Reserve Selection Based on Vegetation in the Brazilian Atlantic Forest

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Abstract

Brazilian Atlantic Forest is recognized as a hottest hotspot of biodiversity, and plant endemism is a key criterion used to this definition. In this biome, although geographic range of most plant species is unknown, it is possible to define limits of vegetation types. Here we performed a reserve selection analysis using vegetation types for Brazilian Atlantic Forest, more specifically in Rio de Janeiro State. The area of 19 vegetation types was calculated in each of the 5 km × 5 cells km superimposed to the Rio de Janeiro State. The representation targets established in the reserve selection procedure was 30% of the total area for more common vegetation types, and a higher target was established for rare vegetation types. The final network that represents all the targets for vegetation types with the smaller possible number of cells contains 351 cells. Many cells selected are coincident with current strictly protected areas, but this study shows the urgency to increase the number of protected areas mainly in the North and Northeast regions of Rio de Janeiro State. Twenty three cells are coincident with priority areas indicated to be created as strictly use reserves by a government agency. However, there are several important cells selected in our analysis that are not covered by the actual strictly reserves system. Four vegetation types are not represented in the current strict use reserve system. Further analyses based on vegetation could be blended with scattered data of species geographic distribution to obtain more comprehensive results and strategies.

Key words: Complementarity, Conservation Planning, Rio de Janeiro State, Protected Areas.

Introduction

What to protect? This emblematic question launched years ago (Margules & Pressey 2000; Vane-Wright *et al.* 1991) persist and it is hard to answer. As a multidisciplinary area, Conservation Biology has many goals and approaches to conservation planning. What are the best targets or biodiversity information to work is an open question and theme for intense debates (see Pressey & Bottrill 2009 and references therein for a recent discussion on this theme). However, a unifying point is that resources destined to conservation are limited, and should be used to minimize the reduction of natural areas and the loss of species and ecosystem services. Therefore, principles of systematic conservation planning should be used, including reserve

selection (Margules & Pressey 2000). This planning is urgent in regions with many endemic species, and under a high pressure of habitat reduction and fragmentation.

Brazilian Atlantic Forest (BAF) is recognized as a hottest hotspot of biodiversity (Myers *et al.* 2000) and it is a matter of many published articles on population viability (e.g. Brito & Grelle 2004, 2006), effects of habitat reduction (e.g. Brooks *et al.* 1999; Grelle *et al.* 1999, 2005) and effects of habitat fragmentation (e.g. Chiarello 1999; Pires *et al.* 2002; Pardini *et al.* 2005; Metzger *et al.* 2009; Vieira *et al.* 2009). This biome has more articles on Conservation Biology than any other Brazilian biome (Grelle *et al.* 2009). However, besides scientific knowledge and the many initiatives for conservation (e.g. Galindo-Leal & Câmara 2003; Rocha *et al.* 2006) articles on conservation planning is lacking. Only gap analysis performed (Paglia *et al.* 2004; Vicente *et al.* 2009) are not sufficient to answer the questions for conservation planning. Thus, there is not synthesis for this biome, except a recent study of reserve selection with endemic primates

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(Pinto & Grelle 2009a). It is important to note that in Brazil there are some governmental and NGOs (non-governmental organizations) conservation planning works used to guide conservation actions (Brasil 2007), although they are not published in scientific journals.

Regarding data availability, for many tropical regions Linnean and Wallacean shortfalls could preclude further analyses using species data. In Brazilian Atlantic Forest our knowledge about taxonomic and distributional range is limited to vertebrate species (see Silva & Casteletti 2003). We don't know the geographic range of plants, but we know the limits of vegetation types. This question is not new, and an alternative is to run analysis based on landscape structure parameters (Lindenmayer *et al.* 2008) such as vegetation. Here we performed a reserve selection analysis using vegetation types for Brazilian Atlantic Forest, specifically in Rio de Janeiro State. Currently BAF presents between 11.4 to 16% of original forest cover, severely fragmented in small remnants (Ribeiro *et al.* 2009), where only 2% is under strictly protected areas (Pinto *et al.* 2006). Originally, the Rio de Janeiro State had a total cover of Atlantic Forest vegetation types, which is now restricted to about 20%. The current strictly protected area network sums 272.745 ha, and inside these reserves 77% are vegetated areas (Fidalgo *et al.* 2009). In addition, this reserve system, that represents only about 6% of Rio de Janeiro original vegetation, seems not to be well distributed among the vegetation types.

The reserve selection approach applied in this study is based on the complementarity concept. Reserve selection problems are actually solved using algorithms based on the complementarity concept (Margules & Pressey 2000; Margules *et al.* 1988; Kirkpatrick 1983). Complementarity is a measure of the relative contribution of an area to the meet the representation targets of biodiversity elements (considered in the study) not yet completely represented in a network (Margules & Pressey 2000; Pressey *et al.* 1993). An area has a high complementarity value when it has a lot of elements not included in other areas already selected. So, this concept is directly related to the beta diversity concept or turnover in the spatial diversity.

Material and Methods

Vegetation cover data were based on Brazilian Atlantic Forest Biome remnant vegetation map produced by the Brazilian Ministry of the Environment – MMA (Cruz *et al.* 2007, downloaded from www.mma.gov.br, accessed on 2008). This map was constructed by an object-based image analysis and supervised classification based mostly on TM/Landsat-5, reference year 2002. The mapping scale presents a meso-scale detail (1:250,000) in vector format. This land cover map depicts classes representing vegetated (vegetation types) and non-vegetated (e.g. urban, pasture, agricultural, silvicultural, rocky outcrops, dunes) covers. In this study only the vegetated classes were considered and

the classification of vegetation types was based on IBGE classification system for Brazilian vegetation (Veloso *et al.* 1992). Individual maps were produced for each vegetation type at a regional scale, clipped by the geographical extent of the Rio de Janeiro State.

A grid formed by cells with 5×5 km of spatial resolution was superimposed to the State of Rio de Janeiro. Because some cells are not entirely filled with the area of the state (those on the edge of the state), only the cells with at least 25% of its area filled with the Rio de Janeiro State were kept in the grid. The final grid contained 2,306 cells. These cells are our units of analysis, in which all data were organized.

The grid was superimposed to vegetation maps in order to calculate the area (hectares) occupied in each of 2,306 cells by each vegetation type. To assure accurate area calculation, the map of each vegetation type was previously projected to a cylindrical equal area projection under South America 1969 datum.

The reserve selection procedure was done using the simulated annealing algorithm, implemented through the software SITES (Andelman *et al.* 1999; Possingham *et al.* 2000, 2006). The algorithm was runned 200 times with 10,000,000 iterations. This algorithm is based on the complementarity concept. It works first selecting a network of random cells, than it proceeds adding, excluding or just changing cells randomly and computing the cost function at each iteration (Andelman *et al.* 1999). This guarantees that it will find the network with the smaller possible number of cells that can represent all the targets stated (Possingham *et al.* 2006). The targets can be stated for each component of the biodiversity being analysed.

Since we used abundance (area occupied in the cell) data for 19 vegetation types in this study, different targets were stated for each of them. For those vegetation types that have a larger total area in the state (more than 3,000 ha), our target was to represent at least 30% of its total area. This threshold was chosen because above 30% of habitat cover the spatial configuration of remnants is expected to play a minor role than the total habitat area for biodiversity persistence in the landscapes (Andrn 1994). Besides, as the remnant vegetation cover in Brazilian Atlantic Forest Biome is highly reduced and fragmented, a threshold below 30% could result in a very low habitat area target. For the vegetation types with total area between 2,000 and 3,000 ha, our target was to represent at least 1,000 ha (if we used 30% as target, the minimum area to be represent would be too small). And for the vegetation types that have a smaller total area than 700 ha, our target was to represent all of it.

Protected areas data (only strictly protected areas – similar of categories I–IV of IUCN) were downloaded from www.ibama.gov.br, accessed on 2008. Priority areas data (Brasil 2007) were downloaded from www.mma.gov.br, accessed on 2009.

Results

There are 19 vegetation types that currently occur in the State of Rio de Janeiro, divided in six main vegetation classes, grouping several physiognomically and floristically distinct types: 1) evergreen forests; 2) semi-deciduous forests; 3) pioneer formations, swamps, marshes, mangroves, and “*restinga*” (lowland vegetation on Quaternary sandy soils near the coast); 4) refuges, “*campos de altitude*” (highland herbaceous vegetation on rocky soils); 5) savanna; and 6) estepic savanna. All of them belong to the Brazilian Atlantic Forest Biome (Table 1).

The vegetation types with the widest distribution are the FODM (*Floresta Ombrófila Densa Montana*, Montane Evergreen Dense Forest), which occurs in 743 cells totaling 496,223 ha, and FODSM (*Floresta Ombrófila Densa Submontana*, Submontane Evergreen Dense Forest), that occurs in 753 cells in an area of 359,639 ha. The smallest vegetation type distribution corresponds to SEGL (*Savana Estépica Gramíneo-Lenhosa*, Herbaceous-Arbustive Estepic Savanna), occupying only two cells in 168 ha. Another vegetation types with very restrict distribution are SEF

(*Savana Estépica Florestada*, Arboreous Estepic Savanna), and FESA (*Floresta Estacional Semidecidual Aluvial*, Aluvial Semi-deciduous Forest), with 487 and 463 ha in three and 21 cells, respectively. Two vegetation types have more than 200,000 ha and the most of them have less than 25,000 ha in area in the State of Rio de Janeiro, which generates a frequency distribution skewed to right (Figure 1).

The richness pattern of the vegetation types is presented in Figure 2a. There is not a clear and homogeneous spatial gradient, and the richest cells have a scatter distribution along the study region. However, there is a great cluster of rich cells located at the east region and another two small clusters in the south and southwest coasts. From the 2,306 grid cells, just nine cells are composed of six vegetation types and five cells contain five vegetation types. Cells with no vegetation types (n = 132) correspond to anthropic areas converted to urban, agriculture or pasture use. Poor cells result from a range of different situations. At one end, all the area of the cell is composed of just one type of vegetation. In the other end, a small portion of the cell is composed of one vegetation type, and most of it is converted to anthropic use.

Table 1. Vegetation type, number of grid cells and total occurrence area (hectares) of each vegetation type, area (hectares) of each vegetation type under Strictly Protected Areas, number of grid cells, represented area (hectares) of each vegetation type and proportion of the total area represented in the final solution.

Vegetation	N. cells	Total area (ha)	Area under SPAs (ha)	N. repres. cells	Repres. area (ha)	% repres.
FODM	743	496,223	129,716	150	148,874	30.00
FODSM	753	359,639	63,618	144	108,154	30.07
FESM	586	113,030	0	71	33,991	30.07
FPIM	201	104,964	14,632	26	31,552	30.06
FESS	803	101,406	1,811	71	30,593	30.17
FODTB	505	62,901	5,992	67	18,974	30.16
FPIFM	180	46,291	2,490	21	13,922	30.07
FODAM	91	23,002	15,923	17	7,367	32.03
FPIFL	151	16,759	801	16	5,217	31.13
FESTB	204	16,303	604	27	4,901	30.06
FODA	155	5,767	352	15	1,751	30.37
RAM	21	3,483	3,031	5	1,265	36.33
SGL	36	2,925	110	5	1,024	35.02
SF	59	2,166	35	6	1,103	50.90
RM	58	2,005	534	9	1,007	50.23
RSM	39	656	84	39	656	100.00
SEF	3	487	0	3	487	100.00
FESA	21	463	0	21	463	100.00
SEGL	2	168	0	2	168	100.00

FODM: Montane Evergreen Dense Forest; FODSM: Submontane Evergreen Dense Forest; FESM: Montane Semi-deciduous Forest; FPIM: Pioneer Formation with Marine Influence, “*restinga*” vegetation; FESS: Submontane Semi-deciduous Forest; FODTB: Lowland Evergreen Dense Forest; FPIFM: Pioneer Formation with Fluviomarine Influence, mangroves and marshes; FODAM: High-Montane Evergreen Dense Forest; FPIFL: Pioneer Formation with Fluvial Influence, swamps; FESTB: Lowland Semi-deciduous Forest; FODA: Aluvial Evergreen Dense Forest; RAM: High-Montane Refuges, “*campos de altitude*” vegetation; SGL: Herbaceous-Arbustive Savanna; SF: Arboreous Savanna; RM: Montane Refuges, “*campos de altitude*” vegetation; RSM: Submontane Refuges, “*campos de altitude*” vegetation; SEF: Arboreous Estepic Savanna; FESA: Aluvial Semi-deciduous Forest; SEGL: Herbaceous-Arbustive Estepic Savanna.

Figure 1. Area (vertical bars) and number of cells (numbers above the bars) of the different vegetation types that occur along the 2,306 grid cells along the State of Rio de Janeiro FODM: Montane Evergreen Dense Forest; FODSM: Submontane Evergreen Dense Forest; FESM: Montane Semi-deciduous Forest; FPIM: Pioneer Formation with Marine Influence, “restinga” vegetation; FESS: Submontane Semi-deciduous Forest; FODTB: Lowland Evergreen Dense Forest; FPIFM: Pioneer Formation with Fluvio-marine Influence, mangroves and marshes; FODAM: High-Montane Evergreen Dense Forest; FPIFL: Pioneer Formation with Fluvial Influence, swamps; FESTB: Lowland Semi-deciduous Forest; FODA: Aluvial Evergreen Dense Forest; RAM: High-Montane Refuges, “campos de altitude” vegetation; SGL: Herbaceous-Arbustive Savanna; SF: Arboreous Savanna; RM: Montane Refuges, “campos de altitude” vegetation; RSM: Submontane Refuges, “campos de altitude” vegetation; SEF: Arboreous Estepic Savanna; FESA: Aluvial Semi-deciduous Forest; SEGL: Herbaceous-Arbustive Estepic Savanna.

There are few cells with the more restricted vegetation types (Figure 2b). Most of them ($n = 2,127$) have no occurrence of these rare vegetation types. We considered restricted vegetation type those that occupy a total area smaller than 30,000 ha. According this cut level, seven vegetation types are signed as rare: SEGL (*Savana Estépica Gramíneo-Lenhosa*): Herbaceous-Arbustive Estepic Savanna; SEF (*Savana Estépica Florestada*): Arboreous Estepic Savanna; FESA (*Floresta Estacional Semidecidual Aluvial*): Aluvial Semi-deciduous Forest; RM (*Refúgio Montano*) Montane Refuges; RSM (*Refúgio Submontano*) Submontane Refuges; SF (*Savana Florestada*): Arboreous Savanna; and SGL (*Savana Gramíneo-Lenhosa*): Herbaceous-Arbustive Savanna. Only one cell has three different rare vegetation types and it is located at the east region of the state. This is the region where can be observed most of the rare grid cells. A total of 37 cells contain two rare vegetation types and 141 cells contain just one type, and they are sparsely distributed along the study region.

The final network that represents all vegetation types with the smaller possible number of cells contains 351 cells (Figure 3). This solution meets all the targets stated for each vegetation type (Table 1). The cells selected in the network have a scatter distribution along the study region, but there are two clusters of selected cells located in eastern and southwestern portions of the Rio de Janeiro State. The strictly protected areas that occur in this state generally include at least one area indicated as priority area in our network solution. However, there are several important cells selected in our analysis that are not covered by the actual strictly reserves system.

Discussion

The total territory of Rio de Janeiro State was originally covered by vegetation types of Brazilian Atlantic Forest. Nowadays, the remnants sum only a fifth of this coverage, located mainly in montane regions, surrounding by a matrix of anthropogenic areas converted to rural and urban use on more flat and accessible regions (see Vieira *et al.* 2009).

Currently, Rio de Janeiro State presents more than 20 strictly protected areas that were created independently, and together represent only about 6% of Rio de Janeiro original vegetation. It is easy to note that most of them are located in the mountains in regions with many cliffs, valleys and riverheads, as many of these were created for water source insurance and scenic beauty preservation. In fact, the most represented vegetation types in strictly protected areas are FODM (Montane Evergreen Dense Forest) and FODSM (Submontane Evergreen Dense Forest). The vegetation types not represented in any of the current strictly protected areas are FESM (Montane Semi-deciduous Forest), FESA (Aluvial Semi-deciduous Forest), SEF (Arboreous Estepic Savanna), and SEGL (Herbaceous-Arbustive Estepic Savanna).

We found a single final reserve selection solution, and the type of data (abundance based on area occupied in each cell), targets stated (with at least 30% of its total area) and rarity of some vegetation types certainly contributed to this unique result. Abundance data crossed with abundance targets turns it more difficult to find solutions with the minimum number of cells. Reserve networks solutions for biodiversity (species or vegetation types) representation using presence-absence data are generally more flexible. The representation target for the rarer vegetation types

Figure 2. a) Richness pattern (number of) and b) rarity pattern (number of restricted) of the vegetation types along the 2,306 grid cells with 5 × 5 km of resolution in the State of Rio de Janeiro. The cells with black outline are the ones included in the final reserve selection solution.

Figure 3. The final reserve selection solution containing 351 cells is represented with black outline. The green polygons are current strictly protected areas (CSPA) and red polygons are priority areas indicated to be created as strictly use reserves (Brasil 2007) in the State of Rio de Janeiro.

was to represent all of them, which also restricts the final solution.

An interesting result is the role of strictly protected areas to conserve the types of vegetation in spite of the level of forest reduction. Actually forest cover in Rio de Janeiro State is scattered and fragmented in more than 10,000 remnants (most < 100 ha) (Fidalgo *et al.* 2009). Many cells selected are coincident with current strictly protected areas (112 of the 351 cells selected, Figure 3), but this study shows the urgency to increase the number of protected areas in the North and Northeast regions of Rio de Janeiro State (Figure 3). Twenty three of the 351 cells are coincident with priority areas indicated to be created as strictly use reserves by a government agency (Brasil 2007, Figure 3). In addition there is rare vegetation types (Figure 2b) not represented in the current strict use reserve system (compare Figure 2b and 3) that are scattered along the entire state. These additional protected areas will be crucial to protect vegetation types with restrict distribution like SEF, SEGL, FESA and FODTB, all of them poorly represented in strictly protected areas network established in Rio de Janeiro State.

Curiously, analysis of reserve selection using vegetation is less common than these analyses using species data. Applying approaches based on broad filter information as land classification and vegetation units can be more advantageous from a data coverage and availability point

of view. However, such strategies have been often criticized by their limited representation of endangered or threatened species requirements (Meynard *et al.* 2009). On the contrary, approaches based on individual species distributions are often data hungry and can be prohibitive in many regions that lack the minimum requirements of occurrence data. Furthermore, this kind of strategy have been often criticized for the biases related to sampling more common taxa and the many uncertainties related to distribution maps (Meynard *et al.* 2009). There is a long discussion about whether reserves selected using vegetation types represent species biodiversity data (Brooks *et al.* 2004). For instance, in a review of articles on reserve selection in South America, Pinto & Grelle (2009b) found only one indexed article that uses vegetation types as target (Sarkar *et al.* 2004), although there are other non-indexed reserve selection studies done in Brazil (*e.g.* Albernaz & Souza 2007). Anyway, vegetation data are widely available for many biomes (including Brazilian Atlantic Forest) and should also be used to perform reserve selection. In addition, analysis based on vegetation could be blended with scattered data of species geographic distribution (mainly vertebrates) to obtain more comprehensive results (see Meynard *et al.* 2009). A possible avenue is to improve the concept of landscape-species (see Cunha & Grelle 2008) and adding this approach to systematic planning of this biome.

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