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Criteria definition for delimiting a buffer zone to a biosphere reserve in southern Brazil

Critérios para definição de zona de amortecimento de impactos para uma reserva da Biosfera no sul do Brasil

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Abstract

Taim Ecological Station (ESEC Taim) is a biosphere reserve (MAB) in southern Brazil located on the coastal plain of the state of Rio Grande do Sul, within a complex system of wetlands and lagoons. Although more than three decades have passed since its implementation in 1978, the situation of ESEC Taim is not well set yet. Among the main problems, there are the land issues, with pending expropriations, and the lack of a buffer zone (BZ) and a management plan, both instruments granted under the Brazilian law. Such is the context in which this study was developed, proposing the elaboration of an environmental study and the identification of criteria for the construction of BZ scenarios for ESEC Taim. The BZ proposals presented in this study were built based on aspects related to geology, landscape ecology, uses of the surroundings, adaptation of limits from Brazilian legislation and directions from the International Union for Conservation of Nature (IUCN). This information was inserted into a digital database in a geographic information system (GIS), where multi-criteria analysis was accomplished, and from which three scenario proposals resulted. Essentially, Scenario "zero" is the current situation of ESEC Taim, with the projection of the minimum distances specified in national decrees for the protection of the surroundings; Scenarios I and II present ecosystem proposals seeking to contemplate all the water system to which the ESEC Taim belongs, maintaining the ecological relationship with the adjacent landscape, with easily recognized boundaries in the field. Scenario II does not include some categories of areas safeguarded by the Brazilian law and under which there is the intention of creating new protected areas. Ideally, we believe that Scenario I, for covering most of the natural environments that are related to the ESEC, as well as the adjacent economic activities, is the one with the greatest potential to constrain threats and to improve the environmental quality of ESEC Taim and its surroundings through more cautious and oriented management of the uses of such territory.

Keywords: protected areas, GIS, wetlands, conservation, Taim.

Resumo

A Estação Ecológica do Taim (ESEC Taim) é uma Reserva da Biosfera no sul do Brasil, localizada na planície litorânea do estado do Rio Grande do Sul, inserida em um complexo sistema de banhados e lagoas. Apesar de já se terem passados mais de três décadas desde a sua implantação, em 1978, sua situação ainda não está bem resolvida. Dentre os principais problemas, encontram-se a questão fundiária, com desapropriações pendentes, e a carência de zona de amortecimento (ZA) e de plano de manejo, ambos instrumentos previstos na lei brasileira. É neste contexto que este trabalho se desenvolveu, propondo-se a elaborar uma avaliação ambiental e a identificação de critérios para a construção de cenários de ZA para a ESEC Taim. As propostas de ZA aqui apresen-

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tadas foram construídas com base em aspectos relacionados à geologia, à ecologia da paisagem, aos usos do entorno e à adaptação de limites da legislação e de instruções de guias da União Internacional para Conservação da Natureza (IUCN). Essas informações foram inseridas em um banco de dados digital em um sistema de informações geográficas (SIG), onde foi realizada uma análise multicritério, a partir da qual foram geradas três propostas de cenário. Essencialmente, Cenário "zero" representa a situação atual da ESEC Taim, com a projeção das distâncias mínimas previstas nas normas nacionais para a salvaguarda do entorno; Cenários I e II apresentam propostas de caráter ecossistêmico que buscam contemplar a integridade do sistema hidrológico ao qual a ESEC Taim pertence, mantendo a relação ecológica com a paisagem do entorno, com limites que facilitem o reconhecimento em campo. Cenário II não contempla algumas categorias de áreas protegidas por leis brasileiras e sob as quais existe a intenção de criação de novas unidades de conservação. Idealmente, acreditamos que o Cenário I, por abranger a maior parte dos ambientes naturais que possuem relação com a ESEC, assim como as atividades econômicas adjacentes, é o que possui maior potencial para a contenção das ameaças e para o aumento da qualidade ambiental da ESEC Taim e de seu entorno, através da condução melhor precavida e orientada dos usos neste território.

Palavras-chave: áreas protegidas, SIG, banhados, conservação, Taim.

Introduction

Protecting specific places of the landscape is a cultural and universal act practiced by people since ancient times when particular areas were segregated for the establishment of hunting reserves and for the protection of places that were considered as sacred by several cultures. The Yellowstone Park, created in 1872 in the United States, is the greatest mark of protected areas (PAs). Thereafter, these areas flourished around the world, mainly established because of the natural beauty of sites. From 1960 on, PAs became an important strategy for promoting the conservation of ecosystems and biodiversity (Eagles *et al.*, 2002; Watson *et al.*, 2014).

However, the advancement of studies on population biology led to the scientific recognition that the spatial limits of many parks were not enough for the movement of some species (Douglas-Hamilton *et al.*, 2005; Alexandre *et al.*, 2010). Concerns about external threats caused by land conversion and due to an increasingly diverse matrix of land use brought several problems to PAs delimitation. Invasion of exotic animals and plants, fire, water pollution, habitat restriction and isolation, construction of new roads and dams, as well as consolidation of new buildings in towns, villages and farms characterized these areas as real 'conservation islands' in the middle of economic activities. Thus, buffer zones (BZs) have been recommended in order to minimize the problem (Shafer, 1999).

Widely disseminated through UNESCO's Man and the Biosphere Programme (MAB) (Batisse, 1997), BZs have currently been applied to avoid human threats to PAs by establishing constraints on the use of natural resources ('hard core' conservationist view). Moreover, BZs add an extra layer of protection, besides providing economic benefits to the rural neighboring communities (socio-conservationist view) (Ebregt and Greve, 2000; Martino, 2001).

However, studies on BZs show no methodological consensus related to the delimitation of these areas. This definition is usually based on distances prescribed in guides (e.g.: 20 km, 10 km, 5 km, 2 km, 500 m) or based on criteria, yet these may vary according to different ecosystems and world regions. Most studies proposed to delimit BZs use multi-criteria analysis conducted with the support of the digital processing of satellite images in GIS – Geographic Information System (Mas, 2005; Costa *et al.*, 2009).

In biological terms, the main subsides have been maps of species distribution and the application of Landscape Ecology principles, including connectivity, heterogeneity, and patch size, through the analysis of land-cover vegetation in the surroundings of PAs (Alexandre *et al.*, 2010; Tambosi, 2008). Geological (geology, slope, soil type) and climate (rainfall, wind direction) aspects together with vegetation analysis, similarity of the surrounding environment, land use, accessibility and distance from urban areas are used to identify the vulnerability and fragility of land and also to support BZ delimitation (Rittl, 2011; Costa *et al.*, 2009; Guimarães *et al.*, 2009; Mas, 2005).

In Brazil, there are different kinds of PAs, such as the areas of permanent preservation, called APPs (e.g. buffers along the banks of rivers and lakes, areas with high declivity with slopes above 45°, hill tops), law reserves (perceptual of natural areas that must be kept in rural properties), excluded fishing areas, and conservation units (CUs), the latter referring to parks and other IUCN categories. The first instrument dedicated to protect the surroundings of Brazilian CUs was a federal decree that defined a minimum of 10 km for the environmental licensing of economic activities (Brasil, 1990).

In 2000, with the creation of the National System of Conservation Units (SNUC, Federal law n° 9.985), the country started to predict BZ in its

legislation (Brasil, 2000). Despite this progress, more than ten years have passed and only few Brazilian CUs accomplished to delimit these areas. Currently, the 10 km BZ, which provided the position of CUs in the licensing process, has decreased to 3 km and 2 km, depending on the type of land use (Brasil, 2010). This fact raises the probability of new threats, which leads to the need of Brazilian CUs to delimit BZs as soon as possible.

However, one of the difficulties has been the definition of a methodology for delimiting these zones. Ideally, the BZ limit must reflect the peculiarities of each CU and consider the existing uses in the surroundings, avoiding the use of general distances that hardly correspond to the needs of each CU context. A document prepared by IBAMA (Brasil, 2002), one of the executive institutions responsible for implementing Brazilian environmental policy, proposes a set of criteria that, together with case studies made by universities, has been guiding BZ definition in the country.

Therefore, aimed at contributing to the advancement of the topic, this paper shows the results of a study dedicated to draft a BZ for Taim Ecological Station – ESEC Taim, a PA in southern Brazil.

Material and methods

Study area

The study area comprises the entire land area of the municipalities of Rio Grande, Santa Vitória do Palmar and Chuí, the region whose central portion is currently occupied by ESEC Taim (32°42'30 S; 52°33'09 W). This area is part of the Quaternary coastal plain of Rio Grande do Sul, which is limited to the south by the border with Uruguay, by the Chuí Stream, to the east by the Atlantic Ocean, to the west by Mirim Lagoon and São Gonçalo channel, and to the north by Patos Lagoon (Figure 1). ESEC Taim, which was established by the federal decree n° 81.603 in 1978, occupies a total area of 33,815 ha, in a limit that has suffered changes by new decrees since the 1980s.

Methods

The main methodological stages used in this study can be visualized in the flowchart below (Figure 2). Considering the difficulty in determining criteria to guide the BZ design, a literature review was carried out in order to identify what kind of criteria has been commonly used or recommended in Brazil and other parts of the world (Brasil, 2002; Mas, 2005; Costa *et al.*, 2009; Guimarães *et al.*, 2009; Rittl, 2011).

Additionally, since understanding local reality is a prerequisite for the criteria establishment (Cicin-Sain and Knecht, 1998), a detailed environmental diagnosis was conducted at ESEC

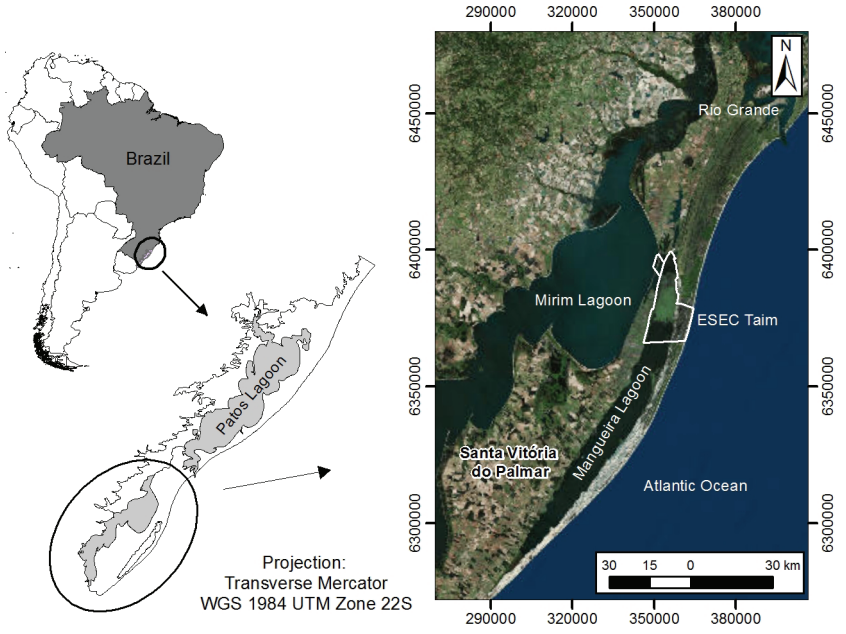

Figure 1. Location of Taim Ecological Station (ESEC Taim), southern Brazil.

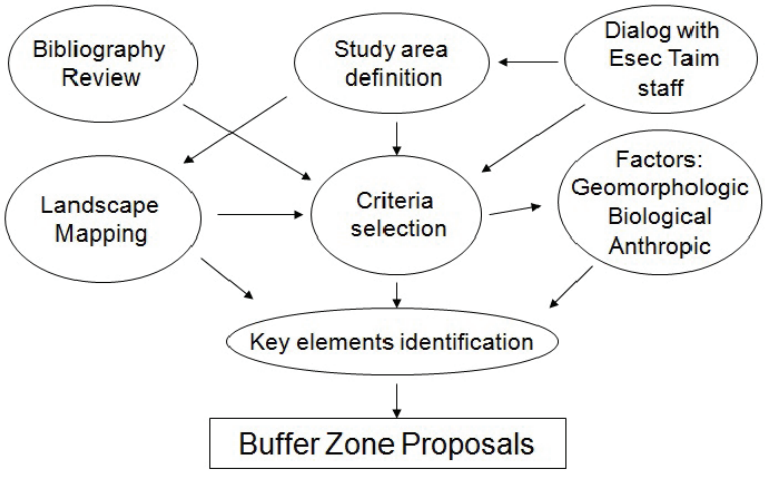

Figure 2. Main methodological stages to delimit the BZs.

Taim and its surroundings. The polygon with the boundary of ESEC Taim was drawn from information contained in azimuths and distances from the federal decree of 1978, the same one that created the Station, using the software CartaLinx. The mapping of land use classes (forestry, agriculture, livestock and urban areas), of natural environments (lagoons, wetlands, forests, sand dunes and grassland) and of the visual references existing in the landscape (roads, paths, fences, creeks, irrigation channels, margins of pounds and shoreline) was performed by visual interpretation of image of ALOS (Advanced Land Observing Satellite), from July 2010, with a 2.5 meters resolution in the panchromatic band, with the aid of field recognition. The polygons and lines were drawn in the CartaLinx software, then rasterized in GIS Idrisi Taiga and stored in a geo-referenced database. Afterwards landscape mapping was carried out an analysis to evaluate its level of modification, which was conducted according to the classification system proposed by Forman and Godron (1986). The information basis of geo-environmental units (Tagliani, 2002) was inserted into the database to enable the recognition and the separation of the environments hydrologically connected to ESEC Taim in the study area.

The criteria used to select the BZ limits were established with the support of the database, detecting the factors responsible for the maintenance of the environmental quality of the ESEC Taim area, as well as the interdependence between the different environments (e.g. hydrological connectivity, landscape connectivity), including those with economic activities. A rationale was established for the inclusion of each BZ criterion, besides the selection of areas or limits associated to each criterion.

The mapping of the potential BZ areas for ESEC Taim enabled three scenarios to be generated ("zero", I and II) based on overlay routine, reclassification, calculation of distances, and areas available in GIS.

Results and discussion

Environments in the ESEC Taim area

The ESEC Taim is a sample of ecologically important environments from the southern Brazilian coastal plain. The lower parts of the land are occupied by extensive wetlands, consisting essentially of pounds and swamps, while in the higher parts there are grasslands, forest remnants and sand dunes, environments that are also distributed in the surrounding farms.

The water connectivity and the existing lagoons and wetlands reflect a geological and geomorphologic evolution occurred in the last 400,000 years, during the later part of the Quaternary Period, directly influenced by changes in the sea level (Villwock and Tomazelli, 1995). The formation of marine terraces during transgressive times barred the continental drainage and allowed the formation of lagoon systems in its internal part (continental). Mirim lagoon was the first major pound to be isled, but keeping a large communication with the Atlantic Ocean in the region of Taim. The ocean retraction in the region during the last 6,000 years caused the end of such communication, originating Taim wetland, as well as forming Mangueira lagoon and the current

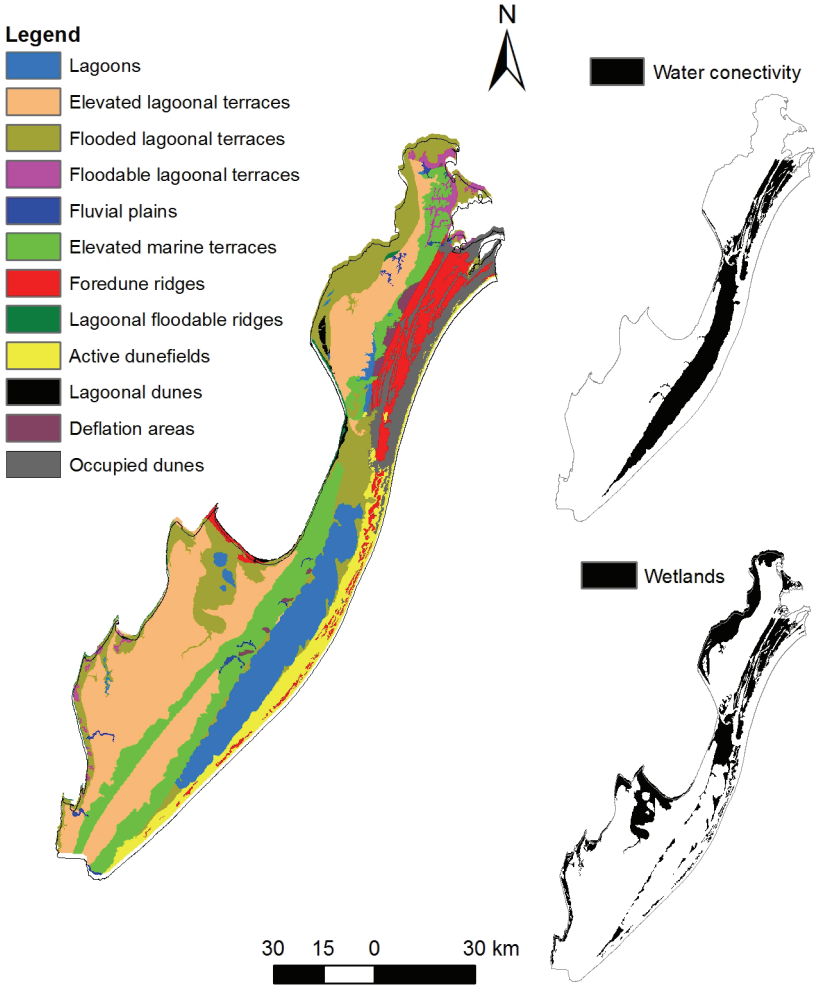

Figure 3. Geological and environmental units, areas connected through water to Taim Ecological Station, southern Brazil, and wetlands occurring inside the CU.

marginal wetlands in the whole lagoon system of the area.

The ESEC Taim area belongs to a broad hydrological system formed by a series of interconnected lagoons and wetlands constituting the Taim Hydrological System (THS), which far exceeds its legal limits (Figures 3, 4). As a result, economic activities that make intensive use of water in the region, such as rice farming, can influence significantly the water conditions inside the CU (Villanueva *et al.*, 2000).

Considering the criteria presented by Forman and Godron (1986) for landscape classification, the environmental diagnosis performed revealed that the surroundings of ESEC Taim are at an intermediate level of modification. There are still large tracts of natural areas, but also a significant part with introduced crop, such as agriculture and forestry, in addition to the grasslands with livestock (Figure 5).

The small villages associated with timber industry and artisanal fisheries (e.g. Capilha Village) are the major urban centers in the region. In addition, there are just scattered seats of farms and ranches. The landscape is intensively geometrized due to roads, irrigation channels and fences that bound the properties (Figure 5). With regular shapes, the number of landscape patches is remarkable; it is common to find remnants of natural patches disconnected from each other or isolated amid the crops.

The main uses and economic activities, as well as the potential threats they represent to the ecosystem of ESEC Taim, have been detected and reported by several authors (IPH, 1996; Villanueva *et al.*, 2000; Santos *et al.*, 2008b). Recently, the land conflict due to unfinished expropriation allowed some landowners to retake the right to use areas that are undergoing such process. Currently, ESEC Taim managers are engaged in resolving the land conflict. Table 1 shows how these uses affect the environmental quality of the CU. Gomes *et al.* (1987) have evinced a concern about the uses in

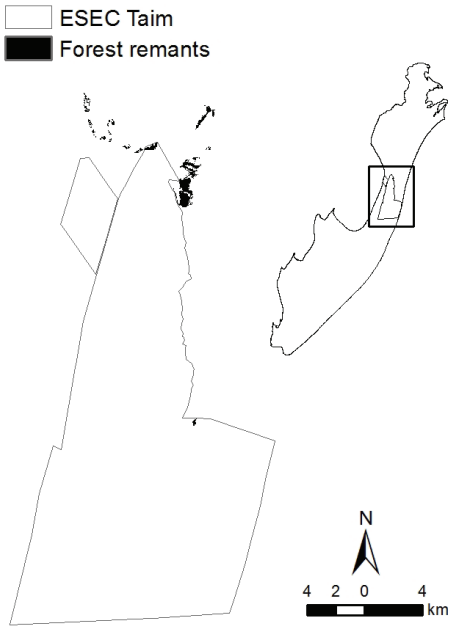

Figure 4. Distribution of forest remnants in Taim Ecological Station and its surroundings, southern Brazil.

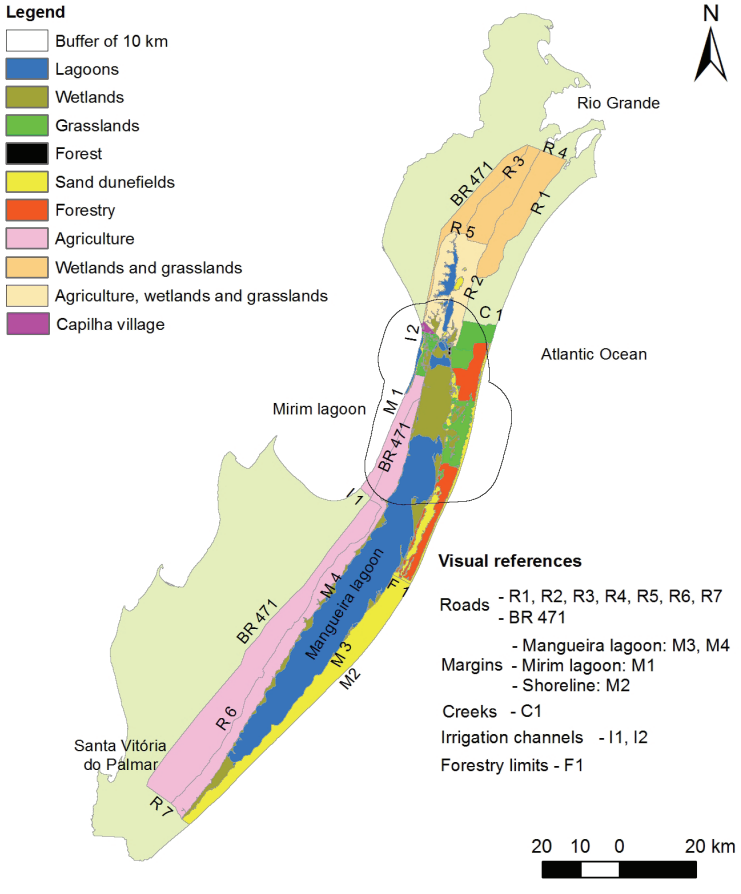

Figure 5. Key-elements to define the BZs for Taim Ecological Station, southern Brazil.

Table 1. Impacts and potential threats related to the main uses of the ground in the surroundings of Taim Ecological Station, southern Brazil.

Source	Threats	References
Agriculture	Excessive decrease of water body level due to water extraction for irrigated rice, threatening biodiversity	IPH (1996); Villanueva *et al*. (2000); Tassi *et al.* (2007)
	Contamination of water bodies by fertilizers and pesticides	Primel *et al.* (2005); Grützmacher *et al.* (2008); Santos *et al.* (2008a); Santos *et al.* (2008b); Andrade *et al.* (2012)
Forestry	Habitat loss and fragmentation; isolation of the landscape	Forman and Godron (1996); Burger (2000)
	Natural dispersion of invasive plants	Pivello (1999)
Livestock	Changes in ground water recharge	Oliveira *et al.* (2002)
	Zoonosis dissemination among wildlife	
	Affects the natural regeneration of vegetation and alters the dynamics of the natural system	Durigan *et al.* (2006)
Roads	Running over wildlife, habitat fragmentation	Monitoring conducted by ESEC Taim; Bager and Rosa (2010)
Energy transmission lines	Potential impact on migratory birds	Inatomi and Udaeta (2005); Jenkins *et al.* (2010)
Hunting and fishing	Poaching within ESEC Taim and use of illegal nets in the vicinity	Burger (2000)
	Pollution by garbage and camping structures	Observation in loco
Fires by anthropic causes	Impact on biodiversity	Morsello (2001)
Expansion of towns and industry	Increase of land use pressure and new potential impacts from anthropic cause	Observation in loco
Sand dunes migration	Suppression of natural environments by landfill	Morsello (2001); Guimarães (2005)
Tourism	Increase of land use pressure and new potential anthropic impacts	Observation in loco

ESEC Taim environs, and highlighted that the CU could not be as an island surrounded by economic activities. These authors also defended that a BZ should be created to guide uses with great caution.

Criteria for delimiting a BZ for ESEC Taim

Given the particular characteristics concerning the socioeconomic context and the local environment of ESEC Taim, several criteria were selected, which should be taken into account when delimiting a BZ for this CU. Such criteria, their rationale and the associated natural environments are shown in Table 2. From the consideration of the discussed criteria, the basic elements for the construction of three BZ scenarios for ESEC Taim were selected from the digital database.

The environmental and geological units adapted from Tagliani (2002), which were defined based on the geological and geomorphologic map of the Brazilian Company of Mineral Resources Research (CPRM, 2000), are shown in Figure 3. From that just the environments showing hydrological connectivity to ESEC Taim, as well as the wetlands, were selected.

Forest remnants are mainly found in the surroundings of ESEC Taim, except for two patches that do not exceed 0.01% of the CU (Figure 4). Although very fragmented by land occupation and use, the forest patches of the region are close to each other in its distribution. Considering the low occurrence of forests inside the limits of ESEC Taim, it is important to encompass this environment within the BZ. Such remnants act as habitat for endangered species related to the CU, such as *Lontra longicaudis* (Olfers, 1818), *Circus cinereus* (Vieillot, 1816), *Leopardus geoffroyi* (d'Orbigny & Gervais, 1844), *Liolaemus occipitalis* Boulenger, 1885, *Ctenomys flamarioni* (Travi, 1981) (Fontana *et al.*, 2003; Machado *et al.*, 2008; Bager and Fontoura, 2013), have great importance to the gene flows in the surroundings. Through a handling operation, the vegetation could be reconnected, thus promoting better integration between the ESEC Taim and the vicinity as well as aggregating better environmental quality to the whole region.

The other environments, locations and elements related to the remaining criteria shown in Table 2 were selected

Table 2. Criteria to BZ delimitation, their rationale and associated environments.

Criterion	Rationale	Environments
Water connectivity	Maintenance of adequate hydrological conditions	Lagoons, wetlands, temporarily flooded areas connected to the Station
Connectivity between patches of forest remnants	Maintenance of genetic flows and remaining natural habitats	Hardwood forests
Landscape heterogeneity	Protection of highly biodiverse areas	Areas composed by three or more types of natural landscape environments
Watershed protection	Maintenance of the quality of water resources	Margins of pounds and wetlands
Inclusion of other classes of protected areas	Intensification of control over such areas	Active and fixed sand dunes, watershed buffers, forests, shore line, etc.
Current uses	Better regulation of the uses for mitigating negative effects	Areas occupied by agriculture, forestry, livestock, urbanization and roads
Visual references in field	Facilitating the identification of BZ limits by the community, as well as its policing	Roads, creeks, shore line, margins of pounds and irrigation channels
Inclusion of historic and human heritage	Obtaining community support and promoting organized tourism	Capilha Village, ancient chapel and Mirim lagoon beach
Adaptation of existing protective buffers in national laws	Using limits traditionally regarded as BZs by the population	Traditionally used by environmental agencies as a base limit for licensing economic activities

from maps integrating the database. They were gathered into one basis-map (Figure 5) from which the three scenarios of BZs were generated.

Proposals for a BZ for ESEC Taim

Scenario "zero" (Figure 6) represents the current situation of the ESEC Taim and its water system, in the absence of a defined BZ, only with the projection of areas established in national legal documents in the surroundings of CUs (buffers of 10, 3 and 2 km), applied to the limit of ESEC Taim. Scenarios I and II (Figure 6) were defined from the consideration of key-elements for the establishment of BZs for ESEC Taim, as shown in Figure 3. Both scenarios include great extensions of lagoons, wetlands, fields, sand dunes, forestry and rice crop. The systemic approach when defining criteria led to the inclusion of areas distant from the CU but indirectly interfering with the environmental conditions of ESEC Taim. The main differences are related to the degree of comprisal of THS, to the inclusion/exclusion of urban areas and to the intention of Brazilian government in creating new CUs over areas included in the proposals (MMA, 2007), where large proportion of these belong to the APPs, other category of protected area predicted in the Brazilian law.

With a total area of 270,000 ha, Scenario I is a more conservative option in which THS was comprised almost entirely. Ideally, this is the most complete proposal, once Scenario I shows a design that enables the PA to fully manage the related surrounding areas, considering that the CU can only act inside its limits and in its BZ. Moreover, by including the urban areas, it may develop a better relation with the traditional community of Capilha Village, which is adjacent to the Station.

When considering the whole THS as in Scenario I, there is a disadvantage of comprising a greatly extensive area (about 200 km), given the nature of such water bodies, which will probably create some discomfort to the landowners. Despite a possible conflict issue, the proposals bring only an external limit. Ideally, a BZ must have distinct levels of restriction of activities (i.e. zoning), which should be reasons for debate and agreement between the individuals who intervene in such process (Hull *et al.*, 2011).

Scenario II has an area of 200,600 ha and results from an effort to consider polemic issues, such as the orientation to exclude from the BZ urban areas predicted in the Comprehensive Plans of the Municipalities (Brasil, 2002). In this scenario, there was also the exclusion of Maçarico wetland, to the north, and Albardão sand dunes, to the south, taking into account that there is the intention to create new CUs throughout these lands as predicted in the list of the Brazilian Priority Areas for the Conservation (Brasil, 2007). Thus, a proposal with smaller total area was possible, where only THS lagoons were included.

Still regarding the size and the composition of scenarios, in the private areas included in the proposals, there are areas previously protected by the Brazilian environmental law, such as natural forests, sand dunes, wetlands and margins of water bodies (State Environmental Code, Law 11.520 of 2000; Resolution no. 303 of CONAMA;

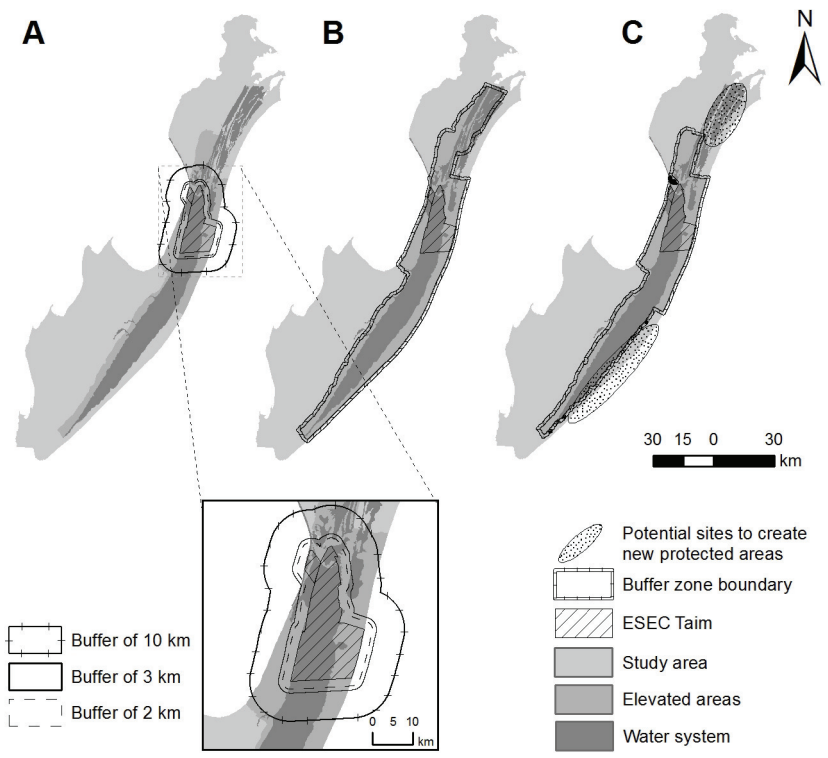

Figure 6. BZ proposals applied to ESEC Taim: (A) Scenario "Zero", (B) Scenario I, (C) Scenario II.

Forest Code, Federal Law no. 12.615 of 2012). Besides, Mangueira, Caiubá and Flores lagoons are areas under the domain of the State of Rio Grande do Sul and represent a substantial proportion of the area of all scenarios.

Related to ESEC Taim, its water system and the other selected criteria, the adoption of visual references to limit BZ parts (especially adjacent roads) made Scenarios I and II identifiable in field, facilitating the recognition of BZ limits by the community, as well as its policing.

Conclusions

Literature shows that various aspects interfering with the delimitation of BZ should be more discussed in the country concerning the concept of the BZ adopted in the Brazilian law and the criteria that have been suggested for its delimitation.

The criteria for delimiting the BZ as proposed by the Brazilian Environmental Institute – IBAMA (Brasil, 2002) are broad, but do not offer elements to deal with economic areas of the vicinity, which frequently represent most part of the CUs surroundings. Despite the difficulty in defining limits, these areas are one of the central management elements because of the potential impacts incorporated by them (van der Meer *et al.*, 2014). The government should organize a national discussion on this issue, similar to what was done to discuss methodological rules and details to guide ecological and economic zoning in the country (Brasil, 2001).

Without comprising the integrity of spaces capable of determining and influencing the environmental conditions inside the limits, the creation of CUs under inadequate delimitations – especially regarding the shape and the spatial dimension of the area – evinces the importance of defining a BZ that contributes effectively to the prevention of external adversities.

The selection of BZs in CUs is a complex task. The main challenges include the identification of criteria that reflect the environmental characteristics of each CU, the quantification of natural processes, which often are little known, and the need to find useful and truly integrated subsidies.

Nowadays, the technological tools for mapping are widely available to managers, which favors discussion and decision making. Besides, with the information planning of the geo-referenced database, data can be handled, altered, updated, and generate other scenarios depending only on the consensus related to the criteria of selection to be used. Such possibility reinforces the excellence of GISs as tools for environmental studies and support to decision making, as already indicated by several studies (Hjortsø *et al.*, 2006; Bunch *et al.*, 2012).

The developed scenarios materialize the first ideas for delimiting a BZ for ESEC Taim and represent the start of a discussion to subsidize its definition. Although established specifically to the surrounding environment of ESEC Taim, the criteria discussed in this study can be used for other CUs in Brazil, as well as the method, always taking into account the environmental characteristics of each PA.

The construction of a harmonic surrounding area for CUs do not depend only on the analysis of environmental licensing processes, since there are other issues that can be solved only through direct agreement with the involved users, such as the reconnection of woody vegetation, and better practices with agriculture and livestock. The success of a BZ implementation depends directly on negotiations and efforts to harmonize conflicts, a task which may be possible if there is ease not only to the CUs but also to the community involved (Cicin-sain and Knecht, 1998; Ahmad *et al.,* 2013). In the case of the ESEC Taim, these possibilities still need to be enumerated, and its mechanisms of implementa-

tion and negotiation with users need to be better known and identified.

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