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Environmental Zoning of the Camaquã State Park – Brazil

Zoneamento Ambiental do Parque Estadual Camaquã – Brasil

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Abstract

Brazil is one of the most megadiverse countries in the world and protected areas are the key to preserving environmental systems that remain from historical threats, such as urbanization, mining, planting of exotic species, and the expansion of agricultural activities like farming and livestock. Environmental zoning is the main tool for the management of protected areas as it is a useful option to mitigate conflicts and a key prescriptive tool for protected areas administration. This paper provides an environmental zoning of the Camaquã State Park (CSP), Brazil. The methodological guideline of the Brazilian Institute of Environment and Renewable Natural Resources was used with adaptations for the study area. It comprises: (i) the analysis of land use/cover changes (supporting land cover conservation criteria); (ii) the analysis of the geomorphological changes (supporting environmental variability criteria); and (iii) the identification and delimitation of homogeneous units for environmental zoning from the combination of land use/cover and geomorphological spatiotemporal data. This assessment was performed by mapping land use/cover and geomorphological changes in the study area in 1964 and 2012 scenarios. Results show that land covers have decreased 3.2%, while land uses had an increase of 12.8%. Irrigated rice represents the main vector of occupation and geomorphological changes. Anthropogenic landforms have had an increase of 189% and served as indicators for the delimitation of impacted areas. Five environmental zones were identified in the CSP, however, two occupy more than 70% of the study area: Intangible zone (40%) and recovery zone (34%). The zoning presented can only be applied in its entirety after land regularizing in the protected area.

Keywords: Protected Areas; Land use/cover; Geomorphological Changes

Resumo

O Brasil é um dos países mais mega diversos do mundo e as áreas protegidas são a chave para preservar os sistemas ambientais que restaram de ameaças históricas, como a urbanização, a mineração, o plantio de espécies exóticas e a expansão de atividades agrícolas, como a agricultura e a pecuária. O zoneamento ambiental é a principal ferramenta para a gestão de áreas protegidas, pois é uma opção útil para mitigar conflitos e uma ferramenta prescritiva chave para a administração de áreas protegidas. Este trabalho apresenta um zoneamento ambiental do Parque Estadual do Camaquã (CSP), Brasil. A diretriz metodológica do Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis foi utilizada com adaptações para a área de estudo. Ele compreende: (i) a análise das mudanças de uso/cobertura da terra (apoiando os critérios de conservação da cobertura da terra); (ii) a análise das alterações geomorfológicas (suporte a critérios de variabilidade ambiental); e (iii) a identificação e delimitação de unidades homogêneas para zoneamento ambiental a partir da combinação de uso/cobertura do solo e dados geomorfológicos espaço-temporais. Essa avaliação foi realizada por meio do mapeamento do uso/cobertura do solo e das mudanças geomorfológicas na área de estudo nos cenários de 1964 e 2012. Os resultados mostram que a cobertura da terra diminuiu 3,2%, enquanto o uso da terra teve um aumento de 12,8%. O arroz irrigado representa o principal vetor de ocupação e alterações geomorfológicas. As formas antrópicas tiveram um aumento de 189% e serviram como indicadores para a delimitação das áreas impactadas. Cinco zonas ambientais foram identificadas no CSP, no entanto, duas ocupam mais de 70% da área de estudo: zona intangível (40%) e zona de recuperação (34%). O zoneamento apresentado só poderá ser aplicado em sua totalidade após a regularização fundiária da área protegida.

Palavras-chave: Áreas Protegidas; Uso/Cobertura da Terra; Alterações Geomorfológicas

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1 Introduction

Protected areas are the cornerstones of biodiversity, geodiversity and ecosystem conservation, as well as more difficult to quantify cultural services such as recreation and spiritual fulfilment (Bernard, Penna & Araújo 2014; DeFries et al. 2007; Ontivero et al. 2008; Geldmann et al. 2015). Brazil is one of the most megadiverse countries in the world and protected areas are the key to preserving environmental systems that remain from historical threats (Mazza et al. 2016; Rylands & Brandon 2005). To avoid the changes caused by the conversion of the land cover into farmlands, forestry, mining and others, a large and complex system of protected areas has been gradually established (De Marques & Peres 2015).

Protected areas in Brazil are recognized as Conservation Units. The National System for Protected Areas (SNUC), created in 2000, administratively managed these areas at federal, state and municipal levels, dividing them into two types: strictly protected and sustainable use areas (Brasil 2000).

Although Brazil has more than 2.506.188 km² of its territory covered by 2.446 protected areas (MMA 2021), the number of paper parks (protected areas that exist only on maps and in regulations, with insufficient implementation) is a reality (Bernard, Penna & Araújo 2014; Del Carmen Sabatini et al. 2007). This conjuncture increases the vulnerability, the environmental losses, the boundaries changes, the reductions in size and, in extreme cases, the complete legal annulment of existing protected areas (De Marques & Peres 2015; Rylands & Brandon 2005).

The Brazilian Institute of Environment and Renewable Natural Resources (Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA) establishes that a management plan should be developed in up to five years after the creation of a protected area. The management plan is a technical document that aims to provide a lack of actions for planning and sustainable use of the natural resources inside and around the protected areas (Abreu 2015).

According to IBAMA (2002), one of the most important tools of the management plan is environmental zoning. This document is a territorial planning instrument, used as a resource to achieve better results in the management of protected areas, as it establishes different uses for each zone, according to its objectives (Dos Santos & Ranieri 2013; Lopes, Trentin & Simon 2019; Mazza et al. 2016).

The assignment of land units to specific uses, known as zoning, is a useful option to mitigate conflicts and a key prescriptive tool for protected areas administration (Walther 1986). The main criticism of zoning is that there is no clear mechanism to operationalize it on the ground (Del Carmen Sabatini et al. 2007; Hull et al. 2011).

Brazil has a specific methodological guideline for environmental planning in protected areas (IBAMA 2002). This methodological guideline describes the procedures for identification, delimitation and characterization of land units for environmental zoning from two physical-spatialized criteria:

Land cover conservation: Land use/cover maps can offer spatial and temporal data to achieve the recognition and delimitation of land units and support this zoning criterion. Areas with conserved land cover have less impact on local ecosystems and should allow the delimitation of zones with a higher degree of protection. These areas have to promote the compatibility of uses, the preservation and restoration of land cover. Finally, the most degraded land cover areas have to delimit recovery zones or zones with high use intensity.

Environmental variability: This criterion is based on the landforms compartmentalization and can be achieved by geomorphological mapping. Spatial organization of landforms and hydrography can explain the different stages of the landscape evolution and the distinct responses of the phytophysiognomies to these stages. Areas with a complex spatial arrangement of landforms and drainage networks must have greater protection. Anthropogenic landforms and geomorphological features resulting from environmental degradation should be recovered for preservation or special uses.

The IBAMA methodological guideline suggests that the land units identified from land use/cover and geomorphological maps could be defined by the following zoning designations: intangible, primitive, extensive use, intensive use, historical-cultural, recovery, special use, conflicting use, temporary occupation, indigenous territory overlap, experimental interference and buffer zone. However, the identification of these zones depends on their existence, the protected area typology (strictly protected or sustainable use areas) and the objectives of the protected area.

The IBAMA methodological guideline (IBAMA 2002) also guided the construction of the zoning of state parks in the state of Rio Grande do Sul, which are in more advanced stages of institution and management. Even so, state parks that have these normative instruments need to review and update their regulations and guidelines, after all, they were formulated more than a decade ago (Secretaria Estadual do Meio Ambiente/Departamento de Floretas e Áreas Protegidas [SEMA/DFAP], 2004; 2005; 2009; 2012; Secretaria Estadual do Meio Ambiente/Departamento de

Floretas e Áreas Protegidas/Fundação Zoobotânica [SEMA/DFAP/FZ], 2006; 2008; 2014).

Of the 12 state park-type conservation units that make up the State System of Conservation Units of the state of Rio Grande do Sul (SEUC/RS), 4 do not have a management plan and zoning: Camaquã State Park (object of this investigation), Papagaio Charão State Park, Podocarpus State Park, Quarta Colônia State Park.

This paper applies a methodological approach for the zoning of protected areas designed by the IBAMA (2002). The study area refers to the delta system inserted in the limits of the Camaquã State Park (CSP), a strictly protected area located in the Rio Grande do Sul state (south Brazil). It is not the definitive zoning scheme, however, it aims to provide the park's managers, as well as the other stakeholders, with an approach to zoning that is scientifically structured and can be discussed with technical staff and local inhabitants.

2 Materials and Methods

2.1 Study Area

A map of the CSP and its location is shown in Figure 1. The park was created on March 22nd of 1975 and covers about 123,08 km². The main objective of the park is to protect the wetlands and the subtropical forest inserted in one of the Brazilian most representative intra-lacustrine deltaic systems. This deltaic system is located in the connection of the Camaquã River (whose catchment basin has about 21,657 km²) with Patos Lagoon (one of the largest chocked coastal lagoons in the world with 10,360 km²) (Moller et al. 1996). It comprises an association of fluvial, lacustrine and maritime morphogenesis and morphodynamics that have been originating a singular landscape, whit environmental and scientific representativeness due to the biodiversity and geodiversity richness.

The CSP is located in the transition of two Brazilian biomes: the Pampa biome (characterized by grasslands scattered with shrubs and trees) and the Mata Altântica biome (semi-deciduous Atlantic forests). Additionally, the Park contains endemic species of both biomes, as the butiazais (palm groves from *Butia capitate* family), juncos (*Juncus spp.* or *Scirpuscalifornicus*), wetlands with the presence of sarandis (*Sebastianiaschottiania*) and corticeiras (*Erythina crista-galli*) (Burger 2000).

Although the environmental relevance and ecosystems fragility, the CSP still does not have a management plan, land regularization or environmental education actions and can be recognized as a paper park (Del Carmen Sabatini et al. 2007). Therefore, scientific studies that support these gaps in the Park management (as the need for environmental zoning) become relevant for the future effectiveness of the protected area.

2.2 Method and Data

In this section, we present the analytic procedures for environmental zoning in CSP, based on IBAMA (2002) methodological guidelines and adaptations according to specific characteristics of the study area. They comprise (i) the analysis of land use/cover changes (supporting land cover conservation criteria); (ii) the analysis of the geomorphological changes (supporting environmental variability criteria); and (iii) the identification and delimitation of environmental zones from the combination of land use/cover and geomorphological spatiotemporal data.

2.3 Land Use/Cover Changes

Two land use/cover maps from CSP were elaborated: one for the scenario before the creation of the Park (in 1964) and the other for the year 2012. Eleven panchromatic aerial photographs with an approximate scale of 1:40,000, dated December 4th and 5th, 1964, made available by the Department of Planning of the State of Rio Grande do Sul/Brazil, were used to elaborate the map of 1964. For the 2012 map, four images from the RapidEye satellite, from March 2012, with a spatial resolution of five meters, made freely available by the Ministry of the Environment (Geocatálogo MMA) were used. The interpretation of the images took place from the colour compositions of the visible range (R3, G4, B5) and false-colour with the addition of the near-infrared (Ir) band.

Land use/cover identification and classification followed the Technical Manual of Land Use guidelines, from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE 2013) and the directions from Simon and Trentin (2009). Three groups of land cover/uses were defined: (1) Agricultural land uses: livestock grazing, forestry, farm buildings, irrigated rice (distinguished because of its relevance in changing landforms and creating anthropogenic morphologies) and other croplands; (2) Non-agricultural land uses: urban area (referring to Santo Antônio local community, inside of CSP); (3) Natural land cover: forest, wetlands, short-grass, mixed-grass, water bodies and sandy surfaces.

Figure 1 Location of the study area and Delta front and tributary plain of the deltaic system of Camaquã State Park.

The following spatiotemporal patterns of the land use/cover maps were considered in the visual definition of land units for environmental zoning: (i) the evolution of primary vegetation over recent geological-geomorphological surfaces; (ii) the maintenance, reduction or fragmentation of land cover over time; (iii) the succession of forest over wetlands; (iv) the evolution of land covers over land uses; (vi) the existence of consolidated land uses over time; (vii) the occurrence of traditional communities (living or not in villages) or indigenous territories; (viii) the occurrence of access ways and proximity to the park borders; and (ix) the evolution of agricultural and non-agricultural land uses.

2.4 Geomorphological Characterization

Two geomorphological detailed maps (scale of 1:25,000), from the years 1964 and 2012, were elaborated from the same remote sensing data used for the development of the land use/cover maps described above. These maps followed the methodology suggested by Cunha (2001) and Cunha, Mendes and Sanchez (2003), who adapted the geomorphological mapping symbology from Tricart (1965); Verstappen and Zuidam (1975). Cunha (2001) proposed a label for geomorphological mapping used in environmental management and, therefore, is suitable for environmental zoning purposes.

Geomorphological features were identified in the geomorphological maps as follows: (i) Hydrographical features: fluvial channels, rain channels, abandoned channels without water, abandoned flooded channels and meander lakes; (ii) Accumulation forms: point bars, sandy bars, beach, lacustrine-fluvial terraces and lacustrine-fluvial plains; (iii) Paleo-landforms: sandy paleo-bars and abandoned meanders; (iv) Anthropogenic landforms: active rectilinear channels and inactive rectilinear channels.

The spatiotemporal patterns of the geomorphological maps were considered in the visual definition of land units for environmental zoning: (i) the existence of geomorphological active phenomena with scientific and environmental relevance (as the deltaic front); (ii) the maintenance of geomorphological features and processes; (iii) the existence of paleo-forms; (iv) drainage network changes (increase or decrease); (v) landforms appropriation and alteration for traditional land uses and practices; (vi) the occurrence of access ways and proximity to the park borders; (vii) the revolution or maintenance of anthropogenic morphologies.

The transition between the main landforms compartments (lacustrine-fluvial terraces and lacustrine fluvial plains) and the major hydrographical features (as the fluvial channels that divides the deltaic system islands) supported the visual delimitation of the zoning homogeneous units. These features are important physical obstacles for the spatial continuity of natural (biotic and abiotic) and anthropogenic processes.

2.5 Environmental Zoning

The identification and delimitation of homogeneous units for the environmental zoning at CSP were performed from the visual interpretation of the qualitative and quantitative spatial information obtained from 1964 and 2012 land use/cover and geomorphological maps. The combination of the physical-spatialized criteria used for the definition of zoning homogeneous units is presented in Table 1.

Fieldtrips were conducted for spatial data verification and update (especially for the data from the year 2012). Fieldtrips also allowed the recognition and the obtaining of photographic registers of the zoning land units presented in the results.

3 Results and Discussion

This section presents initially the results of land use/cover and geomorphological mapping that supported the recognition of homogeneous zoning units. Finally, the proposed environmental zoning for the CSP shall be presented.

3.1 Land Use/Cover Changes

In protected areas, the land use/cover dynamics shows the efficiency of protection policies and the success of the conservation actions developed (Lopes, Trentin & Simon 2019). However, in protected areas that have not been regularized, the land uses evolution analysis has an important role in the process of environmental zoning and the definition of the conservation unit's rules.

Six land covers were identified in the CSP: sandy surfaces, short-grass, mixed-grass, forest, water bodies and wetlands (Table 2). The evolution or maintenance of these land covers supported the identification of primitive and intangible zones.

These land covers have decreased 3.2% during the analyzed period (97.49 km² in 1964 and 95.25 km² in 2012). Although this decrease of the land covers, the forested areas have increased 7% as well as the wetlands (8%) (Table 2), mainly in the remote parts of the CSP, such as the deltaic front, the lacustrine spits and the fluvial islands of the deltaic system.

Table 1 Combination of the physical-spatialized criteria used for the definition of zoning land units.

Environmental Zones		Physical-spatialized criteria		
		Land cover conservation		**Environmental variability**
		Land cover/use maps		**Geomorphological maps**
Primitive Zone	=	Distance from Park borders, access roads and populated areas; Evolution of primary vegetation over recent geological-geomorphological surfaces; Maintenance of land cover or evidence of land cover succession (wetlands to forest) over time.	+	The existence of geomorphological active phenomena with scientific and environmental relevance (as the deltaic front and other accumulation surfaces); Absence of anthropogenic interventions.
Intangible Zone	=	Maintenance and low fragmentation of land cover areas: indicates limited access and low expansion of land uses; Evolution of land cover over land uses over time: indicates land uses contraction or changeover.	+	Maintenance of geomorphological features and processes over time: indicates the equilibrium in geomorphological dynamics; The existence of paleo-forms: indicates advanced stages of geomorphological phenomena and low anthropogenic perturbation; Reduction of drainage density: indicates the transition of wetlands to consolidate surfaces.
Intensive Use Zone	=	Consolidated land use areas (as traditional communities or ancient occupation); Preservation of surrounding land cover: indicates the integration of the inhabitants with the environment.	+	Landforms appropriation for traditional or local communities' practices and land uses; Maintenance of original morphologies and low intervention on geomorphological processes.
Recovery Zone	=	Decrease of land covers; Easy access: border areas of the Park are more susceptible for land use expansion and land cover changes; Agricultural and non-agricultural uses expansion that changes the structural and functional characteristics of the physical environment.	+	Easy access: the existence of primary or secondary roads allow different stages of geomorphological disturbances; Landforms appropriation an alteration for traditional land uses and practices; Evolution or maintenance of anthropogenic morphologies over time.
Indigenous Territory Overlap Zone	=	Existence of indigenous territories overlapping the Park limits; People access checking; Maintenance of low spatial fragmentation of land cover.	+	Little anthropogenic interventions; The existence of paleo-forms: indicates advanced stages of geomorphological phenomena and low anthropogenic perturbation.

Table 2 Spatial quantification of the land uses and land covers identified in the Camaquã State Park in 1964 and 2012.

Land uses and land covers		**1964**			**2012**		**≠**
		km²	**%**		**km²**	**%**	
Land uses	Urban areas	0.3	0.25	**Creation of Camaquã State Park – March 12, 1975**	0.91	0.74	196%
	Irrigated rice	21.04	17.25		13.21	10.73	-38%
	Temporary crops	0.05	0.04		0.07	0.06	50%
	Farms	0.16	0.13		0.61	0.5	285%
	Pastures	2.41	1.98		3.87	3.14	59%
	Forestry	0.17	0.14		0.78	0.63	350%
	Unidentified uses	0.32	0.26		8.38	6.8	2,515%
	Sub-total land uses	**24.45**	**20.05**		**27.83**	**22.6**	**--**
Land covers	Forest	37.97	31.14		41.12	33.41	7%
	Wetlands	22.63	18.56		24.81	20.16	8.20%
	Short-grass	4.54	3.72		7.1	5.77	55%
	Mixed-grass	1.9	1.56		3.51	2.85	82%
	Sandy areas	18.52	15.19		8.81	7.16	-53%
	Water bodies	11.93	9.78		9.9	8.04	-18%
	Sub-total land covers	**97.49**	**79.75**		**95.25**	**77.4**	**--**
	TOTAL*	121.94	100		123.08	100	--

* The increase in the CSP area is due to the evolution of the deltaic front in the analyzed period.

Grasslands (short-grass and mixed-grass) also have increased 55% and 82%, respectively (Table 2). This growth is related to the evolution of the grasslands as primary vegetation over sandy surfaces originated from the deltaic dynamics.

Seven land uses were identified in the CSP, and have supported the delimitation of recovery and intensive use zones: irrigated rice, urban areas, temporary crops, farms, pastures, forestry and unidentified uses (Table 2). Land uses had an increase of 12.8% in the CSP during the analyzed period (24.45 km² in 1964 and 27.83 km² in 2012).

Despite the creation of the CSP in 1975, the urbanized area had an expansion of 196%. The same occurred with agricultural facilities, which expanded by 285% (Table 2). However, these uses do not stand out as the main vectors of spatial occupation in the CSP, as they relate to the expansion of spaces occupied by local communities in a concentrated manner or specific areas of the Park.

Pastures increased by 59% between 1964 and 2012 (Table 2). This land use needs special attention because its expansion occurred, above all, in forest areas and over native countryside coverings.

Irrigated rice represents the main vector of occupation and environmental changes in the Camaquã State Park. Its location occurs predominantly at the edges of the CSP, pressing the evolution towards the interior of the protected area, promoting the conversion and fragmentation of the land cover.

Despite the decrease in the area occupied by irrigated rice (-53%) between 1964 and 2012, many of the areas destined for this agricultural practice were abandoned without the due recovery process.

In these abandoned areas the identification of ongoing processes becomes complex since elements of rice crops coexist (anthropogenic channels and cultivation terraces) as well as evidence of secondary ecological succession after the abandonment of agricultural activity.

For this reason, these areas have been classified as having unidentified uses. These unidentified uses had an increase of 2,515% in the analyzed period (Table 2) and were considered as areas destined for environmental recovery in the CSP.

3.2 Geomorphological Changes

Deltaic systems encompass a diversity of landforms and hydrographic features that present complex dynamics. The spatiotemporal changes of these environments must be understood for the proposition of environmental zoning. The features of fluvial origin gain prominence in deltaic environments and at the same time are the most sensitive to human action.

In the Camaquã State Park hydrographic features, forms of accumulation and paleoform shapes typical of deltaic fluvial/lacustrine environments have been identified: as fluvial channels, pluvial channels, abandoned channels, abandoned meanders, meandering lakes, fluvial-lacustrine plains, fluvial-lacustrine terraces, meandering bars, lagoon beach strip and sandy paleo chords. The anthropic landforms, although restricted, occurs in a generalized way in the CSP and consists of active and inactive anthropogenic channels (Table 3).

The drainage network of the deltaic system inserted in the limits of the CSP has a meandric behaviour and develops predominantly in the river-lake plain compartments. Its morphodynamics gives rise to meander lakes and abandoned channels. Table 3 shows the decrease in 53.6% of the extension of the river channels during 1964 and 2012.

Such decrease is mainly linked to the expansion of abandoned channels (2.067%) resulting from the dynamics of river migration in deltaic environments (Lopes & Simon 2019; Torres 2011). The reduction in the river channels extension is also related to the rectilinearity processes and the creation of active anthropogenic channels used to remove water from the river channels for rice fields irrigation. These anthropogenic features have had an increase of 189% in their extension during the analyzed period (Table 3).

The retraction of the fluvial-lacustrine terrace compartments (10.04 km² in 1964 and 6.59 km² in 2012) (Table 3) is also an indicator of anthropic interventions in relief. Rice crops are the main vectors of mischaracterization and flattening of fluvial-lake terraces. Because of the operation of irrigated rice crops, systems of anthropogenic channels are built that alter the circulation of water.

In some portions of the CSP, where the retraction of irrigated rice crops occurred, inactive anthropogenic channels were identified. Although deactivated, these channels morphology remains in the landscape, segmenting terrace surfaces and fluvial-lacustrine plains and interfering with hydrogeomorphological and biogeographic flows. The existence of active and inactive anthropogenic channels as well as the identification of changes in the compartments of lakeside river terraces served as indicators for the delimitation of areas of intensive use and recovery.

Sandy paleo bars are depositional features characterized by arching in crests and valleys designed by the lake/marine dynamics throughout the Quarternary period. These features suffered a 9% retraction, mainly linked to the leveling of these surfaces by rainfall dynamics. This retraction took place primarily in the uncovered portions of vegetation or areas close to the deltaic front, in contact with the Patos Lagoon.

Table 3 Evolution of hydrographic features and relief forms between 1964 and 2012 in the CSP.

Linear Morpho-Hydrographic Features	**1964**		Creation of Camaquã State Park – March 12, 1975	**2012**	
	km	**%**		**km**	**%**
Riverine Channels*	170.47	51.36		123.68	23.82
Rain Channels	134.1	40.4		205.59	39.6
Abandoned Channels*	1.6	0.48		53.97	10.4
Active Rectilinear Channels	25.77	7.76		116.55	22.45
Inactive Rectilinear Channels	-	-		19.37	3.73
Total	331.94 km	100%		519.16 km	100%
Areal Morpho-Hydrographic Features	**1964**			**2012**	
	km²	**%**		**km²**	**%**
Riverine Channels*	8.44	6.92		8.24	6.7
Abandoned Flooded Channels	0.34	0.29		0.54	0.43
Abandoned Channels Without Water*	0.21	0.18		0.95	0.77
Continental Bodies of Water	1.92	1.59		1.5	1.21
Point Bars	0.77	0.64		0.86	0.69
Meander Lakes	0.04	0.03		0.11	0.09
Abandoned Meanders	0.08	0.06		0.16	0.13
Sandy Bars	0.65	0.5		0.51	0.4
Sandy Paleo Bars	28.76	23.6		27.01	21.5
Beach	1.95	1.6		1.19	0.96
Lacustrine-Fluvial Terraces	10.04	8.23		6.59	5.35
Lacustrine-Fluvial Plains	68.74	56.37		76.03	61.78
Total**	121.94 km²	100%		123.08 km²	100%

* Fluvial channels and abandoned channels appear twice in the Table because they have been identified in line and polygon formats due to the spatial diversity of the CSP hydrographic features. ** The total area of the sand features has increased due to the expansion of the CSP deltaic front in the analyzed period.

The deltaic front of the CSP also showed changes over the analyzed period. There was a bifurcation of the main channel (Camaquã River) and the consolidation of new surfaces of the river-lake plain at the meeting with Patos Lagoon. This set of river and depositional alterations culminate in important indicators for the delimitation of restrictive zones (primitive zone and intangible zone).

3.3 Environmental Zoning

Based on the land use and land cover dynamics, on the described geomorphological changes, and the physical-spatial criteria proposed by IBAMA (2002) (Table 1), five types of environmental zoning were designated for the Camaquã State Park: intangible zone, primitive zone, recovery zone, intensive use zone, and indigenous overlaying zone (Figure 2).

The homogeneous zoning units encompassed the phenomena of relevance for the scientific development of the park,the conservation of the Camaquã River delta and the use of the protected space, including the resident population and the local specificities of the environmental system and its dynamic.

3.3.1. Intangible Zone

Intangible zones are areas with a high degree of nature protection that must remain as close as possible to their original state. Its management purpose is the full protection of ecosystems, genetic resources, and geoecological processes responsible for maintaining biodiversity and geodiversity (IBAMA 2002).

In state parks located in the state of Rio Grande do Sul that have zoning, intangible zones were identified and delimited in the following UCs: Ibitiriá State Park, Turvo State Park, Espinilho State Park and Itapuã State Park. In the mentioned cases, the intangible zones were delimited in areas where the highest levels of preservation of native vegetation or the existence of hydrographic features such as rivers or wetlands were identified (SEAA/DRNR 1996; SEMA/DFAP 2005; 2009; SEMA/DFAP/DUC 2012).

Six homogeneous units belonging to the intangible zone were delimited in the CSP (Figures 2 and 3). This zone occupies the largest extension of the Park (49.11 km²), equivalent to 40% of the conservation unit, and is located predominantly in the central-north portions of the CSP, covering surfaces of river-lake plains inserted in a deltaic front environment with the presence of abandoned meanders.

The geomorphological dynamics in intangible zones are characterized by the preservation of the drainage network and geomorphological features. Abandoned channels generally evolve in length resulting from river dynamics in a deltaic environment. Anthropogenic morphologies are non-existent, indicating a low degree of land use intervention. The evolution of primary covers over sandy paleo bars was verified in some surfaces of these zone (homogeneous unit 6 – Figure 3).

The increase in forest cover in the intangible zone during the analyzed period stands out (Figure 3), especially in areas that, in the 1964 scenario, were occupied by mixed-grass and exposed sandy surfaces. This expansion is considered important given the meaning of forest vegetation cover for the maintenance of biogeographic processes and flows and protecting the local geodiversity elements.

In the portions close to Patos Lagoon, the intangible zone homogeneous units present natural land covers adapted to the water characteristics of the lacustrine-alluvial plains.The sandy paleo bars areas still present the arching of the lagoon paleo-coves and portions with greater flattening in the vicinity of the river courses (Figure 3). Such characteristics are important signs of environmental preservation and maintenance of natural processes.

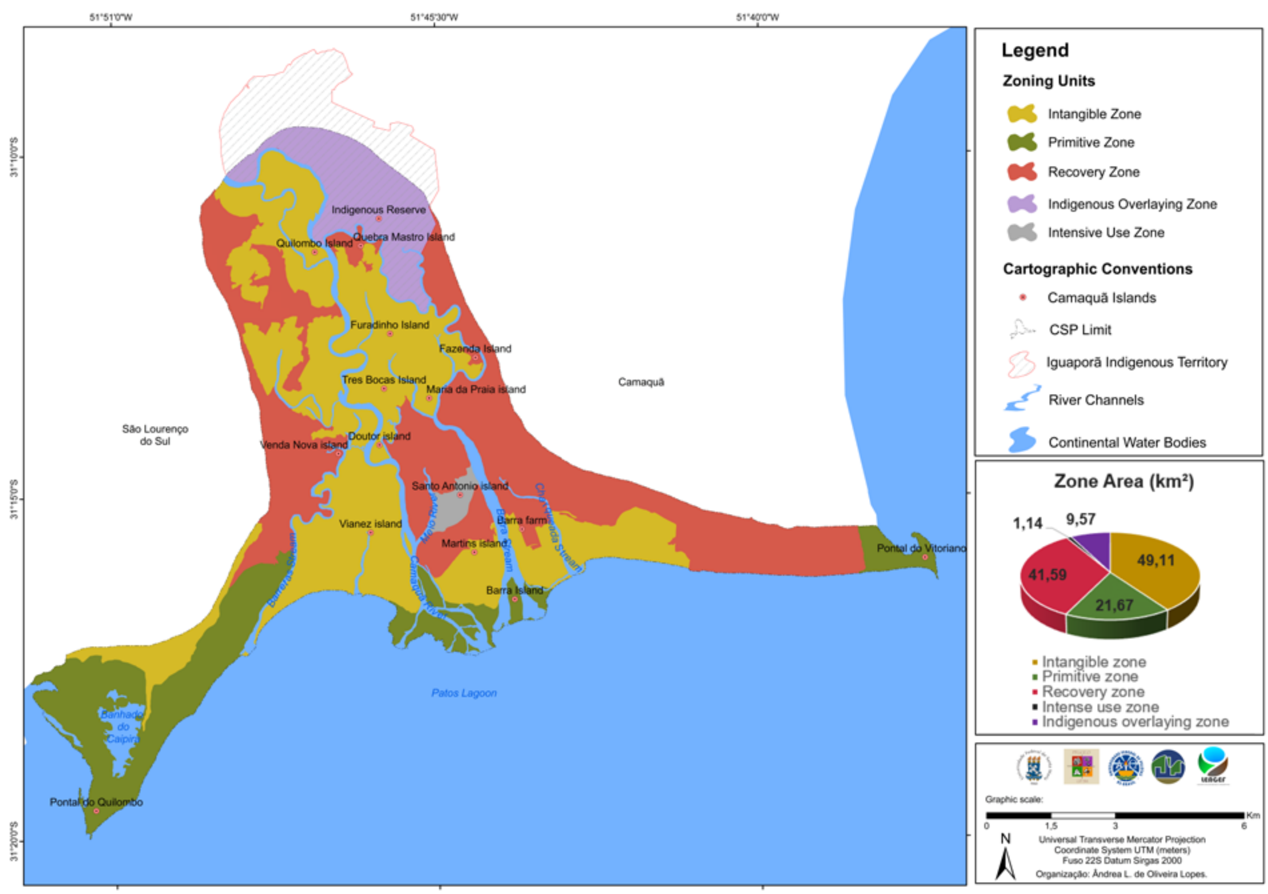

Figure 2 Camaquã State Park Environmental Zone Map.

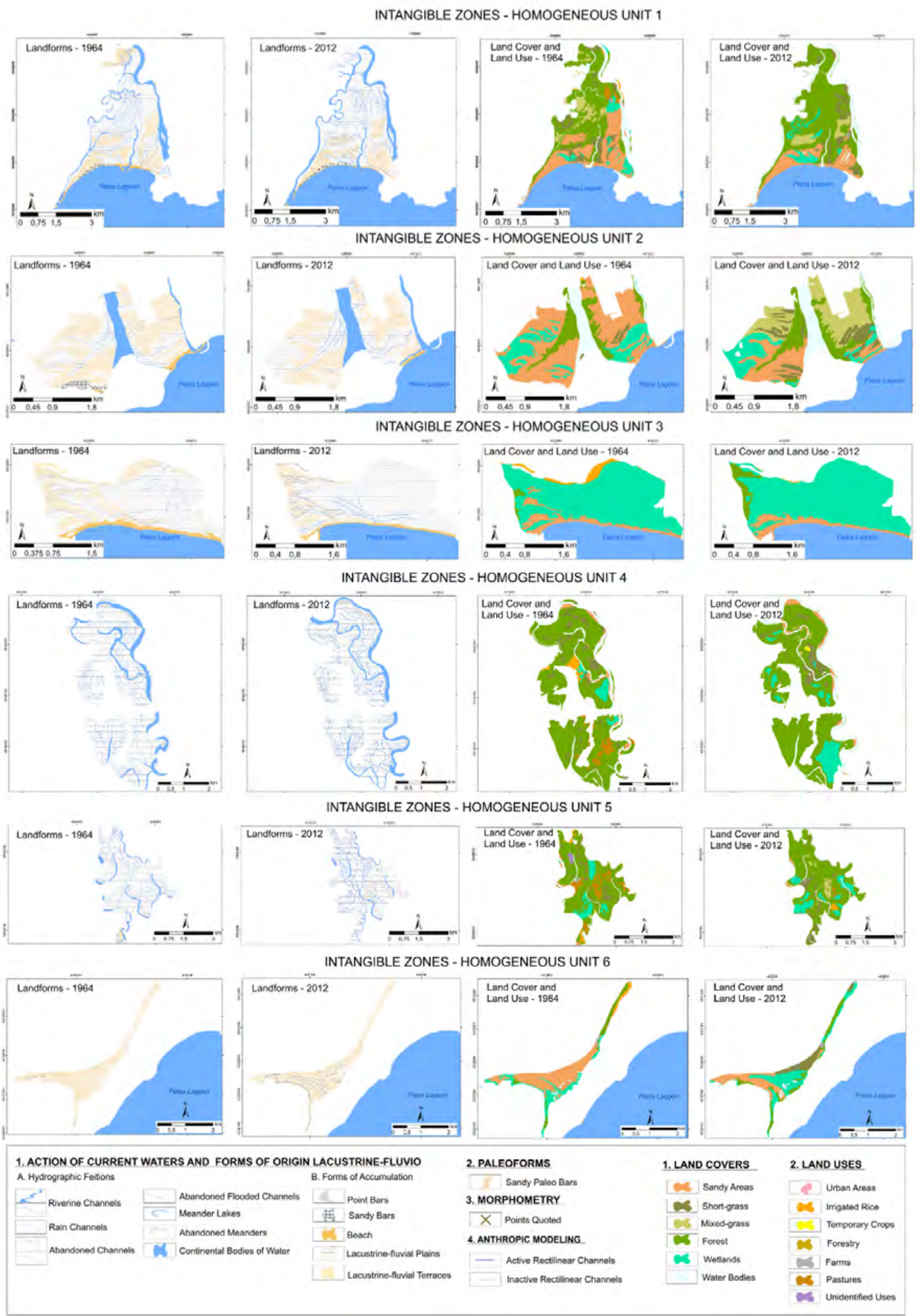

Figure 3 Camaquã State Park intangible zone homogeneous units.

Management Guidelines: Visitation, movement, or any other kind of occupation and infrastructure are not allowed in intangible areas. Human activities should be limited to scientific research (provided they do not compromise existing resources), monitoring and inspection. It is suggested that the access by fishermen and bathers that occurs from the main river channels and by the Patos Lagoon be monitored. Even though these areas are preserved, it is necessary to consider that they are indirectly affected by anthropogenic pressure that occurs in contiguous recovery zones (Figure 2).

3.3.2. Primitive Zone

Primitive zones are characterized by encompassing species or natural phenomena of the biodiversity or geodiversity of great scientific value and under low anthropogenic pressure (IBAMA 2002). In the CSP the primitive zones occupy 21.67 km² and cover the deltaic front areas as well as two important wetland surfaces with recent morphogenesis, where humid areas with vegetation adapted to the water regime, regionally called "banhados", occur (Figure 4). The purpose of primitive zones is to conserve the natural environment and the associated physical, historical, and cultural aspects. At the same time, it intends to facilitate scientific research activities and environmental education (IBAMA 2002).

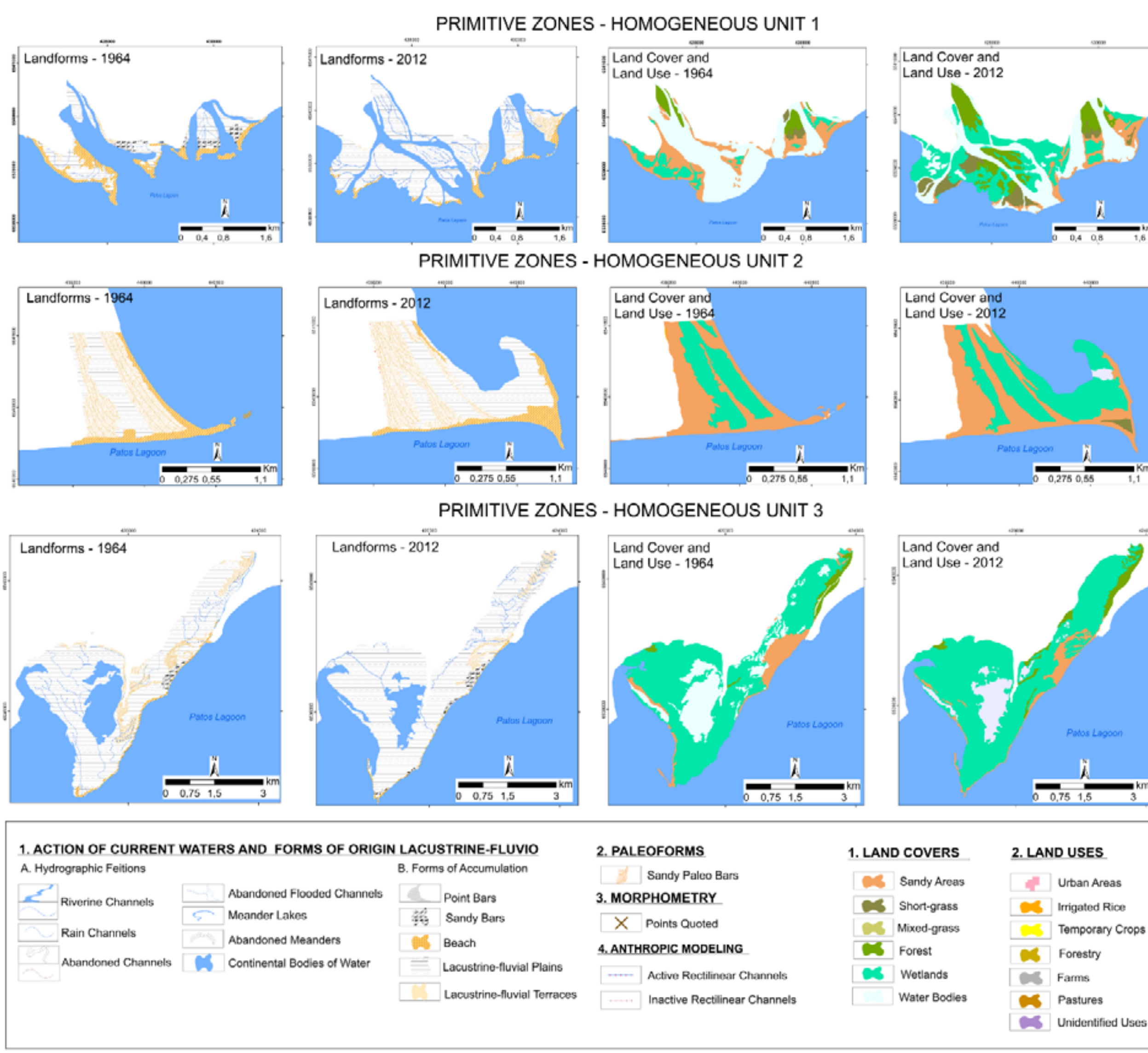

Figure 4 Camaquã State Park primitive zone homogeneous units.

Concerning the dynamics of land use/cover, these areas, both in 1964 and 2012, remained occupied by three land covers: wetlands, exposed sandy areas and forest. The limit established for the homogeneous units of this zone considered the peculiar physical-environmental processes, such as the expansion dynamics of the deltaic front and river mouth bars. This geomorphological dynamic that gave rise to new surfaces resulted in expanding the park area, where new plant stands were established (Figure 4), marking the systemic relationship between geomorphology and land cover dynamics.

Geomorphological processes are under development in the primitive zone. Any intervention in this dynamic balance by anthropogenic activities can compromise ongoing natural processes.

Management Guidelines: Installations, works, or undertakings that may alter the local physical-environmental system, especially the deltaic and lake dynamics, are prohibited. Geoheritage studies should be encouraged due to scenic beauty, environmental fragility, and the scientific relevance of the natural processes present in these zones. The location of these zones in easily accessible areas (by boats) is likely to generate impacts resulting from trails or preferential paths. Therefore, this zone requires continuous monitoring.

Primitive zones are often delimited in zoning, as their objective is to conserve nature combined with scientific development. Therefore, this type of zone is regularly incorporated into zoning. The parks that make up the SEUC/RS and that have primitive zones in their zoning are the following: Itapuã State Park, Tainhas State Park, Turvo State Park, Espigão Alto State Park, Jacuí Delta State Park and the Jacuí State Park do Espinilho (SEAA/DRNR 1996; SEMA/DFAP 2004; 2005; 2009; 2012; SEMA/DFAP/FZ 2006; 2008; 2014).

3.3.3. Recovery Zone

Recovery zone consists of altered and impacted environments, which must be recovered. These zones have the purpose of management linked to the containment of the degradation of the natural heritage and the restoration of the impacted portions (IBAMA 2002).

All state parks in the state of Rio Grande do Sul included by SEUC/RS and which have environmental zoning, include recovery zones within their limits. The impacts identified in these zones are mainly linked to agricultural practices such as irrigated rice cultivation, livestock farming and forestry (SEAA/DRNR 1996; SEMA/DFAP 2004; 2005; 2009; 2012; SEMA/DFAP/FZ 2006; 2008; 2014).

In the CSP, 41.59 km² of impacted areas in need of recovery were identified, equivalent to 34% of the park total area (Figure 4). The recovery zones are located within the limits of the CSP with the buffer zone and in the central portion of the park, in contact with the intensive use zone (Figures 4 and 5).

The homogeneous units of this zone have a conversion of forests and wetlands in irrigated rice areas or other agricultural structures. Recovery zones also include areas where irrigated rice was maintained throughout the analyzed period, as in the homogeneous units 1 and 5 of the recovery zones (Figure 5).

The homogeneous units of the recovery zone have an intense concentration of active and inactive anthropogenic channels that connect to the deltaic distributaries, diverting water to irrigate rice crops (Figure 5). These water diversions cause imbalances in the capacity and competence of the hydrographic system, and may also be linked to the increase of abandoned channels in the analyzed scenarios.

On the surfaces where irrigated rice-growing activities were abandoned over the analyzed period, it was possible to identify small fragments of natural vegetation that can be vectors of spatial dispersion of land covers, assisting in the recovery of impacted areas (Figure 5).

Management Guidelines: Intervention in the recovery process of impacted areas should be conducted to recover the environmental changes arising from the irrigated rice activity (mainly evidenced by the anthropogenic channels). Environmental rehabilitation techniques that enable assimilation of these anthropogenic features to the CSP landscape are suggested since this type of morphology demands significant time to be razed by the rainfall-erosive processes.

It should be noted that, as long as these anthropogenic channels remain on plain or river-lake surfaces or in the areas of sandy paleo bars, they make the gene flows of fauna and flora, as well as surface water circulation, unfeasible. Furthermore, they generate a negative visual impact on the landscape of the CSP.

3.3.4. Intensive Use Zone

The intensive use zone consists of natural areas or areas altered by anthropogenic action with the potential to house the park headquarters, the visitor center, museums, or other facilities and services (IBAMA 2002). The purpose of the intensive use zone is to facilitate public visitation with low environmental impact and in harmony with the environment, providing the necessary infrastructure for scientific, educational, or even recreational activities.

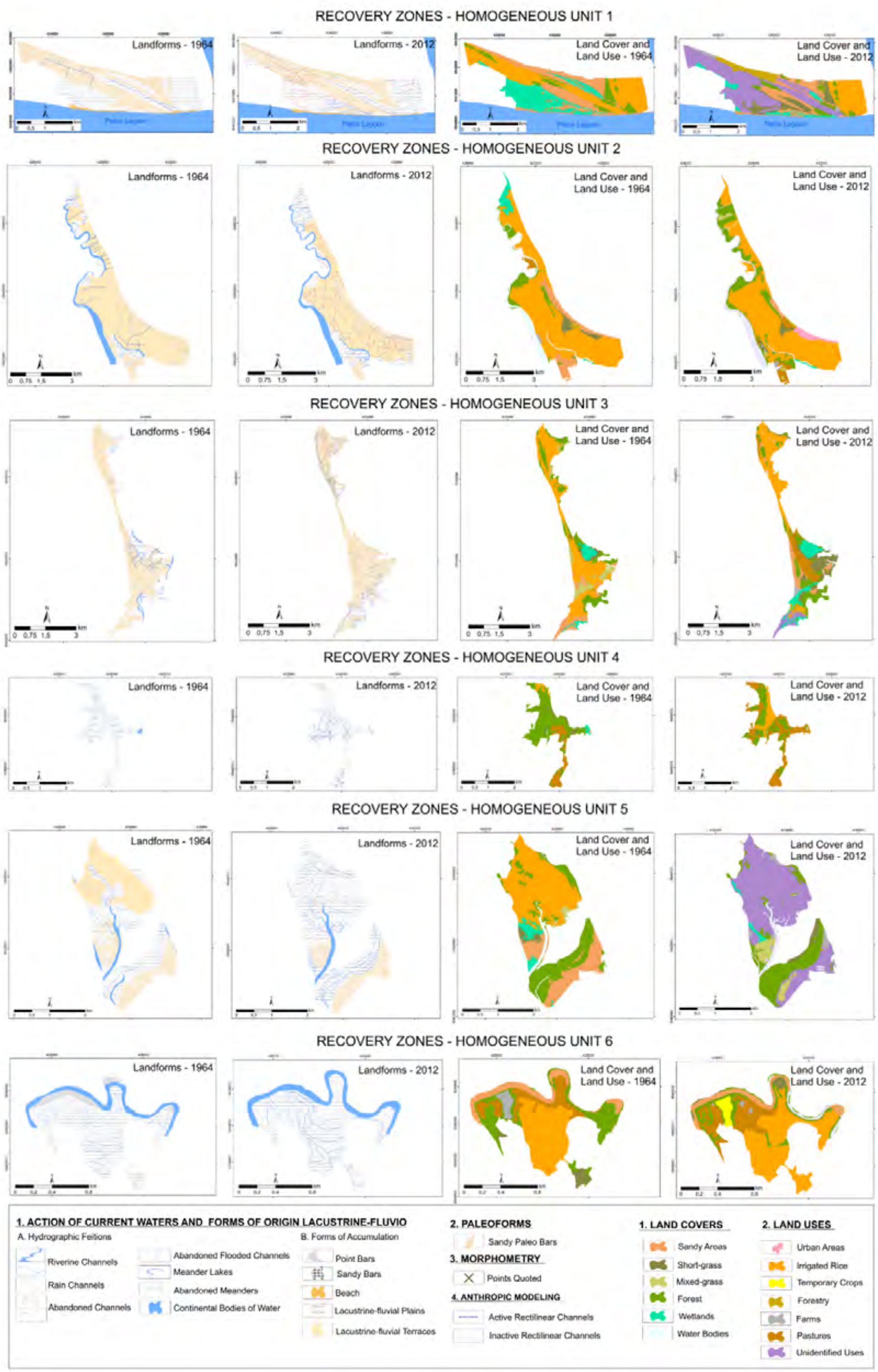

Figure 5 Camaquã State Park recovery zone homogeneous units.

The possibility of functional use supported by intensive use zones, such as the installation of buildings for collective use - offices, accommodation, among others - and infrastructure for receiving visitors, researchers or employees who work in inspection and management actions of the research unit conservation, makes these zones commonly identified in the zoning of state parks in the state of Rio Grande do Sul (SEAA/DRNR 1996; SEMA/DFAP 2004; 2005; 2009; 2012; SEMA/DFAP/FZ 2006; 2008 ; 2014).

In the CSP, the intensive use zone is 1.14 km² and is located on Santo Antônio Island (Figures 4 and 6). This zone was delimited so that the population residing within the CSP could be inserted in the installation and management process of the protected area, gaining a leading role in tourism and environmental education actions.

The primary roads and circulation routes and even the main access entrance to the CSP (by the municipality of Camaquã) are located in this zone, demonstrating its potential to house the CSP headquarters and other necessary structure. The roads, in general, are precarious and with stretches of exposed sand or covered by grass, featuring simple trails through sandy paleo bars or in the river-lake plain (Figure 6).

Management Guidelines: All constructions must be harmoniously integrated into the environment. The issue of infrastructure for visitation can be articulated with the local population, generating income for these residents and compensating them for not exploiting natural resources from the CSP. Ways of life should be incorporated into the practices of this area, and visitation should focus on environmental education strategies.

3.3.5. Indigenous Overlaying Zone

The indigenous overlying zone refers to an area occupied by indigenous ethnic groups overlaying parts of the conservation unit (IBAMA 2002). In the CSP, this zone occupies 9.57 km² (9% of the park area), which overlays the Iguaporã Indigenous Reserve, located in the extreme northeast of the conservation unit (Figure 4).

This zone has its area under a special regime, subject to negotiation between the ethnic group represented by the National Indigenous Foundation (FUNAI in Portugues), the

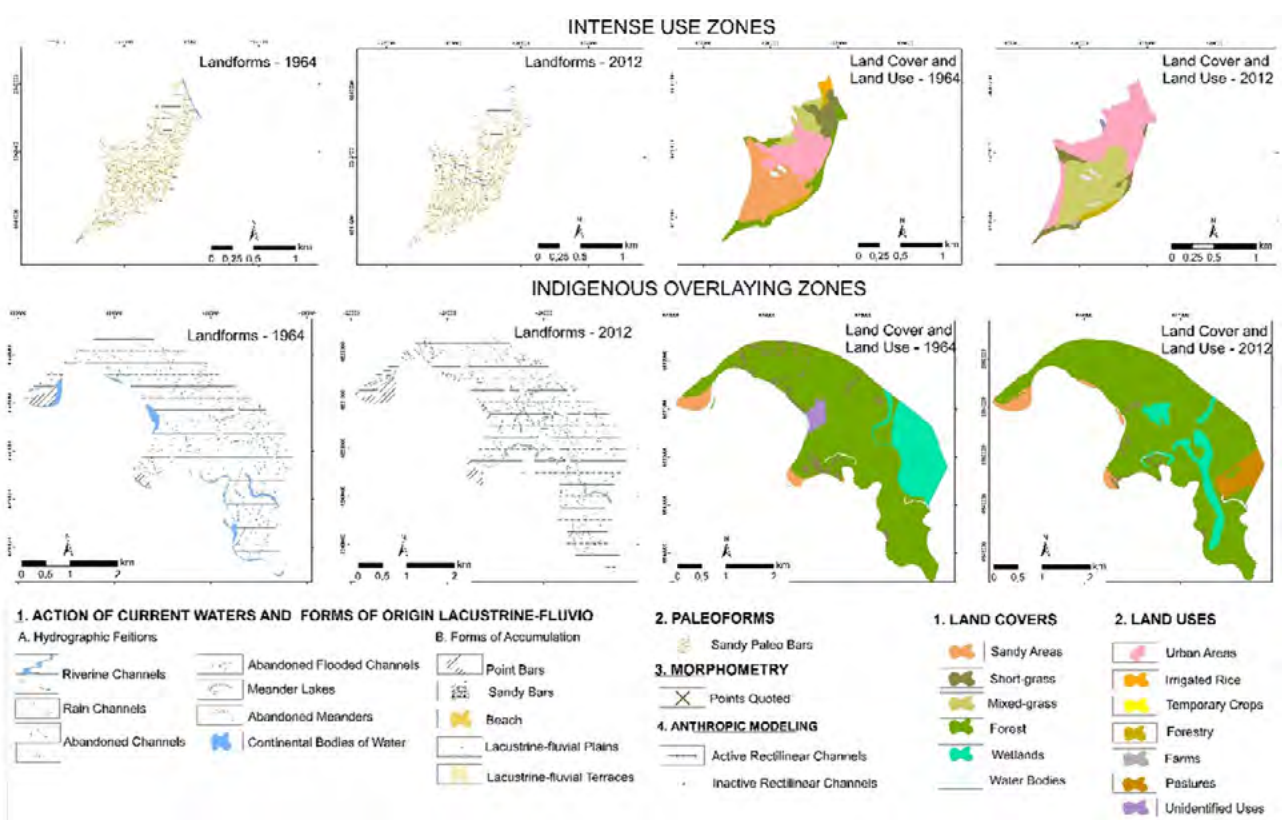

Figure 6 Camaquã State Park intensive use area zone and indigenous overlap zone.

Brazilian body that manages protected spaces for indigenous populations, and the managing bodies responsible for the CSP, SEMA Rio Grande do Sul State Department (Secretaria do Meio Ambiente e Infraestrutura do Estado do Rio Grande do Sul).

The river-lake plain surfaces sustain a diversity of river forms and the forest cover that remained consolidated over the analyzed period in the Iguaporã Indigenous Reserve (Figure 6). This finding reinforces the meaning of traditional people as important social actors in the nature conservation of protected areas.

The forest cover of this zone is dense and with wide canopy and spatial continuity, without fragmentations (Figure 6). River activity is complex in this portion of the CSP, evidenced by river channels, rain channels, abandoned channel beds and abandoned meanders. These abandoned features actively contribute to the river dynamics in situations of maximum water flows.

Management Guidelines: The fact that there is an indigenous reserve overlaying the area of a full conservation unit enables a stronger policy for the conservation of this environment. It reinforces the inspection of the entry of people and the expansion of aggressive activities that manifest themselves around the reservation limits. Additionally, indigenous extractive activities are considered punctual and in line with environmental systems.

The overlapping of boundaries between conservation units and indigenous reserves is recurrent in Brazilian territory (De Araújo Pinto 2015). The territory occupied by indigenous people of the Guarani ethnic group in the area of the Aparados da Serra National Park, also in the state of Rio Grande do Sul, is an example of this overlap.

4 Final considerations

This article exposes the results of the composition of a technical document for a full nature conservation unit not yet implemented. Environmental zoning was based on a methodological guide for managing protected areas in Brazil, characterized as an important social and territorial management contribution.

Although the CSP has expanded its geographic area due to the evolution of the deltaic front surfaces, the land use classes also had their area expanded, even after the park creation. This means that many of the areas covered by pioneer vegetation already have their integrity and environmental balance compromised by the uses developed in the park.

The zoning presented can only be applied in its entirety after regularizing the land tenure in the protected area. The non-regulation of land tenure is one of the main obstacles to complete the installation of the Camaquã State Park. After being put into practice, this zoning must be periodically reviewed to adjust the homogeneous units of a temporary nature, such as the recovery zones and the indigenous overlaying zone.

As long as there is no standardization for using the buffer zone, the recovery process of the areas within the conservation unit is threatened. Therefore, it is necessary to expand this study to this unit buffer zone (10 km buffer from the limits of the Conservation Unit - SNUC 9.985/2000).

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Author contributions

Ândrea Lenise de Oliveira Lopes: conceptualization; data curation; formal analysis; investigation; methodology; fieldwork; validation; visualization; writing – original draft; writing – review and editing. **Gracieli Trentin**: conceptualization; fieldwork; writing – review and editing; supervision. **Adriano Luís Heck Simon**: conceptualization; fieldwork; supervision; writing – review and editing; project administration.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature and cited in references. The geospatial files (.shp) that were created and presented in the results through thematic maps are available by request.

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