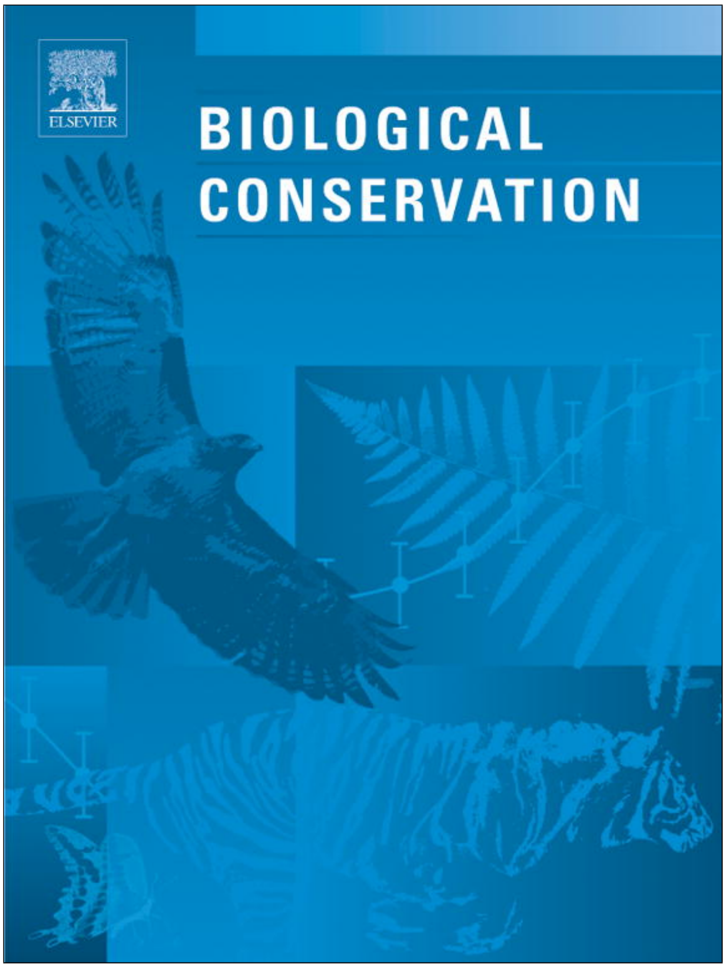

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The importance of using sustainable use protected areas for functional connectivity

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ABSTRACT

Functional connectivity, which represents the animal movement responses to landscape elements, should be considered when configuring protected areas. Each habitat patch has a different contribution to functional connectivity. Functional connectivity can be accessed through the Integral Index of Connectivity (IIC), which considers the habitat patch size, the amount of flux arriving to that patch, and the topological position of the patch within the habitat patch network. These four measures can be used as distinct criteria of functional connectivity to prioritise habitat patches. We analyzed how the spatial patterns of habitat patches varied according to these criteria. For each criterion, we ranked all habitat patches within five levels of importance, and identified whether priority habitat patches are protected. We found a positive relationship between the level of importance and the presence of core areas and corridors. Stepping stones presented the opposite relationship. For each criterion, only the highest levels of importance presented more core areas than connector areas (corridors and stepping stones). In the higher level of importance, core areas are mostly under strictly protected areas (IUCN categories I–IV), while connector areas are under the less restrictive category of sustainable use protected areas (SUAs, IUCN category V). Brazilian decision makers must consider the opportunity to protect connector areas under restrictive SUAs categories, such as Private Natural Heritage Reserve (IUCN category IV). Combine IIC and spatial patterns of habitat patches proved to be helpful to identify priority habitat patches for conservation and to indicate which class/category of protected areas should be established.

1. Introduction

Currently, one of the main strategies used to reduce habitat loss and fragmentation involves the establishment of protected areas (Rylands and Brandon, 2005; Lindenmayer et al., 2006). According to the World Conservation Union's (IUCN) protected areas system, there are two major classes of protected areas: strictly protected areas (hereafter called SPAs, categories I–IV) and sustainable use protected areas (hereafter called SUAs, categories V–VI). The main goal of SPAs is to protect biodiversity, while SUAs must conciliate conservation and economic activities (Locke and Dearden, 2005). Because protected areas are a critical component of conservation biology, it is necessary to choose the appropriate location, class and category of a protected area based on the conservation goals and targets defined by decision makers, and to consider the social and economic contexts surrounding these areas (Locke and Dearden, 2005; Lindenmayer et al., 2008). Several principles for biodiversity conservation have been proposed to indicate which sites must be protected (e.g., Vold and Buffett, 2008). The maintenance or improvement of connectivity, a key principle in conservation biology, tries to minimize the effects of habitat loss and fragmentation, as well as to improve gene flow, wildlife dispersal, population viability and ecosystem services (Lindenmayer et al., 2006; Galpern et al., 2011). Landscape connectivity is 'the degree to which the landscape facilitates or impedes movement among resource patches' (Taylor et al., 1993). Landscape connectivity can be accessed through the physical arrangement of landscape structures (structural connectivity) and/or according to an organism's response to physical structures (functional connectivity). Thus, functional connectivity varies among species in the same landscape, and for the same species among landscapes (Tischendorf and Fahrig, 2000).

Recent advances in spatial graph theory proved to be useful in identifying priority sites for conservation based on functional connectivity indices. In spatial graphs, the nodes have a specific location, area, shape and are considered suitable habitat patches for an animal/plant species, while links with georeferenced routes represent potential species movement among nodes (Urban and Keitt,

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2001; Urban et al., 2009; Galpern et al., 2011). Because each patch has a different contribution to functional connectivity across the landscape, it is essential to quantify the importance and the role of these patches (Saura and Rubio, 2010). Among an array of connectivity-based indices available, most consider only the graph structure (i.e., the topological position of a patch within a network of patches), which results in an inability to prioritise landscape elements to maintain landscape connectivity (Pascual-Hortal and Saura, 2006; Saura and Rubio, 2010). Recently, the Integral Index of Connectivity and the Probability of Connectivity index (hereafter IIC and PC, respectively), were proposed to overcome this limitation (Pascual-Hortal and Saura, 2006). Both indices account for habitat availability for a particular species, considering the habitat patch (a space where connectivity occurs; intra-patch connectivity) and the graph structure (i.e., inter-patch connectivity) to evaluate functional connectivity (Pascual-Hortal and Saura, 2006). Furthermore, partitioning IIC and PC into subcategories allows for the quantification of different roles each landscape element can play to generate functional connectivity (Saura and Rubio, 2010). The three aforementioned subcategories measure the following: the available habitat area provided by the patch itself (Intra); how well the patch is connected to other patches in the landscape, considering the amount of flux arriving to that patch (Flux), and the contribution of a patch as a connecting element between other habitat patches (Connector) (Saura and Rubio, 2010). In conservation management, IIC and PC indices, as well as their subcategories, may be used as distinct criteria to guide the decision makers on habitat prioritisation based on functional connectivity.

The structural landscape indicator, Morphological Spatial Pattern Analysis (hereafter MSPA), is another innovation created to improve the identification of priority areas for conservation. Through mathematical morphological image processing on binary maps (habitat/non-habitat), MSPA classifies habitats into different elements according to geometry and structural connectivity, to assess spatial patterns within landscapes (Vogt et al., 2007; Ostapowicz et al., 2008; Soille and Vogt, 2009). In a landscape context, these elements may represent core areas (large interior areas that may support the widespread movement of species), edges (boundaries of habitat patches that differ from the interior in biotic composition and/or abiotic conditions) and connector areas (elements that act as corridors or stepping stones). Recently, MSPA and spatial graphs/habitat availability were integrated in a combined approach, where the MSPA elements were used to build a graph (i.e., nodes and links corresponding to core areas and corridors, respectively) for prioritising habitat patches that are key structural connectors (Saura et al., 2011). However, structural connectivity does not necessarily imply functional connectivity (Tischendorf and Fahrig, 2000). For example, two isolated habitat patches can be functionally connected for a species whether it can cross the inter habitat patch matrix. In this study we address this gap by combining these two approaches (spatial graph/habitat availability and MSPA) to highlight aspects of functional connectivity. Applying a different methodological point of view, we firstly considered species dispersal abilities to prioritise habitat patches and after we combined these results with MSPA to identify which types of landscape structures were more abundant.

Considering that it is important to indicate priorities patches according to the objective of decision makers (e.g., conserve core or connector areas), our goal was to analyse how the spatial patterns of habitat patches varies according to the distinct criteria of functional connectivity (IIC and its three subcategories) to improve habitat prioritisation for conservation. We illustrated our approach by applying it in forest remnant areas across the state of Rio de Janeiro. Located at the centre of the Brazilian Atlantic Forest, Rio de Janeiro harbors many species committed to extinction (Grelle et al., 2005; Jenkins et al., 2010), and can be viewed as an invaluable laboratory for understanding the effects of habitat fragmentation in tropical regions (Laurance, 2009). We also analyzed which landscape structures are more abundant within each criteria of functional connectivity and determined if forest remnants prioritised based on the criteria of functional connectivity are currently protected. We also analyzed differences in the type of protection of the forest remnants because the Brazilian Protected Area System (SNUC), as well as the IUCN system, divides protected areas into two classes, SPAs and SUAs (Brasil, 2000). Using the landscapes of Rio de Janeiro as a case study, we aimed to: (1) combine two recently developed analyses on landscape connectivity (IIC/its three subcategories and MSPA) to improve habitat prioritisation through the enhancement of functional connectivity, and (2) to help indicate which class and category of protected areas should be implemented in the Brazilian Atlantic Forest hotspot.

2. Methods

2.1. Study area and spatial data

Rio de Janeiro is located along the southeastern coast of the Brazilian Atlantic Forest, which has a total area of approximately 4,370,000 ha (Fig. 1a). Currently, Rio de Janeiro holds about 20% of its original forest cover, totalling approximately 800,000 ha of forested areas surrounded by human-modified landscapes (SOS Mata Atlântica and INPE, 2010). The scattered, fragmented forest cover is made up of more than 10,000 remnants, most of which are less than <100 ha; only 70 fragments are larger than 1000 ha, yet these forest remnants represent 67% of the total remaining forest cover (Fidalgo et al., 2009).

Forest cover data were derived from SOS Mata Atlântica map (SOS Mata Atlântica and INPE, 2010), which was constructed by visual interpretation of TM/Landsat-5, ETM+/7 and CCD/CBERS-2 images from 2009 to 2010, at the scale of 1:50 000, identifying forest remnants with at least 3 ha (Fig. 1a). We considered only forest remnants $\geqslant 15$ ha as suitable habitat patches to be included in the analyses, because is more plausible that forest remnants of these sizes represent effective habitat patches for multi-species analyses (e.g., Vieira et al., 2009, for mammals). Therefore, we took into account 4703 forest remnants throughout the Rio de Janeiro.

Approximately 14.4% of Rio de Janeiro is covered by protected areas, but only 5.9% is under SPAs (Jenkins et al., 2010). When these protected areas are close, juxtaposed or superimposed, the Brazilian government establish a model of regional integrated management (the so-called Mosaics of Protected Areas). Of the six federally established Mosaics of Protected Areas (officially recognized up to August 2010), three are located in Rio de Janeiro (Fig. 1b). We obtained data on protected areas from the database of IBAMA (http://www.ibama.gov.br, access on August 2011). In subsequent analyses we only used the portion of protected areas overlapping forest remnants, instead of the entire delimitation of protected areas (Fig. 1a). All geographic information system data were converted in the UTM projection to assure an accurate area and distance calculations.

2.2. Criteria for habitat prioritisation based on functional connectivity

To conduct functional connectivity analyses, we simulated eleven theoretical focal groups of forest-dwelling species, defined according to previous analyses of the species dispersal abilities in the Atlantic Forest and the configuration of protected areas networks in the Rio de Janeiro (Crouzeilles et al., 2010, 2011, respectively). We assigned the following distance thresholds: 40, 70, 400, 500, 670, 800, 1000, 1350, 2000, 2500, 3300 m. The mean of these distances is similar to the average distance among forest

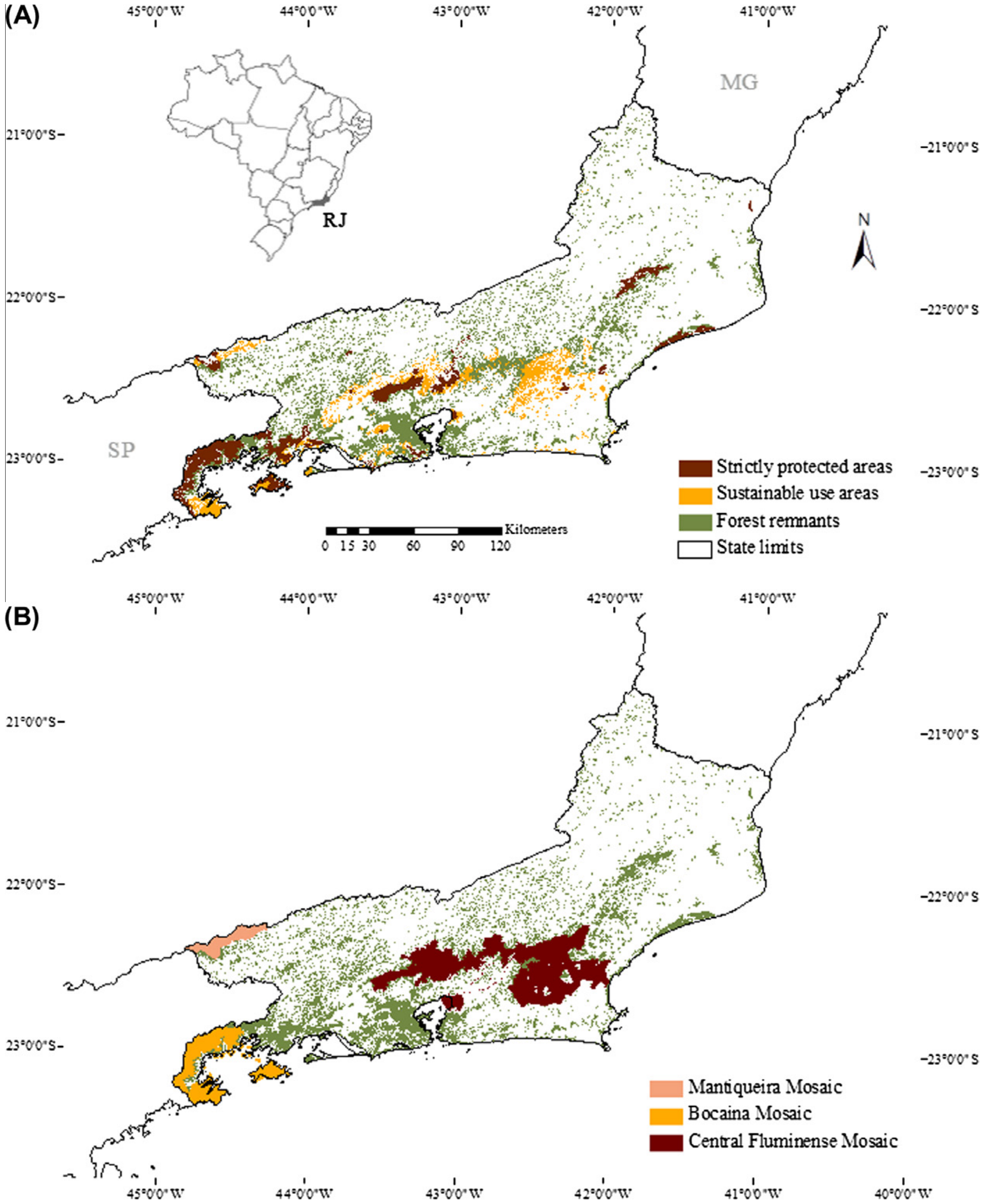

Fig. 1. (A) Forest remnants (⩾15 ha), strictly protected areas and sustainable use protected areas in the state of Rio de Janeiro. (B) The three Mosaics of Protected Areas in Rio de Janeiro.

remnants in Atlantic Forest (Ribeiro et al., 2009), and the maximum value represents the largest inter-patch distance that a species need cross to build protected areas networks in the Rio de Janeiro (Crouzeilles et al., 2011). Dispersal abilities range from a species group that crosses small distances in an inter-patch matrix up to a species group that disperses over large distances.

A buffer of 3.5 km was created around the boundary of Rio de Janeiro to avoid an underestimation of the importance of forest remnants located close to the state boundary. The buffer size was established to encompass the greatest dispersal ability of the focal group species used here (3.3 km; see above).

We analyzed functional connectivity using IIC, an index based on the concept of habitat availability, which quantifies inter-patch connectivity through graph structure (topological position) and intra-patch connectivity through habitat patch dimension (patch size) (Pascual-Hortal and Saura, 2006; Saura and Torné, 2009). We used IIC because it focuses on the topology and availability of the habitat network, allowing for long-term studies of species movement and population mixing, whereas the PC index focuses on the movement of individuals (Bodin and Saura, 2010). The IIC calculation requires two input types of information: (1) the node attributes (e.g., area, suitability, population density) and (2) the connection among each pair of nodes, which can be computed as distance (euclidean or effective), probability (dispersal probabilities) or as a link (link exists = 1 or no = 0) (Saura and Torné, 2009).

Connections based on effective distances, which consider the resistance of landscape elements to animal movements, are conceptually appealing. However, their application can often be precluded by difficulties in defining the resistance of land cover, given that functional connectivity is species-specific, landscape dependent (Urban et al., 2009), and this information is very scarce in the literature (Tischendorf and Fahrig, 2000; Crouzeilles et al., 2010). Because of these constraints, we used patch size (area of forest remnants) as the node attribute and the euclidean distance between forest remnants as the connection attribute for the 11 focal theoretical groups of forest-dwelling species. After importing node and distance attributes from ArcGis 9.3 (ESRI, 2008), using the Input Conefor extension, *IIC* was calculated as:

$$IIC = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{a_i * a_j}{1 + nl_{ij}} \Big/ A_L^2, \tag{1}$$

where n is the number of patches, a_i and a_j are patch sizes, nl_{ij} is the number of links in the shortest path between i and j, and A_L^2 is the square of the geographic area of the region (in our case – the whole Rio de Janeiro) (Pascual-Hortal and Saura, 2006). For each IIC result, it is possible to assess the relative importance of each patch for functional connectivity by finding dI:

$$dI(\%) = 100 * I - I_{remove}/I, \tag{2}$$

where I is the *IIC* value when all of the initially existing nodes are present and I_{remove} is the *IIC* value when any single node is removed (Saura and Pascual-Hortal, 2007). The rank of patch importance can be used as a criterion to prioritise habitat patches based on their functional connectivity. Furthermore, the IIC result of patch importance can be partitioned into three complementary subcategories (IICIntra, IICFlux and IICConn; Saura and Rubio, 2010). These subcategories represent distinct habitat roles and can also be exploited as distinct criteria used for habitat prioritisation based on functional connectivity. IICIntra ranks patches in terms of area, assessing only intra-patch connectivity, and may be used as a criterion to prioritise large habitat blocks. IICConn ranks key patches that assist the species flux between two other patches within the shortest path, assessing inter-patch connectivity, which may be used as a criterion to select priority stepping stones and/or corridors. IICFlux ranks patches according to their area-weighted dispersal flux; IICFlux may be used as a surrogate of how well a patch is connected to other patches when it is the ending or starting point of the flux. For more details on subcategory partitioning, see Saura and Rubio (2010).

We used IIC and its subcategories (IICIntra, IICFlux, IICConn) as four distinct criteria to rank and prioritise forest remnants based on functional connectivity. We ranked each forest remnant according to the mean value for the 11 focal groups to evaluate the forest remnant importance for multiple species. There is a different mean for each of the four criteria. Functional analyses were performed with Conefor Sensinode 2.5.8 software (Saura and Rubio, 2010).

For each criterion, we ranked all forest remnants within five levels of importance. We put the range of two decimal places into each level, encompassing values of 10^9–10^8 within 1st level, 10^7–10^6 within 2nd level, 10^{-1}–10^{-2} within 3rd level, 10^{-3}–10^{-4} within 4th level, and 10^{-5}–10^{-6} within 5th level. We used these categories because the highest values of forest remnants importance were much larger than other forest remnants. As a result, to provide a range of levels within the highest values of forest remnant importance, it was better to have at least two levels of importance within the highest values of forest remnant importance. Besides, we provide a range of forest remnant possibilities in different levels to be chosen by decision makers. It is important to highlight that this classification may be rebuilt in different ways according to the target goals. Moreover, these divisions allowed a comparison of the spatial patterns of forest remnants among the levels of forest remnant importance based on the criteria for functional connectivity to improve habitat prioritisation for conservation (see below).

2.3. Morphological spatial pattern analysis for forest remnants

MSPA operates in raster images at the pixel level (Vogt et al., 2007; Ostapowicz et al., 2008; Soille and Vogt, 2009), where the input map is a binary representation of a landscape coded as foreground (habitat patches) or background (non-habitat patches). Within the foreground, morphological operations such as 'erosion' (shrinks the object), 'dilation' (expands the object), and 'skeletonisation' (removes the boundary pixels until the object is depicted by its skeleton) are used to quantify the connectivity and the geometry of the image components (Vogt et al., 2007). In the final result, each pixel of the foreground (i.e., each forest pixel) is assigned to one of seven mutually exclusive morphological elements (Saura et al., 2011):

Core forest pixels whose distance to the non-forested areas is greater than the given edge width. Core correspond to the focal habitat area.

Edge a set of forest pixels whose distance to the patch edge is lower than or equal to the given edge width and corresponds to the outer boundary of a core area, forming the transition zone between the habitat and non-habitat.

Perforation a transition zone similar to edge but corresponding to the inner boundary of a core area.

Bridge sets of contiguous non-core forest pixels connecting two or more disjunct core areas at their ends, corresponding to structural connectors that link different forest core habitat areas.

Loop similar to bridges but with the ends of the element connecting a core area to different parts of the same core area.

Branch elongated sets of contiguous forest pixels extending from a forest area but that do not reach any other forest area at the other end.

Islet the only unconnected class, corresponding to forest patches that are too small to contain core pixels.

In a functional connectivity point of view, connector structures may be represented by core, loops, bridges, islets and branches. Bridges are corridors that permit connect structurally two or more cores, while core, loops, islets and branches may act as stepping stones. As core areas present a major role as habitat providers, wider than simply act as a connector element, we grouped morphological elements into three basic landscape structures: core, connector (corridors and stepping stones without consider core) and external edge areas. They have relevant role in functional connectivity and have been acknowledged as essential structures to recognize landscape patterns (Lindenmayer et al., 2008). Perforation structure was the only class not evaluated because it has little relevance for functional connectivity in our study.

We carried out the MSPA with the GUIDOS software (Soille and Vogt, 2009), using the 8-neighborhood rule, a pixel size of 50 × 50 m (0.25 ha), and an edge width ranging from one, two and four pixels. These edge widths are equivalent to 50, 100 and 200 m, respectively, which corresponds to tropical forest areas, where edge effects are more intense (Laurance et al., 2002). We analyzed the spatial patterns of forest remnants for the entire state of the Rio de Janeiro, and this result was also used to analyze each one of the five levels of forest remnants importance within each criterion of functional connectivity separately.

Finally, for each level of importance within each criterion, we assessed which forest remnants are currently covered by protected areas and under which category they are protected, using spatial operations in ArcGIS 9.3 software (ESRI, 2008).

3. Results

3.1. Habitat prioritisation

Fig. 2 shows the classification of each forest remnant into five levels of importance based on the four criteria of functional connectivity (IIC, IICIntra, IICFlux and IICConn). In general, the higher the level of importance, the greater the mean size of forest remnants (Table 1). In contrast, there was an inverse relationship between the level of importance and the number of forest remnants. The largest forest remnant found in Rio de Janeiro (153050.89 ha) was in the 1st level of importance for all criteria (Table 1).

For each criterion only the 1st level encompassed more core areas than connectors (corridors and stepping stones; Table 2). The higher the level of importance, the greater the presence of core, edge areas and corridors. However an inverse relationship was found between the level of importance and the presence of stepping stones (Table 2). In Rio de Janeiro, approximately 62% of forest remnants were connector areas, while only approximately 26% were core areas (Table 2). It is important to note that the abundance of MSPA elements were computed using only the foreground (forest remnants), which covers approximately 20% of the total surface of Rio de Janeiro.

When we compared the different criteria of functional connectivity, some general patterns were revealed. Among each criterion, the abundance of landscape structures were more similar between the IICFlux and the IIC criteria (Table 2). For IICIntra criterion we found that the three highest levels of importance presented the largest forest remnant (Table 1), the highest mean size of forest remnants (Table 1), the greatest abundance of core areas (Table 2), and more corridors than stepping stones, except in the 3rd level, where both structures were similarly abundant (Table 2).

In turn, for IICConn criterion, the two lowest levels of importance presented the largest forest remnant, and the lowest level also showed the highest mean size of forest remnants (Table 1). The three highest levels of importance presented the smallest forest remnant, and the same were found in IIC criterion (Table 1). Even for the IICConn criterion, which does not consider habitat area, the 1st level of importance encompassed more core areas than connectors (Table 2). In contrast, in the IICConn the 2nd level of importance presented more connector areas, mainly stepping stones, than all other criteria (Table 2).

3.2. Forest remnants under legal protection

In Rio de Janeiro, more than 50% of the forest remnants are formally covered by protected areas, where approximately 25% are under SPAs and 28% are under SUAs (Table 3). However, virtually

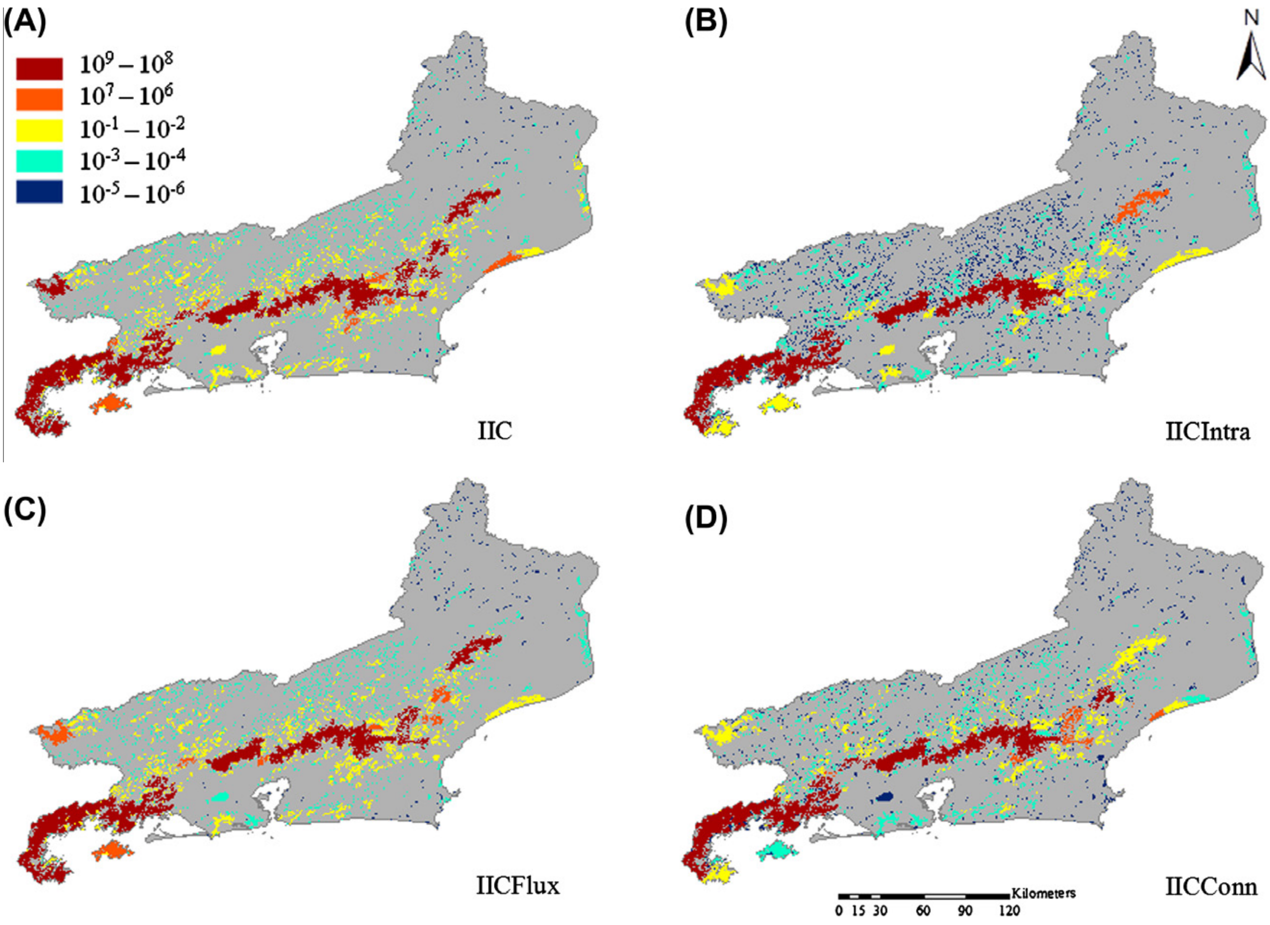

Fig. 2. Five levels of forest remnants importance: 10^9–10^8 within 1st level, 10^7–10^6 within 2nd level, 10^{-1}–10^{-2} within 3rd level, 10^{-3}–10^{-4} within 4th level, and 10^{-5}–10^{-6} within 5th level according to the four criteria of functional connectivity: (A) Integral Index of Connectivity – IIC; (B) IICIntra; (C) IICFlux; and (D) IICConn.

Table 1
Number of forest remnants, size of the smallest forest remnant (ha), size of the largest forest remnant (ha) and the mean size of the forest remnants (ha) in the five levels of importance (1st, 2nd, 3rd, 4th and 5th) based on each functional criterion (IIC, IICIntra, IICFlux and IICConn) for all forest remnants in Rio de Janeiro.

Criteria	Forest remnant importance	Remnants N°	Smallest remnant (ha)	Largest remnant (ha)	Mean remnants (±DP) (ha)
IIC	1st	20	100.39	153050.89	23266.05 (±35848.30)
	2nd	25	27.35	15798.31	2335.83 (±3363.83)
	3rd	773	15.03	8352.83	307.84 (±691.75)
	4th	3307	15	1287.66	46.36 (±64.69)
	5th	578	15.13	215.31	36.82 (±26.96)
IICIntra	1st	4	31226.73	153050.89	68036.89 (±49805.39)
	2nd	1	25549.44	25549.44	25549.44
	3rd	27	2483.78	80611.64	92845.11 (±14567.56)
	4th	274	239.9	7375.4	651.54 (±690.17)
	5th	4397	15	239.49	47.61 (±41.56)
IICFlux	1st	10	7847.66	153050.89	41831.52 (±43023.19)
	2nd	7	2681.57	18045.81	9176.94 (±5416.19)
	3rd	580	29.19	8352.83	425.46 (±864.17)
	4th	3485	15	5351.22	51.60 (±129.92)
	5th	621	15.13	717.04	43.66 (±53.59)
IICConn	1st	12	100.39	153050.89	24261.71 (±42297.85)
	2nd	16	27.35	10418.95	1634.58 (±3044.06)
	3rd	236	15.03	25549.44	824.36 (±2462.59)
	4th	1791	15.01	80611.64	165.15 (±1976.82)
	5th	2648	15	5351.22	48.58 (±127.95)
RJ		4703	15	153050.89	199.08 (±2813.44)

Table 2
Abundance of MSPA elements (core, connector - corridors and stepping stones, edge and NA – not analyzed) in the five levels of importance (1st, 2nd, 3rd, 4th and 5th) based on each functional criterion (IIC, IICIntra, IICFlux and IICConn) for all forest remnants in Rio de Janeiro.

Criteria	Forest remnant importance	Core	Connectors		Edge	NA
			Corridors	Stepping stones		
IIC	1st	44.05	25.28	14.98	14.96	0.73
	2nd	29.31	24.48	27.41	17.98	0.82
	3rd	11.75	8.77	64.96	14.33	0.19
	4th	2.21	1.31	90.92	5.55	0.01
	5th	0.49	0.00	97.23	2.28	0.00
IICIntra	1st	49.03	21.89	14.14	14.09	0.85
	2nd	36.87	29.37	14.53	18.62	0.61
	3rd	31.08	25.10	26.25	17.04	0.54
	4th	9.70	9.87	65.84	14.59	0.01
	5th	0.95	0.45	94.79	3.80	0.01
IICFlux	1st	45.42	24.79	14.30	14.70	0.79
	2nd	36.29	21.70	22.36	18.22	1.43
	3rd	13.23	12.88	59.02	14.76	0.11
	4th	4.02	2.99	86.46	6.29	0.25
	5th	2.03	0.39	92.35	5.23	0.00
IICConn	1st	45.56	24.27	14.83	14.32	1.02
	2nd	17.89	21.76	44.41	15.83	0.11
	3rd	22.28	17.55	43.38	16.42	0.37
	4th	11.40	5.87	70.18	12.39	0.16
	5th	4.77	0.80	87.61	6.74	0.08
RJ		25.57	18.53	43.72	11.61	0.56

all SUAs belong to the least restrictive category of protected areas (APA category, IUCN category V).

In general, for each criterion of functional connectivity the forest remnants assigned to the highest levels of importance are more protected by SPAs, while those assigned to the three lowest levels of importance are more protected by SUAs (Table 3). For the IICIntra criterion, also the forest remnants assigned to the 2nd and 3rd levels of importance are more protected by SPAs (Table 3). On the other hand, for the IICConn criterion the forest remnants classified in the 2nd level of importance are the most protected by SUAs (Table 3). According to the IICConn criterion, SUAs presented a great importance in the protection of forest remnants assigned to the 2nd level of importance, because SPAs protected only 10.59% of these forest remnants (Table 3).

4. Discussion

We showed that spatial graph/habitat availability and MSPA provide complementary information that could be used to improve the prioritisation of habitat patches for conservation. Based on our results, we highlight general patterns of that combination. The core areas were the most abundant only in the 1st level of forest remnant importance for each criterion evaluated. However, in more preserved regions, these core areas that may support the widespread movement of species because of their larger size (Vogt et al., 2009) tend to also be the most abundant element in subsequent levels of importance. When core areas are abundant, we can find more corridors than stepping stones. A reduction in core and edge areas led to the exponential increase of connector areas,

Table 3
The percentage of strictly protected areas (SPAs), sustainable use protected areas (SUAs) and non-protected areas (NP) in the five levels of importance (1st, 2nd, 3rd, 4th and 5th) based on each functional criterion (IIC, IICIntra, IICFlux and IICConn) for all forest remnants in Rio de Janeiro.

Criteria	Forest remnant importance	SPAs%	SUAs%	NP%
IIC	1st	43.09	23.86	33.05
	2nd	37.46	33.95	28.59
	3rd	8.29	23.04	68.66
	4th	1.62	9.75	88.63
	5th	0.10	5.79	94.10
IICIntra	1st	48.21	21.26	30.53
	2nd	67.64	0.00	32.36
	3rd	24.94	38.10	36.96
	4th	7.25	19.71	73.04
	5th	1.49	13.16	85.35
IICFlux	1st	46.63	24.27	29.10
	2nd	38.89	20.30	40.81
	3rd	10.69	27.33	61.98
	4th	3.49	11.78	84.74
	5th	0.08	6.74	93.18
IICConn	1st	45.30	22.24	32.46
	2nd	10.59	33.19	56.22
	3rd	22.74	25.64	51.62
	4th	11.08	15.78	73.14
	5th	3.04	18.76	78.20
RJ		24.64	27.47	47.89

mainly stepping stones, reflecting the high number of forest remnants and a lower mean size of forest remnants for the lower levels of importance; a pattern expected to occur in less compact landscapes (Ostapowicz et al., 2008). Thus, in highly fragmented landscapes, the perimeter to area ratio increases, resulting in landscapes covered mainly by stepping stones.

There are also specific spatial patterns relative to the four criteria of functional connectivity evaluated. The IICIntra criterion ranks patches according to their size. As a result, the IICIntra criterion must be considered when the decision makers' goal is to protect the largest habitat areas, which is a common strategy used worldwide (Ferrari et al., 2007; Saura and Rubio, 2010; Saura et al., 2011) because patch size is related to population viability, species richness, immigration rates and other factors (Lindenmayer et al., 2008). For highly fragmented landscapes, with a low percentage of core areas such as those studied here (25.57%), a large amount of core area is under the highest levels of importance for the IICIntra criterion (1st, 2nd, 3rd levels). Even for the IICConn criterion, which does not consider patch size (forest remnant), the 1st level of importance found core areas as the most abundant structures. Intrinsically, large patches cover large extensions, so they are more likely to be a connector structure than small patches (Saura and Rubio, 2010; Saura et al., 2011). However, many studies have shown the relevance of medium and small patches for connectivity and ecological processes (Lindenmayer et al., 2008; Metzger et al., 2009; Vieira et al., 2009). Therefore, for decision makers to prioritise the most important connector structures (corridors and stepping stones) in the 1st level of importance using the IICConn criterion, the connector structures in MSPA need to be identified. In contrast, as in the 1st level of importance, where connector structures are not the most abundant, the 2nd level of importance for the IICConn criterion may be used to prioritise connector areas because there are many alternative areas in this level (abundant connector structures, mainly stepping stones) to be chosen. This coincides with principles of conservation management that highlight the need to propose alternative choices for decision makers, considering that resources for biodiversity conservation are always limited and should be optimally allocated (Jenkins et al., 2010; Sarkar and Illoldi-rangel, 2010). In addition, other relevant features of landscapes, such as political and socio-economic factors must be evaluated (Lindenmayer et al., 2008).

In real landscapes, the abundance of MSPA elements are expected to be more similar to patterns retrieved from the analysis of neutral maps with intermediate to high contagion than those carried out on simple neutral maps (Riitters et al., 2007), because habitat fragmentation is contagious. Indeed, forest remnants in Rio de Janeiro are more clumped and larger in montane regions, while forest remnants are smaller and scattered in flatter areas (Fidalgo et al., 2009). Therefore, according to each functional criterion, forest remnants in montane regions, as well as some medium forest remnants (>1000 ha), were classified as core areas in the 1st level of importance. Thus, the IIC criterion provides the appropriate weight that intra-patch connectivity should have in the patch (Saura and Rubio, 2010), which results in a greater abundance of core areas in the highest level of importance, even for highly fragmented regions. This was the same pattern found for the IICFlux criterion, which takes into account both the topology of the patch in a network of habitat patches and the area of the habitat patches. In fact, IICFlux criterion has a large contribution to the IIC criterion, especially for species with medium to large dispersal abilities (Saura and Rubio, 2010; Baranyi et al., 2011).

In the past, decision makers in many places of the world created protected areas by prioritizing large areas (Ferrari et al., 2007; Saura and Rubio, 2010; Saura et al., 2011). Criteria similar to the IICIntra were used in the Brazilian Atlantic Forest, which is observed in Rio de Janeiro, where forest remnants assigned to the highest levels of the IICIntra criterion are also protected by SPAs. However, currently there is an agreement that research on conservation and management of biodiversity must be designed to enhance connectivity, through the identification and protection of key connectors (Saura and Rubio, 2010; Saura et al., 2011).

Our analysis showed that the key connectors identified by the IICConn criterion are poorly protected by SPAs. This highlights the importance of SUAs because the 2nd level of importance, which encompasses many key connectors, is more protected by SUAs. However, all of these key connectors are under the less restrictive category of protection in SUAs (APA; IUCN category V), which is closer to a mechanism for land-use management rather than an actual protected area (Rylands and Brandon, 2005). According to Rylands and Brandon (2005) and Silva (2005), two categories of SUAs within SNUC (Area of Relevant Ecological Interest and Private Natural Heritage Reserve, respectively ARIE and RPPN in Portuguese acronyms) only present goals to protect biodiversity, and should be considered as IUCN category IV, which is focused on strict protection. Thus, Brazilian decision makers must consider the opportunity to apply more restrictive categories to SUAs, such as ARIE and RPPN. In Brazil, RPPNs have often been used to protect important forest remnants that are too small to be established as SPAs (Mittermeier et al., 2005). Furthermore, the creation of RPPNs have been widely encouraged and supported by decision makers because this category depends on a particular desire of the landowner, is easy to be implemented, and can be more effective to protect biodiversity than governmental (federal, state or county) protected areas (Mittermeier et al., 2005). Therefore, key connectors identified in the 2nd level of importance in the IICConn criterion must be protected by SUAs' restrictive categories.

Our main results for Rio de Janeiro indicated that, according to each functional criterion, the most important unprotected core and connector areas are located between two of the Mosaics of Protected Areas (Bocaina and Central Fluminense, Figs. 1b and 2). To allow integrated management, the forest remnants between the Mosaics must be incorporated into the current Mosaic of forest remnants to join the two sets of protected areas. Throughout the world, there have been strong political initiatives to enhance connectivity between priority habitat patches (e.g., “Staying

Connected Initiative" – www.stayingconnectedinitiative.org; "Western Governors' Association Wildlife Corridors Initiative" – www.westgov.org/initiatives/wildlife). Currently, the Brazilian Ministry of the Environment (MMA, Portuguese acronym) and the State Institute of Environmental (INEA, Portuguese acronym) have encouraged the implementation of RPPNs and SPAs, primarily between the two Mosaics. In summary, we believe that the combined application of these methods (spatial graph/habitat availability and MSPA) are a useful additional tool for decision makers to identify priority habitats according to specific goals, as well as to help identify which class and category of protected areas must be implemented in the Brazilian Atlantic Forest hotspot.

5. Conclusion

According to our case study, we recommend and highlight the following aspects of conservation management to researchers and decision makers: (1) Functional connectivity is not the only way to prioritise habitat patches, but it is a useful principle to indicate the location of these areas. (2) The structural indicator (MSPA) complements the four criteria of functional connectivity and is useful to improve conservation actions. This was highlighted in the IICConn criterion, where we found the most abundant and important connector areas, mainly represented by stepping stones, in the 2nd level of forest remnant importance. (3) The IICFlux criterion is similar to the IIC criterion in the abundance of landscape structures, making IIC the best criterion to incorporate a reasoned choice of important core and connector areas, which must be protected by SPAs. (4) Specifically for Brazil, the decision makers must consider the opportunity to implement restrictive categories of SUAs (like RPPN) to protect key connectors, which will enhance connectivity in the landscape.

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