How Can We Estimate Buffer Zones of Protected Areas? A Proposal Using Biological Data

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Abstract

A strategy to avoid the loss of habitats and preserve large areas is the establishment of protected areas. Brazil's Conservation Units National System (SNUC) determines that protected areas should be surrounded by buffer zones where human activity is restrict, but the established size of the buffer seems arbitrary. The restrictions provided by SNUC could be based on limits that allow the persistence of species' ecological function. Here we use the "landscape species" concept as a tool for buffer zone design, using the marsupial *Micoureus paraguayanus* as a model organism. We used its minimum area requirement for population viability (5,000 ha) to define the size of buffer zones around protected areas with smaller size than the minimum required area. The amount of habitat within protected areas was negatively correlated with the buffer size. Therefore, the largest the protected area, the smaller should be its buffer zone, provided that it does not have an impermeable barrier. Buffer zones are generally in private properties and, therefore, governmental incentives are essential to stimulate land uses compatible with biological flux through a permeable matrix. The method proposed here provides a simple analysis that can be used to establish the limits of buffer zones.

Key words: Buffer Zones, Atlantic Forest, Landscape Species, *Micoureus paraguayanus*, Reserve Design.

Introduction

Protected areas are elements of complex landscapes that should be managed, allowing the persistence of viable populations and the use for some economic activities (Crooks & Sanjayan 2006). For protected areas to maintain viable populations at the long-term, a minimum amount of habitat area is needed in a single area, or a network with other habitat patches where potential connectivity is possible. Connectivity can be defined as the degree to which the landscape facilitates or impedes movement among resource patches. It can be divided into "structural connectivity", which refers to the spatial arrangement of the elements of the landscape, and "functional connectivity", which refers to the behavior response of organisms to landscape structures (Crooks & Sanjayan 2006).

On the other hand, to reconcile conservation and land-use one of the alternatives is to establish buffer zones around protected areas, within which human activities are subjected to specific rules and restrictions (Gonçalves *et al.* 2009). In Brazil, the protected areas system was established in 2000 by law N° 9.985 of the Conservation Units National System

(SNUC, in the Portuguese acronym), where buffer zones are transition areas that should minimize negative impacts on protected areas. The size of buffer zones is not specified in SNUC, however. In 1990, the National Environment Council Resolution (CONAMA, Portuguese acronym) N° 13 had already defined a 10km buffer zone around protected areas, where any activity that may affect the biota should be licensed (Gonçalves *et al.* 2009). The size proposed by CONAMA, however, is arbitrary and may be inadequate to maintain minimum viable population of some species. Studies performed in wetlands already showed the inefficiency of arbitrary buffer zones to population viability of frogs and salamanders (Harper *et al.* 2008).

Conservation strategies need to be based on data, preferably data that allow for the interaction between biological and socio-economic perspectives. The "landscape species" approach has been used to characterize impacts on the structure and functioning of natural systems (Sanderson *et al.* 2002). It arises as a tool to be used in strategies for conservation and public policies. In this approach, the species are chosen based on the heterogeneity of its habitats, land uses and vulnerability to anthropogenic pressure, ecological functionally and socio-economic significance (Sanderson *et al.* 2002).

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Putting together the landscape species approach and the minimum area needed for species' long-term persistence, it is possible to draw a proposal to delimit buffer zones. Thus, it is expected that the larger the protected area, the smaller should be its buffer zone to achieve a threshold of habitat amount to long-term persistence of populations. However, in highly fragmented landscapes, besides of the amount of forest cover within the protected area, the buffer zone may be enlarged or reduced depending on the amount and arrangement of the natural remnants surrounding protected areas.

In this study, the marsupial *Micoureus paraguayanus* was used as a landscape species to delimit buffer zones. This small species is endemic to the Brazilian Atlantic forest and needs a minimum area of 5,000 ha to maintain a viable population over the long term (Brito & Grelle 2004). We used the minimum forested area required by the species to define the size of buffer zone around protected areas >5,000 ha. We also evaluated whether the increase of forest cover inside protected areas translates into a decrease in the size of buffer zones.

Material and Methods

Region of study

Rio de Janeiro state is located in southeastern Brazil. Its original vegetation is Atlantic forest, which has been radically transformed since the 1500's (Fundação SOS Mata Atlântica & INPE 2010). Rio de Janeiro has more than 16 million people (<http://www.ibge.gov.br/estadosat/perfil.php?sigla=rj> accessed on 12 July 2010), 43.6 million hectares of total area, of which about 800 thousand hectares of forest (or 18% of the state's area, Fundação SOS Mata Atlântica & INPE 2010). Approximately 14% of the forest remnants are under protected areas (Jenkins *et al.* 2010), which can be divided into two classes: Strictly Protected Areas and Sustainable-Use Areas. The former corresponds to categories I-IV of the IUCN, which is established to maintain biodiversity and increase the protection, whereas the second corresponds to categories V-VI of the IUCN, which has the main focus of conciliate conservation and economical activities. Strictly protected areas have 77% of forest cover (Fidalgo *et al.* 2009) and protect about 6% of the remaining forest (Jenkins *et al.* 2010), but sustainable-use areas have only 43% of forest cover (Fidalgo *et al.* 2009). According to the SNUC, protected areas should be surrounded by buffer zones, but this rule has two exceptions in sustainable-use categories: Environmental Protection Area (APA) and Private Natural Heritage Reserve (RPPN).

The forest cover map used is from the cartographic base of Fundação SOS Mata Atlântica & INPE (2010), resulting from TM/Landsat bands 5 or 7, obtained at a scale of 1:50,000 in vector format, mapping forest remnants with at least 10 ha. The land-use map used is from Brazilian Environment Ministerial (MMA in portuguese acronym - <http://mapas.mma.gov.br/mapas/aplic/probio> accessed on November 10th, 2008) and the shapes of protected areas (27 strictly areas and 21 sustainable-use) were downloaded from Brazilian Institute of Environment and Renewable Resource (IBAMA in portuguese acronym - www.ibama.gov.br/patrimonio/ accessed on March, 5th, 2008). All geographical information data used were in Albers projection.

Micoureus paraguayanus as a "Landscape species"

Micoureus paraguayanus (previously *Micoureus travassosi*) is a small didelphid whose adult can weigh up to 130 g, males being slightly larger than females (Rossi *et al.* 2006). It can be found in dense forest and also in secondary vegetation, it is nocturnal and mostly arboreal, although it can descend to the ground (Grelle 2003). The species is widely distributed in the state of Rio de Janeiro, occurring in all vegetation types but *campos de altitude* (highland fields occurring above 2000 a.s.l.) (C.E.V. Grelle unpublished data). The species may cross up to 100 m in matrices composed of grass (Forero-Medina & Vieira 2009), and up to 300 m in matrices composed of grasses, shrubs and pioneer trees (Pires *et al.* 2002). According to Brito & Grelle (2004), *M. paraguayanus* needs a minimum of 5,000 ha forested area to support a viable population of 2,000 individuals that will retain demographic and genetic integrity for 100 years. We used *M. paraguayanus* as landscape species because it has not only the appropriate behavioral ecology, but also sufficient and appropriate data. The species occurs in heterogeneous habitat, being found in different successional stages of vegetation (Forero-Medina & Vieira 2009; Grelle 2003, Pires *et al.* 2002). It has an important ecological function as seeds disperser (Cáceres *et al.* 2002), is vulnerable to anthropogenic threats (Umetsu *et al.* 2008), but even so it may cross different human modified landscapes such as coffee plantation, and has socio-economic significance (Passamani & Ribeiro 2009).

Delimiting buffer zones

First, we overlaid the forest cover and protected areas maps, determining the actual amount of forested habitat for each protected area. Then, we evaluated which protected areas needed buffer zones according to SNUC, and which were >5,000 ha (*i.e.*, the estimated minimum area needed for *M. paraguayanus*). The protected areas that were not large enough, but were structurally connected to other protected areas or forest remnants, were not included in the analysis, even if together with its connecting elements it exceeded 5,000 ha.

For the other protected areas, buffers were created according to protected areas boundaries, drawing concentric areas. Buffer size is then expressed as the radius of these circles and expressed in km. The surrounding forest remnants were incorporated until the total achieved the 5,000 ha landmark.

In each buffer zone, the land use/cover was classified into five categories, according to *M. paraguayanus* preferences: forest remnants (habitat patches), simple matrix (grass; low permeability), complex matrix (grasses, shrubs and pioneer trees; high permeability), large water bodies and urban areas (impermeable). All analyses were performed using ArcView 9.3 (ESRI 2008).

Finally, we tested how the increase of forest cover in protected areas translated into a decrease in buffer zone size, because of the variation in forest cover within protected areas. Spatial autocorrelation in these variables (forest cover and buffer zone size) were tested using Moran's *I* correlograms with five distance classes. To take into account the effects of autocorrelation when correlating buffer size and forest cover, we calculated geographically effective degrees of freedom (ν^*) based on the correlograms (Legendre P. & Legendre L. 1998). All spatial analyses were obtained in SAM (Spatial Analysis in Macroecology), version 4.0, freely available at www.ecoevol.ufg.br/sam (Rangel *et al.* 2010).

Results

Altogether, 31 out of the 48 protected areas in Rio de Janeiro state required buffer zones as proposed in the SNUC. Of these, 16 were smaller than the minimum requirement for *M. paraguayanus*. For these, the average buffer zones size was 9.3 km (Table 1, Figure 1). The protected area with the largest forest cover was "Ilha Grande State Park" (4,302 ha), and that needed the smallest buffer zone (0.45 km), whereas the "Guaxandiba" Ecological Station (1,241 ha) required the largest buffer zone (27.15 km) (Table 1).

Forest Cover and Buffer Zone Size showed a weak and non-significant autocorrelation pattern (Moran's *I* = 0.161,

$P = 0.358$ and Moran's *I* = 0.186, $P = 0.301$, respectively, for the first distance class, around 30 km). Despite the Guaxandiba protected area tends to be an outlier in the relationship, there is a significant correlation between Forest Cover and Buffer Zone Size, even taking into account the small effects of spatial autocorrelation ($r = -0.52$, $\nu^* = 13$, $P = 0.042$; Figure 2). A log-transformation of the buffer size increases the linearity of the relationship, but the relationship in the original data was shown to reveal the larger variance and uncertainty in the buffer size surrounding small protected areas.

Five protected areas required buffer zones larger than 10 km and 10 protected areas had urbanization and/or water bodies in its interior, which are impermeable to the movement of *M. paraguayanus*.

Discussion

Protected areas must be effective to conserve nature, and need to be planned in an association of stakeholders and scientists (Albernaz & Souza 2007; Grelle *et al.* 2010). In reality, most legal actions and guidelines have been defined in an arbitrary way, without considering ecological processes (e.g. Hunter *et al.* 2009). Ecological processes can be quantified in many ways (e.g. minimum forest cover needed for species persistence in forested biomes), which may allow objective definitions of conservation goals (Ficetola & Denoël 2009).

In Brazil, environmental guidelines are determined through legal instruments, as SNUC and CONAMA. However, in some cases, the specifications are insufficient and poorly defined. SNUC determines that the buffer zones should be established by each protected area's management plan,

Table 1. Forest cover, buffer zone size, and landscape elements within buffer zones for the 16 protected areas in Rio de Janeiro State that were smaller than the minimum requirement for *M. paraguayanus*. Landscape elements: (a) forest remnants, (b) complex matrix, (c) simple matrix, (d) water bodies, (e) urban area. S.P – State Park, E.R – Ecological Reserve, B.R. – Biological Reserve, S.R. – State Reserve, N.F. – Natural Forest, N.P – National Park, E.S. – Ecological Station.

Protected area and category	Forest cover (ha)	Buffer size (km)	Landscape elements
Chacrinha S.P	12.16	13.2	a.c.d.e
Jacarepia E.R.	74.88	16.5	a.b.c.d
Guaratiba B.R	87.44	5.45	a.b.c.e
Alcobaca S.R.	98.99	6.5	a.e
Grajaú S.P.	100.65	12.75	a.b.c.d.e
Massambaba E.R.	287.94	21.4	a.b.c.d.e
Mário Xavier N.F.	499.00	9.2	a.c.e
Serra da Concordia S.P.	796.65	6.4	a.c
Serra da Tiririca S.P.	1,072.69	8.0	a.b.c.e
Guaxandiba E.S.	1,241.30	27.15	a.b.c.d
Araras B.R.	1,412.33	3.1	a
Marinho do Aventureiro S.P.	1,785.85	3.8	a
União B.R.	2,053.53	9.6	a.b.c.d.e
Tijuca N.P.	2,615.37	4.6	a.c
Praia do Sul E.R.	3,438.82	0.9	a
Ilha Grande S.P.	4,302.10	0.45	a

Figure 1. Buffer Zones with forest remnants surrounding protected areas in Rio de Janeiro State

Figure 2. Relationship between forest cover and buffer zone size in protected areas in Rio de Janeiro State that were smaller than the minimum requirement for *M. paraguayanus*.

without any specification regarding buffer zone’s size (Vitalli *et al.* 2009), and CONAMA arbitrarily require protected areas to have a 10 km buffer zones surrounding it. The science of determining buffer zones and surrounding areas is very immature, and need more attention. The functional essence of buffer zones is to act as transition areas that should minimize disturbance in protected areas. The size is very important in that sense, as it may be inadequate to deal with the ecological needs of species (*e.g.* sustain minimum viable populations - Harper *et al.* 2008).

We found that, for a small landscape species (*M. paraguayanus*), the average size of buffer zones needed to maintain population viability was lower than 10 km proposed by CONAMA. However, five protected areas would need a larger buffer zone than the proposal. Moreover, not all protected areas needed a buffer zone, because these protected areas were already larger than the minimum required by the species. It is important to note, however, that *M. paraguayanus* is a small species. The result would be different for other species, such as the primate *Brachyteles hypoxantus*, which requires a minimum forested area of 11.600 ha (Brito & Grelle 2006) and had been proposed as landscape species (Cunha & Grelle 2008). However, currently this primate has a restrict distribution in the state of Rio de Janeiro (Cunha *et al.* 2009). Therefore, a single buffer size may be insufficient to maintain ecological processes structured in the landscape.

Conservation planning and actions should be based on ecological needs of species, and here we used the landscape species concept as tool for conservation action. Besides landscape species, there are other kinds of approaches related to target species that can be used in conservation planning, such as focal species, umbrella species and flagship species (Caro *et al.* 2004). The landscape species approach

differs from these in that it depends on the composition and configuration of the landscapes, focusing not only in the conservation of sympatric species, but also in the conservation of the landscape structure, including the ecological functions that depend on landscape heterogeneity (Sanderson *et al.* 2002).

The restrictions provided by law to buffer zones could be based on limits that maintain the ecological function of species (e.g. connectivity). Therefore, the size of buffers zones should be enlarged up to the point where it allows ecological functionality. For *M. paraguayanus*, we found impermeable barriers to dispersal (urbanization and/or water bodies) in 10 buffers zones, eight of which included urban areas. Therefore, the buffer zones would have to be larger than proposed here, in order to guarantee sufficient habitat connectivity for the species to maintain minimum viable populations. We found a relationship between buffer zone size and forest cover, besides differences in this cover forest along protected areas, but the relationship is complex, indicating that other factors must be taken into account when determining buffer size.

For example, an important issue is matrix quality, which determines the possibility of biological flow (Crooks & Sanjayan 2006). Although in Brazil buffer zones are generally in private properties (Vitalli *et al.* 2009), it is important that public policies incentive land uses which increase matrix permeability, as in the implementation of agroforestry systems (McNeely & Schroth 2006). This can facilitate the dispersal of organisms establishing a flexible network among protected areas, and their surrounding habitat forests, and also enabling the maintenance of viable populations of the landscape of species. Indeed, higher variance in the estimated buffer size shows that these effects must be more important for smallest protected. Thus, it is necessary to increase the buffer size or small and isolated protected areas to size up its total area to a threshold to allow population viability. If it is impossible, buffer zone (and their fragments) should be viewed as a strategy for improving landscape connectivity.

In conclusion, our aim here was to propose a new way to achieve buffer zones with information on minimum habitat necessary to maintain viable population. The method proposed here provides a simple analysis that can be used to establish the limits of buffer zones.

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