

Spatial-temporal variation in land use in a coastal watershed under pressure of population growth

Variação espaço-temporal no uso do solo em uma bacia hidrográfica costeira sob pressão do crescimento populacional

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ABSTRACT

Population progress is one of the main factors affecting the environment, modifying the natural dynamics of ecosystems. The Camboriú River Basin is located on the southern coast of Brazil and is strongly affected by population growth. This paper aimed to verify the space-time variation in the land use of the Camboriú River Basin by identifying changes in occupation and land use between 1986 and 2017. The rapid environmental assessment protocol was applied using the following parameters: bottom substrate, habitat complexity, backwaters quality, stability of banks, vegetative protection, vegetative cover, vegetative quality, and riparian vegetation presence. The changes in occupation and land use show rapid urbanization with a rise of 9% in 1986 to 24% in 2017. In riparian forest, higher altitude regions of the watershed show better results when compared to lower course regions, which are, thus, reflected in the environmental integrity of the stretches of stream studied. As for the behavior of urban occupation in space, it was verified that it did not occur continuously in comparison with the population, data during the studied period.

Keywords: anthropogenic pressure; water resources; land use.

RESUMO

O avanço populacional é um dos principais fatores de alteração do meio ambiente, modificando as dinâmicas naturais dos ecossistemas. A Bacia Hidrográfica do Rio Camboriú localiza-se no litoral sul do Brasil e é fortemente afetada pelo crescimento populacional. O presente trabalho teve como objetivo verificar a variação espaço-temporal no uso do solo da Bacia Hidrográfica do Rio Camboriú. Para tanto, foram identificadas mudanças no uso e ocupação do solo ocorridas entre 1986 e 2017. Além disso, foi aplicado o protocolo de avaliação rápida do ambiente, sendo verificados os parâmetros: substrato de fundo, complexidade do habitat, qualidade dos remansos, estabilidade dos barrancos, proteção vegetal dos barrancos, cobertura vegetal das margens, qualidade vegetal das margens e presença de mata ciliar. As mudanças no uso e ocupação do solo mostraram rápido avanço da urbanização, passando de 9% em 1986, para 24% em 2017. Com relação à mata ciliar, foi verificado que regiões altas da bacia hidrográfica apresentaram melhores resultados, quando comparadas às áreas potamais, fato que apresentou similaridade com a integridade ambiental dos trechos de cursos d'água estudados. Quanto ao comportamento da ocupação urbana no espaço ao longo do período estudado, verificou-se que este não ocorreu de forma contínua em comparação com os dados populacionais.

Palavras-chave: pressão antropogênica; recursos hídricos; uso do solo.

INTRODUCTION

Rivers and tributaries are the aquatic ecosystems most affected by human activity. Those located in coastal regions when associated with disordered industrial and urban growth suffer adverse consequences in their environmental quality (TUNDISI; TUNDISI, 2008). The contamination of water resources by anthropogenic activities not only reduces the economic potential of the waters (FIQUEPRON; GARCIA; STENGER, 2013), but also restricts its use for leisure and recreation by presenting a risk to the health of the population.

A key part in the maintenance of quality water resources is made by the riparian forest, which, as an ecotone between the terrestrial and aquatic

environments, provides protection to the watercourses. Riparian zones supply shelter for biota by detritus deposition (branches, trunks, leaves), help stabilize the banks with tree roots, filter sediment in runoff, and store water in the soil in order to refill the water table and the watercourses in periods of lower rainfall (DOSSKEY *et al.*, 2010; ELMORE; BESCHTA, 1987; LACERDA; FIGUEIREDO, 2009; LIMA; ZAKIA, 2000). Despite vast knowledge about the importance of the riparian forest, there has been a reduction with the advancement of population. Land use represented by urban and rural occupation and some types of crops alters the riparian forest which directly and indirectly affects the integrity of the adjacent water resources (BREN, 1993; CAMPOS; RAMIRES; PAULA,

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2011; DONADIO; GALBIATTI; PAULA, 2005; EROL; RANDHIR, 2013; FOLEY *et al.*, 2005; SOUZA; GASTALDINI, 2014; MORING; GARMAN; MULLEN, 1985; POLETO; CARVALHO; MATSUMOTO, 2010; SANTOS; HERNANDEZ, 2013; TUCCI, 2002; VANZELA; HERNANDEZ; FRANCO, 2010).

Statewide, the Camboriú River Watershed is part of the hydrographic region RH7, Itajaí Valley, located in the municipalities of Camboriú and Balneário Camboriú, Santa Catarina State (SANTA CATARINA, 2008). According to the Brazilian Institute of Geography and Statistics demographic census, the municipalities which compose this Basin show accelerated population growth (IBGE, 2018). Furthermore, it shows that Balneário Camboriú is the municipality with the highest population density in the state of Santa Catarina (2,337.67 inhabitants/km²), tending to grow through verticalization. However, the expansion to less inhabited regions such as Camboriú is inevitable due to urban mobility and lack of water supply (PIATTO; POLETTE, 2012). The authors further hold that during holiday season the population of Balneário Camboriú increases tenfold, which overloads basic sanitation systems that are unequipped for such large fluctuations of inhabitants.

Agglomerated population growth poses a risk to the environment due to the concentrated exploitation of natural resources through the expansion of cultivated areas (mainly riziculture), mining, and logging for charcoal and cattle pastures. Studies carried out by Urban (2008) and Padilha (2013) in the

Camboriú River Basin showed signs of this degradation, mainly in relation to the permanent preservation areas where it was verified that more than half of these limits are represented by uses different from vegetal occupation.

In this context, the present study aims to diagnose and dimension the current conditions and land use evolution in light of the pressure exerted by population growth in the Camboriú River Watershed, verifying whether the spatiotemporal distribution of these uses presents a linear model (continuous) or shows pulses over time.

METHODOLOGY

Study area

The study area comprises the region occupied by the Camboriú River Watershed, located in the municipalities of Camboriú and Balneário Camboriú, central-north coast of the state of Santa Catarina, Brazil (Figure 1).

Identification of occupation and land use patterns

The evolution of changes in occupation and land use in the Camboriú Basin in the last three decades was studied based on Landsat 5 and Landsat 8 satellite images provided by the Brazilian National Institute for Space Research (*Instituto*

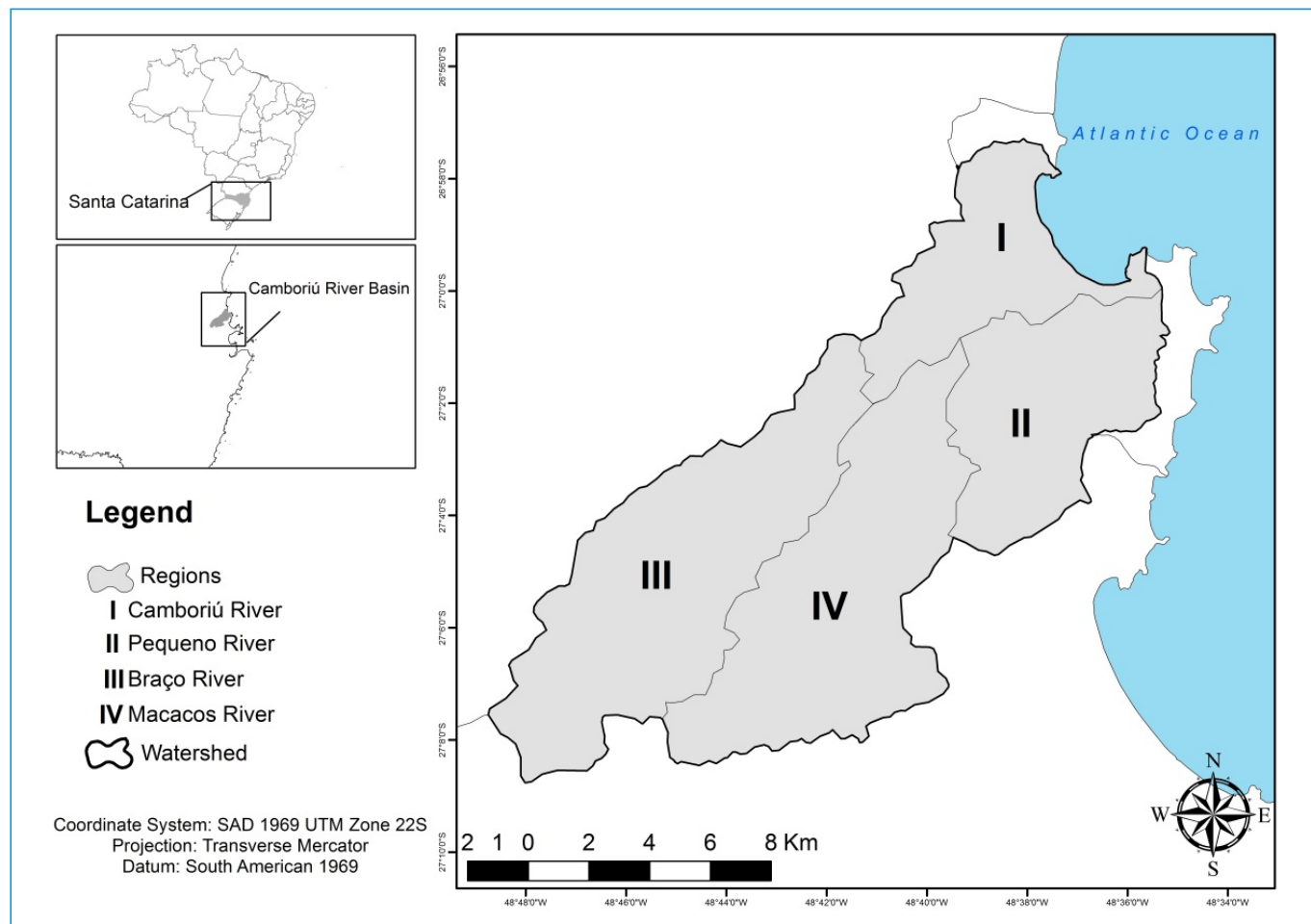


Figure 1 - Map of the location of the Camboriú River Watershed in the state of Santa Catarina (Brazil) with the four study regions.

Nacional de Pesquisas Espaciais – INPE). The years used in the analysis were chosen based on the availability and visibility of the satellite images for the study area, being 1986, 1993, 2004, 2006, 2010, and 2017.

Using photo interpretation with the ArcGis 10.0 software, land occupation was classified into agriculture (where irrigated rice crop predominates), urban area, natural area (presence of medium and advanced stage vegetation), pasture/undergrowth, and water mirror. The uses were chosen based on the quality of the satellite images, making classes such as reforestation areas difficult to interpret. From the analysis it was possible to verify the progress of land use in the area covered by the Camboriú River Basin in the study years. The results of the evolution of land use occupation were analyzed through descriptive statistics and in the form of maps and were subsequently compared with population data obtained by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística – IBGE*).

Riparian forest analysis

The methodologies proposed by Minatti-Ferreira and Beaumord (2006), Cionek, Beaumord and Benedito (2011) and Leal (2012) were applied to determine the condition of the riparian forest along the tributaries of the Camboriú River Basin using aerial images obtained by the Government of the state of Santa Catarina, a photogeoreferenced survey carried out by the Camboriú Committee (2013), and field visits. The methodologies are based on the determination of the quality of the environment through the application of a protocol using parameters directed to the riparian forest. For such, six field trips were carried out between June and August 2015, where 171 points of the River Basin were evaluated throughout four regions: Camboriú River (13), Pequeno River (28), Braço River (72), and Macacos River (58) (Figure 1).

For the classification of the riparian forest, presence and state parameters were considered. Five classification intervals were defined for the presence parameter and four for the riparian forest state. The presence of the riparian forest is the existence of vegetation inside the riverbank plotted according to the distances provided in the Brazilian Forest Code of 2012, quantified through the ArcGis 10.0 software, without considering the provisions in the consolidated areas until July 22nd, 2008 due to its difficult identification (BRASIL, 2012). In this way, it was possible to identify the presence of riparian forest within the limits imposed by legislation through the aerophotogrammetry of the watershed and to classify the area according to the methodology of Leal (2012). The state of the riparian forest is determined by the following parameters applied in field visits: the vegetal quality of the margins, the vegetal cover of the banks, the vegetal protection of the ravines, and its stability.

Application of the rapid environmental integrity assessment protocol

The Rapid Assessment Protocol (RAP) of the environment was based on the simplified model of Minatti-Ferreira and Beaumord (2006), which consists of the *in situ* observation of the environment for analysis of different parameters through a scoring system which will eventually score the environment in a range from optimum to poor. The RAP includes the parameters of: bottom substrate, habitat complexity, and backwater quality. Through field visits and the photogeoreferenced survey provided by the Camboriú Committee, the environmental integrity of the tributaries of the Camboriú River Basin

was determined. The RAP was applied only to streams and upstream regions of the basin, resulting in 54 sample points analyzed.

RESULTS AND DISCUSSION

Land use and occupation patterns

The occupation and land use classification enabled visualize the distribution and quantification of urban, agricultural, natural, and pasture/undergrowth areas in the Camboriú River Basin (Figures 2 and 3; Table 1). Although it is still the most representative class in the basin, the natural area suffered the greatest percentage reduction, reaching almost 10% between 1986 and 1993. In 2006, natural areas began to grow again in places formerly occupied by pasture/undergrowth. The Camboriú River region has the lowest vegetal representation among the studied localities while also seeing the greatest percentage reduction in this class of land use during the period 1986–2017, reaching approximately 12% (Figure 3A).

Difficult access to some forest areas due to hills helps to maintain a great part of its extension, although urban occupation has also advanced in these regions, mainly from 2004 onwards. A study of the Camboriú River Basin by Dortzbach *et al.* (2015) shows that areas with declivity above 20% are represented mainly by forest cover, confirming the hypothesis that difficult access helps to preserve vegetation. On the other hand, the increase of natural areas in environments exposed to stressful factors may be associated with the abandonment of cultivated areas and pasture and planting of species for wood exploitation (DORTZBACH *et al.*, 2015; RUDEL *et al.*, 2005; YACKULIC *et al.*, 2011).

The area occupied by pasture/undergrowth increased more than 8% between 1986 and 1993, including in the upper reaches of the basin, regions such as the Braço and Macacos Rivers. The removal of native vegetation for eucalyptus plantations or cattle occupation in these regions was observed during field visits. This class presents great variation of area in the basin with different land uses over time, a fact also observed in the studies of Yackulic *et al.* (2011), in Puerto Rico, and Dortzbach *et al.* (2015) in the Camboriú River Basin.

Urban area increased from 9 to 10% in the period of 1986–1993, reaching 24% of the land occupation in 2017, making it the class of highest growth in the watershed. The increase of urban areas was more notable in the Camboriú River and Pequeno River regions, in which a gradual densification of urban areas was observed (Figures 3A and 3B). The Pequeno River and the Macacos River regions contain upper areas where new patches of urban occupation were also registered, including near the water springs. In the Pequeno River region, urban area increased from 11% in 1986 to 35% in 2017, the highest relative growth in the Camboriú River Basin. Conversely, the Braço River and Macacos River regions had the lowest urban occupation, however its extension has doubled in the Macacos region between 2006 and 2010. The urbanization process is strongly related to forest cover loss, a fact pointed out by Campos and Souza (2003) while studying the rate of deforestation and colonization of the island of Puerto Rico, Paraná, Brazil.

In general, the agricultural areas remained stable throughout the period, reaching almost 5% of occupation. Agriculture is located mostly in the region of Macacos River, where there was an increase between 1993 and 2006, followed by a reduction in 2010. Furthermore, between 1986 and 2006 there were more agricultural than urban areas in this region, however, the situation was reversed in 2010. The same was verified in the Braço River region, with a representative

agricultural area until 2004, it was overtaken by urban occupation since 2006. The data also revealed that the Camboriú River region was little occupied by this land use class, representing less than 1% until 2006 and has since been no longer registered.

In the spatial-temporal behavior of urban occupation, comparing the occupied area with the data of the resident population in the Camboriú River Basin obtained through IBGE (2018), it was observed that the occupation did not occur in a linear way (Figure 4). Between 1980 and 1996, there was a considerable population increase while the area occupied remained almost unchanged. On the other hand, between 2000 and 2010, a linear growth can be observed for both parameters. The year of 2017 was also below the line of continuous growth seen previously, caused by a population increase of almost 44,000 inhabitants. The urban occupation of the basin in 1980–1996 occurred mainly in already urbanized areas, associated with the accelerated verticalization process in the municipality of Balneário Camboriú (PIATTO; POLETTE, 2012). This municipality exerted a strong influence on the results due to its high population density. The profile presented after 1996 may indicate saturation of the available areas for occupation, thus highlighting a necessity for the expansion to adjacent localities. In addition, the densification in small areas may cause negative effects in a concentrated way on the environment.

Riparian forest analysis

Regarding the state and presence of the riparian forest, the results show that 65% of the studied sections are in poor or regular conditions (Figure 5). In only 13% of the evaluated sections the riparian forest was classified as in an optimal state, while the presence registered 17% of the areas in this category. These data show that the Camboriú River and its tributaries are in misalignment with the Brazilian Forest Code (BRASIL, 2012) considering that the optimal classification refers to the margins 100% covered by vegetation, meaning that the permanent preservation areas (PPA) are being maintained.

The Camboriú River has the worst state of riparian forest, where only 23% of the existing vegetation is in good condition (Figure 6). The sections that compose this region are predominantly occupied by anthropogenic activities with concretized margins in several spots. This leads to a poor classification of the stability of the ravines in these sections due to the decharacterization of the natural environment. Regarding the presence of the riparian forest, the Camboriú River also shows 69% of its sections classified as poor or without vegetation.

The Pequeno River region shows a better state of riparian forest, with 39% of the areas in good condition and 14% in optimal (Figure 7). There were

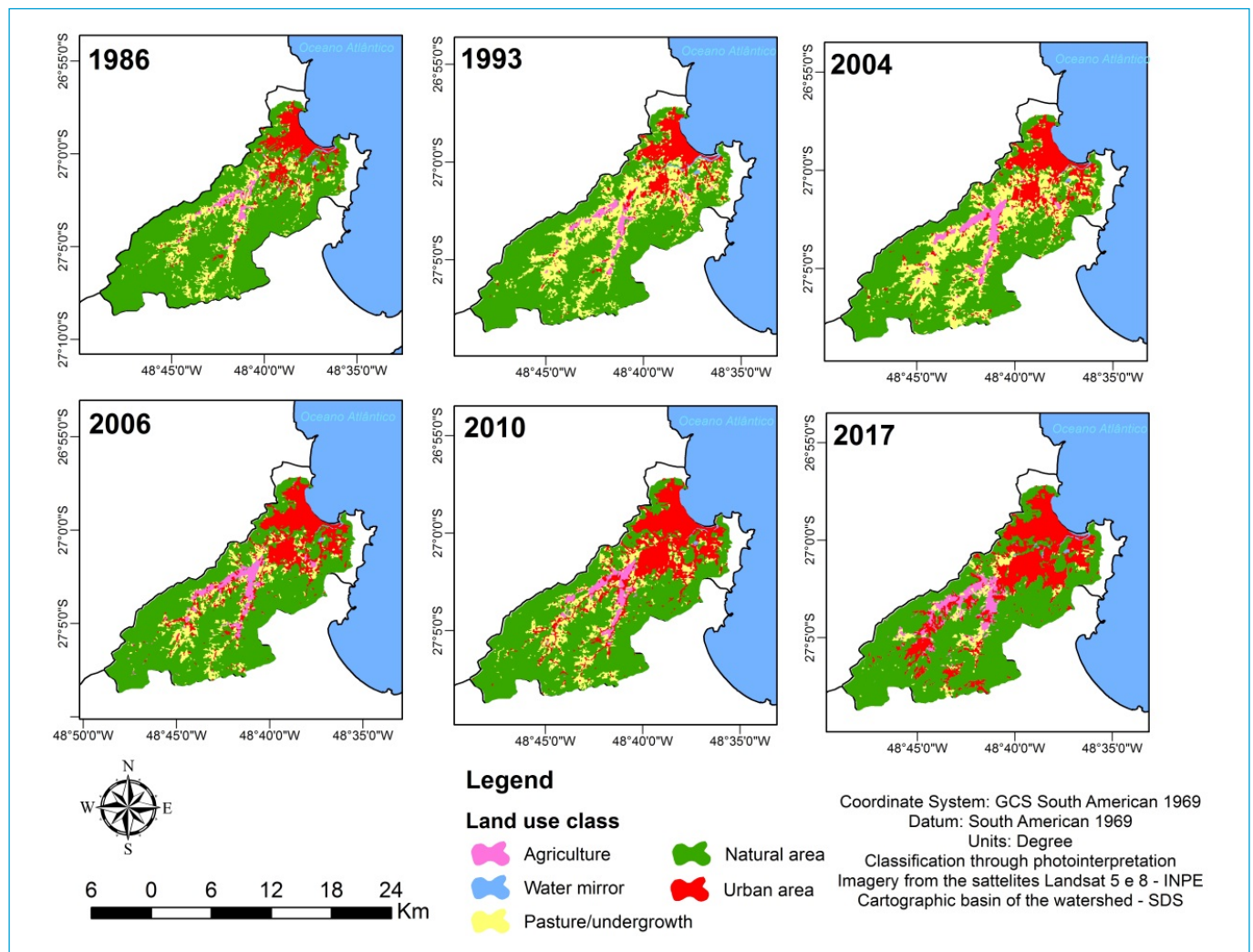


Figure 2 - Map of occupation and land use in the Camboriú River Basin (SC), for the years 1986, 1993, 2004, 2006, 2010, and 2017.

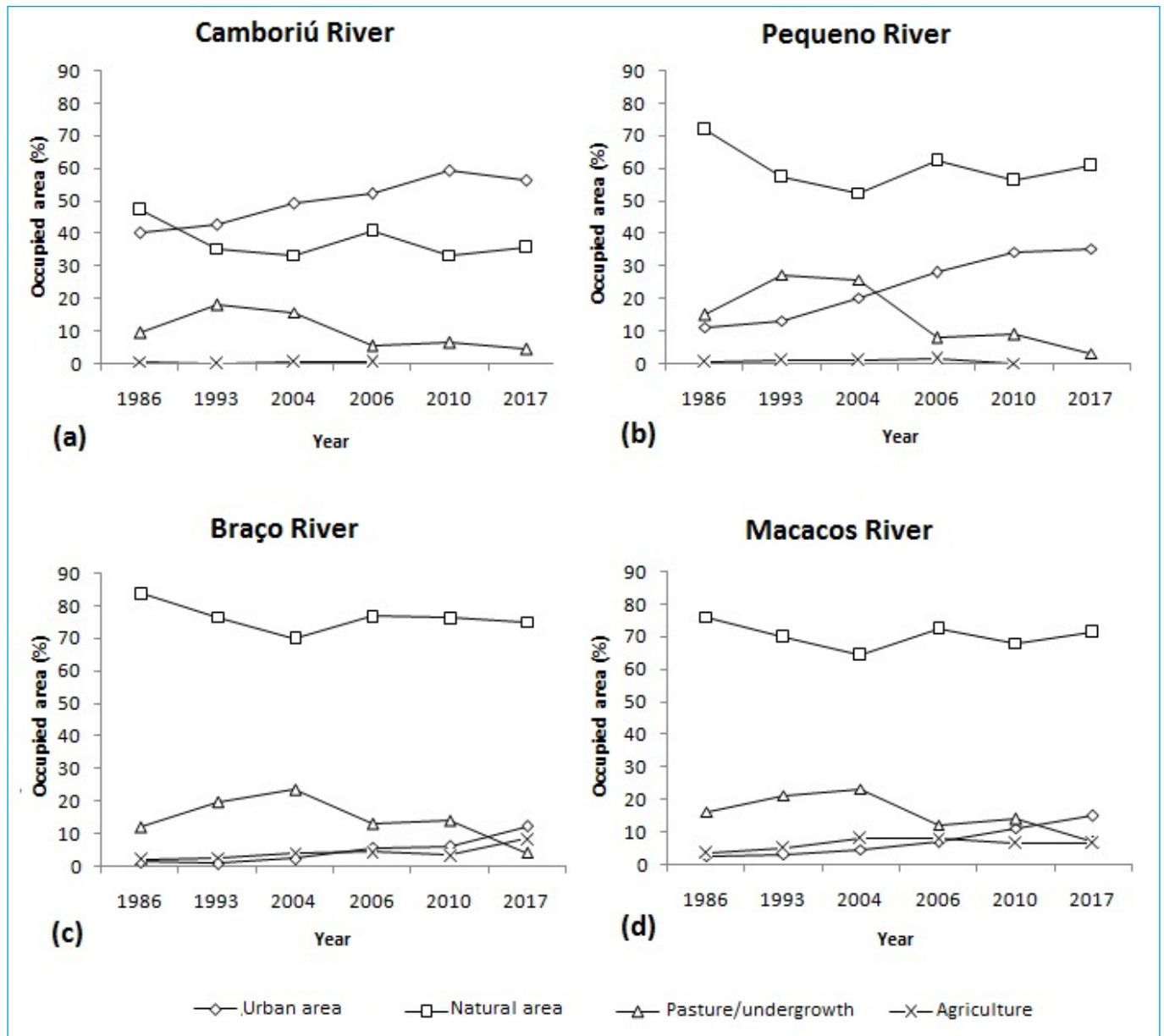


Figure 3 - Area occupied by each class of land use in (A) Camboriú River region, (B) Pequeno River region, (C) Braço River region and (D) Macacos River region, Camboriú River Basin (SC).

Table 1 - Percentage of occupation of each class, for the 1986-2017 period, in the Camboriú River Basin (SC).

Class	Year/Occupation (%)						
	1986	1993	1999	2004	2006	2010	2017
Urban area	9.43	10.19	10.49	13.53	17.50	21.18	24.18
Natural area	73.72	64.30	62.88	59.23	67.65	63.38	65.51
Pasture/ undergrowth	13.40	21.42	23.62	22.71	10.63	11.84	4.85
Agriculture	1.97	2.57	2.51	4.07	3.77	3.23	4.94
Water mirror	0.40	0.65	0.50	0.45	0.45	0.37	0.51
No class	1.09	0.87	0.00	0.00	0.00	0.00	0.00

more recordings of good and optimal ratings in the upstream sections, near the hills, while in the low zones no section obtained the best classification for the state. In the individual analysis of the parameters of the state of riparian forest, the vegetal quality of the margins received the worst ratings with 64% of the sections classified as poor or regular. The region also presented the best score in the parameter presence of the riparian forest with 43% of the sections showing a good or optimal classification. However, as in the Camboriú River region, there were registers of the inexistence of riparian forest in some sections of the Pequeno River, an area amounting to 4%. The optimal and good classifications for the presence of riparian forest were concentrated in the high zones of the region, with no excerpts recorded with such classifications in the lower patches.

The vegetal quality parameter of the margins was also evaluated by Cionek, Beaumord and Benedito *et al.* (2011), which showed that the margins scored lower. The same was verified by Rodrigues, Malafaia and Castro (2008), where the conservation status of the surrounding vegetation received lower scores, including in highland stretches. The results presented by the authors are similar to those recorded in the Camboriú River Basin, which shows that riparian

zones, although classified in good condition, are represented mostly by exotic species. Rodrigues, Malafaia and Castro (2008) reveals that the lower course areas have, in most cases, regular or poor conditions. This situation was also recorded by Minatti-Ferreira and Beaumord (2004) with emphasis on the sub-basin of the Limeira River (Itajaí, SC), which has similar characteristics to the regions of Braço and Macacos River where irrigated rice is cultivated. The fact that the flat regions are home to a greater number of anthropogenic activities may explain the results in the studies of the riparian forest of the Camboriú River Basin, the Limeira River Sub-basin (MINATTI-FERREIRA; BEAUMORD, 2004) and the region of Ouro Preto (MG) (RODRIGUES; MALAFAIA; CASTRO, 2008).

A reduction in the presence of ciliary forest, the worst classified parameter for the Camboriú River Basin, was further witnessed during the period of field visits. Extracts assessed in the present study saw a decline in vegetal cover between January and December 2015. This loss of cover over the span of one year demonstrates the vulnerability of this ecosystem and the speed with which it is modified by anthropogenic actions.

The Braço River region had the greater number of sampling points, mostly located in upper areas of the watershed. Approximately 60% of the stretches in this region were classified as regular or poor (Figure 8). As for the presence of riparian forest, the results are worse, with 43% of the sections in poor conditions. The best-classified sections are in the upstream regions with 12 of the 72 spots recorded in optimal conditions in the state and presence of the riparian forest, while, conversely six sections of the low zone presented a poor classification for both parameters.

The state of riparian forest within the Macacos River region saw 10% of its sections with poor classification and 52% as regular (Figure 9). These results are similar to those obtained for the Camboriú River region. However, it should be noted that the Macacos River is located in upper areas of the watershed where better scores are expected. In the presence of riparian forest, the results show that 66% of the sections are classified as poor or regular, while only four sections have been classified as optimal, which illustrates the threatened nature of the riparian zones of this region.

Overall, the results indicate that even high regions of the watershed are suffering from anthropogenic occupation which can directly disturb the quality of

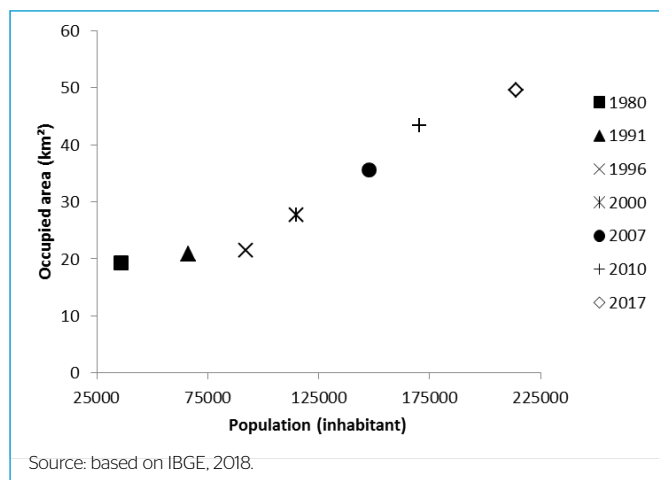


Figure 4 - Area occupied by the urbanization *versus* the resident population in the Camboriú River Basin, from 1980 to 2017.

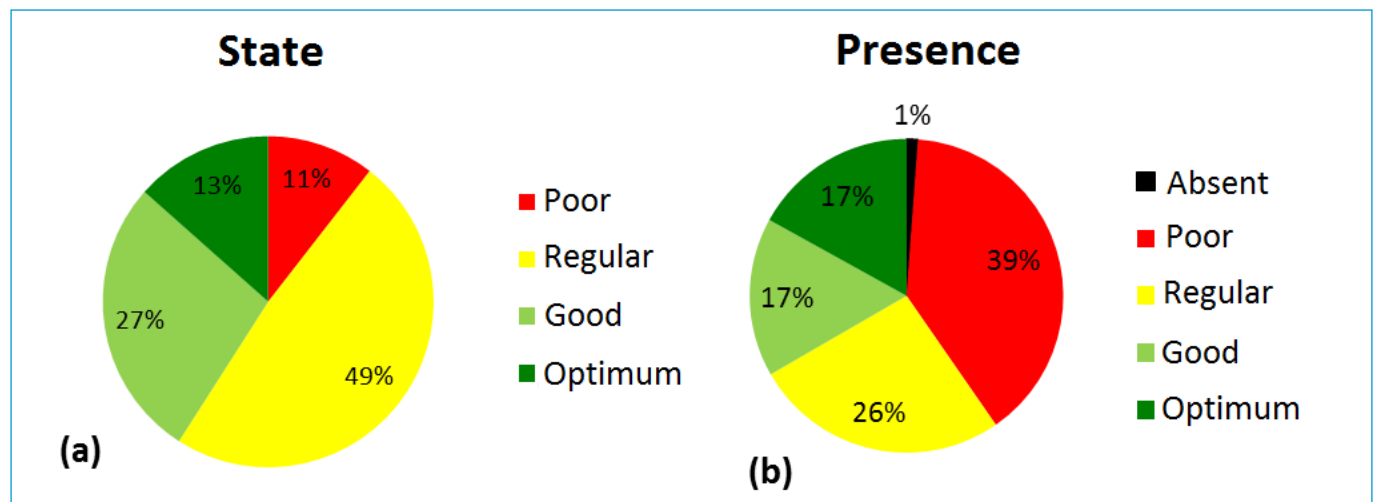


Figure 5 - (A) State and (B) Presence of the riparian forest in the Camboriú River Basin (SC).

the watercourses from the rhithral zones. An example of this can be seen in the regions of the Braço and Macacos River, whose margins are partially occupied by irrigated rice cultivation. In the individual analysis of the parameters that compose the state of the riparian forest (quality and vegetal cover of the margins, vegetal protection and stability of the ravines) it was verified that the vegetal quality presented the worst classifications in all regions of the basin. This indicates that the forested areas are mostly represented by exotic vegetation associated with the presence of anthropogenic impacts or even pasture and urban occupation. In the span of the basin, there are sections with *Brachiaria* sp. in the margins of the watercourses, resulting in a bad classification related to the state parameter of the riparian forest.

Analysis of the environmental integrity

The environmental integrity analysis of the main tributaries of the Camboriú River Basin was carried out exclusively for streams in rhithral areas, thus, the Camboriú River region and low-lying sections were not considered. Of the 171 sections with riparian forest analysis, the environmental integrity was verified in 54 points (Figure 10) as the description of the parameters applies only to these points. Approximately 60% of the evaluated sections received good or optimal ratings. The results found for riparian zone and environmental integrity were distinct, which may be associated with the location and number of stretches analyzed.

In contrast to what was verified regarding the riparian zone, the Pequeno River region saw the worst conditions related to its environmental integrity. Of the evaluated sections, 60% were classified in poor or regular conditions. Furthermore, the Macacos River region had similar results to the Pequeno River region, registering 50% of the areas classified as poor or regular (Figures 10A and 10C). The Braco River region saw 26% of its areas in poor or regular conditions with a predominance of sections classified as good (30%) and optimal (44%) (Figure 10B). In general, environmental integrity parameters such as the bottom substrate and the complexity of the habitat present similar characteristics, providing food and refuge for the biota (MINATTI-FERREIRA; BEAUMORD, 2006).

The situation of the riparian zone found in upper course stretches showed that in preserved areas the environmental integrity of the streams was better classified. This proves that the quality of the riparian zone directly reflects on the integrity of the aquatic ecosystems, a theme addressed by several authors (DEBANO; SCHMIDT, 1989; ELMORE; BESCHTA, 1987; LIMA; ZAKIA, 2000; MISERENDINO *et al.*, 2011; SOUZA *et al.*, 2013). Although the low-course sections have not been evaluated for environmental integrity, the relationship between riparian conditions and watercourses can be indicative of poor quality in these locations where very poor riparian conditions were recorded.

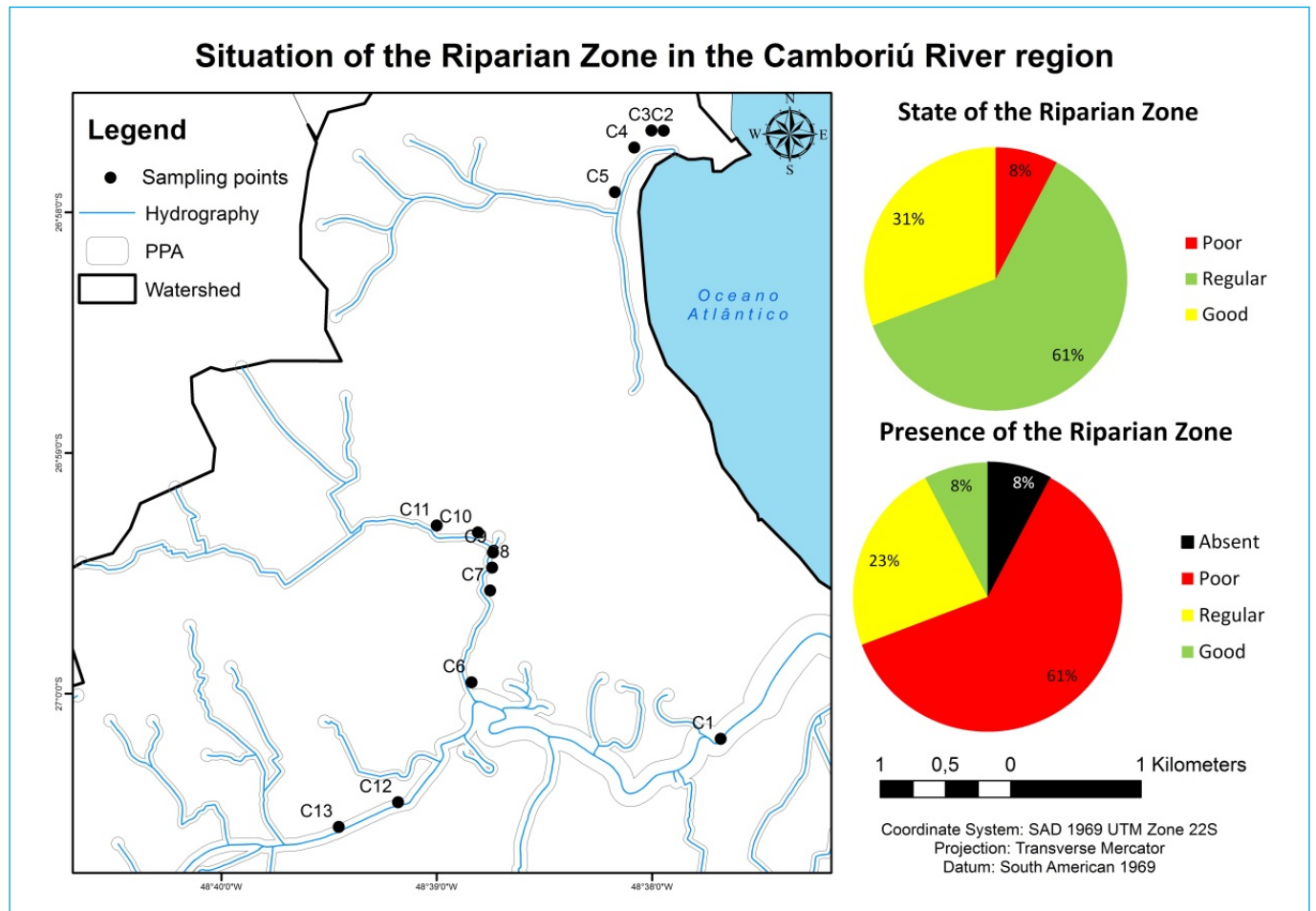


Figure 6 - A map of the situation of the riparian forest in the Camboriú River region, in the Camboriú River Basin (SC).

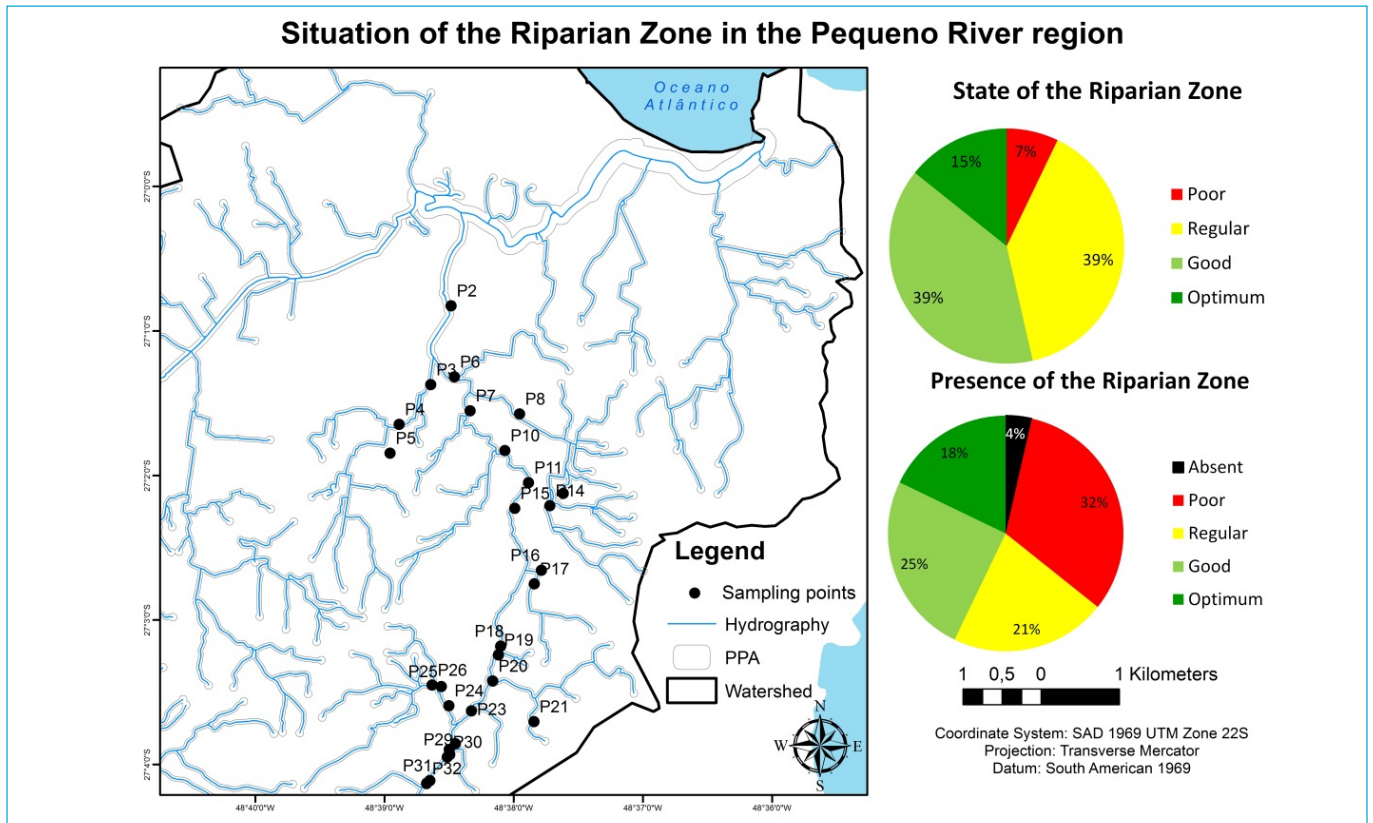


Figure 7 - A map of the situation of the riparian zone of the Pequeno River region, in the Camboriú River Basin (SC).

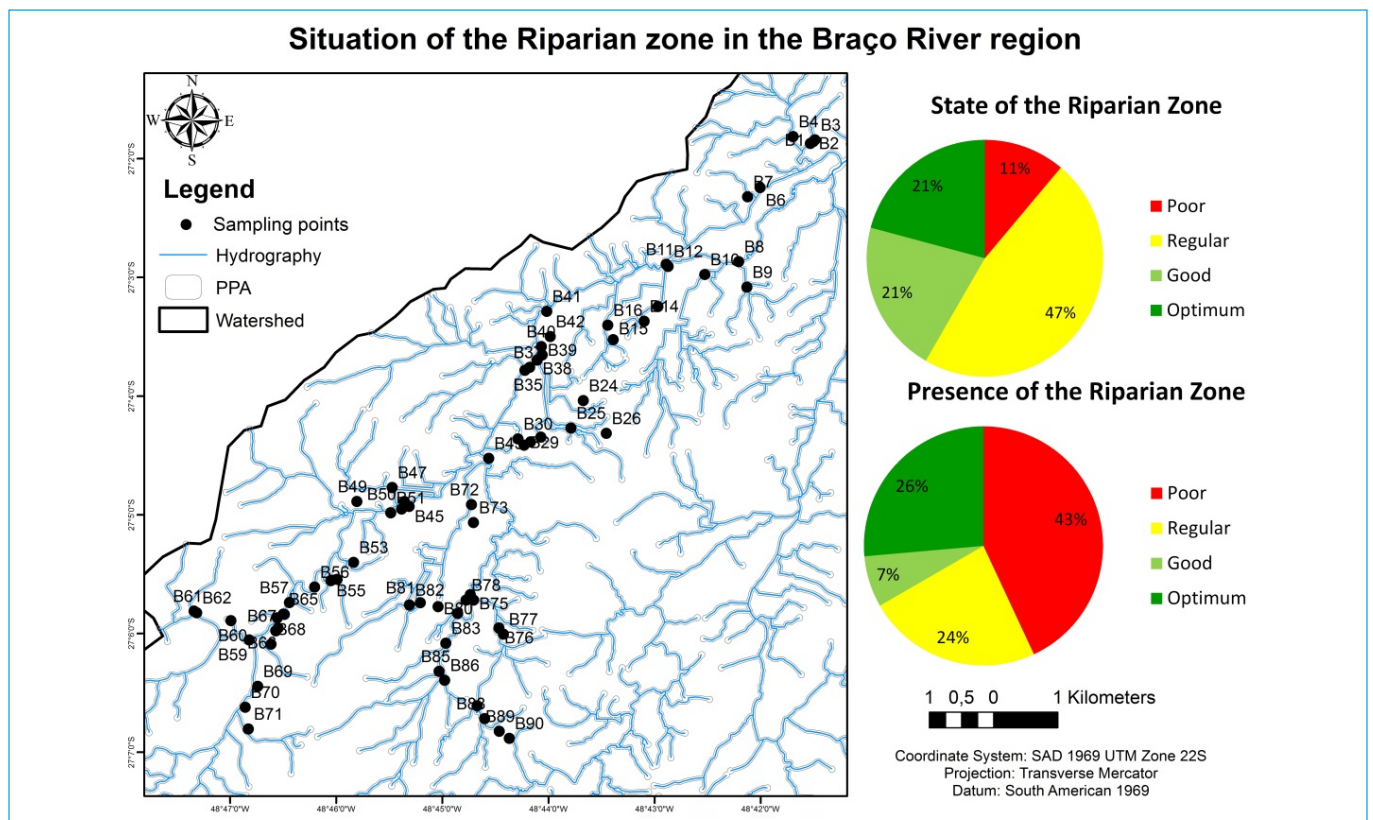


Figure 8 - A map of the situation of the riparian zone of the Braço River region, in the Camboriú River Basin (SC).

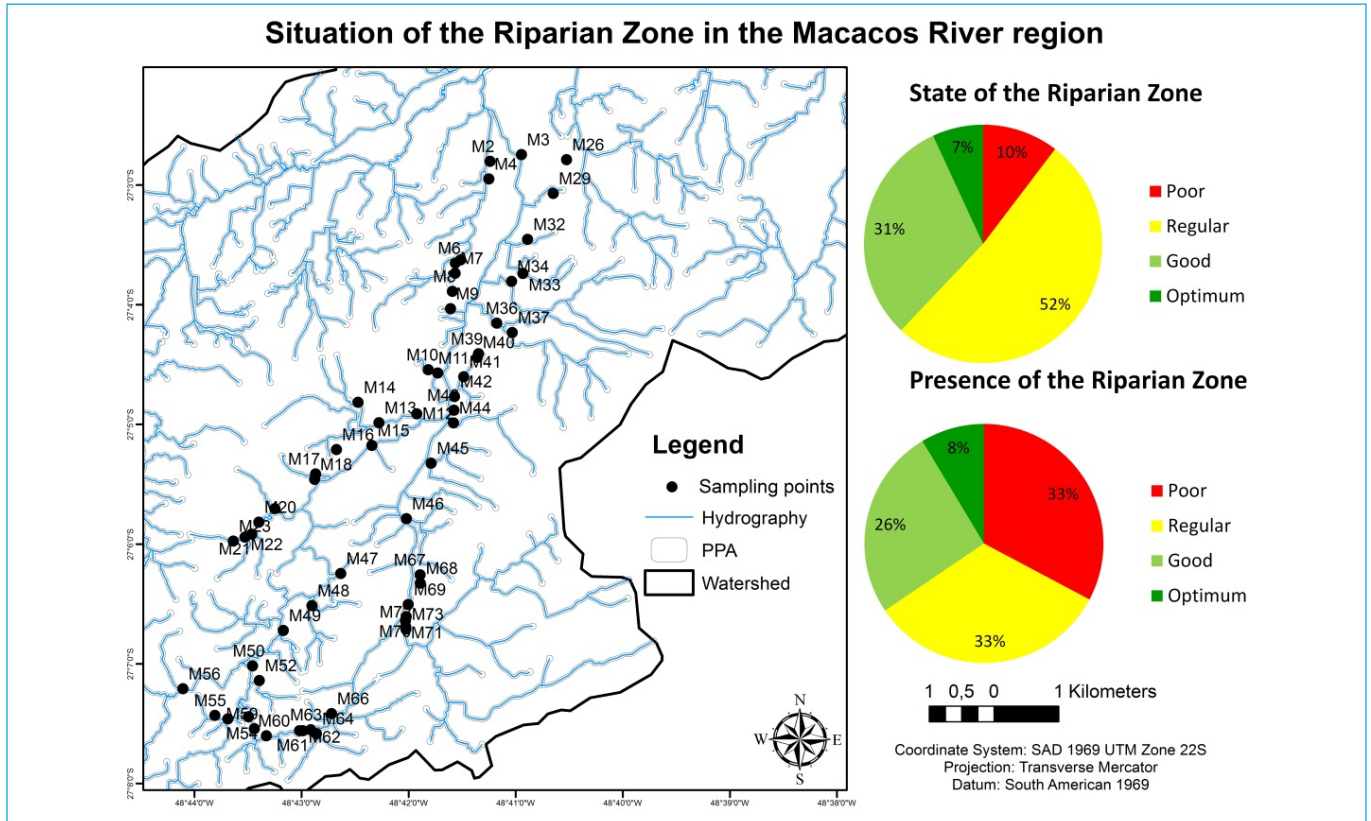


Figure 9 - A map of the situation of the riparian zone of the Macacos River region, in the Camboriú River Basin (SC).

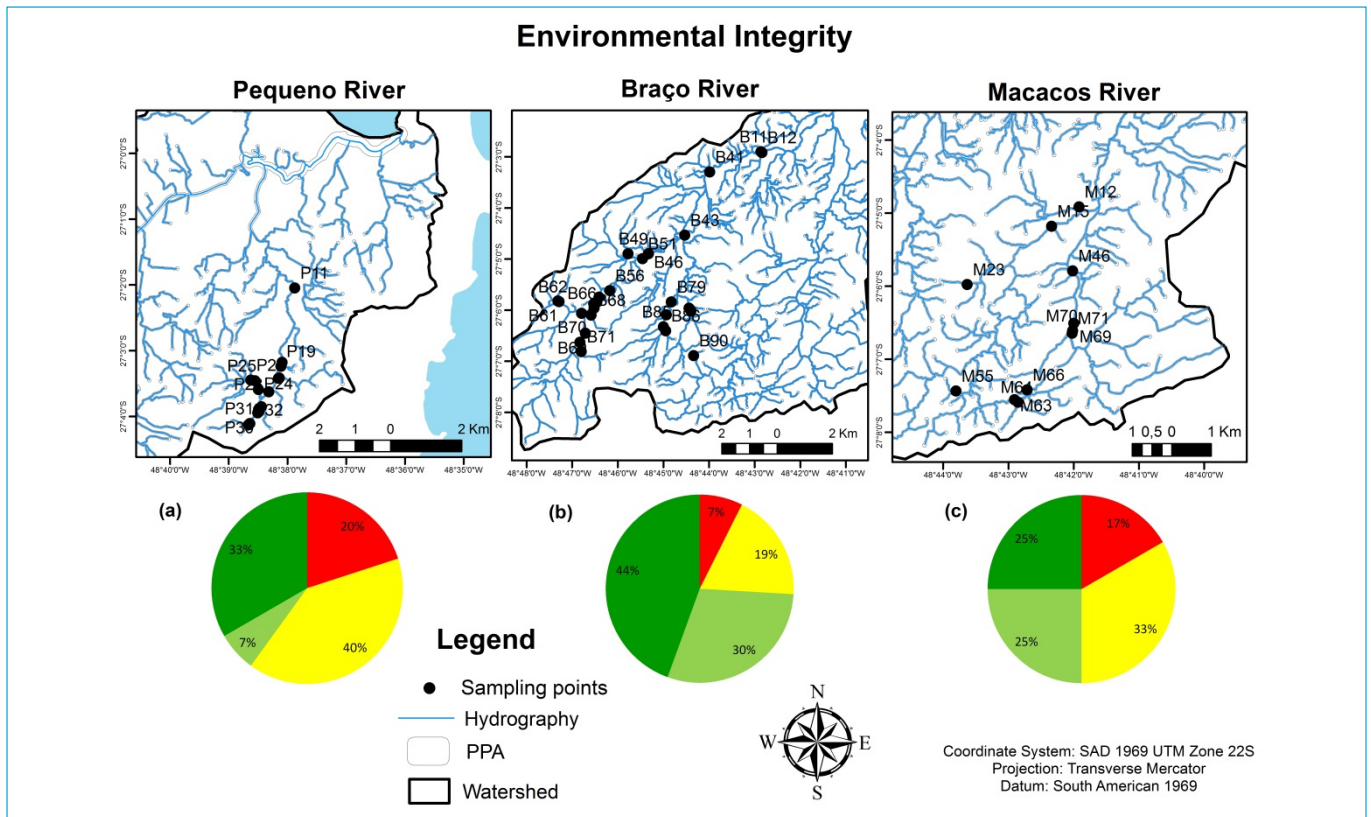


Figure 10 - Map of environmental integrity in the region of (A) Pequeno River, (B) Braço River and (C) Macacos River, in the Camboriú River Basin (SC).

FINAL CONSIDERATIONS

From the results obtained for the Camboriú River Basin (Santa Catarina), in reference to changes in land use and occupation, it was concluded that the urban area of the basin grew by 156% between 1986 and 2017, which led to a reduction of 11% decrease in the natural area during the same period. Although the expansion of urban area was high, this pattern was verified only from the 2000s, thus not presenting a linear model in relation to the number of inhabitants during the studied period. This model of urban occupation over the watershed area is influenced by different external factors which shapes its pattern of dispersion in space. In the case of the studied coastal basin, one characterized by high touristic potential, the growth of urban occupation

occurred vertically. This pattern is associated with periods of elevated population densification, thus reducing the speed of the land occupation process in adjacent areas until the year 2000.

AUTHORS' CONTRIBUTIONS

Pereira-Silva, D. D.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing — Original Draft, Writing — Review & Editing. Schwingel, P. R.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing — Review & Editing.

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