of variation	800	1950–2000	2
Elevation	Meters	1000	various	3
Slope-based accessibility	Relative cost	1000	1996 (cities) and various (elevation)	3, 4
Road-based accessibility	Number of people/100,000	5000	1996 (census) and 2001 (roads)	4, 5
Industry	Number of units	Per city	1996	4
Crop area	Percent area devoted to permanent agriculture plots	Per city	1995	4
Median income	Median income for all people older than 10, in Reais	Per city	2000	4
Fragment size	Unitless (size classes from 1 to 6)	20	1999–2000	6

(1) Hansen et al. 2003; (2) Hijmans et al. 2005; (3) Danko 1992; (4) IBGE 1996; (5) DNIT 2007; (6) Eva et al. 2002.

16.2.4 GIS

For each primate genus, we obtained a grid map containing values of the dependent variable to be used in the tree regression, primate density (individuals/km^2). In order to locate study sites for which density information was available, we used a map of percent tree cover (Modis Vegetation Continuous Fields, Hansen et al. 2003), a forest inventory available for São Paulo state only (BIOTA 2006), and the figures available in the original publications. For large parks in São Paulo state, we used the location of transects buffered by a distance of 500 m. Data were pooled for small, contiguous fragments. Those fragments are (1) Sao Lourenço, Santa Lucia and Augusto Ruschi, and (2) M7 and Putiri, all of them in Espírito Santo state (*see* Chiarello 2003). In these cases, primate densities were averaged across fragments.

In addition, we obtained 12 grid maps representing the independent variables to be used in the tree regression (Table 16.2). Two grid maps are derived from least-cost path estimates used to model human movement across the landscape. The first one contains, for each cell, the number of people that can reach that cell when traveling by road for a maximum of 30 minutes. This was based on human census data for each municipality and a road network map. The model was built using the module Network Analyst within ArcGIS (ESRI, California). We assumed people departed city centroids and traveled along federal and state highways at a speed of 100 km/h. Since location of city streets and dirt roads was not available, it was assumed individuals leaving highways would travel to their final destinations along a straight line, at 50 km/h. A second grid map represents human accessibility, assuming people are moving by foot. The map contains the relative cost to reach each cell from the nearest city, assuming that cost is a function of distance and slope.

Although urban centers are obviously served by a large concentration of roads, some agricultural areas are also located near highways. In order to distinguish between these two land use types, we produced maps containing values of area devoted to agriculture, as well as degree of industrialization. In addition, a map of median income for each municipality (IBGE 1996) was produced in an attempt to obtain a surrogate for anthropogenic disturbance and/or hunting pressure. Last, forest fragments were mapped using a global land cover database (Eva et al. 2002). After excluding areas classified as "mosaic agriculture/degraded forest", the area for each fragment was calculated. We then assigned each cell with a value representing the size, in hectares, of the fragment where the cell is located. Six classes were used: (1) < 100; (2) > 100 and < 316; (3) >316 and < 1000; (4) >1000 and < 3162; (5) > 3162 and $< 159{,}000$; (6) $> 159{,}000$. All maps were rescaled to 500-m resolution. All GIS analyses were performed using ArcGIS 9.2 (ESRI, California). Map layers can be made available upon request to the first author.

16.2.5 Random Forest

The parameters used in the Random Forest run were: 3 independent variables (Table 16.2) could be used at each split; sampling was stratified, in such a way that all study areas were used to grow each tree; 500 trees were grown. After the model was run, we estimated the importance of all independent variables. Random Forest has two measures of variable importance: (i) mean percent increment in square error, calculated as the average increase in prediction error that results from shuffling the values of the predictor variable; (ii) percent increase in node impurity, the within-node variation (residual sum of squares) obtained after reshuffling values of the predictor variable (Breiman 2001; Prasad et al. 2006). Also, partial plots were constructed to study the relationship between the four most important environmental correlate and primate density. These plots are built by computing the relationship between the target predictor and the response averaged over the joint values of the other variables (Berk 2006). Last, the models were used with the entire range of values in the Brazilian southeast in order to predict density values for this region. All statistical analyses were performed in R (R Development Core Team 2007).

16.3 Results

16.3.1 General Aspects

When analyzing data for individual genera, we found no significant relationship between sampling effort (number of kilometers sampled) and density for *Alouatta* ($p = 0.76$), *Brachyteles* ($p = 0.47$), *Callicebus* ($p = 0.59$), *Cebus* ($p = 0.08$) or *Callithrix* ($p = 0.85$). For all genera, most sites were "coldspots" with lower densities and few sites were "hotspots." Within-genus variation in density reached three orders of magnitude for some genera: for *Alouatta*, density (individuals/km^2) ranges from 0.29 to 176.80 (mean ± SD: 23 ± 38, N = 20). For *Brachyteles*, density ranged from 0.42 to 35.11 (9.63 ± 11.6, N = 10). Density values for the genus *Cebus* ranged from 0.90 to 49.88 (16.63 ± 15.25, N = 23). For *Callithrix*, density ranged from 1.83 to 110.3 (22.1 ± 29.4, N = 10). Last, density for *Callicebus* ranged from 3.5 to 157 (24 ± 45.34, N = 9). When comparing among all five genera, we did not observe any significant difference in mean density (Kruskal-Wallis rank-sum test, $p = 0.09$).

16.3.2 Determinants of Primate Density

A tree regression analysis using Random Forest was performed to study the effect of 12 variables (Table 16.2) on primate density. For all genera, the model was able to explain more than 90% of the variability in the training set (*see* Section 16.1.4.2). The output models produced by Random Forest were applied to the entire Brazilian southeast region (Fig. 16.2a–e). For all genera, the five most important predictors of primate density included precipitation and temperature, although genera responded differently to these climatic variables (Table 16.3). The five genera also displayed different responses to land use. For example, an increase in the area devoted to agriculture had a positive impact on the densities of *Callicebus* spp., but a negative impact on *Alouatta* spp.; also *Cebus* spp. displayed higher densities in the vicinity of industrialized cities (Table 16.3). In most cases, partial plots revealed a monotonic increase or decrease in primate density (shown as "+" or "−" on Table 16.3), but sometimes densities peaked at intermediate conditions (in this case, actual values are shown on Table 16.3). For example, density for *Callithrix* spp. was highest at intermediate values of median income and temperature (Table 16.3).

16.4 Discussion

16.4.1 Predicted Primate Density Hotspots

The analyses carried out in the present work enable us to tease apart the effects of anthropogenic impact and forest type on densities of primate species inhabiting a highly disturbed ecosystem. For all species, densities decreased with fragment size, although this variable was not always an important predictor of primate density (Table 16.3). Accessibility by road was not an important predictor of density for any of the target genera (Table 16.3). Accessibility by foot was modeled as a function of slope (*see* Methods) and had a positive impact on *Cebus* spp., *Callithrix* spp. and *Brachyteles* spp. (Table 16.3), that is, areas considered accessible had higher primate densities. This variable is thus probably serving a substitute for slope. Overall, results suggest that patterns of land use and social indicators from municipalities where fragments are located provide better estimates of anthropogenic impact than models of human movement.

For all genera, areas with non-zero predicted density extended beyond the distribution of the species used to train the model (Fig. 16.2a–e). This was expected

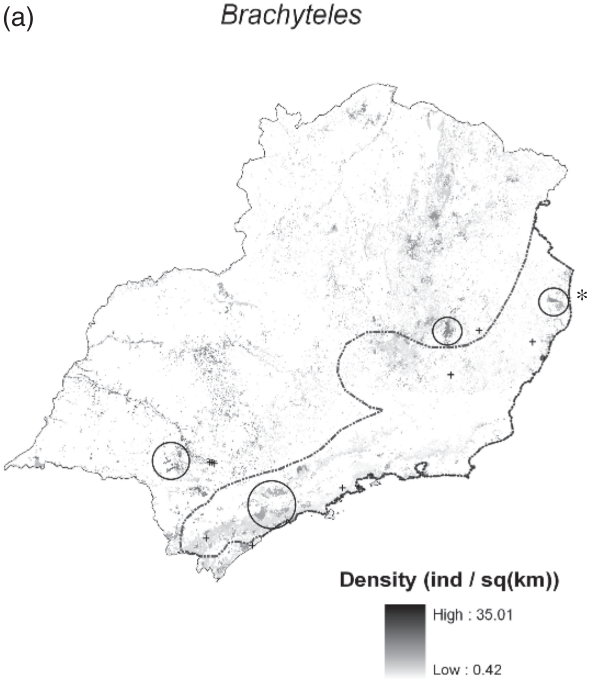
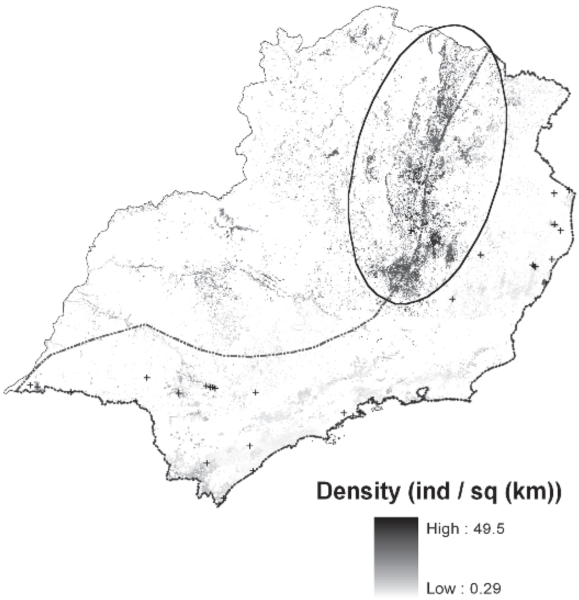


Fig. 16.2 Map of predicted densities of primates in the Brazilian southeast. Species' ranges (from Natureserve; www.natureserve.org) are delimited by an interrupted gray line, and locations of sampling points are shown by an arrow. (**a**) Muriquis (*Brachyteles* spp.). Circles show four predicated hotspots of density (from west to east): semidecididuous forest west of São Paulo, low rainforests in São Paulo State, semideciduous forest in Minas Gerais, and low rainforests in Espírito Santo muriguis are not found in the area indicated with a star (see discussion). (**b**) Howler monkeys (*Alouatta* spp.). Ellipse indicates hotspots of density in semideciduous forest in Minas Gerais. (**c**) Capuchin monkeys (*Cebus* spp.). Ellipses show four hotspots of density (from west to east): semidecididuous forest west of São Paulo state, low rainforests in São Paulo State, semideciduous forest in Minas Gerais, and low rainforests in Espírito Santo. (**d**) Titi monkeys (*Callicebus* spp.). Ellipses show predicted hotspots: Serra do Mar hill chain (*bottom*) and central Minas Gerais (*top*). (**e**) Marmosets (*Callithrix* spp.). Circle indicates predicted hotspot in Espírito Santo forest

(b) *Alouatta*



(c) *Cebus*

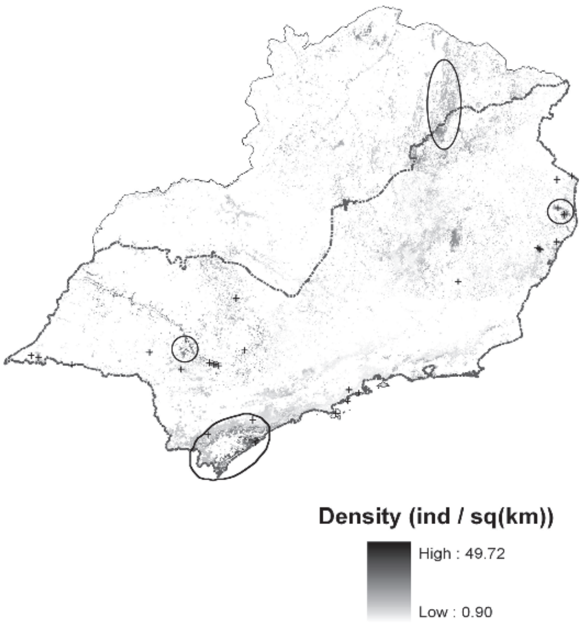
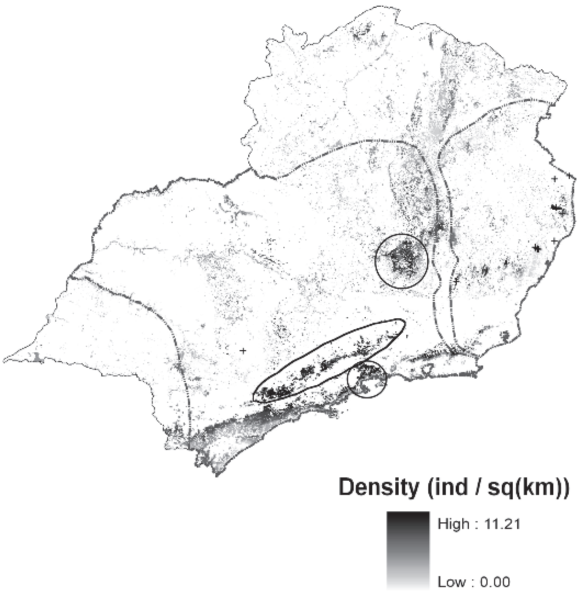


Fig. 16.2 (continued)

(d) *Callicebus*



(e) *Callithrix*

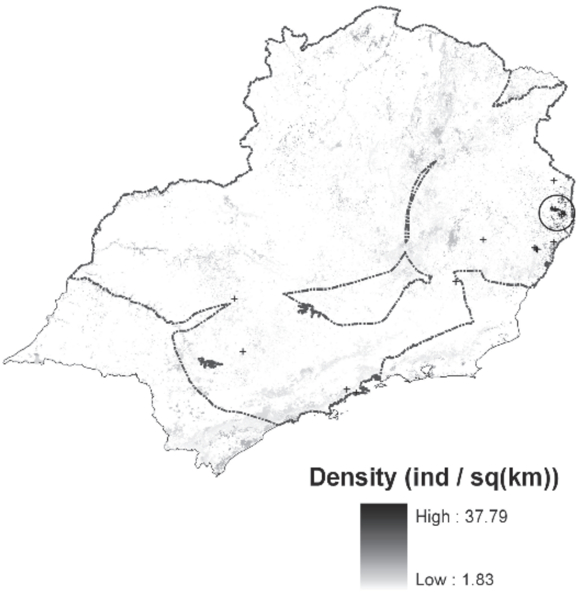


Fig. 16.2 (continued)

Table 16.3 List of the five most important determinants of primate density of five primate genera

Variable	*Brachyteles*	*Alouatta*	*Callicebus*	*Cebus*	*Callithrix*
Percent tree cover			–		
Slope-based accessibility	–				
Mean temperature		20°C	–		24°C
Variance in temperature	+			+	–
Variance in precipitation	+	+		+	
Precipitation		–	+	1400–1800 mm	1200 mm
Elevation	–			–	–
Median income	+		–		R$ 200–300
Industry				+	
Crop area		–	+		
Fragment size		3162–159000 ha			

given that models did not incorporate elements that can greatly influence range limits such as competition and historical factors. For *Callithrix* spp. and *Alouatta* spp., the Random Forest model most likely identified areas in the cerrado (the Brazilian savanna) with climate patterns similar to the Atlantic forest. The cerrado ecosystem is inhabited by primate species that have not been considered in our analyses but that nevertheless belong to the target genera studied here, such as *Callithrix penicillata* and *Alouatta caraya*. Accounts of species' ranges have changed over time, and the range maps shown here (www.natureserve.org) might not display the most current information. For example, *Callicebus* was considered present in the Paranapiacaba region (Rylands and Faria 1993; Hirsh et al. 2006), but is absent in this area (Mittermeier et al. 2008).

The largest genus, *Brachyteles*, did not display a clear preference for a particular forest type, as densities are predicted to be high in coastal zones as well as inland (Fig. 16.2a). Predicted hotspots are low, flat rainforest zones in São Paulo State as well as semideciduous forest in Minas Gerais and west of São Paulo (Fig. 16.2a). Fragments located in municipalities with low income displayed lower densities (Table 16.3). Income has been demonstrated to correlate with hunting pressure in other ecosystems (Shively 1997), although researchers differ in the procedure used to estimate income (Godoy et al. 2006) and many other factors such as employment stability might also play a large role in people's decision to consume wild meat (Siren et al. 2006). Rainforests in Espirito Santo (indicated by a star in Fig. 16.2a) are predicted hotspots. Still, these areas do not support murigui populations (Chiarello & Melo 2001). This suggests that historical factors or other unmeasured variables might be operating in Espirito Santo.

The most folivorous genus, *Alouatta*, showed a clear preference for areas with high precipitation seasonality, low annual precipitation, and high temperature seasonality (Table 16.3). Predicted hotspots are thus areas of semideciduous forest in Minas Gerais (Fig. 16.2b). This is in accordance with recent models developed for the Neotropics as a whole (Peres 1997), which showed that variation in density for *Alouatta* is largely governed by primary productivity. Fragments located in agricultural zones had lower *Alouatta* density, suggesting a negative effect of the landscape matrix that surrounds forest fragments, and/or that inhabitants of rural zones are more likely to engage in hunting activities.

The capuchin monkeys (*Cebus* spp.) showed a preference for areas with low elevation, high mean temperatures, high temperature seasonality, and high precipitation seasonality (Table 16.3). Industrialization had a positive impact on this genus, which is not surprising given its known diet flexibility and adaptability to urban habitats (Galetti and Pedroni 1994; Fragaszy et al. 2004). The hotspots for *Cebus* are low, flat areas in São Paulo and Espírito Santo, as well as semideciduous forests in São Paulo and Minas Gerais (Fig. 16.2c).

Densities for titi monkeys (*Callicebus* spp.) were higher in regions with relatively low mean temperatures, high precipitation, and in fragments embedded in agricultural zones (Table 16.3). The fact that titi monkey densities displayed a positive correlation with agriculture – as opposed to howlers – is interesting and exemplifies the importance of incorporating the landscape context on habitat suitability analyses. Although the mechanism driving these differences is not being examined here, it could be related to hunting pressure. Howlers are diurnal, extremely conspicuous species that forage in medium to large groups. On the other hand, titi monkeys are smaller canopy foragers that live in pairs, thus less likely to be spotted by poachers. The main predicted hotspots for *Callicebus* were the Serra do Mar hill chains in east São Paulo State, as well as central Minas Gerais (Fig. 16.2d). We also predicted high densities in the Paranapiacaba region, but more recent range maps for this genus indicate that it is absent in this area (Mittermeier et al. 2008).

Callithrix displays a preference for locations with intermediate values of climatic variables and income (Table 16.3). The highest estimated density values are associated with ranges of temperature and precipitation that compare favorably with studies done using presence-absence data for this genus (Grelle and Cerqueira 2006). As for the relationship between marmoset density and median income, it is possible that areas with low income have higher hunting pressure, whereas areas with high income also tend to be urbanized. In any case, social indicators proved to be better predictors of marmoset density than land use data. The predicted hotspots for *Callithrix* are the forests in Espírito Santo (Fig. 16.2e).

Overall, our analyses predict that semideciduous forests in Minas Gerais and São Paulo state have a large potential to support primate populations, despite the fact that most large forest tracts are located in the Serra do Mar and Serra da Paranapiacaba hill chains in coastal São Paulo.

16.4.2 Areas in Need of Future Research

Estimates of population sizes derived from the literature suggest that less than half of the study sites in the Brazilian southeast hold viable populations of the five genera studied here (Table 16.1). We assumed 500 individuals was the minimal viable population size (Franklin 1980), although some authors consider it an underestimate (Reed et al. 2003). In this scenario, more synthetic studies are needed to determine the drivers of primate abundance in the Brazilian Atlantic forest. We can identify three areas in need of future research. The first (and most obvious one) is the need to obtain more abundance data. Primate population studies are not yet available for states such as Santa Catarina, Rio de Janeiro, Paraná, and Bahia. These states still have large protected parks (e.g., Iguaçu, Itatiaia, Bocaina, Descobrimento, Una) that may hold large primate populations. The second issue arises in any comparative study: the need to evaluate whether some sites are more likely to violate the assumptions of the line-transect method (e.g., due to differences in forest type or topography).

Here, we encountered a main challenge when trying to scale up from local studies to landscape-scale predictions. Usually, census studies report one density estimate per forest fragment. This limits prediction in two ways: (i) extrapolation to neighboring fragments will be highly dependent on the choice of method to delineate fragment boundaries, and (ii) within-fragment environmental variation can be comparable to between-fragment variation. For example, Jacupiranga State Park covers an area of approximately 1552 km^2. In this park, slope ranges between 0 and 44%, whereas values for the entire study area range between 0 and 63%. The availability of density values associated with smaller, homogeneous areas (e.g., Buss 2001) should help bridge the gap between field studies and ecological modeling.

Finally, we found that variables such as land use and social indicators can serve as surrogates of anthropogenic impact. However, we are presently unable to tease apart the effects of hunting pressure and habitat disturbance. A wealth of socio-economic data is published by IBGE, the Brazilian Institute for Geography and Statistics (www.ibge.gov). If direct estimates of hunting pressure are made available, it would be possible to select the variables that more strongly correlate with hunting pressure.

16.5 Summary

In the present work, we focused on southeast Brazil's Atlantic forest and studied five primate genera: *Alouatta*, *Brachyteles*, *Callithrix*, *Callicebus*, and *Cebus.* After data were compiled from census studies that used the line-transect method, we applied regression trees in order to search for determinants of variation in primate density. Owing to its location in Brazil's most developed region, the Atlantic forest is not only highly fragmented, but also embedded in a landscape matrix encompassing a wide range of land use types and social contexts. Thus, the independent variables used in the regression analyses included not only surrogates of forest type (e.g., climate) and fragment size, but also data on social indicators and estimates of accessibility derived from human movement models. For all genera, we found that density was strongly influenced by forest type, and not influenced by our accessibility estimates. Interestingly, genera differed in their responses to land use and social indicators, a result that emphasizes the importance of incorporating information on the landscape matrix when performing habitat suitability analyses. The regression models produced here were used to construct maps of predicted primate density for the Brazilian southeast. Overall, the maps for all genera showed high predicted primate densities for the inland semideciduous forests, where primary productivity

is expected to be higher. Finally, we suggest that more synthetic work is needed in our study area, and list a few topics in need of research.

Acknowledgments The program BIOTA FAPESP (2001/14463-5) funded the Laboratório de Biologia da Conservação (through a grant for MG) and the census in the protected areas in São Paulo State. MG receives a research fellowship from CNPq. The Teresa Lozano Long Institute of Latin American Studies (LILAS) at Austin, TX for promoting the exchange program between MG and THK. Dr. C. Joly and F. Kronka kindly provided the digital map of vegetation types for São Paulo State. S.K. Gobbo, R.M. Marques, C. Steffler, P. Rubim, and R. Nobre provided unpublished data from their study areas.

References

Aerts, R. 1996. Nutrient resorption from senescing leaves of perennials: are these general patterns? Journal of Ecology 84, 597–608.

Alves, A.C.R., Ribeiro L.F., Haddad C.F.B., and dos Reis, S.F. 2006. Two new species of *Brachycephalus* (Anura: Brachycephalidae) from the Atlantic forest in Parana state, southern Brazil. Herpetologica 62, 221–233.

Berk, R. A. 2006. An introduction to ensemble methods. Sociological Methods and Research 34, 263–295.

Bernardo C.S., and Galetti, M. 2004. Densidade e tamanho populacional de primatas em um fragmento florestal no sudeste do Brasil. Revista Brasileira de Zoologia 21, 827–832.

BIOTA 2006. Atlas Sinbiota: http://sinbiota.cria.org.br/index.

Bovendorp, R.S., and Galetti, M. 2007. Density and population size of mammals introduced on a land-bridge island in southeastern Brazil. Biological Invasions 9, 353–357.

Brashares, J.S., Arcese, P., and Sam, M.K. 2001. Human demography and reserve size predict wildlife extinction in West Africa. Proceedings of the Royal Society of London Series B-Biological Sciences 268, 2473–2478.

Breiman, L. 2001. Random Forests. Machine Learning 45, 5–32.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B, Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., and Hilton-Taylor, C. 2000. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 909–923.

Brown, J.H., Mehlman, D.W., and Stevens, G.C. 1995. Spatial variation in abundance. Ecology 76, 2028–2043.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling*, Oxford University Press, Oxford.

Buss, G. 2001. Estudo da densidade populacional do bugio-ruivo *Alouatta guariba clamitans* (Cabrera, 1940) (Platyrrhini, Atelidae) nas formacoes florestais do morro do campista, Parque Estadual de Itapua, Viamao, RS. Master Thesis. Universidade Federal do Rio Grande do Sul, Brazil.

Câmara, I.G. 2003. Brief history of conservation in the Atlantic forest. In: I. Gusmao-Camara and C. Galindo-Leal (Eds.), *The Atlantic Forest of South America. Biodiversity Status, Threats, and Outlook.* Island Press, Washington, pp. 31–42.

Chiarello, A.G. 1993. Home range of the brown howler monkey, *Alouatta fusca*, in a forest fragment in southeastern Brazil. Folia Primatologica 60, 173–175.

Chiarello, A.G. 2000. Density and population size of mammals in remnants of Brazilian Atlantic Forest. Conservation Biology 14, 1469–1657.

Chiarello, A.G. 2003. Primates of the Brazilian Atlantic forest: the influence of forest fragmentation on survival. In: L.K. Marsh (Ed.), *Primates in Fragments. Ecology and Conservation*. Kluwer Academic, New York, pp. 99–121.

Chiarello, A.G., and Melo, F.R. 2001. Primate population densities and sizes in Atlantic forest remnants of northern Espírito Santo, Brazil. International Journal of Primatology 22, 379–395.

Coley, P.D. 1983. Herbovory and defense characteristics of tree species in a lowland tropical forest. Ecological Monographs 53, 209–233.

Correa, H.K.M., Coutinho, P.E.G., and Ferrari, S.F. 2000. Between-year differences in the feeding ecology of highland marmosets (*Callithrix aurita* and *Callithrix flaviceps*) in south-eastern Brazil. Journal of Zoology 252, 421–427.

Cosenza, B.A.P, and Melo, F. 1998. Primates of the Serra do Brigadeiro State Park, Minas Gerais, Brazil. Neotropical Primates 6, 18–20.

Cullen Jr., L., Bodmer, R.E., and Valladares-Padua, C.V. 2001. Ecological consequences of hunting in Atlantic forest patches, São Paulo, Brazil. Oryx 35, 137–144.

Danko, D.M. 1992. Digital chart of the world. GeoInfo Systems 29–36.

Dean, W. 1996. *A Ferro e Fogo: A História e a Devastação da Mata Atlântica Brasileira.* Companhia das Letras, São Paulo.

DNIT 2007. Atlas das estradas do Brasil. www.dnit.br

Donha, C.G., and Eliasaro, S. 2006. Two new species of *Parmotrema* (Parmeliaceae, lichenized ascomycota) from Brazil. Mycotaxon 95, 241–245.

Eva, H.D., Miranda, E.E., Bella, C.M., Gond, V., Huber, O., Sgrenzaroli, M., Jones, S., Coutinho, A., Dorado, A., Guimaraes, M., Elvidge, C., Achard, F., Belward, A.S., Bartholome, E., Baraldi, A., Grandi,G., Vogt, P., Fritz, S., and Hartley, A. 2002. A vegetation map of South America. EUR 20159, European Commission, Joint Research Centre.

Fragaszy, D.M., Visalberghi, E., and Fedigan, L.M. 2004. Behavioral ecology: how to capuchins make a living? In: D.M. Fragaszy, E. Visalberghi, L.M Fedigan (Eds.), *The Complete Capuchin: the Biology of the Genus Cebus.* Cambridge University Press, Cambridge, UK, pp. 36–54.

Franklin, I.R. 1980. Evolutionary change in small populations. In: M.E. Soule and B.A. Wilcox (Eds.), *Conservation Biology: an Evolutionary-Ecological Perspective.* Sinauer, Sunderland, MA, pp. 135–150.

Galetti, M., and Pedroni, F. 1994. Diet of capuchin monkeys (*Cebus apella*) in a semideciduous forest in South-east Brazil. Journal of Tropical Ecology 10, 27–39.

Garzon, M.B., Blazek, R., Neteler, M., Sanchez de Dios, R., Ollero, H.S., and Furlanello, C. 2006. Predicting habitat suitability with machine learning models: the potential area of *Pinus silvestris* L. in the Iberian peninsula. Ecological Modeling 197, 383–393.

Glander, K.E. 1978. Howler monkey feeding behavior and plant secondary compounds: a study of strategies. In: G.C. Montgomery (Ed.), *The Ecology of Arboreal Folivores*. Smithsonian Press, Washington, pp. 561–574.

Godoy, R., Wilkie, D.S., Reyes-Garcia, V., Leonard, W.R., Huanca, T., McDade, T., Valdez, V., and Tanner, S. 2006. Human body-mass index (weight in kg/stature in m(2)) as a useful proxy to assess the relation between income and wildlife consumption in poor rural societies. Biodiversity and Conservation 15, 4495–4506.

Grelle, C.E., and Cerqueira, R. 2006. Determinantes da distribuicao geografica de *Callithrix flaviceps* (Thomas) (Primates, Callitrichidae). Revista Brasileira de Zoologia 23, 414–420.

Hansen, M.R., DeFries, R., Townshend, J. R., Carroll, M., Dimiceli, C., and Sohlberg, R. 2003. Vegetation Continuous Fields, MOD44B, 2001 percent tree cover, collection 3. University of Maryland, College Park, Maryland.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25, 1965–1978.

Hirota, M.M. 2003. Monitoring the Brazilian Atlantic forest cover. . In: I. Gusmao-Camara and C. Galindo-Leal (Eds.), *The Atlantic Forest of South America. Biodiversity Status, Threats, and Outlook.* Island Press, Washington, pp. 60–65.

Hirsh, A. 1995. Censo de *Alouatta fusca* Geoffroy, 1812 (Platyrrhini, Atelidae) e qualidade do habitat em dois remanescentes de Mata Atlantica em Minas Gerais. Master Thesis. Universidade Federal de Minas Gerais.

Hirsh, A., Dias, L.G., Martins, L.O., Resende, N.A.T. and Landau, E.C. 2006. Database of Georeferenced Occurrence Localities of Neotropical Primates. Department of Zoology, UFMG, Belo Horizonte. http://www.icb.ufmg.br/zoo/primatas/home_bdgeoprim.htm

Hirsh, A., Subira R., and Landau, E.C. 1994. Levantamento de primatas e zoneamento das matas da regiao do Parque Estadual do Ibitipoca, Minas Gerais, Brasil. Neotropical Primates 2, 4–6.

IBGE 1996, 2000. Instituto Brasileiro de Geografia e Estatistica. www.ibge.gov.br

IUCN 2006. Red List of Threatened Species. http://www.iucn.org/themes/ssc/redlist.htm

Laurance, W.F., Croes, B.M., Tchignoumba, L., Lahm, S.A., Alonso, A., Lee, M.E., Campbell, P., and Ondzeano, C. 2005. Impacts of roads and hunting on central African rainforest mammals. Conservation Biology 20, 1251–1261.

Levin, SA 1992. The problem of pattern and scale in ecology. Ecology 73, 1943–1967.

Liaw, A., and Wiener, M. 2002. Classification and regression by random Forest. R News 2, 18–22.

Marsden, S.J., Whiffin, M., Galetti, M. and Fielding, A.H. 2005. How well will Brazil's system of atlantic forest reserves maintain viable bird populations? Biodiversity and Conservation 14, 2835–2853.

Martins, M.M. 2005. Density of primates in four semideciduous forest fragments of São Paulo, Brazil. Biodiversity and Conservation 14, 2321–2329.

Mendes, S.L. 1989. Estudo ecologico de *Alouatta fusca* (Primates: Cebidae) na Estacao Ecologica Caratinga. Revista Nordestina de Biologia 6, 71–104.

Milton, K. 1984. Habitat, diet, and activity patterns of free-ranging woolly spider monkeys (*Brachyteles arachnoides* E. Geoffroy 1806). International Journal of Primatology 5, 491–514.

Michalski, F., and Peres, C.A., 2005. Anthropogenic determinants of primate and carnivore local extinctions in a fragmented forest landscape in southern Amazonia. Biological Conservation 124, 383–396.

Mittermeier R., Coimbra-Filho, A.F., Kierulff, M.C.M., Rylands, A.B., Pissinatti, A, and Almeida, L.M. 2008. Monkeys of the Atlantic Forest of Eastern Brazil. Pocket Identification Guide. Conservation International, Brazil.

Oliveira-Filho, A.T., and Fontes, M.A.L. 2000. Patterns of floristic differentiation among Atlantic forests in southeastern Brazil and the influence of climate. Biotropica 32, 793–810.

Pang, H., Lin, A., Holford, M., Enerson, B.E., Lu, B., Lawton, M.P., Floyd, E., and Zhao, H. 2006. Pathway analysis using random forests classification and regression. Bioinformatics 22, 2028–2036.

Peres, C.A. 1997. Effects of habitat quality and hunting pressure on arboreal folivore densities in Neotropical forests: a case study of howler monkeys (*Alouatta spp.*). Folia Primatologica 68, 199–222.

Pinto, L.P.S., Costa, C.M.R., Strier, K.B., and Fonseca, G.A.B. 1993. Habitat, density, and group size of primates in a Brazilian tropical forest. Folia Primatologica 61, 135–143.

Pontes, A.R.M., Malta, A., and Asfora, P.H. 2006. A new species of capuchin monkey, *Cebus* (Cebidae, Primates): found at the very brink of extinction in the Pernambuco endemis centre. Zootaxa 1200, 1–12.

Prasad, A.M., Iverson, L.R. and Liaw, A. 2006. Newer classification and regression tree techniques: bagging and random forests for ecological prediction. Ecosystems 9, 181–199.

Price E.C., and Piedade H.M. 2001. Diet of northern masked titi monkeys (*Callicebus personatus*). Folia Primatologica 72, 335–338.

R Development Core Team 2007. R: a language and environment for statistical computing. http://www.R-project.org

Reed, D.H., O'Grady, J.J., Brook, B.W., Ballou, J.D., and Frankham, R. 2003. Empirical estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation* 113, 23–34.

Romanini de Oliveira, R.C., Coelho, A.S. and Melo, F.R. 2003. Estimativa de densidade e tamanho populacional de saua (*Callicebus nigrifons*) em um fragmento de mata em regeneracao, Vicosa, Minas Gerais. Neotropical Primates 11, 91–94.

Rylands, A.B., and Faria, D.S. 1993. Habitats, feeding ecology, and home range size in the genus *Callithrix*. In: A.B. Rylands (Ed.), *Marmosets and Tamarins: Systematics, Behavior, and Ecology*. Oxford University Press, Oxford, UK, pp. 262–272.

Rylands, A.B., Coimbra-Filho, A.F., and Mittermeier R.A. 1993. Systematics, geographic distribution, and some notes on the conservation status of the Callitrichidae. In: A.B. Rylands (Ed.), *Marmosets and Tamarins: Systematics, Behavior, and Ecology*. Oxford University Press, Oxford, UK, pp. 11–77.

Shively, G.E. 1997. Poverty, technology, and wildlife hunting in Palawan. Environmental Conservation 24, 57–63.

Siren, A.H., Cardenas, J.C., and Machoa, J.D. 2006. The relationship between income and hunting in tropical forests: an economic experiment in the field. Ecology and Society 11, 44.

Strier, K.B. 1991. Diet in a group of woolly spider monkeys, or muriquis (*Brachyteles arachnoides*) American Journal of Primatology 23, 113–126.

Strier, K.B. 2000. Population viabilities and conservation implications for muriquis (*Brachyteles arachnoides*) in Brazil's Atlantic forest. Biotropica 32, 903–913.

Trevelin, L.C. 2006. Aspectos da ecologia do saua (*Callicebus nigrifons*) no Parque Estadual da Cantareira, SP. Master Thesis. Universidade Estadual Paulista Julio de Mesquita Filho (UNESP).

Wiens, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3, 385–397