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Mangroves of the Warm Temperate Southwestern Atlantic

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Abstract

Mangroves of the Warm Temperate Southwestern Atlantic is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine ecoregions of Rio Grande and Southeastern Brazil. The mapped extent of mangroves in 2020 was 709.5 km^2, representing 0.5% of the global mangrove area. The biota is characterized by three species of true mangroves, *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia schaueriana*. The mangroves are associated with estuaries, coastal lagoons and bays, and the lagoons of barrier islands. This province marks the southernmost latitude for mangroves in South America. Seasonal factors may interact to limit the poleward dispersal of mangrove species. Primary influences include the year-round, northward-directed longshore drift and the high frequency of cold fronts and chilling events during winter. Additionally, seasonal upwelling of cold waters in spring and summer may impact the viability of propagules.

The Warm Temperate Southwestern Atlantic province includes the most populated coastal region of Brazil and includes major cities each with almost 7 million inhabitants. Mangrove forests in this province are subjected to severe degradation and loss due to urban expansion, changes in land use and occupation patterns, and various other factors, including over-harvesting and pollution from domestic, industrial, and agricultural sources. However, the southern part of this province contains important remnants of preserved mangroves.

As of 2020, the net area of Warm Temperate Southwestern Atlantic mangroves has decreased by 0.9% since 1996. If this trend continues an overall change of -0.8% is projected over the next 50 years. Furthermore, under a high sea level rise scenario (IPCC RCP8.5) ≈-13.6% of the Warm Temperate Southwestern Atlantic mangroves would be submerged by 2060. Moreover, 1.4% of the province's mangrove ecosystem is undergoing degradation, with the potential to increase to 4% within a 50-year period, based on a vegetation index decay analysis. Overall, the Warm Temperate Southwestern Atlantic mangrove ecosystem is assessed as **Least Concern (LC).**

Citation:

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Keywords: Mangroves; Red List of ecosystems; ecosystem collapse; threats.

Ecosystem classification:
MFT1.2 Intertidal forests and shrublands
Assessment's distribution:
Warm Temperate Southwestern Atlantic province
Summary of the assessment

Criterion	A	B	C	D	E	Overall
Subcriterion 1	**DD**	**LC**	**DD**	**DD**	**NE**	**LC**
Subcriterion 2	**DD**	**LC**	**LC**	**LC**	**NE**	
Subcriterion 3	**DD**	**LC**	**DD**	**DD**	**NE**	

LC: Least Concern, DD Data Deficient, NE: Not Evaluated

Mangroves of The Warm Temperate Southwestern Atlantic LC

1. Ecosystem Classification

IUCN Global Ecosystem Typology (version 2.1, Keith *et al.* 2022):

Transitional Marine-Freshwater-Terrestrial realm

- MFT1 Brackish tidal biome
  - MFT1.2 Intertidal forests and shrublands
    - **MFT1.2_4_MP_47** Mangroves of the Warm Temperate Southwestern Atlantic

IUCN Habitats Classification Scheme (version 3.1, IUCN 2012):

- 1 Forest
  - 1.7 Forest – Subtropical/tropical mangrove vegetation above high tide level *below water level*[1]
- 12 Marine Intertidal
  - 12.7 Mangrove Submerged Roots

Pristine mangroves in the Warm Temperate Southwestern Atlantic province, which are recognised by UNESCO as a World Heritage Site (Photo credit: Gabriel Marchi).

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[1] Note on the original classification scheme. This habitat should include mangrove vegetation below water level. Mangroves have spread into warm temperate regions to a limited extent and may occasionally occur in supratidal areas. However, the vast majority of the world's mangroves are found in tropical/subtropical intertidal areas.

2. Ecosystem Description

Spatial distribution

The Brazilian mangrove ecosystem extends from the state of Amapá in the northern region to Santa Catarina in the southern region. This assessment is focused on the Mangroves of the Warm Temperate Southwestern Atlantic (WTSA) province, found on the intertidal forests and shrublands in the marine ecoregions of Rio Grande and Southeastern Brazil (refer to Figure 1). In 2020, the province had an estimated area of 709.5 km² covered by mangroves, which accounts for about 0.5% of the total global mangrove area. The mangrove area has experienced a net decrease of 0.9% since 1996, as reported by Bunting *et al*. (2022).

The WTSA province's mangroves are found from Cabo Frio (22° 42'S) in Rio de Janeiro state to Laguna (28° 30'S) in Santa Catarina (Spalding *et al*., 2007). This area represents the southern limit of where mangroves are found in the Americas (Schaeffer-Novelli *et al*., 1990; Soares *et al*., 2012, Tognella *et al*. 2016, Ximenes *et al*., 2023). It is worth mentioning that Figure 1 does not show the distribution of mangroves outside of the Warm Temperate Southwestern Atlantic province. Furthermore, it is important to acknowledge that mangrove ecosystems extend beyond the northern boundaries of the specified province, emphasizing the wider distribution and ecological significance of these essential habitats.

The most recent global mangrove maps, despite using detailed spatial data and advanced classification techniques, tend to fail to accurately represent the southern boundaries of mangroves in Laguna (28° 30'S) (Ximenes *et al*., 2023).

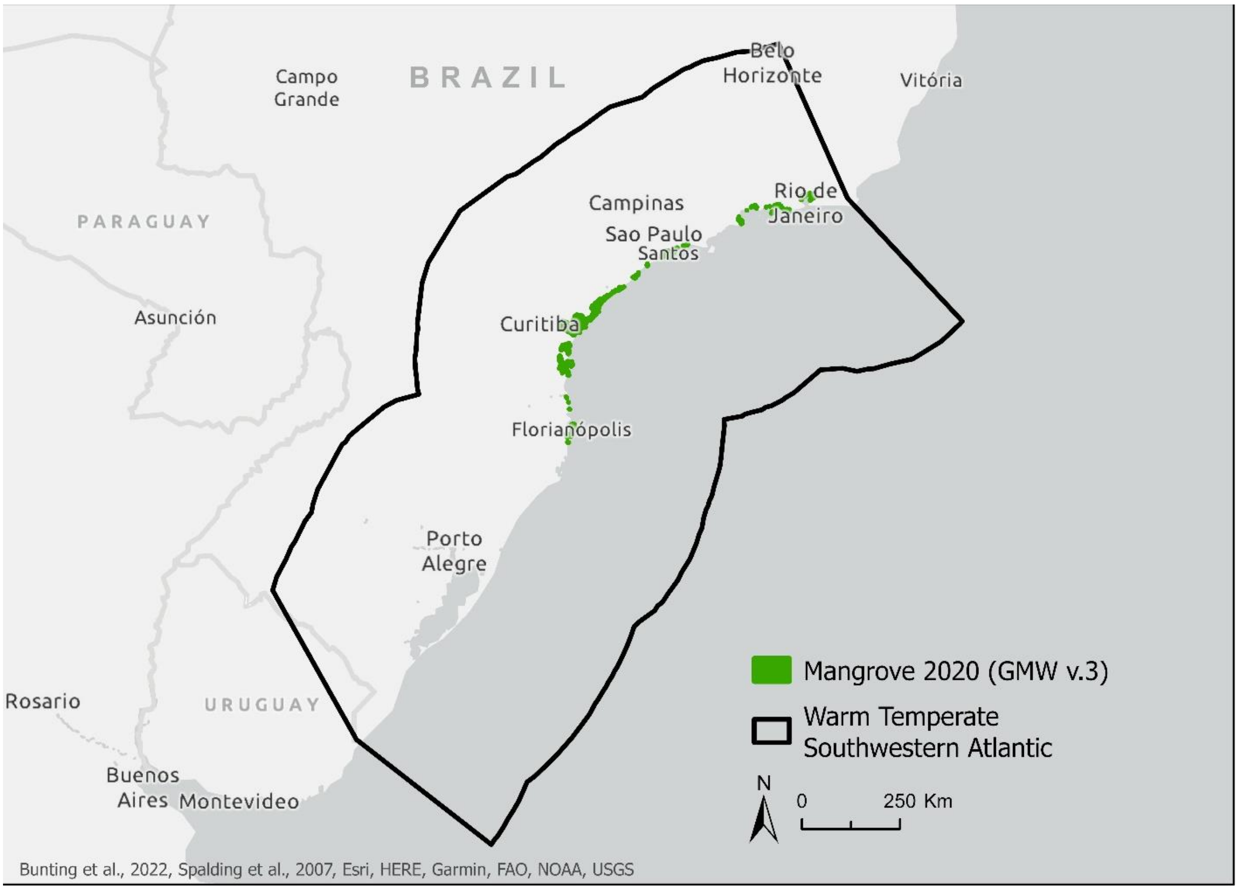


Figure 1. The mangroves of the Warm Temperate Southwestern Atlantic province.

Biotic components of the ecosystem (characteristic native biota)

The Warm Temperate Southwestern Atlantic province boasts a remarkable array of both true mangrove species and associated fauna and flora. Although the number of true mangrove tree species is relatively small, the mangrove fauna and associates in this province is rich. Among the plant species, three true mangrove trees *Rhizophora mangle* (Red Mangrove), *Laguncularia racemosa* (White Mangrove), and *Avicennia schaueriana* (Black Mangrove)—are officially documented and classified as "Least Concern" by the IUCN Red List of Threatened Species (IUCN, 2022). This highlights a striking contrast: while the mangroves here may have a modest number of tree species, the broader ecological community is far more diverse, with the richness of animal life far outstripping the floral diversity. Although the diversity of true mangrove trees species in Brazil is lower compared to Southeast Asia, the ecological adaptability and plasticity of the three true mangrove species present in this region enable them to thrive in a variety of suitable habitats and perform various ecological functions. This means that it can adapt to different coastal environmental setting, including high, medium, and low salinities. Consequently, Brazilian mangroves consistently rank among the top two or three regions globally in terms of total mangrove area, depending on the specific mapping sources used (Bunting *et al*., 2022, Giri *et al*., 2011).

Additionally, the Warm Temperate Southwestern Atlantic province supports a variety of associated mangrove plant species (Cunha *et al*., 2006; Tognella *et al*. 2009). Commonly found species include *Acrostichum aureum* (golden leather fern), *Acrostichum danaeifolium* (giant leather fern), *Conocarpus erectus* (buttonwood), and *Talipariti pernambucensis* (sea hibiscus) (see Annex 1 for a comprehensive list). These plants play crucial roles in the mangrove ecosystem, contributing to its overall biodiversity and ecological function.

Significantly, these mangroves function as vital refuge for diverse biota, including juvenile fish and other marine species as crustaceans, mollusks and marine birds. The intricate root systems of mangrove trees species provide crucial habitats that give shelter and breeding areas for juvenile fish and crustaceans. Several species heavily reliant on mangrove habitats are critical fishing resources, including snook (*Centropomus* spp.), crab-uçá (*Ucides cordatus*), oysters (*Crassostrea brasiliana*), white mullet (*Mugil curema*), anchovy (*Engraulis* spp.), crabs (*Callinectes* spp.), estuarine shrimp (*Litopenaeus schmitti*, *Farfantepenaeus paulensis*, and *F. brasiliensis*), and caitipa mojarra (*Diapterus* spp.) (Cunha-Lignon & Mendonça, 2021). These fishery resources are essential for both coastal and commercial fishing, underscoring the importance of mangrove preservation for maintaining sustainable fisheries and contributing to the blue economy (Cunha-Lignon *et al*., 2021).

Mangroves are also important habitats for Black-Faced Lion Tamarin (*Leontopithecus caissara*), an endangered species listed on the IUCN Red List (Ludwing *et al*., 2021) and a host the endangered Atlantic Petrel (*Pterodroma incerta* and the channel-billed toucan (*Ramphastos vitellinus*).

There are at least six bird species within mangrove habitats that are classified in the IUCN Red List of Threatened Species (IUCN, 2022) as endangered (EN) or vulnerable (VU). Additionally, there are nine other bird species that have been recorded or observed in this province and are considered near-threatened (IUCN, 2022).

In recent decades, both the broad-snouted caiman (*Caiman latirostris*) and capybara (*Hydrochoerus* *hydrochaeris*) have seen notable population increases in certain lagoons with mangroves in Rio de Janeiro (Ximenes, pers. observations). These species have benefited from improved conservation efforts and the availability of suitable habitats within the mangrove ecosystems, which provide abundant water, food, and shelter. The caiman, a semi-aquatic reptile, has adapted well to the brackish waters of the region, while capybaras, the largest rodents in the world, thrive in the dense vegetation. This population growth is also linked to the rise of ecotourism, which, although still in its early stages, is increasing public interest in experiencing these animals up close and exploring the mangrove areas. This growing interest in ecotourism not only highlights the importance of conservation but also introduces new ecological dynamics, such as increased human interaction with wildlife and potential pressure on these delicate habitats.

Capybara mother and her juveniles nestled among mangrove roots in Rio de Janeiro, Brazil. In the back the constructions liming mangrove expansion (Photo Credit: Arimatéa Ximenes).

Broad-snouted caiman and golden leather fern among red mangroves with dense aerial stilt roots in Rio de Janeiro's mangrove ecosystem, Brazil (Photo credit: Arimatéa Ximenes).

Abiotic Components of the Ecosystem

The Brazilian latitudinal coast presents a variety of coastal environments that allow mangrove occurrence and control their distribution and species richness. Although the Warm Temperate Southwestern Atlantic province is classified as a wave-dominated coastline (Klein & Short, 2016), it still provides suitable conditions for mangroves in sheltered areas such as estuaries, deltas, and lagoons. This province features a diverse range of geomorphological environments at a regional scale and the occurrence of mangroves within the coastal plain is limited by the presence of Serra do Mar, a mountainous massif. In certain areas, the massif is close to the coastline, while in others, it is further away, creating the conditions for the development of coastal plains (Schaeffer-Novelli *et al*., 1990; Dominguez, 2009; Muehe, 2010). However, within the same province, besides the mangroves connected to the rivers originating from the mountainous massif, there are also extensive mangrove regions found in the coastal plains or bays as described by Dietter & Lins-De-Barros (2016), particularly in sections where the Serra do Mar is located further away from the coastline, such as Guanabara Bay or the Paraiba do Sul River delta (Bernini & Resende, 2004).

Precipitation and oceanographic events

Historical climate data from the WorldClim v1 database indicate that Cananéia, in São Paulo state, receives notably high precipitation during the warmest quarter along Brazil’s mangrove coastline, with approximately 1029 mm recorded (Ximenes *et al*., 2016). Within the Warm Temperate Southwestern Atlantic (WTSA) province, precipitation varies considerably, particularly in Rio de Janeiro, where annual totals range from 870 mm to 2182 mm (Figure 2). The lowest annual precipitation in this region is observed near Arraial do Cabo, situated at the northern boundary of the WTSA mangrove province in Cabo Frio (22°42'S) (Ximenes *et al*., 2016), where one of Brazil's most intense coastal upwelling zones occurs (Kampel *et al*., 1997). This region also marks the southernmost distribution of *Avicennia germinans*, and this coincides with the presence of intense upwelling (Ximenes *et al*., 2016), also known to impact the distribution of several algal taxa along the Brazilian coast (Guimaraens & Coutinho, 1996).

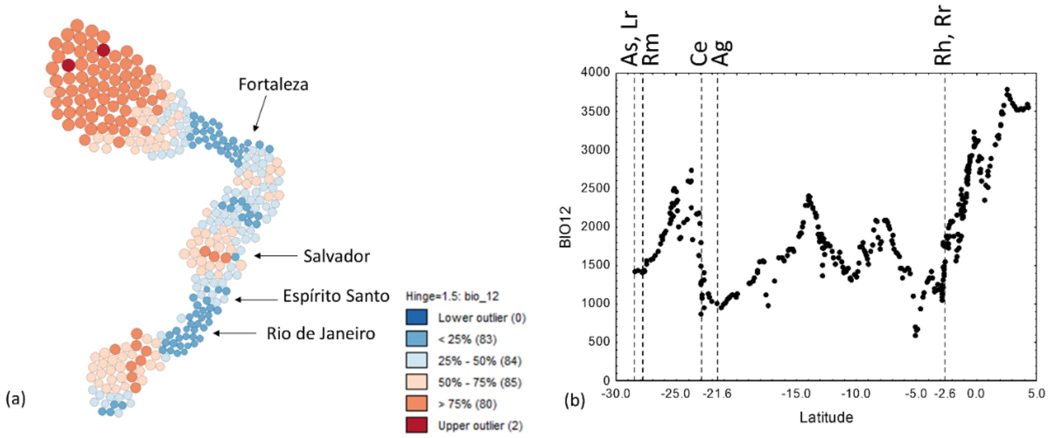


Figure 2. Annual Precipitation (BIO12) in Brazilian Mangroves. (a) Cartogram map showing spatial distortion based on high and low BIO12 values. (b) Scatterplot (n = 334 sample points) illustrating BIO12 values by latitude (decimal degrees), with vertical dashed lines indicating species distribution limits. with species distribution limits marked by vertical dashed lines (from the right to the left) *R. racemosa (Rr)* and *R. harrisonii (Rh)* (at 2.6°S), *A. germinans (Ag)* (at 21.6°S), *C. erectus (Ce)* (at 22.9°S), *Rhizophora mangle (Rm)* (at 27.8°S), and finally *A. schaueriana* (*A*s) and *L. racemosa (Lr)* (together at 28.5°S). (Source: Ximenes *et al*., 2016).

Sea Surface Temperature at the mangrove range limits

Brazilian mangroves with the lowest sea temperature values, including Minimum, Mean, and Maximum Sea Surface Temperatures, are located in the state of Santa Catarina, near the cities of Laguna and Imbituba (Ximenes *et al*., 2016). The annual average sea surface temperature (SST) at Laguna (28°30'S) is around 21°C, with a mean SST of 17.54°C during the winter months (Ximenes *et al*., 2018). These values were determined by calculating monthly averages from January 2003 to September 2018, as observed over a span of 16 years using the Multi-Scale Ultra-High Resolution (MUR) dataset. The winter mean of sea surface temperature (SST) exhibited the lowest values at Praia do Sonho (27°48'S), with a mean of 17.90°C and an absolute minimum daily SST of 14°C. Similarly, Laguna experienced a winter mean SST of 17.54°C, with an absolute minimum daily SST of 13.13°C. The coastal region of Praia do Sonho observed a total of 36 days with sea surface temperatures of 15°C. In comparison, the nearby region of Laguna recorded 59 days with similar temperatures over the same time period, as observed over a span of 16 years (Ximenes *et al*., 2018).

Air Temperature at the mangrove range limits

Brazilian mangroves with the lowest values of air temperature derivatives, including the Annual Mean Temperaure, Mean Temperature of the Coldest Quarter, Minimum Temperature of the Coldest Month, and Mean Temperature of driest Quarter, are found in the state of Santa Catarina, located in the cities of Laguna, Imbituba, Florianópolis, and Camboriú (Ximenes *et al*., 2016). The average air temperature during the coldest month in Laguna was recorded at 15.52°C, while the average yearly air temperature was found to be 19.77°C (Ximenes *et al*., 2021). The air temperature metrics used in this study were derived from data obtained from the Brazilian National Institute of Meteorology (INMET) over a period of eight years, namely from 2011 to

2019. In Santa Catarina state, where the southernmost limit of mangrove distribution in Brazil is found, the region experiences 3 to 4 cold fronts per month, with the highest frequency and intensity typically occurring during the spring (Rodrigues *et al*., 2004; UFSC/CEPED, 2011).

Key processes and interactions

Mangroves trees function as key structural engineers in the environment. They have a range of specialized adaptations such as pneumatophores, salt-excreting glands, vivipary, and buoyant propagules. These characteristics facilitate their ability to survive and effectively reproduce in environments that have limited oxygen, high salinity, unstable sediments, and frequent tidal flooding. In addition, mangroves demonstrate a high level of effectiveness in absorbing nitrogen, recycling nutrients, accumulating metals, metaloids and promoting bioremediation, highlighting their importance in preserving the stability and productivity of ecosystems (Lovelock *et al*., 2006; Tognella *et al*., 2016, D´Áddazio *et al*., 2023).

At the southernmost limit of mangrove forests, structural development diminishes due to harsh climatic conditions, including low temperatures. This is reflected in the smaller average diameter and height of trees, as well as the increased density of trunks and the trunk-to-tree ratio, especially in the limit of distribution of each true mangrove species (Cunha *et al*., 2006a, b; Soares *et al*. 2012). The potential impact of multiple adverse factors beyond the mangroves' current boundaries, as noted by Soares *et al*. (2012), may limit their expansion. Several seasonal factors may interact to limit the poleward dispersal of mangrove species (Ximenes *et al*. 2021). Primary influences include the year-round, northward-directed longshore drift and the high frequency of chilling events during winter. Additionally, seasonal upwelling of cold waters in spring and summer may impact the viability of propagules. In eastern South America, *L. racemosa* and *A. schaueriana* exhibit greater cold resistance than *R. mangle* and *A. germinans*, thriving in wider latitudinal ranges and lower temperature habitats (Ximenes *et al*. 2016, Ximenes *et al*. 2021). Prolonged reductions in sea surface temperature (SST) can negatively impact the viability and growth of certain mangrove propagules, leading to decreased seedling survival rates (Oliveira, 2005). The low environmental temperature decreases the carboxylation efficiency of *R. mangle* which limits its latitudinal distribution to Praia do Sonho in Palhoça. In this place, the three mangrove species have the highest value of water use efficiency in their South Atlantic occurrence (Soares *et al*., 2015).

Laguncularia racemosa in its southern distribution, observed at Santo Antonio Lagoon in Laguna, Santa Catarina state (Photo credits: Monica Tognella).

Plant-animal interactions

Mangroves produce large amounts of detritus (e.g., leaves, twigs, and bark), which is either buried in waterlogged sediments, or consumed by crabs and gastropods, then decomposed further by meiofauna, fungi and bacteria, to produce detritus as a protein-rich food source for other consumers in the mangrove and coastal food web. At the southern limit, the mangrove litterfall production relies more on temperature than on precipitation and this climate factor determines leaf development and senescence (Cunha *et al*, 2005b) and its contribution to the coastal ecosystem.

Mangrove detritus is responsible for feeding different trophic levels as turtle and shrimp. Cananeia System is a feeding area for the endangered *Chelonia mydas* (green turtle) and most of its diet consists of plants, such as *A. schaueriana, Spartina alterniflora* and Liliopsida species (Nagaoka *et al*., 2012). In the Paranaguá Estuarine Complex (Paraná state), *Chelonia mydas* was observed consuming propagules of *A. schaueriana,* which constituted 26% of the contents found in their digestive tracts (Gama *et al*., 2016).

Along the WTSA, mangrove ecosystems provide a feeding, roosting, resting, and breeding purposes for some endangered species and other species of commercial interest that improve familiar income. The Cananéia Complex has a type of artisanal fishing gear, the fixed seine. This type of low-cost and low-energy fishing generates an economic return for fishermen in the order of a monthly minimum wage. The most important resource captured by this gear is *Mugil brasiliensis* and *Mugil platanus* (Tognella, 1995). In the winter, shoals of these species came to the estuary to spawn and feed on mangrove debris.

Mangrove plants and associated vegetation provide crucial connectivity for wetland birds, such as the Marsh antwren (*Stymphalornis acutirostris*), offering protection, foraging, and perching opportunities that support their distribution and movement (Reinert *et al*. 2007). Roseate spoonbills (*Platalea ajaja*), while inhabiting various wetland ecosystems, are primarily found in mangroves, where they forage in shallow waters and nest in trees or shrubs. In Araçá Bay, São Paulo, Mancini *et al*. (2018) emphasize the role of mangroves in the life cycles of various bird species, with the area hosting around 84 species, similar to other coastal regions such as Paranaguá and Guanabara Bays.

Roseate Spoonbill and Egret hidden on a red mangrove trunk in Rio de Janeiro, Brazil (Photo Credit: Arimatéa Ximenes).

Carbon stocks on mangrove ecosystem in the Warm Temperate Southwestern Atlantic province

These ecosystems also serve as major blue carbon sinks, incorporating organic matter into sediments and living biomass. The amount of biomass in mangrove ecosystems differs greatly depending on the latitude, mainly because of the climatic conditions that impact the growth and structure of trees. In regions located in the southern latitudes, characterised by a generally cooler climate and less conducive conditions for plant growth, the amount of biomass is typically lower. Mangrove tree growth and biomass accumulation are constrained by adverse climatic conditions, including lower temperatures and reduced water availability. Leaf fall had a high contribution to the total litter production in the mangroves of Babitonga Bay in summer and described positive correlation with temperature. The low annual litter production in this study area is a result of the temperature and local conditions (flooding and nutrients) that made the habitat unfavourable for the increase of trunk and leaves biomass (Cunha *et al*. 2005).

In this province, the extensive latitudinal variability shapes the environmental gradient, which in turn affects the structure of mangrove trees and the carbon stock in their aboveground biomass (Estrada and Soares, 2017). Although some recent studies have attempted to compile available data on carbon stocks in Brazilian mangroves (Beloto *et al*., 2023; Hatje *et al*., 2023), we consider that the available estimates still have methodological problems to be addressed, such as: (i) low sample size of data obtained in the field (especially for belowground biomass and sediment); (ii) non-standard or inadequate methods for estimating stocks in belowground biomass and sediment, which are the main carbon pools in mangroves; (iii) failure in considering the spatial variability of mangroves (local and regional); (iv) use of data from other regions (especially in estimates of stocks in belowground biomass and sediment); (v) estimates based on inadequate models; (vi) inaccuracy in the spatialization of carbon density to estimate carbon stocks on a regional basis.

To address these issues and ensure accurate and dependable data, it is crucial to undertake comprehensive assessments of carbon sequestration and storage in these mangrove ecosystems.

3. Ecosystem Threats and vulnerabilities

Main threatening process and pathways to degradation

Urban areas and infrastructure

The use of mangroves in the Warm Temperate Southwestern Atlantic region for coastal development, port infrastructure, and industrial activities has centuries of history (Netto & Reis-Neto, 2023). The mangrove ecosystems in this province are undergoing significant degradation and loss due to urban expansion, changes in land use, excessive harvesting, and pollution from domestic, industrial, and agricultural activities (Araujo *et al*., 2021, 2020; Lacerda *et al*., 2022; Netto & Reis-Neto, 2023). In recent decades, the rapid economic development and increased human settlement have significantly intensified the accumulation of both natural and man-made organic pollutants in these mangrove ecosystems. Historical changes in coastal zone configuration, urban expansion has been one of the main agents of loss of mangrove areas, particularly during the mid-20th century, have led to significant consequences such as deforestation and habitat fragmentation, possible resulting in the loss of genetic diversity (Schaeffer-Novelli *et al*., 2018, Soares *et al*., 2023). Human occupation of the coastal zone involves a variety of activities and uses, including the installation of ports, maritime terminals, and industrial complexes, which are mainly stimulated by the facility to receive supplies and dispatch production by sea (Soares *et al*., 2023).

This issue is especially pronounced in major urban centres such as Santos, Bertioga, and São Vicente in São Paulo State, as well as in Rio de Janeiro in Rio de Janeiro State. These cities, located in the Warm Temperate Southwestern Atlantic Province, represent some of the most densely populated regions along the Brazilian coast. For instance, Rio de Janeiro has a population approaching 6.2 million residents, as reported by the Brazilian Institute of Geography and Statistics (IBGE, 2022).

Also, according to IBGE (2022), between 2010 and 2020, the southern sector of this province, with emphasis on municipalities located in the northern portion of the state of Santa Catarina and the southern portion of the state of São Paulo, where there are important remnants of preserved mangroves (e.g. Babitonga Bay and Cananeia-Iguape Coastal System), experienced one of the highest rates of population growth on the entire Brazilian coast. The metropolitan regions of Rio de Janeiro and Santos are urban centres that have taken over mangrove areas and other wetlands. For instance, estimates suggest that Guanabara Bay, the largest metropolitan region on the Brazilian coast, has lost roughly 64% of its original mangrove area since the colonial period (Soares *et al*., 2023).

Deforested mangroves in Santos Bay replaced by informal settlements (Photo credit: Leo Francini).

Many remaining mangrove areas are increasingly threatened by conversion for agricultural purposes, as well as by the expansion of harbours, industrial facilities, and residential developments (Ferreira and Lacerda, 2016). The rapid pace of urbanization and industrialization in these regions has not only transformed the landscape but also resulted in significant chemical contamination. The influx of industrial effluents, urban runoff, and untreated waste has introduced a range of harmful chemicals into these ecosystems. Metal contaminants are found in mangrove sediment and water, as well as in *R. mangle* leaves and *Ucides cordatus* tissues along central and southern coast of São Paulo State. This environmental contamination is dangerous because metals from leaves are biomagnified to the crab, causing cito and genotoxicity (Duarte *et al*. 2017). Accumulation of metals in crab's results in decreased population, as observed in other Brazilians mangroves, and loss of food and income for fishermen.

Impact of Port Activities on Mangrove Ecosystem

Santos Port, the largest harbour complex in South America, exemplifies the impact of industrial and urban development on mangrove ecosystems. Located in a sheltered environment with significant freshwater and terrigenous sediment inputs, the port's extensive industrial and urban complex encompasses sectors such as chemicals, paper, fertilizers, chlorine, styrene, and steelworks (Do Vale *et al*., 2023). These industries are major sources of heavy metal pollutants, including mercury, chromium, copper, lead, and zinc (Rodrigues *et al*., 1999; Santos *et al*., 2012, Duarte *et al*., 2017). The São Sebastião Port has significantly impacted the mangroves in Araçá Bay over the past century due to a range of activities that have shaped the bay's ecological history (Schaeffer Novelli *et al*., 2018).

In contrast, less industrialized regions, such as the southern sector of São Paulo State within the Cananéia-Iguape Coastal System, face different anthropogenic threats. Here, the primary issues involve alterations to hydrological and geomorphological dynamics caused by engineering interventions, especially modifications to drainage systems. These changes disrupt the sedimentary balance, leading to atypical volumes of freshwater entering estuarine environments, which adversely affect the ecological health and functionality of mangrove ecosystems (Cunha-Lignon *et al*., 2011; Prado *et al*., 2019). In particular, the construction of the Valo Grande, a man-made canal built in the mid-19th century to connect the Ribeira de Iguape River to the lagoon system, significantly altered the region's dynamics. By introducing large volumes of freshwater and sediment, it disrupted the natural salinity balance and sedimentation processes. This led to the collapse of extensive mangrove forests, which depend on brackish conditions for survival. The ecological impacts of this intervention persist today, continuing to hinder the recovery of the mangrove ecosystems (Prado *et al*., 2029).

Impacts of oil spill on mangrove ecosystems

Oil spills represent a significant environmental hazard, particularly in coastal and estuarine ecosystems where they can have devastating and long-lasting impacts (Duke, 2016). These incidents not only cause immediate contamination but also lead to persistent ecological problems due to the toxic effects of oil and its byproducts.

In October 1983, a substantial oil spill occurred on the southeastern coast of Brazil, where approximately 300 hectares of mangrove forest were severely affected. The incident, caused by a ruptured pipeline, released 3.5 million litters of crude oil into the environment (Santos *et al*., 2012). Such spills introduce Polycyclic Aromatic Hydrocarbons (PAHs) into the ecosystem, which are known to be persistent pollutants with detrimental effects on wildlife and vegetation.

Research has identified elevated levels of PAHs in areas heavily impacted by oil spills, such as the mangroves of Guanabara Bay in Rio de Janeiro and the Bertioga Channel in São Paulo State (Farias *et al*., 2018; Soares-Gomes *et al*., 2010; Lamparelli *et al*., 1997; Araújo *et al*., 2020; Soares *et al*., 2023). These findings underscore the widespread contamination in estuarine systems, particularly in regions such as Santos and Guanabara Bay. Both are major urban centres and industrial hubs, hosting Brazil's largest ports and significant petrochemical complexes. The mangrove forests in these areas have been notably impacted by frequent oil spills and ongoing contamination, as documented in various studies (Rodrigues *et al*., 1999; Farias *et al*., 2008; Santos *et al*., 2012; Wagener *et al*., 2010, 2012; Araújo *et al*., 2020, 2021).

The persistence of PAHs and other oil-derived pollutants in these environments highlights the need for ongoing monitoring and remediation efforts to mitigate the long-term effects of oil spills on mangrove ecosystems and coastal waters.

Threats to mangrove forests from the oil and gas sector are related to the high risk of oil spills during various stages of the production chain, from the drilling of wells, operation of production fields, and oil transport, storage and refining. Additionally, operational support facilities are also located, in bays and estuaries, the same coastal locations where mangroves occur (Soares *et al*., 2023).

The pressure and impacts exerted by the oil and gas sector on mangroves in the Warm Temperate Southwestern Atlantic province is mainly related to the fact that most of Brazil's oil production is from offshore fields associated with basins located in the southeast of Brazil (Soares *et al*., 2023). According to the National Agency for Petroleum, Natural Gas and Biofuels (ANP, 2023), two basins (Santos & Campos) produced, in September 2023, 97% of the oil and 86% of the natural gas produced in Brazil. Moreover, petrochemical complexes, refineries, ports, urban centres, and operational support facilities for oil and gas production, often associated with coastal systems such as Guanabara Bay in Rio de Janeiro State, are subjected to both acute and chronic sources of petroleum contamination. This contamination originates from both pyrolytic and petrogenic sources (Araújo *et al*., 2020) and in the case of contamination of mangroves by oil and petroleum products, the persistence of the stressor in the system can be quite prolonged. Long-term studies carried out in the mangroves of Guanabara Bay, detected the presence of oil in sub-surface layers of sediment from spills that occurred in the bay in 1975, 1997 and 2000 (Araújo, 2018; Soares *et al*., 2023).

Impact of oil spill on mangroves in Guanabara Bay, Rio de Janeiro, Brazil (Photo credit: NEMA/UERJ).

Pollution

The expansion of coastal development in the Warm Temperate Southwestern Atlantic Province has led to various negative effects on mangrove ecosystems. In addition to the direct destruction of mangrove areas through deforestation and land reclamation, other notable dangers include improper waste disposal, the discharge of untreated or insufficiently treated domestic sewage, and the release of industrial effluents containing pollutants such as heavy metals, oil, and petroleum products (Lacerda *et al*., 2022; Soares *et al*., 2023). Araújo *et al*. (2021) recently investigated the Brazilian coast and found significant fecal contamination in mangrove forests near urban centres such as Rio de Janeiro and Florianópolis. This contamination results from substantial amounts of untreated domestic sewage in metropolitan areas facing rapid, unregulated urban growth, further aggravated by inadequate urban infrastructure.

Impact of pollution on mangroves in Rio de Janeiro, Brazil where birds and plastic bags, along with other plastic materials, blend into the landscape of red mangrove areas (Photo credit: Arimatéa Ximenes).

Climate Change

Climate change events are expected to profoundly affect mangroves through multiple mechanisms, including sea-level rise, shifts in rainfall patterns, more frequent and intense extreme weather events, rising temperatures, higher CO_2 levels, and altered ocean circulation patterns (Alongi, 2008; Gilman *et al*., 2008; Soares, 2009; Friess *et al*., 2023).

Initial observations of climate change impacts on mangroves in Brazil have largely focused on those within the Warm Temperate Southwestern Atlantic province. Since 1996, the mangroves in the Guaratiba Biological Reserve in Rio de Janeiro State have been the subject of a long-term monitoring program (Soares *et al*., 2005). This program has generated a comprehensive dataset over time, providing insights into the ecological responses of mangrove forests to climate variables (PBMC, 2014). The monitoring has documented the inland migration of mangrove forests, driven by the colonization of salt-flats in response to rising sea levels (Soares *et al*., 2005; Soares, 2009; Soares & Chaves, 2018). These observations have contributed to the development of a theoretical framework for understanding mangrove adaptation to sea level rise (Soares, 2009). The findings have informed the creation of public policies and management strategies aimed at mitigating climate change impacts on mangroves, with these efforts extending to mangroves across Brazil. Additionally, monitoring in Guaratiba Biological Reserve has provided valuable information on how variations in rainfall patterns and water availability affect mangrove ecosystem dynamics (PBMC, 2014; Soares & Chaves, 2018).

A severe climatic event happened on May 30, 2019 involving wind gusts of 58 km/h and hail drastically impacted the mangrove forest, leading to the loss of over 94% of the mangrove trees monitored in a permanent plot (13 m × 13 m), at the Cananéia-Iguape Coastal System, southeastern São Paulo State (Lima *et al*., 2023). This wind speed, classified as strong on the Beaufort scale, contributed to catastrophic damage to the mangrove ecosystem. Despite three years having passed since the event, natural recovery has not yet occurred. Continued extreme weather events along the coast have further altered the landscape. As a result, the mangroves remain vulnerable, and their ability to recover is dependent on their current health and resilience (Lima *et al*., 2023).

Dieback of mangrove trees following severe rain and storms, São Paulo state (Photo credit: Marília Cunha Lignon).

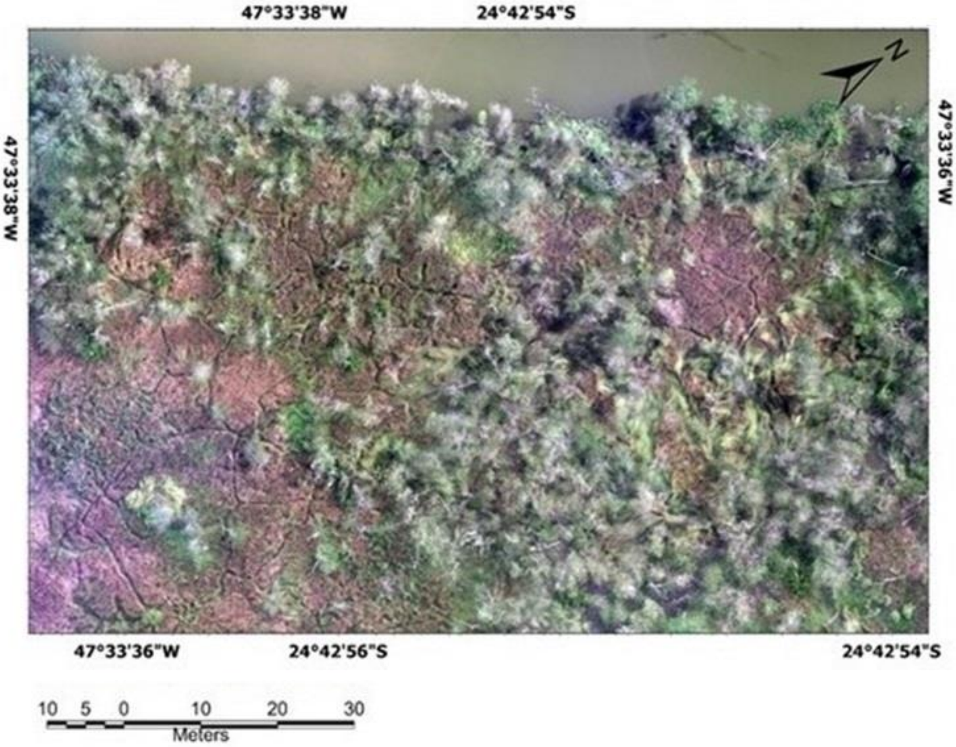


Figure 3. Drone image showing dieback of mangrove trees, identifiable by their distinctive white crowns (Photo credit: Luis Américo Conti).

Alien species

The Natal rock oyster, *Saccostrea cucullata*, from the Indo-Pacific (Lam & Morton, 2006) and the southern and eastern coasts of Africa (Haupt, 2009), was recorded for the first time in 2014 off the Brazilian coast in the region of Bertioga (São Paulo State). Observed near the port of Santos (São Paulo State), the largest commercial port in Latin America, it is believed that its arrival in the country was due to ship activities: ballast water and ship hull fouling (Galvão *et al*., 2017). *S. cucullata* was recorded fixed to natural substrates (mangrove roots, rocky shores and gravel) and artificial substrates (ports, marina, and docks), forming groups of many individuals and cohabiting with native oyster species (*Crassostrea mangle*, *Crassostrea brasiliana* and *Ostrea puelchana*) (Galvão *et al*., 2017). More recently, Amaral *et al*., (2020) recorded this exotic species in the states of Rio de Janeiro, Paraná, and Santa Catarina, and new areas in the state of São Paulo. The significant presence of this exotic oyster in the province (up to 17% in some areas cohabiting with the native species *Crassostrea brasiliana*) highlights the urgent need for monitoring and management strategies to assist in the management of this and other alien and potentially problematic species (Cunha-Lignon and Avellar, 2020). In 2024, local fishermen reported about 50% of the invasive oysters in mangrove forests. In 2023, a multistakeholder network against the invasive alien oyster on the São Paulo and Paraná coasts was created including, local communities, researchers, and state and federal institutions from the Brazilian government (Leal and Spalding, 2024). This network represents an advance in the management of bioinvasion, promoting the integration of knowledge, standardization of a monitoring protocol, and the diagnosis of bioinvasion with a focus on the elaboration of an Action Plan (Kitagami *et al*., 2024).

Eysink *et al*. (2023) documented the first known presence of an exotic mangrove species native to the Indo-Pacific region in Cubatão, São Paulo, Brazil. Their study identified *Sonneratia apetala* in this area, located approximately 2 km from Santos, one of Brazil's major ports. In their study, Eysink *et al*. (2023) identified 85 individuals of the exotic mangrove species *Sonneratia apetala* in the Cubatão region, located approximately 2 km from Santos, a major Brazilian port. Some of these specimens have reached heights exceeding 12 meters, with one tree bearing over 1,000 propagules, each containing up to 60 seeds. These propagules are easily dispersed by tidal movements. The authors hypothesize that this species was likely introduced via ballast water discharge.

In response, the Forestry Foundation of São Paulo, in collaboration with the Brazilian Institute of the Environment (IBAMA) and other researchers, conducted field inspections that confirmed the severity of the situation. Consequently, Early Detection and Rapid Response measures were implemented to manage strategies to suppress exotic individuals in accordance with protocols established by the Integrated Mangrove Management Program of the Forestry Foundation and researchers from São Paulo State University (UNESP). Currently, the population of *Sonneratia apetala* in the area is estimated at 250 individuals. The proliferation of this species poses a significant threat to native biodiversity and the ecosystem services provided by mangroves. Prompt and effective management strategies are essential to preserving the biodiversity of Brazilian mangroves and preventing further spread of *Sonneratia apetala* (Fundação Forestal, 2024).

Definition of the collapsed state of the ecosystem

Ecosystem collapse is recognized when the tree cover of diagnostic true mangrove species dwindles to zero, indicating complete loss (100%). Although the Warm Temperate Southwestern Atlantic Province mangrove ecosystems face threats from climate change, oil spills, and land use changes, they are not probably on the brink of such collapse.

Climate change impacts, such as rising sea levels and increased salinity, stress mangrove species but have not yet led to widespread degradation in this province. Oil spills introduce harmful substances like Polycyclic Aromatic Hydrocarbons (PAHs), causing localized contamination and impairing mangrove health. While oil spills have affected certain areas, they have not resulted in a total loss of mangrove cover in this province.

Urban development and land use changes are the main drivers for deforestation and contribute to habitat loss and pollution but have not reached a level that would lead to the complete collapse of mangrove ecosystems. The specific mechanisms that could drive such collapse, including extreme climatic conditions and severe hydrological disruptions, are not uniformly severe across the WTSW province.

In summary, while our mangrove ecosystems are impacted by various stressors, they have not experienced a complete collapse. The resilience of local mangrove species and the relatively moderate nature of these stressors in our region help maintain ecosystem stability. Continued monitoring and adaptive management will be crucial to ensuring the long-term health and sustainability of these vital ecosystems.

The WTSW province has some restoration programs, such as the Uçá program in Guanabara Bay (Rio de Janeiro state), which has reached the milestone of more than 42 hectares of restored mangroves, planting 126,250 trees of the three mangrove species in the Guapimirim Environmental Protection Area (Guardiões do Mar. (n.d.). In the states of Paraná and Santa Caratina, NGOs and universities have been actively involved in local communities' rehabilitation projects. For example, "*Olha o Clima, Litoral!"* by Mater Natura (https://maternatura.org.br/climalitoral/), "*REBIMAR"* program by Associação MarBrasil (https://marbrasil.org/rebimar/) and "*Raízes da Cooperação*" by Ação Nascente Maquiné (https://raizesdacooperacao.org.br/) among the programs.

The WTSA includes three Ramsar Sites: The Environment Protection Area of Cananéia-Iguape-Peruíbe in São Paulo State, and the Guaraqueçaba Ecological Station and Guaratuba in Paraná State (Ramsar Sites Information Service n.d.). Both the Cananéia – Iguape - Peruíbe Area and the Guaraqueçaba Ecological Station are also designated as World Heritage Sites and UNESCO Biosphere Reserves. Additionally, Guaratuba, a UNESCO Biosphere Reserve, plays a crucial role in protecting *Stymphalornis acutirostris*, a near-threatened species.

In Florianópolis, the Mangrove of Tavares River is home to Brazil's first Marine Extractive Reserve (RESEX), known as Pirajubaé RESEX, which was established in 1992 to protect *Anomalocardia brasiliana* (DOU, 1992). This species is a vital economic resource for local fishermen, who have been managing its exploitation since 1970 (Tognella *et al*., 2019).

Threat Classification

IUCN Threat Classification (version 3.3, IUCN-CMP, 2022) relevant to mangroves of the Warm Temperate Southwestern Atlantic province:

1. Residential & commercial development

- 1.1 Housing & urban areas
- 1.2 Commercial & industrial areas
- 1.3 Tourism & recreation areas

2. Agriculture & aquaculture

- 2.1 Annual & perennial non-timber crops
    - 2.1.2 Small-holder farming
    - 2.1.4 Scale Unknown/Unrecorded
- 2.3 Livestock farming & ranching
    - 2.3.2 Small-holder grazing, ranching or farming
    - 2.3.4 Scale Unknown/Unrecorded
    - 2.4.1 Subsistence/artisanal aquaculture
    - 2.4.3 Scale Unknown/Unrecorded

3. Energy production & mining

- 3.1 Oil & gas drilling

4. Transportation & service corridors

- 4.1 Roads & railroads
- 4.2 Utility & service lines
- 4.3 Shipping lanes
- 4.4 Flight paths

5. Biological resource use

- 5.2 Gathering terrestrial plants
    - 5.2.1 Intentional use (species being assessed is the target)
    - 5.2.3 Persecution/control
    - 5.2.4 Motivation Unknown/Unrecorded
- 5.3 Logging & wood harvesting
    - 5.3.1 Intentional use: subsistence/small scale (species being assessed is the target [harvest]
    - 5.3.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
    - 5.3.5 Motivation Unknown/Unrecorded
- 5.4 Fishing & harvesting aquatic resources
    - 5.4.1 Intentional use: subsistence/small scale (species being assessed is the target) [harvest]
    - 5.4.2 Intentional use: large scale (species being assessed is the target) [harvest]
    - 5.4.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
    - 5.4.4 Unintentional effects: large scale (species being assessed is not the target) [harvest]

6. Human intrusions & disturbance

- 6.1 Recreational activities
- 6.2 War, civil unrest & military exercises
- 6.3 Work & other activities

7. Natural system modifications

- 7.1 Fire & fire suppression
    - 7.1.3 Trend Unknown/Unrecorded
- 7.2 Dams & water management/use
    - 7.2.1 Abstraction of surface water (domestic use)
    - 7.2.2 Abstraction of surface water (commercial use)
    - 7.2.3 Abstraction of surface water (agricultural use)
    - 7.2.4 Abstraction of surface water (unknown use)
    - 7.2.9 Small dams

        - 7.2.10 Large dams
        - 7.2.11 Dams (size unknown)
    - 7.3 Other ecosystem modifications

8. Invasive & other problematic species, genes & diseases

- 8.1 Invasive non-native/alien species/diseases
    - 8.1.1 Unspecified species
    - 8.1.2 Named species
- 8.2 Problematic native species/diseases
    - 8.2.1 Unspecified species
    - 8.2.2 Named species
- 8.3 Introduced genetic material
- 8.4 Problematic species/diseases of unknown origin
    - 8.4.1 Unspecified species
    - 8.4.2 Named species

9. Pollution

- 9.1 Domestic & urban waste water
    - 9.1.1 Sewage
    - 9.1.2 Run-off
    - 9.1.3 Type Unknown/Unrecorded
- 9.2 Industrial & military effluents
    - 9.2.1 Oil spills
    - 9.2.2 Seepage from mining
    - 9.2.3 Type Unknown/Unrecorded
- 9.3 Agricultural & forestry effluents
    - 9.3.1 Nutrient loads
    - 9.3.2 Soil erosion, sedimentation
    - 9.3.3 Herbicides & pesticides
    - 9.3.4 Type Unknown/Unrecorded
- 9.4 Garbage & solid waste
- 9.5 Air-borne pollutants
    - 9.5.4 Type Unknown/Unrecorded

11. Climate change & severe weather

- 11.1 Habitat shifting & alteration
- 11.2 Droughts
- 11.3 Temperature extremes
- 11.4 Storms & flooding
- 11.5 Other impacts

4. Ecosystem Assessment

Criterion A: Reduction in Geographic Distribution

Subcriterion A1 measures the trend in ecosystem extent during the last 50-year time window. Unfortunately, there is currently no common regional dataset that provides information for the entire target area in 1970. The Warm Temperate Southwestern Atlantic mangrove ecosystem is therefore classified as **Data Deficient (DD)** for Subcriterion A1.

Subcriterion A2 measures the change in ecosystem extent in any 50-year period, including from the present to the future: The Warm Temperate Southwestern Atlantic province mangroves show a slight net area change of -0.9% (1996-2020) based on the Global Mangrove Watch (GMW v 3.0) time series (Bunting *et al.*, 2022).

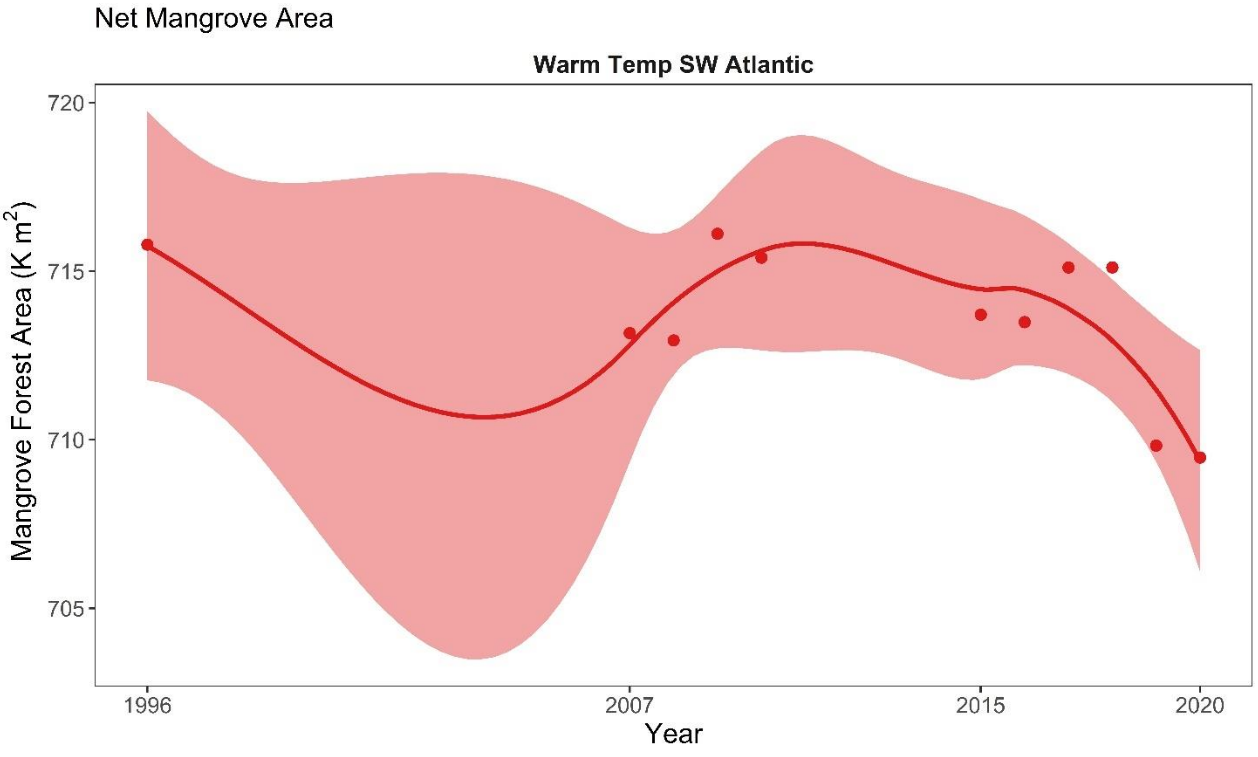
This value reflects the offset between areas gained (+ 0.1%/year) and lost (- 0.1%/year). The GMW v 3.0 map integrates both optical and radar imagery, offering a comprehensive view of mangrove distribution. In contrast, the MapBiomas map relies exclusively on optical imagery from Landsat (Diniz *et al*., 2019). Given the complex topography of the WTSA province, which includes rugged coastal terrain in southeastern Brazil, the GMW v 3.0 map's inclusion of radar imagery enhances its ability to accurately capture mangrove coverage.

However, the GMW v.3 map omits the mangroves at Laguna (28°30'S), which represents the southernmost extent of mangroves in Brazil (Ximenes *et al*., 2023). Despite their small area - 6.1 hectares in 2003 and 106.1 hectares in 2019 (Cohen *et al*., 2020) - Laguna's mangroves are considered important for climate monitoring and biogeographic research (Soares *et al*., 2012). Their exclusion from global maps highlights a significant gap, emphasizing the need to include such key regions for a more comprehensive environmental assessment (Ximenes *et al*., 2023).

Furthermore, the warm temperate southwest Atlantic mangrove extent changes between 1996 and 2020 do not follow a clear linear or exponential trend (R^2 =0.28, figure 4). This weak correlation makes it unreliable to use a regression to predict future changes over a 50-year period (Subcriterion A2b). While the GMW v.3.0 map remains the most robust source for assessing mangrove extent in the Warm Temperate Southwestern Atlantic province, these limitations prevent a reliable evaluation under Subcriterion A2. Therefore, the Warm Temperate Southwestern Atlantic mangrove ecosystem is classified as **Data Deficient (DD)** under Subcriterion A2.

Subcriterion A3 measures changes in mangrove area since 1750. Unfortunately, there are no reliable data on the mangrove extent for the entire province during this period, and therefore the Warm Temperate Southwestern Atlantic mangrove ecosystem is classified as **Data Deficient (DD)** for this subcriterion.

Overall, the ecosystem is assessed as **Data Deficient (DD)** under criterion A.



Area estimates based on GMW v.3.0 - Bunting et al. (2022)

Figure 4. Warm Temperate Southwestern Atlantic province mangrove area (circles) from 1996 to 2020 based on the GMW v3.0 dataset and equations in Bunting *et al*., (2022). The solid line represents a LOESS regression, with shaded area indicating the confidence interval. Neither a linear nor an exponential model provided a good fit to the data ($R^2 = 0.3$).

Criterion B: Restricted Geographic Distribution

Criterion B measures the risk of ecosystem collapse associated with restricted geographical distribution, based on standard metrics (Extent of Occurrence EOO, Area of Occupancy AOO, and Threat-defined locations). These parameters were calculated based on the 2020 Warm Temperate Southwestern Atlantic province mangrove extent (GMW v.3).

Province	Extent of Occurrence EOO (Km^2)	Area of Occupancy (AOO)	Criterion B
The Warm Temperate Southwestern Atlantic	104611.0	101	**LC**

For 2020, AOO and EOO were measured as 101 grid cells 10 x 10 km and 104611.0 km2, respectively (Figure 5). Excluding from the total of 155, those grid cells that contain patches of mangrove forest that account for less than 1% of the grid cell area, (< 1 Km2), the AOO is measured as 101, 10 x 10 km grid cells (Figure 5, red grids).

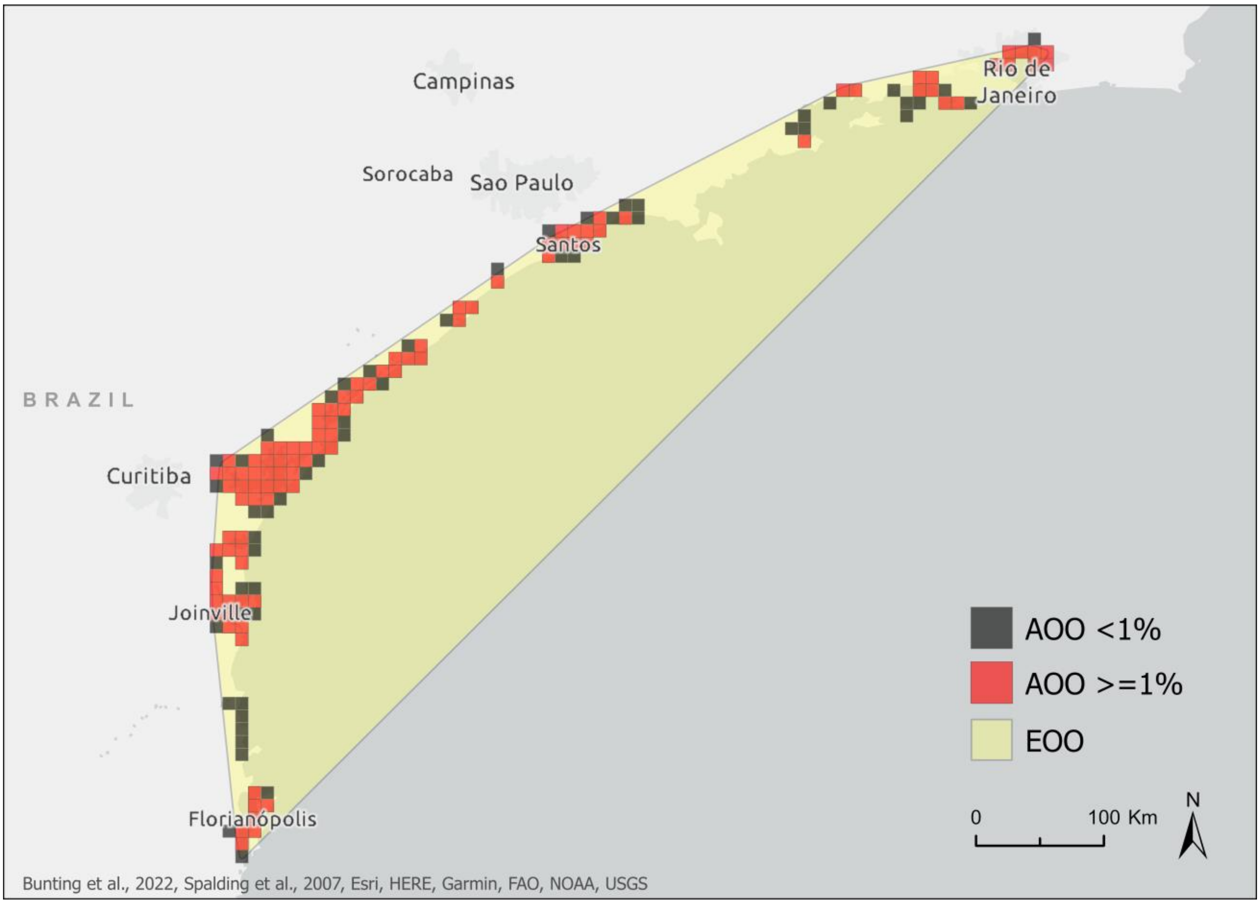


Figure 5. The Warm Temperate Southwestern Atlantic mangrove Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) in 2020. Estimates based on 2020 GMW v3.0 spatial layer (Bunting *et al.*, 2022). The red 10 x 10 km grids (n=101.) are more than 1% covered by the ecosystem, and the black grids <1% (n= 54).

Considering the very high number of threat-defined-locations, there is no evidence of plausible catastrophic threats leading to potential disappearance of mangroves across their extent. Within the WTSA region, this statement implies that although many locations with defined threats have been identified, these threats are currently not strong enough to cause extensive and catastrophic destruction of mangroves. Many localized threats exhibit a range of intensities, with certain areas experiencing significant consequences from human-induced activities or natural calamities, while others maintain a relatively ability to recover. As a result, the Warm Temperate Southwestern Atlantic mangrove ecosystem is assessed as **Least Concern (LC)** under criterion B.

Criterion C: Environmental Degradation

Criterion C measures the environmental degradation of abiotic variables necessary to support the ecosystem.

Subcriterion C1 measures environmental degradation over the past 50 years: There are no reliable data to evaluate this subcriterion for the entire province, and therefore the Warm Temperate Southwestern Atlantic mangrove ecosystem is classified as **Data Deficient (DD)** for subcriterion C1.

Subcriterion C2 measures environmental degradation in the future, or over any 50-year period, including from the present. In this context, the impact of future sea level rise (SLR) on mangrove ecosystems was assessed by adopting the methodology presented by Schuerch *et al.* (2018). The published model was designed to calculate both absolute and relative change in the extent of wetland ecosystems under various regional SLR scenarios (i.e medium: RCP 4.5 and high: RCP 8.5), with consideration for sediment accretion. Therefore, Schuerch *et al*. (2018) model was applied to the Warm Temperate Southwestern Atlantic mangrove ecosystem boundary, using the spatial extent in 2010 (Giri *et al*. 2011) and assuming mangrove landward migration was not possible.

According to the results, under an extreme sea-level rise scenario of a 1.1-meter rise by 2100, the projected submerged area is ~ -13.6% by 2060, which remains below the 30% risk threshold. Therefore, considering that no mangrove recruitment can occur in a submerged system (100% relative severity), but that -13.6% of the ecosystem extent will be affected by SLR, the Warm Temperate Southwestern Atlantic mangrove ecosystem is assessed as **Least Concern (LC)** for subcriterion C2.

Subcriterion C3 measures change in abiotic variables since 1750. There is a lack of reliable historic data on environmental degradation covering the entire province, and therefore the Warm Temperate Southwestern Atlantic province is classified as Data Deficient (DD) for this subcriterion.

Overall, the ecosystem is assessed as **Least Concern (LC)** under criterion C.

Criterion D: Disruption of biotic processes or interactions

The global mangrove degradation map developed by Worthington and Spalding (2018) was used to assess the level of biotic degradation in the Warm Temperate Southwestern Atlantic province. This map is based on degradation metrics calculated from vegetation indices (NDVI, EVI, SAVI, NDMI) using Landsat time series (≈2000 and 2017). These indices represent vegetation greenness and moisture condition.

Mangrove degradation was calculated at a pixel scale (30m resolution), on areas intersecting with the 2017 mangrove extent map (GMW v2). Mangrove pixels were classified as degraded if two conditions were met: 1) at least 10 out of 12 degradation indices showed a decrease of more than 40% compared to the previous period; and 2) all twelve indices did not recover to within 20% of their pre-2000 value (detailed methods and data are available at: maps.oceanwealth.org/mangrove-restoration/). The decay in vegetation indices has been used to identify mangrove degradation and abrupt changes, including mangrove die-back events, clear-cutting, fire damage, and logging; as well as to track mangrove regeneration (Lovelock *et al.*, 2017; Santana, 2018; Murray *et al.*, 2020; Aljahdali *et al.*, 2021; Lee *et al.*, 2021). However, it is important to consider that changes observed in the vegetation indices can also be influenced by data artifacts (Akbar *et al.*, 2020). Therefore, a relative severity level of more than 50%, but less than 80%, was assumed.

The results from this analysis show that over a period of 17 years (~2000 to 2017), 1% of the Warm Temperate Southwestern Atlantic mangrove area is classified as degraded, resulting in an average annual rate of degradation of 0.06%. Assuming this trend remains constant, +2.9% of the Warm Temperate Southwestern Atlantic mangrove area will be classified as degraded over a 50-year period. Since less than 30% of the ecosystem, will meet the category thresholds for criterion D, the Warm Temperate Southwestern Atlantic mangrove province is assessed as **Least Concern** (**LC)** under subcriterion D2b.

No data were found to assess the disruption of biotic processes and degradation over the past 50 years (subcriterion D1) or since 1750 (subcriterion D3). Thus, both subcriteria are classified as **Data Deficient (DD).**

Overall, the Warm Temperate Southwestern Atlantic ecosystem remains **Least Concern (LC)** under criterion D.

Criterion E: Quantitative Risk

No model was used to quantitatively assess the risk of ecosystem collapse for this ecosystem; hence criterion E was **Not Evaluated (NE)**.

5. Summary of the Assessment

CRITERION			
A. Reduction in Geographic Distribution	**A1** Past 50 years	**A2** Future or any 50y period	**A3** Historical (1750)
	DD	**DD**	**DD**
B. Restricted Geo. Distribution	**B1** Extent of Occurrence	**B2** Area of Occupancy	**B3** # Threat-defined Locations < 5
	LC	**LC**	**LC**
C. Environmental Degradation	**C1** Past 50 years (1970)	**C2** Future or any 50y period	**C3** Historical (1750)
	DD	**LC**	**DD**
D. Disruption of biotic processes	**D1** Past 50 years (1970)	**D2** Future or Any 50y period	**D3** Historical (1750)
	DD	**LC**	**DD**
E. Quantitative Risk analysis	**NE**		
OVERALL RISK CATEGORY	**LC**		

DD = Data Deficient; LC = Least Concern; NE = Not Evaluated

Overall, the status of the Warm Temperate Southwestern Atlantic mangrove ecosystem is assessed as **Least Concern (LC).**

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7. Appendices

1. List of Key Mangrove Species

List of plant species considered true mangroves according to Red List of Threatened Species (RLTS) spatial data (IUCN, 2022). We included species whose range maps intersected with the boundary of the marine provinces/ecoregions described in the distribution section.

Class	Order	Family	Scientific name	RLTS category
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia schaueriana*	LC
Magnoliopsida	Myrtales	Combretaceae	*Laguncularia racemosa*	LC
Magnoliopsida	Malpighiales	Rhizophoraceae	*Rhizophora mangle*	LC

2. List of Associated Species

List of taxa that are associated with mangrove habitats in the Red List of Threatened Species (RLTS) database (IUCN, 2022). We included only species with entries for Habitat 1.7: “Forest - Subtropical/Tropical Mangrove Vegetation Above High Tide Level” or Habitat 12.7 for “Marine Intertidal - Mangrove Submerged Roots”, and with suitability recorded as “Suitable”, with “Major Importance” recorded as “Yes”, and any value of seasonality except “Passage”. The common names are those shown in the RLTS, except common names in brackets, which are from other sources.

Class	Order	Family	Scientific name	RLTS category	Common name
Actinopterygii	Anguilliformes	Ophichthidae	*Ahlia egmontis*	LC	Key worm eel
Actinopterygii	Atheriniformes	Atherinopsidae	*Atherinella brasiliensis*	LC	Robust silverside
Actinopterygii	Beloniformes	Belonidae	*Strongylura marina*	LC	Atlantic needlefish
Actinopterygii	Beloniformes	Belonidae	*Strongylura timucu*	LC	Timucu
Actinopterygii	Beloniformes	Hemiramphidae	*Hyporhamphus roberti*	LC	Central American halfbeak
Actinopterygii	Clupeiformes	Clupeidae	*Harengula clupeola*	LC	False Herring
Actinopterygii	Cyprinodontiformes	Rivulidae	*Kryptolebias ocellatus*	LC	Peixe-anual
Actinopterygii	Gobiiformes	Eleotridae	*Dormitator maculatus*	LC	Fat sleeper
Actinopterygii	Gobiiformes	Eleotridae	*Guavina guavina*	LC	Guavina
Actinopterygii	Gobiiformes	Gobiidae	*Bathygobius soporator*	LC	Frillfin goby
Actinopterygii	Gobiiformes	Gobiidae	*Ctenogobius smaragdus*	LC	Emerald goby
Actinopterygii	Mugiliformes	Mugilidae	*Mugil incilis*	LC	Parassi mullet
Actinopterygii	Perciformes	Apogonidae	*Apogon planifrons*	LC	Pale cardinalfish
Actinopterygii	Perciformes	Apogonidae	*Astrapogon puncticulatus*	LC	Blackfin cardinalfish
Actinopterygii	Perciformes	Apogonidae	*Astrapogon stellatus*	DD	Conchfish
Actinopterygii	Perciformes	Blenniidae	*Parablennius marmoreus*	LC	Seaweed blenny
Actinopterygii	Perciformes	Carangidae	*Caranx hippos*	LC	Crevalle jack

Class	Order	Family	Scientific name	RLTS category	Common name
Actinopterygii	Perciformes	Carangidae	*Chloroscombrus chrysurus*	LC	Atlantic bumper
Actinopterygii	Perciformes	Centropomidae	*Centropomus mexicanus*	LC	Largescale fat snook
Actinopterygii	Perciformes	Ephippidae	*Chaetodipterus faber*	LC	Atlantic spadefish
Actinopterygii	Perciformes	Epinephelidae	*Epinephelus itajara*	VU	Atlantic goliath grouper
Actinopterygii	Perciformes	Epinephelidae	*Mycteroperca acutirostris*	LC	Comb grouper
Actinopterygii	Perciformes	Epinephelidae	*Mycteroperca interstitialis*	VU	Yellowmouth grouper
Actinopterygii	Perciformes	Gerreidae	*Diapterus auratus*	LC	Irish mojarra
Actinopterygii	Perciformes	Gerreidae	*Eucinostomus harengulus*	LC	Tidewater mojarra
Actinopterygii	Perciformes	Gerreidae	*Eugerres brasilianus*	LC	Brazilian mojarra
Actinopterygii	Perciformes	Haemulidae	*Anisotremus surinamensis*	DD	Black margate
Actinopterygii	Perciformes	Haemulidae	*Haemulon aurolineatum*	LC	Tomtate
Actinopterygii	Perciformes	Haemulidae	*Haemulon parra*	LC	Sailor's choice
Actinopterygii	Perciformes	Haemulidae	*Haemulon plumierii*	LC	White grunt
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus cyanopterus*	VU	Cubera snapper
Actinopterygii	Perciformes	Polynemidae	*Polydactylus oligodon*	LC	Littlescale threadfin
Actinopterygii	Perciformes	Pomacentridae	*Stegastes variabilis*	LC	Brazilian cocoa damselfish
Actinopterygii	Perciformes	Sciaenidae	*Bairdiella goeldi*	LC	
Actinopterygii	Perciformes	Sciaenidae	*Cynoscion acoupa*	VU	Acoupa weakfish
Actinopterygii	Perciformes	Sciaenidae	*Isopisthus parvipinnis*	LC	Bigtooth corvina
Actinopterygii	Perciformes	Sciaenidae	*Stellifer brasiliensis*	LC	
Actinopterygii	Perciformes	Sparidae	*Archosargus rhomboidalis*	LC	Sea bream
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Citharichthys arenaceus*	LC	Sand whiff
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Citharichthys spilopterus*	LC	Bay whiff
Actinopterygii	Siluriformes	Ariidae	*Bagre marinus*	LC	Gafftopsail sea catfish
Actinopterygii	Siluriformes	Ariidae	*Genidens genidens*	LC	Guri Sea Catfish
Actinopterygii	Siluriformes	Loricariidae	*Loricariichthys castaneus*	LC	Cascudo-viola
Actinopterygii	Syngnathiformes	Syngnathidae	*Hippocampus erectus*	VU	Lined seahorse
Actinopterygii	Syngnathiformes	Syngnathidae	*Hippocampus reidi*	NT	Long-Snout seahorse
Actinopterygii	Syngnathiformes	Syngnathidae	*Pseudophallus mindii*	DD	Freshwater pipefish
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Lagocephalus laevigatus*	LC	Smooth puffer
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Sphoeroides testudineus*	LC	Checkered puffer

Class	Order	Family	Scientific name	RLTS category	Common name
Aves	Accipitriformes	Accipitridae	*Busarellus nigricollis*	LC	Black-collared Hawk
Aves	Accipitriformes	Accipitridae	*Buteo brachyurus*	LC	Short-tailed Hawk
Aves	Accipitriformes	Accipitridae	*Buteogallus aequinoctialis*	NT	Rufous Crab-hawk
Aves	Accipitriformes	Accipitridae	*Buteogallus meridionalis*	LC	Savanna hawk
Aves	Accipitriformes	Accipitridae	*Buteogallus urubitinga*	LC	Great Black hawk
Aves	Accipitriformes	Accipitridae	*Elanoides forficatus*	LC	Swallow-tailedk kite
Aves	Accipitriformes	Accipitridae	*Geranospiza caerulescens*	LC	Crane hawk
Aves	Accipitriformes	Accipitridae	*Ictinia plumbea*	LC	Plumbeous kite
Aves	Accipitriformes	Pandionidae	*Pandion haliaetus*	LC	Osprey
Aves	Anseriformes	Anatidae	*Cairina moschata*	LC	Muscovy duck
Aves	Anseriformes	Anatidae	*Nomonyx dominicus*	LC	Masked duck
Aves	Caprimulgiformes	Caprimulgidae	*Macropsalis forcipata*	LC	Long-trained nightjar
Aves	Caprimulgiformes	Caprimulgidae	*Nyctidromus albicollis*	LC	Pauraque
Aves	Caprimulgiformes	Nyctibiidae	*Nyctibius griseus*	LC	Common potoo
Aves	Caprimulgiformes	Trochilidae	*Chionomesa fimbriata*	LC	Glittering-throated emerald
Aves	Cathartiformes	Cathartidae	*Cathartes burrovianus*	LC	Lesser Yellow-headed vulture
Aves	Charadriiformes	Scolopacidae	*Numenius phaeopus*	LC	Whimbrel
Aves	Ciconiiformes	Ciconiidae	*Mycteria americana*	LC	Wood stork
Aves	Columbiformes	Columbidae	*Patagioenas cayennensis*	LC	Pale-vented pigeon
Aves	Columbiformes	Columbidae	*Zenaida auriculata*	LC	Eared dove
Aves	Coraciiformes	Alcedinidae	*Chloroceryle aenea*	LC	American pygmy-kingfisher
Aves	Coraciiformes	Alcedinidae	*Chloroceryle amazona*	LC	Amazon kingfisher
Aves	Coraciiformes	Alcedinidae	*Chloroceryle americana*	LC	Green kingfisher
Aves	Coraciiformes	Alcedinidae	*Chloroceryle inda*	LC	Green-and-rufous kingfisher
Aves	Coraciiformes	Alcedinidae	*Megaceryle torquata*	LC	Ringed kingfisher
Aves	Cuculiformes	Cuculidae	*Coccyzus melacoryphus*	LC	Dark-billed cuckoo
Aves	Cuculiformes	Cuculidae	*Crotophaga major*	LC	Greater ani
Aves	Cuculiformes	Cuculidae	*Piaya cayana*	LC	Common squirrel-cuckoo
Aves	Falconiformes	Falconidae	*Micrastur semitorquatus*	LC	Collared forest-falcon
Aves	Galliformes	Cracidae	*Penelope superciliaris*	NT	Rusty-margined guan
Aves	Gruiformes	Aramidae	*Aramus guarauna*	LC	Limpkin
Aves	Gruiformes	Rallidae	*Aramides cajaneus*	LC	Grey-cowled wood-rail

Class	Order	Family	Scientific name	RLTS category	Common name
Aves	Gruiformes	Rallidae	*Aramides mangle*	LC	Little wood-rail
Aves	Gruiformes	Rallidae	*Rallus longirostris*	LC	Mangrove rail
Aves	Passeriformes	Fringillidae	*Euphonia chlorotica*	LC	Purple-throated euphonia
Aves	Passeriformes	Furnariidae	*Certhiaxis cinnamomeus*	LC	Yellow-chinned Spinetail
Aves	Passeriformes	Furnariidae	*Sittasomus griseicapillus*	LC	Eastern olivaceous woodcreeper
Aves	Passeriformes	Furnariidae	*Xiphorhynchus guttatus*	LC	Buff-throated woodcreeper
Aves	Passeriformes	Hirundinidae	*Progne chalybea*	LC	Grey-breasted martin
Aves	Passeriformes	Hirundinidae	*Tachycineta albiventer*	LC	White-winged swallow
Aves	Passeriformes	Polioptilidae	*Polioptila plumbea*	LC	Tropical gnatcatcher
Aves	Passeriformes	Thamnophilidae	*Formicivora grisea*	LC	Southern white-fringed antwren
Aves	Passeriformes	Thraupidae	*Coereba flaveola*	LC	Bananaquit
Aves	Passeriformes	Thraupidae	*Conirostrum bicolor*	NT	Bicolored conebill
Aves	Passeriformes	Tityridae	*Pachyramphus polychopterus*	LC	White-winged becard
Aves	Passeriformes	Troglodytidae	*Cantorchilus leucotis*	LC	Buff-breasted wren
Aves	Passeriformes	Troglodytidae	*Cantorchilus longirostris*	LC	Long-billed wren
Aves	Passeriformes	Turdidae	*Turdus fumigatus*	LC	Cocoa thrush
Aves	Passeriformes	Tyrannidae	*Capsiempis flaveola*	LC	Yellow tyrannulet
Aves	Passeriformes	Tyrannidae	*Contopus cinereus*	LC	Southern tropical pewee
Aves	Passeriformes	Tyrannidae	*Myiarchus swainsoni*	LC	Swainson's flycatcher
Aves	Passeriformes	Tyrannidae	*Myiarchus tyrannulus*	LC	Brown-crested flycatcher
Aves	Passeriformes	Tyrannidae	*Myiodynastes solitarius*	LC	Southern streaked flycatcher
Aves	Passeriformes	Tyrannidae	*Phaeomyias murina*	LC	Mouse-colored tyrannulet
Aves	Passeriformes	Tyrannidae	*Philohydor lictor*	LC	Lesser kiskadee
Aves	Passeriformes	Tyrannidae	*Pitangus sulphuratus*	LC	Great kiskadee
Aves	Passeriformes	Tyrannidae	*Tolmomyias flaviventris*	LC	Ochre-lored elatbill
Aves	Passeriformes	Tyrannidae	*Tyrannus melancholicus*	LC	Tropical kingbird
Aves	Passeriformes	Tyrannidae	*Tyrannus savana*	LC	Fork-tailed flycatcher
Aves	Passeriformes	Vireonidae	*Cyclarhis gujanensis*	LC	Rufous-browed peppershrike
Aves	Pelecaniformes	Ardeidae	*Butorides striata*	LC	Green-backed heron
Aves	Pelecaniformes	Ardeidae	*Cochlearius cochlearius*	LC	Boat-billed heron
Aves	Pelecaniformes	Ardeidae	*Egretta caerulea*	LC	Little blue heron
Aves	Pelecaniformes	Ardeidae	*Ixobrychus exilis*	LC	Least bittern

Class	Order	Family	Scientific name	RLTS category	Common name
Aves	Pelecaniformes	Ardeidae	*Nyctanassa violacea*	LC	Yellow-crowned night-heron
Aves	Pelecaniformes	Ardeidae	*Nycticorax nycticorax*	LC	Black-crowned night-heron
Aves	Pelecaniformes	Ardeidae	*Tigrisoma lineatum*	LC	Rufescent tiger-heron
Aves	Pelecaniformes	Threskiornithidae	*Eudocimus ruber*	LC	Scarlet ibis
Aves	Piciformes	Picidae	*Hylatomus lineatus*	LC	Lineated woodpecker
Aves	Piciformes	Picidae	*Veniliornis passerinus*	LC	Little woodpecker
Aves	Psittaciformes	Psittacidae	*Amazona amazonica*	LC	Orange-winged Amazon
Aves	Psittaciformes	Psittacidae	*Amazona brasiliensis*	NT	Red-tailed Amazon
Aves	Psittaciformes	Psittacidae	*Primolius maracana*	NT	Blue-winged macaw
Aves	Psittaciformes	Psittacidae	*Psittacara leucophthalmus*	LC	White-eyed parakeet
Aves	Strigiformes	Strigidae	*Bubo virginianus*	LC	Great horned owl
Aves	Suliformes	Fregatidae	*Fregata ariel*	LC	Lesser frigatebird
Aves	Suliformes	Fregatidae	*Fregata magnificens*	LC	Magnificent frigatebird
Aves	Trogoniformes	Trogonidae	*Trogon viridis*	LC	Green-backed trogon
Chondrichthyes	Carcharhiniformes	Carcharhinidae	*Negaprion brevirostris*	VU	Lemon shark
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis pectinata*	CR	Smalltooth sawfish
Chondrichthyes	Rhinopristiformes	Pristidae	*Pristis pristis*	CR	Largetooth sawfish
Gastropoda	Cycloneritida	Neritidae	*Vitta virginea*	LC	Virgin nerite
Gastropoda	Ellobiida	Ellobiidae	*Melampus coffeus*	LC	Coffee melampus
Gastropoda	Littorinimorpha	Littorinidae	*Littoraria angulifera*	LC	Mangrove periwinkle
Mammalia	Carnivora	Felidae	*Leopardus pardalis*	LC	Ocelot
Mammalia	Carnivora	Felidae	*Panthera onca*	NT	Jaguar
Mammalia	Carnivora	Procyonidae	*Procyon cancrivorus*	LC	Crab-eating Raccoon
Mammalia	Chiroptera	Noctilionidae	*Noctilio leporinus*	LC	Greater bulldog bat
Mammalia	Didelphimorphia	Didelphidae	*Metachirus nudicaudatus*	LC	Brown Four-eyed Opossum
Mammalia	Pilosa	Bradypodidae	*Bradypus variegatus*	LC	Brown-throated sloth
Mammalia	Pilosa	Myrmecophagidae	*Tamandua tetradactyla*	LC	Southern tamandua
Mammalia	Primates	Cebidae	*Sapajus libidinosus*	NT	Bearded capuchin
Mammalia	Rodentia	Echimyidae	*Phyllomys pattoni*	LC	
Mammalia	Rodentia	Echimyidae	*Phyllomys thomasi*	EN	
Reptilia	Squamata	Boidae	*Boa constrictor*	LC	Red-tailed boa
Reptilia	Squamata	Colubridae	*Spilotes pullatus*	LC	Chicken snake
Reptilia	Squamata	Typhlopidae	*Amerotyphlops brongersmianus*	LC	Brongersma's worm snake

Class	Order	Family	Scientific name	RLTS category	Common name
Reptilia	Testudines	Cheloniidae	*Eretmochelys imbricata*	CR	Hawksbill turtle
Agaricomycetes	Hymenochaetales	Hymenochaetaceae	*Fuscoporia bifurcata*	VU	
Agaricomycetes	Hymenochaetales	Not assigned	*Trichaptum sp. nov. 'fissile'*	VU	
Liliopsida	Alismatales	Cymodoceaceae	*Halodule wrightii*	LC	
Magnoliopsida	Boraginales	Heliotropiaceae	*Euploca procumbens*	LC	Four-spike heliotrope
Magnoliopsida	Caryophyllales	Cactaceae	*Hylocereus setaceus*	LC	Rainha de noite
Magnoliopsida	Celastrales	Celastraceae	*Monteverdia littoralis*	LC	
Magnoliopsida	Celastrales	Celastraceae	*Monteverdia obtusifolia*	LC	
Magnoliopsida	Fabales	Fabaceae	*Inga heterophylla*	LC	Pacae
Magnoliopsida	Magnoliales	Annonaceae	*Annona glabra*	LC	Monkey apple
Magnoliopsida	Malpighiales	Clusiaceae	*Symphonia globulifera*	LC	Boarwood
Magnoliopsida	Malpighiales	Erythroxylaceae	*Erythroxylum passerinum*	LC	Bom-nome
Magnoliopsida	Malvales	Malvaceae	*Hibiscus tiliaceus*	LC	Coast cottonwood
Magnoliopsida	Myrtales	Combretaceae	*Conocarpus erectus*	LC	Silver-leaved buttonwood
Polypodiopsida	Polypodiales	Pteridaceae	*Acrostichum danaeifolium*	LC	
Aves	Passeriformes	Corvidea	*Cyanocorax caeruleus*	NT	Azure jay
Aves	Passeriformes	Thraupidae	*Tangara peruviana*	VU	Black-backed tanager

3. National Red List of Species

This table include the species assessed or listed according to Ordinance No. 148, dated June 7, 2022 (BRAZIL, 2022). If blank, the species occurs in this province according to Thurman *et al*. (2013), Zimmermann (1995) but has not yet been formally assessed.

Class	Order	Family	Scientific name	National/subnational Red List category
Aves	Passeriformes	Thraupidae	*Dacnis nigripes*	LC
Crustacea	Decapoda	Crustacea	*Minuca rapax*	LC
Crustacea	Decapoda	Gercacinidae	*Cardisoma guanhumi*	LC/CR
Crustacea	Decapoda	Ocypodidae	*Minuca mordax*	LC
Crustacea	Decapoda	Ocypodidae	*Uca maracoani*	LC
Crustacea	Decapoda	Ocypodidae	*Leptuca thayeri*	
Crustacea	Decapoda	Ocypodidae	*Minuco burguesi*	
Crustacea	Decapoda	Ocypodidae	*Minuca vocator*	

Class	Order	Family	Scientific name	National/subnational Red List category
Crustacea	Decapoda	Ocypodidae	*Minuca victoriana*	
Crustacea	Decapoda	Ocypodidae	*Leptuca cumulanta*	
Crustacea	Decapoda	Ocypodidae	*Leptuca leptodactyla*	LC
Crustacea	Decapoda	Ocypodidae	*Ucides cordatus*	LC

References:

Brazil (2022). Ordinance No. 148, June 7, 2022. *Official Gazette of the Federative Republic of Brazil, Ministry of the Environment Office, Brasília*, DF, No. 108, June 8, 2022. Section 1, p. 74.

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Zimmermann, C. E. (1995). Aspects of *Dacnis nigripes* (Pelzeln) (Passeriformes, Coerebidae) biology in Santa Catarina, Brazil. *Revista Bras. Zool.*, 12(1), 185-188.