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Papers

Impacts of Sea Level Rise and Land Use on Coastal Wetlands: Methodology Applied to Baía da Babitonga (SC)

André Schmidt Filgueras[1]
Tatiana Silva da Silva[2]
Iran Carlos Stalliviere Corrêa[3]

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Abstract
Coastal wetlands are formed by ecosystems with the potential to resist and even expand because of climate change. However, they depend on the preservation of their environmental quality and the ecosystem services they provide, including sediment accumulation, which is essential for maintaining current areas, and the presence of contiguous land areas free from human occupation, allowing for migration to higher areas in response to sea-level rise. To develop a methodology for the joint assessment of the impacts of climate change and land occupation of coastal ecosystems, this study focuses on the mangroves of Baía da Babitonga, located on the northern coast of Santa Catarina. By using projections of sea-level rise and human occupation expansion around the bay based on land cover and land use data, it was possible to identify immediate effects of sea-level rise and human occupation in the short, medium, and long term, as well as the potential expansion area for mangroves. The results indicate the need for the expansion of conservation areas, considering displacement zones towards the mainland, and the control of various stress factors that can interfere with the ecosystem's health and its ability to maintain current areas.

[1] Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. andresfilga@gmail.com
[2] Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. tatiana.silva@ufrgs.br
[3] Universidade Federal do Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. iran.correa@ufrgs.br

INTRODUCTION

Coastal wetlands, characterized by their location between the mainland and the ocean, present a multitude of other interfaces, such as the interface between fresh and saline water, past and present, population and nature, adaptation and mitigation, and conservation and restoration (Emmett-Mattox; Simpson, 2018). These ecosystems are comprised of resilient systems with the potential to adapt to sea level rise through the elevation of existing wetland areas (vertical movement) or by migrating inland (horizontal movement) from current wetland areas to adjacent continental zones (Osland et al., 2022; Ward et al., 2016). They possess the capability to contribute directly and indirectly to sediment accretion, enabling vertical migration (elevation) that could sustain existing areas despite rising sea levels, contingent on the ecosystem's preservation level and sediment influx (Alongi, 2018; Krauss et al., 2014). Conversely, horizontal migration relies on the presence of barriers, either natural or man-made, in the new areas to be incorporated into the coastal wetland zone (Hopkinson et al., 2019; Woodroffe et al., 2016).

Up to this point, the relative sea-level rise has likely posed a lesser threat to these environments than non-climate-related anthropogenic stressors, such as alterations in hydrology (reduction of freshwater and sediment inflow into systems due to the construction of irrigation diversions or dams) and the increased deposition of domestic and industrial waste resulting from human occupation of coastal areas, leading to changes in the structure and composition of these environments (Gilman et al., 2008; Gorman, 2018; Lovelock et al., 2018). The process of "squeeze" caused by rising sea levels and expanding human land use has the potential to yield serious consequences, including decreased biodiversity and heightened coastal erosion and flooding (Gilman et al., 2008; Li et al., 2018; Woodroffe et al., 2016).

Coastal wetlands provide vital ecosystem services, including direct resources such as food and biomaterials, wildlife habitat, carbon sequestration, storm protection, and sediment accumulation, among others (Li et al., 2018; Wright et al., 2019). However, this capacity to deliver services, including the sediment accretion necessary for the maintenance of their current areas, relies on the preservation and health of ecosystems (Alongi, 2018; Din et al., 2017; Gilman et al., 2008; Godoy; Lacerda, 2015).

Remote sensing imagery enables an understanding of wetlands within a broader landscape context, providing managers with more precise and timely information for decision-making (Lang et al., 2015). For the analysis of ecosystem services provision in coastal wetlands, the spatiotemporal assessment of changes in their biophysical characteristics is crucial. Structural aspects, changes in coverage within these ecosystems, as well as the management of anthropogenic factors, must be analyzed through satellite imagery (RAHIMI et al., 2020). Medium-resolution satellites, such as those from the Landsat series, facilitate the monitoring of wetland ecosystems, especially for identifying rapid changes across extensive areas (Giri, 2018; Guo et al., 2017; Klemas, 2015). In Brazil, national-scale land cover and land use maps, derived from Landsat images captured since 1985, have been developed by a multidisciplinary working network called MapBiomas. Various categories of natural cover and human land uses, including the distribution of wetland ecosystems, are classified using the Google Earth Engine (GEE) platform (Diniz et al., 2019; Souza et al., 2020).

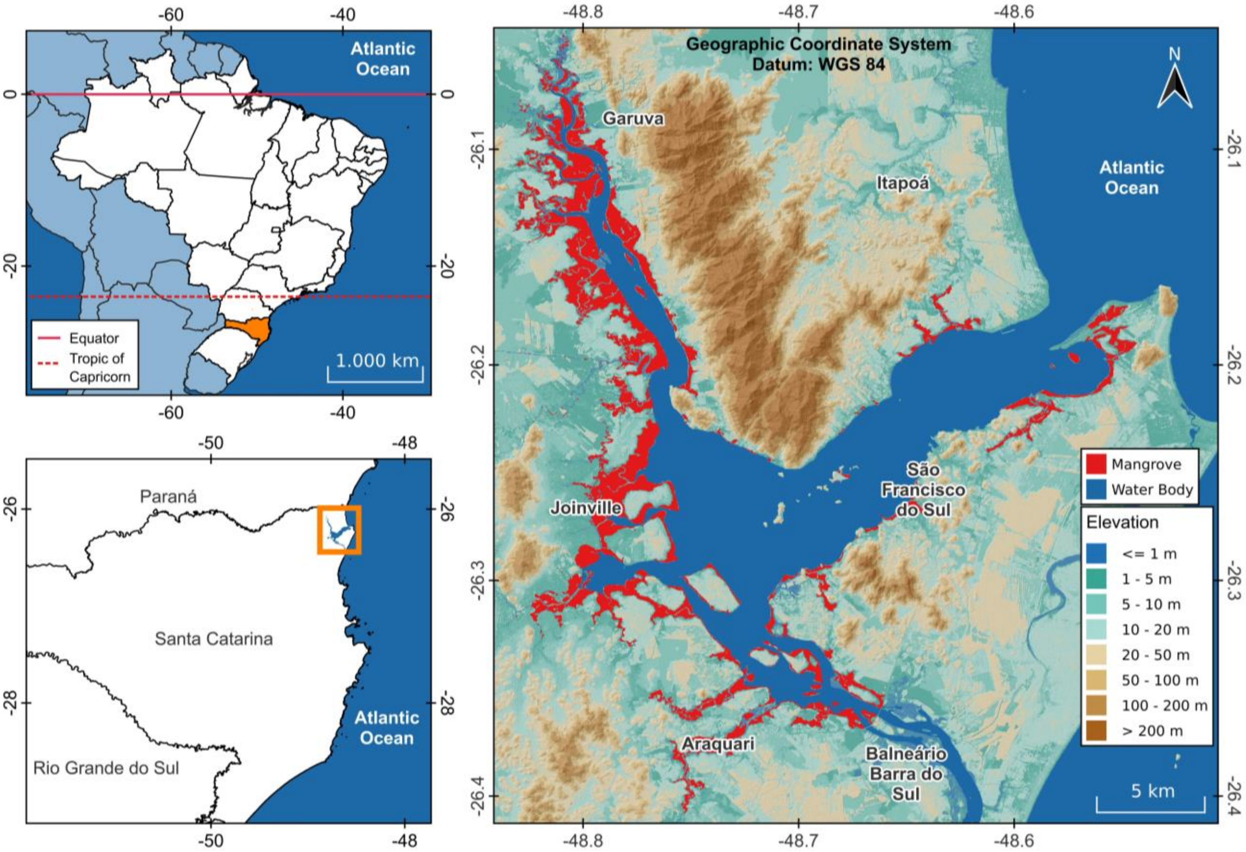
The current study aims to develop a qualitative-quantitative methodology for assessing the potential combined effects of climate change and land use, known as coastal squeeze (Pontee, 2013). Additionally, the study seeks to identify necessary actions to enhance the resilience capacity of coastal wetlands in the face of climate change. The research area for this study is the baía da Babitonga, characterized by harboring 75% of the mangroves in the state of Santa Catarina and a population of 700,000 inhabitants. Furthermore, the bay houses the largest industrial park and the second-largest port system in the state (Kilca et al., 2019).

Study Area

The estuarine complex of baía da Babitonga is situated between latitudes 26° 07' and 26° 27' South, establishing itself as the largest estuarine complex in the state of Santa Catarina. Encompassing an area of 160 km², its hydrographic basin covers a surface of 1,567 km², draining land from five out of the six municipalities bordering the estuary. The northern boundary of wetland occurrence is observed in the municipalities of Itapoá, Joinville, and Guaratuba, while to the south it extends into the municipalities of Araquari and Balneário Barra do Sul (Kilca et al., 2019; Vieira et al., 2008). Geomorphologically, the region is classified as a Ria, which denotes a river valley submerged due to rising sea levels. It has been primarily filled with fluvial and estuarine sediments since the upper Quaternary period (Mazzer; Gonçalves, 2012). The adjacent oceanic environment is characterized by a micro-tidal regime (tidal ranges less than 2 m). However, within the bay, there is a tidal height amplification due to the narrowing of the main channel, leading to tidal elevations of up to 2.3 m (Kilca et al., 2019; Truccolo et al., 2006; Truccolo; Schettini, 1999).

In terms of morphology, baía da Babitonga can be divided into three sectors. It features a main channel oriented NE/SW, with a width of approximately 3.8 km and depths of up to 28 m. Additionally, there are two elongated axes in the SE/NW direction that are narrower, with a maximum width of 1.5 km and an average depth of 4 m (Vieira et al., 2008). The northern axis, referred to as the Palmital Channel, receives the most significant hydrological and sediment contributions originating from the watershed of the Serra do Mar escarpment. On the other hand, the southern axis, known as the Linguado Channel, underwent a hydrological alteration in 1937 due to the closure of the channel for the construction of a highway to access São Francisco do Sul Island. This closure has led to substantial sedimentation within this channel since then (Barros et al., 2010; Engel et al., 2017). Due to this interruption and the resultant separation of water bodies, the region of the Linguado Channel south of the access point to São Francisco do Sul was not considered in the study area (Figure 1).

Figure 1 - Location of baía da Babitonga (SC) and distribution of wetlands in the region.

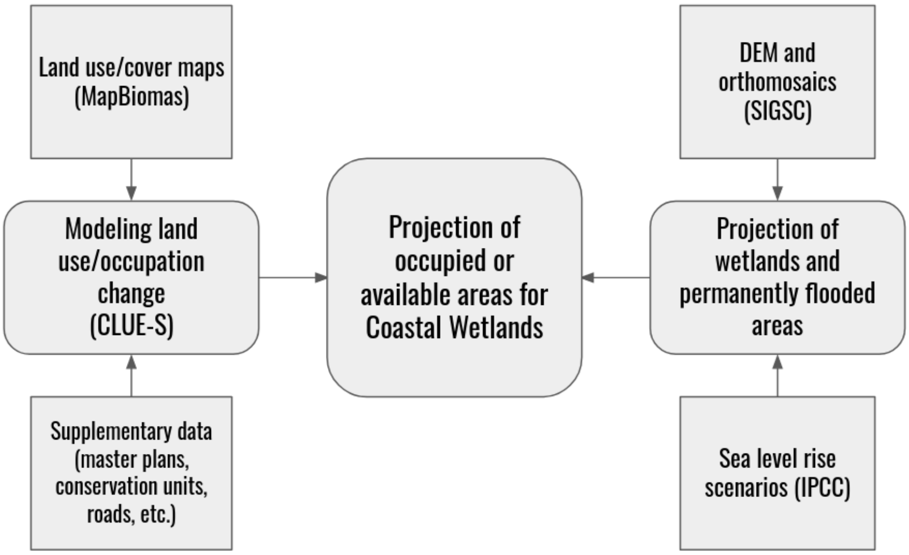


Source: the authors (2023) based on data from IBGE (2021) and the Sistema de Informações Geográficas Santa Catarina (2010).

MATERIALS AND METHODS

The employed methodology is divided into two main stages: the first involves projecting sea-level rise, while the second is related to projecting changes in land use and land cover (Figure 2).

Figure 2 - Schematic representation of the methodology employed for projecting the potential distribution of Coastal Wetlands.



Source: The authors (2023).

For projecting future scenarios of sea-level rise, the 50th percentile of two Shared Socio-Economic Pathways (SSPs) presented in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) were utilized (Masson-Delmotte et al., 2021):

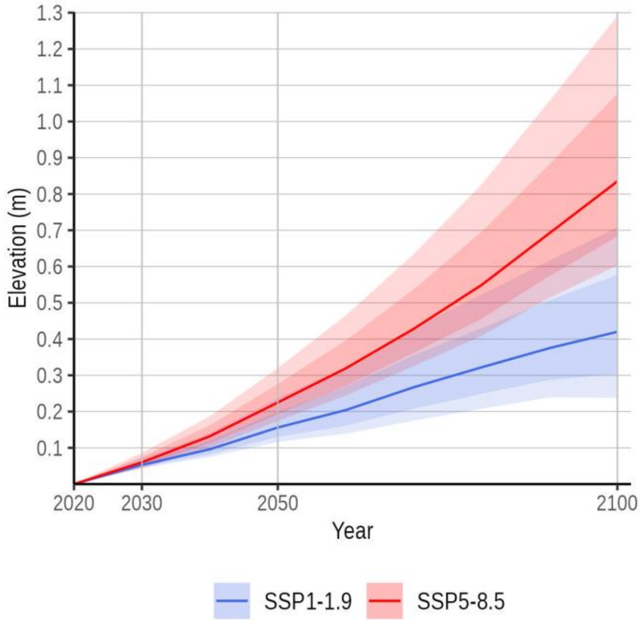
SSP1-1.9 - an "optimistic" scenario in which the temperature increase is kept to approximately 1.5°C relative to the 1850-1900 period up to 2100. This scenario implies achieving net-zero CO2 emissions by mid-century, aligning with the Paris Agreement's target.

SSP5-8.5 - a "pessimistic" scenario that lacks additional climate policies, occurring in a high-development world driven by fossil fuels (Figure 3). In this latter scenario, global warming surpasses 4°C by the end of the 21st century.

The projection of these scenarios was obtained using the IPCC AR6 Sea Level Projection Tool (Garner et al., 2022), with data from the closest available regional source, located in Cananéia (SP).

The estimation of the sea-level rise impact on the distribution of wetlands in baía da Babitonga was conducted using aerial photogrammetry data and digital elevation models – DEM (with spatial resolutions of 0.39 m and 1 m, respectively) obtained between 2010 and 2012 and provided by the Sistema de Informações Geográficas de Santa Catarina - (Santa Catarina, 2010),which is a tool for public access to spatial data from the state of Santa Catarina. These sea-level variations were subsequently applied based on the IPCC scenarios to project land cover/land use changes in the region for the years 2030, 2050, and 2100.

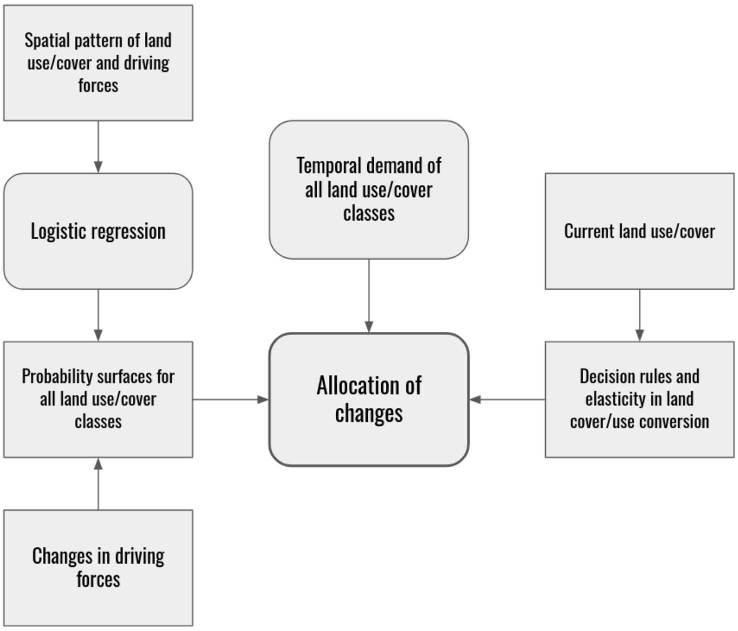
Figure 3 - Projection of sea-level rise at the 50th percentile (lines) and within the intervals of 17 to 83% (darker areas) and 5 to 95% (lighter areas) for the SSP1-1.9 scenario (blue) and SSP5-8.5 scenario (red)



Source: Garner et al. (2022). Adapted by the authors (2023).

The projections of land use changes in the region were derived from data available since 1985 through the Brazilian Annual Land Cover and Land Use Mapping Project - MapBiomas (Souza et al., 2020). This was achieved using land cover and land use maps based on Landsat mosaics (with a resolution of 30 m) and employing the Conversion of Land Use and its Effects at Small Regional Extent (CLUE-S) model (Verburg et al., 2002) through the lulcc (Land-use and land-cover change) package in the R platform (Moulds et al., 2015). The CLUE-S model allocates areas to be converted among land use/land cover classes through an iterative process involving both non-spatial factors, such as temporal demand projections for changes in each class area, and subjective rules like a decision matrix (indicating possibilities of conversion between classes) and elasticity (the potential of a class to revert to its previous state). It also considers spatial factors, such as the current distribution of land use/land cover classes and other conversion-influencing elements like proximity to roads, conservation units, master plans, etc. (Figure 4). The programming codes of the lulcc package are described by Moulds et al. (2015) and can also be found in the reference manual (Moulds, 2019).

Figure 4 - Schematic representation of the allocation procedure for changes in land use/cover.



Source: Verburg et al. (2002). Adapted by the authors (2023).

For the delineation of the area to be included in the modeling, a distance of up to 5 km from the current locations of the mangrove areas was considered. This distance was sufficient to encompass a significant portion of the urban areas in the four municipalities whose urban structure is in proximity to baía da Babitonga (Joinville, São Francisco do Sul, Araquari, and Garuva). The projection of the quantity of areas for each category up to the year 2100, used for the model allocation process (temporal demand), was performed in the R platform using the forecast package (Hyndman; Khandakar, 2008). This package provides methods and tools for displaying and analyzing forecasts of univariate time series, including exponential smoothing through state space models, which were utilized in this study.

After a preliminary evaluation, the original land cover and land use categories from MapBiomas were divided into five classes: the Forest and Mangrove classes, equivalent to the "1.1 Forest Formation" and "1.3 Mangrove" categories in MapBiomas; the Primary Occupation class, comprising categories from MapBiomas that directly advanced over natural areas; the Rural Occupation class, formed by categories within the "Agriculture" class of MapBiomas whose expansion mainly encroached upon the Primary Occupation class; and the Urban Occupation class, which advanced over the other classes, primarily the Primary Occupation (Chart 1). In addition to these classes, a sixth class was added, called Transition, characterized by areas not classified as Mangrove but situated within the upper limit of water level elevation inside baía da Babitonga (2.3 m). This class mainly consists of ecotones between terrestrial and marine environments, where predominant herbaceous vegetation is observed, as well as areas between the water body and the mangrove, occupied by salt marshes or areas without consolidated vegetation (Charlier-Sarubo, 2015; Schaeffer-Novelli, 2008).

Considering that, in a preliminary study (submitted for publication), we observed that changes within mangrove areas were identified by MapBiomas were actually mainly related to alterations in mangrove structure rather than conversion of mangrove into other land cover and land use classes. This study considered the total area of mangroves that had been classified as such since 1985 and had not been converted into Urban Occupation. The "apicuns" were included in the Mangrove class since they are considered a type of herbaceous mangrove and thus an integral part of the mangrove ecosystem (Schmidt *et al*., 2013).

The assessment of the impact of climate change and land use changes, in addition to sea-level rise scenarios and land cover/land use projections, will present the distribution of coastal wetlands (CW) with two scenarios for mangrove vegetation: one that considers sea-level rise affecting the current mangrove area elevations without vertical migration, referred to as Instantaneous CW, and another scenario that considers the mangrove's capacity to adjust to sea-level rise, preserving the areas depicted in 2020, referred to as Potential CW.

Chart 1 - Reclassification of classes from MapBiomas used in the present study.

MapBiomas Classes (v6.0)	New Classification
1. Forest	
1.1 Forest Formation	Forest
1.3. Mangrove	Mangrove
1.4. Wooded Restinga	Forest
2. Non-Forest Natural Formation	
2.3. Apicum	Mangrove
3. Farming	
3.1. Pasture	Rural Occupation
3.2. Agriculture	Rural Occupation
3.3. Silviculture	Rural Occupation
3.4. Mosaic Agriculture and Pasture	Primary Occupation
4. Non-Vegetated Area	
4.2. Urbanized Area	Urban Occupation
4.4. Other Non-Vegetated Areas	Primary Occupation

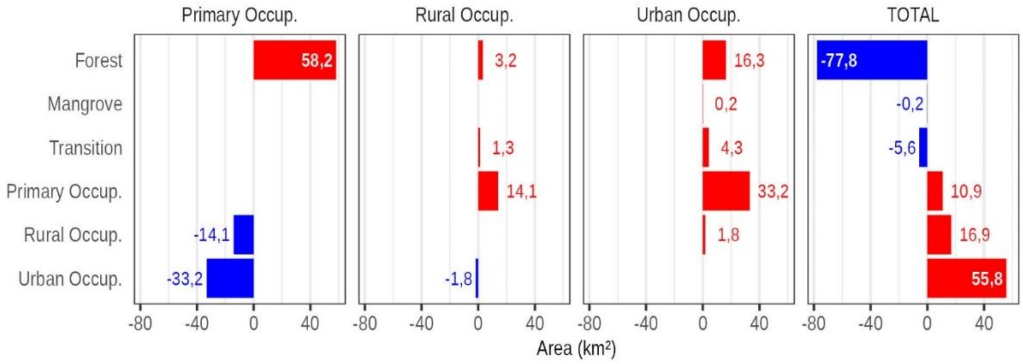
Source: The authors (2023).

RESULTS AND DISCUSSION

Transitions Observed (1985-2020) and Projections of Land Cover/Land Use Classes

Analyzing the transitions between land cover/land use classes from 1985 to 2020, there is an increase in human occupation primarily at the expense of Forest areas. However, this transition mainly occurs through the Primary Occupation class, responsible for 75% of the loss in Forest areas. The other occupation classes advance mainly over Primary Occupation areas, with Urban Occupation being the only class advancing overall categories (Figure 5). The areas classified as Primary Occupation represent, based on these results, regions with incipient/intermittent agricultural activity or areas where vegetation is cleared to facilitate short-term urban expansion.

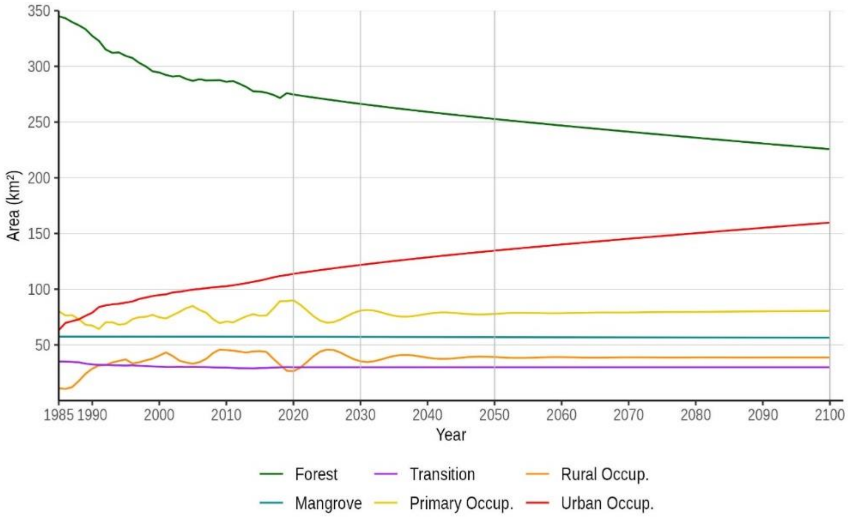
Figure 5 - Transitions of areas among land cover/land use classes between 1985 and 2020.



Source: The authors (2023).

The area values for each land cover/land use class between 1985 and 2020 indicate a continuous increase in Urban Occupation areas and a reduction in Forest areas, showing the transition between these two classes as observed previously. The other classes did not show a clear trend of change in their areas, thus maintaining the values observed since 1985. In the case of Rural Occupation, there is a concentrated increase between 1985 and the mid-1990s, followed by fluctuations around 38 km². The projections between 2020 and 2100 followed these patterns, with a continuous increase in Urban Occupation at the expense of Forests, and the other classes not exhibiting distinct trends, maintaining consistent projections (Figure 6).

Figure 6 - Distribution of land cover/land use from 1985 to 2020 and projection up to the year 2100 for the new classes.



Source: The authors (2023).

Horizontal Migration (Instantaneous CW)

The obtained results indicate that the coastal wetlands (CW) in baía da Babitonga show a trend of increasing from 106.9 km² in 2020 to values ranging between 108.3 km² in 2030 (SSP1-1.9) and 116.7 km² in 2100 (SSP5-8.5). Despite this increase in area, a continuous decrease in the percentage of occupation by the original mangrove and wetland areas (Mangrove + Transition) is observed, at the expense of both terrestrial forest areas and the three classes of human occupation/land use. By 2100, under the worst-case sea-level rise scenario (SSP5-8.5), only 26.4 km² of Mangrove and 20.52 km² of Transition will remain, representing 57.86% and 31.12% of the 2020 areas, respectively (Table 1).

For the long-term scenarios (2100), the terrestrial natural areas (Forests) within the wetlands will not be sufficient for the migration and maintenance of the original mangrove area in the "pessimistic" scenario. Considering the CW as a whole (Mangrove + Transition), there will not be an insertion of Forest areas in a sufficient quantity to maintain the observed quantity in 2020 as early as 2030, for both the SSP5-8.5 scenario and the "optimistic" (SSP1-1.9) scenario.

The lack of natural areas for horizontal mangrove migration, despite the increasing total area of CWs over time, is attributed to the expanding human presence in these regions. In 2020, the combined primary, rural, and urban occupations within the CWs of baía da Babitonga accounted for 11% of the total area, while by 2100, this expands to 24.4% in the SSP1-1.9 scenario and 33.6% in the SSP5-8.5 scenario. Urban occupation areas in 2030 will surpass the combined areas of the three human occupation classes in 2020, in both scenarios analyzed. Among the municipalities surrounding baía da Babitonga, Joinville, which contributed 47.7% of the CW areas in 2020, accounts for 83.5% of the urban occupation areas within these regions.

Joinville experienced a significant migration of workers from the 1960s to the 1990s towards its developing industrial hub. A combination of housing shortages and the lack of public housing policies led to the precarious occupation of the mangroves, lacking basic infrastructure. This trend continued until the late 1980s, when the Núcleo de Bacias Hidrográficas da Prefeitura de Joinville (Joinville municipal watershed group) was established. A man-made canal was constructed to physically contain the occupation process on the mangroves and to provide infrastructure in the already occupied areas.

These areas, occupied within the CWs and exposed to astronomical and meteorological tides, along with rainfall inputs, frequently suffer from inundations. As a consequence of the urbanization of CW areas, there is a clear trend of drastic mangrove area reduction in some regions of Joinville until 2100, with urban occupation areas directly exposed to water bodies (Figure 7).

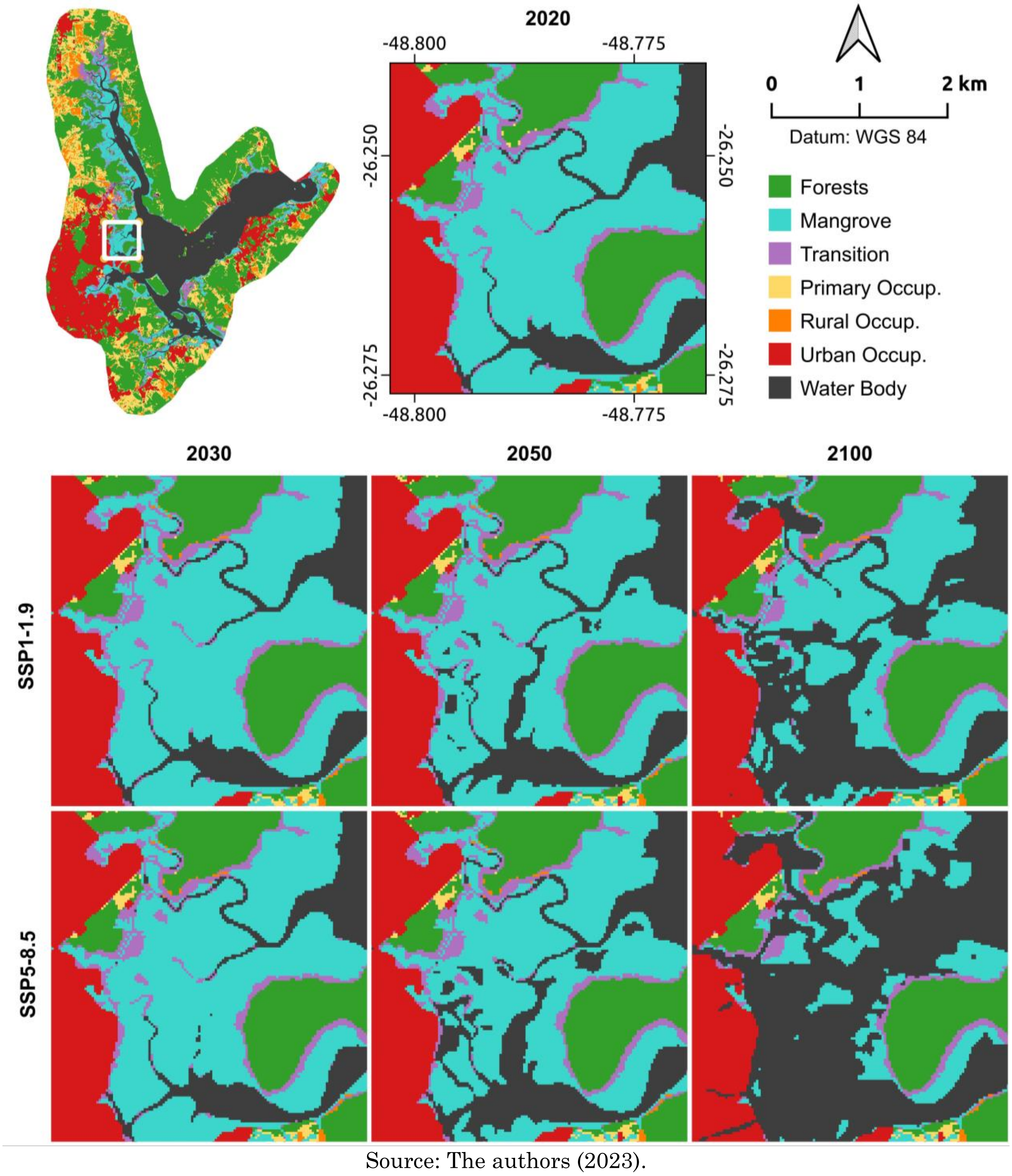
Table 1 - Distribution of areas (km²) covered by each class in the CWs in 2020 and projections for 2030, 2050, and 2100 regarding sea-level rise (SSP1-1.9 and SSP5-8.5, respectively) and regarding the mangrove's potential for vertical migration (Potential CW and Instantaneous CW, respectively).

	Category		SSP1-1.9				SSP5-8.5			
		2020	**2030**	**2050**	**2100**	Loss to the Water Body**	**2030**	**2050**	**2100**	Loss to the Water Body**
Instantaneous CW	Forests	-	0,88 (0,81%)	6,24 (5,61%)	17,29 (14,92%)	-	1,31 (1,21%)	10,34 (9,13%)	30,61 (26,24%)	-
	Mangrove	61,85 (57,86%)	61,57 (56,85%)	57,30 (51,53%)	46,03 (39,73%)	15,82 (72,93%)	61,28 (56,36%)	54,28 (47,90%)	26,40 (22,63%)	35,45 (77,16%)
	Transition	33,27 (31,12%)	29,65 (27,38%)	28,08 (25,25%)	24,42 (21,07%)	5,75 (26,51%)	29,49 (27,13%)	27,06 (23,88%)	20,52 (17,59%)	9,81 (21,35%)
	Primary Occupation	0,24 (0,22%)	2,32 (2,14%)	3,65 (3,28%)	6,84 (5,90%)	0,005 (0,02%)	2,49 (2,29%)	4,57 (4,04%)	11,02 (9,45%)	0,035 (0,08%)
	Rural Occupation	2,16 (2,02%)	3,43 (3,17%)	3,99 (3,59%)	5,16 (4,45%)	0,013 (0,06%)	3,53 (3,24%)	4,35 (3,84%)	6,41 (5,50%)	0,050 (0,11%)
	Urban Occupation	9,38 (8,77%)	10,44 (9,65%)	11,95 (10,74%)	16,14 (13,93%)	0,104 (0,48%)	10,62 (9,77%)	12,71 (11,22%)	21,70 (18,60%)	0,597 (1,30%)
	TOTAL	**106,9**	**108,3**	**111,2**	**115,9**	**21,7**	**108,7**	**113,3**	**116,7**	**45,9**
Mangrove Loss*		-	0,28	4,55	15,82	-	0,57	7,57	35,45	-
Potential CW		**106,9**	**108,6**	**115,8**	**131,7**	**-**	**109,3**	**120,9**	**152,1**	**-**

*in relation to 2020.

**permanently flooded areas between 2020 and 2100.Source: The authors (2023).

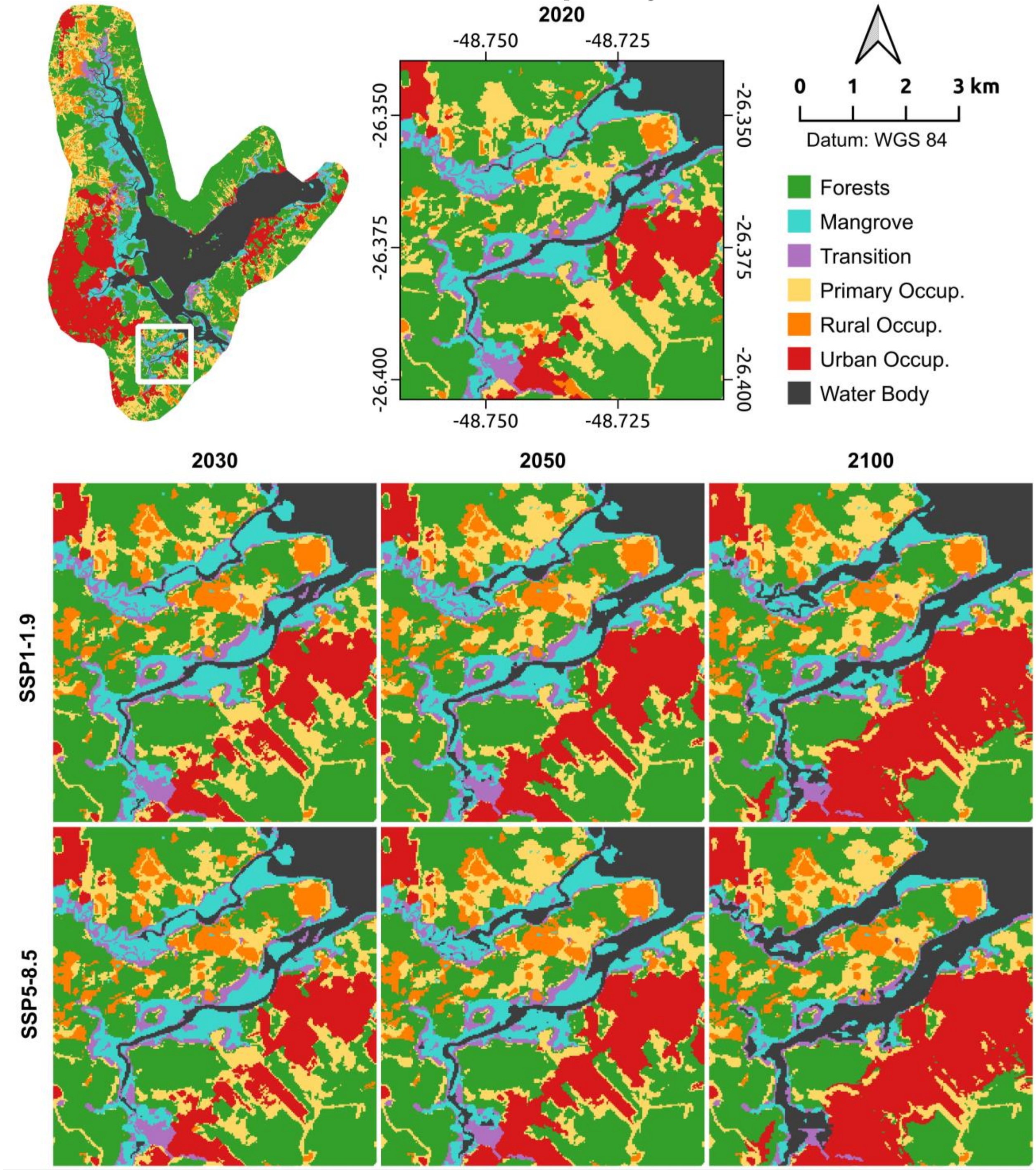
Figure 7 - Distribution of Land Cover and Land Use Classes for 2020 and Projected Loss Due to Sea-Level Rise in the Joinville Region.



Source: The authors (2023).

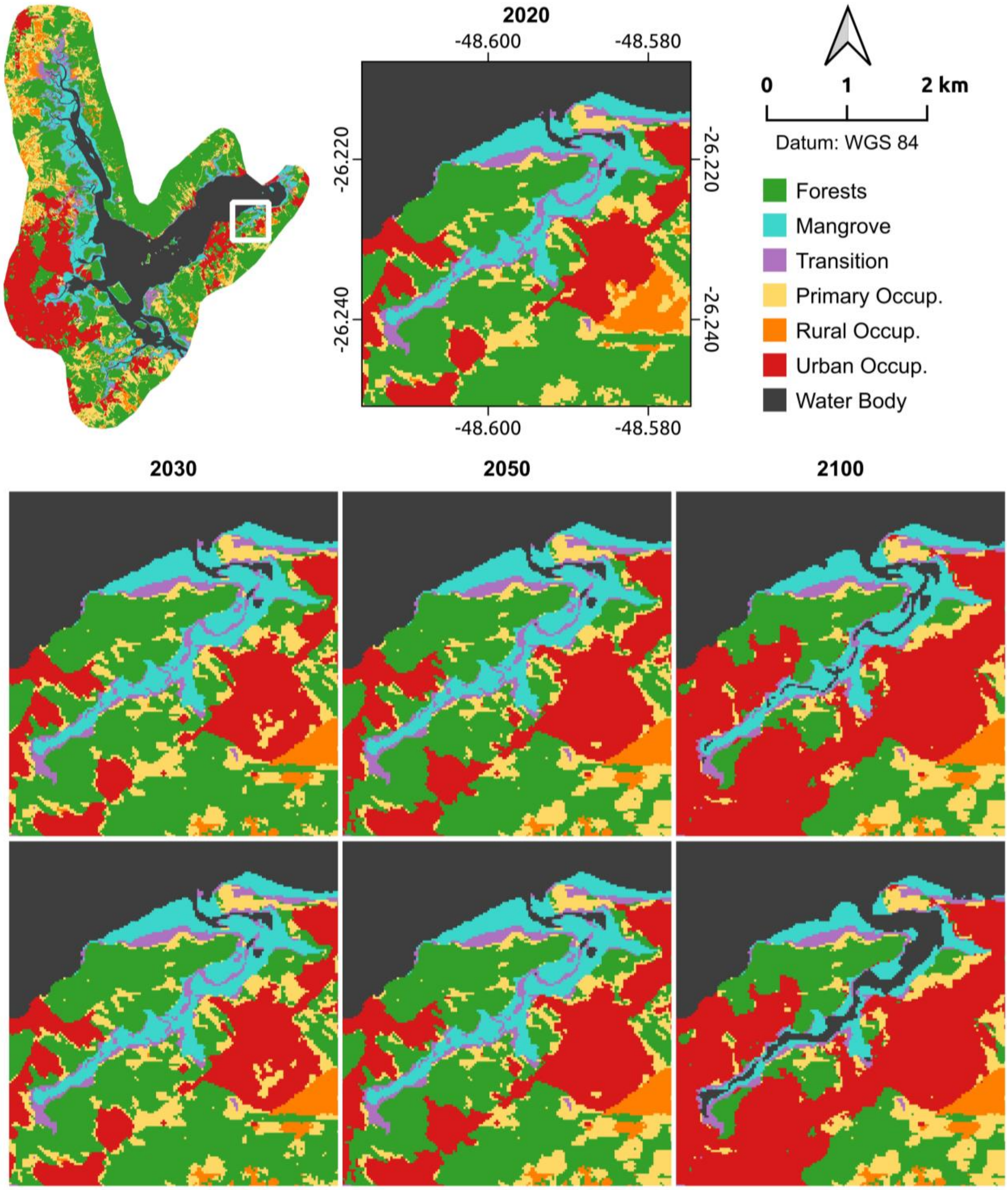
Mangroves provide the ecosystem service of coastal protection, reducing the energy of waves that impact adjacent terrestrial regions (Kamil et al., 2021; Lee et al., 2021; Menéndez et al., 2020). However, these urban areas will not only experience increased flooding due to rising sea levels, but they will also be more exposed to the potential destructiveness of extreme climate events, whose occurrence and intensity are expected to increase due to global warming (Duarte et al., 2013; Schaeffer-Novelli et al., 2016). Other urban areas neighboring mangrove ecosystems, such as Araquari and São Francisco do Sul (Figures 8 and 9), while not experiencing mangrove occupation to the extent observed in Joinville, are witnessing urban growth around current CW areas outlined in their development plans. This intensifies the risks of coastal constriction, loss of ecosystem services, and future urban inundations.

Figure 8 - Distribution of Land Cover and Land Use Classes for 2020 and Projected Loss Due to Sea-Level Rise in the Araquari Region.



Source: The authors (2023).

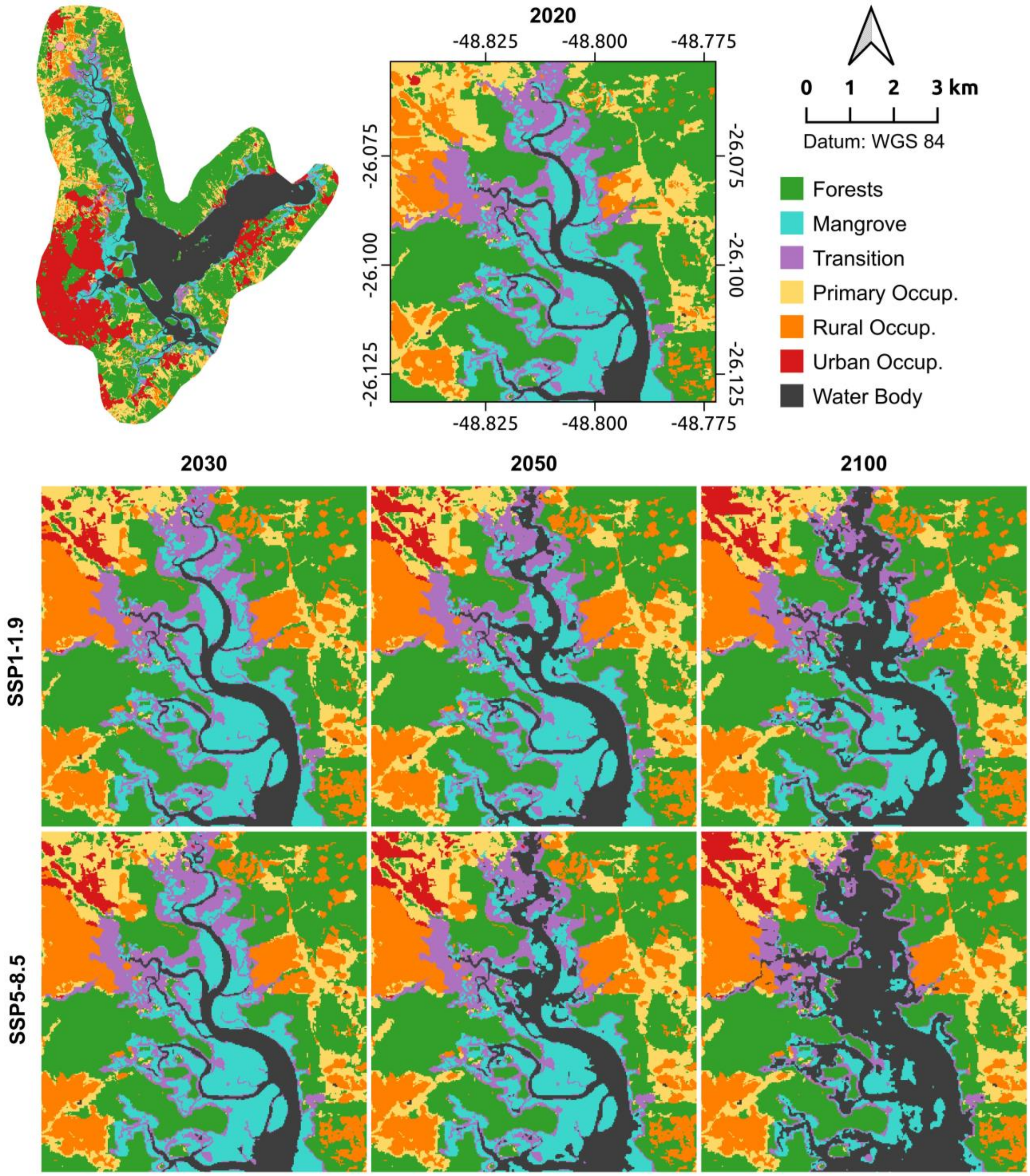
Figure 9 - Distribution of Land Cover and Land Use Classes for 2020 and Projected Loss Due to Sea-Level Rise in the São Francisco do Sul Region.



Source: The authors (2023).

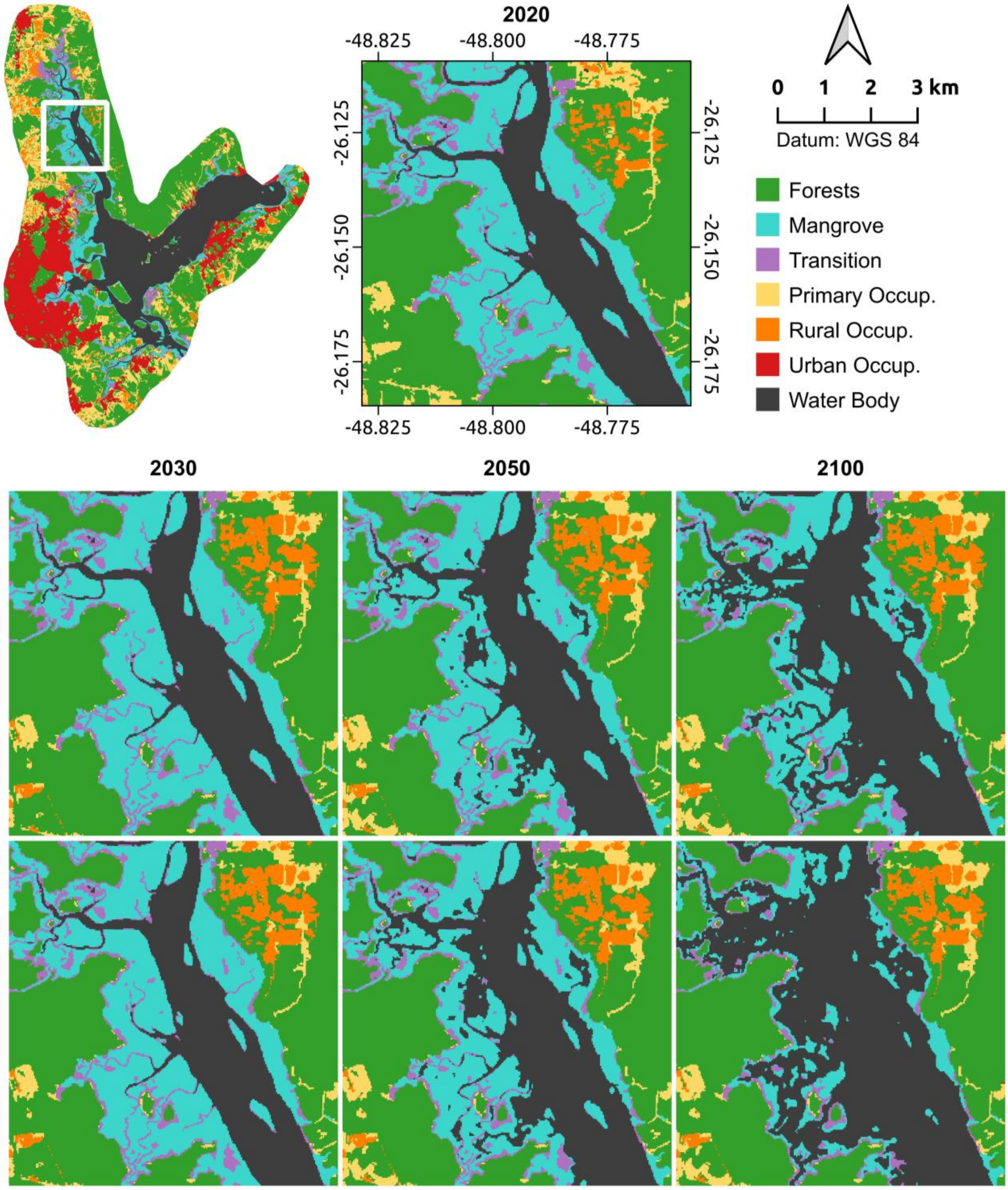
The municipality of Garuva, located north of the Palmital river (Figure 10), does not have an urban center adjacent to the current wetlands, with most of the areas surrounding the wetlands categorized as controlled-use rural areas, with the surrounding areas of wetlands classified predominantly as Forests. The ZUCs located in the Palmital channel, as they have large areas and low occupation in their surroundings, covered mainly by forests, appear to be the region most conducive to the horizontal migration of mangroves from Babitonga Bay in the 21st century (Figure 11). Among human land occupations, Urban has the greatest impact on the expansion of mangroves due to its virtual irreversibility (minimum elasticity), while Rural and Primary can more easily return to the original cover (Verburg *et al.*, 2002).

Figure 10 - Distribution of Land Cover and Land Use Classes for 2020 and Projected Loss Due to Sea-Level Rise in the Garuva Region.



Source: The authors (2023).

Figure 11 - Distribution of Land Cover and Land Use Classes for 2020 and Projected Loss Due to Sea-Level Rise in the Palmital River Region, between the municipalities of Garuva, Joinville, and São Francisco do Sul.



Source: The authors (2023).

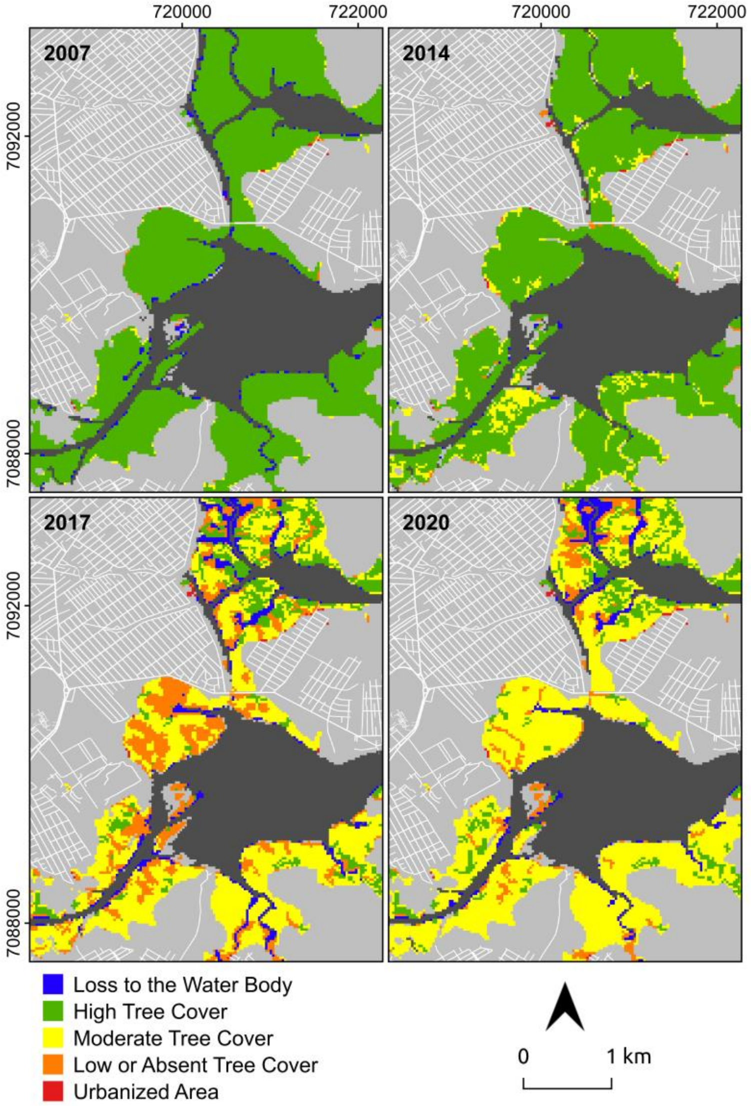
Vertical Migration (Potential CW)

Using paleorecords of mangrove vertical accretion, the ecosystem's vertical sediment accretion and migration rate is estimated at 6.1 mm per year. In contrast, sea-level rise throughout the 21st century can range from 5 mm (optimistic scenario) to 10 mm/year (pessimistic scenario), making the preservation of current mangrove areas viable (Saintilan et al., 2020). Maintaining existing mangrove areas through vertical migration, the natural CWs of baía da Babitonga (encompassing mangroves, transition zones, and forests) could expand from 95 km² (2020) to 103.6 km² (SSP1-1.9) or 113 km² (SSP5-8.5) by 2100. This potential CW area (including areas occupied by humans) could reach between 131.7 and 152.1 km² by the end of the century, respectively (Table 1). The vertical movement of these ecosystems, however, heavily depends on the interplay between sediment accretion (both allochthonous and autochthonous) and relative sea-level change, involving non-linear biogeomorphic feedbacks among hydrodynamic conditions, sediment input, vegetation productivity, and elevation rates (Godoy; Lacerda, 2015; Osland et al., 2022; Woodroffe et al., 2016). The bay receives sediment input from drainage basins, possibly reaching 0.02x106 t/year (Lessa et al., 2018). It features depositional environments, especially in the western main channel near Joinville's urban area, and intense sedimentation in its southern part due to hydrodynamic changes from the grounding of the Linguado channel. Alongside sediment accretion and coastal protection, maintaining or expanding mangrove areas facilitates numerous other services, including carbon sequestration—an essential component of climate regulation (Kuwae; Hori, 2019). Coastal wetlands sequester and store more carbon per unit area than almost all other ecosystems, making them a conservation priority. Compared to ecosystems worldwide, the loss of vegetation in these wetlands results in disproportionately higher emissions of carbon into the atmosphere or coastal oceans (Alongi, 2018).

Despite the presented indications of significant sediment influx and retention within the bay, predicting the response of baía da Babitonga's mangroves to climate change and subsequent sea-level rise remains inconclusive due to the complexity of involved processes. Nevertheless, ensuring suitable environmental conditions for the comprehensive development of this ecosystem is imperative, optimizing its potential (Alongi, 2018; Schaeffer-Novelli et al., 2016; Shrestha et al., 2019). Therefore, continuous monitoring is necessary for assessing the environmental quality of this ecosystem and for devising actions that ensure the maintenance and optimization of its environmental quality. Based on a study submitted for publication, we identified a rapid degradation of baía da Babitonga's mangroves since 2016, likely caused by a combination of industrial urban effluent impacts, climatic variations (El Niño), and an attack by an invasive species (moth - *Hyblaea puera*). This environmental degradation was concentrated in mangrove areas closer to Joinville municipality, further reinforcing indications of a correlation with intensified human occupation in this region and potential impacts related to urban and industrial effluents (Figure 12).

Given the presented results, the development of public policies becomes crucial to delineate coastal wetlands classified as permanent protection areas (PPAs) in dimensions compatible with potential horizontal expansion caused by rising sea levels and/or incorporating this expansion into municipal master plans and other territorial planning instruments. Additionally, it's important to assess the environmental quality within these ecosystems to mitigate losses to the marine environment. Eco-engineering solutions may prove valuable in optimizing the ecosystem services provided by mangroves (Duarte et al., 2013). Local population awareness is of utmost importance, as while the beneficiaries of ecosystem services may span local, regional, national, or even global levels, local resource users hold the greatest influence over the future supply of mangrove ecosystem services (Lee et al., 2014). Payments for Ecosystem Services (PES) can offer an additional income source for local communities to protect mangrove forests, enabling them to accumulate more sediments and carbon, in addition to other ecosystem services (Alongi, 2011; Manez et al., 2014; Thompson; Friess, 2019). On a global scale, the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD) program aims to assist developing countries in preparing and implementing national strategies, addressing not only deforestation and forest degradation but also encompassing the roles of conservation, sustainable forest management, and increasing forest carbon stocks in emissions reduction, known as REDD+ (Alongi, 2011).

Figure 12 - Distribution of tree cover classes identified in mangrove areas near the municipality of Joinville in 2007, 2014, 2017, and 2020.



Source: The authors (2023).

FINAL REMARKS

The preservation of wetland areas is of paramount importance for maintaining current coastlines and preserving the quality of life, both for populations inhabiting these regions and on a global scale. Considering the potential impacts arising from identified sea-level rise and land occupation, it is concluded that the planning and management of the baía da Babitonga coastal zones must not only consider the present location of mangroves and wetlands in general but also the areas susceptible to horizontal expansion by these ecosystems. Efficient policies for their preservation in terms of environmental quality optimization, enhancing sediment retention capacity, and sustaining original areas are essential. Consequently, this would allow the expansion of coastal wetlands and the services they provide at regional, national, and global levels. The methodology developed in this study, by comparing a future without mangrove preservation (instantaneous CW) to a scenario where they are fully preserved (potential CW), has proven its relevance in illustrating the importance of conserving current areas in terms of environmental quality.

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AUTHOR CONTRIBUTION

Tatiana Silva da Silva and Iran Carlos Stalliviere Corrêa guided the preparation of the study, while André Schmidt Filgueras carried out the data analysis and processing and wrote the text.