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A framework for biological zoning of protected areas of the Brazilian Cerrado

Uma ferramenta para o zoneamento biológico de áreas protegidas no Cerrado brasileiro

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Abstract

The zoning of protected areas is a fundamental step in planning for natural resources management and conservation. However, its development presents several challenging features. Sometimes, the biological aspects of the protected areas are poorly considered in the final zoning, which becomes a controversial issue, since the biological conservation is the main objective of these areas. Herein, we propose an index to evaluate the biological relevance of different landscape units (Biological Importance Value – BIV), specially tailored for the zoning of protected areas. We also present a case study where the BIV was used for zoning the Serra do Tombador Natural Reserve (RNST). A layer of spatial information was produced attributing a BIV value for each landscape entity. This layer was included in a weighted overlay framework with the vegetation types, hydrograph, and roads. We found eight different biological relevance levels in the RNST. These values composed the basis for the final reserve zoning. The BIV associated with the weighted overlay framework reflected the observed faunal distribution in the area and represents an important tool for the implementation of protected areas management practices.

Keywords: protected areas zoning, biological relevance index, weighted overlay, Serra do Tombador Natural Reserve.

Resumo

O zoneamento de áreas protegidas é uma etapa fundamental do planejamento para a conservação e para o manejo dos recursos naturais. No entanto, seu desenvolvimento apresenta diversos aspectos subjetivos. Algumas vezes, as características biológicas das áreas protegidas são pouco consideradas na proposta final de zoneamento. Essa é uma questão controversa, já que a preservação dos aspectos biológicos são os maiores objetivos dessas áreas. Nesse estudo, propomos um índice de importância biológica para diferentes unidades da paisagem (Valor de Importância Biológica – VIB), especialmente planejado para o uso no zoneamento de áreas protegidas. Também apresentamos um estudo de caso onde o VIB foi utilizado para o zoneamento da Reserva Natural Serra do Tombador (RNST). Foi gerado um mapa dos valores do VIB por meio da atribuição desses valores às unidades de paisagem. Esse mapa foi incluído em uma ferramenta de álgebra de mapas, com mapas de vegetação, hidrografia e estradas. Foram encontradas oito diferentes classes de relevância biológica na RNST. Esses valores compõem a base do zoneamento final da reserva. O VIB, associado à ferramenta de álgebra de mapas, refletiu a distribuição da fauna observada na área, representando uma prática de manejo importante para a implementação de áreas protegidas.

Palavras-chave: zoneamento de áreas protegidas, índice de relevância biológica, álgebra de mapas, Reserva Natural Serra do Tombador.

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Introduction

The zoning of protected areas is an important framework for its management (Dudley, 2008), aiming to restrict and organize the use of natural resources in zones by different attributes and potentials, located inside or adjacent to the conservation units. In Brazil, law 9985 (Brasil, 2000) stipulates that all protected areas must be zoned using the following categories: fully-protected zones (without any human intervention), primitive zones (with minimum human intervention, allowing only research, education activities, and some specific kinds of tourism), public use zone (public use), intensive use (allowing museums and touristic support services), historical-cultural zone (for relevant historical, cultural or archeological sites), recovery zones (for ecosystem recovery), and special use zones (support services for reserve administration).

The creation of the protected areas (PA) zoning is typically based on the compilation of data based on an inventory of biological, physical, socioeconomic and cultural aspects, the analysis of this information, and an integrated analysis of these different thematic studies (Thomaziello *et al.*, 2004). However, this approach leads to biased results, due to differences in the quality of biological data available for different PAs, as well as different interpretations by managers in the final result of zoning, leading to subjective results that reflect only the cluster of superficially similar regions (Thomaziello *et al.*, 2004). The consequence of this subjective zoning of protected areas is the minimal influence of biological data on the final zoning establishment of protected areas. Since biological conservation is the main goal of the protected areas, this process is one of the most evident paradoxes in preservation management.

Thus, the development of standardized protocols for data integration is necessary for the suitable zoning of protected areas. In addition, the use of indices for biodiversity characterization and quantification is a very promising approach for PA zoning (Liu and Li, 2008). However, such indices are still poorly applied for PA zoning in Brazil.

In other countries, such as Italy and China, there are several examples of appropriate use of data analysis and application for PA zoning. In Italy, a method to assess the suitability of different areas to host a ski center, according to their biological, physical, and landscape impact was applied in a systematic way to produce valid preservation zones (Geneletti, 2008a). In another Italian initiative, the biological and physical data were combined in a map to integrate the results into a planning support tool as part of an Environmental Impact Assessment (Geneletti, 2008b). The Laoxiancheng Natural Reserve in China had its zones redesigned using an approach based on a biological index system to guide zoning (Liu and Li, 2008). An approach was used for design a marine reserve zoning, combining different variables (fishing, recreation, conservation) and GIS (geographic information system), aiming to map marine areas for different uses and degrees of protection (Villa *et al.*, 2002). Borges *et al.* (2004) developed a method based on the overlap of geology, phytophysiognomies and human uses aiming to study biodiversity and helping the protected areas management, but without proposing any zoning for the Jaú National Park, where the methodology was carried out. Brandão *et al.* (2011) suggested an index (Biological Importance Value - BIV) combined with a weight GIS tool that aims to diminish the subjectivity of reserve zoning. The BIV evaluates the biological attributes associated with each landscape unit of the studied landscape, thus allowing the spatial visualization of biological gradients. The use of that index was efficient to minimize the subjectivity of the procedure (Brandão *et al.*, 2011). Herein we propose an adaptation for this BIV index that better accounts for biological value of landscape units. In addition, we present a case study for the biological zoning of an 8,900 hectare Private Reserve of the Natural Heritage (a Brazilian category of PA) in the Brazilian Cerrado (woodland savanna), using the BIV.

Materials and methods

Study area

The study was carried out in Serra do Tombador Natural Reserve (RNST) which covers 8,900 hectares and is located in the northern part of Goiás, Brazil (Figure 1). This area was bought by Fundação O Boticário de Proteção à Natureza (FBPN) in 2007 as a contribution to the conservation of the Cerrado biome. This important remaining region of the Cerrado creates a connection between other protected areas (Françoso and Brandão, 2013). The landscape of the RNST and the surrounding areas is composed of a mosaic of open fields (predominant), savannas (cerrado *sensu stricto*, according to Ribeiro and Walter, 1998), and riparian forests (gallery and ciliar forests). Until 2007 the area was a cattle farm and the cerrado *sensu stricto* was the physiognomy most used for pasture. The pastures have been abandoned since 1997 and the native vegetation is regenerating.

Method

Landscape units

The zoning tool proposed here is based on the spacialization of biological data and environmental attributes for each landscape unit (LU). The vegetation structure and its spectral characteristics are the basis for the landscape analysis, since it is a biophysical element that can be cartographically represented (Fabré and Ribeiro, 2007). Since the composition of biological communities is affected by biological, physical and historic characteristics of the ecosystems (Kremen *et al.*, 1993),

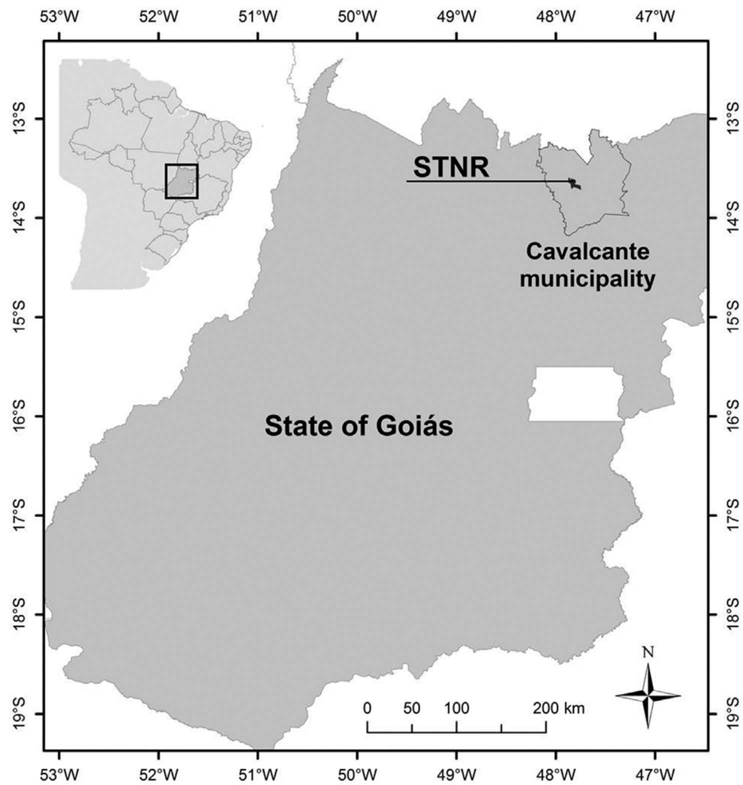

Figure 1. Study area in the Cavalcante Municipality, in northern Goiás, Brazil.

the distribution of different phytophysiognomies throughout the landscape could reflect the distribution of different faunal Cerrado communities (Alho, 1986; Costa *et al.*, 2007). Landscape units can be determined by the overlay of different spatial characteristics, such as geomorphology, vegetation, soil use and occupation, topography, hydrograph, hypsometry, and declivity (Bittencourt and Pivello, 1998). Therefore, homogeneous units could be considered more faithful models for subsidizing the ecological zoning of PA, since similar faunal taxocenoses can be expected to occur in similar landscape unities (Oliver *et al.*, 2004). Landscape Units (LU) are the basis for BIV spatialization.

Herein, landscape units (LU) were identified as the combination of vegetation classes (physiognomies) and lithologic classes. We assume that the LU represents local diversity, acting as a spatial surrogate for biodiversity.

The lithological classes on RNST, three in total, correspond to geological groups present in the Reserve: Araí-Arraias (AA), Araí-Traíras (AT), and Paranoá (P). After the landscape unit identification we determined the sites for faunal sampling so all landscape units are covered with at least one sampling site.

The vegetation classes were obtained through supervised classification of Ikonos images, taken in June 2008. This classification was later checked in the field. Natural vegetation classes were defined as Cerrado *sensu stricto*, rock cerrado, open fields, veredas, and forests. Recovery forests, natural pasture, and planted pasture were considered altered vegetation classes. Natural vegetation classes were considered more relevant for biodiversity and therefore, its weight was higher than altered vegetation classes. Altered classes were hierarchically grouped, according to their degree of human impact. Planted pastures were the most altered class due to deforestation, presence of exotic grasses, and past livestock grazing level. The native pastures experienced grazing for a long time period, and sparse invasion of exotic grasses facilitated by the cattle affected the recovery of some areas on RNST. Regenerated forests experienced intensive removal of biomass, but most areas have been recovered by pioneer species.

Biological Importance Index

To map the biological data we used the Biological Importance Index (BIV) (Brandão *et al.*, 2011). The BIV (Brandão *et al.*, 2011) is based on faunal richness (total number of species), autoecological characteristics such as habitat associations or physical constraints, and the species' conservation status, determined by following the Brazilian Official List of Threatened Species (mainly MMA, 2003). It is calculated for each LU, multiplying the richness (R) of the LU by the number of indicator species (I). One issue with this equation is that the two variables are equally important to the weight of the BIV, independent of whether the species are native or invasive. We propose generating the BIV value by dividing the number of indicator species (I) by the richness (R) of the LU (Equation 2). In this way, the indicator species (I) is the most important parameter of the BIV and is the proportion of indicator species of the LU. The BIV must be calculated by taxon, and the total BIV of the LU is the sum of these partial BIVs:

$$\mathbf{BIV = I \times R} \qquad \text{Equation (1)}$$

$$\mathbf{BIV = I / R,} \qquad \text{Equation (2)}$$

where,
I = number of indicator species
R = species richness

The indicator species are those cited in red lists (MMA, 2003), or by having certain autoecological character-

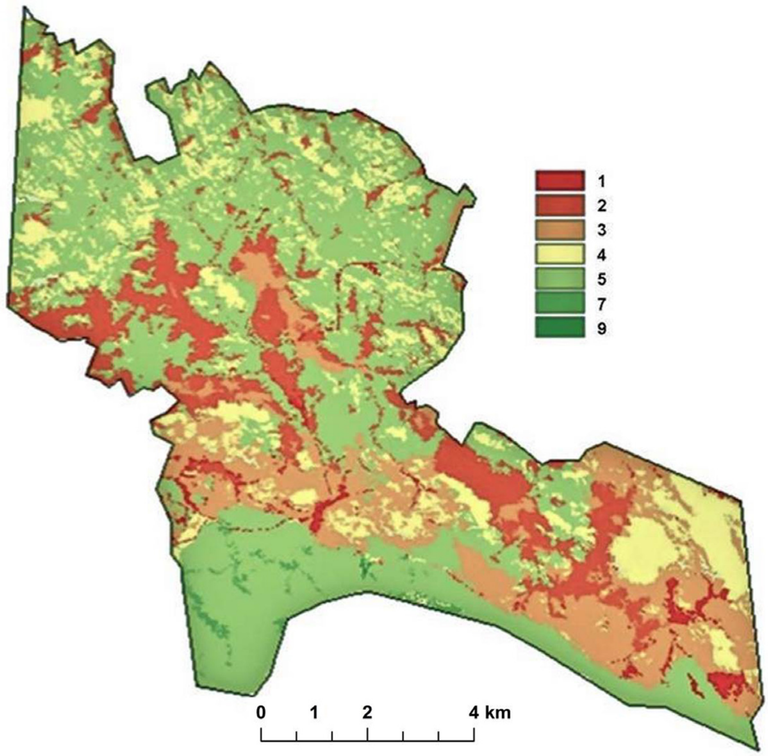

Figure 2. Values attributed for each Landscape Unities of Serra do Tombador Natural Reserve, Goiás, Brazil, based only on Values of Biological Importance (BIV). The scale is from the lowest value of importance for biodiversity (1) to the highest one (9).

istics, or other special local function (hunting, commercial uses, being high level predators). These categories are not exclusive, i.e., species can be classified as threatened, hunted, and habitat-specialist simultaneously. In cases where the species harbors more than one importance class such species are counted according to the "I" value.

The faunal sampling methods must be adjusted to the objective and taxonomic groups, but the sampling effort must be the same for all sampling sites. If one LU is sampled twice, the BIV for this LU is the mean of the values found, to attribute the same BIV for the same LU. The taxonomic groups used as indicators may vary with researchers' financial resources, management objectives, and the area characteristics.

Data on the presence of medium and large terrestrial mammals, birds and reptiles were sampled in June 2008 by a specialist team that used the Rapid Ecological Assessment (RAP) protocols (Sayre *et al.*, 2003). Mammals were sampled by tracking and direct visualization. Reptiles were sampled along transects by carefully checking retreat sites and birds were recorded by direct observation and zoophony. The BIV was calculated based on the faunal sampling results for each LU, producing a layer of spatial information (Table 1). The total VIB was adjusted in classes between 1 and 9 (less important to most important) to be used in the GIS tool described below.

Aditional data

Besides the VIB and the vegetation classes, we used density of roads (line density in a 100 m radius) and a hydrographic buffer (30 m) drawn above Ikonos images.

Although some organisms are not directly affected by roads (Forman and Deblinger, 2000), this kind of disturbance on environment interferes with the behavior of several species, leading to changes on habitat use, movements, and reproductive success (Trombulak and Frissell, 2000). Roads affect soil density, temperature, water quality, insolation, and sedimentation (Trombulak and Frissell, 2000). Furthermore, the majority of animal mortality occurs in points of high-quality habitats crossed by roads (Pereira *et al.*, 2011). Road density was produced by the "line density" command framework of ArcGis 9.2, which calculates the magnitude of linear features by area unit, in a previous choice radius from the lines (ESRI, 2009). In this case, the radius was established to be 100 meters, reflecting a minimum area of a road's influence on natural communities (Forman and Deblinger, 2000). The road density resulted in one class of strong disturbance and three classes of small disturbance. The main road was considered of strong impact (weight 3). One old road in a sloped area received weight 2, due to some erosions in its bed, and the other roads, that are rarely used, received weight 1.

The same procedure was done for the hydrograph. We used a buffer of 30 meters from the drainage, following the Brazilian legislation for the Permanent Protected Areas (APP). Riparian habitats are of fundamental relevance for several taxonomic groups. Even intermittent creeks are important, due to the presence of endemic habitat specialist species (Brandão, 2002).

Areas of Biological Relevance

We used a GIS framework for weighted overlay to create the Areas of Biological Relevance (ABR), a single layer of information to support the zoning of the STRN. This framework performs arithmetic operations between the spatial information layers and their layer classes. It allows us to stagger data from different scale, applying a standardized unit of measure (ESRI, 2009). We attributed an influ-

Table 1. Biological importance values for landscape units in a protected area of the Cerrado biome, Brazil, and its weight for the weighted overlay (AA= Araí-Arraias geologic group; AT = Araí-Traíras geological group; P = Paranoá geological group). The final BIV was adjusted to a 1 to 9 scale in Weight Overlay tool.

Landscape unit	BIV mammals	BIV reptiles	BIV birds	BIV Total	Class adjusted value
AA Forest	2.33	1.00	0.27	3.60	7
AA Field	1.00	1.00	0.36	2.36	4
AA rock Cerrado	1.625	0.80	0.34	2.765	5
AA Vereda	2.00	2.00	0.44	4.44	9
AT Cerrado	1.33	0.50	0.35	2.19	3
Natural Pasture	1.60	0.75	0.34	2.69	5
AT Forest	1.00	0.00	0.09	1.09	1
AT Field	1.00	0.50	0.35	1.85	3
AT rocky Cerrado	1.00	1.00	0.29	2.29	4
AT Vereda	2.00	0.00	0.30	2.30	4
P Forest	1.00	0.25	0.30	1.55	2
P Vereda	1.50	1.00	0.35	2.85	5
P Field	1.33	1.00	0.29	2.62	5
Planted Pasture	1.33	0.25	0.24	1.83	2
Recovering Forest	1.00	1.00	0.16	2.16	3
P Cerrado	1.83	0.67	0.31	2.81	5
P Rocky Cerrado	1.00	1.00	0.46	2.46	4

ence weight for each class (vegetation classes, BIV, density of roads, and a hydrographic buffer) into the layers, ranging from 1 (least important) to 9 (most important), using interpolation (Table 2). The weighting was attributed as percent distribution for all layers. The result is a new layer representing different classes with a range of conservation importance.

Results

In Serra do Tombador Natural Reserve (RNST), the veredas were identified as the most relevant habitat (Figure 2), reflecting their large number of endemic and or threatened species. Furthermore, the veredas are very fragile ecosystems that are a rare habitat in the reserve landscape. The largest BIV were obtained, respectively, in the AA Vereda and in the AA Forest (Table 1, Figure 2). Fluctuations on BIV values for the same LU are a product of sampling biases or intrinsic differences caused by factors such as seasonality and populational changes in space and time.

We found nine classes of ABR in RNST (Figure 3). The areas of larger values of biological relevance must be treated as restrictive management zones, whereas those with smaller values must be included in zones destined for ecosystem recovery and management. Some of these areas are located close to roads, and are very altered and fragile.

Discussion

All current methodologies for PA zoning are subjective (Silva and Santos, 2004). These methodologies are not replicable and do not clearly incorporate the biological data. The methodology proposed here reduces the subjectivity of the zoning and clearly combines layers of spatialized information within which the influence of each one is specified and controlled.

In the environmental zoning of the Arroio Grande basin (State of Rio Grande do Sul, Brazil) map algebra was used to combine soil characteristics, slope, lithology and land use (Ruhoff *et al.*, 2005). In a small protected area in the State of São Paulo, the zoning was based on grouping similar UPs which were associated with slope and different protection needs (Bitencourt and Pivello, 1998). These two examples do not incorporate biological data into the zoning, or its use is subjective and may lead to faunal losses in these PAs. In the Rola Moça Park, State of Minas Gerais, the criteria used for zoning were based on physical and biological features, where the biological data obtained by a RAP was extrapolated for phytophysiognomies (Drummond and Martins, 2007). Brandão *et al.* (2011) also used phytophysiognomies as LU in National Parks of Serra da Bodoquena and Chapada dos Guimarães. This method prioritized some vegetation classes without clear reasons, and this may reflect negatively in the zoning. The absence of standard values of faunal diversity affected the zoning of another area in South Brazil (Zanin *et al.*, 2005).

Most PA zoning present no biological data or non standardized sampling efforts and methodologies that are restricted to a few points in the area (Bitencourt and Pivello, 1998; Borges *et al.*, 2004; Ruhoff *et al.*, 2005). In the State Park of Desengano, a multicriterion analysis was conducted using physical attributes and a single layer of fauna and vegetation fragility (Jamel *et al.*, 2007), which not necessarily reflects real biological attributes. Such studies expose the gap between the data gathered in the field on diversity and the PA zoning. The use of the BIV and ABR brings new insights because the biological data is the driving factor for zoning planning. Moreover, this framework allows the prompt use of biological data on the zoning, showing which areas harbor more fragile or relevant animal communities.

The sample design and the implementation of biological inventories must be standardized, allowing the direct com-

Table 2. Attributed weighted overlay values for the zoning of Serra do Tombador Natural Reserve (RNST), Goiás, Brazil. The effect is the percent value attributed to each layer and the weight is the class value of the layer.

Permanent Protected Area (PPA)	**Effect**	**10%**
Outside PPA	**weight**	1
Inside PPA		9
Vegetation	**Effect**	**35%**
Exposed soil		1
Planted pasture		2
Natural Pasture	**weight**	3
Recovery Forest		4
Natural Phytophysiognomies		9
Roads	**Effect**	**10%**
High		1
Medium	**weight**	2
Low		-
Inexistent		9
BIV	**Effect**	**45%**
Slope		-
AT Forest		1
P Forest, Planted Pasture		2
AT Cerrado, AT Field, Recovery Forest	**weight**	3
AA Field, AT Rock Cerrado, AT Vereda, P Rock Cerrado		4
AA Rock Cerrado, Natural Pasture, P Vereda, P field, P Cerrado		5
AA Forest		7
AA Vereda		9

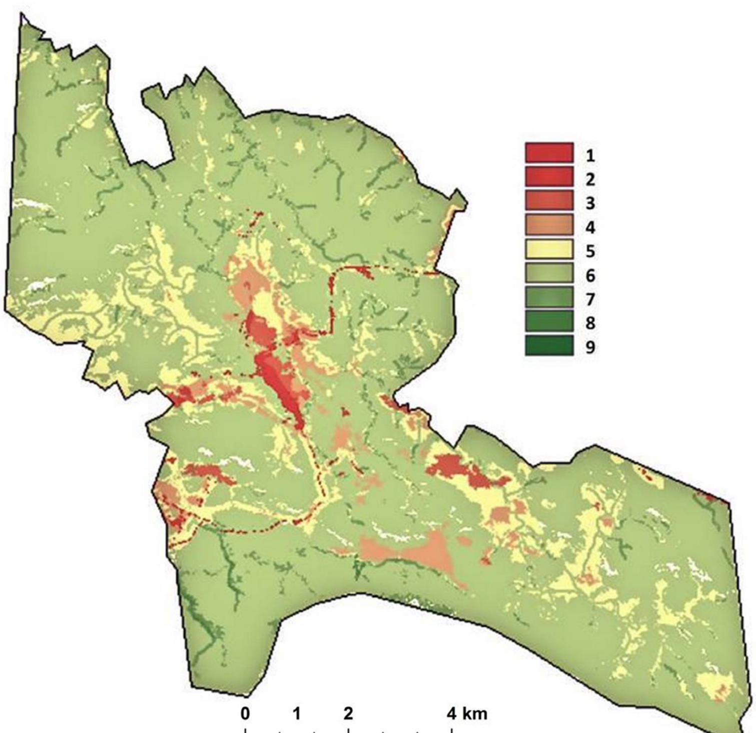

Figure 3. Areas of Biological Relevance (ABR) proposed to be used for zoning Serra do Tombador Natural Reserve, Goiás, Brazil, based on the result of the weighted overlay performed with vegetation classification, buffer of hydrology, buffer of roads and Biological Importance Value (BIV). Values represent the classes used to design the zones of the PA, between 1-3 areas for intensive use, including buildings and specific recovery activivites; 4-5 areas for natural recovery, touristic, and educational use; and up to 6 fully-protected zone.

parison between different LU and different PA. The sampling in LU is the most suitable to produce relevant data for zoning because it can act as a more efficient diversity surrogate than sampling only vegetation, as it has been done in other studies (Bitencourt and Pivello, 1998). One of the premises for the BIV use is the standard sampling for all LU. Two essential preconditions for standard sampling are the previous identification of the LU and a thorough planning of the sampling. This process represents a conceptual gain for PA zoning and RAP methodology.

Conclusions

The classes with larger ABR values must be considered more restrictive zones, allowing only research, management or educational activities. Zones destined for special use (accomodation, buildings, offices, and garages) or intensive use (touristic accomodation, restaurants, gift shops, or snack bar) must be allocated in areas with low ABR, especially those previously used. Zones for ecosystem recovery could be established in intermediary ABR values. These recovery classes demand different management actions due to different kinds of affected habitat and previous human activities (exotic pastures, gully erosions, roads). Tourist attractions could be implanted in the most restrictive zone, but access and trails would have to be delimited to specific sites, since there is no need to allow tourism activities in larger areas in certain zones. The relief characteristics of RNST limit these activities.

It is important to note that the zoning produced by the BIV methodology must always be evaluated by the reserve managers and administrators to include the local reality and political considerations before the final reserve zoning. However, this proposed zoning method provides essential subsidy and spatial information, that must be used as the conceptual basis for an effective zoning.

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